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STAGS User Manual

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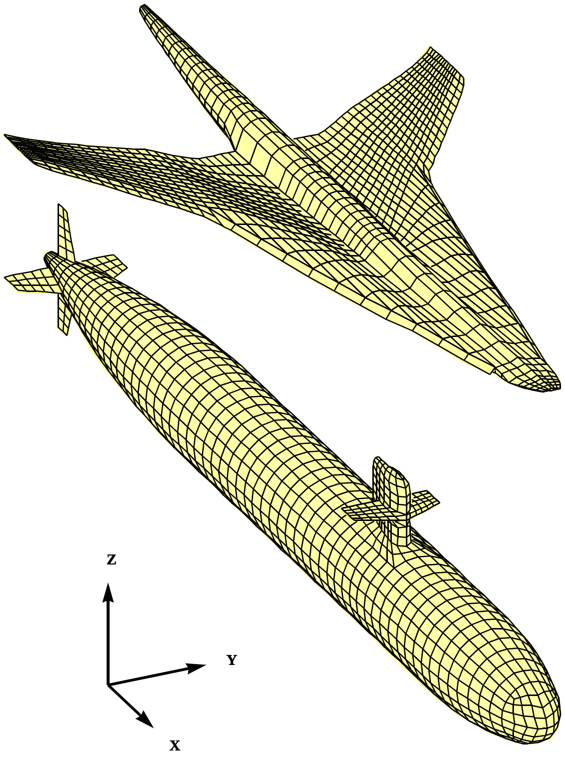

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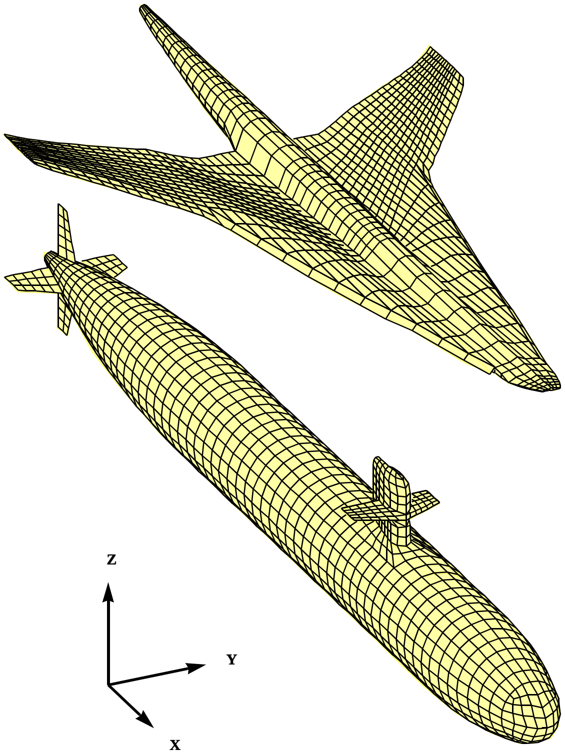

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Preface

This *User Manual* is the largest of three reference documents for the current version (version 5.0) of the **STAGS** (**ST**ructural **A**nalysis of **G**eneral **S**hells) structural analysis program. The primary purposes of this document are (a) to describe the basic capabilities and features of the **STAGS** program and the most important post-analysis processors that can be used with it, and (b) to describe the input requirements for and the output generated by each of these programs. The other two reference documents for the current version of **STAGS** are the ***STAGS** Elements Manual* and the ***STAGS** Test Cases Manual*.

This document is an extensively updated version of large portions of the ***STAGS** User Manual* that was released when version 4.0 of the **STAGS** program was "frozen" in May of 2001. Many of the updates in this document describe new capabilities that have been introduced into **STAGS** since that date—new analysis features, 18-node sandwich elements, higher-level features of user-developed elements, and superelements, for example. Other updates in this document correct some of the errors and omissions that found (or failed to find) their way into earlier descriptions of older **STAGS** capabilities.

The first version of this *User Manual* document was released when version 2.0 of the **STAGS** program was released in June of 1994. That document was revised repeatedly until mid-1997, when it was "frozen" for version 2.4 of **STAGS** program. The **STAGS** 2.4 *User Manual* was revised repeatedly from mid-1997 through May of 2001, as **STAGS** 2.4 evolved into **STAGS** 3.0 and then into **STAGS** 4.0. This document is our "best shot" at describing **STAGS** 5.0.

Early versions of this *User Manual* were written for off-line use as printed documents. The current version of this document still has a very strong "printed reference" orientation; but the publication and distribution of this document in Adobe's PDF format give it additional, platform-independent, on-line utilities that the earlier versions lacked. PDF versions of *this* document, the ***STAGS** Elements Manual* document and the ***STAGS** Test Cases Manual* document can be read and printed with Adobe's Acrobat Reader application—which is widely-available, easy-to-use and free.

It is appropriate to digress briefly here to tell the reader that the **STAGS** program has a long and illustrious history. The **STAGS** program started out and in many important respects is still on the cutting edge of structural analysis technology. The earliest versions of what became the **STAGS** program (in the mid- to late-1960's) were energy-based, *finite difference* codes that were designed to perform linear and nonlinear analyses of single-unit and multi-celled thin shell structures—principally (but not exclusively) for structures of interest to the aerospace and military communities. The earliest versions of **STAGS** were research-oriented, special-purpose programs that were developed on and designed to exploit the high-speed, large-problem computational capabilities of the CDC-6000-series mainframe computer systems that were the cream of the crop in the computer world during that time frame. During the early 1970's, **STAGS** was "generalized" (to treat shell and other configurations that cannot easily be generated analytically) and converted into a research-oriented, general-purpose *finite element* program. During that decade and well into the second lustrum of the next, development of **STAGS** was centered on and designed to exploit the higher-speed, larger-problem capabilities of the CDC 7600 and the CRAY XMP, YMP and TS mainframe systems that were the performance champions of that era.

The 1.0 version of **STAGS** was an (early 1970's) evolutional extension of the special-purpose, research-oriented **STAGS** C-1 program). **STAGS** 2.0 was an (early 1980's) evolutional extension of **STAGS** 1.0. **STAGS** 2.0 evolved into **STAGS** 2.1, 2.2, 2.3, 2.4, 3.0, 3.5 and 4.0 over the next decade or so (from the mid-1980's to the midpoint of 2002). The most recent (current) version of the program is **STAGS** 5.0.

The computer world has changed significantly over the last two decades, and **STAGS** has changed with it. "*Omnia mutantur, nos et mutamur in illis.*" Large, powerful mainframe systems were challenged by and eventually yielded to smaller (but still powerful) mainframe alternatives (the Convex and Stardent systems, in particular). These in turn were challenged by and yielded to still-smaller (and increasingly powerful) desktop workstation systems (by DEC, HP, IBM, SGI and SUN, principally). Versions of **STAGS** were developed for, and have been and continue to be effectively used on all of those machines. The shift from huge to smaller and smaller computer systems continues—with today's desktop workstations being strongly challenged by today's increasingly more powerful (and affordable) "personal" computer systems. Over the last several years, **STAGS** 4.0 and 5.0 have been transported to and are now being utilized effectively on many Linux, Windows and Macintosh-based personal computer systems.

Returning from that digression to the main theme of this Preface, we note again that the earliest versions of **STAGS** were research-oriented, special-purpose programs that evolved from there into the user-oriented, general-purpose **STAGS** system that we have today. The primary efforts in developing **STAGS** during the early and middle years (from the late 1960's to the early 1990's) were very strongly focused on implementation of stat-of-the-art computer and innovative analysis technologies, with little energy (or funding) remaining for generating usable, up-to-date documentation. During those years, the **STAGS** User Manual was a thin, terse document that was updated from time to time (energy and funding permitting) to keep pace (as well as it could) with the program as it evolved. This was "tolerated" during those years because **STAGS** was viewed then as a cutting-edge tool that could be used most effectively by a relatively small number of computationally sophisticated researchers and analysts. This "once but no longer tolerable" documentation situation changed significantly when **STAGS** 1.0 evolved into **STAGS** 2.0, and the much-improved *User Manual* for **STAGS** 2.0 was developed to fill this need. Significant efforts have been made to update and improve that breakthrough *User Manual* to stay as up-to-date and as close as possible with **STAGS** and its companion programs during their evolutions from there to and including today's **STAGS** 5.0 system.

It is also appropriate to note here that compatibility with **STAGS** C-1 was a major design consideration in the development of **STAGS** 1.0 and **STAGS** 2.0—and that maximization of compatibility with the most recent versions of **STAGS** has been a continuing consideration with each successive version of the program. With each new program capability and feature, however, changes to model-definition and solution-control input data have been inevitable. Strong efforts have been made to minimize those changes and keep them evolutional rather than revolutionary.

Input-data requirements for model definition and solution control are described in detail in Chapters 5 through 11 of this document and are summarized in one-line-per-record memory joggers in Appendix B. Input requirements for utilizing *user-written subroutines* in model-definition and analysis operations are described in Chapter 12. The basic approach that **STAGS** supports for implementing and utilizing *user-defined elements* is described in Chapter 13.

Users of earlier versions of the **STAGS** program and of the post-analysis processors that can be used in conjuction with **STAGS** should check the appropriate documentation very carefully to determine changes that are necessary before attempting to use any existing input files or attempting to employ user-written subroutines with version 5.0 of **STAGS**. We strongly suggest that, to determine where input changes are necessary and to discover new program capabilities and input features that make **STAGS** 5.0 easier to use and faster, users of earlier versions of the **STAGS** program should compare this document with the earlier documentation before using **STAGS** 5.0.

This *User Manual* is a *reference* document with a lot of gory detail in it. It is most appropriately used off-line, in its printed form; but it is also accessible and can be used on-line *via* Acrobat Reader. The ***STAGS** Elements Manual* contains more detailed descriptions of many (but not all) of the standard "spring" elements, "beam" elements, triangular and quadrilateral shell elements, solid elements, shell/solid sandwich elements and “contact” elements that are implemented in **STAGS** 5.0 and its post-analysis processors. The ***STAGS** Elements Manual* also contains detailed descriptions of the input and interface requirements for implementing and utilizing *user-developed* elements in **STAGS** 5.0. The ***STAGS** Test Cases Manual* contains capsule descriptions of **STAGS**’ basic and special-purpose capabilities and in-depth descriptions of a number of illustrative and instructive test cases that are of interest to new and experienced **STAGS** users. The ***STAGS** Test Cases Manual* is an interesting and a very promising “work in progress.”

We also recommend the ***STAR** Reference Manual* as another valuable off-line companion to this User Manual and its other input/output-oriented companions. The ***STAR** Reference Manual* documents the **STAGS** Access Routines (STAR)—a library of FORTRAN routines that gives the user access to the **STAGS** Virtual Database (VDB). Major features of **STAGS** 5.0, STAR and VDB combine to give more sophisticated **STAGS** users high-level read/write access to model and solution data—facilitating the development of software for interfacing **STAGS** with other computational tools (such as graphical pre-/post-processors).

STAGS 5.0 is the most recent result of an ambitious project to enhance and rewrite large portions of the **STAGS** software and documentation. Development of **STAGS** and its companion programs continued under the leadership of Dr. Charles C. Rankin at the Lockheed–Martin Advanced Technology Center in Palo Alto, California—until his retirement from that company in April of 2003. Development of **STAGS** and its companion programs continues under his leadership now at the Rhombus Consultants Group in Mountain View, California. Additional code and documentation releases are anticipated in the future as more improvements are made.

Using this Document and its Companion Documents

Basic conventions used throughout this document for input-record descriptions are described in Chapter 5. Methods for *navigating* within the printed version of this document are described there and in the Table of Contents. The same record-description conventions and navigation methods used in this document are also used in the companion ***STAGS** Test Cases Manual*.

The most important navigation decisions that the analyst who is trying to use **STAGS** must make are usually related to the question “what is the next input requirement that must be satisfied?” These questions are answered by the ***“where to go from here”*** information that is at the end of each input-record description. For the example that is described in Chapter 5, the ***“where to go from here”*** information looks like this:

✦ **NESP** (I-1) number of points on the (σ, ε) curve

```
if (NESP > 0) then go to I-3
else follow instructions at end of I-3a
```

The ✦ symbol, here, tells the user that important navigation information follows.

The key parts of this navigation information are in FORTRAN-like statements that tell the user which model-definition or solution-control record to consider next. More often than not, the next record depends on the value of one or more parameters on the current record and/or on previous records. Each parameter that was specified on a previous record is listed before the *if-then-else* constructs—the record identified by its alphanumeric index (I-1, in this example) in parentheses. The next record that the analyst must consider is identified by the pseudo-code that follows. In this example, the analyst is directed to the I-3 record if he/she gave a positive value to **NESP** on the most recent I-1 record, or to the navigation instructions at the end of the I-3a record if **NESP** was not positive.

The analyst who is using Acrobat Reader to view this document and/or its companion documents can transfer immediately to *any* page in the document being viewed with the “bookmark” facility that the Acrobat Reader application provides—and can also move around freely within that document using any of Reader’s other navigation and text-searching facilities.

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Introduction

1.1 About this Manual

The “Preface” to this *User Manual* contains important information about input-data differences between version 5.0 of **STAGS** and previous versions of the program. The “Using This Documentation” section between the “Preface” and the “Table of Contents” describes methods for navigating within this document and within its companion ***Elements*** and ***Test Cases*** documents. Some of the key topics covered in this Manual are highlighted in the following Table:

1.2 About STAGS

STAGS is fundamentally a finite element code for general-purpose analysis of shell structures of arbitrary shape and complexity, with additional capabilities for analysis of solids and other types of structural configurations. Shells to be analyzed by **STAGS** may be thin or thick, unstiffened or stiffened, with stiffeners modeled either as beams or as shells. The availability of numerous wall-fabrication and stiffener-cross-section options combined with a variety of material models permits tremendous flexibility in modeling a wide spectrum of construction types. Analysis capabilities include stress, stability, vibration, and transient analyses, with both material and geometric nonlinearities permissible.

STAGS has a long and distinguished history—starting in the late 1960’s in the Lockheed Missiles and Space Company’s Research and Development Division (R&DD) as a company-sponsored research code to study the stability of shells, and continuing to the present at Lockheed-Martin’s Advanced Technology Center. The primary goal of the **STAGS** group at Lockheed and at Lockheed-Martin has always been to achieve the best shell stability code available anywhere. Research with and development of **STAGS** has been under continuous sponsorship from U.S. government agencies and Lockheed’s Independent Research program from the beginning.

STAGS 5.0—Selected Topics

Topic	Reference
Installation and execution	Chapter 2 “Installation and Execution”
Tutorial	Chapter 3 “Getting Started”
Coordinate systems	Section 4.1 “Coordinate Systems”
Input data	Chapter 5 “Model Input” Chapter 6 “Model Input—Shell Units” Chapter 7 “Model Input—Element Units (1)” Chapter 8 “Model Input—Element Units (2)” Chapter 9 “Model Input—Element Units (3)” Chapter 10 “Model Input—Element Units (4)” Chapter 11 “Solution Input” Appendix B “**STAPL** Input” Appendix L “Design Parameter Derivatives”
User-written subroutines	Chapter 12 “User-Written Subroutines”
User-defined elements	Chapter 13 “User–Defined Elements”
Input and output files	Chapter 17 “Input/Output Files”
Developing an interface between **STAGS** and a pre- or post-processor	**STAR** Reference Manual

Today, **STAGS** has a world-wide distribution and is used extensively throughout government, industry and academia.

Analysis and structure types

STAGS has the following analysis capabilities:

- linear elastic stress analysis
- geometrically nonlinear elastic stress analysis
- geometrically linear inelastic stress analysis
- geometrically nonlinear inelastic stress analysis
- linear bifurcation buckling analysis based upon either a linear or a nonlinear stress state
- branch on bifurcation from a primary path to a secondary solution path
- linear vibration analysis based upon either a linear or a nonlinear stress state
- transient response analysis, elastic or inelastic, geometrically linear or nonlinear

STAGS is used extensively throughout the aerospace, shipbuilding and other industries for analysis of panels, pressure vessels, and general shell structures. While it can be efficiently applied to routine linear systems, **STAGS**' forte is the analysis of complex, nonlinear systems that depend on post-buckling strength and require analysis well into the post-buckled regime. **STAGS** is routinely used for pre- and post-test verifications of complex systems—especially those that are sensitive to initial geometric imperfections, which can be defined in **STAGS** with ease and flexibility.

STAGS has been used by NASA for Space Shuttle and Aging Aircraft analyses. It was used to perform a buckling analysis of the pear-shaped orbiter fuselage, and it was used for analysis of the solid rocket booster during the redesign activities following the Challenger event. It has been used for analysis of advanced aircraft, such as the High Speed Civil Transport (HSCT), and is currently being used for analyses of crack propagationss, delaminations, and other phenomena that occur in aging aircraft structures.

STAGS has played a major role in pressure-hull design of U.S. Navy submarines, and it has been coupled with **USA** (Underwater Shock Analysis) in the **USA-STAGS** code for the shock-load analysis of submarine structures.

STAGS has been used for analysis of nuclear reactor containment vessels, strategic missiles, and advanced solid rocket motor cases. It is also used for the analysis of almost every structure designed in the Lockheed's RDD for cryogenic coolers, space experiments, and satellite systems such as antennas, mirrors, and telescopes.

Following is a summary of some of the structure types for which **STAGS** is applicable:

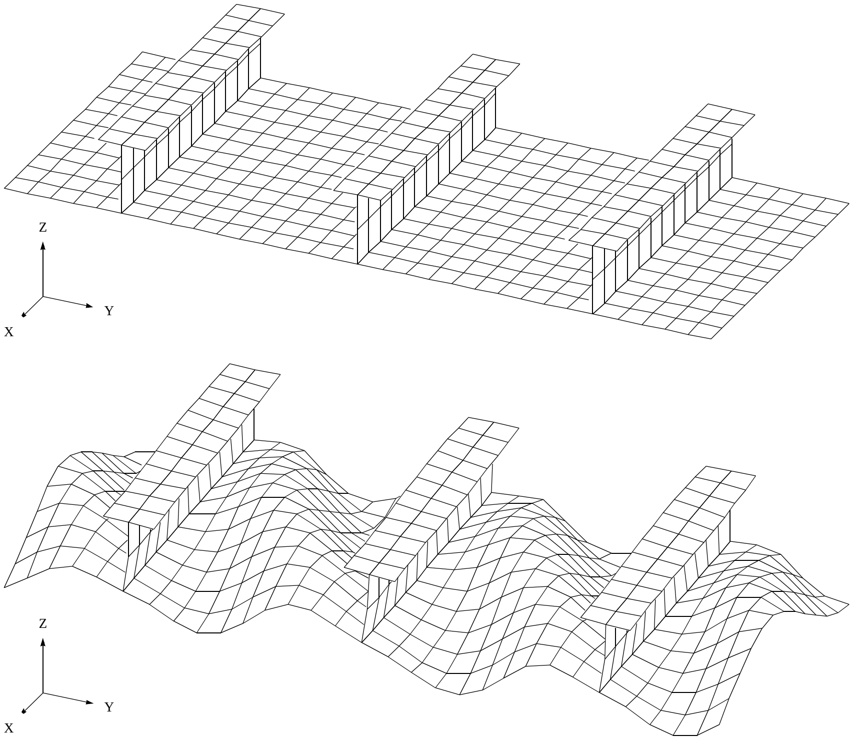


Figure 1.1 Section of a tee-stiffened panel. Above: undeformed shape. Below: highly-stressed, post-buckled shape due to normal pressure and shear.

- panels
- pressure vessels
- aircraft
- spacecraft
- offshore oil platforms
- ships
- submarines
- cryogenic coolers
- reactor containment vessels
- solid rocket motor cases
- satellite systems
- space experiments
- strategic missiles
- general shell structures

STAGS’ capabilities for solution of difficult, nonlinear shell problems are typified by Figure 1.1 through Figure 1.4, which show examples of some of the kinds of problems for which **STAGS** is applicable.

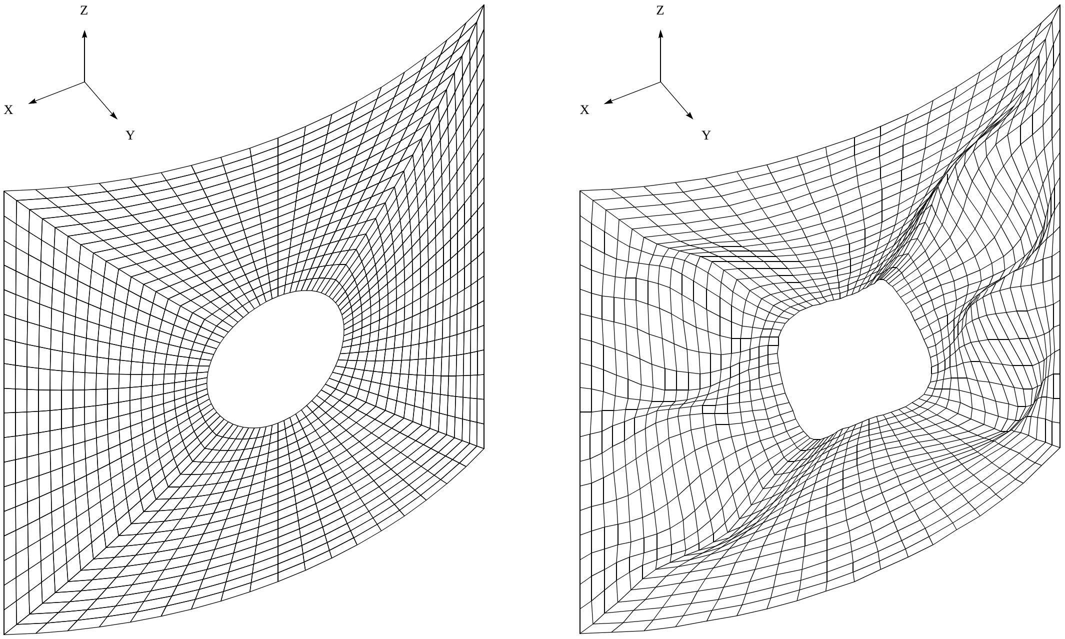


Figure 1.2 Cylindrical panel with circular cutout. Left: undeformed shape. Right: buckled shape due to axial compression.

Solution algorithms

Solution control in **STAGS** is quite sophisticated, ranging from simple load control to the advanced Riks arc-length parameter technique that enables traversal of limit points into the post-buckling regime, to equivalence transformation methods to obtain solutions during mode-jumping behavior that may occur in bifurcation and post-buckling response. For arc-length algorithms, the solution can be directed to stop at maximum load, or to go into a negative direction for determination of permanent set. Two load systems with different histories can be defined at the same time and can be controlled separately during the solution process.

STAGS solutions can be saved according to user instructions for restart or for postprocessing. The state at termination is always saved for future use. Flexible restart procedures permit switching from one strategy to another during an analysis; this includes a shift from static to transient, or from transient to static with modified boundary conditions and loadings.

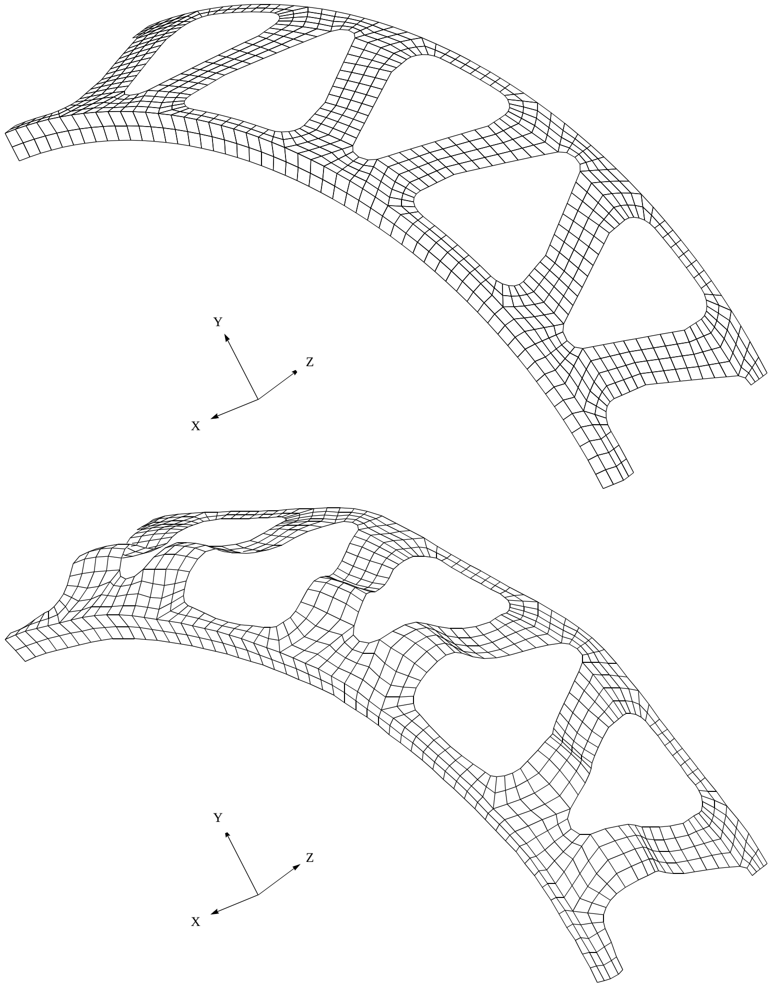


Figure 1.3 One-quadrant model of a jet aircraft engine support ring. Above: undeformed shape. Below: deformation due to a severe thermal gradient, plasticity, and creep.

STAGS provides solutions to the generalized eigenvalue problem for buckling and vibration from a linear or nonlinear stress state. A robust solution algorithm allows for efficient shifting to the neighborhood of eigenvector-eigenvalue pairs sought.

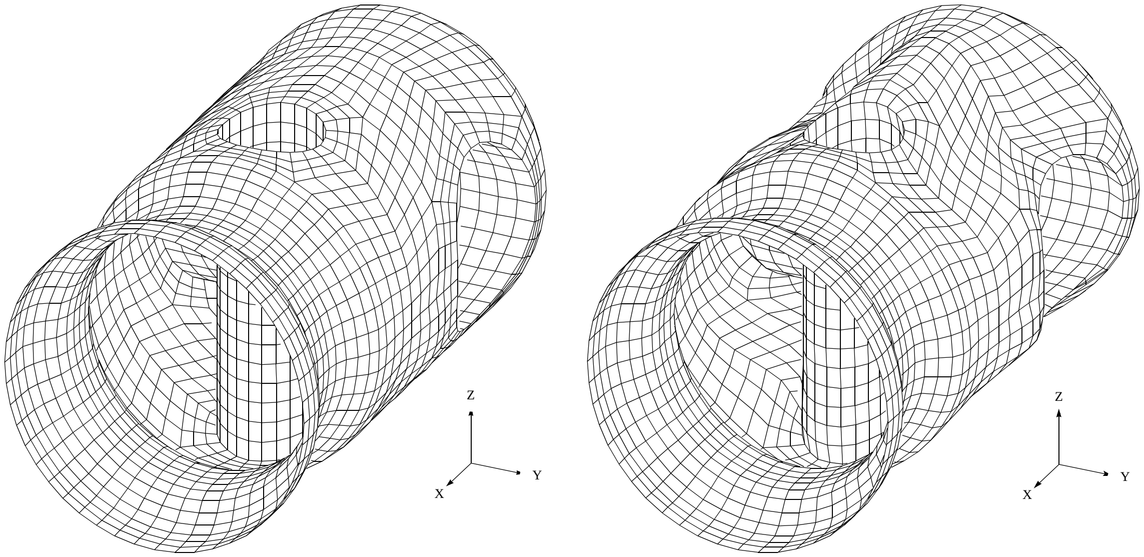


Figure 1.4 Complex titanium pressure vessel. Left: undeformed shape. Right: plastic collapse analysis under hydrostatic pressure.

An element-independent, large rotation algorithm is in place, allowing for analysis of structures undergoing arbitrary displacements and moderate strains, with no artificial stiffening due to large rotations. Not only are all elements objective to arbitrary rigid-body motion, but the first and second variations of the strain energy are consistent, resulting in quadratic convergence for true-Newton iteration sequences.

STAGS can also treat some types of structural contact problems—with very efficient element-on-element (Hertzian) PAD-type contact elements when the contact region is known *a priori*, with more general point/surface contact elements when the contact region is not known *a priori* and/or when element-on-element contact is not expected and/or slippage occurs, and with line and line-interaction contact elements.

Modeling

Quadratic surfaces can be modeled automatically in **STAGS**, with minimal user input, as individual substructures, called *shell units*. An important feature here is that the analytic geometry is represented exactly—there is no need to be concerned with accuracy limitations imposed by parametric representation, such as that typically found in modern finite-element modeling software. These shell units can be generated and interconnected along edges, along internal grid lines, or in more general ways, with provisions in the program for treating either partial or complete compatibility. Using these techniques, complex structures can be assembled. In addition to these automatically-generated shell units describing quadratic surfaces, *element units* may be defined as arbitrary assemblages of nodes and elements. Element units may be used to complement a structure that is made up of **STAGS**-generated shell units and/or to form a self-contained structural model generated by **STAGS** and/or by other programs.

Material, wall & stiffener properties

A variety of material models is available, including both plasticity and creep. This, with numerous wall-fabrication and stiffener-cross-section options, permits tremendous flexibility in modeling a wide spectrum of construction types. **STAGS** handles isotropic and anisotropic materials, including composites consisting of up to 100 layers of arbitrary orientation. Four plasticity models are available, including the often used isotropic strain hardening, White-Besseling (mechanical sublayer model), kinematic strain hardening, and deformation theory. Progressive failure analysis models are available for laminated composite structures using five common failure criteria and material degradation models. Easily defined standard wall types include orthotropic laminate, fiber-wound, and corrugation-stiffened. Additional generality is provided by the option for direct input of stiffnesses relating stress and moment resultants to surface strains and curvatures. Stiffener cross sections may be built-up from subelements described either by explicit geometry or by geometric properties. Smeared stiffeners are also an option.

Loads

Two independent load sets, each composed from simple parts that are easily specified with minimal input, define a spatial variation of loading. Any number of prescribed displacements, point loads, line loads, surface tractions, thermal loads, and “live” pressure loads (hydrostatic pressure that remains normal to the shell surface throughout large deformations) can be combined in this manner to make a load set. Inertial loadings can be specified for the structure as well. For transient analysis, the user may select from a menu of convenient loading histories; or he/she may specify a completely-general temporal variation *via* a user-written subroutine.

Boundary conditions

Boundary conditions (BCs) may be imposed either by reference to certain standard conditions or by the use of single-point and multi-point constraints. Simple support, symmetry, antisymmetry, clamped, or user-defined BCs can be specified on a shell unit edge. Single-point constraints which allow individual freedoms to be free, fixed, or a prescribed nonzero value may be applied to grid lines and surfaces in shell units. A useful feature for buckling analysis allows these constraints to differ for the prestress and eigenvalue analyses. Lagrangian constraint equations containing up to 100 terms may be easily defined to impose multi-point constraints. Advanced features include a "moving-plane" boundary permitting arbitrary motion of a boundary while requiring all nodes on the boundary to remain coplanar.

Element library

STAGS has a variety of finite elements that are suitable for the analysis of stiffened plates, shells, and solids.

Simple 4-node quadrilateral plate elements with a cubic lateral displacement field provide a very effective and efficient building block for the description of complex post-buckling thin-shell response. A linear or quadratic membrane interpolation can be selected. For thicker shells in which transverse shear deformation is important, **STAGS** provides the Assumed Natural Strain (ANS) 9-node element which has proven to be a sturdy performer for complex structures. A 2-node beam element that is compatible with the 4-node quadrilateral plate element is provided to simulate stiffeners and beam assemblies. For irregular geometries, Clough-Tocher triangular plates can be combined automatically to make quadrilaterals. In addition to these standard shell elements, there are two mesh-transition shell elements that can be used very effectively with shell structures in which there are transitions from finer to coarser grids. One of these is used along an edge that has 2N shell elements on one side and N shell elements along the other (with two elements on the first side paired with a single element on the second). The other is used at junctures where two (or three) finely-meshed shell regions meet a coarsely-meshed region at a single point. Each of these elements is capable of describing large-displacement, moderate-strain response because the element-independent large rotation algorithm, described previously, functions with all types of finite elements.

STAGS has four standard solid elements that are suitable for treating thick shells and 3-D solid structures. The simplest of these elements—the 8-node brick—can be used very effectively in structural regions that have minimal geometric and material variations and that experience reasonably uniform or slowly varying responses. The other three solid elements—which have 18, 20 and 27 nodes—are suitable for structural regions in which geometric, material and structural characteristics and responses are nonuniform in any or all of these domains.

STAGS has a two standard elements that are suitable for treating sandwich shell structures. The simpler of these elements—the 8-node sandwich—uses two 4-node quadrilateral shell elements to model the upper and lower surfaces (one each) and one or more 8-node bricks to model the solid core between the upper and lower surfaces of the element. This hybrid element can be used most effectively in structural regions that have minimal geometric and material variations and that experience reasonably uniform or slowly varying responses. The more refined—18-node sandwich—element uses two 9-node quadrilateral shell elements to model the upper and lower surfaces and one or more 18-node solid elements to model the core. This element is must useful in structural regions where geometric, material and structural characteristics and responses are more complex. In addition to these two standard sandwich elements, there are two mesh-transition sandwich elements that can be used very effectively with structures in which there are transitions from finer to coarser sandwich-element grids. One of these is used along an edge that has 2N sandwich elements on one side and N sandwich elements along the other (with two elements on the first side paired with a single element on the second). The other is used at junctures where two (or three) finely-meshed sandwich regions meet a coarsely-meshed sandwich region at a single point.

In addition to these standard and hybrid finite elements, **STAGS** provides several types of specialized elements. For transition from a finer to a coarser grid, there is a line-constraint element that enforces edge compatibility of the fine mesh with the coarse mesh. The nonlinear mount element is a generalized spring with a user-input force-displacement-velocity profile that can serve as a connector, with offset, between any two nodes in the system. By a suitable choice of input, the user can model very complex mount response, including nonlinear damping. Other specialized elements are involved in the moving-plane boundary condition described previously.

Initial geometric imperfections

Initial imperfections can be defined automatically in a variety of ways, permitting imperfection-sensitivity studies to be performed with minimal effort. This can be an invaluable aid in numerous situations, such as when analyzing a weight-critical design where there is uncertainty about knockdown factors for buckling, and/or for determining allowable manufacturing tolerances. Imperfections can be generated from linear combinations of previously-computed buckling modes; from a trigonometric expansion using a simple input of mode numbers, shell-surface locations, and amplitudes; or from user-written subroutines. A special random imperfection capability allows for randomly-generated amplitudes with specified standard deviation and mean values. Combinations of buckling modes and trigonometric data are permitted. A higher-order definition of the imperfection waveform is used in element computations.

User-written subroutines

The option of using user-written subroutines is a very powerful feature of **STAGS**. User-written subroutines can be used in very basic ways as elegant alternatives to lengthy input decks, or in more sophisticated ways to extend the generality of the code. Users can easily define arbitrary functional relationships, such as spatially-varying geometric and constitutive properties in a wall fabrication, or general time-varying pressure loads. Nearly all aspects of model definition, from the most basic to extremely complex ones, can be performed *via* user-written subroutines. See Chapter 12 for more about this feature.

User-defined elements

The current version of **STAGS** gives the user the very powerful capability to install and employ User-defined elements. See Chapter 13 for more about this feature.

2
Installation and Execution

Methods for installation, maintenance and execution of **STAGS** programs on various computer platforms are described in this chapter. Before getting into that, however, a few words about how the **STAGS** program system is organized and about how this chapter is organized are in order.

One important thing to note here is that the **STAGS** program system "looks" the same (*i.e.*, it has the same software components and is organized in the directory structure) on all of the (UNIX, Linux, Macintosh and Windows-based) computer platforms on which it operates. The directory structure that **STAGS** uses on all of these platforms is described in Section 2.1 of this chapter. The "administrator" who *installs* **STAGS** on any given machine should read Section 2.1 because he (or she) must understand this directory structure and operate within it. Anyone who *uses* **STAGS** on any installation needs to understand this directory structure, too. This is especially true for users who want or need to construct and execute *customized* versions of **STAGS** processors utilizing user-written subroutines, user-defined elements, or any other non-standard components.

Methods for installing, maintaining and executing **STAGS** are discussed next. Computer requirements, installation procedures, maintenance methods and execution procedures for **STAGS** are generally computer-system and computing-environment dependent. These four subjects are discussed in a separate section of this chapter for each of the currently supported platforms:

Platform	**Section**
UNIX	2.2 "UNIX-Based Systems" on page 2-6
Linux	2.3 "Linux-Based Systems" on page 2-17
Macintosh	2.4 "Macintosh-Based Systems" on page 2-26
Windows	2.5 "Windows-Based Systems" on page 2-35

In each of these four platform-specific sections, there are three subsections: the first contains a concise summery of the basic system requirements (operating systems supported, free disk space needed, utilities and compilers needed, *etc.*) for installing and executing **STAGS** programs on the platform in question; the second has important information that the administrator who installs **STAGS** on that platform needs; and the third has vital information that anyone who executes **STAGS** programs on that platform needs. **STAGS** administrators should read the “Basic... System Requirements” and the “Installation...” subsections for the platform onto which **STAGS** is to be installed. All users should read the “Execution...” part of the section for the platform on which **STAGS** is to be executed.

The final section of this chapter (“Installation Verification” on page 2-36) contains information that the **STAGS** administrator needs to validate the installation and performance of **STAGS** on any of these platforms. This information may be of interest and value to other **STAGS** users, as well.

2.1 STAGS Directory Structure (all platforms)

The most important components of the **STAGS** directory structure (on all platforms) are shown schematically in Figure 2.1:

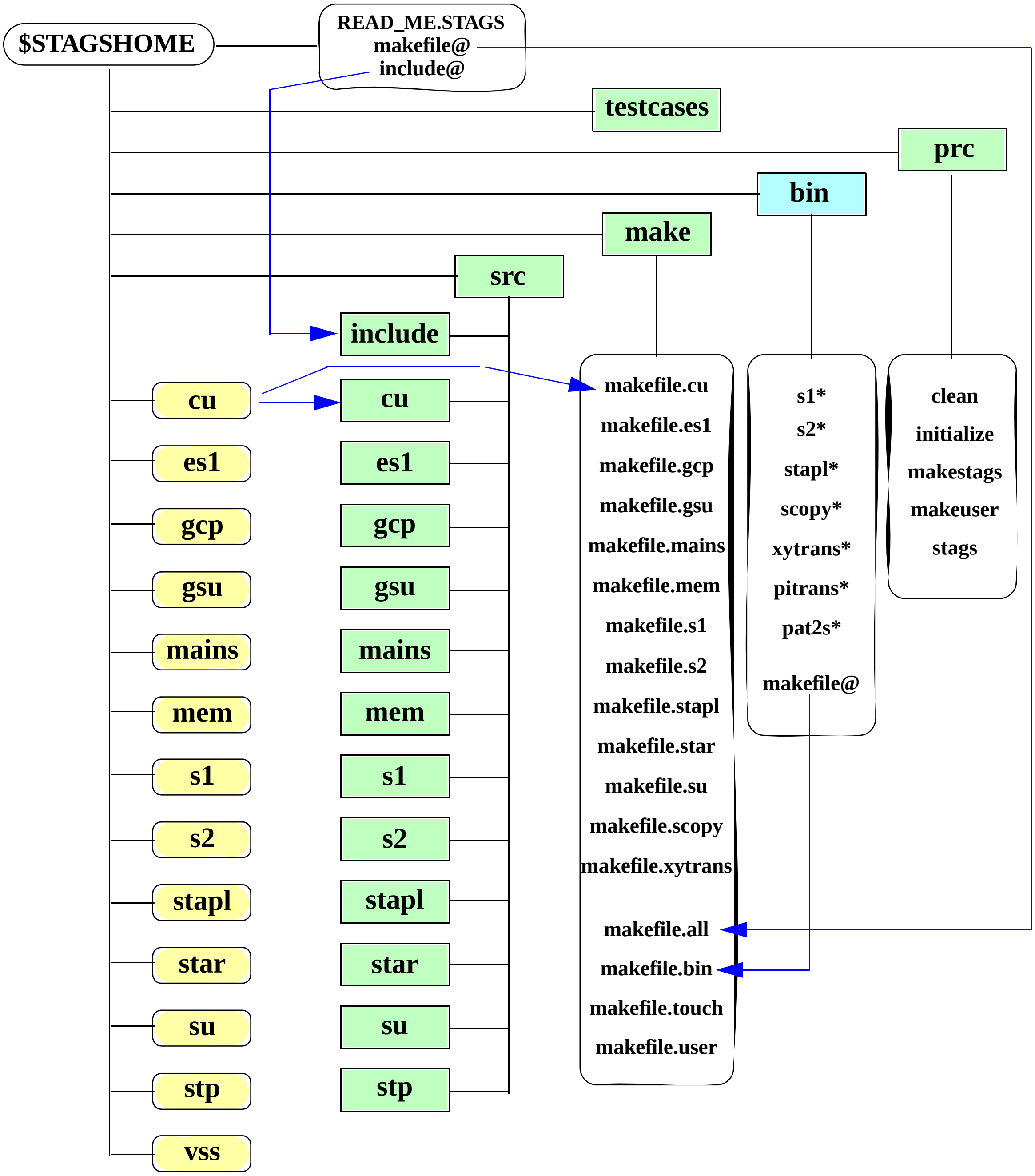


Figure 2.1 **STAGS** directory structure (all platforms)

Symbols, conventions and meanings of graphic and text elements in Figure 2.1 are explained in Figure 2.2:

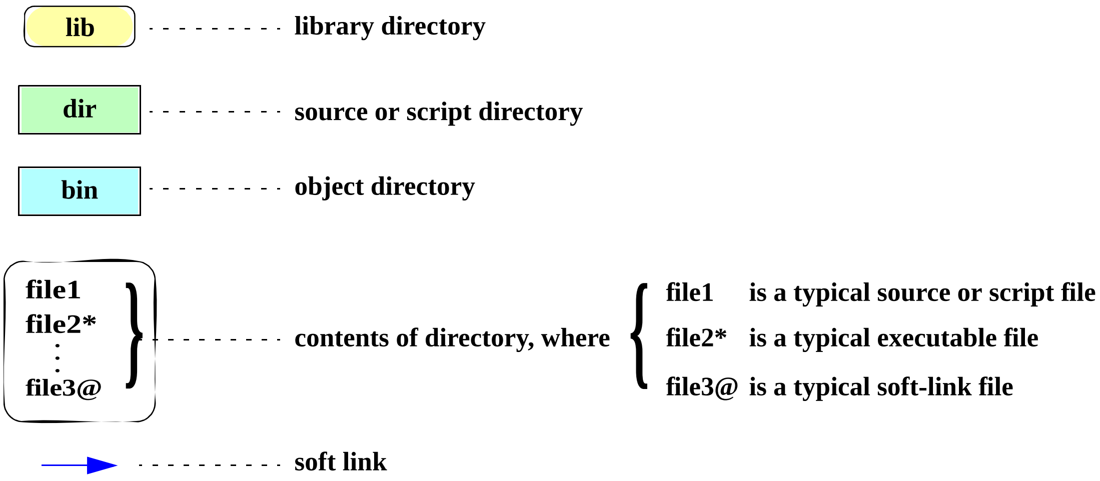

lib
library directory
dir
source or script directory
bin
object directory
file1
file2*
file3@
contents of directory, where
file1 is a typical source or script file
file2* is a typical executable file
file3@ is a typical soft-link file
soft link

Figure 2.2 Symbols used in the **STAGS** directory diagram.

With one exception, each (yellow) **$STAGSHOME/lib** library directory contains three files:

makefile@ this is a soft link to the makefile (makefile.lib, in the “make” directory) that is actually used to build the desired library file lib.a for this particular library directory; only one of these soft links (for the **cu** library) is shown (as a blue, arrow-tipped line) in Figure 2.1

src@ this is a soft link to the (green) subdirectory (src/lib) that contains the FORTRAN or C-language source code that is required to build the library file for this particular library directory; only one of these soft links (for the **cu** library) is shown (as a blue, arrow-tipped line) in Figure 2.1

lib.a this is the desired library file for this particular library directory

The sole exception to this pattern is the **$STAGSHOME/vss** library directory. Source code for the vss equation solver is proprietary and is not typically distributed with the **STAGS** program, so the **$STAGSHOME/vss** library directory only contains the pre-built library file vss.a for the platform to be used.

When **STAGS** is installed correctly, the **$STAGSHOME/bin** directory (see Figure 2.1) contains seven executable **STAGS** processors (**s1**, **s2**, **stapl**, **scopy**, **xytrans, pitrans** and **pat2s**) and one soft-link file (**makefile**). The **makefile** soft link (a blue, arrow-tipped line, in Figure 2.1) “points” to the **$STAGSHOME/make/makefile.all**: this is a makefile script that is used to “make” *all* of the libraries and programs in the **STAGS** system.

When **STAGS** is installed correctly, the **$STAGSHOME/prc** directory contains a number of script and other files that are used to establish a standardized **STAGS** environment, to run **STAGS** programs, and to manage **STAGS** resources and **STAGS**-related user files. These processors, links, scripts and files are discussed in the following subsections.

2.2 UNIX-Based Systems

2.2.1 Basic UNIX System Requirements

Basic system requirements that must be met to install **STAGS** on a UNIX system are summarized in the following table and text:

Machine	Type	OS	Disk Space
DEC	Alpha workstation	??	??
HP	32-bit architecture workstation	HP-UX	80 MB
HP	64-bit architecture & code, 4-byte integers	HP-UX	80 MB
HP	64-bit architecture & code, 8-byte integers	HP-UX	80 MB
IBM	RS_6000 workstation	??	??
SGI	32-bit IRIS workstation	??	140 MB
SGI	64-bit architecture, 32-bit object code	??	140 MB
SGI	64-bit architecture & code, 4-byte integers	??	140 MB
SGI	64-bit architecture & code, 8-byte integers	??	140 MB
SUN	SUN-4 / SPARC workstation	Solaris	85 MB
SUN	SPARC workstation	SunOS	85 MB

Compilers required	FORTRAN & C-languages

Other system requirements that must be met (and should be comfortably exceeded) to execute **STAGS** programs on a UNIX system are summarized in the following table:

Processor speed requirements	300 MHz
Memory requirements	256 MB
Storage requirements	512 MB

2.2.2 Installation of STAGS on a UNIX System

On a UNIX system, one *must* be running the C-Shell to install **STAGS**. If the C-Shell is not your default shell, you must change to csh to perform the installation.

Installing STAGS on a UNIX system

UNIX versions of **STAGS** are typically distributed on CDs or *via* “ftp” as compressed tar or gzip-formatted archive files. The first step in installing **STAGS** on a UNIX system is to transfer the contents of the distribution media onto the computer system to be used.

When **STAGS** is distributed as a compressed tar archive file, the name of the file is typically `stags_{type}.tar.Z`, where `{type}` is an abbreviation for the type of machine onto which **STAGS** is to be installed. In this case,

1) Move the compressed tar file to the directory in which you want the stags directory to reside (into */usr/local*, for example).

2) Issue the following command, to decompress the compressed tar file and construct the desired **stags** directory:

```
% zcat stags_{type}.tar | tar xvf -
```

When **STAGS** is distributed as a gzip-formatted archive file, the name of the file is typically `stags_{type}.tgz`, where `{type}` is an abbreviation for the type of machine onto which **STAGS** is to be installed. In this case,

1) Move the gzip-compressed archive file to the directory in which you want the stags directory to reside (into */usr/local*, for example).

2) Issue the following command, to unzip the compressed archive file into its tar-formatted form:

```
% gunzip stags_{type}.tgz
```

3) Issue the following command, to unwrap the tar-formatted file and construct the desired **stags** directory:

```
% tar xf stags_{type}.tar
```

Having unloaded (and decompressed) the archive file, you should then have a new subdirectory, named **stags**, that is installed in the current working directory. This directory is referred to as **$STAGSHOME** in the file directory diagram that is shown in Figure 2.1. Continue the installation process by executing the `RUN.ME.FIRST` script from the new **stags** subdirectory, as follows:

```
% cd stags
% RUN.ME.FIRST
```

The `RUN.ME.FIRST` script modifies certain **STAGS** files to complete the installation, then it commits suicide by deleting itself. Installation is now complete. Before **STAGS** can be executed, however, it is necessary to perform an initialization step that establishes a number of command aliases and environmental variables that are needed to operate on and with **STAGS** programs.

Initializing STAGS on a UNIX system

Issue the following command once per login session prior to changing or running **STAGS**:

```
% source $STAGSHOME/prc/initialize
```

where **$STAGSHOME** is the complete path name to the **stags** directory structure that is shown in Figure 2.1. The **$STAGSHOME/prc/initialize** procedure establishes a number of command aliases and environmental variables that are necessary to operate on and/or to execute the **STAGS** programs. For example, **$STAGSHOME** is defined as an environmental variable that contains the path name of the **stags** directory.

It is strongly recommended that each **STAGS** user inspect the **$STAGSHOME/prc/initialize** file to see the aliases and variables that it creates, and install this command (or define an alias for it) in his or her .login file.

Making STAGS on a UNIX system (as and if necessary)

For UNIX installations, **STAGS** is typically distributed with source code and with object libraries and executables, for specific machine architectures. Normally, it is not necessary for the administrator who installs **STAGS** or for the typical **STAGS** user to “make” **STAGS** programs. In unusual circumstances—such as when inconsistencies exist between the environment used to create the **STAGS** distribution software and the environment on the user’s machine—it may be necessary for the administrator (and/or for the user) to do so. The computationally-sophisticated user may elect to recompile and re-link **STAGS** components to take advantage of high-performance compilation and/or optimization features that may be available on his or her machine.

To make **STAGS**, simply execute the UNIX `make` command from the **$STAGSHOME** directory. To make specific libraries or executables, issue the following command from any directory:

```
% makestags [target]
```

See the file **$STAGSHOME/prc/makestags** for a list of valid targets. To remake the star library, for example, execute the command:

```
% makestags star.a
```

Invocation of the `makestags` command, with no arguments, will make all of **STAGS**. It is equivalent to executing the `make` command from **$STAGSHOME**.

Coping with installation errors (as and if necessary)

Some common causes of installation difficulties include insufficient disk space, lack of write permission in the selected directory, attempting to perform installation from a shell other than the C-shell, nonexistence of UNIX commands that are required for the installation procedure, and installer boneheadedness. If installation is not successful, identify and correct the problem; then delete the entire **$STAGSHOME** directory and start over again at the 2.2.2 "Installation of STAGS on a UNIX System" point.

Verifying that STAGS operates correctly

Correct operation of **STAGS** can be verified by running the small suite of test cases in the **$STAGSHOME/testcases** directory and examining selected portions of the output. Basic concepts and procedures for executing **STAGS** processors on UNIX systems are described in the following subsection—which the administrator who installs **STAGS** and anyone who uses it on such a system must master. A first-level operation verification procedure for **STAGS** is discussed in Section 2.6 (at the end of this chapter).

2.2.3 Execution of STAGS on a UNIX System

Before we address this subject, it is important for the reader to understand that there are two basic types of executable **STAGS** programs:

- *default* executables — these are the standard versions of the **STAGS** processors (**s1**, **s2**, **stapl, scopy** and **xytrans**) that are supplied with the program and used for most applications; these executables are stored in the **$STAGSHOME/bin** directory
- *custom* executables — these are application-dependent versions of **s1**, **s2**, **stapl, scopy** and/or **xytrans**—which are typically created by linking with user-written subroutines and/or user-defined elements and are typically stored in user-controlled directories.

On UNIX systems, the **$STAGSHOME/prc** directory contains a number of procedure files that facilitate the execution and construction of **STAGS** programs. These procedure files (scripts) are described in the **$STAGSHOME/README** file. The most important of these (in the "execution" department) is the **stags** procedure—which is typically used to run

• **s1**	**STAGS'** model processor
• **s2**	**STAGS'** solution processor
• **stapl**	**STAGS'** plotting post-processor
• **scopy**	**STAGS'** file-copy processor
• **pitrans**	**STAGS'** translator/post-processor
• **xytrans**	**STAGS'** post-processor to generate data for XY plots

to construct a **STAGS** model, to perform one or more analyses with it, to perform pre- and/or post-analysis plotting operations, and to do other things with data on **STAGS** I/O files.* The most important of these procedures (in the "construction" department) is **makeuser**—which is used to "make" custom versions of **STAGS** processors when it is necessary to do so. The remainder of this subsection is devoted to descriptions of these two procedures:

`stags`: On UNIX systems, one typically "runs" the **STAGS** program(s) by invoking the **$STAGSHOME/prc/stags** procedure; this is typically done *via* the `stags` alias, which is constructed by **$STAGSHOME/prc/initialize** when the user initializes **STAGS** prior to exercising it; the `stags` procedure can be used to run **STAGS** with default and/or with custom **STAGS** executables.

See "Executing STAGS with stags (UNIX)" on page 2-12 for information about the **stags** procedure, and "Initializing STAGS on a UNIX system" on page 2-8 for more information about the initialization process.

* See Chapter 17 "Input/Output Files" for documentation on **STAGS** I/O files.

`makeuser` Custom, user-owned versions of executable **STAGS** processors may be created with the **$STAGSHOME/prc/makeuser** procedure, which is generally executed *via* the `makeuser` alias that **$STAGSHOME/prc/initialize** defines when the user initializes **STAGS** prior to exercising it; custom executables must be created and executed when user-written subroutines and/or user-defined elements are employed.

See “Creating custom STAGS executables with makeuser (UNIX)” on page 2-14 for more information about the `makeuser` procedure.

See “Initializing STAGS on a UNIX system” on page 2-8 for information about the initialization process.

See Chapter 12 “User-Written Subroutines” for more information about user-written subroutines, and Chapter 13 “User–Defined Elements” for more information about user-defined elements.

Users can also create special-purpose versions of **STAGS** code, since source code is distributed with the program; this type of advanced use is outside the scope of this document, but the sophisticated analyst may find occasion to customize **STAGS** for specific applications.

Executing STAGS with stags (UNIX)

Synopsis

```
stags [options] casename [options]
```

Options

`-b` – run **STAGS** in background; the default nice value is 10.

`-n [nice_value]` – set nice value for non-queued jobs; if option `-n` is selected, but a nice value is not supplied, the default is 10.

`-sm` – send email message upon termination of background jobs; default is send no email; queued jobs always send email upon termination.

`-q` – submit **STAGS** job to NQS (Network Queuing System) queue.

`-t seconds` – set time-limit for queued job to `seconds`; the default is 900.

`-1 [s1_executable]` – run **s1**; a user-specified **s1** executable is optionally defined.

`-2 [s2_executable]` – run **s2**; a user-specified **s2** executable is optionally defined.

`-rh [remote_hostname]` – copy files from specified hostname into local $TMPDIR for execution and then put the results back on the remote host upon completion. `remote_hostname` must appear in user’s ~/.netrc file; primarily intended for use on highly-impacted systems such as CRAYs.

`-rd [remote_directory]` – directory on remote machine from which to copy input data files and to which to copy output files; valid only when `remote_hostname` is specified; default is ~.

Examples

- run the default **s1** and **s2** executables interactively or in the foreground

  ```
  % stags casename
  ```

  If neither `-1` nor `-2` is present, then both **s1** and **s2** will be run in succession, using the default executables.

- run a custom version of **s2** with the default version of **s1**

  ```
  % stags  -1  -2 [s2_executable]  casename
  ```

- run a custom version of **s1** with the default version of **s2**

  ```
  % stags  -2  -1 [s1_executable]  casename
  ```

- run default **s1** and custom **s2** in background, then send email upon completion

  ```
  % stags -b -1 -2 ~/my_s2 -sm mycase
  ```

- run custom **s2** in the background, then send mail upon completion

  ```
  % stags -b -sm -2 ~/my_s2 mycase
  ```

- run **s1** in the foreground

  ```
  % stags mycase -1
  ```

Note that options `-1`/`-2` appear after `mycase` in the above/below examples. Any argument following `-1` or `-2` must be either a valid **STAGS** executable (custom or default) or another option (*i.e.*, an argument beginning with a `-`).

- run **s2** in the foreground

```
% stags mycase -2
```

- NQS queuing system

```
% stags -q -t 1000 mycase
```

The above command will submit the **STAGS** job using `mycase` as input to the queue that runs jobs for at least `1000` seconds. Both the default **s1** and **s2** will be executed.

- remote get & put of I/O files

```
% stags -rh trinity.rdd -rd work/stags mycase -q
```

On some machines (often CRAYs), available user disk space may be at a premium; users may wish to store input and output data on their local machines and instruct **STAGS** to get the input files and put the output files using ftp; the above command will fetch input files for `mycase` from directory `~/work/stags` on remote host `trinity.rdd`, submit the job to the NQS queue of the current host computer, and copy the output files back to `trinity.rdd`; diagnostics will always be emailed when using the remote host option because the “mycase.log” file always gets left behind on the executing machine; users should be aware that previous generations of output files are not retained when using this option; the warning that the input files cannot be found on the current host may be ignored.

Creating custom STAGS executables with makeuser (UNIX)

Synopsis

```
makeuser [-g] [-l userlib.a] [target]
```

Options

`-g` – compile .F files with standard debug option

`-cpp "cppflags"` – where cppflags are valid cpp options; user-entered cppflags are both *prepended* and *appended* to the default cppflags; the user-entered cppflags are prepended so that, if given, alternate include-file directories can be searched before the standard include-file directories; the user-entered cppflags are also appended so that default cpp definitions can be reset by the user; the user-entered cppflags do not replace the default cppflags because **STAGS** code will not compile correctly without certain default cpp definitions that the user is likely to forget to include.

Example: `-cpp "-D_debug_"`

`-fc "fcflags"` – where user-entered fcflags (FORTRAN compiler options) *replace* the default compiler options for all modes of compilation: no optimization, partial optimization, full optimization, and debug; on most machines, users should remember to include the "-c" flag if they exercise this option.

Example: `-fc "-c -g -O2"`

`-cc "ccflags"` – where user-entered ccflags (C compiler options) *replace* the default compiler options.

Example: `-cc "-c -g -O2"`

`-ld "linkflags"` – where user-entered linkflags (linker options) *replace* the default linker options.

Example: `-ld "-M -Bstatic"`

`-l userlib.a` – link library userlib.a when target is made; more than one library can be linked using additional "-l" arguments.

`target` is a target in **$STAGSHOME/make/makefile.user**. Valid targets are:

- `s1` creates a custom version of **s1**, the **STAGS** model processor
- `s2` creates a custom version of **s2**, the **STAGS** solution processor
- `scopy` creates a custom version of **scopy**, a **STAGS** data postprocessor
- `pitrans` creates a custom version of **pitrans**, a **STAGS** translator/postprocessor
- `xytrans` creates a custom version of **xytrans**, a **STAGS** xy-plot-data translator
- `clean` removes custom object and executable files from the current working directory

If no `target` is specified, then `makeuser` attempts to make all **STAGS** executables, placing them in the current working directory (see Table 2.1).

Table 2.1 makeuser target summary

target	action
`s1`	All of the source files (.F, .c, and .h) in the current directory are compiled and the object files produced by those compilations are placed in the user.a library. All of the **s1** program files in user.a are extracted and linked ahead of all other libraries to create the **us1** executable.
`s2`	All of the source files (.F, .c, and .h) in the current directory are compiled and the object files produced by those compilations are placed in the user.a library. All of the **s2** program files in user.a are extracted and linked ahead of all other libraries to create the **us2** executable.
`stapl`	All of the source files (.F, .c, and .h) in the current directory are compiled and the object files produced by those compilations are placed in the user.a library. All of the **stapl** program files in user.a are extracted and linked ahead of all other libraries to create the **ustapl** executable.

`scopy`
`pitrans`
`xytrans`
	All of the source files (.F, .c, and .h) in the current directory are compiled and the object files produced by those compilations are placed in the user.a library.
	All of the files in user.a are extracted and linked ahead of all other libraries to create the **scopy**, **pitrans** and **xytrans** executables.

`clean`	Any of the following files which exist in the current working directory are removed: __* *.o *any* **STAGS** *executable* user.a

Each user-written subroutine must be in a .F source file. Routines called by user-written subroutines, if any, can be in .c files, .F files, and/or in .a library files; do *not* duplicate any **STAGS** names.

The `makeuser` procedure compiles source files (.F, .c, and .h, as appropriate) in the current working directory and links these files ahead of the standard **STAGS** libraries. If user libraries are included, they will be linked after any source files in the current directory but before any **STAGS** libraries.

The `makeuser` procedure operates exclusively on files that are in the current working directory ($cwd) and has no effect on the **$STAGSHOME** file system or on any other file system.

CAUTION: Existing .o files are erased by `makeuser`. These may be placed in a .a library file, which may be linked with the "`-l`" option.

`makeuser` attempts to "force link" any object modules produced from source files, and some linkers will abort if asked to force link a name that is not referenced.; this vexation can be avoided by ensuring that $cwd includes only those source files containing program modules whose names are referenced by the `target`.

Examples

Suppose the current working directory contains the following files:

```
-rw-r--r--  1 stags       12833 Jan 12 10:30 mylib1.a
-rw-r--r--  1 stags       78294 Jan 12 10:30 mylib2.a
-rw-r--r--  1 stags        1242 Jan 12 10:30 user2.F
-rw-r--r--  1 stags        7231 Jan 12 10:30 user1.F
```

- create a custom version of **s2**, incorporating user1.F and user2.F
  ```
  % makeuser s2
  ```
- create a custom version of **s2**—with user1.F and user2.F compiled for symbolic debugging
  ```
  % makeuser -g s2
  ```
- create a custom version of **s2**—linking in mylib1.a and mylib2.a, in addition to user1.F and user2.F
  ```
  % makeuser -l mylib1.a -l mylib2.a s2
  ```
- create a custom version of **s2**—linking in mylib1.a and mylib2.a, together with user1.F and user2.F compiled for symbolic debugging;
  ```
  % makeuser -g -l mylib1.a -l mylib2.a s2
  ```

In all of these examples, `makeuser` will produce a user.a user–library file and a **us2** user–executable file. Since no .c files and no .h files exist in the current directory, makeuser will also create dummy files dummyc.c and dummyi.h.

2.3 Linux-Based Systems

PRELIMINARY:

The good news here is that **STAGS** can be installed easily and can be executed effectively on various flavors of Linux-based machines. The bad news here is that this seriously underfunded section of Chapter 2 is still “under construction” and is somewhat incomplete, right now. While this is the case, we recommend that anyone who experiences difficulties in installing and executing **STAGS** on a Linux-based system contact contact Dr. Charles C. Rankin, at

Rhombus Consultants Group
2565 Leghorn Street
Mountain View, CA 94043

or Dr. Frank C. Weiler, at

Lockheed-Martin Missiles & Space Co., Inc.
ATC Org. L9-21; Bldg. 204
3251 Hanover Street
Palo Alto, CA 94304

2.3.1 Basic Linux System Requirements

Basic system requirements that must be met to install **STAGS** on a Linux system are summarized in the following:

Minimum disk space required	85 MB
System utilities required	fpp & fsplit (supplied)
Compilers required	gcc & g77

System requirements that must be met (and should be comfortably exceeded) to execute **STAGS** programs on a Linux system are summarized in the following table:

Processor speed requirements	300 MHz
Memory requirements	256 MB
Storage requirements	512 MB

2.3.2 Installation of STAGS on a Linux System

STAGS is conveniently installed on Linux systems while operating within the framework of a C-Shell environment.

Installing STAGS on a Linux system

Linux versions of **STAGS** are typically distributed on CDs or *via* “ftp” as a pair of gzip-compressed archive files—the primary distribution file (`stags_linux.tgz)` and a secondary (but necessary) utility file (`ftp_split.tgz`). Installation of **STAGS** on a Linux system is typically a six-step process:

1) Establish the root directory into which **STAGS** is to be installed (the */home/stags* directory, for example)—creating it as and if necessary; make this directory the current working directory.

2) Copy the two **STAGS** distribution files from their distribution medium into this working directory.

3) Extract **STAGS** from the `stags_linux.tgz` file and the **fpp** and **fsplit** utilities from the `fpp_fsplit.tgz` file by issuing the following two commands:

```
% tar xfz stags_linux.tgz
% tar xfz fpp_fsplit.tgz
```

The first operation in this step creates a new subdirectory (named **stags**) within the current working directory. This new subdirectory is called **$STAGSHOME** in the directory structure diagram that is shown in Figure 2.1. After creating this new subdirectory, the first operation constructs the **STAGS** program system within it.

The second operation in this step creates two additional subdirectories (named **fpp** and **fsplit**) within the current working directory. The **fpp** and **fsplit** subdirectories contain two utility programs that are needed whenever it is necessary to compile **STAGS** routines and/or to “make” **STAGS** executables.

4) Continue the installation process by executing the `RUN.ME.FIRST` script from the new **stags** subdirectory, as follows:

```
% cd stags
% RUN.ME.FIRST
```

The `RUN.ME.FIRST` script modifies the **STAGS** initialization file (discussed next); then it commits suicide by deleting itself.

5) Continue the installation process by transferring from the **stags** subdirectory to **fpp** (one of **stags**’ two siblings) and performing the following operations:

```
% cd ../fpp
% make fpp
```

The **`make fpp`** command compiles and “makes” the **fpp** utility program, producing **fpp***. Transfer (copy or move) **fpp*** from the current working directory into the */usr/local/bin* directory (which *must* be in the user’s path).

6) Conclude the installation process by transferring from the **fpp** subdirectory to **fsplit** (**stags**' other sibling) and performing the following operations:

```
% cd ../fsplit
% make fsplit
```

The `make fsplit` command compiles and "makes" the **fsplit** utility program, producing **fsplit***. Transfer (copy or move) **fsplit*** from the current working directory into the */usr/local/bin* directory (which *must* be in the user's path).

Installation is now complete. An initialization procedure must be performed, however, before **STAGS** can be executed.

Initializing STAGS on a Linux system

Issue the following command once per login session prior to changing or running **STAGS**:

```
% source $STAGSHOME/prc/initialize
```

where **$STAGSHOME** is the complete path name to the **stags** directory structure that is shown in Figure 2.1. The **$STAGSHOME/prc/initialize** procedure establishes a number of command aliases and environmental variables that are necessary to operate on and/or to execute the **STAGS** programs. For example, **$STAGSHOME** is defined as an environmental variable that contains the path name of the **stags** directory.

It is strongly recommended that each **STAGS** user inspect the **$STAGSHOME/prc/initialize** file to see the aliases and variables that it creates, and install this command (or define an alias for it) in his or her .login file.

Making STAGS on a Linux system (as and if necessary)

For Linux installations, **STAGS** is typically distributed with source code, object libraries, and executables for specific machine architectures. Normally, it is not necessary for the installing administrator or for the typical user to "make" the **STAGS** programs. In unusual circumstances—such as when inconsistencies exist between the environment used to create the **STAGS** distribution software and that which is resident on the user's machine—it may be necessary to do so. The computationally-sophisticated user may elect to recompile and re-link **STAGS** components to take advantage of high-performance compilation and/or optimization features that may be available on his or her machine.

To make **STAGS**, simply execute the `make` command from the **$STAGSHOME** directory. To make specific libraries or executables, issue the following command from any directory:

```
% makestags [target]
```

See the file **$STAGSHOME/prc/makestags** for a list of valid targets. To remake the star library, for example, execute the command:

```
% makestags star.a
```

The `makestags` command, with no arguments, will make all of **STAGS**. It is equivalent to executing the `make` command from **$STAGSHOME**.

Coping with installation errors (as and if necessary)

Some common causes of installation difficulties include insufficient disk space, lack of write permission in the selected directory, nonexistence of Linux commands that are required for the installation procedure, and installer boneheadedness. If installation is not successful, identify and correct the problem; then delete the entire **$STAGSHOME** directory and start over again at the 2.3.2 “Installation of STAGS on a Linux System” point.

Verifying that STAGS operates correctly

Correct operation of **STAGS** can be verified by running the small suite of test cases in the **$STAGSHOME/testcases** directory and examining selected portions of the output. Basic concepts and procedures for executing **STAGS** processors on Linux systems are described in the following subsection—which the installing administrator and anyone who uses **STAGS** on such a system must master. A first-level operation verification procedure for **STAGS** is discussed in Section 2.6 (at the end of this chapter).

2.3.3 Execution of STAGS on a Linux System

There are two basic types of executable **STAGS** programs:

- *default* executables — these are the standard versions of the **STAGS** processors (**s1**, **s2**, **stapl, scopy** and **xytrans**) that are supplied with the program and used for most applications; these executables are always stored in the **$STAGSHOME/bin** directory
- *custom* executables — these are application-dependent versions of **s1**, **s2**, **stapl, scopy** and/or **xytrans**—which are typically created by linking with user-written subroutines and/or user-defined elements and are typically stored in user-controlled directories.

On Linux systems, the **$STAGSHOME/prc** directory contains a number of procedure files that facilitate the execution and construction of **STAGS** programs. These procedure files (scripts) are described in the **$STAGSHOME/README** file. The most important of these (in the “execution” department) is the **stags** procedure—which is typically used to run

•	**s1**	**STAGS'** model processor
•	**s2**	**STAGS'** solution processor
•	**stapl**	**STAGS'** plotting post-processor
•	**scopy**	**STAGS'** file-copy processor
•	**pitrans**	**STAGS'** translator/post-processor
•	**xytrans**	**STAGS'** post-processor to generate data for XY plots

to construct a **STAGS** model, to perform one or more analyses with it, to perform pre- and/or post-analysis plotting operations, and to do other things with data on **STAGS** I/O files.* The most important of these procedures (in the "construction" department) is **makeuser**—which is used to "make" custom versions of **STAGS** processors when it is necessary to do so. The remainder of this subsection is devoted to descriptions of these two procedures:

`stags`: On Linux systems, one typically "runs" the **STAGS** program(s) by invoking the **$STAGSHOME/prc/stags** procedure; this is typically done *via* the `stags` alias, which **$STAGSHOME/prc/initialize** constructs when the user initializes **STAGS** prior to exercising it; the `stags` procedure can be used to run **STAGS** with default and/or with custom **STAGS** executables.

See "Executing STAGS with stags (Linux)" on page 2-22 for information about the **stags** procedure, and "Initializing STAGS on a Linux system" on page 2-19 for more information about the initialization process.

`makeuser` Custom, user-owned versions of executable **STAGS** processors may be created with the **$STAGSHOME/prc/makeuser** procedure, which is generally executed *via* the `makeuser` alias that **$STAGSHOME/prc/initialize** defines when the user initializes **STAGS** prior to exercising it; custom executables must be created and executed when user-written subroutines and/or user-defined elements are employed.

See "Creating custom STAGS executables with makeuser (Linux)" on page 2-23 for more information about the `makeuser` procedure.

See "Initializing STAGS on a Linux system" on page 2-19 for information about the initialization process.

See Chapter 12 "User-Written Subroutines" for more information about user-written subroutines, and Chapter 13 "User–Defined Elements" for more information about user-defined elements.

Users can also create special-purpose versions of **STAGS** code, since source code is distributed with the program; this type of advanced use is outside the scope of this document, but the sophisticated analyst may find occasion to customize **STAGS** for specific applications.

* See Chapter 17 "Input/Output Files" for documentation on **STAGS** I/O files.

Executing STAGS with stags (Linux)

Synopsis

```
stags [options] casename [options]
```

Options

`-b`	–	run **STAGS** in background; the default nice value is 10.
`-n [nice_value]`	–	set nice value for non-queued jobs; if option `-n` is selected, but a nice value is not supplied, the default is 10.
`-sm`	–	send email message upon termination of background jobs; default is send no email: queued jobs always send email upon termination.
`-1 [s1_executable]`	–	run **s1**; a user-specified **s1** executable is optionally defined.
`-2 [s2_executable]`	–	run **s2**; a user-specified **s2** executable is optionally defined.

Examples

- run the default **s1** and **s2** executables interactively or in the foreground

  ```
  % stags casename
  ```

  If neither `-1` nor `-2` is present, then both **s1** and **s2** will be run in succession, using the default executables.

- run a custom version of **s2** with the default version of **s1**

  ```
  % stags  -1  -2 [s2_executable]  casename
  ```

- run a custom version of **s1** with the default version of **s2**

  ```
  % stags  -2  -1 [s1_executable]  casename
  ```

- run default **s1** and custom **s2** in background, then send email upon completion

  ```
  % stags -b -1 -2 ~/my_s2 -sm mycase
  ```

- run custom **s2** in the background, then send mail upon completion

  ```
  % stags -b -sm -2 ~/my_s2 mycase
  ```

- run **s1** in the foreground

  ```
  % stags mycase -1
  ```

  Note that options `-1`/`-2` appear after `mycase` in the above/below examples; any argument following `-1` or `-2` must be either a valid **STAGS** executable (custom or default) or another option (*i.e.,* an argument beginning with a `-`).

- run **s2** in the foreground

  ```
  % stags mycase -2
  ```

Creating custom STAGS executables with makeuser (Linux)

Synopsis

```
makeuser [-g] [-l userlib.a] [target]
```

Options

`-g` – compile .F files with standard debug option

`-cpp “cppflags”` – where cppflags are valid cpp options; user-entered cppflags are both *prepended* and *appended* to the default cppflags; the user-entered cppflags are prepended so that, if given, alternate include-file directories can be searched before the standard include-file directories; the user-entered cppflags are also appended so that default cpp definitions can be reset by the user; the user-entered cppflags do not replace the default cppflags because **STAGS** code will not compile correctly without certain default cpp definitions that the user is likely to forget to include.

Example: `-cpp “-D_debug_”`

`-fc “fcflags”` – where user-entered fcflags (FORTRAN compiler options) *replace* the default compiler options for all modes of compilation: no optimization, partial optimization, full optimization, and debug; on most machines, users should remember to include the “-c” flag if they exercise this option.

Example: `-fc “-c -g -O2”`

`-cc “ccflags”` – where user-entered ccflags (C compiler options) *replace* the default compiler options.

Example: `-cc “-c -g -O2”`

`-ld “linkflags”` – where user-entered linkflags (linker options) *replace* the default linker options.

Example: `-ld “-M -Bstatic”`

`-l userlib.a` – Link library userlib.a when target is made; more than one library can be linked using additional “-l” arguments.

`target` is a target in **$STAGSHOME/make/makefile.user**. Valid targets are:

- `s1` creates a custom version of **s1**, the **STAGS** model processor
- `s2` creates a custom version of **s2**, the **STAGS** solution processor
- `scopy` creates a custom version of **scopy**, a **STAGS** data postprocessor
- `pitrans` creates a custom version of **pitrans**, a **STAGS** translator/postprocessor
- `xytrans` creates a custom version of **xytrans**, a **STAGS** xy-plot-data translator
- `clean` removes custom object and executable files from the current working directory

If no `target` is specified, then `makeuser` attempts to make all **STAGS** executables, placing them in the current working directory (see Table 2.2).

Each user-written subroutine must be in a .F source file. Routines called by user-written subroutines, if any, can be in .c files, .F files, and/or in .a library files; do *not* duplicate any **STAGS** names.

Table 2.2 makeuser target summary

target	action
`s1`	All of the source files (.F, .c, and .h) in the current directory are compiled and the object files produced by those compilations are placed in the user.a library. All of the **s1** program files in user.a are extracted and linked ahead of all other libraries to create the **us1** executable.
`s2`	All of the source files (.F, .c, and .h) in the current directory are compiled and the object files produced by those compilations are placed in the user.a library. All of the **s2** program files in user.a are extracted and linked ahead of all other libraries to create the **us2** executable.
`stapl`	All of the source files (.F, .c, and .h) in the current directory are compiled and the object files produced by those compilations are placed in the user.a library. All of the **stapl** program files in user.a are extracted and linked ahead of all other libraries to create the **ustapl** executable.

`scopy`
`pitrans`
`xytrans`
	All of the source files (.F, .c, and .h) in the current directory are compiled and the object files produced by those compilations are placed in the user.a library.
	All of the files in user.a are extracted and linked ahead of all other libraries to create the **scopy**, **pitrans** and **xytrans** executables.

`clean`	Any of the following files which exist in the current working directory are removed: __* *.o *any* **STAGS** *executable* user.a

The `makeuser` procedure compiles source files (.F, .c, and .h, as appropriate) in the current working directory and links these files ahead of the standard **STAGS** libraries. If user libraries are included, they will be linked after any source files in the current directory but before any **STAGS** libraries.

The `makeuser` procedure operates exclusively on files that are in the current working directory ($cwd) and has no effect on the **$STAGSHOME** file system or on any other file system.

CAUTION: Existing .o files are erased by `makeuser`. These may be placed in a .a library file, which may be linked with the "`-l`" option.

`makeuser` attempts to "force link" any object modules produced from source files, and some linkers will abort if asked to force link a name that is not referenced. This vexation can be avoided by ensuring that $cwd includes only those source files containing program modules whose names are referenced by the `target`.

Examples

Suppose the current working directory contains the following files:

```
-rw-r--r--  1 stags       12833 Jan 12 10:30 mylib1.a
-rw-r--r--  1 stags       78294 Jan 12 10:30 mylib2.a
-rw-r--r--  1 stags        1242 Jan 12 10:30 user2.F
-rw-r--r--  1 stags        7231 Jan 12 10:30 user1.F
```

- create a custom version of **s2**, incorporating user1.F and user2.F

  ```
  % makeuser s2
  ```
- create a custom version of **s2**—with user1.F and user2.F compiled for symbolic debugging

  ```
  % makeuser -g s2
  ```
- create a custom version of **s2**—linking in mylib1.a and mylib2.a, in addition to user1.F and user2.F

  ```
  % makeuser -l mylib1.a -l mylib2.a s2
  ```
- create a custom version of **s2**—linking in mylib1.a and mylib2.a, together with user1.F and user2.F compiled for symbolic debugging;

  ```
  % makeuser -g -l mylib1.a -l mylib2.a s2
  ```

In all of these examples, `makeuser` will produce a user.a user–library file and a **us2** user–executable file. Since no .c files and no .h files exist in the current directory, makeuser will also create dummy files dummyc.c and dummyi.h.

2.4 Macintosh-Based Systems

PRELIMINARY:

The good news here is that **STAGS** can be installed and executed on Macintosh-based machines. The bad news here is that this seriously underfunded section of Chapter 2 is also “under construction” and is also incomplete. We recommend that anyone who experiences difficulties in installing and executing **STAGS** on a Macintosh system contact Dr. Charles C. Rankin, at

Rhombus Consultants Group
2565 Leghorn Street
Mountain View, CA 94043

2.4.1 Basic Macintosh System Requirements

Basic system requirements that must be met to install **STAGS** on a Macintosh system are summarized in the following:

Operating system	OS X (10.2)
Minimum disk space required	85 MB
System utilities required	fpp & fsplit (supplied)
Compilers required	gcc & g77

System requirements that must be met (and should be comfortably exceeded) to execute **STAGS** programs on a Macintosh system are summarized in the following table:

Processor speed requirements	300 MHz
Memory requirements	256 MB
Storage requirements	512 MB

2.4.2 Installation of STAGS on a Macintosh system

To install **STAGS** on a Macintosh system, one must be in a terminal window.

Installing STAGS on a Macintosh system

Macintosh versions of **STAGS** are typically distributed on CDs or *via* “ftp” as a pair of gzip-compressed archive files—the primary distribution file (`stags_mac.tgz`) and a secondary (but necessary) utility file (`ftp_split.tgz`). Installation of **STAGS** on a Macintosh system is typically a six-step process:

1) Establish the root directory into which **STAGS** is to be installed (the */home/stags* directory, for example)—creating it as and if necessary; make this directory the current working directory.

2) Copy the two **STAGS** distribution files from their distribution medium into this working directory.

3) Extract **STAGS** from the `stags_mac.tgz` file and the **fpp** and **fsplit** utilities from the `fpp_fsplit.tgz` file by issuing the following two commands:

```
% tar xfz stags_mac.tgz
% tar xfz fpp_fsplit.tgz
```

The first operation in this step creates a new subdirectory (named **stags**) within the current working directory. This new subdirectory is called **$STAGSHOME** in the directory structure diagram that is shown in Figure 2.1. After creating this new subdirectory, the first operation constructs the **STAGS** program system within it.

The second operation in this step creates two additional subdirectories (named **fpp** and **fsplit**) within the current working directory. The **fpp** and **fsplit** subdirectories contain two utility programs that are needed whenever it is necessary to compile **STAGS** routines and/or to “make” **STAGS** executables.

4) Continue the installation process by executing the `RUN.ME.FIRST` script from the new **stags** subdirectory, as follows:

```
% cd stags
% RUN.ME.FIRST
```

The `RUN.ME.FIRST` script modifies the **STAGS** initialization file (discussed next); then it commits suicide by deleting itself.

5) Continue the installation process by transferring from the **stags** subdirectory to **fpp** (one of **stags**’ two siblings) and performing the following operations:

```
% cd ../fpp
% make fpp
```

The **`make fpp`** command compiles and “makes” the **fpp** utility program, producing **fpp***. Transfer (copy or move) **fpp*** from the current working directory into the */usr/local/bin* directory (which *must* be in the user’s path).

6) Conclude the installation process by transferring from the **fpp** subdirectory to **fsplit** (**stags**’ other sibling) and performing the following operations:

```
% cd ../fsplit
% make fsplit
```

The **`make fsplit`** command compiles and “makes” the **fsplit** utility program, producing **fsplit***. Transfer (copy or move) **fsplit*** from the current working directory into the */usr/local/bin* directory (which *must* be in the user’s path).

Installation is now complete. An initialization procedure must be performed, however, before **STAGS** can be executed.

Initializing STAGS on a Macintosh system

Issue the following command once per login session prior to changing or running **STAGS**:

```
% source $STAGSHOME/prc/initialize
```

where **$STAGSHOME** is the complete path name to the **stags** directory structure that is shown in Figure 2.1. The **$STAGSHOME/prc/initialize** procedure establishes a number of command aliases and environmental variables that are necessary to operate on and/or to execute the **STAGS** programs. For example, **$STAGSHOME** is defined as an environmental variable that contains the path name of the **stags** directory.

It is strongly recommended that each **STAGS** user inspect the **$STAGSHOME/prc/initialize** file to see the aliases and variables that it creates, and install this command (or define an alias for it) in his or her .login file.

Making STAGS on a Macintosh system (as and if necessary)

For Macintosh installations, **STAGS** is typically distributed with source code and with object libraries and executables, for specific machine architectures. Normally, it is not necessary for the installing administrator or for the typical user to “make” the **STAGS** programs. In unusual circumstances—such as when inconsistencies exist between the environment used to create the **STAGS** distribution software and that which is resident on the user’s machine—it may be necessary to do so. The computationally-sophisticated user may elect to recompile and re-link **STAGS** components to take advantage of high-performance compilation and/or optimization features that may be available on his or her machine.

To make **STAGS**, simply execute the `make` command from the **$STAGSHOME** directory. To make specific libraries or executables, issue the following command from any directory:

```
% makestags [target]
```

See the file **$STAGSHOME/prc/makestags** for a list of valid targets. To remake the star library, for example, execute the command:

```
% makestags star.a
```

The `makestags` command, with no arguments, will make all of **STAGS**. It is equivalent to executing the `make` command from **$STAGSHOME**.

Coping with installation errors (as and if necessary)

Some common causes of installation difficulties include insufficient disk space, lack of write permission in the selected directory, nonexistence of Macintosh commands that are required for the installation procedure, and installer boneheadedness. If installation is not successful, identify and correct the problem; then delete the entire **$STAGSHOME** directory and start over again at the 2.4.2 “Installation of STAGS on a Macintosh system” point.

Verifying that STAGS operates correctly

Correct operation of **STAGS** can be verified by running the small suite of test cases in the **$STAGSHOME/testcases** directory and examining selected portions of the output. Basic concepts and procedures for executing **STAGS** processors on Macintosh systems are described in the following subsection—which the installing administrator and anyone who uses **STAGS** on such a system must master. A first-level operation verification procedure for **STAGS** is discussed in Section 2.6 (at the end of this chapter).

2.4.3 Execution of STAGS on a Macintosh System

There are two basic types of executable **STAGS** programs:

- *default* executables — these are the standard versions of the **STAGS** processors (**s1**, **s2**, **stapl, scopy** and **xytrans**) that are supplied with the program and used for most applications; these executables are always stored in the **$STAGSHOME/bin** directory
- *custom* executables — these are application-dependent versions of **s1**, **s2**, **stapl, scopy** and/or **xytrans**—which are typically created by linking with user-written subroutines and/or user-defined elements and are typically stored in user-controlled directories.

On Macintosh systems, the **$STAGSHOME/prc** directory contains a number of procedure files that facilitate the execution and construction of **STAGS** programs. These procedure files (scripts) are described in the **$STAGSHOME/README** file. The most important of these (in the “execution” department) is the **stags** procedure—which is typically used to run

• **s1**	**STAGS'** model processor
• **s2**	**STAGS'** solution processor
• **stapl**	**STAGS'** plotting post-processor
• **scopy**	**STAGS'** file-copy processor
• **pitrans**	**STAGS'** translator/post-processor
• **xytrans**	**STAGS'** post-processor to generate data for XY plots

to construct a **STAGS** model, to perform one or more analyses with it, to perform pre- and/or post-analysis plotting operations, and to do other things with data on **STAGS** I/O files.[*] The most important of these procedures (in the “construction” department) is **makeuser**—which is used to “make” custom versions of **STAGS** processors when it is necessary to do so. The remainder of this subsection is devoted to descriptions of these two procedures:

`stags:` On Macintosh systems, one typically “runs” the **STAGS** program(s) by invoking the **$STAGSHOME/prc/stags** procedure; this is typically done *via* the `stags` alias, which is constructed by **$STAGSHOME/prc/initialize** when the user initializes **STAGS** prior to exercising it; the `stags` procedure can be used to run **STAGS** with default and/or with custom **STAGS** executables.

See “Executing STAGS with stags (Macintosh)” on page 2-31 for information about the **stags** procedure, and “Initializing STAGS on a Macintosh system” on page 2-28 for more information about the initialization process.

`makeuser` Custom, user-owned versions of executable **STAGS** processors may be created with the **$STAGSHOME/prc/makeuser** procedure, which is generally executed *via* the `makeuser` alias that **$STAGSHOME/prc/initialize** defines when the user initializes **STAGS** prior to exercising it; custom executables must be created and executed when user-written subroutines and/or user-defined elements are employed.

See “Creating custom STAGS executables with makeuser (Macintosh)” on page 2-32 for more information about the `makeuser` procedure.

See “Initializing STAGS on a Macintosh system” on page 2-28 for information about the initialization process.

See Chapter 12 “User-Written Subroutines” for more information about user-written subroutines, and Chapter 13 “User–Defined Elements” for more information about user-defined elements.

Users can also create special-purpose versions of **STAGS** code, since source code is distributed with the program; this type of advanced use is outside the scope of this document, but the sophisticated analyst may find occasion to customize **STAGS** for specific applications.

[*] See Chapter 17 “Input/Output Files” for documentation on **STAGS** I/O files.

Executing STAGS with stags (Macintosh)

Synopsis

```
stags [options] casename [options]
```

Options

```
                -b  –  run STAGS in background; the default nice value is 10.
 -n [nice_value]  –  set nice value for non-queued jobs; if option -n is selected,
                       but a nice value is not supplied, the default is 10.
               -sm  –  send email message upon termination of background jobs;
                       default is send no email: queued jobs always send email
                       upon termination.
                 -1 [s1_executable]–run s1; a user-specified s1 executable is optionally
                       defined.
                 -2 [s2_executable]–run s2; a user-specified s2 executable is optionally
                       defined.
```

Examples

- run the default **s1** and **s2** executables interactively or in the foreground

  ```
  % stags casename
  ```

  If neither `-1` nor `-2` is present, then both **s1** and **s2** will be run in succession, using the default executables.

- run a custom version of **s2** with the default version of **s1**

  ```
  % stags  -1  -2 [s2_executable]  casename
  ```

- run a custom version of **s1** with the default version of **s2**

  ```
  % stags  -2  -1 [s1_executable]  casename
  ```

- run default **s1** and custom **s2** in background, then send email upon completion

  ```
  % stags -b -1 -2 ~/my_s2 -sm mycase
  ```

- run custom **s2** in the background, then send mail upon completion

  ```
  % stags -b -sm -2 ~/my_s2 mycase
  ```

- run **s1** in the foreground

  ```
  % stags mycase -1
  ```

  Note that options `-1`/`-2` appear after `mycase` in the above/below examples; any argument following `-1` or `-2` must be either a valid **STAGS** executable (custom or default) or another option (*i.e.*, an argument beginning with a `-`).

- run **s2** in the foreground

  ```
  % stags mycase -2
  ```

Creating custom STAGS executables with makeuser (Macintosh)

Synopsis

```
makeuser [-g] [-l userlib.a] [target]
```

Options

`-g` – compile .F files with standard debug option

`-cpp "cppflags"` – where cppflags are valid cpp options; user-entered cppflags are both *prepended* and *appended* to the default cppflags; the user-entered cppflags are prepended so that, if given, alternate include-file directories can be searched before the standard include-file directories; the user-entered cppflags are also appended so that default cpp definitions can be reset by the user; the user-entered cppflags do not replace the default cppflags because **STAGS** code will not compile correctly without certain default cpp definitions that the user is likely to forget to include.

Example: `-cpp "-D_debug_"`

`-fc "fcflags"` – where user-entered fcflags (FORTRAN compiler options) *replace* the default compiler options for all modes of compilation: no optimization, partial optimization, full optimization, and debug; on most machines, users should remember to include the "-c" flag if they exercise this option.

Example: `-fc "-c -g -O2"`

`-cc "ccflags"` – where user-entered ccflags (C compiler options) *replace* the default compiler options.

Example: `-cc "-c -g -O2"`

`-ld "linkflags"` – where user-entered linkflags (linker options) *replace* the default linker options.

Example: `-ld "-M -Bstatic"`

`-l userlib.a` – Link library userlib.a when target is made; more than one library can be linked using additional "-l" arguments.

`target` is a target in **$STAGSHOME/make/makefile.user**. Valid targets are:

- `s1` creates a custom version of **s1**, the **STAGS** model processor
- `s2` creates a custom version of **s2**, the **STAGS** solution processor
- `scopy` creates a custom version of **scopy**, a **STAGS** data postprocessor
- `pitrans` creates a custom version of **pitrans**, a **STAGS** translator/postprocessor
- `xytrans` creates a custom version of **xytrans**, a **STAGS** xy-plot-data translator
- `clean` removes custom object and executable files from the current working directory

If no `target` is specified, then `makeuser` attempts to make all **STAGS** executables, placing them in the current working directory (see Table 2.3).

Table 2.3 makeuser target summary

target	**action**
`s1`	All of the source files (.F, .c, and .h) in the current directory are compiled and the object files produced by those compilations are placed in the user.a library. All of the **s1** program files in user.a are extracted and linked ahead of all other libraries to create the **us1** executable.
`s2`	All of the source files (.F, .c, and .h) in the current directory are compiled and the object files produced by those compilations are placed in the user.a library. All of the **s2** program files in user.a are extracted and linked ahead of all other libraries to create the **us2** executable.
`stapl`	All of the source files (.F, .c, and .h) in the current directory are compiled and the object files produced by those compilations are placed in the user.a library. All of the **stapl** program files in user.a are extracted and linked ahead of all other libraries to create the **ustapl** executable.

`scopy`
`pitrans`
`xytrans`
	All of the source files (.F, .c, and .h) in the current directory are compiled and the object files produced by those compilations are placed in the user.a library.
	All of the files in user.a are extracted and linked ahead of all other libraries to create the **scopy**, **pitrans** and **xytrans** executables.

`clean`	Any of the following files which exist in the current working directory are removed: __* *.o *any* **STAGS** *executable* user.a

Each user-written subroutine must be in a .F source file. Routines called by user-written subroutines, if any, can be in .c files, .F files, and/or in .a library files; do *not* duplicate any **STAGS** names.

The `makeuser` procedure compiles source files (.F, .c, and .h, as appropriate) in the current working directory and links these files ahead of the standard **STAGS** libraries. If user libraries are included, they will be linked after any source files in the current directory but before any **STAGS** libraries.

The `makeuser` procedure operates exclusively on files that are in the current working directory ($cwd) and has no effect on the **$STAGSHOME** file system or on any other file system.

CAUTION: Existing .o files are erased by `makeuser`. These may be placed in a .a library file, which may be linked with the “`-l`” option.

`makeuser` attempts to “force link” any object modules produced from source files, and some linkers will abort if asked to force link a name that is not referenced. This vexation can be avoided by ensuring that $cwd includes only those source files containing program modules whose names are referenced by the `target`.

Examples

Suppose the current working directory contains the following files:

```
-rw-r--r--  1 stags       12833 Jan 12 10:30 mylib1.a
-rw-r--r--  1 stags       78294 Jan 12 10:30 mylib2.a
-rw-r--r--  1 stags        1242 Jan 12 10:30 user2.F
-rw-r--r--  1 stags        7231 Jan 12 10:30 user1.F
```

- create a custom version of **s2**, incorporating user1.F and user2.F

  ```
  % makeuser s2
  ```
- create a custom version of **s2**—with user1.F and user2.F compiled for symbolic debugging

  ```
  % makeuser -g s2
  ```
- create a custom version of **s2**—linking in mylib1.a and mylib2.a, in addition to user1.F and user2.F

  ```
  % makeuser -l mylib1.a -l mylib2.a s2
  ```
- create a custom version of **s2**—linking in mylib1.a and mylib2.a, together with user1.F and user2.F compiled for symbolic debugging;

  ```
  % makeuser -g -l mylib1.a -l mylib2.a s2
  ```

In all of these examples, `makeuser` will produce a user.a user–library file and a **us2** user–executable file. Since no .c files and no .h files exist in the current directory, makeuser will also create dummy files dummyc.c and dummyi.h.

2.5 Windows-Based Systems

The current version of **STAGS** can be installed and executed on Windows-based machines, but we strongly recommend that anyone who wants to do that should seriously consider Linux-based alternatives. This section of Chapter 2 is not "under construction" yet, so we recommend that anyone who is determined to install and execute **STAGS** on a Windows system should contact Dr. Frank C. Weiler, at

Lockheed-Martin Missiles & Space Co., Inc.
ATC Org. L9-21; Bldg. 204
3251 Hanover Street
Palo Alto, CA 94304

2.5.1 Basic Windows System Requirements

2.5.2 Installation of STAGS on a Windows System

Installing STAGS on a Windows system

Initializing STAGS on a Windows system

Making STAGS on a Windows system (as and if necessary)

Coping with installation errors (as and if necessary)

Verifying that STAGS operates correctly

2.5.3 Execution of STAGS on a Windows System

2.6 Installation Verification

Correct operation of **STAGS** can be verified by running the small suite of test cases in the **$STAGSHOME/testcases** directory and examining portions of the output. The precise way in which this is done depends on the user's platform (and is described in the appropriate section of this chapter, above. For simplicity, the first-level verification process for a UNIX-based system is described here. Administrators and users with other platforms can make the necessary adjustments to this narrative for the platform of interest.

Change your current working directory to **$STAGSHOME/testcases** and follow the instructions below. If all three test cases produce correct results, then you may assume that **STAGS** is operating correctly on your machine.

Test 1: sxybuck

This is a small test case in which the shear buckling setup, boundary conditions and behavior are examined for a model with exotic material layup angles.

Execute **STAGS** [see "Executing STAGS with stags (UNIX)" on page 2-12 (for example) for information about the `stags` command):

```
% stags sxybuck
```

Examine the eigenvalues in the ***sxybuck.out2*** output file and compare them to the correct values shown below. The results should be accurate to 4 or 5 significant digits.

```
                                CRITICAL LOAD FACTOR COMBINATION
 NO.       EIGENVALUE           LOAD SYSTEM A      LOAD SYSTEM B
  1    -0.18683774E+04         -0.186838E+04      0.000000E+00
  2    -0.22704978E+04         -0.227050E+04      0.000000E+00
```

Test 2: pcats

This standard plasticity test case, with a simple model, is frequently used to test the effects of variations in material and other parameters.

Execute **STAGS**:

```
% stags pcats
```

Execute xytrans:

```
% xytrans pcats <<EOF
  3
  f
  q
  q
```

```
        EOF
```

The file *pcats.step* should look like the file below. Results should be accurate to 4 or 5 significant digits.

```
There are 13 loadsteps for this case.
==============================================================================
Loadstep of initial plastic yield: 6
Choose the loadstep for which you want to create a loadstep data file.

Loadstep       Load Factor A      Load Factor B         time        # of modes
     0          0.100000E-01       0.000000E+00      0.000000E+00         0
     1          0.100000E-01       0.000000E+00      0.000000E+00         0
     2          0.200000E-01       0.000000E+00      0.000000E+00         0
     3          0.312503E-01       0.000000E+00      0.000000E+00         0
     4          0.447805E-01       0.000000E+00      0.000000E+00         0
     5          0.607618E-01       0.000000E+00      0.000000E+00         0
     6          0.791830E-01       0.000000E+00      0.000000E+00         0
     7          0.986861E-01       0.000000E+00      0.000000E+00         0
     8          0.116296E+00       0.000000E+00      0.000000E+00         0
     9          0.123024E+00       0.000000E+00      0.000000E+00         0
    10          0.125273E+00       0.000000E+00      0.000000E+00         0
    11          0.127322E+00       0.000000E+00      0.000000E+00         0
    12          0.128000E+00       0.000000E+00      0.000000E+00         0
```

Test 3: dynela

This is a small test case for an elastica model experiencing nonlinear dynamic transient response.

Execute **STAGS**:

```
      % stags dynela
```

Execute xytrans:

```
      % xytrans dynela <<EOF
        4
        f
        11
        q
        q
        EOF
```

Issue the UNIX command:

```
      % head -4 dynela.velo.11
```

The lines below should be printed to your screen. Again, results should be accurate to 4 or 5 significant digits.

```
Case: dynela, Loadstep: 11, Nodal Velocities
      22       22  -0.205472E+00       10        6
Load Factors: A (PA) = 0.00000E+00, B (PB) = 0.00000E+00
Maximum Velocity (w) = -0.20547E+00 at global node: 10
```

3
Getting Started

The first part of this chapter (Sections 3.1 through 3.6) presents a quick overview of **STAGS** by guiding the user step-by-step through an example nonlinear analysis. Though everything here is covered in more detail in other parts of the manual, this material provides a convenient reference to facilitate comprehension of the detailed explanations given in the chapters that follow. While it will be most useful to the new user, even an experienced user will benefit from a study of this example. The final part of this chapter (Section 3.7) is a brief description of some of the test problems that **STAGS** developers employ to verify that the program is working correctly and that **STAGS** users should study to become more familiar and confident with the program.

Some key concepts which are introduced in the following example problem are summarized below. These concepts should be kept in mind as the example problem is followed. At this point, details are unimportant, and the reader should not be concerned with understanding every aspect of the example analysis. What is important is to get a feel for what **STAGS** does and how it interacts with the user. It will be helpful to refer back to this chapter, scrutinizing it thoroughly, as other parts of the manual are absorbed.

- model definition

  Models are defined in a model input file, *casename*.inp, where *casename* is a character identifier supplied by the user. The model input file is referred to as the *INP* file. See Chapters 5–10.

- solution specification

  The analysis type and solution strategy are specified in a solution input file, *casename*.bin. The solution input file is referred to as the *BIN* file. Just as there are separate input files for model definition and solution specification, there are separate executable programs (**s1** & **s2**) for the two analysis phases. The concept of independent model definition and solution specification is fundamental to the tremendous power and flexibility provided by **STAGS** to restart an interrupted analysis, even switching analysis types (as from transient to static) at arbitrary points in the solution process. See Chapter 11 “Solution Input”.

- file systems

  STAGS uses various file systems: text input/output files, binary database files, and scratch files. Two text input files (*INP* & *BIN*) are mentioned above. Understanding these file systems is important for effective use of **STAGS**. This is especially so for restarting an analysis, for pre/postprocessing, and for interfacing with the database *via* **STAR**, the **STAGS** Access Routines. See Chapter 17 “Input/Output Files”.

- program execution

  STAGS execution involves various command procedures which manipulate I/O files and run the **STAGS** executables: **s1**, the model processor, and **s2**, the solution processor. When using user-written subroutines, custom, application-dependent executables are run in lieu of the standard ones. See Chapter 2 “Installation and Execution”.

3.1 Infinite Cylinder Under Hydrostatic Pressure

The infinite cylinder is a structure that is of great theoretical and practical interest. Figure 3.1 shows a finite-element model of a short segment from the middle of a cylinder of infinite length. It is a right circular cylinder, with a radius of $R = 10.0\ inches$ and a wall thickness of $t = 0.1\ inch$. The resulting ratio $R/t = 100$ indicates a thin-shell approximation. “Symmetry” boundary conditions (BCs) on the $\theta = 0°$ & $\theta = 90°$ planes permit a $360°$ structure to be modeled with a $90°$ arc, and the symmetry BCs on the $x = 0$ & $x = L$ planes permit a cylinder of infinite length with a symmetric response to be modeled as one having a finite length. The applied loading is a ‘live’ hydrostatic pressure of $p = 1.0\ psi$, acting in the inward radial direction. Live pressure is a **STAGS** traction loading which remains normal to the deformed surface throughout geometrically-nonlinear deformations. This “hydrostatic” pressure ignores the $N_a = pR/2$ end load since axial motion is constrained at both ends. The solution provided by thin-shell theory is

$$\Delta R = (1-\nu^2)pR^2/Et \qquad \begin{array}{ll} \varepsilon_c = \Delta R/R & \varepsilon_a = 0 \\ \sigma_c = pR/t & \sigma_a = \nu\sigma_c \end{array}$$

where the subscript *c* indicates the circumferential direction, and *a* the axial direction.

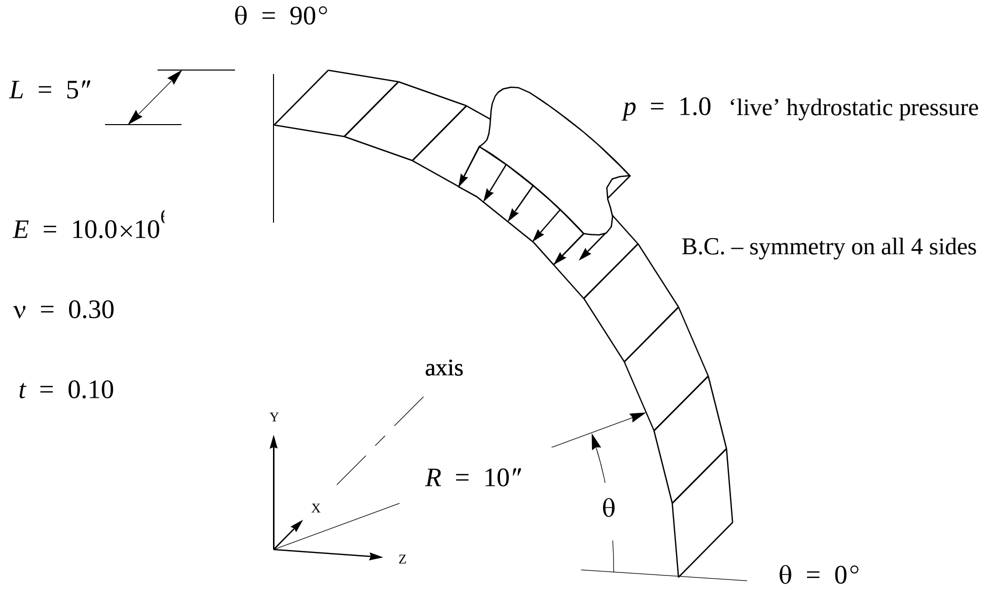

θ = 90°
L = 5″
p = 1.0 'live' hydrostatic pressure
E = 10.0×10
B.C. – symmetry on all 4 sides
ν = 0.30
t = 0.10
axis
Y
R = 10″
X
θ
Z
θ = 0°

Figure 3.1 Example: Infinite cylinder under “live” hydrostatic pressure.

A perfect cylinder (one whose shape is perfectly cylindrical with an absolutely uniform wall thickness) fabricated from an ideal material (one which remains linearly elastic under arbitrary strain states) will remain stable as it undergoes large displacements caused by increasing hydrostatic pressure. Eventually, the perfect cylinder will be compressed until its radius becomes zero, maintaining linear strain-displacement and constitutive behavior throughout. For such a structure, a linear static analysis will determine the load level corresponding to a given stress criteria, and a linear eigenanalysis will predict bifurcation-buckling load levels. Often, such linear analyses are adequate to determine allowable loads on a structure, but some applications warrant a more rigorous approach.

Real cylinders do not have perfect geometry and are not made of ideal materials. Moreover, some thin-shell structures buckle at fractions of their design loads, and their utility depends upon post-buckling strength—a linear analysis is of limited value for such a structure. Our analysis objective is to find the nonlinear collapse mode of such an imperfect cylinder. A rigorous collapse analysis must account for initial geometric imperfections as well as nonlinear behavior. The example presented here accounts for initial geometric imperfections and nonlinear strain-displacement relations, but does not include nonlinear material behavior. Applied to the analysis of thin shells, this strategy often reveals instability at load levels lower than those predicted by a linear buckling analysis, while stress levels are well below the yield criterion for the material.

The solution strategy followed in our example problem consists of three phases:

- linear buckling analysis

  The first two eigenmodes are computed based upon a linear stress state. A linear combination of the eignenvectors will be used to specify an initial geometric imperfection for the nonlinear analysis, which follows.

- begin nonlinear static analysis

  The nonlinear analysis begins with a small load magnitude and proceeds up to a level just below the critical buckling load. Behavior is essentially linear in this region, but the effects of the geometric imperfections are important.

- restart nonlinear analysis

  The analysis restarts at the final load factor of the previous execution and continues through very large displacements as the cylinder collapses. The collapse mode is triggered by the presence of the initial geometric imperfections.

Each analysis phase is now described, in turn. Reference is made to various input files in the following descriptions. These input files are listed in Section 3.6 “Input Files” on page 3-10. Please refer to that section as needed throughout this chapter.

3.2 Linear Bifurcation Buckling

As explained in the introduction to this chapter, two text input files are required to perform an analysis. The *INP* file (*casename*.inp) describes the model, and the *BIN* file (*casename*.bin) specifies the solution strategy. The *casename* chosen for this analysis is “ring”. The *INP* file describing the model is given in “ring.inp.1” on page 3-11, and the *BIN* file is in “ring.bin.1”. Detailed explanations for the model and solution input are given in Chapter 5 “Model Input” through Chapter 11 “Solution Input”. It may be beneficial to preview these chapters now, to gain some understanding of the ring *INP* and *BIN* files. This is not essential, however.

The main point is that we are going to perform a buckling analysis of our cylindrical thin-shell structure. To do so, we must have an input file to describe the model and a second input file to specify the analysis type and solution strategy. So, let us perform the buckling analysis. First, create a scratch space to contain the files that will be used for our sample problem. For example, user “newton” might create the directory “/user/newton/stags/practice/ring”. Here the scratch directory will be referred to symbolically as “$RING”. Create a linear buckling analysis subdirectory, for example “$RING/buckling”, and in it install the input files for the buckling analysis, copying them from the *$STAGSHOME/examples/ring directory, and giving them the required names of *casename*.inp and *casename*.bin. These operations are indicated symbolically using a metalanguage, as follows:

```
Copy $STAGSHOME/examples/ring/ring.inp.1  to  $RING/buckling/ring.inp
Copy $STAGSHOME/examples/ring/ring.bin.1  to  $RING/buckling/ring.bin
```

At this point, the $RING/buckling directory contains two files, *ring.inp* (the *INP* file) and *ring.bin* (the *BIN* file). Make $RING/buckling the default directory, and execute the buckling analysis by issuing the "stags" command, giving "ring" (the *casename*) as an argument. To run the buckling analysis interactively in the foreground, issue the following command:

```
stags ring
```

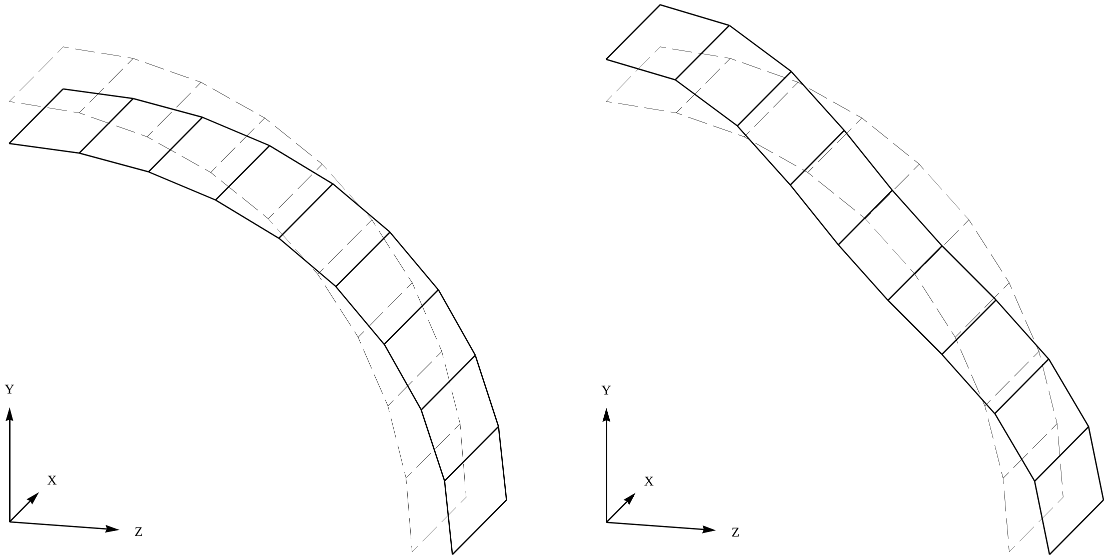
For a complete discussion of the stags command, see "Executing STAGS with stags (UNIX)" on page 2-12. On completion of the buckling analysis (which should take only a few seconds to perform), the $RING/buckling directory will contain the following files:

ring.inp	model input
ring.bin	solution input
ring_m.pdf	model plot (PDF format)
ring.out1	model text output
ring.out2	solution text output
ring.sav	binary model data
ring.rst, ring.res, ring.imp, ring.egv	binary solution data
ring.log	execution summary text file

See "File Systems" on page 3-8 and Chapter 17 "Input/Output Files" for explanations of these and all **STAGS** files.

Plots of the first two buckling modes, which were just computed, are shown in Figure 3.2. For availability of graphical postprocessors for **STAGS**, see your site **STAGS** manager.

* **$STAGSHOME** is a system variable (a UNIX environmental variable) that refers to the top-level **STAGS** directory for your particular installation. See "Initializing STAGS on a UNIX system" on page 2-8.



Mode 1, λ = 2.76

Mode 2, λ = 13.8

Figure 3.2 Linear elastic buckling modes of a perfect cylinder.

3.3 Large-Deflection Analysis of an Imperfect Cylinder

Next, we will begin the nonlinear collapse analysis, including initial geometric imperfections. It is necessary to create a new model in order to include the initial geometric imperfections. This new model is developed by modifying the previous (*ring.inp*) input file to account for the initial imperfections—simply by editing the existing file. Then, in order to run the nonlinear analysis, we must specify the analysis type and solution strategy. The *INP* file describing the model is given in “ring.inp.2” on page 3-12, and the *BIN* file is in “ring.bin.2”. Create a nonlinear analysis subdirectory, “$RING/collapse”, and in it install the input files for the nonlinear analysis, copying them from the **$STAGSHOME**/examples/ring directory, and giving them the required names of *casename*.inp and *casename*.bin. As before, this operation is indicated symbolically as:

```
Copy $STAGSHOME/examples/ring/ring.inp.2  to  $RING/collapse/ring.inp
Copy $STAGSHOME/examples/ring/ring.bin.2  to  $RING/collapse/ring.bin
```

The initial geometric imperfections are defined as a linear combination of the first two buckling modes as

$$\Phi = \alpha_1\phi_1 + \alpha_2\phi_2$$

where ϕ_1 is the eigenvector corresponding to the first buckling mode, and ϕ_2 is the second mode. The α_i are constants, and Φ is the resulting imperfection vector. Inspection of the *INP* file reveals that $\alpha_1 = 0.0030$ and $\alpha_2 = 0.0015$. With $t = 0.10''$, and with each eigenvector ϕ_i scaled so that the largest *translational* component has a value of 1.0, it can be seen that the imperfection is specified to be a linear combination of the first buckling mode, having a maximum amplitude equal to 3.0% of the shell thickness, plus the second buckling mode, having a maximum amplitude equal to 1.5% of the shell thickness. All translational components of the eigenvector are used to generate the initial imperfection shape. This shape is then output in the model plot file (*casename_m.pdf* or *casename_m.ps*).

The eigenvectors are contained in the file pair (*IMP,EGV*) computed in the linear buckling analysis. These files must be present in the $RING/collapse directory since they are indirectly referenced in the *INP* file. Install them as indicated below:

```
COPY $RING/buckling/ring.imp TO $RING/collapse/ring.imp
COPY $RING/buckling/ring.egv TO $RING/collapse/ring.egv
```

To execute the first phase of the collapse analysis interactively, issue the following command in the $RING/collapse directory:

```
stags ring
```

Upon completion of the this analysis (which should take only a few seconds to perform), the $RING/collapse directory will contain the following files:

ring.inp	model input
ring.bin	solution input
ring_m.pdf	model plot (including imperfection)
ring.out1	model text output
ring.out2	solution text output
ring.sav	binary model data
ring.rst, ring.res, ring.imp, ring.egv	binary solution data
ring.log	execution summary text file

3.4 Restarting a Nonlinear Analysis

A new *BIN* file is needed to restart the nonlinear collapse analysis. This is found in **$STAGSHOME**/examples/ring/ring.bin.3. Copy this file to the $RING/collapse directory, as follows:

```
Copy $STAGSHOME/examples/ring/ring.bin.3  to  $RING/collapse/ring.bin
```

The above operation will overwrite the existing ring.bin, so save it with a different name, such as “ring.bin.first”, if desired. To resume the collapse analysis interactively, issue the following command in the $RING/collapse directory:

```
stags ring -2
```

After completion of the restarted analysis, (again, taking only a few seconds to perform), the $RING/collapse directory will contain the following files:

ring.inp	model input
ring.bin	solution input
ring_m.pdf	model plot (including imperfection)
ring.out1	model text output
ring.out2	solution text output
ring.out2.1	previous ring.out2 (renamed)
ring.sav	binary model data
ring.rst, ring.res, ring.imp, ring.egv	binary solution data
ring.log	execution summary text file

The final deformed shape is shown in Figure 3.3, and the load-deflection history is shown in Figure 3.4. Note that for a load factor of nearly four the radial displacement at $\theta = 0°$ is about $3.7''$, and at $\theta = 90°$, about $8.0''$. Compare these radial displacements with the cylinder radius, $R = 10''$ and shell thickness $t = 0.1''$.

3.5 File Systems

Table 3.1 is a summary of the files which are discussed in the foregoing example problem. This table is included as a quick reference to help introduce the user to **STAGS** file systems. For complete documentation of all **STAGS** files, see Chapter 17 “Input/Output Files”. The meaning of the information in the six-column format is as follows:

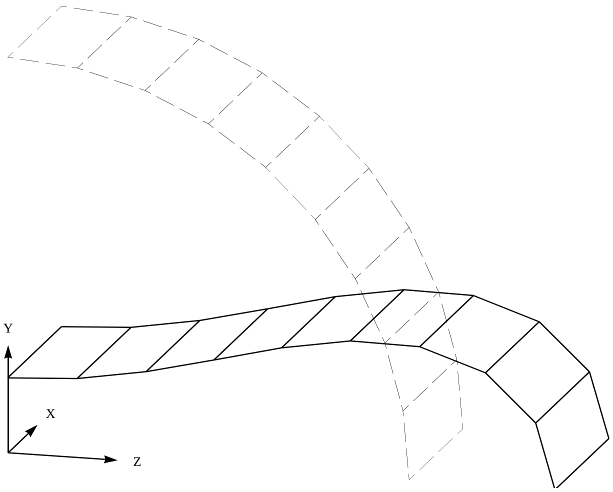


Figure 3.3 Deformed shape (true magnitude) at a load corresponding to $P_A = 4.0$. Compare with Figure 3.4, the load-displacement curve.

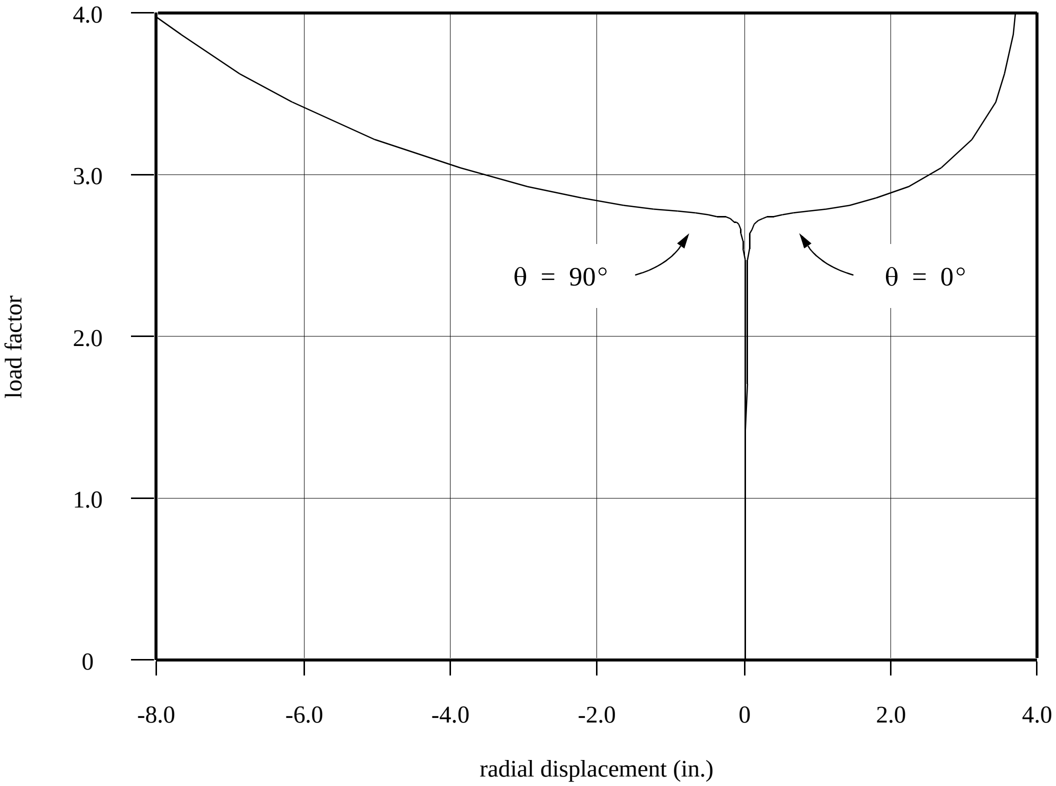


Figure 3.4 Load-displacement curves, showing radial displacement *vs*. load-factor P_A at $\theta = 0°$ & $\theta = 90°$.

- file — *general* file name, used to refer to a file without reference to a specific *casename*.
- name — *particular* file name, where *casename* is a user-assigned alphanumeric string of ≤ 10 characters. *casename* is “ring” for the example problem.
- type — either T for text (ASCII) or B for binary.
- s1, s2 — indicates action taken by each of the two processors:
  s1, the model processor, and **s2**, the solution processor.
  This will be one of four categories: R (read), W (write),
  R/W (read &write), or null (no action).
- description — a brief explanation of the file contents

Table 3.1 **STAGS** files.

file	name	type	s1	s2	description
INP	*casename.inp*	text	R		model input
BIN	*casename.bin*	text		R	solution input
OUT1	*casename.out1*	text	W		model output
OUT2	*casename.out2*	text		W	solution output
OUT2.i	*casename.out2.i*	text			*OUT2*, previous run
LOG	*casename.log*	text			execution summary
SAV	*casename.sav*	binary	W	R	model data
PDF	*casename_m.pdf*	text	W		configuration plot
PS	*casename_m.ps*	text	W		configuration plot
RES	*casename.res*	binary		R/W	solution data
RST	*casename.rst*	binary		R/W	solution data addresses
EGV	*casename.egv*	binary		R/W	solution data
IMP	*casename.imp*	binary		R/W	solution data addresses

3.6 Input Files

The input files used in the example problem described in this section are supplied with the **STAGS** program system, located in the **$STAGSHOME**/examples/ring directory, with names as summarized below. This section concludes with a listing of each of these files.

analysis	*model*	*solution*
• linear buckling analysis	ring.inp.1	ring.bin.1
• start nonlinear analysis	ring.inp.2	ring.bin.2
• restart nonlinear analysis	—	ring.bin.3

Linear buckling analysis

ring.inp.1

```
Infinite Cylinder, Live Hydrostatic Pressure
 0                   $ B-1
 1                   $ B-2   1 Shell unit
 1 0 1               $ B-3   1 material type, 1 wall type
 2 10                $ F-1   2 rows, 10 columns for 10 degree hoop spacing
 1                   $ I-1   Material number 1
 1.E7 .3 0. .1       $ I-2   Modulus, Poisson’s ratio, density
 1 1 1               $ K-1   Wall ID #, wall type, # layers
 1 0.1               $ K-2   Layer 1 has material 1, thickness 0.1
$
$ Begin Shell Unit Definition
$
 5                   $ M-1   Shell type 5 means CYLINDER
 0. 5.   0. 90. 10.  $ M-2A  Axial Coord. 1 and 2, 0. to 90. Deg
 1                   $ M-5   Wall type 1 used
 410                 $ N-1   The 410 element will be used
 4 4 4 4             $ P-1   Symmetry on all boundaries
 1                   $ Q-1   1 load system defined
 1 1                 $ Q-2   1 record on A system
 -1. 5 3 0 0         $ Q-3   Live hydrostatic pressure everywhere
 0                   $ R-1   Print nothing except diagnostics
```

ring.bin.1

```
Linear Buckling Solution Control
 1 1                 $ B-1   Do linear bifurcation and archive displs and modes
 1.0                 $ C-1   Reference load set to unity
 0                   $ D-2
 2                   $ D-3   Two modes
```

Start nonlinear analysis

ring.inp.2

```
Infinite Cylinder, Small Imperfection, Live Hydrostatic Pressure
 0                   $ B-1
 1 0 0 0 0 0 2       $ B-2   1 Shell unit and 2 imperfection modes read
 1 0 1               $ B-3   1 material type, 1 wall type
 .0030 0 1 1         $ B-5   Weight .0030, step 0, mode 1, run 1
 .0015 0 2 1         $ B-5   Weight .0015, step 0, mode 2, run 1
 2 10                $ F-1   2 rows, 10 columns for 10 degree hoop spacing
 1                   $ I-1   Material number 1
 1.E7 .3 0. .1       $ I-2   Modulus, Poisson’s ratio, density
 1 1 1               $ K-1   Wall ID #, wall type, # layers
 1 0.1               $ K-2   Layer 1 has material 1, thickness 0.1
$
$ Begin Shell Unit Definition
$
 5                   $ M-1   Shell type 5 means CYLINDER
 0. 5.   0. 90. 10.  $ M-2A  Axial Coord. 1 and 2, 0. to 90. Deg
 1                   $ M-5   Wall type 1 used
 410                 $ N-1   The 410 element will be used
 4 4 4 4             $ P-1   Symmetry on all boundaries
 1                   $ Q-1   1 load system defined
 1 1                 $ Q-2   1 record on A system
 -1. 5 3 0 0         $ Q-3   Live hydrostatic pressure everywhere
 0                   $ R-1   Print nothing except diagnostics
```

ring.bin.2

```
Nonlinear Static Analysis Solution Control
 3 1                     $ B-1   Nonlinear static analysis, saving displacements
 0.5  0.5  2.7           $ C-1   Start load, delta-load, final load
 0 300 12 -20 0 1.0E-6   $ D-1   Begin new case, 12 cuts, true Newton,
$                                begin with load control, error tol. = 1.0E-6
 0                       $ ET-1  Default Riks arc-length control
```

Restart nonlinear analysis

ring.bin.3

```
Restart Nonlinear Static Analysis
 3 1                       $ B-1   restart nonlinear analysis, saving disp.
 2.7  1.0  4.0             $ C-1   Start load, Riks scale factor, final load
 15 300 12 -20 -1 1.0E-6   $ D-2   Restart at 15, 12 cuts, true Newton,
$                                  continue Riks, error tol. = 1.e-6
 0                         $ ET-1  Assume solution is continuous on restart
```

3.7 Test problems

As noted above, this section contains brief descriptions of some of the test problems that **STAGS** developers employ to verify that the program is working correctly and that **STAGS** users should study to become more familiar and confident with the program. The test cases subject is large and filled with complexities that cannot be discussed in any meaningful way within the severe constraints of this document—especially in view of the nonexistent funding for and the limited energies of individuals who might contribute to those efforts. The best that we can do under the circumstances at hand is to present the information in the following table, which contains one-line descriptions of (some of) the problems that **STAGS** developers exercise to determine whether or not the program is functioning properly after it has been modified and/or ported to another computer system. The input (and printed output) files for this suite of test cases can be found on the **$STAGSHOME**/testcases directory and on directories that are subordinate to it. We encourage the interested (or desperate) reader to study those cases that are of greatest interest to him/her and/or which have the most relevance to his/her problems.

Table 3.2 Suite of Test Cases for **STAGS**.

case #	*case name*	*description*
1	*acoro*	test plastic collapse capabilities (historical fabrication methods)
2	*acoro_gcp*	test plastic collapse capabilities (GCP fabrication methods)
3	*annular*	test pole functionality; test auto-generation of triangular elements at a pole
4	*arch*	test snap-through path-following under dead loading
5	*arch1*	test snap-through path-following under dead loading
6	*bebox*	test G-1 connections along various boundary lines (including ‘reverse’ numbering)
7	*bplast*	test beam plasticity; test plasticity tangent stiffness
8	*bra_1*	test planar boundary conditions; test solver treatment of Lagrange constraints; test path-following solution algorithm; test ‘cable moment’ loading
9	*cone*	test buckling eigensolver
10	*contact1*	test general point/surface contact algorithms
11	*contact2*	same as contact1, adding generalized fastener
12	*contact3*	test general point/surface contact algorithms for configuration with large contact region

case #	*case name*	*description*
13	*disk*	test response of disk to center load
14	*disk1*	same as disk, permitting only *w* at the center
15	*doors*	test G-2 partial compatibility connectivity specifications
16	*dynela*	test nonlinear dynamic transient response, using the Park-method integrator, for elastica problem
17	*elplas*	test multi-segment White-Besseling curve for plasticity problem
18	*ep130*	test plasticity option with E130 fastener elements
19	*f15s*	reference crack test: crack introduced by changing boundary conditions; test E510 mesh-transition elements in presence of stiffener blades; test continuities in stress plots (with **stapl**)
20	*f15t*	similar to f15s, with more complexities
21	*f15t2*	similar to f15s, without blade stiffeners
22	*f15tr2*	test mesh-transition boundaries with G-1 instead of G-2 compatibility specifications; test multiple transitions with re-entrant corner, modeled with E510 and E710 transition elements
23	*fast2*	simple fastener test case
24	*fast3*	test looping input in element unit with E130 (fastener) elements
25	*fast4*	test looping capabilities, with user points as well as elements
26	*g2e410*	test soccer-ball pinched-hemisphere problem; test warping
27	*ground*	test cylindrical panel with ground motions
28	*he130*	test E130 fastener elements with hyperelastic properties
29	*indisp*	test ring problem, with initial displacements
30	*lamequad*	test default Lame routine and G-1 connectivities, for triangle constructed entirely with quadrilateral plate elements
31	*mountd*	test use of mount tables and elements to reproduce inverse-square attraction forces; test stability of dynamic transient response algorithms under tough conditions
32	*pad1*	test E810 Pad Hertzian contact element with beam-hitting-beam problem
33	*pad2*	same as pad1, with a twist: test sideslip capability of E810 Pad element
34	*pcats*	standard plasticity test case; easy to alter to test effects of material and other parameters

case #	*case name*	*description*
35	*plive*	test complete collapse of ring under external pressure
36	*poste*	test accuracy of planar boundary conditions
37	*riks*	original test case for the Riks path-following solution algorithm
38	*shin_320*	test thermal analysis capabilities for model with E320 triangle elements (patch test)
39	*shin_410*	test thermal analysis capabilities for model with E410 quadrilateral elements (patch test)
40	*sphere*	test response of sphere to point force loading; test nonlinear collapse for a model with imperfections
41	*straw*	nonlinear test case for Brazier problem in shear
42	*sxybuck*	test shear buckling setup, boundary conditions, and behavior of model with exotic material layup angles
43	*truequad*	similar to lamequad, but using standard quadrilateral shell units; test UGRID = 1 option
44	*vibrate*	vibration analysis of infinite cylinder
45	*vibrum*	vibration analysis for model with added mass
46	*yusernum*	test arbitrary user node numbering

The interested reader is also encouraged to spend time and energy studying the interesting and informative test cases that are documented (with varying levels of detail) in the ***STAGS*** *Test Cases Manual*.

4
Fundamentals

4.1 Coordinate Systems

Effective use of **STAGS** demands a thorough understanding of the many coordinate systems it employs to define shell structures. These systems are described in alphabetical order in this section. Table 4.1 on page 4-2 summarizes coordinate systems that **STAGS** uses, giving brief descriptions along with references to sketches where graphical representation of various coordinate systems can be found. A word of encouragement to the new user: do not be daunted by this list of coordinate systems. You will quickly discover that they are easy to understand and natural to use; and they are all orthogonal coordinate systems.

(x, y, z) *branch (or shell unit) coordinates*

Branch coordinate system, a Cartesian coordinate system that is defined independently for each shell unit. The geometry of the surface is determined by the relations

$$x = x(X, Y) \qquad y = y(X, Y) \qquad z = z(X, Y)$$

where (X, Y) are surface coordinates. See "Standard Shell Surfaces" beginning on page 6-2, where these surface-to-branch relations are given for each of the standard shell types. Note that a shell unit is fixed with respect to its branch coordinate system.

(x'', y'', z'') *computational coordinates*

A rectilinear system which defines the directions of the displacement unknowns at all nodes in a unit. In shell units, including the user-generated shell unit (**ISHELL** $= 1$, M-1), the (x'', y'', z'') system is identical to the shell (X', Y', Z') system. In element units, the auxiliary system (x_a, y_a, z_a), where defined, determines the nodal freedoms; otherwise, the nodal-global system $(\bar{x}_g, \bar{y}_g, \bar{z}_g)$ is used.

Table 4.1 **STAGS** coordinate systems.

symbol	name	use	sketch
(x, y, z)	*branch*	shell-unit definition	Figure 4.1 on page 4-6 “Standard Shell Surfaces” beginning on page 6-2
(x'', y'', z'')	*computational*	primary solution (nodal *dof*)	Figure 7.1 on page 7-6
$(\bar{y}, \bar{z})$	*cross-section*	beam cross-section	Figure 5.5 on page 5-122 Figure 6.5 on page 6-52 Figure 8.1 on page 8-12 Figure 16.4 on page 16-10
(x', y', z')	*element*	element computations	Figure 8.1 on page 8-12 Chapter 14 “The Element Library”
(x_e, y_e, z_e)	*element-edge*	line loads	Figure 4.2 on page 4-7
(x_s, y_s, z_s)	*element-surface*	surface traction	Figure 4.2 on page 4-7
$(\bar{x}, \bar{y})$	*fabrication*	wall fabrication	Figure 5.7 on page 5-133 Figure 6.2 on page 6-28 Figure 8.3 on page 8-20
(x_g, y_g, z_g)	*global*	reference for all coordinate systems	Figure 4.1 on page 4-6 Figure 7.1 on page 7-6
(ϕ_1, ϕ_2)	*material*	material properties	Figure 5.7 on page 5-133
(x_a, y_a, z_a)	*nodal-auxiliary*	option for nodal *dof*, element unit	Figure 7.1 on page 7-6
$(\bar{x}_g, \bar{y}_g, \bar{z}_g)$	*nodal-global*	option for nodal *dof*, element unit	Figure 7.1 on page 7-6
(X', Y', Z')	*shell*	nodal *dof*, shell unit	Figure 4.1 on page 4-6 Figure 6.2 on page 6-28 Figure 6.5 on page 6-52 Figure 6.6 on page 6-58
(X, Y)	*surface*	shell-unit surface parameters	Figure 4.1 on page 4-6 “Standard Shell Surfaces” beginning on page 6-2 Figure 6.1 on page 6-19 Figure 6.6 on page 6-58
(x_w, y_w)	*wall-reference*	reference for fabrication system	Figure 6.2 on page 6-28 Figure 8.2 on page 8-19

$(\bar{y}, \bar{z})$ *cross-section coordinates*

A Cartesian system used in definition of beam cross-sections. For convenience, the beam axial direction is sometimes represented by the symbol $\bar{x}$, $(\bar{x}, \bar{y}, \bar{z})$ forming a 3-D orthogonal system. For shell-unit stiffeners, $\bar{x}$ is parallel to Y' for rings and to X' for stringers; see Figure 6.5 on page 6-52. For element-unit beams, $\bar{x}$ is parallel to the beam element x' axis; see Figure 8.1 on page 8-12.

NOTE: Do not confuse $(\bar{x}, \bar{y}, \bar{z})$ cross-section coordinates with $(\bar{x}, \bar{y}, \bar{z})$ fabrication coordinates. The distinction will be clear from the context in which the particular coordinate system is referenced.

(x', y', z') *element coordinates*

A Cartesian system defined independently for each element in both shell units and element units. Chapter 14 “The Element Library” contains an explanation for each element type. Generally, for shell elements, only the element normal z' is of importance to the user, since pressure is the only data for input or output that refers to these coordinates. Although various computations are performed in element coordinate systems, quantities are always transformed to other systems for presentation to the user. For nonlinear analysis using corotation, (x', y', z') rotates rigidly with the element as it deforms.

(x_e, y_e, z_e) *element-edge coordinates*

A local element system which is independently defined on each element edge. The y_e direction is defined by the vector pointing from edge-node 1 to edge-node 2, projected onto the element plane. z_e is the same as z', the element normal, and x_e, directed outward from the edge, completes a right-handed system.

(x_s, y_s, z_s) *element-surface coordinates*

A local element system in which the x_s direction is defined by the vector pointing from element-node 1 to element-node 2, projected onto the element plane. z_s is the same as z', the element normal; and y_s, in the element plane, completes a right-handed system.

$(\bar{x}, \bar{y})$ *fabrication coordinates*

A 2-D Cartesian system used as a reference for defining a wall fabrication. $(\bar{x}, \bar{y})$ are in the plane of the shell or element, which is determined by the shell normal Z' in shell units and by the element normal z' in element units. For convenience, the normal direction is sometimes represented by the symbol $\bar{z}$ (please see Figure 5.7 on page 5-133), $(\bar{x}, \bar{y}, \bar{z})$ forming a 3-D orthogonal system. The fabrication coordinate system is oriented in the surface-tangent plane by rotating the wall-reference system (x_w, y_w) through the angle **ZETA**, a right-handed rotation about $\bar{z}$ (see Figure 6.2 on page 6-28 and Figure 8.2 on page 8-19).

NOTE: Do not confuse $(\bar{x}, \bar{y}, \bar{z})$ fabrication coordinates with $(\bar{x}, \bar{y}, \bar{z})$ cross-section coordinates. The distinction will be clear from the context in which the particular coordinate system is referenced.

(x_g, y_g, z_g) *global coordinates*

A global Cartesian coordinate system. The orientations of all local systems for shell units or the element units are defined with respect to this system.

(ϕ_1, ϕ_2) *material coordinates*

A 2-D Cartesian system in the plane of the shell or element. The material properties of individual shell wall layers are defined in the (ϕ_1, ϕ_2) directions, which are established by rotating the fabrication coordinates $(\bar{x}, \bar{y})$ through the angle **ZETL**, a right-handed rotation about $\bar{z}$, which is uniquely defined for each layer. See Figure 5.7 on page 5-133.

(x_a, y_a, z_a) *nodal-auxiliary coordinates*

An arbitrary, rectangular system which may optionally be defined by the user at each node in an element unit. Where defined, the nodal-auxiliary system determines the directions of the computational freedoms (see the *computational coordinates* description, above), which are determined by the nodal-global system, defined next.

$(\bar{x}_g, \bar{y}_g, \bar{z}_g)$ *nodal-global coordinates*

A Cartesian system with its origin at a finite element node and with coordinate axes parallel to (x_g, y_g, z_g) (*i.e.*, a simple translation of the global system to a particular node).

(X', Y', Z') *shell coordinates*

A local rectilinear system defined at each point on the reference surface of shell units. The (X', Y') coordinates are tangents to the coordinate lines defined by the surface coordinates (X, Y). Z' is the shell normal, directed "outward", outward being defined by the sense of the cross product $(X' \times Y')$. Note that (X', Y', Z') have units of length, whereas (X, Y) are surface parameters whose units are dependent upon the specific shell type (see "Standard Shell

Surfaces" beginning on page 6-2). In a cylindrical shell, for example, X is the meridional distance (axial length) and Y is the circumferential distance (arclength in degrees).

For the standard **STAGS** shell units (**ISHELL** = 2–12; see "Standard Shell Surfaces" beginning on page 6-2), the (X', Y', Z') shell coordinates naturally form an orthogonal set, with the single exception of the Elliptic Cone (**ISHELL** $= 9$). For the Elliptic Cone and for shell units that are generated by user-written subroutine LAME (**ISHELL** $= 1$), (X', Y', Z') is orthogonalized in the following ways. Z' is the surface normal in every case. For **ISHELL** $= 9$, the circumferential (Y) and shell-normal directions are chosen as the (Y', Z') directions, and $Y' \times Z' = X'$ establishes the orthogonal system. For **ISHELL** $= 1$ (LAME), the user optionally selects either X' or Y' by reference to the corresponding surface coordinate (X or Y). The remaining axis is computed to establish a right-handed system.

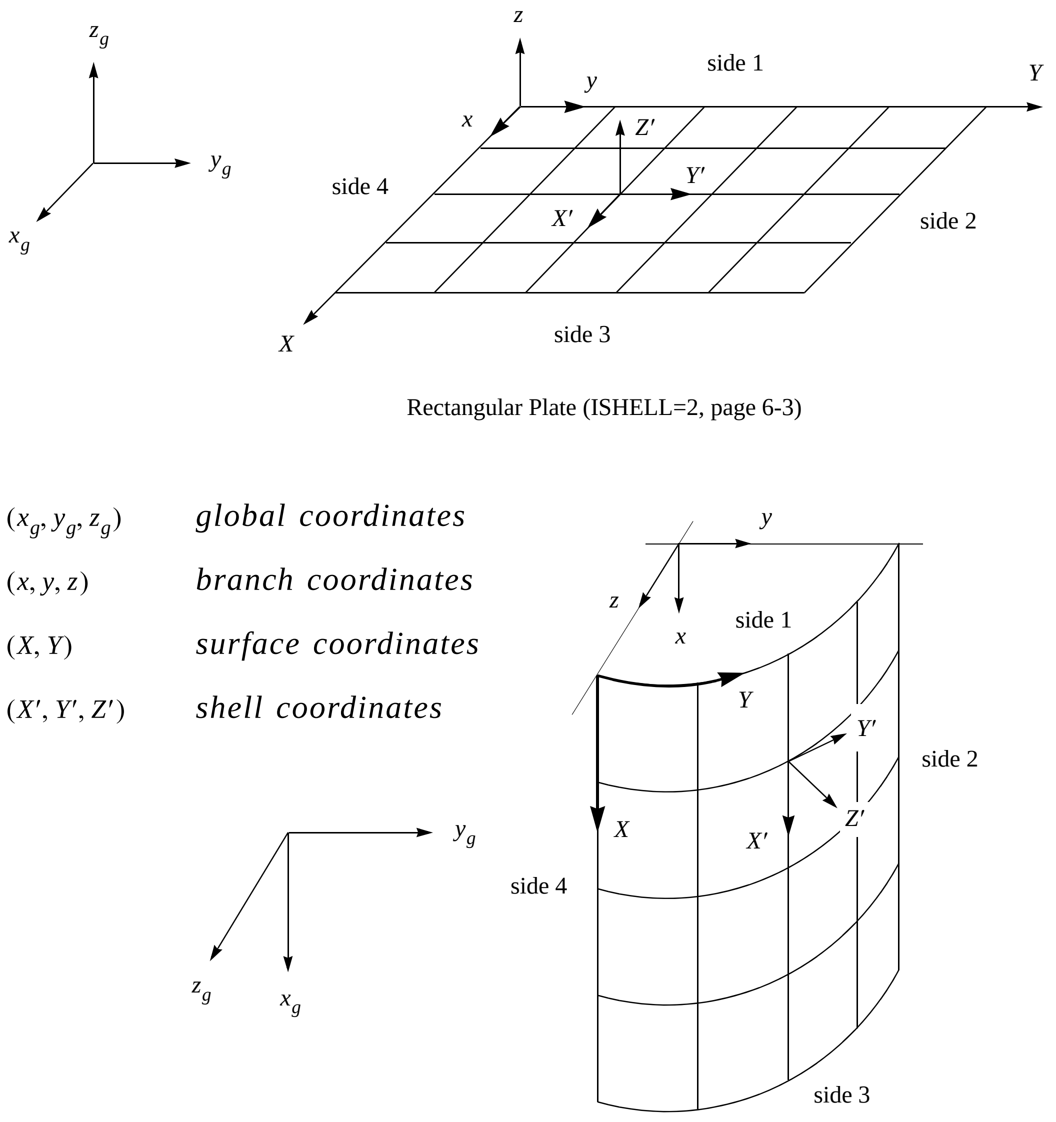
NOTE: For convenience, the symbol Z' sometimes is used to indicate "either the shell normal Z' or the element normal z', as applicable." For example, see Figure 5.6 on page 5-130. The perceptive reader will have no difficulty making this distinction.

(X, Y) *surface coordinates*

Basic curvilinear surface coordinates for shell units. A pair of values (X, Y) specifies the position of a point on the shell reference surface. These coordinates also define the directions of the in-plane displacements (u, v), and may also be used for grid generation. These are parametric coordinates on a plane that is mapped onto a two dimensional surface imbedded in three dimensional space. An example is the mapping of the spherical angles (ψ, θ) into three-space in the generation of a spherical shell. The mapping of (X, Y) into branch coordinates (x, y, z) for all the standard **STAGS** shell units can be found in "Standard Shell Surfaces" beginning on page 6-2. (X, Y) form an orthogonal set, with the single exception of the Elliptic Cone (**ISHELL** $= 9$).

(x_w, y_w) *wall-reference coordinates*

A 2-D Cartesian system used as a reference for orienting a wall fabrication in the plane of the shell or element. By default, (x_w, y_w) are coincident with the (X', Y') shell coordinates in shell units (see Figure 6.2 on page 6-28) and are established by selecting and projecting one of the (x_g, y_g) global direction vectors onto the element surface in element units (see Figure 8.2 on page 8-19). For both shell units and element units, there is an option for establishing the wall-reference system by projecting a user-defined "wall-reference vector" onto the element surface. See Figure 8.3 on page 8-20 for element units; this option is currently unavailable for shell units.


z_g
y_g
x_g
z
y
x
side 1
Y
Z'
Y'
X'
side 4
side 2
side 3
X
(x_g, y_g, z_g) global coordinates
(x, y, z) branch coordinates
(X, Y) surface coordinates
(X', Y', Z') shell coordinates
y
z
x
side 1
Y
Y'
side 2
Z'
X
X'
side 4
side 3
y_g
z_g
x_g

Rectangular Plate (ISHELL=2, page 6-3)

Cylindrical Shell (ISHELL=5, page 6-5)

Figure 4.1 Shell-unit coordinate systems.

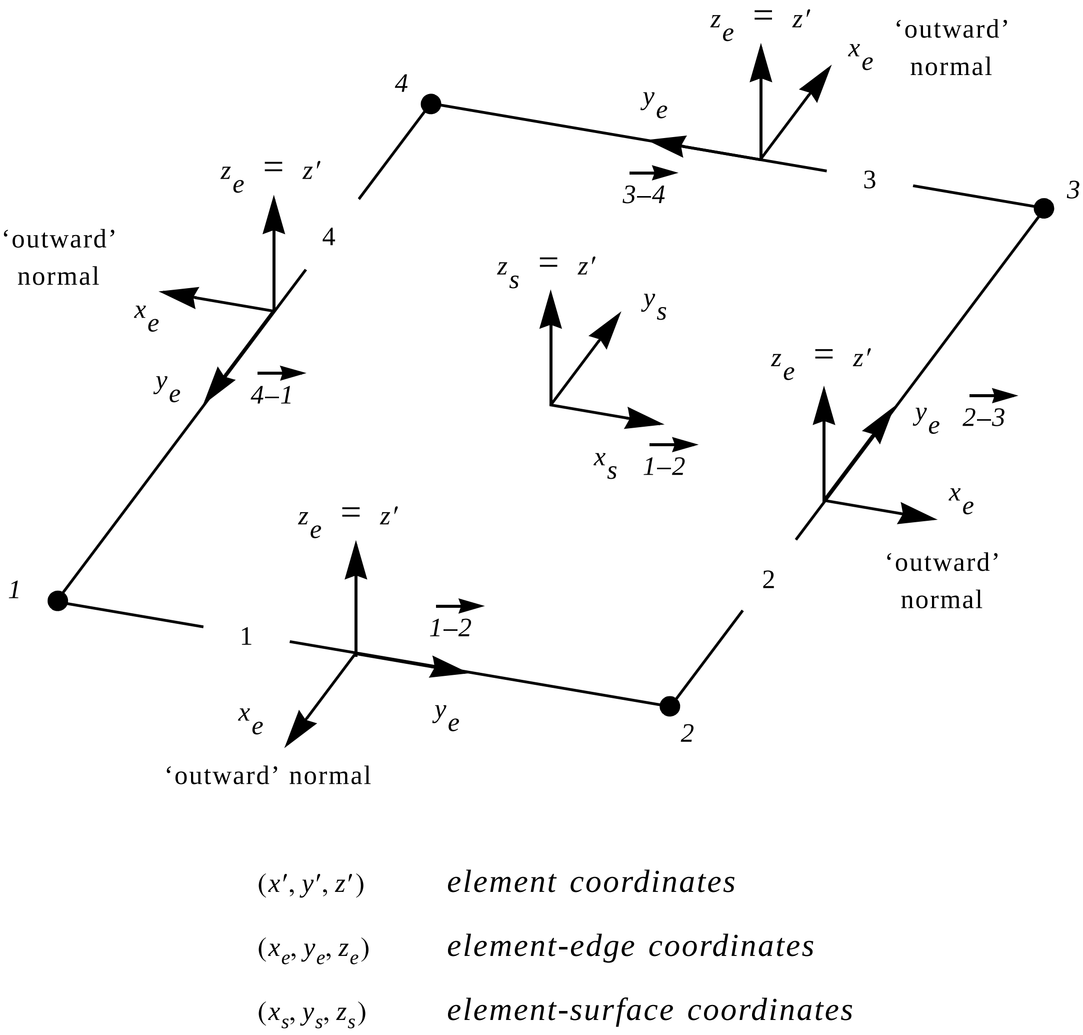

$z_e = z'$
x_e
'outward' normal
4
y_e
$\overrightarrow{3\text{–}4}$
3
3
$z_e = z'$
'outward' normal
4
x_e
y_e
$\overrightarrow{4\text{–}1}$
$z_s = z'$
y_s
x_s
$\overrightarrow{1\text{–}2}$
$z_e = z'$
y_e
$\overrightarrow{2\text{–}3}$
x_e
'outward' normal
2
1
$z_e = z'$
1
$\overrightarrow{1\text{–}2}$
x_e
y_e
2
'outward' normal
(x', y', z') element coordinates
(x_e, y_e, z_e) element-edge coordinates
(x_s, y_s, z_s) element-surface coordinates

Figure 4.2 Element coordinate systems.

4.2 Shell Unit

STAGS models are composed of one or more individual *substructures*. Each substructure is either a *shell unit* or an *element unit*. A shell unit (a quadratic surface which is automatically generated and meshed) is chosen from a library of “standard geometries”, while an element unit is an arbitrary assemblage of user-defined nodes and elements. There are no limitations placed on the number of substructures in a model.

The configuration of a shell unit is described by the use of a reference surface. The location of any point on the reference surface can be uniquely defined by use of a set of two independent parameters (X, Y). The geometry of the reference surface is given after a functional relationship has been established that defines the coordinates in a Cartesian system (x, y, z) as functions of the values of these two parameters:

$$x = x(X, Y) \qquad y = y(X, Y) \qquad z = z(X, Y) \tag{4.1}$$

The parameters (X, Y) defining the position of a point on a surface are referred to as *surface coordinates*, and (x, y, z) are referred to as *branch coordinates*. For the shell and plate configurations contained in the library of standard geometries, the user need not be concerned with these relations.

If one of the surface coordinates (X, Y) is held constant and the other is varied over a range, a trace is obtained on the surface. Such a trace is referred to as a coordinate line. Two sets of such coordinate lines are always used to define the surface grid needed in a finite element analysis.

For each shell unit, a unique branch coordinate system (x, y, z) is defined to describe that unit, or *branch*. Another Cartesian system (x_g, y_g, z_g) is selected as a *global coordinate* system. Special parameters are used to specify the orientation of each branch coordinate system with respect to the global system, unless the position of the unit is uniquely determined by connection to a previously defined shell unit.

At the intersection of grid lines on the shell reference surface (grid points), a local Cartesian system (X', Y', Z') is defined. In this *shell coordinate* system, the (X', Y') axes are in the directions of the tangents to the grid lines, the Z' axis is chosen to form a right-handed orthogonal system. Loads, displacements, stiffener spacings, and eccentricities are generally defined in terms of these local coordinates. In computer output, primes are not used.

In the manual as well as in the computer output, reference is made to an inside and an outside surface. The outside surface is always defined as the shell wall surface corresponding to the largest positive or least negative value of Z'.

If the shell wall or layer of the shell wall is orthotropic with respect to some direction, then the stiffness properties are most easily defined in an orthogonal system (ϕ_1, ϕ_2) in the plane of the shell. This is referred to as the *material coordinate* system. Internally in the program the properties of the shell wall (or of its layers) are transformed from the (ϕ_1, ϕ_2) system to the (X', Y') system. See Figure 5.7 on page 5-133.

Stiffeners are structural elements that are attached to the shell surface. Their cross-sections cannot deform or warp. At times in the manual, stiffeners following the grid lines corresponding to constant Y-values are referred to as stringers, while those on constant X-values are called rings. The *cross-section coordinate* system $(\bar{y}, \bar{z})$ is a special local Cartesian system used for the definition of cross-section properties. Stiffeners can either be considered as discrete, in which case they are defined one by one, or their contribution to the shell wall stiffness can be “smeared” over the shell surface. Smeared stiffeners are used for convenience (to reduce input requirements) or in order to suppress local deformation between stiffeners. The use of smeared stiffeners also reduces the demand on limited computer resources.

The *element coordinate* system (x', y', z') is used for local Cartesian systems defining the orientation of finite elements (element unit). **STAGS** also uses such a frame for every element, but except for stress output requested in the element frame, these coordinates can be ignored by the user for the standard geometries.

A shell unit may be mapped onto a rectangular domain (the mapping is analytic if the surface coordinates (X, Y) are used). Consequently, it can always be considered as a surface with four sides (see Figure 4.3, on the following page). These sides are referred to in the user instructions by the integers 1, 2, 3, 4. The node points are arranged in a rectangular numbering system, so that each is given a row and a column index. Side 1 is always the side on which the node points have the row number 1; Side 4 is the side on which the column numbers are 1. If (X, Y) coordinates are used, Side 1 is the side on which the X is zero, Side 4 is the side on which Y is zero. Side 3 is opposite Side 1, and Side 2 is opposite Side 4. The sides are arranged in clockwise order. As examples, a rectangular plate and a cylindrical shell are shown in Figure 4.1.

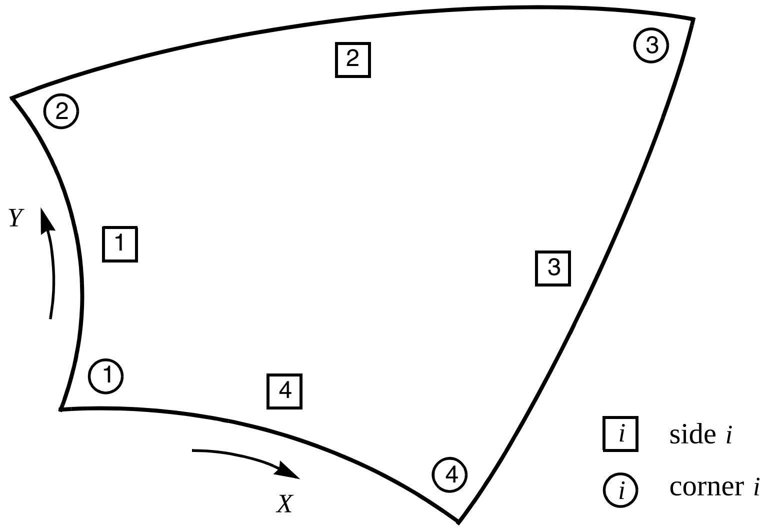


Figure 4.3 Shell-unit boundary- and corner-numbering schemes.

4.3 The Element Unit

In preparation.

4.4 Assembled Structures

In preparation.

4.5 Boundary Conditions

In preparation.

4.6 Loads

ROUGH DRAFT

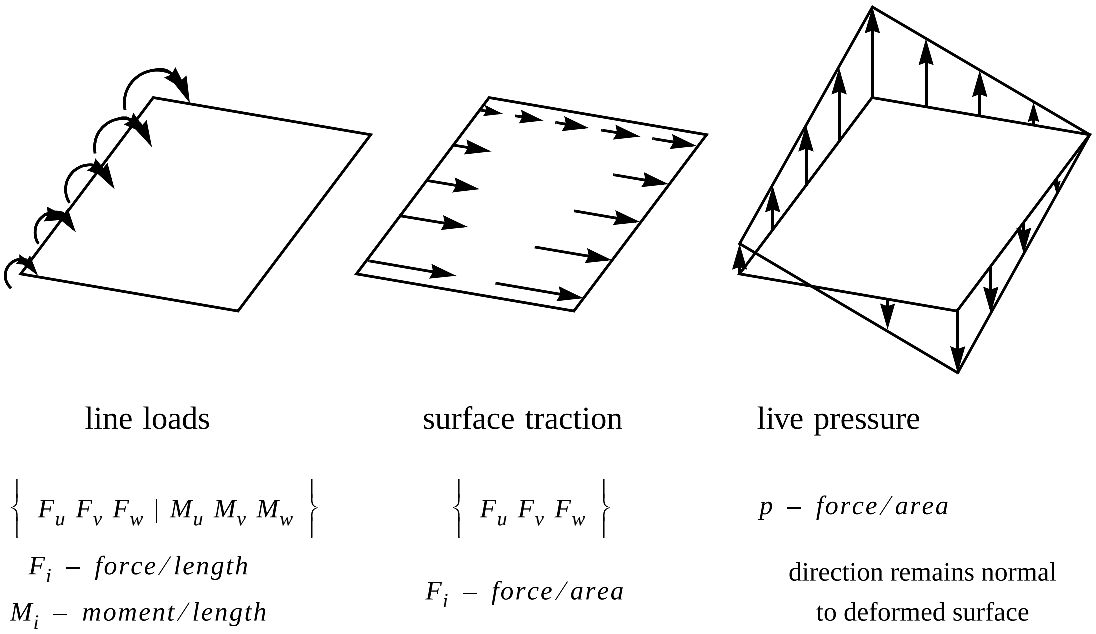


Figure 4.4 **STAGS** distributed loading types.

Table 4.2 Shell unit distributed loading.

coordinate system	line loads	traction	live pressure
(x_g, y_g, z_g)	✔	✔	
(X', Y', Z')	✔	✔	
z'			✔

Table 4.3 Element unit distributed loading.

coordinate system	line loads	traction	live pressure
(x_g, y_g, z_g)	✔	✔	
(x_e, y_e, z_e)	✔		
(x_s, y_s, z_s)		✔	
z'			✔

4.7 Summary of Modeling Techniques

Before preparation of input data, the user should carefully consider the modeling of the structure and the computation strategy to be followed. The choice of analysis type and problems connected with modeling and strategy are discussed in Chapter 11. Some control and summary data occurring early in the input can be defined only after the discretization and the computational strategy have been determined.

Execution of the **STAGS** program always proceeds in two distinct steps, the first being the model setup phase (S1) and the second being the analysis phase (S2). In previous versions of the program, all data were read in at the beginning, including solution strategy and control data. This was true even though in principle it was not necessary to execute the model setup step again for changes in the solution parameters. These data were always available at the beginning of the analysis phase. **STAGS** now provides *two* sets of input data: one for model setup (see Chapters 5–10) and one for solution control (see Chapter 11). To maintain upward compatibility of **STAGS** input run streams, solution control records that previously appeared in the initial input have been preserved. These records will be repeated in the input to the analysis program, and include records B-1, C-1, and all D and E records. The advantage of having two separate input files is that it permits a user to restart or change strategies using previously-saved model data, making additional executions of the model setup step unnecessary. The very brief input stream for the analysis phase is described in Chapter 11.

The model setup is defined in terms of shell units and element units:

- Shell units. These modeling units are typically thin plate or shell components—but they may also be single- or multi-layered sandwich or solid components. Their discretization is defined by reference to a numbering system based on rows and columns. Different options are available for discretization.
- Element units. These modeling units consist of thin, shell-type and/or thicker sandwich and/or solid-type finite elements defined either individually on regular data records or in batches through user-written subroutines. Such batches can be used, for example, for definition of a shell segment with a discretization that does not fit into the row and column scheme required for a shell unit. Finite element models developed using modeling pre-processor software systems such as **PATRAN** or **I-DEAS** typically generate element unit input data.

For a better overview, the different logical records have been divided into groups so that the contents of the records within the same group contain information of similar type. The groups of data in the model setup step are contained in the INP file and include the following groups of input records:

- Title record. Title of the model and analysis problem.
- Summary and Control Parameters. Various model controls—including the number of modeling units, the number of materials, the types of material models, and so forth.
- Discretization and Connectivity Summary. These records define the shell unit discretization in terms of the number of rows and columns in each shell unit, the number of nodes and elements in each element unit, connectivities among the modeling units, crack modeling, MPC definitions, and partial compatibility constraints
- Data Tables. These include the Material Table, the Generic Constitutive Processor Table, the Beam Cross-Section Table, the Shell Wall Property Table, and the User Parameter Table:
    - Material Table. This table defines elastic properties and, if necessary, stress-strain curves for a number of materials.
    - Generic Constitutive Processor Table. This table defines material properties, stress-strain curves (as necessary), and shell and solid fabrication types—with **STAGS**' Generic Constitutive Processor (GCP) functionality.
    - Beam Cross-Section Table. This table defines cross-sections and (with reference to the Material Tables) materials of beams and stiffeners.
    - Shell Wall Property Table. This table defines geometry and (with reference to the Material Table) material of shell wall configurations.
    - User Parameter Table. This table defines constants (integers) and floating point numbers, that are read in for possible use in user-written subroutines.

Next follows detailed information about all modeling units. For each modeling unit the following groups of input records are read in order.

- Geometry and Material
- Discretization
- Discrete Stiffeners
- Boundary Conditions
- Loads
- Output Control

The input for one unit is completed before any entry is made for the following unit. Shell and element units are numbered in the order in which they are specified and are referred to in the output by this "unit" number. Properties are defined by reference to the Data Tables whenever appropriate.

The last groups of input records are referred to as Element Units. In contrast to shell units, all available finite element types can be intermingled within the same unit.

Detailed information is given in Chapters 7–10 and in the ***STAGS** Elements Manual* about the properties of finite elements in the **STAGS** element library. The available elements include:

- Mount and Fastener Elements (general nonlinear springs)
- General Beams (torsional and axial bars)
- Rigid-Link and Soft-Link Beam Elements
- Triangular Plate/Shell Elements
- Quadrilateral Plate/Shell Elements
- Quadrilateral Plate/Shell Mesh Transition Elements
- Solid Elements and Shell/Solid Sandwich Elements
- Solid and Sandwich Mesh Transition Elements
- Surface/Surface, Point/Surface, and Line Contact Elements

Some considerations and restrictions should be noted:

- The E210 beam element, in **STAGS**, is compatible with the E320 triangular shell element and with the E410 quadrilateral shell element. It is *not* compatible with higher-order elements.
- The E330 triangular shell element, in **STAGS**, is not compatible with other the shell elements.
- GCP functionality, in the current version of **STAGS**, is available with the E330, E410 and E480 shell elements and with all solid and sandwich elements. GCP functionality has not been implemented for the E210 beam element or for the E320 shell element.
- The Poisson’s ratio parameter specified on the I-2 record is the minor Poisson’s ratio. The Poisson’s ratio required for GCP input is the major Poisson’s ratio.
- Material density, in the current version of **STAGS**, is defined as *weight* density in the traditional (I-record) specifications—and as *mass* density within the GCP.
- The *plasticity* option can only be used with an initially isotropic material. It cannot be used with material properties that vary with the surface coordinates. The stress-strain curve must be independent of temperature.
- Bifurcation buckling and small vibration analysis may not include plasticity.
- Progressive failure analysis, in **STAGS**, is supported only under the GCP and is not active for linear stress and/or eigenvalue analyses.

and

- The default definition of the gravitational acceleration constant *(g)* is 386.1 in/sec^2.
- When the very first character in any record of a **STAGS** input file is an upper case “C” or a “$” sign, the entire record is treated as a comment. When the very first character is a lower case “c” the record is treated as input data.

Experienced users may find it convenient to utilize the Input Record Catalog, Appendix B.

The groups of data in the solution control step are contained in the BIN file, which contains the following groups of input records:

- Title record. Title of the model and analysis problem.
- Summary and Control Parameters. Specifies analysis type, equation solver, corotation options, higher-order imperfection flag, output options, and so forth.
- Computational Strategy Parameters. These records specify load factors, solution strategies, eigenvalue analysis control parameters, time integration parameters, convergence controls, and so on.

5
Model Input

STAGS user input consists of two text files, the *INP* file and the *BIN* file (see Chapter 17 “Input/Output Files” for a summary description of all I/O files). The *INP* file is described in Chapters 5–10, and the *BIN* file is described in Chapter 11. Each of these two input files consists of a sequence of input records, which have a required order of appearance. Moreover, data have a required order of entry on each record. Chapters 5–11 describe the input records sequentially, in the required order of appearance in the *INP* and *BIN* files. Each record description indicates the required order of input data comprising that record. See Appendix B “Input Record Catalog” for a summary of input records.

Conventions used in describing input records are presented in Section 5.1 “Conventions Used in Input-Record Descriptions”. An example input-record description, for a typical *INP-file* record, is presented in 5.2 “Example Input-Record Description”. Conventions governing required input-data format for most of the *INP-file* records and for all of the *BIN-file* records are presented in Section 5.3 “Input Format Conventions”. Conventions used in defining *User elements* are described in Chapter 13.

Special Fonts

• Record-ID	See ***Record ID and title***, on the following page
• **DATA**	See ***Data summary***, on the following page

5.1 Conventions Used in Input-Record Descriptions

Conventions used in input-record descriptions in this document are explained *via* reference to an example — “I-2 Material Elastic Properties” on page 5-59. Each record description consists of five sections.

Record ID and title

The first line of each record description contains the *record ID* followed by the *record title*. In the example “I-2 Material Elastic Properties”, the record ID is “I-2” and the record title is “Material Elastic Properties.” Records are sometimes identified by referring to their record ID’s, which appear in a special font. For example, “see I-2” and “(I-2)” are shorthand notations for “see the documentation for the I-2 record.”

Discussion

A short discussion regarding the data that are entered on the record follows the record ID and title line.

Data summary

This is a one-line summary of data that are entered on the record, indicating the required order of entry. The I-2 record contains seven data items. Each input datum is identified by a *datum name*. Data names appear in uppercase in a special font, as in **RHO**. The notation “**RHO** (I-2)” is shorthand for “the datum **RHO** on the I-2 record”. If it is clear that the I-2 record is indicated, then **RHO** may appear without the corresponding record ID.

Data description

Each datum is described in detail, in the order it is entered on the record.

Where to go from here

Input records have a required, application-dependent, order of appearance. Some records are always included, while others are required only under certain circumstances. The final section of each record description contains logic, written in pseudo-code, which indicates the next record to appear in the input file. This section is marked with a compass symbol, shown in the box to the right of this paragraph, suggesting its use in navigating through the hazardous waters of **STAGS** input data.

✦

5.2 Example Input-Record Description

In the following, each of the five record description parts is identified for the chosen example, "I-2 Material Elastic Properties" on page 5-59.

Record ID and title:

I-2 Material Elastic Properties

Discussion:

In plate or shell analysis the plane stress assumption is used; the transverse normal stress is assumed to be zero. In that case, the elastic properties are defined by a matrix *C* such that

⋮

If the material is isotropic, it is not necessary to input all the four material constants. When the shear modulus is set to zero, it is assumed that the material is isotropic, *i.e.*, that $E_2 = E_1$ and $G = E_1 / [2(1 + \nu_{12})]$. If a material with a zero shear modulus must be defined, input a very small value for *G*. If the coefficient of thermal expansion in the ϕ_2 direction is set equal to zero, it is assumed that $\alpha_1 = \alpha_2$ (**A1** = **A2**).

Data summary:

E1 U12 G RHO A1 E2 A2

Data description:

E1 elastic modulus in ϕ_1 direction

⋮

A2 coefficient of thermal expansion in ϕ_2 direction, α_2. Setting **A2** $= 0$ causes enforcement of the relationship $\alpha_2 = \alpha_1 = \alpha$.

Where to go from here:

NESP (I-1) number of points on the (σ, ε) curve

if (**NESP** > 0) then *go to* I-3
else *follow instructions at end of* I-3a

5.3 Input Format Conventions

A free-form input record contains a number of *data fields*—each of which is separated from its neighbor(s) by one of several *data terminators*—and optional *comments* that may be placed after the end of input data and are ignored by the program. Most of the input records for **STAGS** *INP* and *BIN* files contain only *numerical* data, consisting of one or more *integer-type* and/or *floating-point-type* data fields. Each numerical data field specifies zero or more integer or floating point data values. The *zero or more* part of this statement is describe below, after the following bulleted notes about numerical data fields:

- Unless otherwise noted, an entry on a data record is an integer if the variable name starts with I–N. Otherwise it is to be treated as a floating-point number.
- Integer field widths cannot exceed 10 characters, including the optional plus or minus sign. Leading blanks and a terminating character are not counted.

- Floating-point numbers must contain a decimal point; an exponent is optional. The exponent may be in any form allowed by regular FORTRAN “E” type format. The following data forms are all equivalent:

```
1450.   1.45E+03   .145+4   1.45E3
```

- Floating-point decimal field widths are unlimited, however floating-point data are truncated to about 7 or 8 decimal digits.

- A numerical data field may begin with any number of blanks (which are ignored) and is terminated with one of the following characters:

`" "`	blank
`","`	comma
`"/"`	slash
`"$"`	dollar sign

  or by the end of **STAGS**’ record-input character-string buffer, which can accommodate up to (but not more than) 255 characters.

- Blanks are ignored everywhere on records containing numerical data, except when they occur between two numerical data fields; then the first field is terminated by the blank. Thus input integers or floating-point numbers may never contain embedded blanks.

  WARNING: ***For most of the INP file (see Chapter 9 for exceptions to this) and for all of the BIN file, a totally blank line is not ignored; it produces a single logical record.***

- A comma is normally used to terminate a data field when the logical record contains additional data. Hence, when the last data field on one line is terminated with a comma, the comma functions as a continuation character and indicates that the logical record continues with the next input line. Otherwise, the logical record is terminated when the end of data on the line is reached. Successive commas on a line may be used to generate blank values of integer items in a list. For example, `"20,,,10"` is equivalent to `"20, 0, 0, 10"`, which is equivalent to `"20 0 0 10"`.

- A slash terminates a logical record, and means that any following data field begins a new logical record. Thus, several logical records may be constructed with one input line (whereas with the use of commas, several input records might comprise a single logical record). A slash following a comma prevents continuation and the comma then functions as a simple terminator.

- A dollar sign (or the “C” character) in column 1 indicates that the entire record is a comment. A comment record may appear anywhere in an input file, except for the first record, which is taken to be the title “card” (see “A-1 Case Title” on page 5-7). A dollar sign in any other column signals the end of data on the record and means that the remaining information on the line is ignored. Space following the dollar sign may be used for comments. A dollar sign may also be used when the data field on a line is terminated by a comma, *i.e.*, when the logical record continues on the following input line.

The current version of **STAGS** recognizes the **[N*]V** construct for data-field specification, where the brackets surrounding the **N*** prefix indicate that it is optional, and where ***V*** represents a specific integer or floating-point value. Omission of the **N*** prefix specifies a single instance of ***V*** for the data field in question. Use of the **N*** prefix, with ***N*** a non-negative integer, makes **STAGS** interpret **N*V** as ***N*** successive instances of the specified value ***V***. For example, **STAGS** interprets "`2*33.`" as "`33. 33.`" and "`4*20`" as "`20 20 20 20`".

Some **STAGS** input records in the *INP* file begin with a *character-type* command entry that is (usually) followed by one or more *integer-type* and/or *floating-point-type* numeric data entries. **STAGS** recognizes the **[N*]V** construct for character-type information, too; but the current version of **STAGS** does not expect more than one consecutive character-type data field.

5.4 Summary and Control Parameters

The first group of input records consists of the A and B records.

The first two, A-1 and B-1, appear in both the *INP* (model input) file and the *BIN* (solution input) file. These are the only two records that appear in both input files.

A-1 is the Case Title record, which contains a character string strictly for the user's convenience. B-1 is the Analysis Type Definition record.

☞ The *INP* B-1 record is *not* interchangeable with the *BIN* B-1 record. They contain different input data altogether.

A-1 Case Title

The case title is read on the first line and may contain any alphanumeric characters. This text is printed at the beginning of the output for the case and for identification on any disk file saved for possible restart. Subsequently any number of comment records can be added provided they begin with a “$” in column 1. Comments can also be included at the end of a data line—a “$” terminating data, and the comment following. A list of the complete input file, including any comment records, is printed at the beginning of all text output files. The user is urged to use this record as a way to document the analysis.

COMMENT

COMMENT case title

✦ *go to* B-1

B-1 Analysis Type Definition

This is a revised version of the B-1 record found in earlier versions of **STAGS**. Note that the *BIN* (solution input) file also includes a B-1 record, but that it contains data that are different than those found here. The B-1 records in the *INP* & *BIN* files are *not* interchangeable.

☞ The B-1 record in the *INP* file is *not* interchangeable with the B-1 record in the *BIN* file. They contain different input data altogether.

IGRAV ICHECK ILIST INCBC NRUNIT NROTS KDEV

IGRAV gravitational constant, g, definition option; **IGRAV** is needed for mass computation, since density (RHO, I-2) and nodal mass (**GM**, Q-4 and U-4) are defined using units of force rather than mass.

0 – $g = 386.1\ \mathit{inches/second}^2$
1 – g will be read on B-4

ICHECK
0 – normal execution
1 – quick execution for model verification only

ILIST data printout option

0 – normal printout
1 – full printout

INCBC *incremental* boundary condition (BC) flag.
(See 6.4 “Boundary Conditions” on page 6-57.)

0 – incremental BC are not used
1 – incremental BC are included

When incremental BC are included ($\mathbf{INCBC} = 1$), the default condition is that they are the same as *basic* BC. Default incremental BC may be selectively overridden in the following ways:

Shell Units: **IBOND** (P-1)

Shell Units and Element Units: load system B specified displacements ($\mathbf{LT} = -1$, Q-3/U-3) are interpreted as incremental BC. In this situation, the value of the displacement (**P**, Q-3/U-3) is ignored, and a *dof* constraint is imposed (*i.e.*, specified zero).

NRUNIT model plot control variable

0 – plot the entire model

>0 – plot units listed in B-1a

NROTS plot rotation specification variable

0 – use the default plot orientation

>0 – use sequence of rotations given in B-1b list

KDEV plot device indicator

0 – use the pdf (Acrobat) format for model plot

1 – use the PostScript file format for model plot

-1 – generate no model plot

NRUNIT (B-1) model plot control variable

NROTS (B-1) plot rotation specification variable

```
if      (NRUNIT > 0)    then  go to  B-1a
elseif  (NROTS > 0)     then  go to  B-1b
else                    go to B-2
```

B-1a Model Unit List

List of units to be included in the model plot.

(IUNIS(i), i = 1, NRUNIT)

IUNIS(i) unit number to be included in the model plot.

✦ **NROTS** (B-1) plot rotation specification variable

if (**NROTS**> 0) then *go to* B-1b
else *go to* B-2

B-1b Sequence of Model Rotations

Sequence of rotations to be imposed on model plot. Record B-1b is repeated **NROTS** times. Each rotation is in the *global body system*, which is initially coincident with the (x_g, y_g, z_g) global system. The current global body system is the result of all previous rotations; this corresponds to the "relative rotation" option in **PATRAN**. A particular application of this principle is the situation where you wish to alter the orientation of the model plot after having chosen the default value **NROTS** =0. If **NROTS** =0, **STAGS** will choose an orientation based on the model dimensions, with the rotation angles and axes displayed on the model plot. If you want to alter the orientation based on the picture, you must first input the sequence (of up to three rotations) printed by **STAGS**, after which any number of additional rotations may be specified. An example of this is the situation where you like the **STAGS** default orientation but wish to view the other side. Suppose in this case, you want to rotate 180 degrees about the current x axis, and suppose **STAGS** has printed 93 degrees about x, -26 degrees about y, and 15 degrees about z; then you would input **NROTS**=4, followed by the following four B-1b records:

```
1  93.
2 -26.
3  15.
1 180.
```

Alternatively, these four model rotations can be specified on a single line of text using the logical record separator; that is,

```
1  93. / 2 -26. / 3  15. / 1 180.$ B-1b Model Rotations
```

IROT ROT

IROT rotation axis.

1 – rotation about the global body x axis
2 – rotation about the global body y axis
3 – rotation about the global body z axis

ROT rotation angle (degrees)

✦ *go to* B-2

B-2 General Model Summary

This record consists of an overall summary of model characteristics, such as the number of shell and element units, the number of units with stiffeners, what kind of constraints are required, and whether there are initial imperfections.

Very small initial geometric imperfections must sometimes be used to trigger deformation in the buckling mode. Imperfections of somewhat larger amplitudes must be included in the analysis model if the degree of imperfection sensitivity of the collapse load is to be established.

A number of different ways to include geometric imperfections is available. One of the options is to use a linear combination of buckling modes computed in an earlier execution of the program to define the shape of the imperfections. If this option is employed, the user must specify on the B-2 record the number of buckling modes **NIMPFS** to be read from the *IMP* file. The amplitudes of the imperfection modes are read on the B-5 record. Other options to define geometric imperfections are described on the M-5 record.

STAGS also permits the user to impose a *moving plane* boundary condition. The moving plane acts in the same way as an ordinary symmetry condition except that the plane of symmetry is allowed to translate and rotate as part of the system response. Thus, all translations along the specified boundary are restricted to lie in a plane, and only rotations normal to the plane are permitted. The program automatically introduces the appropriate Lagrange constraints in the proper order to enforce the boundary condition. The method is in force for all solution options, including the default nonlinear large rotation (corotational) algorithm. **STAGS** treats the moving plane boundary as new line elements of special type **E250**, which are treated just like the other beams in the 200 series. These “beams” can be invoked either directly in the element units, or as special rings or stringers to be placed along any row or column line in a shell unit that *initially* satisfies the planar condition. Users should visualize the new input as a new kind of stiffener of special cross section -1 (reserved internally by **STAGS**) that cannot deform out of plane (large area moment), cannot twist (large torsional constant), but is free to deform within the plane (small area moment). It should be noted that the code enforces the boundary exactly, and does not actually put cross-section properties on this boundary. The user must increment **NSTFS** by one for each planar boundary used (below).

NUNITS NUNITE NSTFS NINTS NPATS NCONST NIMPFS INERT NINSR NPATX NSTIFS

NUNITS number of shell units

NUNITE number of element units; if **NUNITE** > 0, include an H-1 record for each element unit

NSTFS number of shell units with discrete stiffeners. Do not forget the F-2 record. User must also supply a stiffener for each moving plane boundary desired. Moving plane boundaries can, of course, be mixed with ordinary stiffeners, including real stiffeners on the boundary itself.

NINTS number of (G-1-record) specifications of connections between shell units. Each such specification establishes displacement compatibility for two shell unit boundary lines. G-1 can also be used to define the internal connection in closed shell units.

NPATS number of records (G-2) used to define partial compatibility of displacements at specified node pairs (all types of units); also see **NPATX**, below

NCONST number of constraint relations defined in user-written subroutine UCONST or on G-4 records. If there is a subroutine UCONST, **NCONST** equals the number of times CONSTR is called in UCONST. For bifurcation buckling or for small vibrations, constraints defined by UCONST apply both to the stress state and the incremental displacement. If **NCONST** < 0, |**NCONST**| constraints will be read on the G-3 and G-4 records called “regular constraints.”

NIMPFS number of buckling modes read from the *IMP* file to be used to generate imperfections. If **NIMPFS** > 0, scale factors must be provided on the B-5 record.

INERT number of inertial-load records (B-6)

NINSR number of inserted node/element sets (G-5–G-7) defining cracks

NPATX number of records (G-2c) used to define partial compatibility of displacements at specified node pairs in multi-layered shell and/or element units; also see **NPATS**, above

NSTIFS number of linear-stiffness-matrix contributions (W-1)

go to B-3

B-3 Data Tables Summary

This record specifies the number of library entries for materials, cross sections, wall fabrications, user input, and mount elements. It also specifies whether or not **STAGS**' version of the Generic Constitutive Processor (GCP) is to be used for material-property and wall-fabrication information, in addition to or instead of the above-mentioned libraries (the traditional **STAGS** approach). Whenever data in a library entry or in the GCP system are needed, the appropriate library is referenced by an integer identifier, as explained in records I, J and K. The User Parameter records L provide a means to pass user-defined data to user-written subroutines.

NTAM NTAB NTAW NTAP NTAMT NGCP

NTAM number of entries (materials) in the Material Table (I-1).

NTAB number of entries (cross-sections of beams or stiffeners) in the Beam Cross-Section Table (J-1).

NTAW number of entries (shell wall types) in the Shell Wall Property Table (K-1).

NTAP

0 – User Parameters are not included (L-1).

1 – User Parameters are included (L-1).

NTAMT number of tables for mount elements (nonlinear springs) and/or for penalty-function tables (used with contact elements)

NGCP GCP-utilization flag:

0 – The GCP system will *not* be used

1 – The GCP system *will* be used

IGRAV	(B-1)	gravitational constant, g, definition option
NIMPFS	(B-2)	number of buckling modes read from the *IMP* file
INERT	(B-2)	number of inertial-load records
NUNITS	(B-2)	number of shell units

```
if      (IGRAV = 1)    then  go to B-4
elseif  (NIMPFS > 0    then  go to B-5
elseif  (INERT > 0)    then  go to B-6
elseif  (NUNITS > 0)   then  go to F-1
else                   follow instructions at end of G-1
```

B-4 Gravitational Acceleration

This record modifies the gravitation constant if the units used are other than inches and seconds. It is included only if **IGRAV** $= 1$ (B-1).

GRAV

GRAV gravitational acceleration (*e.g.*, $g = 9.80665\ m/s^2$)

NIMPFS	(B-2)	number of buckling modes read from the *IMP* file
INERT	(B-2)	number of inertial-load records
NUNITS	(B-2)	number of shell units

```
if      (NIMPFS > 0)  then  go to B-5
elseif  (INERT > 0)   then  go to B-6
elseif  (NUNITS > 0)  then  go to F-1
else                  follow instructions at end of G-1
```

B-5 Buckling Mode Imperfections

These records are included only if **NIMPFS** > 0 (B-2). **STAGS** allows the user to include imperfections from a number of *eigenvalue executions* of the same case. For example, one may have initially performed a linear bifurcation analysis, followed by a nonlinear collapse analysis, followed by a mode computed from the nonlinear stress state. Another execution could be run from the beginning, including all the modes accumulated so far. For each eigenvalue execution, **STAGS** produces two files, *IMP* and *EGV*, that contain all the modes computed during the entire history of the case. These modes are identified by the load step number, **IMSTEP**; the mode number, **IMMODE**; and the eigenvalue-execution ID number, **IMRUN**. These mode-identifying data are found in the *OUT2* files corresponding to the specified eigenvalue executions. The user can generate any linear combination of these modes by specifying their amplitudes (remember, for eigenmodes computed by **STAGS**, the largest *translational* component is normalized to unity). These imperfections are combined with any imperfections generated by M-6 records or by user-written subroutine DIMP. The eigenvectors identified on the B-5 record are read from the *EGV/IMP* file set; see Chapter 17 “Input/Output Files”. Note that the buckling mode amplitude **WIMPFA** multiplies all translational components in the eigenvector—not just the transverse component.

This record is repeated **NIMPFS** times.

WIMPFA IMSTEP IMMODE IMRUN

WIMPFA	buckling mode amplitude; may be positive or negative
IMSTEP	load step number
IMMODE	mode number
IMRUN	eigenvalue-execution ID number

NIMPFS	(B-2)	number of buckling modes read from the *IMP* file
INERT	(B-2)	number of inertial-load records
NUNITS	(B-2)	number of shell units

```
if  (NIMPFS modes have been defined)  then
    if      (INERT > 0)    then  go to B-6
    elseif  (NUNITS > 0)   then  go to F-1
    else                         follow instructions at end of G-1
elsecontinue defining B-5
```

B-6 Inertial Loads Summary

This record is included only for inertial loading, INERT > 0 (B-2). Each of the INERT inertial load records is defined *via* a B-6–B-6d sequence and may be independently added to Load System A or to Load System B. Inertial loading constitutes part of the *base loads*, which are scaled by the *load factors* P_A and P_B (see Section 6.5).

A general inertial field which acts over the entire structure is achieved by prescribing:

- components of an acceleration vector $(\mathbf{a}_o)$ acting in the global coordinate directions (x_g, y_g, z_g)
- components of an angular velocity vector (ω_o), acting about the axes of a coordinate system whose directions are parallel to (x_g, y_g, z_g) and whose origin is specified by the position vector $(\mathbf{x}_o)$
- components of an angular acceleration vector (α_o), acting about the axes of the coordinate system described above for (ω_o)

The resulting inertial loads are computed on a nodal basis as

$$\mathbf{f}_i = m_i(-\mathbf{a}_i)$$

where $\mathbf{f}_i$ is the inertial force vector which acts on node i due to the product of m_i, the “lumped mass” at node i, and $\mathbf{a}_i$, the acceleration at node i, computed as the sum of gravitational acceleration and centripetal acceleration according to

$$\mathbf{a}_i = \mathbf{a}_o + \omega_o \times (\omega_o \times \mathbf{r}_i) + \alpha_o \times \mathbf{r}_i$$

where $\mathbf{a}_o$ is the input acceleration vector, ω_o is the input angular velocity vector, α_o is the input angular acceleration vector, and $\mathbf{r}_i$ is the relative location of node i, computed as

$$\mathbf{r}_i = \mathbf{x}_i - \mathbf{x}_o$$

where $\mathbf{x}_o$ is the vector which positions the origin of the coordinate system used to compute centrifugal loading, and $\mathbf{x}_i$ contains the (x_g, y_g, z_g) coordinates of node i.

Notice the minus sign in the expression for $\mathbf{f}_i$, which expresses the principle that inertial forces oppose acceleration. For example, to impose gravity loading on a structure with the negative z_g axis pointing towards the center of the earth, specify $\mathbf{a}_o = (0, 0, g)$, $\omega_o = 0$, and $\alpha_o = 0$.

ISYS IA IOM IAL IOPT

ISYS load system option

1 – Load system A

2 – Load system B

IA acceleration ($\mathbf{a}_o$) option

0 – acceleration vector omitted

1 – acceleration vector specified on B-6a

IOM angular velocity (ω_o) option

0 – angular velocity vector omitted

1 – angular velocity vector specified on B-6b

IAL angular acceleration (α_o) option

0 – angular acceleration vector omitted

1 – angular acceleration vector specified on B-6c

IOPT coordinate system option for angular velocity/acceleration

0 – ω_o, α_o are about the (x_g, y_g, z_g) system; $\mathbf{x}_o = 0$

1 – ω_o, α_o are about a set of axes which are parallel to (x_g, y_g, z_g) and centered at the *center of mass* for the structure; $\mathbf{x}_o$ is computed by **STAGS**

2 – ω_o, α_o are about a set of axes which are parallel to (x_g, y_g, z_g) and centered at a user-specified position; $\mathbf{x}_o$ is input on B-6d

```
if      (IA = 1)    then  go to B-6a
elseif  (IOM = 1)   then  go to B-6b
elseif  (IAL = 1)   then  go to B-6c
elseif  (IOPT = 2   then  go to B-6d
else                      follow instructions at end of B-6d
```

B-6a Inertial Loads — Acceleration

AX AY AZ

AX, AY, AZ components of the acceleration vector $\mathbf{a}_o$; units are $length/time^2$ (*e.g.*, m/s^2 or ft/s^2)

IOM	(B-6)	angular velocity (ω_o) option
IAL	(B-6)	angular acceleration (α_o) option
IOPT	(B-6)	coordinate system option for angular velocity/acceleration

```
if       (IOM = 1)   then   go to B-6b
elseif   (IAL = 1)   then   go to B-6c
elseif   (IOPT = 2)  then   go to B-6d
else                        follow instructions at end of B-6d
```

B-6b Inertial Loads — Angular Velocity

OMX OMY OMZ

OMX,OMY,OMZ components of the angular velocity vector ω_o; units are *radians/time*, (*e.g.*, *radians/s*)

IAL	(B-6)	angular acceleration (α_o) option
IOPT	(B-6)	coordinate system option for angular velocity/acceleration

```
if       (IAL = 1)   then   go to B-6c
elseif   (IOPT = 2)  then   go to B-6d
else                        follow instructions at end of B-6d
```

B-6c Inertial Loads — Angular Acceleration

ALX ALY ALZ

ALX,ALY,ALZ components of the angular acceleration vector α_o; units are $radians/time^2$, ($e.g.,$ $radians/s^2$)

IOPT (B-6) coordinate system option for angular velocity/acceleration

if (**IOPT** = 2)	then *go to* B-6d
else	*follow instructions at end of* B-6d

B-6d Inertial Loads — Position Vector

This record is included only when the user is specifying a position vector for angular velocity (**IOPT** = 2, B-6).

X Y Z

X, Y, Z (x_g, y_g, z_g) components of the position vector $\mathbf{x}_o$

✦

INERT	(B-2)	number of inertial-load records
NUNITS	(B-2)	number of shell units

```
if      (INERT inertial-load records have been defined)  then
        if   (NUNITS > 0)   then   go to F-1
        else                       follow instructions at end of G-1
else    return to B-6
```

5.5 Discretization and Connectivity Summary

The next group of records in the INP file provides a summary of the discretization of each of the modeling units and specifies connectiivities among these units—including crack definitions (if any). Shell unit discretizations are defined *via* F-1 Grid Summary and F-2 Stiffener Summary records. Element unit discretizations are summarized on the H-1 Element Unit Summary record. Connectivites among the modeling units, partial compatibility constraints, and multi-point constraints are defined *via* G-1 through G-4 record groups. Crack definitions are specified *via* G-5, G-6 and G-7 records.

F-1 Grid Summary

The grid point summary record gives the number of rows and columns for each of the **NUNITS** (B-2) shell units. While in most cases, these coincide with the element edges, for nine-node shell elements with full-fledged midside nodes, every other gridline coincides with the element edges. Thus, for the nine-node **E480** element, for example, the element spans three gridlines instead of two. That is, a grid specified by three rows and three columns (a 3x3 grid) accommodates a single 9-node quadrilateral element or four 4-node quadrilateral elements. **NROWS** and **NCOLS** must be odd to accommodate these elements. For ordinary quadrilateral shell elements, the number of elements N_{er} along a row is

$$N_{er} = \mathbf{NCOLS} - 1$$

while for nine-node shell elements it is

$$N_{er} = (\mathbf{NCOLS} - 1)/2$$

with corresponding formulas for the number of elements along a column.

(NROWS(i) NCOLS(i) , i = 1, NUNITS)

NROWS(i) number of rows for shell unit *i*

NCOLS(i) number of columns for shell unit *i*

NOTE: All of the data here are on a single logical record; when the user's model has a large number of shell units, it is generally necessary to divide this logical record into two or more subrecords, each (except the last) of which is terminated with a record-continuation character (comma) (see 5.3 "Input Format Conventions" on page 5-4).

NSTFS (B-2) number of shell units with discrete stiffeners
NINTS (B-2) number of shell-unit-connection records required
NPATS (B-2) number of G-2 type partial-compatibility records required
NPATX (B-2) number of G-2c type partial-compatibility records required
NCONST(B-2) number of Lagrange-constraint equations
NINSR (B-2) number of inserted node/element sets defining cracks
NUNITE (B-2) number of element units

```
if      (NSTFS > 0)    then  go to F-2
elseif  (NINTS > 0)    then  go to G-1
elseif  (NPATS > 0)    then  go to G-2
elseif  (NPATX > 0)    then  go to G-2c
elseif  (NCONST < 0)   then  go to G-3
elseif  (NINSR > 0)    then  go to G-5
elseif  (NUNITE > 0)   then  go to H-1
else                   follow instructions at end of H-1
```

F-2 Stiffener Summary

This record is included if and only if there are shell units with discrete stiffeners, *i.e.*, when **NSTFS** > 0 (B-2); this includes any *moving plane* boundary conditions. Ordinary stiffeners and moving plane boundaries can be mixed together in any order, and can lie on top of one another.

This record is repeated **NSTFS** times.

IUNIT NRGS NSTR

IUNIT shell unit number

NRGS number of discrete stiffeners or moving plane boundaries in the row direction (constant X)

NSTR number of discrete stiffeners or moving plane boundaries in the column direction (constant Y).

NSTFS	(B-2)	number of shell units with discrete stiffeners
NINTS	(B-2)	number of shell-unit connections
NPATS	(B-2)	number of G-2 type partial-compatibility records required
NPATX	(B-2)	number of G-2c type partial-compatibility records required
NCONST	(B-2)	number of Lagrange-constraint equations
NINSR	(B-2)	number of inserted node/element sets defining cracks
NUNITE	(B-2)	number of element units

```
if   (NSTFS F-2 records have been defined)  then
     if      (NINTS > 0)    then   go to  G-1
     elseif  (NPATS > 0)    then   go to  G-2
     elseif  (NCONST < 0)   then   go to  G-3
     elseif  (NINSR > 0)    then   go to  G-5
     elseif  (NUNITE > 0)   then   go to  H-1
     else                          follow instructions at end of  H-1
else   continue defining  F-2
```

G-1 Shell Unit Connections

Type G-1 record(s) are required when displacement compatibilities between pairs of shell unit boundary lines have been specified by defining **NINTS**>0 (B-2). Each G-1 record specifies one or (if the *looping* feature described below is used) more than one pair of shell-unit boundary lines for which displacement compatibilities are to be enforced.

Typically, G-1 records are used to join pairs of shell units that are constructed with thin-shell elements or to connect pairs of shell units that are constructed with solid elements. For some models, one or more G-1 records may be used to join pairs of shells where one is a thin-shell unit and the other is a solid-element (multi-layered) unit. Please see the note about that situation, later in this description.

In any event, the user should know that shell units are automatically numbered by the order in which they are defined. The boundary lines of the shell units are numbered as shown in Figure 6.6 on page 6-58. A G-1 shell unit connection record specifies compatibility between one boundary line on a shell unit m and a second boundary line on a shell unit n. Shell unit m must be chosen as the unit with the lower number of the two units involved in one G-1 record. G-1 can only be used to connect boundary lines of shell units. Connections can be defined at internal grid lines either by partial compatibility (G-2 and/or G-2c) records, with Lagrange constraints (G-3), or as user-written constraints.

If more than two shell units are connected at the same line, the m unit on all of the corresponding G-1 records must be the same.

G-1 can be used to define a connection between two boundary lines on the same shell unit. This feature is used to define a closed shell. In that case, **MUNIT** = **NUNIT**; and **MBOUND**, **NBOUND** are set to connect boundaries 1-to-3 or 2-to-4, as those are the only permissible ways to effect an intraunit connection. For example, a closed cylinder must be connected on the $\theta = 0°$ and $\theta = 360°$ boundaries (2-to-4); otherwise a “slit” cylinder results.

If **NBOUND** < 0, the juncture line on the unit n is connected to the unit m in reverse order. This option is used if the shell coordinate X or Y in the two connected units is increasing in opposite directions along the common boundary.

The user must insure that the grid lines in each unit are compatible along the line of juncture; this means that the number of rows or columns in one unit must equal either the number of rows or the number of columns in the other (F-1). For example, if a juncture line along a *row* on unit 1 is joined along a *column* in unit 2, the number of columns in unit 1 must be equal to the number of rows in unit 2 for a compatible fit. If compatibility conditions are not satisfied, a diagnostic message is printed.

Typically, a single G-1 record will be used to define each of the **NINTS** shell-unit connections for the problem at hand. For some configurations, however, it is convenient to use the G-1 *looping* feature described below to specify two or more connections with a single G-1 record; in this case, the number of G-1 records required will be less than **NINTS** (but must be sufficient to define all **NINTS** connections).

If one or the other (but not both) of the two units on a G-1 record identifies a multi-layered shell, it is

MUNIT MBOUND NUNIT NBOUND NDEFS INC1 INC2 INC3 INC4

MUNIT the magnitude of **MUNIT** identifies the *lower-numbered* shell unit $(m \le n)$; see the note following this description for important information about the sign of **MUNIT**

MBOUND boundary line number, for unit *m*

NUNIT the magnitude of **NUNIT** identifies the *higher-numbered* shell unit $(n \ge m)$; see the text above for important information about the sign of **NUNIT**

NBOUND boundary line number, for unit *n*

NDEFS the number of shell-unit connections specified *via* the current G-1 record; **STAGS** sets **NDEFS** equal to unity if it is nonpositive or if it is omitted

INC1 incrementation parameter for **MUNIT**

INC2 incrementation parameter for **MBOUND**

INC3 incrementation parameter for **NUNIT**

INC4 incrementation parameter for **NBOUND**

Note: A shell unit that is modeled with thin shell elements only needs a single layer of node points to define those elements. The shell may be a multi-layered shell in terms of its material fabrication properties; but it is a single-layered shell, geometrically. A shell unit that is modeled with sandwich or solid elements must have two or more layers of nodes in the thickness direction to accommodate those elements. The user typically establishes a “reference” layer of node points by specifying a geometry type (**ISHELL**) on an M-1 record and parameters associated with that type of shell on the M-2 companion for that M-1 record. When the user specifies the use of sandwich or solid elements for constructing the shell unit (on the N-1 record for that unit), **STAGS** starts with the reference layer of nodes (the reference grid) and generates additional nodal layers by “pulling” the reference layer through the thickness. The shell unit constructed by this process may be single-layered with respect to its fabrication (regardless of the number of nodal layers required) but it is always multi-layered in a geometric sense. If one or the other (but not both) of the two units that are specified here identifies a multi-layered shell (with two or more nodal layers), the user must give a negative sign to the unit-specification variable for the multi-layered unit (*i.e.*, to **MUNIT** or **NUNIT**, depending on which of the two units is the multi-layered one). This tells **STAGS** to generate soft links (**E121** elements) and Lagrange multipliers automatically, to enforce the displacement compatibilities that are needed to join pairs of shells when one of them is nodally multi-layered.

Example 1: the following G-1 record:

```
10 2 20 4  3  1 0 1 0   $ G-1 record
```

generates the same three shell-unit connections as the following three G-1 records:

```
10 2 20 4                $ G-1 record
11 2 21 4                $ G-1 record
12 2 22 4                $ G-1 record
```

Example 2: the following G-1 record:

```
-13 2 23 4               $ G-1 record
```

specifies a single connection in which a thin-shell unit is joined to a solid-shell unit.

NINTS	(B-2)	number of shell-unit connections
NPATS	(B-2)	number of G-2 type partial-compatibility records required
NPATX	(B-2)	number of G-2c type partial-compatibility records required
NCONST	(B-2)	number of Lagrange-constraint equations
NINSR	(B-2)	number of inserted node/element sets defining cracks
NUNITE	(B-2)	number of element units

```
if   (NINTS shell unit connections have been defined)  then
     if        (NPATS > 0)    then   go to  G-2
     elseif    (NPATX > 0)    then   go to  G-2c
     elseif    (NCONST < 0)   then   go to  G-3
     elseif    (NINSR  > 0)   then   go to  G-5
     elseif    (NUNITE  > 0)  then   go to  H-1
     else                            follow instructions at end of  H-1
else      continue defining  G-1
```

G-2 Partial Displacement Compatibility

Record(s) of type G-2 are required when partial compatibility between displacements at particular nodes has been specified by defining **NPATS** > 0 (B-2). **NPATS** G-2 records must be included. Each G-2 record specifies one or more partial displacement compatibility conditions, depending on whether or not the G-2 record *exterior-looping* feature (described below) is used.

If G-2 records are used to connect single-layered shell units, **IGLOBE** (M-1) must be 0, 3, 4, or 5. A single-layered-shell-unit displacement component is identified by its unit, row, column, and component (direction) numbers. A displacement component in element units is identified by node number (**IR1**), a zero for **IC1**, and a value for the direction (**ID1**). The first 8 items on each G-2 record define a pair of displacement components. The two units referenced may be the same. The first shell unit (**IU1**) must not be greater than the second (**IU2**).

The *zero rule* applies to the variables **IR1**, **IC1**, **IR2**, **IC2**: if any of these variables is set to zero in a shell unit, it means the compatibility condition applies to an entire row or column, respectively. For example, to enforce compatibility of the *u* freedom along row 1 of unit 1, the single G-2 record shown below can be used:

```
1 1 1 1     1 1 0 1
```

When either a row (or column) entry is zero for both the master and slave sets of integers, a loop over all rows (or columns) is implied, generating *nrow* (or *ncol*) separate constraints, where *nrow* and *ncol* are the number of rows and columns in the shell unit. For example, the single G-2 record

```
1 0 1 3     1 0 14 3
```

means that for each row, the *w* freedom (**ID1** $= 3$) on column 14 is equated with the *w* freedom on column 1. When this capability is used with two different shell units, the number of rows (columns) must of course be the same.

If the value of **IR2** or **IC2** (for the slave nodes) is negative, the compatibility between units **IU2** and **IU1** is enforced in reverse order (this is identical to what happens with the **NBOUND** variable on G-1 records). This option is used if the shell coordinate X or Y in the two connected units is increasing in opposite directions along the common boundary.

Since no transformations are performed, the specified nodes should not lie on a boundary line involved in a shell unit connection (G-1) unless the two shell units have the same orientation with respect to the global coordinates.

A special option is provided for joining shell units using G-2 records. If both **ID1** and **ID2** are zero, then full compatibility is enforced between the nodes on **IU1** and **IU2**. This means that the components on the node belonging to **IU2** are first transformed into the local system in **IU1** before the compatibility condition is enforced, which is the same thing that happens when shell units are joined using G-1 records. The *zero rule* also applies to the row and column indices here; thus, to join shell unit 2, row 1 to shell unit 1, row 13, the single record

```
1 13 0 0     2 1 0 0
```

suffices. Here, row 13 could be in the interior of the unit. The user must be very careful when using this option. First, he must insure the same row or column compatibility as required for the G-1 records; second, the user cannot set **ID2** to zero to transform the coordinates in unit 2 to the master unit system when only a single component is specified in unit 1 (**ID1** not zero); third, he must insure that the lines involved in the juncture actually coincide in space, since the code will not check for the physical coincidence of the juncture lines. The user can take advantage of **IGLOBE** options 3, 4, or 5 (M-1) to move the units around until they meet in the right place.

The next six items (**ND1A** through **INC2**) on the G-2 record are optional input variables allowing the user to specify full compatibility for a range of nodes. These data are ignored unless the following logical expression evaluates to ‘True’:

$$\{(\mathbf{IR1} = 0 \quad or \quad \mathbf{IC1} = 0) \quad and \quad (\mathbf{IR2} = 0 \quad or \quad \mathbf{IC2} = 0)\}.$$

These optional input variables provide a convenient (interior-looping) method for specifying compatibility between any portion of a row or column of one unit and a portion of a row or column of another unit. This type of input may also be used in element units provided the range of nodes has a fixed increment. For both shell and element units, increasing and decreasing ranges are allowed. If $\mathbf{INC1} = 0$ or $\mathbf{INC2} = 0$, an increment of *+1* is used for increasing ranges and *-1* for decreasing ranges.

Typically, one G-2 record will be used to define each of the **NPATS** partial displacement compatibility conditions for the problem at hand. For some configurations, however, it is convenient to use the G-2 *exterior-looping* feature described below to make two or more specifications with a single G-2 record. The final item (**NDEFS**) on the G-2 record is an optional control parameter that, when omitted or set equal to any integer less than or equal to unity, causes the G-2 record to generate a single (set of) partial displacement compatibility specification(s)— or, when **NDEFS** > 1, causes the G-2 record (with information on the G-2a record following it) to generate **NDEFS** sets of partial compatibility specifications (see the example following the G-2a description, below).

If the exterior-looping feature is *not* used on any of the G-2 records given, the **NPATS** G-2 records define **NPATS** partial displacement compatibilities; if the exterior-looping feature *is* used, the **NPATS** G-2 records given define more than **NPATS** partial displacement compatibility conditions.

IU1 IR1 IC1 ID1 IU2 IR2 IC2 ID2 ND1A ND1B INC1 ND2A ND2B INC2 NDEFS

IU1 unit number of first node. **IU1** $=$ **NUNITS** $+ k$ indicates element unit k; **IU1** must be the lower number (**IU1** $\le$ **IU2**); see *CAUTION*, below.

IR1 row number of first node or node number in element unit; if **IR1** $= 0$, then either **IR2** $= 0$ or **IC2** $= 0$ must be set.

IC1 column number of first node. **IC1** $= 0$ in element unit; if **IC1** $= 0$, then either **IR2** $= 0$ or **IC2** $= 0$ must be set.

ID1 Indicates the component involved at the first node; **ID1** = 1, 2, 3, 4, 5 or 6 for *u*, *v*, *w*, *ru*, *rv*, *rw*, respectively; if **ID1** $= 0$, then all components are involved, and **ID2** $= 0$ must be set.

IU2 unit number of second node; **IU2** $=$ **NUNITS** $+ k$ for element unit k;
IU2 must be the higher number (**IU2** $\ge$ **IU1**); see *CAUTION*, below.

IR2 row number of second node or node number in element unit.

IC2 column number of second node; **IC2** $= 0$ in element unit.

ID2 indicates the component involved at the second node. **ID2** = 1, 2, 3, 4, 5 or 6 for *u*, *v*, *w*, *ru*, *rv*, *rw*, respectively; if **ID2** $= 0$, then the components are first transformed to the **IU1** system before partial compatibility is enforced. Note: if **ID2** $= 0$, then **ID1** must also be 0.

ND1A first node of: (row, if **IR1** $= 0$) or (column, if **IC1** $= 0$)

ND1B last node of: (row, if **IR1** $= 0$) or (column, if **IC1** $= 0$)

INC1 increment for nodes from **ND1A** to **ND1B**

ND2A first node of: (row, if **IR2** $= 0$) or (column, if **IC2** $= 0$)

ND2B last node of: (row, if **IR2** $= 0$) or (column, if **IC2** $= 0$)

INC2 increment for nodes from **ND2A** to **ND2B**

NDEFS number of partial compatibility specifications generated *via* this G-2 record; set to unity by **STAGS** if nonpositive or omitted

CAUTION*:* when different shell or element units are involved, the lower-numbered unit must be given first. This rule also applies to node numbers within a specific unit; the lower-numbered node must be given first. In shell units, nodes are numbered in row-major order; *i.e.*, along row 1, starting at column 1; then along row 2, starting at column 1; *etc.*

```
if   (NDEFS > 0)     then go to  G-2a
else                  follow instructions at end of G-2a
```

G-2a Partial Compatibility Incrementations

A single record of type G-2a must be included immediately after each type G-2 record on which the **NDEFS** parameter is greater than unity. Eight incrementation variables are specified here for use with the G-2 record *exterior-looping* capabilities.

JU1 JR1 JC1 JD1 JU2 JR2 JC2 JD2

JU1 incrementation variable for use with the **IU1** (unit-specification) variable on the parent G-2 record

JR1 incrementation variable for use with **IR1** (on G-2)

JC1 incrementation variable for use with **IC1** (on G-2)

JD1 incrementation variable for use with **ID1** (on G-2)

JU2 incrementation variable for use with **IU2** (on G-2)

JR2 incrementation variable for use with **IR2** (on G-2)

JC2 incrementation variable for use with **IC2** (on G-2)

JD2 incrementation variable for use with **ID2** (on G-2)

Any of these incrementation variables may be negative, zero or positive.

Exterior-looping example: the following G-2/G-2a record combination:

```
63 2 0 4   71 2 0 4   1 7 1  1 7 1  3  $ G-2  record
 0 0 0 1    0 0 0 1                    $ G-2a record
```

generates the same three partial compatibility definitions as the following three G-2 records:

```
63 2 0 4   71 2 0 4   1 7 1   1 7 1    $ G-2 record
63 2 0 5   71 2 0 5   1 7 1   1 7 1    $ G-2 record
63 2 0 6   71 2 0 6   1 7 1   1 7 1    $ G-2 record
```

NPATS	(B-2)	number of G-2 type partial-compatibility records required
NPATX	(B-2)	number of G-2c type partial-compatibility records required
NCONST	(B-2)	number of Lagrange-constraint equations
NINSR	(B-2)	number of inserted node/element sets defining cracks
NUNITE	(B-2)	number of element units

```
if    (NPATS G-2 records have been defined)  then
      if        (NPATX > 0)     then   go to  G-2c
      elseif    (NCONST < 0)    then   go to  G-3
      elseif    (NINSR > 0)     then   go to  G-5
      elseif    (NUNITE > 0)    then   go to  H-1
      else                             follow instructions at end of  H-1
else      return to continue defining  G-2
```

G-2c Partial Displacement Compatibility

Record pair(s) of type G-2c and G-2d are required when partial compatibility between displacements at particular nodes has been specified by defining **NPATX** > 0 (B-2): this protocol for specifying partial-compatibility conditions can be used with *single-layered* shell and/or element units; but it is most suitable for use with *multi-layered* shell and/or element units.

The term “single-layered” in this context refers to modeling units (or regions) where a single layer of node points (a two-dimensional grid) is needed to model the structure with a single layer of two-dimensional plate and/or shell elements. The term “multi-layered” refers, here, to units (or regions) where two or more layers of nodes are required to model a structural component with sandwich or solid elements that have two or more nodes in the “thickness” direction.

In any event, **NPATX** G-2c/G-2d record pairs must be included. Each G-2c record specifies one or more partial displacement compatibility conditions, depending on whether or not the *exterior-looping* feature is used on the G-2d record (described below). Each G-2c record must be followed immediately by a G-2d record.

If G-2c records are used to connect shell units, **IGLOBE** (M-1) must be 0, 3, 4, or 5. A displacement component in a single-layered shell unit is identified by its unit, row, column, shell-layer, and component (direction) numbers—with the shell-layer number set equal to zero. A displacement component in a multi-layered shell unit is identified by its unit, row, column, shell-layer, and component (direction) numbers—with the layer number set to a positive value that is less than or equal to the number of nodal layers in the unit. A displacement component in an element unit is identified by its node number (**IR1**), a zero for **IC1**, a zero for **IL1**, and a value for the direction (**IDIR**). The first 10 items on each G-2c record define a pair of displacement components. The two units referenced may be the same. The first unit number (**IU1**) must not be greater than the second (**IU2**).

The *zero rule* applies to the variables **IR1**, **IC1**, **IR2**, **IC2**: if any of these variables is set to zero in a shell unit, it means the compatibility condition applies to an entire row or column, respectively. For example, to enforce compatibility of the *u* freedom along row 7 on nodal layer 5 of unit 2, the following G-2c record can be used:

```
2 7 1 1 5   2 7 0 1 5
```

When either a row (or column) entry is zero for both the master and slave sets of integers, a loop over all rows (or columns) is implied, generating *nrow* (or *ncol*) separate constraints, where *nrow* and *ncol* are the number of rows and columns in the shell unit. For example, the G-2c record

```
2 0 1 3 5   2 0 14 3 5
```

means that for each row of nodal layer 5, the *w* freedom (**IDIR** = 3) on column 14 is equated with the *w* freedom on column 1. When this capability is used with two different shell units, the number of rows (columns) must of course be the same.

If the value of **IR2** or **IC2** (for the slave nodes) is negative, the compatibility between units **IU2** and **IU1** is enforced in reverse order (this is identical to what happens with the **NBOUND** variable on G-1 records). This option is used if the shell coordinate *X* or *Y* in the two connected units is increasing in opposite directions along the common boundary.

Since no transformations are performed, the specified nodes should not lie on a boundary line involved in a shell unit connection (G-1) unless the two shell units have the same orientation with respect to the global coordinates.

As is the case with the G-2 record, a special option is provided for joining shell units using G-2c/G-2d record pairs. If the **ID1** and **ID2** variables are both zero, then full compatibility is enforced between the nodes on **IU1** and **IU2**. This means that the components on the node belonging to **IU2** are first transformed into the local system in **IU1** before the compatibility condition is enforced, which is the same thing that happens when shell units are joined using G-1 records. The *zero rule* also applies to the row and column indices here; thus, to join shell unit 2, row 1, nodal layer 5 to shell unit 1, row 13, nodal layer 7, the single record

```
1 13 0 0 7   2 1 0 0 5
```

suffices. Here, row 13 could be in the interior of the unit. The user must be very careful when using this option. First, the user must insure the same row or column compatibility as required for the G-1 records; second, the user must insure that the lines involved in the juncture actually coincide in space, since the code will not check for the physical coincidence of the juncture lines. The user can take advantage of **IGLOBE** options 3, 4, or 5 (M-1) to move the units around until they meet in the right place.

The next six items (**ND1A** through **INC2**) on the G-2c record are optional input variables allowing the user to specify full compatibility for a range of nodes. These data are ignored unless the following logical expression evaluates to ‘True’:

$$\{(\mathbf{IR1} = 0 \quad or \quad \mathbf{IC1} = 0) \quad and \quad (\mathbf{IR2} = 0 \quad or \quad \mathbf{IC2} = 0)\}$$

These optional input variables provide a convenient (interior-looping) method for specifying compatibility between any portion of a row or column of one unit and a portion of a row or column of another unit. This type of input may also be used in element units provided the range of nodes has a fixed increment. For both shell and element units, increasing and decreasing ranges are allowed. If **INC1** = 0 or **INC2** = 0, an increment of *+1* is used for increasing ranges and *-1* for decreasing ranges.

Typically, one G-2c record will be used to define each of the **NPATX** partial displacement compatibility conditions for the problem at hand. For some configurations, however, it is convenient to use the G-2c *exterior-looping* feature described below to make two or more specifications with a single G-2c record. The final item (**NDEFS**) on the G-2c record is an optional control parameter that, when omitted or set equal to any integer less than or equal to unity, causes the G-2c record to generate a single (set of) partial displacement compatibility specification(s) — or, when **NDEFS** > 1, causes the G-2c record (with information on the G-2d record following it) to generate **NDEFS** sets of partial compatibility specifications (see the example following the G-2d description, below).

If the exterior-looping feature is *not* used on the G-2d record immediately following a G-2c record, the G-2c record defines a single set of partial displacement compatibilities; if the exterior-looping feature *is* used, the G-2c/G-2d record pair defines **NDEFS** sets of conditions.

IU1 IR1 IC1 IL1 ID1 IU2 IR2 IC2 IL2 ID2 ND1A ND1B INC1 ND2A ND2B INC2

IU1 unit number of first node; **IU1** = **NUNITS** + k indicates element unit k; **IU1** must be the lower number (**IU1** ≤ **IU2**); see *CAUTION*, below.

IR1 row number of first node or node number in element unit; if **IR1** = 0, then either **IR2** = 0 or **IC2** = 0 must be set.

IC1 column number of first node. **IC1** = 0 in element unit; if **IC1** = 0, then either **IR2** = 0 or **IC2** = 0 must be set.

IL1 nodal layer number for the first node; set **IL1** = 0 if unit **IU1** is a single-layered shell unit, or to a positive value not exceeding the number of layers of nodes in unit **IU1** if it is a multi-layered (solid) shell unit.

ID1 Indicates the component involved at the first node; **ID1** = 1, 2, 3, 4, 5 or 6 for u, v, w, ru, rv, rw, respectively; if **ID1** = 0, then all components are involved, and **ID2** = 0 must be set.

IU2 unit number of second node; **IU2** = **NUNITS** + k for element unit k;
IU2 must be the higher number (**IU2** ≥ **IU1**); see *CAUTION*, below.

IR2 row number of second node or node number in element unit.

IC2 column number of second node; **IC2** = 0 in element unit.

IL2 nodal layer number for the second node; set **IL2** = 0 if unit **IU2** is a single-layered shell unit, or to a positive value not exceeding the number of layers of nodes in unit **IU2** if it is a multi-layered (solid) shell unit.

ID2 indicates the component involved at the second node. **ID2** = 1, 2, 3, 4, 5 or 6 for *u*, *v*, *w*, *ru*, *rv*, *rw*, respectively; if **ID2** = 0, then the components are first transformed to the **IU1** system before partial compatibility is enforced. Note: if **ID2** = 0, then **ID1** must also be zero.

ND1A first node of: (row, if **IR1** = 0) or (column, if **IC1** = 0)

ND1B last node of: (row, if **IR1** = 0) or (column, if **IC1** = 0)

INC1 increment for unit **IU1** nodes from **ND1A** to **ND1B**

ND2A first node of: (row, if **IR2** = 0) or (column, if **IC2** = 0)

ND2B last node of: (row, if **IR2** = 0) or (column, if **IC2** = 0)

INC2 increment for unit **IU2** nodes from **ND2A** to **ND2B**

CAUTION: when different shell or element units are involved, the lower-numbered unit must be given first. This rule also applies to node numbers within a specific unit; the lower-numbered node must be given first. In shell units, nodes are numbered in row-major order; *i.e.*, along row 1, starting at column 1; then along row 2, starting at column 1; *etc*.

✦ *go to* G-2d

G-2d Partial Compatibility Looping and Incrementations

A single type G-2d record must be included immediately after each type G-2c record. The *external looping* parameter (**NDEFS**) and ten incrementation variables are specified here for use with information provided on the G-2c record.

NDEFS JU1 JR1 JC1 JL1 JD1 JU2 JR2 JC2 JL2 JD2

NDEFS number of partial compatibility specifications generated *via* this G-2c/G-2d record pair; set to unity by STAGS if nonpositive.

JU1 incrementation variable for use with the **IU1** (unit-specification) variable on the parent G-2c record

JR1 incrementation variable for use with **IR1** (on G-2c)

JC1 incrementation variable for use with **IC1** (on G-2c)

JL1 incrementation variable for use with **IL1** (on G-2c)

JD1 incrementation variable for use with **ID1** (on G-2c)

JU2 incrementation variable for use with **IU2** (on G-2c)

JR2 incrementation variable for use with **IR2** (on G-2c)

JC2 incrementation variable for use with **IC2** (on G-2c)

JL2 incrementation variable for use with **IL2** (on G-2c)

JD2 incrementation variable for use with **ID2** (on G-2c)

Any of these incrementation variables can be negative, zero or positive.

Example: the following G-2c/G-2d record combination:

```
   63 2 0 3 4   71 2 0 3 4   1 7 1   1 7 1   $G-2c record
3   0 0 0 0 1    0 0 0 0 1                   $G-2d record
```

generates 3 sets of partial compatibility definitions, using the *interior-looping* feature of the G-2c record to enforce compatibility between nodes on row 2 of (nodal layer 3) of shell units 71 and 63, and using the *exterior-looping* feature of the G-2d record to specify *direction-5* and *direction-6* components in addition to the *direction-4* component that is specified on the G-2c record.

NPATX	(B-2)	number of G-2c type partial-compatibility records required
NCONST	(B-2)	number of Lagrange-constraint equations
NINSR	(B-2)	number of inserted node/element sets defining cracks
NUNITE	(B-2)	number of element units

```
if   (NPATX G-2c records have been defined)  then
     elseif   (NCONST < 0)  then   go to  G-3
     elseif   (NINSR > 0)    then   go to  G-5
     elseif   (NUNITE > 0)   then   go to  H-1
     else                           follow instructions at end of  H-1
else      return to continue defining  G-2c
```

G-3 Constraint—Record 1

This record is read if **NCONST** < 0 (B-2). The sequence G-3, G-4 is repeated |**NCONST**| times, each sequence defining one or more Lagrange constraints of the type

$$\sum_{i=1}^{n} c_i x_i + c_0 + c_A P_A + c_B P_B = 0$$

where

x_i are displacement unknowns, scaled by constant coefficients, c_i;

c_0 is a constant term;

P_A and P_B are the load factors (see 6.5 “Loads” on page 6-64), scaled by constant coefficients, c_A and c_B;

and where the *number* of constraints defined *via* any given G-3, G-4 record sequence depends on whether or not the *exterior looping* feature, described subsequently, is used.

In general, Lagrange constraints have $n + 3$ terms, where $n \geq 1$ is required. Each of the remaining three terms is optional. The displacement unknowns (x_i) are defined by specification of unit number, local node number, and *dof* direction. The constant term (c_0) and the constant coefficients (c_i, c_A, c_B) are defined as real numbers.

Each Lagrange constraint is enforced by one of two methods, described below, which is independently specified for each constraint. The *direct-elimination method* is generally preferable, as each constraint of this type removes an equation, whereas selection of the *constraint-equation method* adds an equation.

Constraint-equation method

Constraint equations are assembled into the stiffness matrix along with the other freedoms. For each constraint, a new freedom is introduced. In order to avoid numerical difficulties, it may be necessary to scale constraint equations. This is achieved by multiplying the constant coefficients (c_i, c_A, c_B), as well as the constant term (c_0), by a scale factor, which should be chosen so that each term is roughly the order of magnitude of the other stiffness matrix elements. We suggest a scale factor equal to the material modulus or modulus times wall thickness.

One additional feature of Lagrange constraints is that for each equation a negative root will appear in the stiffness matrix. It is important to take this into account when using properties of the stiffness matrix to determine structural stability characteristics.

Choose the constraint-equation method when it is difficult to select a set of unique dependent freedoms from the total set of freedoms involved in all constraints; see NOTE, p. 5-43. Constraint equations are very general, and there are no limitations whatsoever regarding ordering of terms in a constraint equation or on the appearance of *dof* in other constraints, including direct elimination constraints.

Direct-elimination method

This results in one freedom, the *dependent freedom*, being defined in terms of the other freedoms, the *independent freedoms*, and eliminated from the system of equations. Thus, rather than adding a constraint equation, this method results in the elimination of one equation for each constraint. Scaling, as in the constraint-equation method, is not necessary for direct elimination.

Choose the direct-elimination method when it is possible to express a dependent freedom as a linear combination of “independent” freedoms. By independent, we mean that the particular freedom does not appear as a dependent freedom in any other direct-elimination constraint.

A maximum of 100 terms in a single constraint is allowed. Given the very poor bandwidth such a large number of terms creates, this is a very generous limit. A very effective way around the limitation on the number of terms and the resulting bandwidth problems is to nest constraints. Nesting means to define intermediate nodes first and break up the constraints into smaller components. For example, if freedom k equals the sum of 400 particular freedoms, one could define 8 extra freedoms. On the lowest level, 8 freedoms are each set equal to the sum of 50 different freedoms taken from the set of 400, forming the inner level of the nest. The outer level is simply a constraint setting the desired freedom to be the sum of the 8 newly-defined freedoms. Nesting can, in principal, be carried to any level. The bandwidth is limited to the maximum number of terms in a given constraint.

NTERMS NX INC1 INC2 INC3 INC4 INC5

NTERMS |**NTERMS**| defines the number of terms in the constraint; |**NTERMS**| ≤ 100.
NTERMS > 0 specifies the constraint-equation method.
NTERMS < 0 specifies the direct-elimination method.

NX Looping parameter; defines the number of Lagrange constraints to be generated with information on the current G-3, G-4 record sequence; set equal to unity by **STAGS** if nonpositive or omitted.

INC1 Incrementation parameter for *all* of the **IU** variables specified on G-4 records in the current G-3, G-4 sequence (used only if **NX** > 1).

INC2 Incrementation parameter for *all* of the **IX** variables specified on G-4 records in the current G-3, G-4 sequence (used only if **NX** > 1).

INC3 Incrementation parameter for *all* of the **IY** variables specified on G-4 records in the current G-3, G-4 sequence (used only if **NX** > 1).

INC4 Incrementation parameter for *all* of the **ID** variables specified on G-4 records in the current G-3, G-4 sequence (used only if **NX** > 1).

INC5 Incrementation parameter for *all* of the **IZ** variables specified on G-4 records in the current G-3, G-4 sequence (used only if **NX** > 1).

EXAMPLE: **NTERMS** $= 5$ specifies one or more constraints with 5 terms, implemented *via* the constraint-equation method.
NTERMS $= -5$ specifies one or more constraints with 5 terms, implemented *via* the direct-elimination method.

go to G-4

G-4 Constraint—Record 2

This record is read **NTERMS** times in each G-3/G-4 sequence. The number of Shell Units is **NUNITS** (B-2). For element unit l, the variable **IU** is set to k, where $k = \mathbf{NUNITS} + l$. Constraints on displacement or rotation components at a juncture line must be defined in terms of the freedoms on the shell unit with the lowest number of those involved in the juncture. Constraints at element unit node points located at shell unit nodes must be defined in terms of the freedoms at the shell unit node.

CAUTION: Slave *dof* may not appear in constraint equations. Master/slave *dof* relationships are created automatically by **STAGS** where compatibility has been prescribed. There are three different modeling features which result in such relationships:

- shell-unit junctures (G-1)
- displacement compatibility (G-2)
- nodal definition in a *higher-numbered* unit by reference to a *lower-numbered* unit (S-1)

IU(i) IX(i) IY(i) ID(i) CC(i) IZ(i)

IU(i) $\mathbf{IU}(\mathbf{i}) = 0$ indicates that either the constant term (c_0) or one of the load-factor coefficients (c_A, c_B) is defined. Currently, only one record defining the constant term (**IU(i)**=0) is allowed (per constraint), and this record must be the last one defined for this constraint.

$\mathbf{IU}(\mathbf{i}) > 0$ indicates that one of the *dof* coefficients (c_i) is defined; **IU(i)** specifies the unit where the unknown x_i is located.

$\mathbf{IU}(\mathbf{i}) = \mathbf{IUNIT}$ for a shell unit, where **IUNIT** is the unit number

$\mathbf{IU}(\mathbf{i}) = k$ for element unit l (see above)

NOTE: In a direct-elimination constraint, the first freedom specified is taken to be the dependent freedom, the one that is eliminated. A dependent freedom must not otherwise be constrained by a BC; and it must not appear in any other direct-elimination constraint, either as the dependent freedom or as an independent freedom. It may appear in any number of constraint equations.

IX(i) node/row where the unknown x_i is located. **IX(i)** is defined as:

$\mathbf{IU}(\mathbf{i}) = \mathbf{IUNIT}$: **IX(i)** = row number

$\mathbf{IU}(\mathbf{i}) = k$: **IX(i)** = node number

IY(i) column where the unknown x_i is located. **IY(i)** is defined as:

$\mathbf{IU}(\mathbf{i}) = \mathbf{IUNIT}$: **IY(i)** = column number
$\mathbf{IU}(\mathbf{i}) = k$: **IY(i)** is irrelevant

ID(i) term identifier, interpreted according to the value of **IU(i)**, as follows:

$\mathbf{IU}(\mathbf{i}) = 0$

1 – load-factor coefficient c_A
2 – load-factor coefficient c_B
3 – constant term, c_0

$\mathbf{IU}(\mathbf{i}) > 0$

1 – *dof* coefficient; x_i refers to the displacement component *u*
2 – *dof* coefficient; x_i refers to the displacement component *v*
3 – *dof* coefficient; x_i refers to the displacement component *w*
4 – *dof* coefficient; x_i refers to the displacement component *ru*
5 – *dof* coefficient; x_i refers to the displacement component *rv*
6 – *dof* coefficient; x_i refers to the displacement component *rw*

CC(i) coefficient as required by the specification of **ID(i)**, above.

IZ(i) nodal layer (in a shell unit) to which this constraint applies.

Example: the following G-3/G-4 record sequence:

```
2 3 0 0 0 1
1 511 0 4  1.000E6  1
1 515 0 4 -1.000E6  1
```

generates the same three Lagrange constraint definitions as the following three G-3/G-4 record sequences:

```
2                             $ G-3 record for definition # 1
1  511  0  4   1.000E6  1     $ G-4 record for definition # 1
1  515  0  4  -1.000E6  1     $ G-4 record for definition # 1
2                             $ G-3 record for definition # 2
1  511  0   5   1.000E6 1     $ G-4 record for definition # 2
1  515  0   5  -1.000E6 1     $ G-4 record for definition # 2
2                             $ G-3 record for definition # 3
1  511  0   6   1.000E6 1     $ G-4 record for definition # 3
1  515  0   6  -1.000E6 1     $ G-4 record for definition # 3
```

Only one of the five incrementation parameters should be used with any given G-3/G-4 record sequence.

NTERMS(G-3)	number of terms in constraint equation
NCONST(B-2)	number of Lagrange-constraint-definition sequences
NINSR (B-2)	number of inserted node/element sets defining cracks
NUNITE (B-2)	number of element units

```
if    (NTERMS G-4 records have been defined) then
      if  (NCONST G-3 records have been defined) then
            if        (NINSR > 0)     then   go to G-5
            elseif    (NUNITE > 0)    then   go to H-1
            else                             follow instructions at end of H-1
      else            return to G-3
else      continue defining G-4
```

G-5 Crack Inserted Node Set—Record 1

G-5 is included when **NINSR** > 0 (B-2). The G-5–G-7 series is repeated **NINSR** times.

Generation of a crack requires the association of an ordered set of nodes in the structural model with the crack face; these nodes must be ordered either from left end of the crack to the right end of the crack, or *vice versa*. These nodes are collocated with nodes already defined in the model but have independent displacement components after the crack opens. A number of elements must also be specified to show which elements are to use the new nodes instead of the original nodes. All crack nodes required for a series of analyses must be defined before the first execution. The growth of a crack during a static or dynamic analysis is defined by choosing a subset of such nodes to be "open," with the freedoms on the remainder of the nodes (closed nodes) set (or "slaved") to the corresponding node on the other side of the crack. As the crack grows, a larger number of nodes is designated as open. In default operation, **STAGS** keeps a record of the growth of the crack, so that upon restart, the crack history at the desired restart step is retrieved and used. A solution option exists to override the **STAGS** history at restart and use a new crack configuration specified in these records.

If the user has already generated slave nodes corresponding to a crack, then he can specify these nodes on record G-6. In this case, G-6 consists of *two* sets of crack nodes. The first set refers to the master nodes, and the second to the slave nodes. The lists must be of identical length so that a one-to-one correspondence between the first list and second list exists. No G-7 records are needed when the user has already defined the slave nodes and the elements that contain them.

If the user inputs only one list on G-6, **STAGS** generates the second set of crack nodes. In this case, if a section of a crack lies along a line that contains two sets of nodes (slave/master relation defined by G-1 or G-2 records), the crack nodes in the G-6 record should refer only to the slave nodes. The G-7 records should refer only to elements which contain these slave nodes.

More than one crack can be defined in a given model, with each crack given a unique identifier (**NCRACK**) which starts with one and increments by one for every new crack defined. If **NCRACK** < 0, a hinged crack is created with the identifier |**NCRACK**| (see the parameter definition list).

STAGS can be made to grow a crack automatically along the predetermined path defined by these records, given a crack growth criterion. At present, only the Crack Tip Opening Angle (CTOA) criterion is implemented (see [1],* for example). If the variable **ITEAR** is nonzero, the variable **ACRIT** is interpreted as the CTOA that must be attained before the crack tip node is automatically released. **STAGS** will continue the execution with the strategy chosen by the user until some other termination criteria are reached, or the crack tip exhausts the list of closed nodes defined on the given crack. More than one crack with CTOA growth can be defined.

* Numbers in square brackets, here, indicate references at the end of this chapter.

NCRACK INNODS INELTS ITEAR ACRIT CTOD
ACRITT SAWL SAWT CSCALE IDREC

NCRACK crack identifier; if **NCRACK** < 0, only the translations will be constrained along closed portions of a crack; this is the so-called “hinged crack”

INNODS number of inserted node records (G-6)

INELTS number of element records (G-7)

ITEAR automatic crack growth indicator

0 – no automatic crack extension; **ACRIT** is ignored

1 – crack extension according to the CTOA criterion

-1 – crack extension according to CTOA, but along a symmetry boundary (where only the upper or lower surface of the crack is actually modeled)

ACRIT the critical opening angle (CTOA), in degrees, for the L (longitudinal) direction; always input the full angle, even when the crack is along a symmetry boundary (**ITEAR** = -1)

CTOD the distance from the crack tip to the point from which **ACRIT** is measured; if **CTOD** is 0, the node adjacent to the tip is used; if **ACRIT** cannot be generated with the user’s **CTOD**, the adjacent node is also used

ACRITT the critical opening angle (CTOA), in degrees, for the T (transverse) direction, if different from **ACRIT**; if zero, **ACRITT** is set to **ACRIT** inside **STAGS**

SAWL the critical opening angle (CTOA), in degrees, or the longitudinal direction for the first node released in a *sawcut;* if zero, **STAGS** uses **ACRIT**

SAWT the critical opening angle (CTOA), in degrees, for the transverse direction for the first node released in a *sawcut;* if zero, **STAGS** uses **SAWL**

CSCALE scale factor for Lagrangian constraints used to close the crack; recommended value is 1.0 (the default value, if not specified)

IDREC component index for the shell normal coordinate; defaults to 3 if zero or omitted

go to G-6

G-6 Crack Inserted Node Set—Record 2

The nodes defining a crack are specified here. G-6 is repeated **INNODS** (G-5) times. The **ICUNIT**, **JCUNIT** and **ICOPEN** parameters on this record have special roles, as described in the following paragraphs.

If the unit that is identified by the **ICUNIT** parameter has sandwich or solid elements, the *sign* of **ICUNIT** specifies that the crack is on the *lower* or on the *upper* surface of that unit. In particular, the crack will be on the lower surface of unit **ICUNIT** if $\mathbf{ICUNIT} > 0$, or it will be on the upper surface of unit $|\mathbf{ICUNIT}|$ if $\mathbf{ICUNIT} < 0$.

If **JCUNIT** is greater than zero, the set **JCROW1**, **JCCOL1**, **JCROW2**, and **JCCOL2** refer to a second set of nodes already defined in **STAGS** that are associated one-to-one with the first set specified by **ICUNIT**, **ICROW1**, **ICCOL1**, **ICROW2**, and **ICCOL2**. When the crack nodes are open, the corresponding associated node on the other side of the crack is independent; when closed, it is slaved. If **JCUNIT** is zero, **STAGS** generates the other set of crack nodes; and a G-7 record specifying the elements belonging to the new nodes must be provided.

ICOPEN requires special treatment when there is a line of symmetry (**ITEAR** = -1). When there is no line of symmetry, any positive value of **ICOPEN** will cause the released node to be completely free. However, this procedure is not always suitable for symmetry, since two symmetry lines can cross at a corner. For this special case, we have added two additional options, as listed below. In addition, if the user defines his own slave crack nodes (**JCROW1**, **JCCOL1**, **JCROW2**, **JCCOL2**), the released nodes always have the user-defined freedom pattern (see S-1, for example).

ICOPEN ICUNIT ICROW1 ICCOL1 ICROW2 ICCOL2
JCUNIT JCROW1 JCCOL1 JCROW2 JCCOL2 THETA

ICOPEN

0 – node is “closed” or “slaved” to the parent node on the other side of the crack

1 – node is “open” or independent, with its own freedom set. Use this choice when **ITEAR =** 0 (G-5 – no line of symmetry). New node is completely free (full set of freedoms).

1 – if **ITEAR** = -1 (symmetry) input 1 if the symmetry line is along a row in a shell unit. For an element unit, release u and R_v.

2 – if **ITEAR** = -1 (symmetry) input 2 if the symmetry line is along a column in a shell unit. For an element unit, release v and R_u.

3 – treat the adjacent tip as a *sawcut*. The CTOA for the first node refers to **SAWL** or **SAWT**; newly released nodes default back to the original **ACRIT** or **ACRITT.** In all other respects, this option is identical to **ICOPEN** = 1.

4 – treat the adjacent tip as a *sawcut*. The CTOA for the first node refers to **SAWL** or **SAWT**; newly released nodes default back to the original **ACRIT** or **ACRITT.** In all other respects, this option is identical to **ICOPEN** = 2.

5 – ignore all symmetry and free up the node unconditionally. For **ITEAR =** 0, all positive choices for **ICOPEN** are equivalent after the first node has opened.

For conditions not covered by the above options, the user can arbitrarily define his own slave node set boundary conditions (see discussion above). Another way to override the automatic freeing of dependent crack nodes is to assign them a vanishingly small specified displacement, which causes the opened node to inherit that constraint.

ICUNIT unit number; a given crack can span more than one unit. Remember that crack nodes must be defined in order along the crack face, even when spanning more than one unit (this requires more than one G-6 record).

ICROW1 row number of first node (shell unit); number of first node (element unit)

ICCOL1 column number of first node (shell unit); number of last node (element unit)

ICROW2 row number of last node (shell unit) Increment in passing from node **ICROW1** to **ICCOL1** (element unit); nodes must be numbered in order along the crack face.

ICCOL2 column number of last node (shell unit) (not used in element unit); nodes must be numbered in order along the crack face.

JCUNIT unit number containing nodes already defined that will form the other side of the crack.

JCROW1 row number of first node (shell unit); number of first node (element unit).

JCCOL1 column number of first node (shell unit); number of last node (element unit).

JCROW2 row number of last node (shell unit); increment in passing from node **JCROW1** to **JCCOL1** (element unit); nodes must be numbered in order along the crack face and correspond one-to-one with nodes on the other side of the crack.

JCCOL2 column number of last node (shell unit) (not used in element unit); nodes must be numbered in order along the crack face and correspond one-to-one with nodes on the other side of the crack.

THETA used only when **ACRITT** is nonzero (G-5), or is different from **ACRIT. THETA** is equal to the angle (in degrees) between the longitudinal direction associated with **ACRIT** and the x computational coordinate direction (x'').

INNODS (G-5) number of node records

if (**INNODS** G-6 records have been defined) then *go to* G-7
else *continue defining* G-6

G-7 Crack Inserted Node Set—Record 3

In most situations, the elements associated with inserted crack nodes can be defined either on one side of the crack or the other. Remember to include the elements associated with the crack tip nodes. G-7 is repeated **INELTS** (G-5) times.

Note: If a beam on a shell unit is specified (**JETYPE**=1), row and column identifiers must be provided for both ends of the beam. Hence, either **JCROW2** must be different from **JCROW1**, or **JCCOL2** must be different from **JCCOL1**. This requirement eliminates the ambiguity between a beam that lies parallel to the crack and one that is perpendicular to the crack.

JETYPE JCUNIT JCROW1 JCCOL1 JCROW2 JCCOL2

JETYPE
0 – skin elements
1 – stiffener elements

JCUNIT unit in which elements defined below are referenced.

JCROW1 row number of first node (shell unit); number of first element (element unit)

JCCOL1 column number of first node (shell unit); number of last element (element unit)

JCROW2 row number of last node (shell unit); increment in passing from element **JCROW1** to **JCCOL1** (element unit); elements can appear in any order.

JCCOL2 column number of last node (shell unit) (not used in element unit); elements can appear in any order.

Example:

To illustrate this feature, let us assume that a **STAGS** model with an element edge length of 0.0625 inches has been created and that a crack is to be inserted within shell unit number 5. Let us also assume that a portion of the crack is defined as being initially “open” and the remainder is defined as “closed.” The self-similar crack growth path for this crack is specified by all of this. The input records are

```
1   2   1   1    4.6  0.0625   $ G-5 Crack-inserted node set
1   5   5   1    5    32       $ G-6 Open crack   (2 inches long)
0   5   5  33    5    97       $ G-6 Closed crack (4 inches long)
0   5   4   1    4    96       $ G-7
```

The G-5 record indicates that only one crack is defined, that two inserted node records are used, that automatic crack extension by the CTOA criteria will be used, that the critical crack tip opening angle (CTOA) is 4.6 degrees, and that the point where the opening angle is calculated is 0.0625 inches from the crack tip. The first G-6 record indicates that this crack is “open”, that it is in unit 5, and that it is open from row 5 and column 1 up to row 5 and column 32. This is equivalent, assuming uniform grid spacing of 0.0625 inches along the crack, to a 2-inch-long initial crack (32 elements with crack tip at row 5 and column 33). The second G-6 record indicates that this crack segment is “closed” initially but potentially can “open” during the analysis, that the crack is in unit 5, that the crack tip is at row 5 and column 33, and that it could grow along row 5 up to column 97 (*i.e.*, that there is a 4-inch-long potential crack growth). The G-7 record indicates that crack is in skin elements, that unit 5 contains the crack, that the crack definition starts in the fourth row and first column of elements, and it can potentially grow to the 96th column of elements in the fourth row.

INELTS	(G-5)	number of element records
NINSR	(B-2)	number of inserted node/element sets defining cracks
NUNITE	(B-2)	number of element units

```
if  (INELTS G-7 records have been defined)  then
     if   (NINSR inserted node/element sets have been defined)  then
          if  (NUNITE > 0)     then   go to  H-1
          else                        follow instructions at end of  H-1
     else     return to  G-5
else     continue defining  G-7
```

H-1 Element Unit Summary

If **NUNITE** > 0 on the user's B-2 record, then a single H-1 record is required for each of the **NUNITE** element units in the model. The H-1 record for a given element unit specifies (or postpones the specification of) one parameter (**NUPT**) that is used to select the method to be used in the node-specification process and six parameters (**NT1, NT2, NT3, NT4, NT5** and **NS5**) that are used to select the method(s) and element(s) to be used in the element-specification process for that element unit, as described below. H-1 also allows the user to specify three parameters (**IUWP**, **IUWE** and **IUDIMP**) that trigger the employment of *user-written subroutines* to define some or all of the nodes, elements and/or imperfections in that element unit. H-1 also allows the user to specify a single parameter (**IUWLE**) that tells **STAGS** that user-defined element numbers may (or may not) be employed in that element unit.

For each element unit, the user must identify and define the location of each node point that is referenced in that element unit. This may include a subset of some or all of the nodes that are defined in one or more shell units and/or a set of auxiliary nodes that are defined in the element unit itself with their global system coordinates. In any event, the complete set of nodes that are involved in the element unit is referred to as its *user points*. The current version of **STAGS** gives the user two protocols for using "regular" data records to define some or all of these user points. These protocols are described in Chapters 8 and 9 of this document. **STAGS** also supports the employment of *user-written subroutines* to define some or all of the user points in the element unit. This approach is described in Chapter 12. Alternatively, **PATRAN** may be used to model the structure and output a **STAGS** input file (see Appendix D – **PAT2STAGS**).

The current version of **STAGS** gives the user two protocols for using "regular" data records to define the elements that are used in a given element unit. The first of these—the ***Edef*** *(element–definition)* protocol that has been used in every version of **STAGS** since finite elements and element units were introduced—is described in Chapter 8; and the second—the ***Ecom*** *(element–command)* protocol that uses a command-line approach and gives the analyst much more control and flexibility in the element–specification process—is described in Chapter 9. The current version of **STAGS** accommodates the use of either or both of these protocols—as the user wishes and/or as convenience dictates. **STAGS** also supports the employment of *user-written subroutines* to define some or all of the elements in the element unit. See Chapter 12 for more information about this.

The current version of **STAGS** gives the user single protocols for employing "regular" data records to define point and distributed loadings on the nodes and elements of the element unit.

These are described in Chapter 10 of this document. **STAGS** also supports the employment of *user-written subroutines* to define some or all of these loadings. With the current version of **STAGS**, imperfections in an element unit can only be accommodated *via* user-written subroutines. See Chapter 12 for more information about this.

NUNITE records of the following type are required:

NUPT NT1 NT2 NT3 NT4 NT5 IUWP IUWE IUDIMP IUWLE NS5

NUPT control parameter for defining user points .... see Note 1, below

NT1 control parameter for defining "spring" elements .... see Note 2, below
NT2 control parameter for defining "beam" elements .... see Note 2, below
NT3 control parameter for defining "triangular" elements .... see Note 2, below
NT4 control parameter for defining "quadrilateral" elements .... see Note 2, below
NT5 control parameter for defining "other" elements .... see Note 2, below

IUWP *user-points-via-subroutines* parameter:

0 – all user points are defined on regular data records
1 – some user points are defined in user-written USRPT

IUWE *elements-via-subroutines* parameter:

0 – all elements are defined on regular data records
1 – some elements are defined in user-written USRELT .... see Note 3, below

IUDIMP *imperfections-via-subroutines* parameter:

0 – no initial imperfections
1 – initial imperfections are defined in user-written DIMP

IUWLE *user-element-numbers* parameter:

0 – no user element numbers are specified
1 – user element numbers are specified (in element units)

NS5 *line–line-contact-definitions* parameter:

0 – no line-contact-interaction specifications
>0 – number of line-contact-interaction specifications

Note 1: **STAGS** gives the user two methods for specifying the user points that are utilized in an element unit: the so-called ***upts*** protocol that has been used in every version of **STAGS** since element units were introduced, and the ***user-points*** protocol that gives the analyst more flexibility in the point–specification process. The older *upts* protocol is supported for use with existing models and for use with any new models that may be constructed manually or with software that does not "know" about and/or support the newer *user-points* protocol. The value that the user specifies for the **NUPTS** parameter, on H-1, determines which of these two protocols is to be employed:

NUPTS = 0 — the *user-points* protocol is to be employed, to define an unspecified number of user points (where the user lets **STAGS** count the points)

NUPTS > 0 — the *upts* protocol is to be employed, to define **NUPTS** user points

NUPTS = -1 — no user points are to be defined

The point-definition protocols are described fully in Chapter 7 of this document.

Note 2: **STAGS** gives the user two methods for specifying the elements that are utilized in an element unit: the older (and more rigid) ***Edef*** *(element–definition)* protocol that has been used in every version of **STAGS** since finite elements and element units were introduced, and the newer (and more flexible) ***Ecom*** *(element-command)* protocol that uses a command-line approach. The older of these—the *Edef* protocol—is supported for use with existing models and for use with any new models that may be constructed manually or with software that does not "know" about and/or support the new *Ecom* protocol. As noted above, the current version of **STAGS** allows the user to employ either or both of these protocols—as the user wishes and/or as convenience dictates. The choice of which of these two methods is to be used (or to use both methods) is made *via* the values that are specified for the **NT1**, **NT2**, **NT3**, **NT4** and **NT5** parameters on H-1:

If one or more of these parameters is positive, **STAGS** starts its element-specification operations by using the historic *Edef* protocol (which is described in Chapter 8) to define **NT1** "spring" (type **E110**, **E120**, **E121** and/or **E130**) elements, **NT2** "beam" (type **E210** and/or **E250**) elements, **NT3** "triangle" (type **E320** and/or **E330**) elements and/or **NT4** "quadrilateral" (type **E410**, **E411**, **E420**, **E430**, **E480**, **E510** and/or **E710**) elements. After doing that, **STAGS** examines the **NT5** parameter to determine what to do next. If **NT5** = 0 on H-1, **STAGS** stops processing element-specification records and starts processing loading specifications. If **NT5** = 1 on H-1, **STAGS** continues its element-specification operations by reading a type T-5 control record (see Chapter 8) and using the parameters that are specified there to define one or more type (type **E810**, **E820** and/or **E822** (contact) elements, one or more type **E830**, **E840**, **E845**, **E847** and/or **E849** (sandwich) elements and/or one or more of the **E880**-family elements—and then moves forward to the processing of loading specifications. If **NT5** = 2 on H-1, **STAGS** continues its element-specification operations by reading a type T-5 control record

(Chapter 8) and using the parameters specified there to define one or more contact, sandwich and/or solid elements—and then switches over to the *Ecom* protocol to define one or more elements of any type (as described in Chapter 9), before moving forward to the processing of loading-specification records.

If the **NT1**, **NT2**, **NT3**, **NT4** and **NT5** parameters are **all** zero on H-1, **STAGS** recognizes the fact that the user only needs or wishes to employ the newer *Ecom* protocol for *all* element-specification operations. See Chapter 9 for more information about this protocol.

If the user wishes to construct an element unit that has user points but does not have any elements, he (or she) should set **NT1**, **NT2**, **NT3**, **NT4** or **NT5** equal to -1 on H-1.

Note 3: In no case does the inclusion of user-written element-definition subroutines preclude transmission of additional information on regular or on *Ecom* data records.

NUNITE	(B-2)	number of element units
NTAM	(B-3)	number of entries in the Material Table
NTAMT	(B-3)	number of entries in the Mount Element Table
NGCP	(B-3)	GCP-utilization flag
NTAB	(B-3)	number of entries in the Cross Section Table
NTAW	(B-3)	number of entries in the Wall Fabrication Table
NTAP	(B-3)	user parameters flag
NUNITS	(B-2)	number of shell units

```
if    (NUNITE H-1 records have been defined)  then
      if       ( NTAM     > 0 )  then  go to  I-1
      elseif   ( NTAMT    > 0 )  then  go to  I-4a
      elseif   ( NGCP     > 0 )  then  go to  I-5a
      elseif   ( NTAB     > 0 )  then  go to  J-1
      elseif   ( NTAW     > 0 )  then  go to  K-1
      elseif   ( NTAP     > 0 )  then  go to  L-1
      elseif   ( NUNITS   > 0 )  then  go to  M-1
      else     follow instructions at the end of  R-3
else     continue defining  H-1
```

5.6 Data Tables

The records in this group (I–L) contain information as summarized below:

- I records: Material Table & Mount Element Table;
  GCP Materials & GCP Fabrications Tables
- J records: Cross Section Table
- K records: Wall Fabrication Table
- L records: User Parameters

I-1 Material Properties

Records I-1 and I-2 must be defined for each Material Table material. Furthermore, I-3 must be defined where plastic properties are specified, and I-3a must be defined where creep properties are specified. Creep properties cannot be defined for an elastic material.

ITAM NESP IPLST ITANST ICREEP IPLANE

ITAM user-assigned material number; $1 \le$ **ITAM** $\le$ **NTAM** (B-3)

NESP number of points on the $\varepsilon - \sigma$ curve (I-3), excluding the origin, which is defined to be $(\varepsilon, \sigma) = (0, 0)$. If plasticity is not included for this material, set **NESP** $= 0$. **NESP** cannot be greater than 10.

IPLST plasticity theory

0, 1 – White-Besseling theory

2 – ~~isotropic strain hardening~~ — INACTIVE

3 – ~~kinematic strain hardening~~ — INACTIVE

4 – ~~deformation theory~~ — INACTIVE

ITANST material stiffness approximation

0 – initial strain

1 – tangential stiffness

ICREEP ~~creep flag~~ — INACTIVE

0 – no creep

1 – creep

IPLANE plane strain flag (White-Besseling plasticity or elastic only)

0 – plane stress theory

1 – plane strain theory

✦ *go to* I-2

I-2 Material Elastic Properties

In plate or shell analysis the plane stress assumption is used; the transverse normal stress is assumed to be zero. In that case, the elastic properties are defined by a matrix C such that

$$\left\{\begin{matrix}\sigma_1\\ \sigma_2\\ \tau\end{matrix}\right\} = \left[\, C \,\right] \left\{\begin{matrix}\varepsilon_1\\ \varepsilon_2\\ \gamma\end{matrix}\right\}$$

If the material is defined in terms of the principle directions (a normal stress in the principle directions causes no shear deformation), the material is orthotropic and

$$\left[\, C \,\right] = \begin{bmatrix} \dfrac{E_1}{1-\nu_{12}\nu_{21}} & \dfrac{\nu_{12}E_1}{1-\nu_{12}\nu_{21}} & 0 \\ \dfrac{\nu_{21}E_2}{1-\nu_{12}\nu_{21}} & \dfrac{E_2}{1-\nu_{12}\nu_{21}} & 0 \\ 0 & 0 & G_{12} \end{bmatrix}$$

where $\nu_{12}E_1 = \nu_{21}E_2$. Materials must be defined with respect to the principle material directions (ϕ_1, ϕ_2) $(i.e., \ C_{13}, C_{23} = 0)$.

If the material is isotropic, it is not necessary to input all the four material constants. When the shear modulus is set to zero, it is assumed that the material is isotropic, $i.e.$, that $E_2 = E_1$ and $G = E_1/[2(1+\nu_{12})]$. If a material with a zero shear modulus must be defined, input a very small value for G. If the coefficient of thermal expansion in the ϕ_2 direction is set equal to zero, it is assumed that $\alpha_1 = \alpha_2$ $(\mathbf{A1} = \mathbf{A2})$.

E1 U12 G RHO A1 E2 A2

E1 elastic modulus in ϕ_1 direction

U12 Poisson's ratio, ν_{12}, where $\nu_{12}E_1 = \nu_{21}E_2$.

CAUTION: The ν-subscript conventions used above are different from those used in many references. Be sure that the ν_{12} defined here satisfies the above relationship.

G shear modulus, G. Setting $G = 0$ indicates an isotropic material; this causes enforcement of the $E_2 = E_1 = E$ and the $G = E/(2(1+\nu))$ relationships; set **G** to a small value to define a material with a zero shear modulus.

RHO weight density, in units of *force/volume* (*e.g.*, N/m^3 or lb/in^3)

A1 coefficient of thermal expansion in ϕ_1 direction, α_1

E2 elastic modulus in ϕ_2 direction; input zero for isotropic materials

A2 coefficient of thermal expansion in ϕ_2 direction, α_2; setting **A2** = *0* causes enforcement of the relationship $\alpha_2 = \alpha_1 = \alpha$.

NESP (I-1) number of points on (σ, ε) curve

if (**NESP** > 0) then *go to* I-3
else *follow instructions at end of* I-3a

I-3 Material Plastic Properties

This record is included only if **NESP** > 0 (I-1). The two plasticity theories of choice available in **STAGS** are the White-Besseling theory (or mechanical sublayer model), and isotropic strain hardening. Both have their limitations but perform adequately for a moderate-strain analysis of metals. Each theory is based on a piecewise linear stress-strain curve, described on the data records by definition of strain and stress at the corners. The slope of the stress-strain curve must decrease at each corner. For a general layered shell, Simpson's rule is used for integration through the thickness of each layer, while for a stiffener, the plastic strain is considered constant within each of a number of subelements. If, during a run, the strain exceeds the value of the last strain point given below, the code assumes that another segment beyond those input exists. This segment has a zero slope (perfectly plastic behavior), as shown in Figure 5.1. The first point must agree with elastic behavior, or the modulus times the strain; if this condition is not satisfied, a diagnostic is provided.

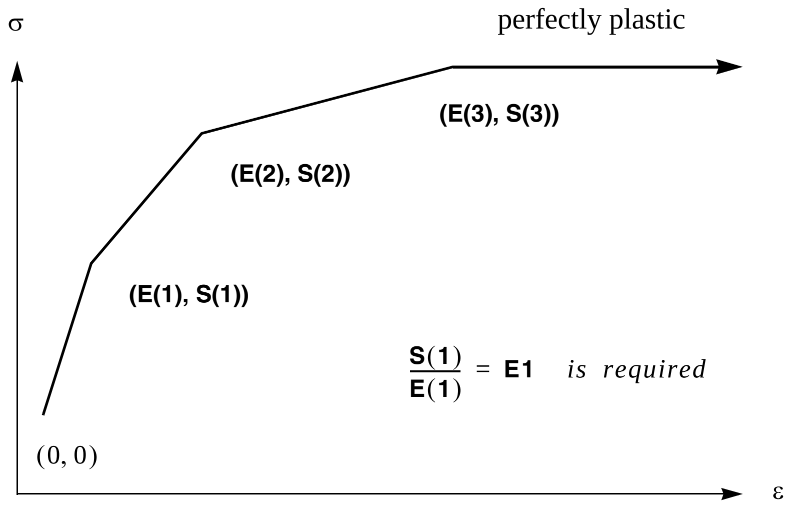


Figure 5.1 Stress-strain curve.

☞ Definition of material plastic properties does not automatically include nonlinear material effects in an analysis. Parameters for each shell unit, stiffener, or element control whether or not plasticity is included for that structural segment. Users often find it convenient to specify plastic properties when defining a material and then selectively control plasticity effects as appropriate for each geometric region independently of the material definition records. Where plasticity has been suppressed, material behavior is elastic (I-2).

(E(i), S(i)), i=1,NESP

E(i) ε_i, the strain value corresponding to the i^{th} point on the (ε, σ) curve. Note that the origin, $(\varepsilon, \sigma) = (0, 0)$, is *not* included as a data point. Additionally, $(\mathbf{E}(1), \mathbf{S}(1))$ must be defined to satisfy the relation $\sigma_1 = E\ \varepsilon_1$; where $\varepsilon_1 = \mathbf{E}(1)$, $\sigma_1 = \mathbf{S}(1)$, and $E = \mathbf{E1}$ (the modulus of elasticity on I-2).

S(i) σ_i, the stress value corresponding to the i^{th} point on the (ε, σ) curve

✦ **ICREEP** (I-1) creep properties flag

if (**ICREEP** > 0) then *go to* I-3a
else *follow instructions at end of* I-3a

I-3a Material Creep Properties

INACTIVE

I-3a is included only if **ICREEP** > 0 (I-1). A simple power-law creep theory is implemented, with the effective creep strain $\bar{\varepsilon}^c$ dependent on creep time $\bar{t}$ by $\bar{\varepsilon}^c = A\,(\bar{\sigma}/B)^m\,\bar{t}^n$, where $\bar{\sigma}$ is the effective stress, A and B are material creep constants, and n and m are the material creep exponents. Creep is permissible with the following options only (I-1):

- ~~isotropic strain hardening~~, **IPLST** = 2 — INACTIVE
- ~~kinematic strain hardening~~, **IPLST** = 3 — INACTIVE

☞ Assigning creep properties to a material does *not* automatically cause their effects to be included in an analysis. Creep effects are controlled by load system B load factor data (see "C-1 Load Multipliers" on page 11-11).

ACO BCO M N

ACO creep constant A

BCO creep constant B

M creep exponent m

N creep exponent n

✦

NTAM	(B-3)	number of entries in the Material Table
NTAMT	(B-3)	number of entries in the Mount Element Table
NTAB	(B-3)	number of entries in the Cross Section Table
NTAW	(B-3)	number of entries in the Wall Fabrication Table
NTAP	(B-3)	User Parameters flag
NUNITS	(B-2)	number of shell units

```
if   (NTAM materials have been defined)  then
     elseif   (NTAMT > 0)   then   go to I-4a
     elseif   (NTAB > 0)    then   go to J-1
     elseif   (NTAW > 0)    then   go to K-1
     elseif   (NTAP > 0)    then   go to L-1
     elseif   (NUNITS > 0)  then   go to M-1
     else                          follow instructions at end of R-3
else    return to I-1
```

I-4a Mount Element Table Size

The Mount Element provides the capability of defining a generalized one dimensional force acting between two points in space with properties defined by the user. The force generated by the mount is directed along the line defined by the two points, like a “nonlinear spring.” These two points in turn are connected to nodes by rigid links, as shown in Figure 14.1 “E110 Mount element” on page 14-6, so that the net result will be, in general, both moments and forces at the structural nodes. If there are no rigid links, the mount element is presumed to be “pinned” to the two nodes. The stiffness and damping characteristics of the mount element are nonlinear functions of the axial relative displacement and axial relative velocity and are described by either **STAGS** input records or by a user-written subroutine.

Because of the action of the rigid links, the element force vectors and the stiffness and damping matrices computed for the **E110** Mount Element will contain contributions for all six degrees of freedom at the nodes **N1** and **N2**.

Mount reactions, or forces, that vary nonlinearly with both relative displacement and velocity between the ends of the mount are described best in tabular form that reflects how they were acquired—load tests at constant velocities with forces measured at prescribed displacements. This can be visualized as in Table 5.1 “Force-displacement-velocity profile” on page 5-66.

The I-4 records described in this section allow the user to define a force-displacement-velocity profile in tabular form for each mount with different behavior. The mounts themselves refer to the tables by the table identifier **IMNT** (below); these must be ordered consecutively.

The I-4 records described in this section also allow the user to define a *penalty-function* table that can be used with **E810**, **E820** and/or **E830** contact elements. In this case, the table must specify a stiffness parameter as a function of displacement. **STAGS** uses this penalty function to calculate forces and stiffnesses acting to enforce (non-penetration) compatibility conditions when contact occurs. The displacement parameter in a penalty-function table is sometimes called the “gap” in descriptions elsewhere in this Manual. A positive value of displacement measures the *penetration* of one contact point, line or surface into the line or surface that it contacts. In a penalty-function table, therefore, displacement must start at zero and increase monotonically; and the so-called “force” function should be given monotonically increasing *stiffness* values

The I-4a record is the first of the I-4a/b/c/d series that are input **NTAMT** times (B-3). This record contains the number of relative displacements **NRD** and the number of relative velocities **NRV** defined in records I-4b and I-4c respectively.

IMNT NRD NRV

IMNT mount element or penalty function table id; table entries must be defined consecutively

NRD for a mount element table: number of relative displacements, **NRD** ≥ 1; relative displacement is $|l| - |l_0|$, where l_0 and l are the initial and final distances between the ends of the mount; if **NRD** $= 1$, forces are ndependent of displacement; for a penalty function table:
number of “gap” (penetration) values, **NRD** ≥ 3

NRV for a mount element table: number of relative velocities. **NRV** ≥ 1;
if **NRV** $= 1$, forces are independent of velocity; for a penalty function table, **NRV** must be unity

✦ *go to* I-4b

Table 5.1 Force-displacement-velocity profile

	d_1	d_2	d_3	$\cdot\ \cdot\ \cdot$	d_{nrd}
v_1	F_{11}	F_{12}	F_{13}	$\cdot\ \cdot\ \cdot$	$F_{1\ nrd}$
v_2	F_{21}	F_{22}	F_{23}	$\cdot\ \cdot\ \cdot$	$F_{2\ nrd}$
v_3	F_{31}	F_{32}	F_{33}	$\cdot\ \cdot\ \cdot$	$F_{3\ nrd}$
$\vdots$	$\vdots$	$\vdots$	$\vdots$	$\vdots$	$\vdots$
v_{nrv}	$F_{nrv\ 1}$	$F_{nrv\ 2}$	$F_{nrv\ 3}$	$\cdot\ \cdot\ \cdot$	$F_{nrv\ nrd}$

v_i is relative velocity i, d_j is relative displacement j

F_{ij} is the force corresponding to d_j at v_i

✔ The $d_j\ , j\ =\ 1, nrd$ relative displacements are defined on I-4b

✔ The $v_i\ , i\ =\ 1, nrv$ relative velocities are defined on I-4c

✔ I-4d is repeated nrv times, once for each relative velocity

✔ I-4d record i contains $(F_{ij}\ , j = 1, nrd)$, the complete set of relative forces associated with v_i, and comprises row i of Table 5.1

I-4b Relative Displacement Vector

This record contains the **NRD** relative displacements (or penetrations) for which mount forces (or contact stiffnesses) will be provided in record I-4d. These displacements must be entered starting with the smallest value and increasing to the largest value. For a mount element table, a positive relative displacement implies extension of the nonlinear spring, and a negative displacement implies compression. The relative displacement is explicitly $|l| - |l_0|$, where l_0 and l are the initial and final distances between the ends of the mount, respectively. For a penalty function table, a positive displacement corresponds to penetration when contact occurs, and a negative value is meaningless.

DISP(j), j = 1, NRD

DISP(j) relative displacement (or penetration) *j*

✦ *go to* I-4c

I-4c Relative Velocity Vector

This record contains the **NRV** relative velocities for which mount forces will be provided in record. These velocities must entered starting with the smallest value and increasing to the largest value. A positive relative velocity implies extension of the mount, and a negative relative velocity implies compression.

RVEL(i), i = 1, NRV

RVEL(i) relative velocity *i*

✦ *go to* I-4d

I-4d Mount Force Matrix

For a mount element table, this record contains the mount forces corresponding to each of the relative displacements for a particular relative velocity. The complete set of forces in the force-displacement-velocity profile can be visualized as in Table 5.1 “Force-displacement-velocity profile” on page 5-66.

For a penalty function table, this record contains the stiffness value corresponding to each of the penetrations given on record I-4b. These should be monotonically increasing. Best results are usually obtained when the *stiffness vs. penetration* curve is “S” shaped, with a “toe” at the origin.

FORCE(j), j = 1, NRD

FORCE(j) for a mount table: the force corresponding to relative displacement *j*
for penalty function table: the stiffness corresponding to penetration *j*

Note that I-4d contains **NRD** entries and is repeated **NRV** times.

NRV	(I-4a)	number of relative velocities
NTAMT	(B-3)	number of entries in the Mount Element Table
NGCP	(B-3)	GCP-utilization flag
NTAB	(B-3)	number of entries in the Cross Section Table
NTAW	(B-3)	number of entries in the Wall Fabrication Table
NTAP	(B-3)	User Parameters flag
NUNITS	(B-2)	number of shell units

```
if  (NRV I-4d records have been defined)  then
    if  (NTAMT mount tables have been defined)  then
        if  (NGCP > 0)         then   go to  I-5a
        elseif  (NTAB > 0)     then   go to  J-1
        elseif  (NTAW > 0)     then   go to  K-1
        elseif  (NTAP > 0)     then   go to  L-1
        elseif  (NUNITS > 0)   then   go to  M-1
        else                   follow instructions at end of  R-3
    else    return to  I-4a
else    continue defining  I-4d
```

I-5a GCP Command Record

This record is read if and only if the **NGCP** (GCP-utilization) flag is 1 on the B-3 record. I-5a departs from **STAGS**' traditional integer/real-data input-format conventions and uses the command-oriented conventions used in NASA's COMET program, from which the original versions of the Generic Constitutive Processor (GCP) routines used in **STAGS** were taken. The first item on this record is a command "verb" that instructs **STAGS** to read and catalog data for a specific type of material or fabrication, or to stop reading such data and proceed to the next type of model-definition input that is required.

COMMAND INFO(j), j = 1, 7

COMMAND command verb instructing **STAGS** to read a specific type of material or wall-fabrication data, or to cease doing so; **STAGS** currently recognizes and responds to the following commands:

ISOELASTIC_MATERIAL	–	linear, elastic, isotropic material
ORTHOELAST_MATERIAL	–	linear, elastic, orthotropic material
~~PLANE_STRAIN_MATERIAL~~	–	~~elastic/plastic plane-strain material~~
PLASTIC_WB_MATERIAL	–	mechanical-sublayer (White-Besseling) material
ORT_EL_BR_MATERIAL	–	linear orthotropic elastic brittle material
ABAQUS_UMAT_MATERIAL	–	user-defined material model developed for **ABAQUS**
PDLAM_MATERIAL	–	Chang's progressive damage model, using crack density state variable
SHM_MEMBRANE_MATERIAL	–	Stein-Hedgepeth-Miller membrane wrinkling model
NL_ORT_ELAST_MATERIAL	–	Orthotropic elastic model, with Hahn nonlinearity
SHELL_FABRICATION	–	shell fabrication
SOLID_FABRICATION	–	solid fabrication
END	–	end of GCP data

INFO integer vector of supplementary information: the meanings and permitted values of entries in **INFO** depend on the command verb; *see the descriptions for records* I-6a, I-7a, I-8a, I-9a, I-10a, I-11a, I-12a, I-13a, I-14a, I-21a *and* I-22a *for those details.*

The command verb on record I-5a is case-independent. Each of the material- and fabrication-specification commands can be abbreviated to anything from its shortest form to its complete form—as shown in the following table:

Table 5.2 GCP Command Record Summary

GCP	GCP Command			
Material	Complete	Shortest	Status	Comment
Type	Form	Form		
1	ISOELASTIC_MATERIAL	ISOEL	✔	Isotropic, linear elastic model
2	ORTHOELAST_MATERIAL	ORTHO	✔	Orthotropic, linear elastic model
3	PLASTIC_WB_MATERIAL	PLAST	✔	Isotropic, elasto-plastic White-Besseling model
4	ORT_EL_BR_MATERIAL	ORT_E	✔	Orthotropic, linear elastic model with brittle failure
5	SHAPE_MEM_MATERIAL	SHAPE	Planned	Shape memory alloy model
6	PLANE_STRAIN_MATERIAL	PLANE	Planned	Plane-strain-plasticity model
7	PDLAM_MATERIAL	PDLAM	✔	Chang’s progressive damage model, with crack density state variable
8	ABAQUS_UMAT_MATERIAL	ABAQUS_UMAT	✔	**ABAQUS** UMAT compatible model
9	SHM_MEMBRANE_MATERIAL	SHM_MEMB	Under development	Stein-Hedgepeth-Miller membrane wrinkling model
10	NL_ORT_ELAST_MATERIAL	NL_ORT_EL	Under development	Orthotropic elastic model, with Hahn nonlinear in-plane shear stress-strain relation
	SHELL_FABRICATION	SHELL	✔	Shell element fabrication
	SOLID_FABRICATION	SOLID	✔	Solid element fabrication
	END	END	✔	End of GCP input data

The 3-character ‘END’ command cannot be abbreviated.

The following example shows how I-5a and other GCP–related records might be used in a typical **STAGS** input deck:

```
PCATS_6_gcp: 6-layer pcats problem
0 0 1 0 0 0 -1                $ B-1
1                             $ B-2
0 0 0 0 0 1                   $ B-3
2 15                          $ F-1
$ ===================================================================
PLASTIC_WB_MATERIAL 1 1 1 2 0  $ I-5a  matid,ngroups,nstates,onetwo
72000.0 0.3 0.0 0.0 6 0.0      $ I-9a  E1, Gnu, Rho, Beta, Nx, T
0.00600 432.0 .00702 490.0,    $ I-9b  {strain,stress} values
0.00787 510.0 .01008 530.0,    $ I-9b  {strain,stress} values
0.01247 540.0 .01900 555.0     $ I-9b  {strain,stress} values
$ ------------------------------------------------------------------
SHELL_FABRICATION   1 1 1 0 0  $ I-5a  fabid,nlayer,ipts,ishr,isym
1                              $ I-21a matid
5                              $ I-21b intshl
2.0                            $ I-21c thkshl
0.0                            $ I-21d angshl
$ -------------------------------------------
END                            $ I-5a  cease
$ ===========================================
5                              $ M-1
0. 5. 0. 90. 100.              $ M-2
-1 0 0. 0. 1 1                 $ M-5
410                            $ N-1
3 0 3 4                        $ P-1
100 100                        $ P-2
1 0 0 0                        $ Q-1
1 2                            $ Q-2
-100. 3 3 0 1                  $ Q-3
0. -1 1 1                      $ Q-3
1 0 0 0 0 0                    $ R-1
```

The first two I-5a records in this example can be abbreviated as

```
PLASTIC_WB          1 1 1 2 0  $ I-5a
```

and

```
SHELL_FAB           1 1 1      $ I-5a
```

or as

```
PLAST  1 1 1 2
```

and

```
SHELL  1 1 1
```

if the user wishes.

NTAB	(B-3)	number of entries in the Cross Section Table
NTAW	(B-3)	number of entries in the Wall Fabrication Table
NTAP	(B-3)	User Parameters flag
NUNITS	(B-2)	number of shell units

```
if      ( COMMAND = 'ISOELASTIC_MATERIAL' )        then   go toI-6a
elseif  ( COMMAND = 'ORTHOELAST_MATERIAL' )        then   go toI-7a
elseif  ( COMMAND = '~~PLANE_STRAIN_MATERIAL~~' )  then   go to~~I-8a~~
elseif  ( COMMAND = 'PLASTIC_WB_MATERIAL' )        then   go toI-9a
elseif  ( COMMAND = 'ORT_EL_BR_MATERIAL' )         then   go toI-10a
elseif  ( COMMAND = 'PDLAM_MATERIAL' )             then   go toI-11a
elseif  ( COMMAND = 'ABAQUS_UMAT_MATERIAL' )       then   go toI-12a
elseif  ( COMMAND = 'SHM_MEMB_MATERIAL' )          then   go toI-13a
elseif  ( COMMAND = 'NL_ORT_ELAST_MATERIAL' )      then   go toI-14a
elseif  ( COMMAND = 'SHELL_FABRICATION' )          then   go toI-21a
elseif  ( COMMAND = 'SOLID_FABRICATION' )          then   go toI-22a
elseif  ( COMMAND = 'END' )  then
    if      (NTAB > 0)     then   go to  J-1
    elseif  (NTAW > 0)     then   go to  K-1
    elseif  (NTAP > 0)     then   go to  L-1
    elseif  (NUNITS > 0)   then   go to  M-1
    else                          follow instructions at end of  R-3
else
    return to  I-5a
endif
```

I-6a Linear Elastic Isotropic GCP Material

This record—which concludes the specification of properties for a linear, elastic, isotropic GCP material—is read when **COMMAND** on I-5a is ‘ISOELASTIC_MATERIAL’, or is an acceptable abbreviation of that character string (as discussed in the I-5a record description). Under these circumstances, the **INFO** vector on I-5a contains the following information:

INFO(1) = **MATID** — material identifier, in the GCP Materials Table

INFO(2) = **NGROUPS** — number of material groups (must be 1, currently)

INFO(3) = **NSTATES** — number of material states in each group (must be 1, currently)

INFO(4) = not used, currently

INFO(5) = not used, currently

INFO(6) = not used, currently

INFO(7) = not used, currently

The following record is required for specification of the properties of the linear, elastic, isotropic GCP material for each state within each group of states (a single record, currently):

E GNU RHO ALPHA BETA T M

E	elastic modulus
GNU	Poisson’s ratio
RHO	mass density
ALPHA	coefficient of thermal expansion
BETA	coefficient of hygroscopic expansion
T	reference temperature
M	reference moisture content

go to I-5a

I-7a Linear Elastic Orthotropic GCP Material

This record—which continues the specification of properties for a linear, elastic, orthotropic GCP material—is read when **COMMAND** on I-5a is 'ORTHOELAST_MATERIAL', or is an acceptable abbreviation of that character string (as discussed in the I-5a record description). Under these circumstances, the **INFO** vector on I-5a contains the following information:

INFO(1) = **MATID** — material identifier, in the GCP Materials Table

INFO(2) = **NGROUPS** — number of material groups (must be 1, currently)

INFO(3) = **NSTATES** — number of material states in each group (1, currently)

INFO(4) = not used, currently

INFO(5) = not used, currently

INFO(6) = not used, currently

INFO(7) = not used, currently

The following record is required for specification of the properties of the linear, elastic, orthotropic GCP material for each state within each group of states (this is a single record, currently, and all entries must be specified):

E1 E2 E3 G12 G13 G23 P12 P13 P23 RHO A1 A2 A3 B1 B2 B3 T M

E1, E2, E3	elastic moduli (E_1, E_2 and E_3)
G12, G13, G23	shear moduli (G_{12}, G_{13} and G_{23})
P12, P13, P23	Poisson's ratios (ν_{12}, ν_{13} and ν_{23})
RHO	mass density
A1, A2, A3	coefficients of thermal expansion
B1, B2, B3	coefficients of hygroscopic expansion
T	reference temperature
M	reference moisture content

The complete ***C*** matrix, which relates strains to stresses, is given by

$$[\boldsymbol{C}] = \begin{bmatrix} \delta(1-\nu_{23}\nu_{32})E_1 & & & & & \\ \delta(\nu_{12}+\nu_{13}\nu_{32})E_2 & \delta(1-\nu_{13}\nu_{31})E_2 & & & Sym & \\ \delta(\nu_{13}+\nu_{12}\nu_{23})E_3 & \delta(\nu_{23}+\nu_{13}\nu_{21})E_3 & \delta(1-\nu_{12}\nu_{21})E_3 & & & \\ 0 & 0 & 0 & G_{23} & & \\ 0 & 0 & 0 & 0 & G_{13} & \\ 0 & 0 & 0 & 0 & 0 & G_{12} \end{bmatrix}$$

where

$$\nu_{21} = \nu_{12} \cdot E_2 / E_1$$

$$\nu_{31} = \nu_{13} \cdot E_3 / E_1$$

$$\nu_{32} = \nu_{23} \cdot E_3 / E_2$$

and

$$\delta = 1/(1-\nu_{12}\nu_{21}-\nu_{23}\nu_{32}-\nu_{13}\nu_{31}-2\nu_{21}\nu_{32}\nu_{13})$$

Note that the ν_{ij} conventions here are *not* the same as on the I-2 record, described previously.

✦ *go to* I-5a

I-8a ~~Plane-Strain-Plasticity GCP Material~~

INACTIVE

This record—which concludes the specification of properties for an elastic/plastic, plane-strain GCP material—is read when **COMMAND** on I-5a is 'PLANE_STRAIN_MATERIAL', or is an acceptable abbreviation of that character string (as discussed in the I-5a record description). Under these circumstances, the **INFO** vector on I-5a contains the following information:

INFO(1) = **MATID** — material identifier, in the GCP Materials Table

INFO(2) = **NGROUPS**— number of material groups (must be 1, currently)

INFO(3) = **NSTATES** — number of material states in each group (must be 1, currently)

INFO(4) = not used, currently

INFO(5) = not used, currently

INFO(6) = not used, currently

INFO(7) = not used, currently

The following record is required for specification of the properties of the elastic/plastic, plane-strain GCP material for each state within each group of states (a single record, currently):

E GNU RHO ALPHA BETA T M

E	elastic modulus
GNU	Poisson's ratio
RHO	mass density
ALPHA	coefficient of thermal expansion
BETA	coefficient of hygroscopic expansion
T	reference temperature
M	reference moisture content

go to I-5a

I-9a Mechanical Sublayer Plasticity GCP Material

This record—which continues the specification of properties for a mechanical sublayer plasticity (White–Besseling) GCP material—is read when the **COMMAND** parameter on the I-5a record is 'PLASTIC_WB_MATERIAL', or is an acceptable abbreviation of that character string (as discussed in the I-5a record description). Under these circumstances, the **INFO** vector on I-5a contains the following information:

INFO(1) = **MATID** — material identifier, in the GCP Materials Table

INFO(2) = **NGROUPS** — number of material groups (must be 1, currently)

INFO(3) = **NSTATES** — number of material states in each group (must be 1, currently)

INFO(4) = **ONETWO** — dimensionality flag:
ONETWO = 1 — use one-dimensional theory
ONETWO = 2 — use two-dimensional theory

INFO(5) = **IFLAG** — material behavior flag:
IFLAG = 0 — elastic/plastic material behavior
IFLAG = 1 — elastic/plastic, plane-strain material behavior

INFO(6) = not used, currently

INFO(7) = not used, currently

The following record is required for specification of the properties of the mechanical sublayer (White–Besseling) plasticity material for each state within each group of states (a single record, currently) — each such record followed by an I-9b record containing the specified number of (e,s) = (strain,stress) points on the curve for that state. This is strikingly similar to the White-Besseling input that is described for the I-3 record.

E GNU RHO ALPHA NSUBS T

E	elastic modulus
GNU	Poisson's ratio
RHO	mass density
ALPHA	coefficient of thermal expansion
NSUBS	number of points on the $\varepsilon - \sigma$ curve, excluding the origin, which is defined to be $(\varepsilon, \sigma) = (0, 0)$
T	reference temperature

✦ *go to* I-9b

I-9b Stress-Strain Curve for a Given State

The White-Besseling theory (or mechanical sublayer model) has its limitations, but it performs adequately for a moderate-strain analysis of metals. This theory is based on a piecewise linear stress-strain curve, described on the data records by definition of strain and stress at the corners. The slope of the stress-strain curve must decrease at each corner. The first point on this curve must agree with elastic behavior, or the elastic modulus times the first strain value.

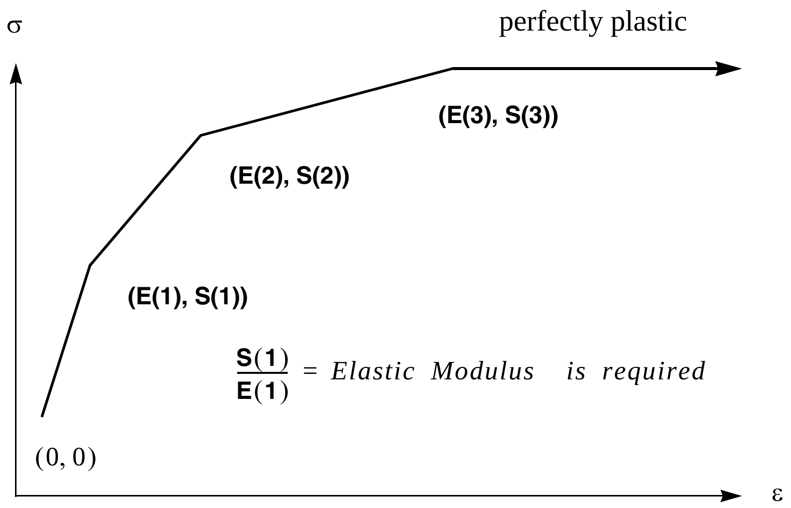


Figure 5.2 Stress-strain curve.

(E(i),S(i) , i = 1, NSUBS)

E(i) ε_i, the strain value corresponding to the i^{th} point on the (ε, σ) curve; the origin, $(\varepsilon, \sigma) = (0, 0)$, is *not* included as a data point; $(\mathbf{E}(1), \mathbf{S}(1))$ must be defined to satisfy the relation $\sigma_1 = E\ \varepsilon_1$; where $\varepsilon_1 = \mathbf{E}(1)$, $\sigma_1 = \mathbf{S}(1)$, and $E = \boldsymbol{E}$ (the modulus of elasticity on I-9a).

S(i) σ_i, the stress value corresponding to the i^{th} point on the (ε, σ) curve

✦ *go to* I-5a

I-10a Linear Orthotropic Elastic Brittle GCP Material

This record[*]—which continues the specification of properties for a linear orthotropic elastic brittle GCP material—is read when **COMMAND** on I-5a is ‘ORT_EL_BR_MATERIAL’, or is an acceptable abbreviation of that character string (as discussed in the description of the I-5a record). Under these circumstances, the **INFO** vector on I-5a contains the following information:

INFO(1) = **MATID** — material identifier, in the GCP Materials Table
INFO(2) = **NGROUPS** — number of material groups (must be 1, currently)
INFO(3) = **NSTATES** — number of material states in each group (1, currently)
INFO(4) = not used, currently
INFO(5) = not used, currently
INFO(6) = not used, currently
INFO(7) = not used, currently

The following record is required for specification of the properties of the linear, orthotropic elastic brittle GCP material for each state within each group of states. This is a single record currently, and all 44 entries must be specified as floating–point (real) entries. These data items are stored in this order in an internal real array named **mpd** as the original input material data. Caution must be exercised when converting from the traditional **STAGS** material model (I-2 records) to the GCP approach with regard to the definition of Poisson’s ratio (compare the description of the I-2 record with that of the I-7a record). All strain and strength allowable values are stored as positive numbers.

E1 E2 E3 G12 G13 G23 P12 P13 P23 RHO A1 A2 A3 B1 B2 B3 T M
EPS1C EPS1T ESP2C EPS2T EPS6F EPS3C EPS3T EPS4F EPS5F
XC XT YC YT SXY ZC ZT SYZ SXZ ALPHA F12 BETA IFAIL IDGRD
VISF0 VISF1 VISFF

E1, E2, E3	elastic moduli (E_1, E_2 and E_3)
G12, G13, G23	shear moduli (G_{12}, G_{13} and G_{23})
P12, P13, P23	major Poisson’s ratios (ν_{12}, ν_{13} and ν_{23})
RHO	mass density
A1, A2, A3	coefficients of thermal expansion
B1, B2, B3	coefficients of hygroscopic expansion
T	reference temperature for thermal calculations

[*] This description of the I-10a input requirements is based on that given in [2].

M reference moisture content for hygroscopic calculations

EPS1C, **EPS1T** compressive and tensile strain allowable values in the 1–direction (ε_{1C} and ε_{1T})

EPS2C, **EPS2T** compressive and tensile strain allowable values in the 2–direction (ε_{2C} and ε_{2T})

EPS6F shear strain allowable value in the 1–2 plane $(\gamma_{12})_a$

EPS3C, **EPS3T** compressive and tensile strain allowable values in the 3–direction (ε_{3C} and ε_{3T})

EPS4F shear strain allowable value in the 2–3 plane $(\gamma_{23})_a$

EPS5F shear strain allowable value in the 1–3 plane $(\gamma_{13})_a$

XC, **XT** strength allowable values in the 1–direction (X_C and X_T)

YC, **YT** strength allowable values in the 2–direction (Y_C and Y_T)

SXY shear strength allowable value in the 1–2 plane (S_{xy} or S)

ZC, **ZT** strength allowable values in the 3–direction (Z_C and Z_T)

SYZ shear strength allowable value in the 2–3 plane (S_{yz})

SXZ shear strength allowable value in the 1–3 plane (S_{xz})

ALPHA nonlinear shear stress-strain coefficient, α

F12 coupling coefficient for the Tsai–Wu failure polynomial, F_{12}

BETA scale factor for degrading material properties (*e.g.*, 0.1 or 10^{-6}); if **BETA** is positive, then recursively degrade; if it is negative, then degrade only once (*i.e.*, multiply elastic property by β only once)

IFAIL failure model identifier:

0 = pass through failure routines, but do not allow failure to occur
1 = maximum strain criteria
2 = maximum stress criteria
3 = Tsai–Wu failure polynomial
4 = Hashin criteria
5 = Chang–Chang criteria
99 = subroutine USRFPF, provided by the user

IDGRD material degradation model identifier:

1 = ply discounting of single modulus for maximum stress and maximum strain criteria
2 = ply discounting of normal and shear moduli for maximum stress and maximum strain criteria
3 = ply discounting for Tsai–Wu polynomial (same as 1)
4 = ply discounting for Hashin criteria
5 = ply discounting for Chang–Chang criteria
99 = subroutine USRDGD, provided by the user

VISF0 artificial viscous damping factor ζ_0—multiplying all damping terms when convergence problems occur:

> 1	increase damping when nonconvergence occurs
< 1	reduce damping when nonconvergence occurs
$= 0$	eliminate all artificial viscous damping
$= 1$	maintain uniform damping

VISF1 artificial viscous damping factor ζ_1 associated with global damping; becomes active after damage is detected and remains active, independent of damage state; scaled by the longitudinal modulus, E_{11} (that is, ζ_1 E_{11})

VISFF artificial viscous damping factor ζ_f associated with local damping; becomes active after damage is detected, is held constant for 5 solution steps, and is then ramped linearly to zero over the next 5 steps; scaled by the longitudinal modulus, E_{11} (that is, ζ_f E_{11})

The artificial viscous damping factor at a material point after damage has been detected has the form

$$\zeta = \zeta_0^{\alpha}(\zeta_1 E_{11} + \zeta_f E_{11})$$

where the exponent α is determined by using the initial user-specified step increment ΔP_0 (on the C-1 record of the *case.bin* input file for ***s2***) and on the current step increment ΔP; that is,

$$\alpha \approx \log((\Delta P_0)/(\Delta P))$$

where $\Delta P \le \Delta P_0/10$ before activation. When convergence difficulties arise that cause the step size to be cut smaller than the initial value, the exponent α increases. If **VISF0** is greater than one, the artificial damping will increase; if **VISF0** is less than one, it will decrease; and if **VISF0** is equal to zero, artificial damping will not be applied.

The complete **C** matrix, which relates strains to stresses, is given in Section I-7a. The user may specify either the strain or strength allowables or both. However, as a minimum, a zero must be entered for each unspecified value. If the strain allowables are given and the first strength allowable is zero, then all strength allowables are computed by multiplying the appropriate strain allowable value by its elastic modulus (or shear modulus in the case of shear). If the strength allowables are specified and the first strain allowable is zero, then all strain allowables are computed by dividing the appropriate strength allowable value by its elastic modulus (or shear modulus in the case of shear).

A sample input record is shown next:

```
ORT_EL_BR_MATERIAL  1 1 1           $ I-5a GCP COMMAND RECORD
20.2E+6 1.41E+6 1.41e+6 ,           $ I-10a E1 E2 E3=E2
0.81E6 0.81E6 0.40E6    ,           $ I-10a G12 G13=G12 G23
0.29 0.29 0.29          ,           $ I-10a NU12 NU13=NU12 NU23=NU12
1.5E-4                    ,         $ I-10a Mass density (not weight)
0.0 0.0 0.0             ,           $ I-10a CTE'S
0.0 0.0 0.0             ,           $ I-10a Moisture Coefficients
0.0 0.0                 ,           $ I-10a Ref. Temp and Moisture contents
0.0109 0.0108 0.0227 0.0014 0.0074 ,$ I-10a E1C  E1T  E2C  E2T  GAM12F
0.0227 0.0014 0.0074 0.0074        ,$ I-10a E3C  E3T  GAM23F  GAM13F
0.0 0.0 0.0 0.0 0.0 0.0 0.0 0.0 0.0,$ I-10a Xc,Xt,Yc,Yt,Sxy  Zc,Zt,Syz,Sxz
0.8E-14 0.0 1.0E-6,                 $ I-10a Alpha F12 Beta
1 1               ,                 $ I-10a Ifail Idgrd
1.0 1.0E-9 1.0E-4                   $ I-10a Visf0 Visf1 Visff
```

Failure prediction models based on stresses are implemented in subroutines named FPFi which are called by GCP subroutine CS4F. The output from each routine is an array named **flag** of length **numcol**. For C^1 shell elements (*e.g.*, **E410** shell elements), **numcol** is equal to 3; for C^0 shell elements (*e.g.*, **E480** shell elements), **numcol** is equal to 5; for solid elements (*e.g.*, **E881**, **E883** and **E885** solid elements), **numcol** is equal to 6.

The entries in the **flag** array are integers that have values that are equal to zero for no failure, positive for tensile–related failures, or negative for compression–related failures. Shear–related failures are always positive. For shell elements, the first entry, **flag**(1), relates to the fiber direction; the second entry, **flag**(2), relates to the direction transverse to the fibers (matrix); and the third entry, **flag**(3), relates to inplane shear. The fourth and fifth entries, **flag**(4) and **flag**(5), relate to transverse shear failures. The absolute value of each entry in the flag array corresponds to the solution step number at which that failure mode occurred. For solid elements, the first three entries in **flag** relate to the normal stress components; and the next three entries relate to the shear stress components.

The following five failure models are implemented in the current version of **STAGS**:

- FPF1—Failure detection based on maximum strain criteria (**IFAIL**=1). These criteria are not interacting and simply compare the inplane mechanical strain to the user–specified strain allowable value.

  For shell elements, the failure modes here are:

Fiber tensile failure:	$\frac{\varepsilon_{11}}{\varepsilon_{1t}} \geq 1$	when $\varepsilon_{11} > 0$;	**flag**(1) > 0
Fiber compressive failure:	$\frac{\varepsilon_{11}}{\varepsilon_{1c}} < -1$	when $\varepsilon_{11} < 0$;	**flag**(1) < 0
Matrix tensile failure:	$\frac{\varepsilon_{22}}{\varepsilon_{2t}} \geq 1$	when $\varepsilon_{22} > 0$;	**flag**(2) > 0
Matrix compressive failure:	$\frac{\varepsilon_{22}}{\varepsilon_{2c}} \leq -1$	when $\varepsilon_{22} < 0$;	**flag**(2) < 0
Inplane shear failure:	$\frac{\lvert\gamma_{12}\rvert}{(\gamma_{12})_a} \geq 1$;		**flag**(3) > 0
Transverse shear failure:	$\frac{\lvert\gamma_{13}\rvert}{(\gamma_{13})_a} \geq 1$;		**flag**(4) > 0
Transverse shear failure:	$\frac{\lvert\gamma_{23}\rvert}{(\gamma_{23})_a} \geq 1$;		**flag**(5) > 0

  For solid elements, the failure modes are:

Fiber tensile failure:	$\frac{\varepsilon_{11}}{\varepsilon_{1t}} \geq 1$	when $\varepsilon_{11} > 0$;	**flag**(1) > 0
Fiber compressive failure:	$\frac{\varepsilon_{11}}{\varepsilon_{1c}} \leq -1$	when $\varepsilon_{11} < 0$;	**flag**(1) < 0
Matrix tensile failure:	$\frac{\varepsilon_{22}}{\varepsilon_{2t}} \geq 1$	when $\varepsilon_{22} > 0$;	**flag**(2) > 0
Matrix compressive failure:	$\frac{\varepsilon_{22}}{\varepsilon_{2c}} \leq -1$	when $\varepsilon_{22} < 0$;	**flag**(2) < 0
Interlaminar normal tensile failure:	$\frac{\varepsilon_{33}}{\varepsilon_{3t}} \geq 1$	when $\varepsilon_{33} > 0$;	**flag**(3) > 0
Interlaminar normal compressive failure:	$\frac{\varepsilon_{33}}{\varepsilon_{3c}} \leq -1$	when $\varepsilon_{33} < 0$;	**flag**(3) < 0
Transverse shear failure:	$\frac{\lvert\gamma_{23}\rvert}{(\gamma_{23})_a} \geq 1$;		**flag**(4) > 0
Transverse shear failure:	$\frac{\lvert\gamma_{13}\rvert}{(\gamma_{13})_a} \geq 1$;		**flag**(5) > 0
Inplane shear failure:	$\frac{\lvert\gamma_{12}\rvert}{(\gamma_{12})_a} \geq 1$;		**flag**(6) > 0

- FPF2—Failure detection based on maximum stress criteria (**IFAIL**=2). These criteria are not interacting and simply compare the inplane stress components to the user–specified stress/strength allowable values.

  For shell elements, the failure modes here are:

Fiber tensile failure:	$\frac{\sigma_{11}}{X_t} \geq 1$	when $\sigma_{11} > 0$;	**flag**(1) > 0
Fiber compressive failure:	$\frac{\sigma_{11}}{X_c} \leq -1$	when $\sigma_{11} < 0$;	**flag**(1) < 0
Matrix tensile failure:	$\frac{\sigma_{22}}{Y_t} \geq 1$	when $\sigma_{22} > 0$;	**flag**(2) > 0
Matrix compressive failure:	$\frac{\sigma_{22}}{Y_c} \leq -1$	when $\sigma_{22} < 0$;	**flag**(2) < 0
Inplane shear failure:	$\frac{\lvert\tau_{12}\rvert}{S_{xy}} \geq 1$;		**flag**(3) > 0
Transverse shear failure:	$\frac{\lvert\tau_{13}\rvert}{S_{xz}} \geq 1$;		**flag**(4) > 0
Transverse shear failure:	$\frac{\lvert\tau_{23}\rvert}{S_{yz}} \geq 1$;		**flag**(5) > 0

  For solid elements, the failure modes are:

Fiber tensile failure:	$\frac{\sigma_{11}}{X_t} \geq 1$	when $\sigma_{11} > 0$;	**flag**(1) > 0
Fiber compressive failure:	$\frac{\sigma_{11}}{X_c} \leq -1$	when $\sigma_{11} < 0$;	**flag**(1) < 0
Matrix tensile failure:	$\frac{\sigma_{22}}{Y_t} \geq 1$	when $\sigma_{22} > 0$;	**flag**(2) > 0
Matrix compressive failure:	$\frac{\sigma_{22}}{Y_c} \leq -1$	when $\sigma_{22} < 0$;	**flag**(2) < 0
Interlaminar normal tensile failure:	$\frac{\sigma_{33}}{Z_t} \geq 1$	when $\sigma_{33} > 0$;	**flag**(3) > 0
Interlaminar normal compressive failure:	$\frac{\sigma_{33}}{Z_c} \leq -1$	when $\sigma_{33} < 0$;	**flag**(3) < 0
Transverse shear failure:	$\frac{\lvert\tau_{23}\rvert}{S_{yz}} \geq 1$;		**flag**(4) > 0
Transverse shear failure:	$\frac{\lvert\tau_{13}\rvert}{S_{xz}} \geq 1$;		**flag**(5) > 0
Inplane shear failure:	$\frac{\lvert\tau_{12}\rvert}{S_{xy}} \geq 1$;		**flag**(6) > 0

- FPF3—Failure detection based on the Tsai–Wu failure polynomial [3] (**IFAIL**=3). This criterion is interacting but does not identify a mode of failure (*e.g.*, fiber failure, matrix failure). Most of the polynomial coefficients are computed based on user–specified strength allowable values—with the exception of F_{12}, which must be supplied by the user as well. The complete polynomial is given by:

$$F_1\sigma_{11} + F_2\sigma_{22} + F_3\sigma_{33} + F_{11}\sigma_{11}^2 + F_{22}\sigma_{22}^2 + F_{33}\sigma_{33}^2 + 2F_{12}\sigma_{11}\sigma_{22} + 2F_{13}\sigma_{11}\sigma_{33} + 2F_{23}\sigma_{22}\sigma_{33} + F_{44}\sigma_{23}^2 + F_{55}\sigma_{13}^2 + F_{66}\sigma_{12}^2 \geq 1.0$$

where
$$F_1 = \frac{1}{X_t} - \frac{1}{X_c},$$

$$F_2 = \frac{1}{Y_t} - \frac{1}{Y_c},$$

$$F_3 = \frac{1}{Z_t} - \frac{1}{Z_c},$$

$$F_{11} = \frac{1}{X_t X_c},$$

$$F_{22} = \frac{1}{Y_t Y_c},$$

$$F_{33} = \frac{1}{Z_t Z_c},$$

$$F_{44} = \frac{1}{S_{yz}^2},$$

$$F_{55} = \frac{1}{S_{xz}^2},$$

$$F_{66} = \frac{1}{S_{xy}^2},$$

$$F_{12} = -\frac{1}{2}\frac{1}{\sqrt{X_t X_c Y_t Y_c}},$$

$$F_{13} = -\frac{1}{2}\frac{1}{\sqrt{X_t X_c Z_t Z_c}},$$

and
$$F_{23} = -\frac{1}{2}\frac{1}{\sqrt{Y_t Y_c Z_t Z_c}}.$$

In this model, only a single value is checked to see whether failure occurred or not. In order to have set the failure flags used in the material degradation models, the approach used by Reddy and Reddy [4] is adopted. This approach determines the relative contributions of each stress component to the failure polynomial and if the contribution for that component is a dominant component, then the corresponding failure flag is made nonzero. Half the cross term is considered in both the σ_{11} term and in the σ_{22} term. For shell elements, the coefficients F_3, F_{33}, F_{13} and F_{23} are zero because of the plane stress assumptions.

- FPF4—Failure detection based on the Hashin criteria [5] (**IFAIL**=4). These criteria identify the mode of failure using specified stress/strength allowable values.

For shell elements, the failure modes here are:

Fiber tensile failure: $\left(\frac{\sigma_{11}}{X_T}\right)^2 + \left(\frac{\sigma_{12}}{S_{xy}}\right)^2 \geq 1$ when $\sigma_{11} > 0$; **flag**(1) > 0

Fiber compressive failure: $\frac{\sigma_{11}}{X_c} \leq -1$ when $\sigma_{11} < 0$; **flag**(1) < 0

Matrix tensile failure: $\left(\frac{\sigma_{22}}{Y_T}\right)^2 + \left(\frac{\sigma_{12}}{S_{xy}}\right)^2 \geq 1$ when $\sigma_{22} > 0$; **flag**(2) > 0

Matrix compression model: $\left(\frac{\sigma_{22}}{2S_{xy}}\right)^2 + \left[\left(\frac{Y_c}{2S_{xy}}\right)^2 - 1\right]\frac{\sigma_{22}}{Y_c} + \left(\frac{\sigma_{12}}{S_{xy}}\right)^2 \geq 1$ when $\sigma_{22} < 0$; **flag**(2) < 0

Inplane shear failure: $\frac{|\tau_{12}|}{S_{xy}} \geq 1$; **flag**(3) > 0

Transverse shear failure: $\frac{|\tau_{13}|}{S_{xz}} \geq 1$; **flag**(4) > 0

Transverse shear failure: $\frac{|\tau_{23}|}{S_{yz}} \geq 1$; **flag**(5) > 0

For solid elements, the failure modes are:

Fiber tensile failure: $\left(\frac{\sigma_{11}}{X_T}\right)^2 + \left(\frac{\sigma_{12}}{S_{xy}}\right)^2 \geq 1$ when $\sigma_{11} > 0$; **flag**(1) > 0

Fiber compressive failure: $\frac{\sigma_{11}}{X_c} \leq -1$ when $\sigma_{11} < 0$; **flag**(1) < 0

Matrix tensile failure: $\left(\frac{\sigma_{22}}{Y_T}\right)^2 + \left(\frac{\sigma_{12}}{S_{xy}}\right)^2 \geq 1$ when $\sigma_{22} > 0$; **flag**(2) > 0

Matrix compression model: $\left(\frac{\sigma_{22}}{2S_{xy}}\right)^2 + \left[\left(\frac{Y_c}{2S_{xy}}\right)^2 - 1\right]\frac{\sigma_{22}}{Y_c} + \left(\frac{\sigma_{12}}{S_{xy}}\right)^2 \geq 1$ when $\sigma_{22} < 0$; **flag**(2) < 0

Interlaminar normal tensile failure: $\frac{\sigma_{33}}{Z_t} \geq 1$ when $\sigma_{33} > 0$; **flag**(3) > 0

Interlaminar normal compressive failure: $\frac{\sigma_{33}}{Z_c} \leq 1$ when $\sigma_{33} < 0$; **flag**(3) < 0

Transverse shear failure: $\frac{|\tau_{23}|}{S_{yz}} \geq 1$; **flag**(4) > 0

Transverse shear failure: $\frac{|\tau_{13}|}{S_{xz}} \geq 1$; **flag**(5) > 0

Inplane shear failure: $\frac{|\tau_{12}|}{S_{xy}} \geq 1$; **flag**(6) > 0

- FPF5—Failure detection based on the Chang–Chang criteria [6] (**IFAIL**=5). These criteria identify the mode of failure using specified stress/strength allowable values.

  <u>For shell elements, the failure models here are</u>:

  Fiber breakage and fiber–matrix shearing model:

  $\left(\frac{\sigma_{11}}{X_T}\right)^2 + \bar{\tau} \ge 1$ when $\sigma_{11} > 0$; **flag**(1) > 0 and **flag**(3) > 0

  Fiber compressive failure: $\frac{\sigma_{11}}{X_c} \le -1$ when $\sigma_{11} < 0$; **flag**(1) < 0

  Matrix cracking model: $\left(\frac{\sigma_{22}}{Y_T}\right)^2 + \bar{\tau} \ge 1$ when $\sigma_{22} > 0$; **flag**(2) > 0

  Matrix compression model: $\left(\frac{\sigma_{22}}{2S}\right)^2 + \left[\left(\frac{Y_c}{2S}\right)^2 - 1\right]\frac{\sigma_{22}}{Y_c} + \bar{\tau} \ge 1$ when $\sigma_{22} < 0$; **flag**(2) < 0

  where $\bar{\tau} = \left(\frac{\sigma_{12}}{S}\right)^2 \left\{\frac{1 + \frac{3}{2}\alpha G_{12}\sigma_{12}^2}{1 + \frac{3}{2}\alpha G_{12}S^2}\right\}$

  Inplane shear failure: $\frac{|\tau_{12}|}{S_{xy}} \ge 1$; **flag**(3) > 0

  Transverse shear failure: $\frac{|\tau_{13}|}{S_{xz}} \ge 1$; **flag**(4) > 0

  Transverse shear failure: $\frac{|\tau_{23}|}{S_{yz}} \ge 1$; **flag**(5) > 0

  <u>For solid elements, the failure models are</u>:

  Fiber breakage and fiber–matrix shearing model:

  $\left(\frac{\sigma_{11}}{X_T}\right)^2 + \bar{\tau} \ge 1$ when $\sigma_{11} > 0$; **flag**(1) > 0 and **flag**(6) > 0

  Fiber compressive failure: $\frac{\sigma_{11}}{X_c} \le -1$ when $\sigma_{11} < 0$; **flag**(1) < 0

  Matrix cracking model: $\left(\frac{\sigma_{22}}{Y_T}\right)^2 + \bar{\tau} \ge 1$ when $\sigma_{22} > 0$; **flag**(2) > 0

  Matrix compression model: $\left(\frac{\sigma_{22}}{2S}\right)^2 + \left[\left(\frac{Y_c}{2S}\right)^2 - 1\right]\frac{\sigma_{22}}{Y_c} + \bar{\tau} \ge 1$ when $\sigma_{22} < 0$; **flag**(2) < 0

  where $\bar{\tau} = \left(\frac{\sigma_{12}}{S}\right)^2 \left\{\frac{1 + \frac{3}{2}\alpha G_{12}\sigma_{12}^2}{1 + \frac{3}{2}\alpha G_{12}S^2}\right\}$

  Interlaminar normal tensile failure: $\frac{\sigma_{33}}{Z_t} \ge 1$ when $\sigma_{33} > 0$; **flag**(3) > 0

  Interlaminar normal compressive failure: $\frac{\sigma_{33}}{Z_c} \le -1$ when $\sigma_{33} < 0$; **flag**(3) < 0

  Transverse shear failure: $\frac{|\tau_{23}|}{S_{yz}} \ge 1$; **flag**(4) > 0

  Transverse shear failure: $\frac{|\tau_{13}|}{S_{xz}} \ge 1$; **flag**(5) > 0

Inplane shear failure: $\frac{|\tau_{12}|}{S_{xy}} \geq 1$; **flag**(6) > 0

Material degradation models based on ply discounting for each of the failure models are implemented in subroutines named DGRADi that are called by GCP subroutine CS4F. At present, the five material degradation models implemented include:

- DGRAD1—Material degradation model for the maximum strain and maximum stress failure models based on the inplane values only (**IDGRD**=1).

  For shell elements, the material degradation rules here are:

  If **flag**(1) is nonzero, set **E11** = β E_{11}, **P12** = β ν_{12} and **P21** = β ν_{21} where β is a user–specified value (*e.g.*, 10^{-6}) read on the `ORT_EL_BR_MATERIAL` input data

  If **flag**(2) is nonzero, set **E22** = β E_{22}, **P12** = β ν_{12} and **P21** = β ν_{21}

  If **flag**(3) is nonzero, set **G12** = β G_{12}

  If **flag**(4) is nonzero, set **G13** = β G_{13}

  If **flag**(5) is nonzero, set **G23** = β G_{23}

  For solid elements, the material degradation rules are:

  Fiber failure (tension or compression) (**flag**(1) $\neq 0$):

  set $C'_{11} = \beta C_{11}$, $C'_{12} = \beta C_{12}$ and $C'_{13} = \beta C_{13}$

  Matrix failure (tension or compression) (**flag**(2) $\neq 0$):

  set $C'_{22} = \beta C_{22}$, $C'_{21} = \beta C_{21}$ and $C'_{23} = \beta C_{23}$

  Interlaminar normal failure (tension or compression) (**flag**(3) $\neq 0$):

  set $C'_{33} = \beta C_{33}$, $C'_{31} = \beta C_{31}$ and $C'_{32} = \beta C_{32}$

  Interlaminar shear failure (**flag**(4) $\neq 0$): set $C'_{44} = \beta C_{44}$

  Interlaminar shear failure (**flag**(5) $\neq 0$): set $C'_{55} = \beta C_{55}$

  In-plane shear failure (**flag**(6) $\neq 0$): set $C'_{66} = \beta C_{66}$

- DGRAD2—Also a material degradation model for the maximum strain and maximum stress failure models based on the inplane values only (**IDGRD**=2). This model also degrades the inplane shear modulus when either fiber or matrix failures are detected.

  For shell elements, the material degradation rules here are:

  If **flag**(1) is nonzero, set **E11** = β E_{11}, **G12** = β G_{12}, **P12** = β ν_{12} and **P21** = β ν_{21}
  where β is a user–specified value (*e.g.*, 10^{-6}) read on the ORT_EL_BR_MATERIAL
  input data.

  If **flag**(2) is nonzero, set **E22** = β E_{22}, **G12** = β G_{12}, **P12** = β ν_{12} and **P21** = β ν_{21}

  If **flag**(3) is nonzero, set **G12** = β G_{12}

If **flag**(4) is nonzero, set **G13** = β G_{13}

If **flag**(5) is nonzero, set **G23** = β G_{23}

<u>For solid elements, the material degradation rules are</u>:

Fiber failure (tension or compression) (**flag**(1) $\neq 0$):

set $C'_{11} = \beta C_{11}$, $C'_{12} = \beta C_{12}$ and $C'_{13} = \beta C_{13}$

Matrix failure (tension or compression) (**flag**(2) $\neq 0$):

set $C'_{22} = \beta C_{22}$, $C'_{21} = \beta C_{21}$ and $C'_{23} = \beta C_{23}$

Interlaminar normal failure (tension or compression) (**flag**(3) $\neq 0$):

set $C'_{33} = \beta C_{33}$, $C'_{31} = \beta C_{31}$ and $C'_{32} = \beta C_{32}$

Interlaminar shear failure (**flag**(4) $\neq 0$): set $C'_{44} = \beta C_{44}$

Interlaminar shear failure (**flag**(5) $\neq 0$): set $C'_{55} = \beta C_{55}$

In-plane shear failure (**flag**(6) $\neq 0$): set $C'_{66} = \beta C_{66}$

- DGRAD3—Material degradation model for the Tsai–Wu failure model [3] based on the inplane values only (**IDGRD**=3). The material degradation rules follow those given by Reddy and Reddy [4].

<u>For shell elements, the material degradation rules here are</u>:

If **flag**(1) is nonzero, set E11 = β E_{11}, **P12** = β ν_{12} and **P21** = β ν_{21} where β is a user–specified value (*e.g.*, 10^{-6}) read on the ORT_EL_BR_MATERIAL input data.

If **flag**(2) is nonzero, set **E22** = β E_{22}, **P12** = β ν_{12} and **P21** = β ν_{21}

If **flag**(3) is nonzero, set **G12** = β G_{12}

If **flag**(4) is nonzero, set **G13** = β G_{13}

If **flag**(5) is nonzero, set **G23** = β G_{23}

<u>For solid elements, the material degradation rules are</u>:

Fiber failure (tension or compression) (**flag**(1) $\neq 0$):

set $C'_{11} = \beta C_{11}$, $C'_{12} = \beta C_{12}$ and $C'_{13} = \beta C_{13}$

Matrix failure (tension or compression) (**flag**(2) $\neq 0$):

set $C'_{22} = \beta C_{22}$, $C'_{21} = \beta C_{21}$ and $C'_{23} = \beta C_{23}$

Interlaminar normal failure (tension or compression) (**flag**(3) $\neq 0$):

set $C'_{33} = \beta C_{33}$, $C'_{31} = \beta C_{31}$ and $C'_{32} = \beta C_{32}$

Interlaminar shear failure (**flag**(4) $\neq 0$): set $C'_{44} = \beta C_{44}$

Interlaminar shear failure (**flag**(5) $\neq 0$): set $C'_{55} = \beta C_{55}$

In-plane shear failure (**flag**(6) $\neq 0$): set $C'_{66} = \beta C_{66}$

- DGRAD4—Material degradation model for the Hashin [5] failure model based on the inplane values only (**IDGRD**=4). This model also degrades the inplane shear modulus when either fiber or matrix failures are detected. There is no inplane shear failure mode (*i.e.*, **flag**(3) will always be zero).

  For shell elements, the material degradation rules here are:

  If **flag**(1) is nonzero, set **E11** = β E_{11}, **G12** = β G_{12}, **P12** = β ν_{12} and **P21** = β ν_{21} where β is a user–specified value (*e.g.*, 10^{-6}) read on the `ORT_EL_BR_MATERIAL` input data.

  If **flag**(2) is nonzero, set **E22** = β E_{22}, **G12** = β G_{12}, **P12** = β ν_{12} and **P21** = β ν_{21}

  If **flag**(3) is nonzero, set **G12** = β G_{12}

  If **flag**(4) is nonzero, set **G13** = β G_{13}

  If **flag**(5) is nonzero, set **G23** = β G_{23}

  For solid elements, the material degradation rules are:

  Fiber failure (tension or compression) (**flag**(1) $\neq 0$):

  set $C'_{11} = \beta C_{11}$, $C'_{12} = \beta C_{12}$ and $C'_{13} = \beta C_{13}$

  Matrix failure (tension or compression) (**flag**(2) $\neq 0$):

  set $C'_{22} = \beta C_{22}$, $C'_{21} = \beta C_{21}$ and $C'_{23} = \beta C_{23}$

  Interlaminar normal failure (tension or compression) (**flag**(3) $\neq 0$):

  set $C'_{33} = \beta C_{33}$, $C'_{31} = \beta C_{31}$ and $C'_{32} = \beta C_{32}$

  Interlaminar shear failure (**flag**(4) $\neq 0$): set $C'_{44} = \beta C_{44}$

  Interlaminar shear failure (**flag**(5) $\neq 0$): set $C'_{55} = \beta C_{55}$

  In-plane shear failure (**flag**(6) $\neq 0$): set $C'_{66} = \beta C_{66}$

- DGRAD5—Material degradation model for the Chang–Chang failure model [6] based on the inplane values only (**IDGRD**=5). This model also degrades the inplane shear modulus when either fiber or matrix failures are detected.

  For shell elements, the material degradation rules here are:

  If **flag**(1) is nonzero (fiber breakage), set **E11** = β E_{11}, **E22** = β E_{22}, **G12** = β G_{12}, **P12** = β ν_{12} and **P21** = β ν_{21}, where β is a user–specified value (*e.g.*, 10^{-6}) read on the ORT_EL_BR_MATERIAL input data. Chang and Chang actually use an exponentially degrading value based on the area of the damage zone. These factors are not in the current version.

  If **flag**(2) is nonzero and positive (matrix cracking), set **E22** = β E_{22}, **G12** = β G_{12}, **P12** = β ν_{12} and **P21** = β ν_{21}

  If **flag**(2) is nonzero and negative (matrix compression), set **E22** = β E_{22}, **P12** = β ν_{12} and **P21** = β ν_{21}

  If **flag**(3) is nonzero (fiber-matrix shearing), set **E11** = β E_{11}, **E22** = β E_{22}, **G12** = β G_{12}, **P12** = β ν_{12} and **P21** = β ν_{21}

If **flag**(4) is nonzero, set **G13** = β G_{13}

If **flag**(5) is nonzero, set **G23** = β G_{23}

<u>For solid elements, the material degradation rules are</u>:

Fiber failure (tension or compression) (**flag**(1) $\neq 0$):

set $C'_{11} = \beta C_{11}$, $C'_{12} = \beta C_{12}$ and $C'_{13} = \beta C_{13}$

Matrix failure (tension or compression) (**flag**(2) $\neq 0$):

set $C'_{22} = \beta C_{22}$, $C'_{21} = \beta C_{21}$ and $C'_{23} = \beta C_{23}$

Interlaminar normal failure (tension or compression) (**flag**(3) $\neq 0$):

set $C'_{33} = \beta C_{33}$, $C'_{31} = \beta C_{31}$ and $C'_{32} = \beta C_{32}$

Interlaminar shear failure (**flag**(4) $\neq 0$): set $C'_{44} = \beta C_{44}$

Interlaminar shear failure (**flag**(5) $\neq 0$): set $C'_{55} = \beta C_{55}$

In-plane shear failure (**flag**(6) $\neq 0$): set $C'_{66} = \beta C_{66}$

The progressive failure analysis implementation in **STAGS** provides the historical material database for postprocessing. For this material type, there are 12 data items for C^1 shell elements and 14 data items for C^0 shell elements, for each material point—the current material properties (E_{11}, E_{22}, E_{33}, G_{23}, G_{13}, G_{12}, ν_{23}, ν_{13} and ν_{12}), and the failure flags (3 or 5). These values may be plotted on an element level by layer, with **STAGS**’ **stapl** postprocessing program.

go to I-5a

I-11a PDLAM GCP Material

This record—which contains the specification of properties for a progressive damage laminated composite material model based on the crack density state variable model of Shahid and Chang and implemented as a GCP material (Material Type 7)—is read when **COMMAND** on I-5a is 'PDLAM_MATERIAL', or is an acceptable abbreviation of that character string (as discussed in the description of the I-5a record). Under these circumstances, the **INFO** vector on I-5a contains the following information:

INFO(1) = **MATID** — material identifier, in the GCP Materials Table
INFO(2) = **NGROUPS** — number of material groups (must be 1, currently)
INFO(3) = **NSTATES** — number of material states (must be 1, currently)
INFO(4) = not used, currently
INFO(5) = not used, currently
INFO(6) = not used, currently
INFO(7) = not used, currently

The following record is required for specification of the properties of the PDLAM material model for each state within each group of states (this is currently a single 36-item real-data record, and all entries must be specified). These data items are stored, in this order, in an internal array named **mpd** as the original input material data. These data can be on a single line or on multiple lines with a comma denoting continuation of the record.

E1	**E2**	**E3**	**G12**	**G13**	**G23**	**P12**	**P13**	**P23**
RHO	**A1**	**A2**	**A3**	**B1**	**B2**	**B3**	**T**	**M**
XC	**XT**	**YC**	**SXZ**	**SYZ**	**ALPHA**	**CURET**	**G1C**	**G2C**
VISF0	**VISF1**	**VISFF**	**DPHI0**	**DELTA**	**DFMIN**	**BETA**	**ETA**	**BETAC**

E1, E2, E3 elastic moduli for each material direction ($E_{11,}$ E_{22} and E_{33})

G12, G13, G23 elastic shear moduli (G_{12}, G_{13} and G_{23})

P12, P13, P23 major Poisson's ratios (ν_{12}, ν_{13} and ν_{23})

RHO mass density, ρ

A1, A2, A3 coefficients of thermal expansion

B1, B2, B3 coefficients of hygroscopic expansion

T reference temperature for thermal calculations

M reference moisture content for hygroscopic calculations

XC compression strength allowable values in the 1–direction (X_c)

XT tensile strength allowable value in the 1–direction (X_t)

YC compression strength allowable value in the 2–direction (Y_c)

SYZ transverse shear strength allowable value in the 23–direction (S_{yz})

SXZ transverse shear strength allowable value in the 13–direction (S_{xz})

ALPHA nonlinear shear stress–strain coefficient, $\alpha=\alpha_0(G_{12})^3$ where α_0 is the usual coefficient having values in the range of 10^{-14}

CURET laminate cure temperature

G1C mode I fracture toughness, G_{Ic}

G2C mode II fracture toughness, G_{IIc}

VISF0 global artificial damping factor independent of damage

VISF1 global artificial damping coefficient, combined with longitudinal modulus

VISFF artificial damping coefficient after first fiber failure, combined with longitudinal modulus

DPHI0 crack density increment, $\Delta\phi$

DELTA fiber interaction zone, δ

DFMIN lower limit of degradation factor

BETA fiber failure degradation rate, β

ETA fiber/matrix shear-out failure degradation rate, η

BETAC compression failure degradation rate, β_c

The complete **C** matrix, which relates strains to stresses, is given in Section I-7a. Tension strength allowable value in the 2–direction (Y_T) and the inplane shear strength allowable value (S) are dependent on the crack density state variable ϕ. These values as well as degraded reduced stiffness coefficients are computed *a priori* using a stand–alone unit–cell plane–strain analysis of the laminate.

Failure detection is based on the Shahid–Chang criteria [7]. These criteria identify the mode of failure and utilize user–specified stress/strength allowable values.

- Fiber breakage mode: $\left(\frac{\sigma_{11}}{X_T}\right)^2 \geq 1$ when $\sigma_{11} > 0$
- Fiber compression/shear mode: $\left(\frac{\sigma_{11}}{X_C}\right)^2 + \left(\frac{\sigma_{12}}{S(\phi)}\right)^2 \geq 1$ when $\sigma_{11} < 0$
- Fiber–matrix shear-out mode: $\left(\frac{\sigma_{11}}{X_T}\right)^2 + \left(\frac{\sigma_{12}}{S(\phi)}\right)^2 \geq 1$ when $\sigma_{11} > 0$

  $\left(\frac{\sigma_{11}}{X_C}\right)^2 + \left(\frac{\sigma_{12}}{S(\phi)}\right)^2 \geq 1$ when $\sigma_{11} < 0$
- Matrix cracking mode: $\left(\frac{\sigma_{22}}{Y_T(\phi)}\right)^2 + \left(\frac{\sigma_{12}}{S(\phi)}\right)^2 \geq 1$ when $\sigma_{22} > 0$
- Matrix compression mode: $\left(\frac{\sigma_{22}}{Y_C}\right)^2 + \left(\frac{\sigma_{12}}{S(\phi)}\right)^2 \geq 1$ when $\sigma_{22} < 0$

Material degradation follows the formulation presented by Shahid and Chang using crack density ϕ as a state variable. Prior to performing a nonlinear progressive failure analysis, the **STAGS** user firsts performs a plane–strain, unit–cell analysis of the laminate using the internal versions of subroutines **PDCOMP** and **RDSE**. This analysis yields the reduced material stiffness coefficients as a function of crack density for each layer in the laminate. Once failure is detected using the failure criteria listed previously, the degraded material stiffness coefficients for the corresponding crack density are used in the subsequent analysis step.

The present implementation of the `PDLAM` material formulation in **STAGS** assumes that a maximum of ten `PDLAM` material types can be present in a given model and that each shell fabrication using this material type uses a single `PDLAM` definition for all layers in that laminate. The current implementation of `PDLAM` is limited to symmetric laminates.

go to I-5a

I-12a ABAQUS UMAT GCP Material

This record—which contains the specification of properties for a user-defined material model developed for **ABAQUS** and implemented as a GCP material (Material Type 8)—is read when **COMMAND** on I-5a is 'ABAQUS_UMAT_MATERIAL', or is an acceptable abbreviation of that character string (as discussed in the description of the I-5a record). Under these circumstances, the **INFO** vector on I-5a contains the following information:

INFO(1) = **MATID** — material identifier, in the GCP Materials Table
INFO(2) = **NGROUPS** — number of material groups (must be 1, currently)
INFO(3) = **NSTATES** — number of material states (must be 1, currently)
INFO(4) = not used, currently
INFO(5) = not used, currently
INFO(6) = not used, currently
INFO(7) = not used, currently

The following record is required for specification of the properties of the **HKS/ABAQUS** `UMAT` material model for each state within each group of states (this is currently a single 40-item real-data record, and all entries must be specified). These data items are stored, in this order, in an internal real array named **mpd** as the original input material data. These data can be on a single line or on multiple lines with a comma denoting continuation of the record.

PROPS(1) PROPS(2) ... PROPS(40)

PROPS(i) material property data items (i=1, 2, ..., 40)

See the **Note**, immediately after the following navigation instruction:

go to I-5a

Note: The main purpose of a user-defined material model is to return a trial stress state and trial values for the constitutive coefficients for the given strain state. Input values to an **HKS/ABAQUS** `UMAT` subroutine[8] include the strain state from the previous solution step (**STRAN**) and the increment in strain from that point to the current iteration cycle (**DSTRAN**). Then `UMAT` essentially returns the current strain state (**STRAN** on exit), trial stress state (**STRESS**) and trial constitutive coefficients (**DDSDDE**), and updated state variables set by the user (**STATEV**). These trial values are computed based on the strain state from the previous solution step, the increment in strain from that point to the present iteration cycle of the current solution step, and the trial constitutive coefficients corresponding to the present iteration cycle of the current solution step.

The calling sequence for `UMAT` based on the **HKS/ABAQUS** documentation is:

```
      SUBROUTINE UMAT ( STRESS, STATEV, DDSDDE, SSE,    SPD,    SCD,
     1                  RPL,    DDSDDT, DRPLDE, DRPLDT, STRAN,  DSTRAN,
     2                  TIME,   DTIME,  TEMP,   DTEMP,  PREDEF, DPRED,
     3                  CMNAME, NDI,    NSHR,   NTENS,  NSTATV, PROPS,
     4                  NPROPS, COORDS, DROT,   PNEWDT, CELENT, DFGRDO,
     5                  DFGRD1, NOEL,   NPT,    LAYER,  KSPT,   KSTEP,
     6                  KINC )
```

The functional status of the `UMAT` calling arguments for **STAGS** is given in Table 5.3 (at the end of this note). Not all of the **HKS/ABAQUS** `UMAT` arguments are active at this point. However, allocation of space and definition of variable type needs to be provided. The arguments in the `UMAT` calling sequence are defined as follows:

- **STRESS** – stress vector at the beginning of the solution step on entry and updated to the trial stress vector at the present iteration of the current step; dimensioned **NTENS**
- **STATEV** – array of state variables saved from the previous solution step at each material point and updated on exit to the trial values at the present iteration for the current solution step; defined by the `UMAT` developer; can be graphically displayed as a contour plot by **stapl**; dimensioned **NSTATV**
- **DDSDDE** – matrix of secant constitutive coefficients; dimensioned **NTENS** × **NTENS**
- **SSE** – strain energy density at a material point
- **SPD** – specific plastic dissipation at a material point
- **SCD** – specific creep or viscous dissipation at a material point
- **RPL** – volumetric heat generation per unit time
- **DDSDDT** – variation of the stress increments with respect to temperature; dimensioned **NTENS**
- **DRPLDE** – variation of **RPL** with respect to strain increment; dimensioned **NTENS**
- **DRPLDT** – variation of **RPL** with respect to temperature increment; dimensioned **NTENS**
- **STRAN** – total strain from the previous solution step on entry; total strain for present iteration of the current step on exit; dimensioned **NTENS**
- **DSTRAN** – strain increment from previous solution step to present iteration of the current solution step; dimensioned **NTENS**
- **TIME** – array with two entries; **TIME**(1) is the value of time at beginning of the current increment; **TIME**(2) is the value of total time at the beginning of the current increment
- **DTIME** – time increment or step size in a static analysis

- **TEMP** – temperature at the beginning of the increment
- **DTEMP** – increment of temperature
- **PREDEF** – array of interpolated values of predefined field variables at this material point at the start of this increment
- **DPRED** – array of increments of predefined field variables
- **CMNAME** – name of material within this UMAT subroutine
- **NDI** – number of direct stress terms: **NDI**=2 for shell elements
- **NSHR** – number of shear stress terms: **NSHR**=1 for C^1 shell elements; **NSHR**=3 for C^0 shell elements
- **NTENS** – size of the stress or strain component array; dimensioned **NDI**+**NSHR**
- **NSTATV** – number of state variable to be archived at each material point; maximum of twenty variables (see the *csumat.h* header file)
- **PROPS** – material properties and parameters for this material model; defined and ordered by the UMAT developer; dimensioned **NPROPS**
- **NPROPS** – number of properties and values defined for this material model; maximum of forty variables
- **COORDS** – array containing the coordinates of this material point; dimensioned 3
- **DROT** – rotation increment matrix; dimensioned 3 × 3
- **PNEWDT** – ratio of suggested new time increment to the time increment being used
- **CELENT** – characteristic element length
- **DFGRD0** – array containing the deformation gradient at the beginning of the increment; dimensioned 3 × 3
- **DFGRD1** – array containing the deformation gradient at the end of the increment; dimensioned 3 × 3
- **NOEL** – element number for this material point
- **NPT** – surface integration point number within the **NOEL** element
- **LAYER** – layer number within the total laminate for this material point
- **KSPT** – section point within the current layer in the laminate; continuous numbering of the layer integration points throughout the laminate from bottom layer to top layer
- **KSTEP** – **ABAQUS** analysis step number; typically constant and equal to unity
- **KINC** – **ABAQUS** solution increment number in the analysis; **STAGS** step number

STAGS uses the variable **KSTEP** as a controlling flag to compute the initial constitutive coefficients (**KSTEP**=1), to perform a complete pass through UMAT (**KSTEP**=1), or to compute the current stress state in a post-processing step (**KSTEP**=2). This use is somewhat different than how **HKS/ABAQUS** uses the variable **KSTEP**. **STAGS** uses the variable **KINC** as the solution step number similar to the “time” increment number of **HKS/ABAQUS** (*i.e.,* pseudo-time step). The linear solution always corresponds to a value of zero for **KINC**, and special provisions are included so that only linear elastic constitutive coefficients and stresses are computed.

Table 5.3 Implementation Status of **ABAQUS** `UMAT` Variables in **STAGS**

Arguments to be Defined Within `UMAT`			
`UMAT` **Argument Name**	**Active Now?**	**Not Available**	**Available in Future**
STRESS (**NTENS**)	✔		
STATEV (**NSTATV**)	✔		
DSSDDE (**NTENS**,**NTENS**)	✔		
SSE	✔	✔	
SPD		✔	
SCD		✔	
RPL		✔	
DDSDDT (**NTENS**)		✔	
DRPLDE (**NTENS**)		✔	
DRPLDT		✔	
Arguments Passed to `UMAT` **as Information**			
`UMAT` **Argument Name**	**Active Now?**	**Not Available**	**Available in Future**
STRAN (**NTENS**)	✔		
DSTRAN (**NTENS**)	✔		
TIME (1)	✔		
TIME (2)		✔	
DTIME	✔		
TEMP			✔
DTEMP			✔
PREDEF (1)		✔	
DPRED (1)		✔	
CMNAME			✔
NDI	✔		
NSHR	✔		
NTENS (=**NDI**+**NSHR**)	✔		
NSTATV	✔		
PROPS (**NPROPS**)	✔		
NPROPS	✔		
COORDS (3)			✔
DROT (3,3)			✔
CELENT		✔	
DFGRD0 (3,3)		✔	
DFGRD1 (3,3)		✔	
NOEL	✔		
NPT	✔		
LAYER	✔		
KSPT	✔		
KSTEP	✔		
KINC	✔		
Arguments that can be Updated within `UMAT`			
`UMAT` **Argument Name**	**Active Now?**	**Not Available**	**Available in Future**
PNEWDT		✔	

I-13a SHM-Membrane GCP Material

This record—which contains the specification of properties for the Stein-Hedgepeth-Miller membrane wrinkling model, implemented as a GCP material (Material Type 9)—is read when **COMMAND** on I-5a is 'SHM_MEMBRANE_MATERIAL', or is an acceptable abbreviation of that character string (as discussed in the I-5a record description). Under these circumstances, the **INFO** vector on I-5a contains the following information:

INFO(1) = **MATID** — material identifier, in the GCP Materials Table
INFO(2) = **NGROUPS** — number of material groups (must be 1, currently)
INFO(3) = **NSTATES** — number of material states in each group (must be 1, currently)
INFO(4) = not used, currently
INFO(5) = not used, currently
INFO(6) = not used, currently
INFO(7) = not used, currently

The following record is required for specification of the nine properties of the Stein-Hedgepeth-Miller membrane wrinkling material model for each state within each group of states (this is a single record, currently, and all entries must be specified). These data items are stored, in this order, in an internal array named **mpd** as the original input material data. These data can be on a single line or on multiple lines with a comma denoting continuation of the record.

E GNU RHO ALPHA BETA T M PENLTY IWRINK ISTATE

E	elastic modulus
GNU	Poisson's ratio, ν
RHO	mass density, ρ
ALPHA	coefficient of thermal expansion
BETA	coefficient of hygroscopic expansion
T	reference temperature
M	reference moisture content
PENLTY	penalty factor for the slack state
IWRINK	wrinkling criteria:

1 = Wong principal stress criteria
2 = Wong principal strain criteria
3 = Wong mixed or combined principal stress-strain criteria
4 = Adler principal stress criteria
5 = Adler principal strain criteria
6 = Adler mixed or combined principal stress-strain criteria

ISTATE initial membrane state for each iteration:

0 = initially always taut
1 = defined from previous converged solution

The complete **C** matrix, which relates strains to stresses, is given in Section I-7a. This matrix is changed during the computations, depending on the membrane state (taut, slack or wrinkled).

A sample input record for this material model is shown next:

```
SHM_MEMB 1 1 1          $ I-5a   GCP command record
3530.0    ,             $ I-13a  Young's modulus, N/mm^2
0.30      ,             $  "     Poisson's ratio
1.50E-6   ,             $  "     mass density, kg/mm^3
4*0.0     ,             $  "     ALPHA, BETA,T & M
1.00E-6   ,             $  "     penalty factor for slack state
3         ,             $  "     Wong's mixed criteria
1                       $  "     initial state from previous step
```

See the **Note**, immediately after the following navigation instruction:

go to I-5a

Note: The basic concept behind the Stein-Hedgepeth-Miller model [9,10] is to examine points within the thin membrane structure and determine the current stress state. Since the structure is ultra-thin, bending is often neglected and the stress state is assumed constant through the thickness at a given planar coordinate. Denoting the planar deformation field as the *xy*-plane and given the state of strain (ε_{xx},ε_{yy},γ_{xy}) at a material point in that plane, the principal strains (ε_1,ε_2) are determined from:

$$\varepsilon_1 \ , \ \varepsilon_2 \ = \ \frac{\varepsilon_{xx} + \varepsilon_{yy}}{2} \pm \sqrt{\left(\frac{\varepsilon_{xx} - \varepsilon_{yy}}{2}\right)^2 + \left(\frac{\gamma_{xy}}{2}\right)^2} \qquad (5.1)$$

where the subscript 1 denotes major principal value and subscript 2 denotes the minor principal value. The orientation of the principal axes relative to *x*-axis is obtained from:

$$\tan \ 2\alpha \ = \ \frac{\gamma_{xy}}{\varepsilon_{xx} - \varepsilon_{yy}} \qquad (5.2)$$

The stress state at that material point can be determined using the strain state and the generalized Hooke's law for an isotropic linear elastic material:

$$\begin{Bmatrix} \sigma_{xx} \\ \sigma_{yy} \\ \sigma_{xy} \end{Bmatrix} = \begin{bmatrix} Q_{11} & Q_{12} & Q_{16} \\ Q_{12} & Q_{22} & Q_{26} \\ Q_{16} & Q_{26} & Q_{66} \end{bmatrix} \begin{Bmatrix} \varepsilon_{xx} \\ \varepsilon_{yy} \\ \gamma_{xy} \end{Bmatrix} \tag{5.3}$$

where

$$\begin{aligned} Q_{11} &= Q_{22} = \frac{E}{1-\nu^2} \\ Q_{12} &= \frac{\nu E}{1-\nu^2} \\ Q_{66} &= G = \frac{E}{2(1+\nu)} \\ Q_{16} &= Q_{26} = 0 \end{aligned} \tag{5.4}$$

and E is the elastic or Young's modulus and ν is Poisson's ratio. Given this plane stress state, the principal stresses can be calculated according to:

$$\sigma_1\ ,\ \sigma_2 = \frac{\sigma_{xx}+\sigma_{yy}}{2} \pm \sqrt{\left(\frac{\sigma_{xx}-\sigma_{yy}}{2}\right)^2 + (\sigma_{xy})^2} \tag{5.5}$$

where the subscript 1 denotes major principal value and subscript 2 denotes the minor principal value. The orientation of the principal axes relative to x-axis is obtained from:

$$\tan\ 2\beta = \frac{2\sigma_{xy}}{\sigma_{xx}-\sigma_{yy}} \tag{5.6}$$

The Stein-Hedgepeth-Miller model then examines these principal stress values and modifies the local constitutive relations for the membrane. Wong [11] and Adler [12] consider three criteria to define the membrane state: stress criteria; strain criteria; and a combined or mixed stress-strain criteria. While similar in concept, the actual criteria are slightly different and six different ones are implemented. The first three follow Wong [11] and the next three follow Adler [12]. These criteria are:

- Wong [11] stress criteria based on principal stresses (**IWRINK**=1)

  Taut state: $\sigma_2 > 0$

  Slack state: $\sigma_1 \le 0$ and $\sigma_2 \le 0$

  Wrinkled state: $\sigma_1 > 0$ and $\sigma_2 \le 0$

- Wong [11] strain criteria based on principal strains (**IWRINK**=2)

  Taut state: $\varepsilon_2 > 0$

  Slack state: $\varepsilon_1 \le 0$ and $\varepsilon_2 \le 0$

  Wrinkled state: $\varepsilon_1 > 0$ and $\varepsilon_2 \le 0$

- Wong [11] mixed stress-strain criteria based on both principal stresses and principal strains (**IWRINK**=3)

  Taut state: $\sigma_2 > 0$

  Slack state: $\varepsilon_1 \le 0$ and $\sigma_1 \le 0$

  Wrinkled state: $\varepsilon_1 > 0$ and $\sigma_2 \le 0$

- Adler [12] stress criteria based on principal stresses (**IWRINK**=4)

  Taut state: $\sigma_2 > 0$

  Slack state: $\sigma_1 \le 0$

  Wrinkled state: $\sigma_1 > 0$ and $\sigma_2 \le 0$

- Adler [12] strain criteria based on principal strains (**IWRINK**=5)

  Taut state: $\varepsilon_1 > 0$ and $\varepsilon_2 > -\nu\varepsilon_1$

  Slack state: $\varepsilon_1 \le 0$

  Wrinkled state: $\varepsilon_1 > 0$ and $\varepsilon_2 \le -\nu\varepsilon_1$

- Adler [12] mixed stress-strain criteria based on both principal stresses and principals trains (**IWRINK**=6)

  Taut state: $\sigma_2 > 0$

  Slack state: $\varepsilon_1 \le 0$

  Wrinkled state: $\varepsilon_1 > 0$ and $\sigma_2 \le 0$

Of these criteria, the mixed stress-strain criteria appear to be the more commonly accepted criteria. Once the membrane state is determined at a material point, the constitutive model for the material point is set accordingly:

$$Q_{ij} \quad = \quad \begin{cases} Q_{ij}^{slack} & slack\ \ state \\ Q_{ij}^{wrinkle} & wrinkled\ \ state \\ Q_{ij}^{taut} & taut\ \ state \end{cases} \tag{5.7}$$

For the slack behavior, the constitutive coefficients are set to a penalty factor κ (input parameter **PENLTY**) that is typically a very small number approaching zero and are given by:

$$[\ Q^{slack}\ ] \quad = \quad \kappa \begin{bmatrix} 1 & 1 & 1 \\ 1 & 1 & 1 \\ 1 & 1 & 1 \end{bmatrix} \tag{5.8}$$

For the taut behavior, the constitutive coefficients are the original plane stress values for a linear elastic, isotropic material given by:

$$[\ Q^{taut}\ ] \quad = \quad \frac{E}{1-\nu^2} \begin{bmatrix} 1 & \nu & 0 \\ \nu & 1 & 0 \\ 0 & 0 & \frac{1-\nu}{2} \end{bmatrix} \tag{5.9}$$

For the wrinkled behavior, the constitutive coefficients are changed and are given by:

$$[\ Q^{wrinkle}\ ] \quad = \quad \frac{E}{4} \begin{bmatrix} 2(1+P) & 0 & Q \\ 0 & 2(1-P) & Q \\ Q & Q & 1 \end{bmatrix} \tag{5.10}$$

where $P = \cos 2\alpha = (\varepsilon_{xx}\text{-}\varepsilon_{yy})/(\varepsilon_1\text{-}\varepsilon_2)$ and $Q = \sin 2\alpha = \gamma_{xy}/(\varepsilon_1\text{-}\varepsilon_2)$.

The wrinkling process is considered to be an elastic process where wrinkles may form and then disappear if the local stress state at a material point would permit it.

This material model can be used with membrane elements (constraint all bending degrees of freedom to zero using the Q-records) and also with plate/shell elements. Within **STAGS**, membrane behavior is modeled by constraining all out-of-plane deformation degrees of freedom (transverse displacement and two bending rotations) using the loading records (Q-records). The **E410** shell element uses the “drilling degree of freedom” to increase the order of the in-plane displacement field approximations; the **E330** and **E480** shell elements do not have this freedom and so it must also be constrained. Using this material model with plate/shell elements means that the local material stiffness terms are modified in the same way based on the wrinkling criteria and in addition, the bending stiffness terms are computed and used in the stiffness matrix evaluation.

I-14a Nonlinear Orthotropic Elastic GCP Material

This record—which continues the specification of properties for a nonlinear orthotropic elastic GCP material model based on the Hahn nonlinear in-plane shear stress-strain definition [13,14], implemented as a GCP material (Material Type 10)—is read when **COMMAND** on I-5a is 'NL_ORT_ELAST_MATERIAL', or is an acceptable abbreviation of that character string (as discussed in the I-5a record description). Under these circumstances, the **INFO** vector on I-5a contains the following information:

INFO(1) = **MATID** — material identifier, in the GCP Materials Table
INFO(2) = **NGROUPS** — number of material groups (must be 1, currently)
INFO(3) = **NSTATES** — number of material states in each group (1, currently)
INFO(4) = not used, currently
INFO(5) = not used, currently
INFO(6) = not used, currently
INFO(7) = not used, currently

The following record is required for specification of the nineteen properties of the nonlinear orthotropic elastic material model for each state within each group of states (this is a single record, currently, and all entries must be specified). These data items are stored, in this order, in an internal array named **mpd** as the original input material data. These data can be on a single line or on multiple lines with a comma denoting continuation of the record.

E1 E2 E3 G12 G13 G23 P12 P13 P23 RHO A1 A2 A3 B1 B2 B3 T M S6666

E1, E2, E3	elastic moduli (E_1, E_2 and E_3)
G12, G13, G23	shear moduli (G_{12}, G_{13} and G_{23})
P12, P13, P23	Poisson's ratios (ν_{12}, ν_{13} and ν_{23})
RHO	mass density, ρ
A1, A2, A3	coefficients of thermal expansion
B1, B2, B3	coefficients of hygroscopic expansion
T	reference temperature
M	reference moisture content
S6666	nonlinear parameter for in-plane shear stress-strain relations

The complete linear elastic ***C*** matrix, which relates strains to stresses, is given in Section I-7a.

A sample input record for this material model is shown next:

```
NL_ORT_EL 1 1 1                 $ I-5a   GCP command record
19.00E+6 1.89E+6 1.89E+6 ,      $ I-14a  elastic moduli [psi]
 0.93E+6 0.93E+6 0.93E+6 ,      $  "     shear moduli   [psi]
 0.38    0.38    0.38    ,      $  "     Poisson's ratios
 2.59E-5                 ,      $  "     mass density [slugs]
 3*0.0   3*0.0   2*0.0   ,      $  "     CTEs, CMEs, T & M
 1.00E-6                        $  "     nonlinear shear parameter
```

See the **Note**, immediately after the following navigation instruction:

go to I-5a

Note: The basic concept behind the Hahn-Tsai [14] and Hahn [13] mode is to formulate a complementary strain energy density function and determine the strain-stress relations. From Hahn and Tsai [14], a unique solution for the in-plane shear strain-stress relations is derived to have the form of a cubic equation given by:

$$e_6 = 2\varepsilon_{12} = S_{66}\sigma_{12} + S_{6666}\sigma_{12}^3 = \frac{1}{G_{12}}\sigma_{12} + \frac{\alpha}{G_{12}^3}\sigma_{12}^3 \tag{5.11}$$

A unique solution to the cubic equation exists if:

$$\frac{de_6}{d\sigma_{12}} = S_{66} + 3S_{6666}\sigma_{12}^2 \neq 0 \tag{5.12}$$

For real material systems, the coefficient S_{66} is a positive real number; hence a unique solution requires that S_{6666} be a real positive number greater than zero for all values of the shear stress. Hahn and Tsai [14] then conclude that there is only one real root of the nonlinear shear strain-stress equation, and the solution is denoted by:

$$\sigma_{12} = \left[\frac{1}{S_{66}} + f(e_6) \right] e_6 \tag{5.13}$$

where $f(e_6)$ is the real root of the cubic equation given by:

(5.14)

$$y^3 + \frac{3}{S_{66}}y^2 + \left(\frac{3}{S_{66}^2} + \frac{S_{66}}{S_{6666}}\frac{1}{e_6^2}\right)y + \frac{1}{S_{66}^3} = 0 \tag{5.15}$$

A general cubic equation of the form

$$y^3 + py^2 + qy + r = 0 \tag{5.16}$$

can be reduced to

$$x^3 + ax + b = 0 \tag{5.17}$$

by substituting $y = x - \frac{P}{3}$ and noting the following definitions for the constants *a* and *b:*

$$a = \frac{1}{3}(3q - p^2) \quad and \quad b = \frac{1}{27}(2p^3 - 9pq + 27r) \tag{5.18}$$

There will be one real root and two conjugate imaginary roots if

$$c = \frac{b^2}{4} + \frac{a^3}{27} > 0 \tag{5.19}$$

The solution for *x* (and therefore *y*) is then obtained in terms of *A* and *B*:

$$x = A + B \ , \ -\frac{A+B}{2} + \frac{A-B}{2}\sqrt{-3} \ , \ -\frac{A+B}{2} - \frac{A-B}{2}\sqrt{-3} \tag{5.20}$$

where

$$A = \sqrt[3]{-\frac{b}{2} + \sqrt{c}} \quad and \quad B = \sqrt[3]{-\frac{b}{2} - \sqrt{c}} \tag{5.21}$$

The solution to this cubic equation is calculated in subroutine CROOT (see croot.F in the GCP subdirectory). The coefficients (*p*, *q* and *r*) are calling arguments and the real root is returned from the subroutine.

Within the GCP of **STAGS**, the material model is entered with a given strain state and returns trial stress values and, for nonlinear materials, trial constitutive coefficients. Thus, given the value of the in-plane shear strain $e_6 = \gamma_{12} = 2\varepsilon_{12}$, the linear elastic shear modulus G_{12} and the nonlinear parameter S_{6666}, the in-plane shear stress can be determined by solving the cubic equation using the approach just described. The S_{6666} term has units of the reciprocal of stress to the third power. That is,

$$S_{6666} = \frac{\alpha}{G_{12}^3} \tag{5.22}$$

and has a value on the order of 1 x 10^{-15} $(\mathrm{psi})^{-3}$ or 10 $(\mathrm{GPa})^{-3}$ or 1 x 10^{-8} $(\mathrm{Mpa})^{-3}$ and hence the order of α is in the 1000's. This term is an experimentally determined quantity from off-axis tension tests [14].

I-21a GCP Shell Fabrication Record

This record—which continues the specification of a shell fabrication in the GCP—is read when **COMMAND** on I-5a is 'SHELL_FABRICATION', or is an acceptable abbreviation of that character string (as discussed in the I-5a record description). Under these circumstances, the **INFO** vector on I-5a contains the following information:

INFO(1) = **FABID** — shell fabrication identifier, in the GCP Fabrications Table:
> 0— use material and fabrication properties specified here for all elements referencing this **FABID**
< 0— call user-written subroutine USRFAB to determine if an element referencing this fabrication uses material and fabrication properties specified here or properties that are specified in USRFAB (see Chapter 12)

INFO(2) = **NLAYER**— total number of material layers in the fabrication;
$1 \leq \mathbf{NLAYER} \leq 100$

INFO(3) = **IPTS** — through-layer-integration-points flag:
0 — integrate at 2 points (bottom & top) for each layer
1 — specify number of through–layer points for each layer

INFO(4) = **ISHR** — shear–factor-specification flag:
0 — do not specify shear-correction factors
1 — specify shear-correction factors

INFO(5) = **ISYM** — layer–symmetry flag:
0 — general layup; specify data for all of the layers of the layup (*i.e.*, set **NX** = 1)
1 — fabrication is symmetric through the thickness; specify data for the top layers—from layer number $\mathbf{NX} = \mathbf{NLAYER}/2 + 1$ to layer number **NLAYER** (which must be even); **STAGS** will then symmetrize the layup

INFO(6) = not used, currently

INFO(7) = not used, currently

Note:

For C^0 shell elements, the stress and strain components have the following orders:

$$\sigma_1, \quad \sigma_2, \quad \tau_{12}, \quad \tau_{13}, \quad \tau_{23}$$
$$\varepsilon_1, \quad \varepsilon_2, \quad \gamma_{12}, \quad \gamma_{13}, \quad \gamma_{23}$$

For C^1 shell elements, the stress and strain components have the following orders:

$$\sigma_1, \quad \sigma_2, \quad \tau_{12}$$
$$\varepsilon_1, \quad \varepsilon_2, \quad \gamma_{12}$$

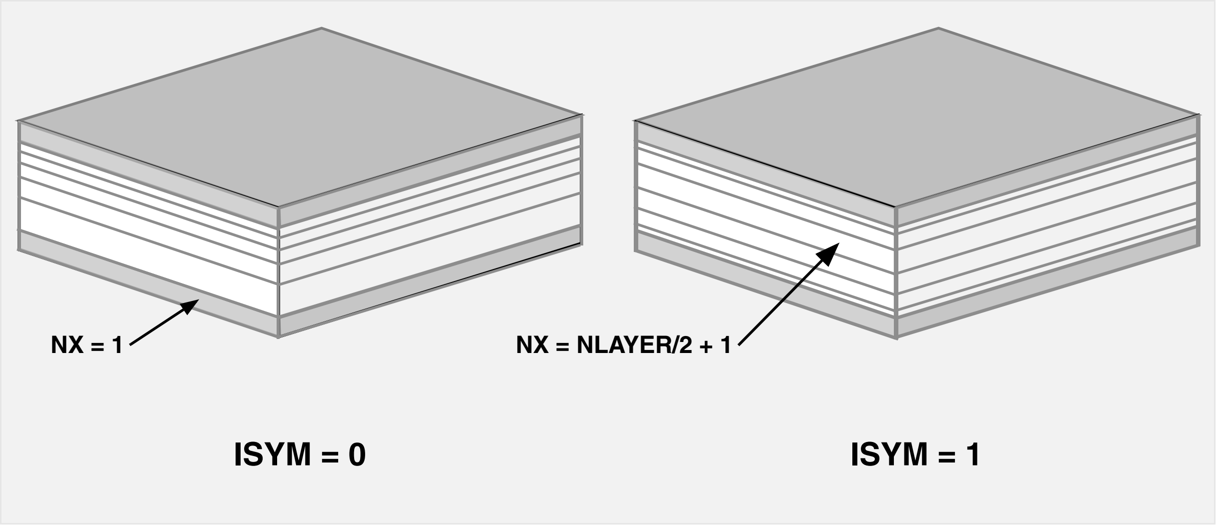


Figure 5.3 GCP Shell Fabrication

MATID(j) j = NX, NLAYER

MATID(j) material identifier (in the GCP Materials Table) for the jth layer, where **NX** = 1 (when **ISYM** = 0) or **NX** = **NLAYER**/2 + 1 (when **ISYM** = 1)

✦ **INFO**(3) ≡ **IPTS** (I-5a) through-layer-integration-points flag

if (**IPTS** > 0) *go to* I-21b
else *go to* I-21c

I-21b GCP Shell Integration Points Record

This record—which continues the specification of a shell fabrication in the GCP—should be included if and only if **IPTS** $= 1$ on I-21a: it specifies the number of through-layer integration points to be used for each layer for which data are being specified.

INTSHL(j)   j = NX, NLAYER

INTSHL(j) number of integration points to be used for the jth layer of the layup, where **NX** $= 1$ (when **ISYM**=0) or **NX** $=$ **NLAYER** $/2+1$ (when **ISYM** = 1)

Note:

It is appropriate to set

INTSHL$_j = 1$ when any bending within a layer is assumed negligible

INTSHL$_j = 0$ *or* 2 to integrate at two locations within each layer (at $\pm\frac{1}{\sqrt{3}}\ (h_k/2)$, on either side of the midsurface of that layer); this is exact when stress varies linearly over the layer; this is **STAGS**’ default value

INTSHL$_j > 2$ to integrate using Simpson’s 1/3 rule (odd values only):

$$\int_a^b f(\xi)d\xi \approx \frac{1}{3}(b-a)\ \left[f(a)+4f\left(\frac{a+b}{2}\right)+f(b)\right]$$

go to I-21c

I-21c GCP Shell Layer Thickness Record

This record—which continues the specification of a shell fabrication in the GCP—must be included: it specifies the thickness of each layer for which data are being specified.

THKSHL(j) j = NX, NLAYER

THKSHL(j) thickness of the jth layer, where **NX** $= 1$ (when **ISYM**=0) or **NX** $=$ **NLAYER**$/2+1$ (when **ISYM** = 1)

go to I-21d

I-21d GCP Shell Layer Orientation Record

This record—which continues the specification of a shell fabrication in the GCP—must be included: it specifies the fabrication orientation angle for each layer for which data are being specified.

ANGSHL(j)   j = NX, NLAYER

ANGSHL(j) fabrication orientation angle for the jth layer,
where **NX** $= 1$ (when **ISYM**=0) or **NX** $= ($**NLAYER**$+ 1)/2$ (when **ISYM**=1)

INFO$(4) \equiv$ **ISHR** (I-5a) shear-factor-specification flag

if (**ISHR** > 0) *go to* I-21e
else *go to* I-5a

I-21e Shear Factor Specification Record

This record—which concludes the specification of a shell fabrication in the GCP—must be included when **ISHR** = 1 on the I-21a record: it specifies the two shear-correction factors to be for all layers of the current fabrication.

SCF1 SCF2

SCF1 first shear-correction factor; if **ISHR** = 0, **STAGS** sets **SCF1** = 1.0

SCF2 second shear-correction factor; if **ISHR** = 0, **STAGS** sets **SCF2** = 1.0

Note 1: The nominal value for each of these parameters is 5/6, for isotropic materials.

Note 2: Under the traditional **STAGS** approach for shell wall fabrications using K records, **STAGS** internally assumes that **SCF1** = **SCF2** = 0.83333333 = 5/6 when C^0 elements are used.

go to I-5a

I-22a GCP Solid Fabrication Record

This record—which continues the specification of a solid fabrication in the GCP—is read when **COMMAND** on I-5a is ‘SOLID_FABRICATION’, or is an acceptable abbreviation of that character string (as discussed in the I-5a record description). Under these circumstances, the **INFO** vector on I-5a contains the following information:

INFO(1) = **FABID** — solid fabrication identifier, in the <u>GCP Fabrications Table:</u>
> 0 — use material and fabrication properties specified here for all solid elements referencing this **FABID**
< 0 — call user-written subroutine USRFAB to determine if an element referencing this fabrication uses material and fabrication properties specified here or properties that are specified in USRFAB (see Chapter 12)

INFO(2) = **MATID** — material identifier, in the <u>GCP Materials Table</u>, for the GCP material used in this solid fabrication

INFO(3) = **IANG** — fabrication-orientation flag:
0 — set orientation angles to zero
1 — input orientation angles [in degrees]

INFO(4) = **NIPZ** — number of through–thickness integration points (1 or 2) (default = 2); **NIPZ** is meaningful only for the core components of **E800**-series sandwich elements

INFO(5) = not used, currently

INFO(6) = not used, currently

INFO(7) = not used, currently

Note:

For solid elements, the stress and strain components have the following orders:

$$\begin{array}{llllll} \sigma_1, & \sigma_2, & \sigma_3, & \tau_{23}, & \tau_{13}, & \tau_{12} \\ \varepsilon_1, & \varepsilon_2, & \sigma_3, & \gamma_{23}, & \gamma_{13}, & \gamma_{12} \end{array}$$

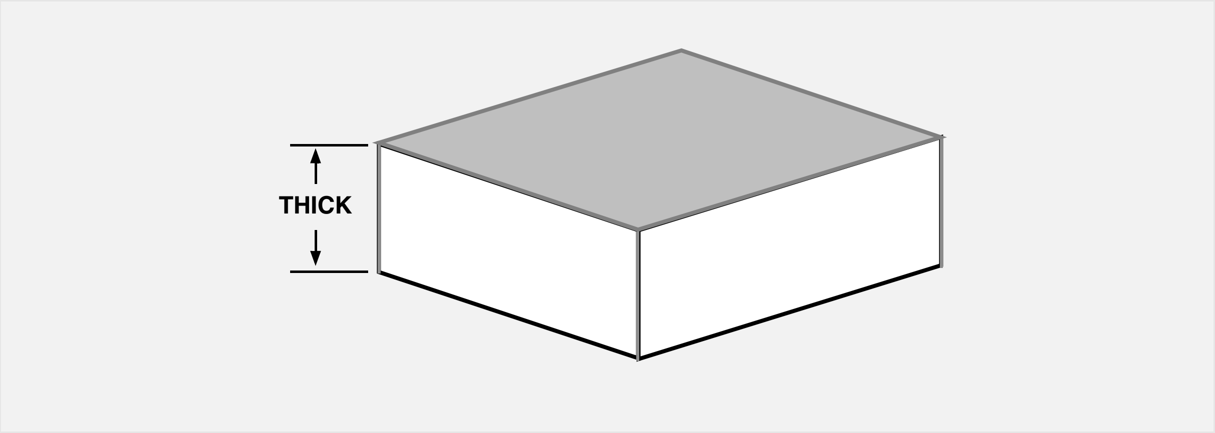


Figure 5.4 GCP Solid Fabrication

THICK

THICK element thickness

✦ **INFO**(3) ≡ **IANG** (I-5a) fabrication-orientation flag

if (**IANG** > 0) *go to* I-22b
else *go to* I-5a

I-22b GCP Solid Fabrication Orientation Record

This record—which concludes the specification of a solid fabrication in the GCP—must be included if **INFO**(3) ≡ **IANG** = 1 on the I-5a record: it specifies the orientation angle to be used for the current solid fabrication.

ANGLE

ANGLE orientation angle, in degrees (in the x-y plane; rotations are measured about the z-axis in a right-hand-rule sense)

✦ *go to* I-5a

J-1 Cross-Section

The records J-1–J-3 are included only if there are beam elements or stiffeners to be defined, **NTAB** > 0 (B-3). The record sequence is repeated **NTAB** times. These records define cross-section properties, including, *via* reference to the Material Table (I records), material properties. These data can be referenced in subsequent definitions of beam elements and stiffeners.

In the case of elastic deformation, the strain energy in a beam (stiffener) can be expressed in terms of a few parameters such as cross-sectional area and moments of inertia. Whenever a beam (stiffener) is defined by use of such data, we refer to its cross-section as being of the general type.

If plastic deformation is included or if thermal expansion varies nonlinearly within the cross-section, the total strain is still linear but the stresses are not. In that case the elastic strain energy in the beam (stiffener) depends on the actual shape of the cross-section. For such applications cross-sections of subelement type are defined. The cross-section is decomposed into a number of subelements, each sufficiently small so that thermal expansion and plastic strain may (as a good approximation) be considered constant within the subelement. Generally, then the moments of inertia of the subelements about their own axes are negligible. If more than **NSUB** subelements must be included, two or more beams (stiffeners) may be co-located (with the same effect as the inclusion of one cross-section with a larger number of subelements). Plasticity and thermal effects can be included in stiffeners of the subelement type only (**KCROSS** $= 2$ or 3).

The subelement type of cross-section is useful even in elastic analysis without thermal effects. A T-stiffener, for example, can be defined as a subelement type cross-section with two rectangular subelements.

A beam (stiffener) cross-section is defined in $(\bar{y}, \bar{z})$ cross-section coordinates (see Section 4.1). When a beam (stiffener) element is defined, the user can specify an angle between the z' (element unit) or Z' (shell unit) axis and the cross-section $\bar{z}$ axis. An eccentricity, the (y', z') (element unit) or (Y', Z') (shell unit) coordinates at the origin of the $(\bar{y}, \bar{z})$ system, can also be specified (see Figure 6.5 on page 6-52 and Figure 8.1 on page 8-12).

An elastic Timoshenko beam capability can be used with the 200-series beams in **STAGS**. These beams include those automatically introduced when rings and stringers are called for on shell units discretized using the 300- and 400-series shell elements (see the description of the N-1 record in Chapter 6, and Sections 14.4 and 14.5 in Chapter 14). The following considerations should be kept in mind when using the Timoshenko option:

- Bending stresses and curvatures are computed correctly only at the midspan of the beam element. Bending stress resultants and moments, however, are valid at all element integration points.
- Plasticity cannot be used with the Timoshenko option, since the contribution of the shear stress cannot be correctly accounted for.
- Timoshenko beam cross-sectional properties must be defined with respect to the principal axes of the section, *i.e.*, the product of inertia must be zero in the $(\bar{y}, \bar{z})$ system, as expressed below.

$$I_{\bar{y}\bar{z}} = \int_A \bar{y}\bar{z}dA = 0$$

The sequence of J records is repeated **NTAB** times (B-3).

See Section 16.2 for more information about this.

ITAB KCROSS MATB NSUB TORJ SCY SCZ NSOYZ KAPY KAPZ

ITAB user-assigned cross-section number; $1 \le$ **ITAB** $\le$ **NTAB** (B-3)

KCROSS cross-section type. Thermal loading is permitted (*via* user-written subroutine TEMP) only for **KCROSS** $= 2$ or 3. Plasticity is permitted only for **KCROSS** $= 2$ or 3.

1 – general
2 – general subelement
3 – rectangular subelement
4 – arbitrary; elements of “stiffness matrix” defined

MATB material number, as defined by **ITAM** in the Material Table (I-1)

NSUB number of subelements (**NSUB** ≤ 10); meaningful for subelement stiffeners (**KCROSS** $= 2$ or 3) only

TORJ torsional constant, J, having units of l^4, where l is length. The torsional stiffness for a beam of length L is JG/L, where G is the shear modulus. For example, $J = (1/3)C\sum bh^3$ for open sections composed of long, narrow rectangles. Stiffeners of shapes such as “blade”, “tee”, “I” fall into this category; but “hat” stiffeners do not, since they form a closed cross-section. In the above expression for J, h is the smallest dimension for each rectangle and C is a correction factor, generally taken as 1.0 for stiffeners of normal proportions. **TORJ** is not used for **KCROSS** $= 4$.

SCY $\bar{y}$ coordinate of shear center

SCZ $\bar{z}$ coordinate of shear center

NSOYZ number of stress output points per cross-section; **NSOYZ** ≤ 4. **NSOYZ** is meaningful for **KCROSS** $= 1$ only.

KAPY dimensionless transverse-shear shape factor, $\kappa_{\bar{y}}$, accounting for flexural shear deformation in the $(\bar{x}, \bar{y})$ plane (*i.e.*, bending about the $\bar{z}$-axis). Set **KAPY** $= 0$ to omit the effects of flexural-shear deformation. This is a floating point entry.

KAPZ dimensionless transverse-shear shape factor, $\kappa_{\bar{z}}$, accounting for flexural shear deformation in the $(\bar{x}, \bar{z})$ plane (*i.e.*, bending about the $\bar{y}$-axis). Set **KAPZ** $= 0$ to omit the effects of flexural-shear deformation. This is a floating point entry.

$\kappa_{\bar{y}}$, $\kappa_{\bar{z}}$ are shape factors, accounting for variation of transverse shear stress over the beam cross section in the $(\bar{y}, \bar{z})$ directions, respectively. As an example, for parabolic variation over a rectangular cross-section, $\kappa_{\bar{x}} = \kappa_{\bar{y}} = \kappa = 5/6$.

STAGS will not report transverse shear stress values $(\tau_{\bar{y}}, \tau_{\bar{z}})$. However, stress resultants $(V_{\bar{y}}, V_{\bar{z}})$ are computed, and these are related to $\kappa_{\bar{y}}$, $\kappa_{\bar{z}}$ by the expressions

$$V_{\bar{y}} = \kappa_{\bar{y}}\, GA\, \bar{\gamma}_{\bar{y}} \qquad\qquad V_{\bar{z}} = \kappa_{\bar{z}}\, GA\, \bar{\gamma}_{\bar{z}} \tag{5.23}$$

where G is the shear modulus, A is the cross-sectional area, and $(\bar{\gamma}_{\bar{y}}, \bar{\gamma}_{\bar{z}})$ are the average transverse shear strains. If a discrete value of $(\tau_{\bar{y}}, \tau_{\bar{z}})$ is desired, the analyst may compute this by referring to the assumption of shear-stress variation which was used to derive $\kappa_{\bar{y}}$, $\kappa_{\bar{z}}$. For parabolic variation in a particular coordinate direction, the maximum stress, occurring at mid-depth, is $\tau_{max} = (3/2)\tau_{avg}$.

The cross-sectional area effective in developing transverse shear stress is sometimes assumed to be different than that effective in developing normal stress. For example, a common assumption for shapes similar to “tee”, “I”, channel, *etc*., is that the flanges do not develop shear stress. Thus, the “shear area” is taken as the area of the web (A_w), with the familiar $\kappa = 5/6$, since the web is a simple rectangle. Since **STAGS** does not permit independent shear area definition, this effect can be accounted for in the specification of κ. Thus, one might define $\kappa = (5/6) \cdot (A_w/A)$ for a “tee” cross-section. This is left to the analyst’s judgment.

CAUTION: Some references define a *form factor* (f) which is the inverse of the *shape factor* used by **STAGS** $(f = 1/\kappa)$. $\kappa_{\bar{y}}$, $\kappa_{\bar{z}}$, as used in **STAGS**, must satisfy (5.23).

```
if      (KCROSS = 1)   then   go to  J-2a
elseif  (KCROSS = 2)   then   go to  J-3a
elseif  (KCROSS = 3)   then   go to  J-3b
elseif  (KCROSS = 4)   then   go to  J-4a
```

J-2a General Cross-Section—Record 1

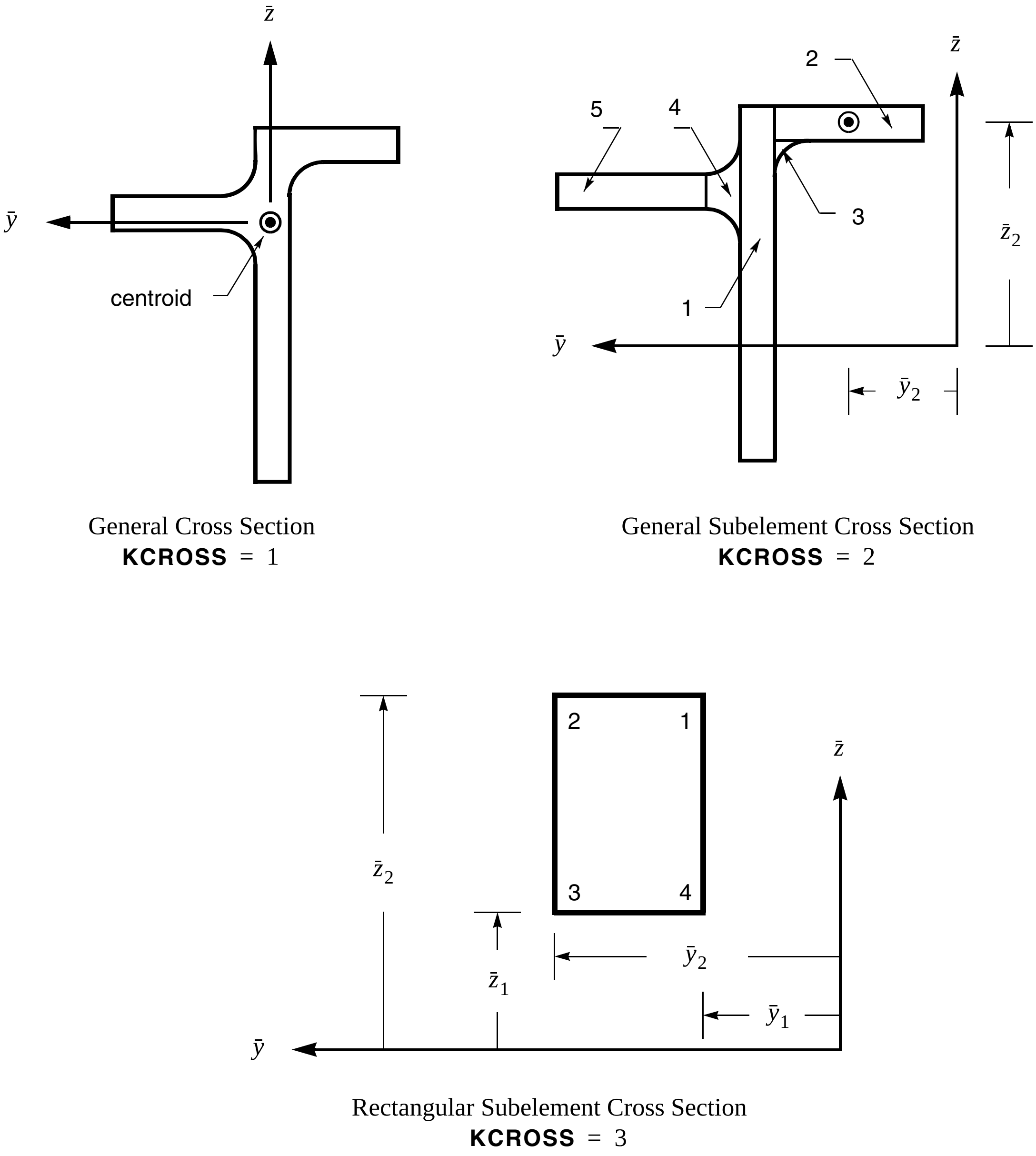
Records of type J-2a/b are included only if the cross-section is of general type, **KCROSS** = 1 (J-1). Record J-2a gives the section properties of a beam (stiffener) of general type. The origin of the $(\bar{y}, \bar{z})$ cross-section coordinate system must coincide with the cross-section centroid; $(\bar{y}, \bar{z})$ may be oriented to simplify computation of cross-sectional properties. See Figure 5.5 on page 5-122.

BA BIY BIZ BIYZ

BA	cross-sectional area
BIY	moment of inertia about $\bar{y}$-axis
BIZ	moment of inertia about $\bar{z}$-axis
BIYZ	product of inertia, $\int_A \bar{y}\bar{z}dA$

✦ **NSOYZ** (J-1) number of stress output points

if	(**NSOYZ** > 0)	then *go to* J-2b
else		*follow instructions at end of* J-2b



General Cross Section
KCROSS = 1

General Subelement Cross Section
KCROSS = 2

Rectangular Subelement Cross Section
KCROSS = 3

Figure 5.5 Beam cross sections.

$\bar{x}$, the beam *cross-section axis*, completes a right-handed $(\bar{x}, \bar{y}, \bar{z})$ cross-section coordinate system. The cross-section is *positioned* by specifying **ECY** and **ECZ**, and it is *oriented* by specifying **ZETA**.

See Figure 6.5 on page 6-52 and Figure 8.1 on page 8-12.

J-2b General Cross-Section—Record 2

This record is included only if stress output points are to be defined for the cross-section, **NSOYZ** > 0 (J-1). Locations for stress output are defined in $(\bar{y}, \bar{z})$ cross-section coordinates.

(SOY(i), SOZ(i) , i = 1, NSOYZ)

SOY(i) $\bar{y}$ coordinate of stress output point *i*

SOZ(i) $\bar{z}$ coordinate of stress output point *i*

NTAB (B-3) number of entries in Cross Section Table

```
if (NTAB cross sections have been defined) then
    follow instructions at end of J-4b
else return to J-1
```

J-3a General Subelement Cross-Section

This record is included only if **KCROSS** = 2 (J-1). It is substituted by a J-3b record if **KCROSS** = 3 (subelements are rectangular). One record is used for each subelement, *i.e.*, the record is repeated **NSUB** times (J-1) for each cross section of this type. For subelement cross-sections of this type, stress output is always given at the centroid. See Figure 5.5 on page 5-122.

SA(i) SY(i) SZ(i) SIY(i) SIZ(i) SIYZ(i) ISP(i)

SA(i) area of subelement

SY(i) $\bar{y}$ coordinate at centroid of subelement

SZ(i) $\bar{z}$ coordinate at centroid of subelement

SIY(i) subelement moment of inertia relative to its centroid, **SZ(i)**, about a line parallel to the $\bar{y}$ axis

SIZ(i) subelement moment of inertia relative to its centroid **SY(i)**, about a line parallel to the $\bar{z}$ axis

SIYZ(i) subelement product of inertia relative to its centroid **(SY(i), SZ(i))** for the $(\bar{y}, \bar{z})$ directions

ISP(i) print flag for stress output. Stress output must be activated on the R-1 record (output control) for each shell unit in which stress output is desired and on the V-1 record for each element unit; thus, stress results are printed only when specified on R-1/V-1 *and* on the associated J-3a.

0 – print stresses for this subelement

1 – do not print stresses for this subelement

NSUB	(J-1)	number of subelements
NTAB	(B-3)	number of entries in the Cross Section Table

```
if   (NSUB subelements have been defined)  then
     if  (NTAB cross sections have been defined)  then
              follow instructions at end of  J-4b
     else     return to  J-1
else     continue defining  J-3a
```

J-3b Rectangular Subelement Cross-Section

This record is included only if **KCROSS** = 3 (J-1). One record is used for each subelement, *i.e.*, the record is repeated **NSUB** times (J-1) for each cross section of this type. Stress output can be obtained only at subelement corners. See Figure 5.5 on page 5-122.

Y1(i) Y2(i) Z1(i) Z2(i) ISOC(i)

Y1(i) $\bar{y}_1$ for subelement *i*

Y2(i) $\bar{y}_2$ for subelement *i*

Z1(i) $\bar{z}_1$ for subelement *i*

Z2(i) $\bar{z}_2$ for subelement *i*

ISOC(i) a 4-digit binary integer governing stress output. The four digits correspond to corners 1–4 as shown in Figure 5.5, in that order; a one indicates stress output at the corresponding corner, a zero suppresses output. For example, **ISOC**(i) = 0101 specifies stress output ar corners 2 and 4 of subelement *i*.

NSUB (J-1) number of subelements
NTAB (B-3) number of entries in the Cross Section Table

```
if (NSUB subelements have been defined) then
    if (NTAB cross sections have been defined) then
        follow instructions at end of J-4b
    else  return to J-1
else  continue defining J-3b
```

J-4a Arbitrary Cross-Section—Record 1

This record is included only if **KCROSS** = 4 (J-1). The area input here is used to compute the mass per unit length of the beam from the density referenced by material number **MATB** (J-1).

BMA

BMA cross-section area

✦ *go to* J-4b

J-4b Arbitrary Cross-Section—Record 2

This record is for input of the general material stiffness matrix for a beam cross section. The matrix relates stress resultants to reference-axis strain, curvature, and unit twist by the relation

$$\begin{Bmatrix} N_x \\ M_z \\ M_y \\ T \end{Bmatrix} = \begin{bmatrix} C_{11} & C_{12} & C_{13} & C_{14} \\ C_{21} & C_{22} & C_{23} & C_{24} \\ C_{31} & C_{32} & C_{33} & C_{34} \\ C_{41} & C_{42} & C_{43} & C_{44} \end{bmatrix} \begin{Bmatrix} \varepsilon_x \\ \kappa_z \\ \kappa_y \\ \alpha \end{Bmatrix}$$

κ_z, M_z are associated with bending about the z axis, and κ_y, M_y are associated with bending about the y axis. Stress resultants are related to axial and torsional-shear stresses by the relations

$$N_x = \int_A \sigma_{xx}(y, z)\ dydz \qquad M_z = \int_A y\sigma_{xx}(y, z)\ dydz \qquad M_y = \int_A z\sigma_{xx}(y, z)\ dydz$$

$$T = \int_A [y\tau_{xz}(y, z) - z\tau_{xy}(y, z)]\ dydz$$

Reference-axis strain, curvature, and unit twist are defined by the relations

$$\varepsilon_x = u,_x \qquad \kappa_z = -v,_{xx} \qquad \kappa_y = -w,_{xx} \qquad \alpha = (R_x^2 - R_x^1)/l$$

where l is the length of the beam, R_x^1 and R_x^2 are the axial rotations at nodes 1 and 2, and the unit twist (α) has units of $radians/length$. In all of the above equations, (x, y, z) represents the $(\bar{x}, \bar{y}, \bar{z})$ cross-section coordinate system, and (u, v, w) are displacements in the $(\bar{x}, \bar{y}, \bar{z})$ directions (see Figure 6.5 on page 6-52 and Figure 8.1 on page 8-12).

Note that the full matrix is input, even though it must be symmetric.

(CCC(i,j), j=1,4), i=1,4

CCC(i,j) element C_{ij} in the cross-section stiffness matrix

NOTE: 16 entries on one record, input in row-major order.

NTAB	(B-3)	number of entries in the Cross Section Table
NTAW	(B-3)	number of entries in the Wall Fabrication Table
NTAP	(B-3)	User Parameters flag
NUNITS	(B-2)	number of shell units

```
if  (NTAB cross sections have been defined)  then
    if      (NTAW > 0)      then   go to  K-1
    elseif  (NTAP > 0)      then   go to  L-1
    elseif  (NUNITS > 0)    then   go to  M-1
    else                           follow instructions at end of  R-3
else    return to J-1
```

K-1 Shell Wall Properties

The records K-1–K-6 define various shell wall configurations. They are included only if **NTAW** > 0 (B-3).

Data in the Wall Fabrication Table are defined either by input on regular data records or by a user-written subroutine WALL. A user-written subroutine must be used if

- The shell wall construction is not included among the standard types defined below.
- Properties or dimensions vary with the surface coordinates.
- Material properties vary continuously (not stepwise at interface between layers) through the shell wall thickness.

Shell wall properties are defined in $(\bar{x}, \bar{y})$ fabrication coordinates (see Section 4.1).* These coordinates are chosen so that definition of material properties is as easy as possible. They need not coincide with shell or element coordinates.

The shell wall constructions that can be defined by use of data records are:

1) Shells consisting of a number of orthotropic layers.

2) Shells consisting of fiberwound layers.

3) Shells reinforced by a corrugated skin.

4) Properties defined by use of the elements of the shell wall stiffness matrix.

5) Any of the above with smeared stiffeners. These stiffeners need not be along coordinate lines, but the angle between the coordinate directions and the stiffener attachment line may not vary along the stiffener.

A shell with a homogenous isotropic or orthotropic wall is defined by use of option (1).

Fiberwound layered shells may be defined by use of option (2). The shell wall stiffness parameters are then computed from the basic properties of the constituent materials. However, no method by which such parameters are computed has been generally accepted. If the stiffness parameters for the individual layers are known (from test, for example), better results may be obtained by use of option (1). The computation of the stiffness matrix from constituent material

* Note the similarity to beam cross-section coordinates, in which the $\bar{x}$ coordinate defines the beam axis, with the $(\bar{y}, \bar{z})$ coordinates lying in the cross-section. For shells, the $(\bar{x}, \bar{y})$ coordinates lie in the shell surface, with $\bar{z}$ defining the shell normal.

data should be used only if the individual layer properties required for option (1) cannot be obtained.

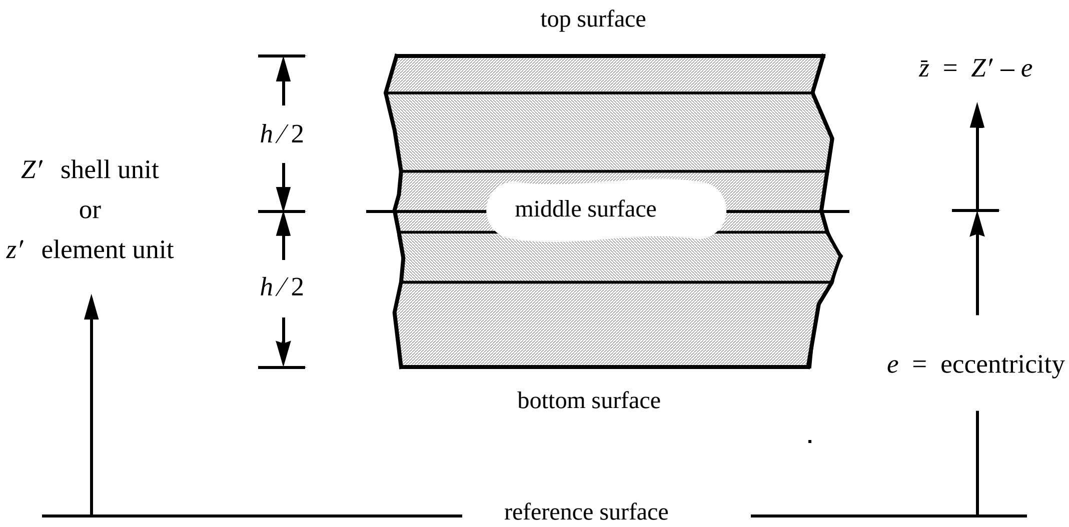


Figure 5.6 Layered wall. Notice the relationships of: reference surface, middle surface, top surface, bottom surface, shell normal (Z'), element normal (z'), fabrication normal ($\bar{z}$), and eccentricity (e).
Also, see Figure 6.2 on page 6-28.

Material properties in each layer are defined in (ϕ_1, ϕ_2) material coordinates (see Section 4.1), which are established by rotating the $(\bar{x}, \bar{y})$ fabrication coordinates through an angle ζ, a right-handed rotation about the $\bar{z}$ axis. (ϕ_1, ϕ_2) and ζ are independently defined for each layer.

For a shell wall consisting of only a corrugated skin, use option (3).

If stiffeners are defined as “smeared,” their contribution to the shell wall stiffness is “smeared out” uniformly over the shell surface. As a consequence they cannot be used if temperatures vary within the structure.

For an “isogrid” or a skin with skew stiffeners, or for any wall whose stiffness properties have been computed by other means, use option (4).

Properties of smeared stiffeners can be defined by reference to the Cross Section Table. If stiffener spacing, the cross-section properties, or the angle with respect to the coordinate lines varies with the shell coordinates, the data must be defined in a user-written subroutine WALL. Stiffener data in the Cross Section Table can be referenced in WALL.

Some of the data defined on this record refer to layered shells $(\mathbf{KWALL} = 1 \text{ or } 2)$. For walls with corrugations, **NLAY**, **NLIP** are irrelevant. The ϕ_1 direction for corrugated shells coincides with the axis of the corrugations.

The sequence of K records is repeated **NTAW** times (B-3).

See 16.1 “Shell Results” on page 16-1 for more information.

ITAW KWALL NLAY NLIP NSMRS SHEAR1 SHEAR2

ITAW user-assigned wall configuration number; $\mathbf{ITAW} \le \mathbf{NTAW}$ (B-3)

KWALL wall construction type

1 – general layered

2 – ~~fiberwound~~ — INACTIVE

3 – corrugated

4 – general; elements of “stiffness matrix” defined

NLAY number of layers through the thickness $(\mathbf{NLAY} \le 100)$;
relevant for layered walls $(\mathbf{KWALL} = 1 \text{ or } 2)$ only

NLIP number of integration points through the thickness of each individual layer to be used for plasticity and thermal effects. Setting $\mathbf{NLIP} = 0 \text{ or } 1$ implies that all properties, including temperature, are considered uniform within each layer. For plasticity, **NLIP** must be odd and $0 \le \mathbf{NLIP} \le 9$. See Table 5.4.

Table 5.4 Suggested values for **NLIP**.

NLIP	material behavior	thermal loading
1	linear elasticity	uniform temperature
3		linear gradient
5	plasticity	quadratic gradient
7	severe plasticity	
9		

NSMRS number of sets of smeared stiffeners $(\textbf{NSMRS} \le 3)$; material behavior is restricted to linear elasticity in walls containing smeared stiffeners

SHEAR1 shear correction factor (see note, below)

SHEAR2 shear correction factor (see note, below)

Note: The default value for each of these shear correction factors is 5/6—which implies a parabolic distribution through the thickness (exact for homogeneous, isotropic prismatic fabrications). Setting either factor to unity implies a uniform distribution, which is unconservative.

```
if      (KWALL = 1)  then  go to  K-2
elseif  (KWALL = 2)  then  go to  K-3a
elseif  (KWALL = 3)  then  go to  K-4a
elseif  (KWALL = 4)  then  go to  K-5a
```

K-2 Layered Wall

The K-2 record defines a layered shell wall. It is included only if **KWALL** $= 1$ (K-1) and is repeated **NLAY** times. Records to be defined later will control whether stresses are printed in any given shell unit or part of the element unit. The layers are stacked in the order read and in the direction of increasing $\bar{z}$. The origin of the $(\bar{x}, \bar{y})$ system is located at the middle surface of the shell (see Figure 5.6 on page 5-130). Eccentricity with respect to the reference surface is defined on the M-5 record. The material properties for each layer are given through reference to the Material Table (I-1).

MATL TL ZETL LSOL

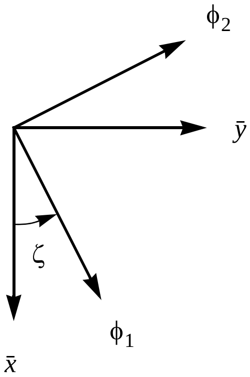
MATL layer material number; select from the Material Table

TL layer thickness

ZETL material (*e.g.*, fiber) orientation angle, in degrees; a right-handed rotation about $\bar{z}$. **ZETL** is the angle ζ between ϕ_1 and $\bar{x}$.

LSOL layer stress output control:

0 – do not print stresses this layer
1 – print stresses this layer; applicable only at locations where overall stress output is required
2 – print stresses and strains at all **NLIP** (K-1) integration points through the thickness; applicable only in plastic analysis



ζ = **ZETAL** layered wall

ζ = **ZETW** fiber-reinforced wall (INACTIVE)

Figure 5.7 Coordinate systems for walls.

NLAY (K-1) number of layers
NSMRS (K-1) number of sets of smeared stiffeners

```
if   (NLAY layers have been defined)  then
     if  (NSMRS > 0)    then   go to K-6
     else                      follow instructions at end of K-6
else     continue defining K-2
```

K-3a Fiber Reinforced Wall—Record 1

INACTIVE

Records K-3a/b define a fiber reinforced wall by use of the properties of the constituent materials. Material properties for the matrix and fibers are obtained from the Material Table (I-1). Usually, better results are obtained if the layer properties can be defined directly on K-2 records.

The K-3a/b records are included only if **KWALL** = 2 (K-1).

MATF MATM

MATF	material number (I-1) for fibers
MATM	material number (I-1) for matrix

go to K-3b

K-3b Fiber Reinforced Wall—Record 2

INACTIVE

The layers are numbered in the direction of increasing value of $\bar{z}$. The ϕ_1 direction for the layer coincides with the winding angle.

One K-3b record is read for each layer, *i.e.*, the record is repeated **NLAY** times (K-1).

TT XX ZETW O

TT	layer thickness
XX	matrix content (by volume)
ZETW	winding angle in degrees
O	contiguity factor

NLAY	(K-1)	number of layers
NSMRS	(K-1)	number of sets of smeared stiffeners

```
if   (NLAY layers have been defined)  then
     if  (NSMRS > 0)     then   go to  K-6
     else                       follow instructions at end of  K-6
else     continue defining  K-3b
```

K-4a Corrugation Stiffened Wall—Record 1

The records K-4a/b define a corrugation stiffened wall, **KWALL** = 3 (K-1).

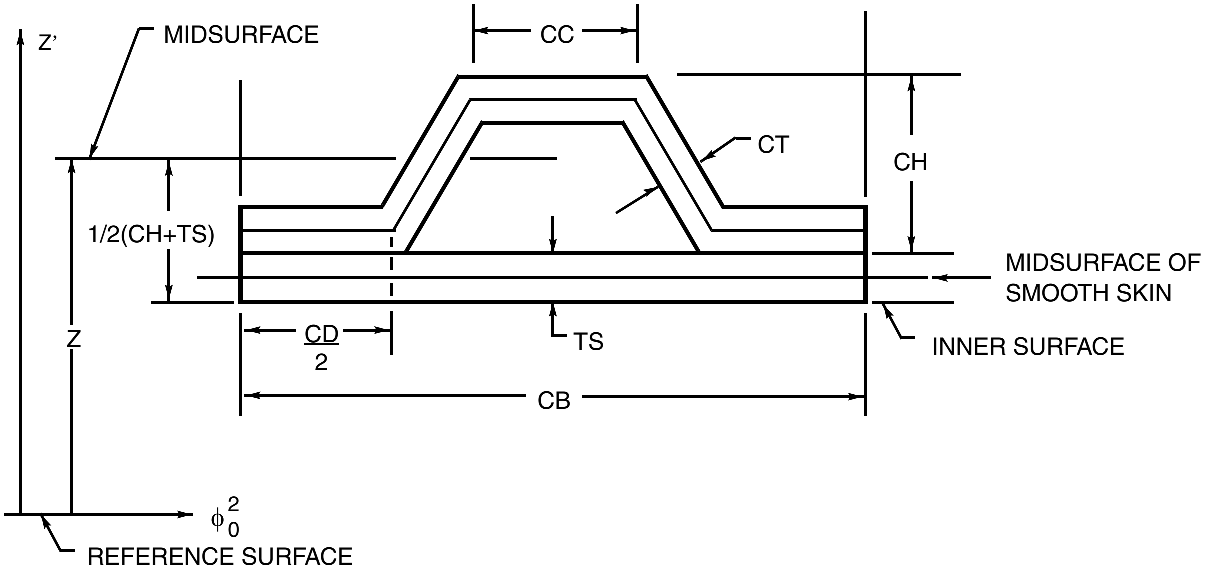


Figure 5.8 Corrugation-stiffened shell wall.

MATC MATS CT CC CH CD CB

MATC material number (I-1) for corrugated sheet

MATS material number (I-1) for skin

CT thickness of corrugated sheet

CC

CH See Figure 5.8

CD

CB centerline-to-centerline spacing of corrugations

✦ *go to* K-4b

K-4b Corrugation Stiffened Wall—Record 2

TS PHI ANC

TS	thickness of smooth skin
PHI	reduction factor for torsional stiffness
ANC	corrugation location 0 – inside corrugation 1 – outside corrugation

✦ **NSMRS** (K-1) number of sets of smeared stiffeners

if (**NSMRS** > 0) then *go to* K-6
else *follow instructions at end of* K-6

K-5a General Wall—Record 1

This record is included only if **KWALL** = 4 (K-1). The thickness needs to be defined to permit mass matrix computation and for thermal analysis (**ITEMP**, C-1). Mass per unit area is **TA** · **RHO**, where **RHO** is the weight density given on the I-2 record. The I-2 record is included so that density and thermal expansion coefficients can be defined; the other entries are irrelevant.

TA MAT ITVS

TA shell wall thickness

MAT material number

ITVS transverse shear flag

0 – ignore transverse shear
1 – include transverse shear coefficients (K-5c)

ITVS must be set to 1 if this wall is to be assigned to an element which is transverse-shear deformable (currently, only the **E330** triangular and the **E480** quadrilateral shell elements). Otherwise, the element stiffness matrix will be singular. For elements which do not permit transverse-shear deformation, **ITVS** is irrelevant.

go to K-5b

K-5b General Wall—Record 2

This record is for input of the general material stiffness matrix. This matrix relates stress resultants to reference-surface strains and curvatures by the relation

$$\left\{\begin{matrix} N_{xx} \\ N_{yy} \\ N_{xy} \\ \\ M_{xx} \\ M_{yy} \\ M_{xy} \end{matrix}\right\} = \begin{bmatrix} C_{11} & C_{12} & C_{13} & C_{14} & C_{15} & C_{16} \\ C_{21} & C_{22} & C_{23} & C_{24} & C_{25} & C_{26} \\ C_{31} & C_{32} & C_{33} & C_{34} & C_{35} & C_{36} \\ \\ C_{41} & C_{42} & C_{43} & C_{44} & C_{45} & C_{46} \\ C_{51} & C_{52} & C_{53} & C_{54} & C_{55} & C_{56} \\ C_{61} & C_{62} & C_{63} & C_{64} & C_{65} & C_{66} \end{bmatrix} \left\{\begin{matrix} \varepsilon_{xx} \\ \varepsilon_{yy} \\ \gamma_{xy} \\ \\ \kappa_{xx} \\ \kappa_{yy} \\ \kappa_{xy} \end{matrix}\right\}$$

where (x, y, z) represent $(\bar{x}, \bar{y}, \bar{z})$ fabrication coordinates.

NOTE: Engineering strains are used: $\gamma_{xy} = \varepsilon_{xy} + \varepsilon_{yx}$ and $\kappa_{xy} = -2w_{xy}$

The full matrix is input, even though it must be symmetric.

(CCC(i,j), j = 1, 6), i = 1, 6

CCC(i,j) element C_{ij} in the shell wall stiffness matrix

Note*:* 36 entries on one record, input in row-major order.

ITVS (K-5a)	transverse shear flag
NSMRS (K-1)	number of sets of smeared stiffeners

if (**ITVS** > 0) then *go to* K-5c
elseif (**NSMRS** > 0) then *go to* K-6
else *follow instructions at end of* K-6

K-5c General Wall—Record 3

Record K-5c is used to input the two-by-two matrix of transverse shear coefficients used only for transverse shear-deformable elements such as the **E480** quadrilateral shell (see Section 14.5). This record is read only if **ITVS** > 0 (K-5a).

This matrix relates transverse shear stress resultants to transverse shear strains by the relation below, where the bar over γ indicates average through-thickness values.

$$\begin{Bmatrix} Q_x \\ Q_y \end{Bmatrix} = \begin{bmatrix} C_{11} & C_{12} \\ C_{21} & C_{22} \end{bmatrix} \begin{Bmatrix} \bar{\gamma}_{zx} \\ \bar{\gamma}_{yz} \end{Bmatrix}$$

Note: Engineering strains are used: $\bar{\gamma}_{zx} = \varepsilon_{xz} + \varepsilon_{zx}$ and $\bar{\gamma}_{yz} = \varepsilon_{yz} + \varepsilon_{zy}$

The full matrix is input, even though it must be symmetric.

(CTS(i,j), j = 1, 2), i = 1, 2

CTS(i,j) transverse shear element C_{ij} in the shell wall stiffness matrix

NOTE: 4 entries on one record, input in row-major order.

NSMRS (K-1) number of sets of smeared stiffeners

if (**NSMRS** > 0) then *go to* K-6
else *follow instructions at end of* K-6

K-6 Smeared Stiffener

This record defines the properties of smeared stiffeners by referring to the Cross Section Table. The record is not included if **NSMRS** = 0 (K-1).

The record is repeated **NSMRS** times (K-1).

ICROSM SPASM ZETSM XSISM ECZSM

ICROSM cross-section number, as defined by **ITAB** (J-1) in the Cross Section Table; **ICROSM** = 0 indicates that the stiffener is defined in user-written CROSS

SPASM stiffener spacing; see the following discussion regarding units

If **SPASM** > 0, then its units are taken to be *length*.

If **SPASM** < 0, then its units are interpreted according to the following. When **ZETSM** $= 0°$ (smeared stringers) or **ZETSM** $= 90°$ (smeared rings), **SPASM** is input in the same units as the Y surface coordinate (stringer) or the X surface coordinate (ring). For smeared *skew* stiffeners ($0° < |\mathbf{ZETSM}| < 90°$) **SPASM** is interpreted according to

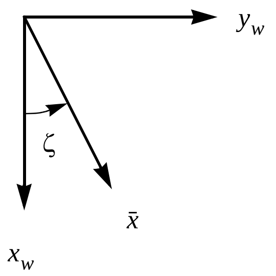
$$\Delta S = \alpha_1 \Delta\theta \sqrt{\frac{1}{(\sin \mathbf{ZETSM})^2 + (\alpha_1 / \alpha_2)^2 (\cos \mathbf{ZETSM})^2}}$$

where $dS_1 = \alpha_1 dX$, $dS_2 = \alpha_2 dY$, and $\Delta\theta = |\mathbf{SPASM}|$. It can be seen in the above equation that when **ZETSM** $= 0°$ or $90°$, **SPASM** is expressed in the same units as Y or X, respectively.

ZETSM angle ζ between the $\bar{x}$ axis and the x_w axis (see Figure 5.9 on page 5-142)

XSISM angle ξ between the $\bar{z}$ axis and the Z' axis (see Figure 6.5 on page 6-52)

ECZSM eccentricity of the smeared stiffener with respect to the shell reference surface, *i.e.*, the value of the shell coordinate Z' at the origin of the $(\bar{y}, \bar{z})$ cross-section coordinate system (see Figure 6.5 on page 6-52)



ζ = **ZETSM** *smeared stiffener*

Figure 5.9 Orientation of smeared stiffener.

NSMRS	(K-1)	number of sets of smeared stiffeners
NTAW	(B-3)	number of entries in the Wall Fabrication Table
NTAP	(B-3)	User Parameters flag
NUNITS	(B-2)	number of shell units

```
if   (NSMRS K-6 records have been defined)  then
     if  (NTAW wall fabrications have been defined)  then
          if       (NTAP > 0)      then   go to  L-1
          elseif   (NUNITS > 0)    then   go to  M-1
          else                     follow instructions at end of  R-3
     else    return to  K-1
else     continue defining  K-6
```

L-1 User Parameters Summary

The L-1/L-2a/L-2b series is used to define constants for access in user-written subroutines. This L record series is included only if **NTAP** > 0 (B-3).

NPI NPF

NPI number of integer parameters to be read on L-2a; **NPI** ≤ 200

NPF number of floating-point parameters to be read on L-2b; **NPF** ≤ 200

```
if      (NPI > 0)   then   go to  L-2a
elseif  (NPF > 0)   then   go to  L-2b
else                       follow instructions at end of  L-2b
```

L-2a Integer Parameters

This record is used to read **NPI** integers (L-1). These integer parameters may then be accessed in any user-written subroutine *via* the FORTRAN type and labeled common statements:

```
INTEGER      UserInt
COMMON /UPI/ UserInt(200)
```

USERINT(i), i = 1, NPI

USERINT(i) integer constant

✦ **NPF** (L-1) number of floating-point parameters

if (**NPF** > 0) then *go to* L-2b
else *follow instructions at end of* L-2b

L-2b Floating-Point Parameters

This record is used to read **NPF** floating-point constants (L-1). These floating-point parameters may then be accessed within any user-written subroutine *via* the FORTRAN type and labeled common statements:

```
REAL          UserFlo
COMMON /UPF/  UserFlo(200)
```

USERFLO(i), i = 1, NPF

USERFLO(i) floating-point constant

✦ **NUNITS** (B-2) number of shell units

if (**NUNITS** > 0) then *go to* M-1
else *follow instructions at end of* R-3

5.7 References for Chapter 5

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4 Reddy, Y. S. and J. N. Reddy, *"Three–Dimensional Finite Element Progressive Failure Analysis of Composite Laminates Under Axial Compression,"* Journal of Composite Technology and Research, Vol. 15, No. 2, Summer 1993, pp. 73–87

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10 Miller, Richard K. and John M. Hedgepeth, *'An Algorithm for Finite Element Analysis of Partly Wrinkled Membranes,"* AIAA Journal, Vol. 20, No. 12, December 1982, pp. 1761–1763

11 Wong, Yew Wei, *"Analysis of Wrinkle Patterns in Prestressed Membrane Structures,"* Master of Philosophy Dissertation, Department of Engineering, University of Cambridge, U.K., August 2000

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13 Hahn, H.T., *"Nonlinear Behavior of Laminated Composites,"* Journal of Composite Materials, Vol. 7, No. 2, April 1973, pp. 257–271

14 Hahn, H.T. and S.W. Tsai, *"Nonlinear Elastic Behavior of Unidirectional Composite Laminae,"* Journal of Composite Materials, Vol. 7, No. 1, January 1973, pp. 102–118

6
Model Input—Shell Units

Shell units are numbered sequentially, in the order in which they are defined, from 1 to **NUNITS**, where **NUNITS** is the number of shell units (B-2).

The group of records in the M–R series describes the shell units. They are defined in serial fashion, completely describing one shell unit before proceeding to the next. When **NUNITS** ≥ 2, the M–R series is defined for the first shell unit, the series is repeated for the second shell unit, and so forth, until all of the **NUNITS** shell units have been defined.

The **NUNITE** (B-2) element units are then defined in a similar manner using the S–V series (see Chapter 7 “Model Input—Element Units (1)”).

The M–R records contain information as summarized below:

M records:	Geometry
N records:	Discretization
O records:	Discrete Stiffeners
P records:	Boundary Conditions
Q records:	Specified Loadings and/or Displacements
R records:	Output Control

☞ A **STAGS** model may contain any number of shell units, combined with any number of element units. Restrictions in previous versions of **STAGS** on the allowable number of units have been removed.

6.1 Geometry

Standard Shell Surfaces

Definition of standard shell surfaces requires particular awareness of four coordinate systems (see Section 4.1 “Coordinate Systems” on page 4-1):

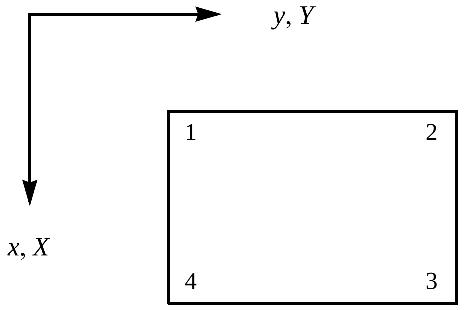
(x, y, z)	*branch coordinates*
(X, Y)	*surface coordinates*
(X', Y', Z')	*shell coordinates*
(x_g, y_g, z_g)	*global coordinates*

The standard shell surfaces, **ISHELL** = 2–12 (M-1), are shown in the following figures. Each figure contains a sketch of a particular shell type, along with labeled coordinate axes for both branch coordinates and surface coordinates. Equations to the right of each figure define user input (**PROPS**, M-2) in terms of these two coordinate systems. Furthermore, expressions relating branch coordinates to surface coordinates are given beneath each sketch. While the user generally need not be concerned with these surface-to-branch relationships, they are definitive for resolving any ambiguity.

Shell coordinates form an orthogonal set, without exception, and at each shell-unit node, the computational degrees-of-freedom (*dof*) are determined by this system. That is to say, (x'', y'', z'') is coincident with (X', Y', Z') at each node in a shell unit. (X, Y) also form an orthogonal set, (X', Y') being coincident, with the single exception of the Elliptic Cone (**ISHELL** $= 9$). On this type of surface, the meridians and parallels do not cross at right angles, except for the three degenerate surfaces (elliptic cylinder, circular cone, circular cylinder). However, the (X', Y', Z') system is still orthogonal in this case. The circumferential (Y) and shell-normal directions are chosen as the (Y', Z') directions, and $Y' \times Z' = X'$ establishes the orthogonal system.

After defining a shell unit (branch) *via* **ISHELL/PROPS**, it must be positioned in global space *via* **IGLOBE** (M-1). Globally positioning a shell branch is logically equivalent to defining a branch-to-global transformation, that is specifying where the origin of the branch coordinate system is located, and how it is oriented (rotated) to position the shell branch properly. **STAGS** provides tremendous flexibility and automation for globally positioning shell branches, so the user need not be concerned with mathematical details. Still, it is insightful to bear in mind that the effect of **IGLOBE** selection is to define a branch-to-global transformation. For example, in the simplest case, **IGLOBE** = 0, the branch system is coincident with the global system, thus defining the identity transformation.

RECTANGULAR PLATE **ISHELL** = 2



PROP(1) = X_1

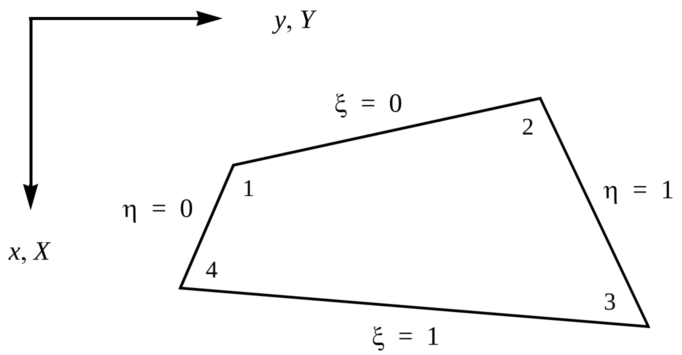
PROP(2) = X_4

PROP(3) = Y_1

PROP(4) = Y_2

$x = X \quad y = Y \quad z = 0$

QUADRILATERAL PLATE **ISHELL** = 3



PROP(1) = X_1

PROP(2) = Y_1

PROP(3) = X_2

PROP(4) = Y_2

PROP(5) = X_3

PROP(6) = Y_3

PROP(7) = X_4

PROP(8) = Y_4

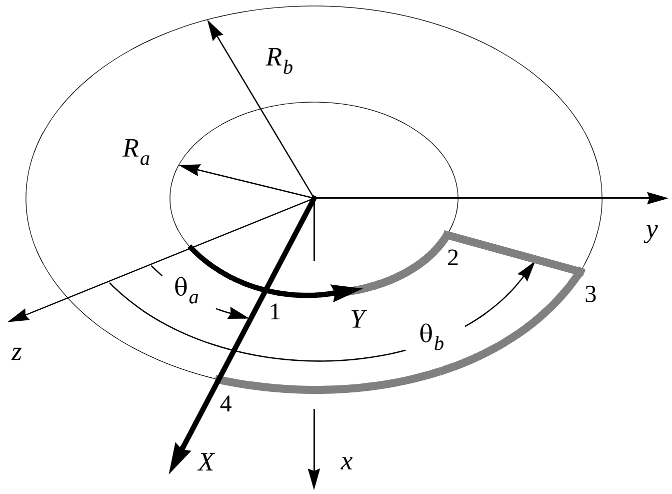
$$f_1 = (1-\xi)(1-\eta) \qquad f_2 = (1-\xi)\eta \qquad f_3 = \xi\eta \qquad f_4 = \xi(1-\eta)$$

$$x = f(X, Y) = \sum_{i=1}^{4} f_i \cdot X_i \qquad y = g(X, Y) = \sum_{i=1}^{4} f_i \cdot Y_i \qquad z = 0$$

NOTE: $(X, Y) = (x, y)$; *i.e.*, the surface coordinate directions are parallel to the branch coordinate directions.

A quadrilateral plate with (X, Y) derived from the (ξ, η) lines can be generated with a user-defined shell surface (**ISHELL** = 1). For an example, see “LAME Reference Surface Geometry” on page 12-19.

ANNULAR PLATE **ISHELL** = 4



PROP(1) = $X_1 = R_a$

PROP(2) = $X_4 = R_b$

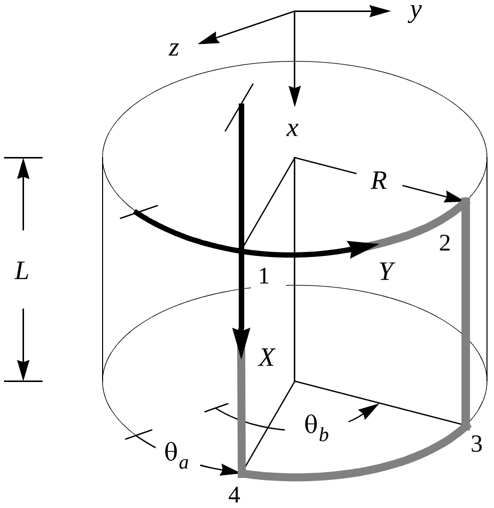
PROP(3) = $Y_1 = \theta_a$

PROP(4) = $Y_2 = \theta_b$

$$y^2 + z^2 = r^2 = X^2$$

$$x = 0 \qquad y = g(X, Y) = X\sin Y \qquad z = h(X, Y) = X\cos Y$$

CYLINDER **ISHELL** = 5



PROP(1) = $X_1 = x_1$

PROP(2) = $X_4 = x_4$

PROP(3) = $Y_1 = \theta_a$

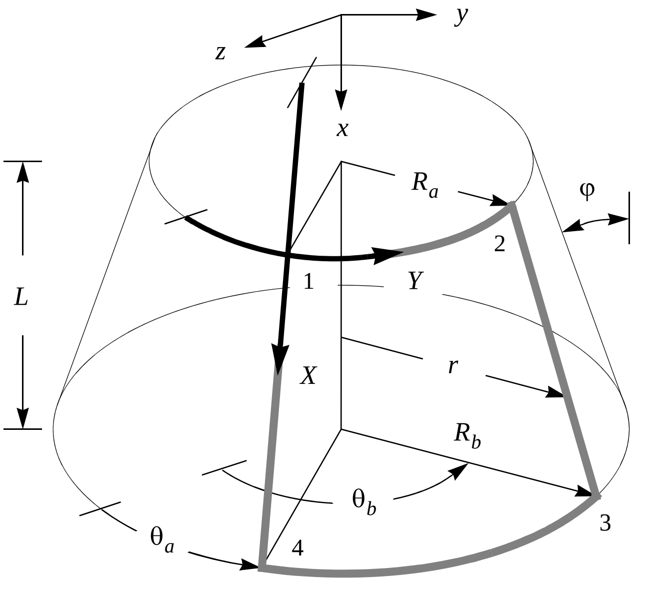
PROP(4) = $Y_2 = \theta_b$

PROP(5) = R

$$L = X_4 - X_1 \qquad y^2 + z^2 = R^2$$

$$x = X \qquad y = g(X, Y) = R\sin Y \qquad z = h(X, Y) = R\cos Y$$

CONE **ISHELL** = 6



PROP(1) = x_1

PROP(2) = x_4

PROP(3) = $Y_1 = \theta_a$

PROP(4) = $Y_2 = \theta_b$

PROP(5) = R_a

PROP(6) = R_b

$R_a > R_b$ OK

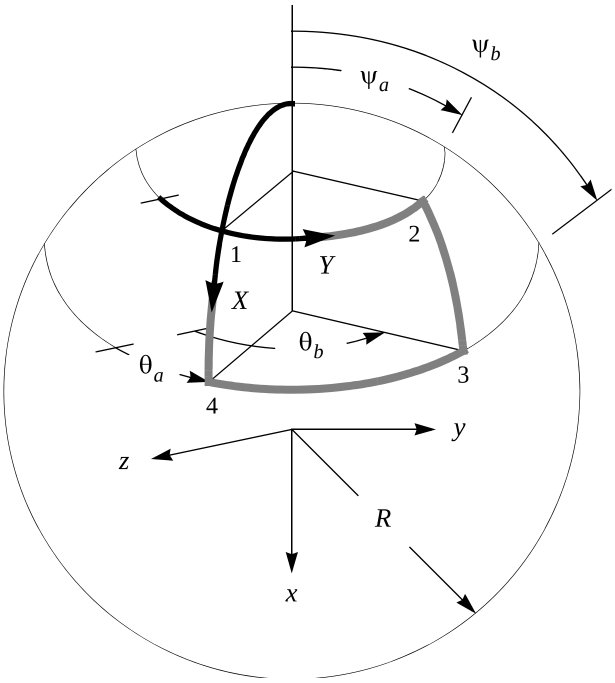
$$L = x_4 - x_1$$

$$\tan\varphi = (R_b - R_a)/L$$

$$r = R_a + (x - x_1)\tan\varphi$$

$$y^2 + z^2 = r^2 \qquad y = g(x, Y) = r\sin Y \qquad z = h(x, Y) = r\cos Y$$

SPHERE **ISHELL** = 7



PROP(1) = $X_1 = \psi_a$

PROP(2) = $X_4 = \psi_b$

PROP(3) = $Y_1 = \theta_a$

PROP(4) = $Y_2 = \theta_b$

PROP(5) = R

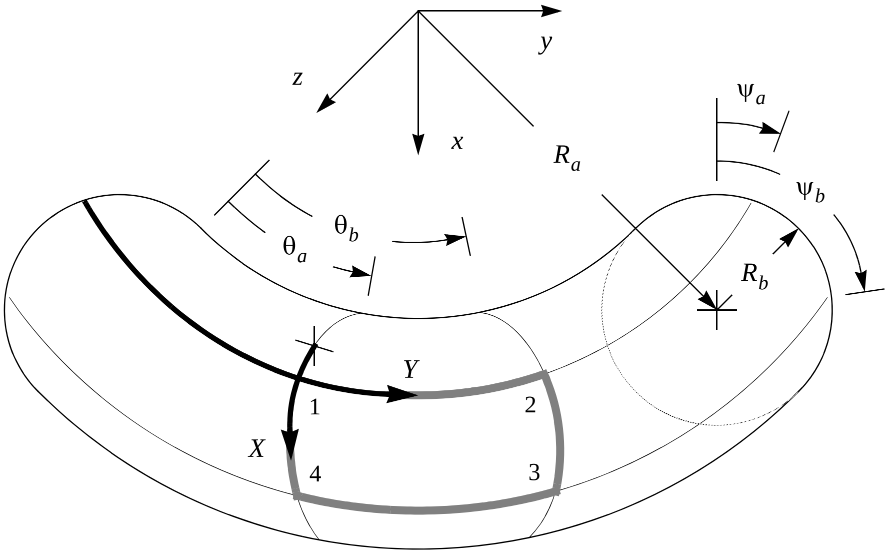
$$x^2 + y^2 + z^2 = R^2$$

$$x = f(X, Y) = -R\cos X$$

$$y = g(X, Y) = R\sin X\sin Y$$

$$z = h(X, Y) = R\sin X\cos Y$$

TORUS **ISHELL** = 8



$$\bar{R} = R_a + R_b \sin X$$

$$x = f(X, Y) = -R_b \cos X$$

$$y = g(X, Y) = \bar{R} \cdot \sin Y$$

$$z = h(X, Y) = \bar{R} \cdot \cos Y$$

PROP(1) = $X_1 = \psi_a$

PROP(2) = $X_4 = \psi_b$

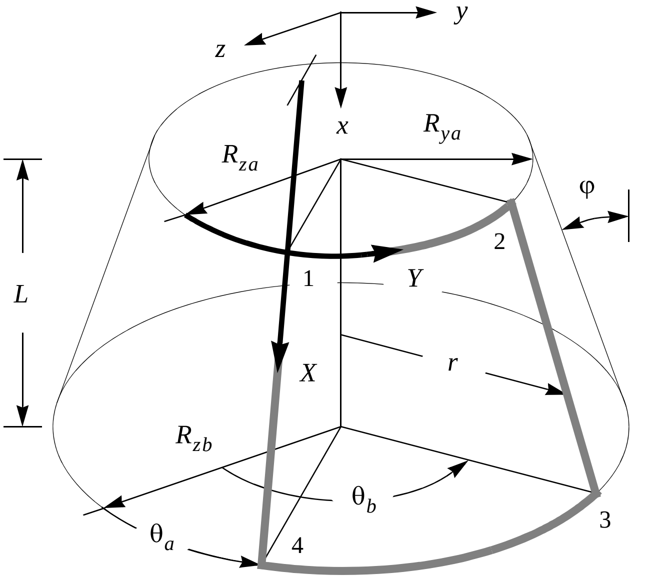
PROP(3) = $Y_1 = \theta_a$

PROP(4) = $Y_2 = \theta_b$

PROP(5) = R_a

PROP(6) = R_b

ELLIPTIC CONE/CYLINDER **ISHELL** = 9



PROP(1) = x_1

PROP(2) = x_4

PROP(3) = $Y_1 = \theta_a$

PROP(4) = $Y_2 = \theta_b$

PROP(5) = R_{za}

PROP(6) = R_{ya}

PROP(7) = R_{zb}

$$R_{za} > R_{zb} \text{ OK}$$

$$L = x_4 - x_1$$

$$\tan\varphi = (R_{zb} - R_{za})/L$$

$$R_{za}, R_{ya}, R_{zb} \quad \Rightarrow \quad \textit{elliptic cone}$$

$$R_{za} = R_{zb} = R_z \ ; \ R_{ya} = R_y \quad \Rightarrow \quad \textit{elliptic cylinder}$$

$R_{za} = R_{ya} = R_a \ ; \ R_{zb} = R_b \quad \Rightarrow \quad$ *circular cone* (**ISHELL** = 6)

$R_{za} = R_{ya} = R_{zb} = R \quad \Rightarrow \quad$ *circular cylinder* (**ISHELL** = 5)

$$R_{za} < R_{zb} \ : \ X_{ap} = x - x_1 + (R_{za}/\tan\varphi)$$

$$R_{za} \geq R_{zb} \ : \ X_{ap} = x_4 - x + (R_{zb}/\tan\varphi)$$

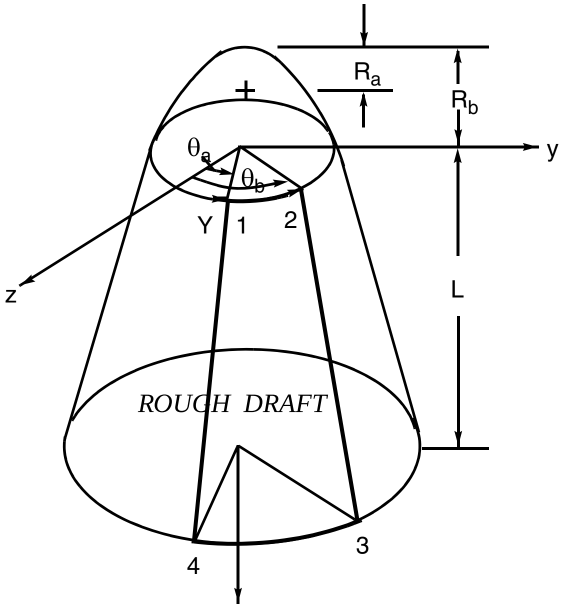
$$r_y = (R_{ya}/R_{za})X_{ap}\tan\varphi \qquad\qquad r_z = X_{ap}\tan\varphi$$

$$\frac{y^2}{r_y^2} + \frac{z^2}{r_z^2} = 1$$

$$y = g(x, Y) = r_y \sin Y \qquad z = h(x, Y) = r_z \cos Y$$

NOTE: (X, Y) are non-orthogonal for the *elliptic cone* only; see page 6-2.

PARABOLOID **ISHELL** = 10



PROP(1) = x_1

PROP(2) = x_4

PROP(3) = $Y_1 = \theta_a$

PROP(4) = $Y_2 = \theta_b$

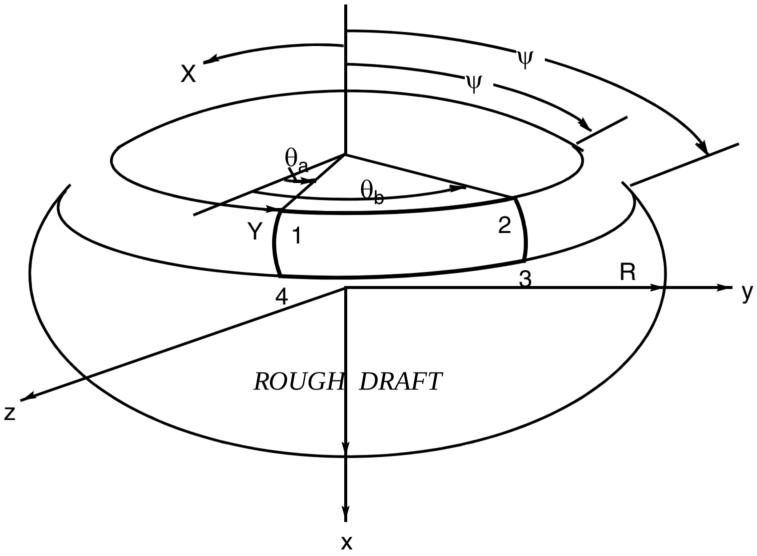
PROP(5) = R_a

PROP(6) = R_b

$$y^2 + z^2 = r^2 = 4R_a(x + R_b) \qquad \bar{R} = 2\sqrt{R_a(x + R_b)}$$

$$y = g(x, Y) = \bar{R} \cdot \sin Y \qquad z = h(x, Y) = \bar{R} \cdot \cos Y$$

ELLIPSOID **ISHELL** = 11



PROP(1) = $X_1 = \psi_a$

PROP(2) = $X_4 = \psi_b$

PROP(3) = $Y_1 = \theta_a$

PROP(4) = $Y_2 = \theta_b$

PROP(5) = R_x

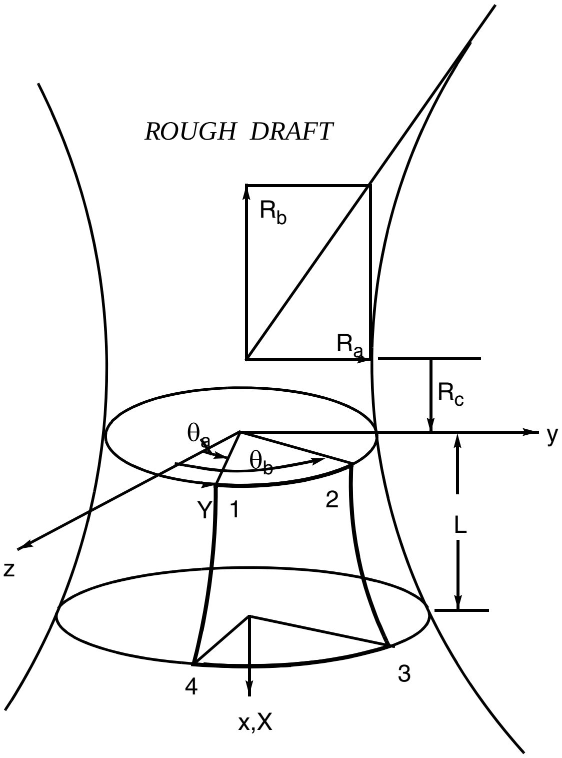
PROP(6) = R_{yz}

$$\frac{y^2 + z^2}{R_{yz}^2} + \frac{x^2}{R_x^2} = 1$$

$$X^e = \operatorname{atan}\left(\frac{R_x}{R_{yz}}\tan X\right) \qquad x = f(X, Y) = -R_x \cos X^e$$

$$y = g(X, Y) = R_{yz}\sin X^e \sin Y \qquad z = h(X, Y) = R_{yz}\sin X^e \cos Y$$

HYPERBOLOID **ISHELL** = 12



PROP(1) = x_1

PROP(2) = x_4

PROP(3) = $Y_1 = \theta_a$

PROP(4) = $Y_2 = \theta_b$

PROP(5) = R_a

PROP(6) = R_b

PROP(7) = R_c

$$\frac{y^2 + z^2}{R_a^2} - \frac{(x + R_c)^2}{R_b^2} = 1 \qquad \bar{R} = \frac{R_a}{R_b}\sqrt{R_b^2 + (x - x_1 + R_c)^2}$$

$$y = g(x, Y) = \bar{R} \cdot \sin Y \qquad z = h(x, Y) = \bar{R} \cdot \cos Y$$

M-1 Shell Type

Six basic parameters are required by **STAGS** to define the geometry of a shell unit. The first of these (**ISHELL**) is used to specify the *type* of shell surface that is to be generated; the second (**IGLOBE**) can be used to identify the method by which the shell unit is positioned within the (x_g, y_g, z_g) global coordinate system; the third and fourth (**NROWS** & **NCOLS**) are reserved for ***future*** use for specifying how the shell surface is to be tessellated (into an I-J grid) for constructing the finite elements required for the model; the fifth (**NLAYS**) is used to specify the number of elements to be generated through the thickness of a *solid* shell unit; and the sixth (**NFABS**) is used to specify the number of fabrications that are required for the elements to be generated.

The twelve choices that are available for the **ISHELL** parameter in the current version of **STAGS** are described below. The **NROWS** and **NCOLS** parameters on M-1 are currently ignored by the program, which uses information from the F-1 record to form the I-J nodal grid(s) required for the shell unit: the user should set these two parameters equal to zero (or omit them entirely if **NLAYS** and **NFABS** are also omitted or zero (see the discussion below). With these things in mind, the remainder of this preamble concentrates on the **IGLOBE**, **NLAYS** and **NFABS** parameters.

STAGS interprets the specification that $\textbf{IGLOBE} = 0$ to mean that the (x, y, z) branch coordinate system for the shell unit coincides with the (x_g, y_g, z_g) global coordinate system, and that no positioning transformation is required. (Please refer to “Standard Shell Surfaces” on page 6-2 & Section 4.1 “Coordinate Systems” on page 4-1.) If $\textbf{IGLOBE} = 1$ the program automatically selects 3 points on the boundary line that is common with previously defined shell units and uses these data for location of the unit. (To find out how units are joined together, see records G-1 and G-2.) If only one side of the unit is connected to a previously defined unit and that side is a straight line or has only two points, additional information is needed, and $\textbf{IGLOBE} = 1$ will not work. The $\textbf{IGLOBE} = 2$ option was originally intended for this case and is retained for compatibility, but its use is not recommended since newer, more robust, options have made it obsolete. Full generality is provided by the addition of options $\textbf{IGLOBE} = 3$, 4 and 5. With $\textbf{IGLOBE} = 3$, the M-4a record is used to define the global coordinates for the corner points 1, 2, and 3 on the shell unit. (See Figure 6.1 on page 6-19 for corner-numbering conventions.) The options $\textbf{IGLOBE} = 4$ and 5 give the user the opportunity to specify both a translation and an Euler rotation for either the origin of the branch coordinate system or corner point 1. These options will be needed for closed shell units such as complete cylinders and annular plates, where the three corner points all lie along a line; in that case, the $\textbf{IGLOBE} = 3$ option cannot be used.

The **NLAYS** parameter was not required in previous versions of **STAGS** because shell units there could only be created with one-dimensional beam and/or two-dimensional thin-shell elements. The current version of **STAGS** uses the **NLAYS** parameter to determine whether or not solid-type elements are used for the current shell unit and (if so) how many solid elements are to be generated in the thickness direction at any given location. Specification that **NLAYS** = 0 (or omission of the **NLAYS** specification) instructs **STAGS** to generate a single layer of one-dimensional and/or thin-shell elements through the thickness of the shell unit. Under these circumstances, the **NFABS** parameter should be set equal to 0 or 1 so that **STAGS** will read a single M-5 record identifying the fabrication to be used.

Specification that **NLAYS** > 0 instructs **STAGS** to generate **NLAYS** layers of solid elements through the thickness of the shell at each location. Under these circumstances, the **NFABS** parameter must be set equal to 0, to 1, to **NLAYS**, or to (**NLAYS** + 2)—depending on the type of element to be used for the shell unit (see the N-1 record, on 6-34).

When type **E830**, **E840** or **E849** (sandwich) elements are used, the **NLAYS** parameter must be set equal to the number of *core* elements to be used through the thickness of the shell, and the **NFABS** parameter must be set equal to **NLAYS** + 2 or **NLAYS** + 3 . With single-core-section **E830**, **E840** or **E849** elements, three fabrications are required: the first of these is used for the *lower face sheet element*, the second is used for the *core element*, and the third is used for the *upper face sheet element* of the **E830**, **E840** or **E849** assembly at each location on the shell unit. With multiple-core-section **E830**, **E840** or **E849** sandwiches, the **NLAYS** parameter specifies the number of *core components* to be used for each **E830**, **E840** or **E849** element, and **NFABS** must be set equal to **NLAYS** + 3 . In this case, the first of these **NFABS** fabrications (identified *via* the **NFABS** M-5 records following M-1 *et al.*) is used for the *lower face sheet*, the second is used for the *lowest core element*, the third is used for the *next core element*, ... and so on, and the next-to-last fabrication is used for the *upper face sheet* of the **E830**, **E840** or **E849** assembly at each location on the shell. **STAGS** uses the last (**NFABS**th) fabrication to construct a “fictitious” **E330**, **E410** or **E480** element at each of the interfaces between successive layers of the **NLAYS** *core-section* components. It is recommended that each layer of elements have a fabrication record defined.

When **E881**, **E882**, **E883** or **E885** elements are used, **NFABS** may be 0, 1 or **NLAYS**: if **NFABS** = 0 or 1, **STAGS** will read a single M-5 record that identifies the fabrication to be used for all of those elements; if **NFABS** = **NLAYS**, **STAGS** will read an M-5 record for each layer of elements—starting with the bottom layer (defined by the **ISHELL** parameter and the information on the record(s) following the current M-1 record) and continuing through and including the topmost layer of the construction.

In any event, the sequence of records M-1 through R-3 is repeated **NUNITS** times (B-2).

ISHELL IGLOBE NROWS NCOLS NLAYS NFABS

ISHELL indicates basic shell geometry; see "Standard Shell Surfaces" on page 6-2:

1 – defined by user-written subroutine LAME
2 – rectangular plate
3 – quadrilateral plate
4 – annular plate
5 – cylinder
6 – cone
7 – sphere
8 – torus
9 – elliptic cone/cylinder
10 – paraboloid
11 – ellipsoid
12 – hyperboloid

IGLOBE global positioning option

0 – the (x, y, z) branch coordinate system for the shell unit coincides with the (x_g, y_g, z_g) global coordinate system

1 – the shell unit is positioned automatically by use of points on a common boundary line; do not use if the connected side is straight or has only two grid points

2 – *OBSOLETE*; retained for compatibility, but use is not recommended due to the addition of the more general, more robust options below.

3 – the shell unit is positioned by specifying the global coordinates of three corner points

4 – the shell unit is positioned by positioning the origin of the (x, y, z) branch coordinate system at a specified location, followed by three rotations about axes centered at the (x, y, z) origin and parallel to the (x_g, y_g, z_g) global coordinate directions

5 – the shell unit is positioned by positioning corner point 1 at a specified location, followed by three rotations about axes centered at corner point 1 and parallel to the (x_g, y_g, z_g) global coordinate directions

NROWS reserved for future use; set equal to zero

NCOLS reserved for future use; set equal to zero

NLAYS element-layering parameter:

- ≤ 0 – generate one layer of standard (non-solid) elements
- > 0 – generate **NLAYS** layers of solid elements in the thickness direction (see N-1, on 6-34)

NFABS fabrication-specification parameter:

- ≤ 1 – one M-5 record is required
- > 1 – **NFABS** M-5 records required

go to M-2

M-2 Shell Surface Constants

This record specifies properties of the reference surface. The type of surface is indicated by **ISHELL** (M-1). "Standard Shell Surfaces" on page 6-2 shows what these properties mean for the standard surface types defined by **ISHELL** = 2–12. M-2 is also read when a user-written LAME is used (**ISHELL** = 1). In that case, the properties have the following meaning:

PROP(1) = X value for boundary line 1

PROP(2) = X value for boundary line 3

PROP(3) = Y value for boundary line 4

PROP(4) = Y value for boundary line 2

PROP(5) through **PROP(8)** may be used for other parameters in user-written LAME.

Boundary lines are numbered as shown in Figure 6.1 on page 6-19.

When **ISHELL** = 1 and **IUGRID** = 1 (N-1), the range of (X, Y) is automatically set to

$$0 \le X \le 1 \qquad 0 \le Y \le 1$$

PROP remains intact, but it is not used by **STAGS** when **IUGRID** = 1 is set in conjunction with **ISHELL** = 1. In that case, the user may assign any values to the **PROP** array. See "LAME Reference Surface Geometry" on page 12-19.

PROP(i), i=1,8

PROP(i) surface properties depending on **ISHELL** (M-1); all angles are in degrees for **ISHELL** = 2–12.

☞ Refer to "Standard Shell Surfaces" on page 6-2. For clarity of presentation, **PROP**s are shown as having positive values in the sketches there. Negative values are also permissible, except for radius values, such as R_a, R_b in the Annular Plate. However, the following relations must be satisfied:

$$\textbf{PROP}(\textbf{2}) > \textbf{PROP}(\textbf{1})$$

$$\textbf{PROP}(\textbf{4}) > \textbf{PROP}(\textbf{3})$$

Some of these shell surfaces may include poles. **STAGS** will recognize the existence of a pole and will generate triangular elements at the pole under the conditions that are summarized in Table 6.1.

Table 6.1 Triangular shell elements at poles.

ISHELL	type	conditions
4	annular plate	**PROP(1)** = 0
6	cone	**PROP(5)** or **PROP(6)** = 0
7	sphere	**PROP(1)** or **PROP(2)** = 0 **PROP(1)** or **PROP(2)** = 180 **PROP(2)** = 360
9	elliptic cone	**PROP(5)** or **PROP(6)** = 0
10	paraboloid	**PROP(6)** = 0
11	ellipsoid	**PROP(1)** or **PROP(2)** = 0 **PROP(1)** or **PROP(2)** = 180 **PROP(2)** = 360

IGLOBE (M-1) global position option

```
if       (IGLOBE = 2)        then  go to  M-3
elseif   (IGLOBE = 3)        then  go to  M-4a
elseif   (IGLOBE = 4 or 5)   then  go to  M-4d
else                         go to  M-5
```

M-3 Shell Unit Orientation—Straight-Line Boundary

OBSOLETE

> This option is retained for compatibility, but its use is not recommended due to the addition of the more general, more robust options **IGLOBE** = 3 – 5.

This record is used only if **IGLOBE** = 2 (M-1). It defines the (x_g, y_g, z_g) global coordinates of one reference point on the surface of the shell unit. Any point can be chosen as long as it is not located on a line of juncture with a previously defined unit.

NREP NCEP XGEP YGEP ZGEP

NREP row number of reference point

NCEP column number of reference point

XGEP, YGEP, ZGEP (x_g, y_g, z_g) global coordinates of reference point

✦ *go to* M-5

M-4a Shell Unit Orientation—Corner Point 1

The records M-4a, M-4b and M-4c are used only if **IGLOBE** = 3 (M-1). They define the global coordinates of the three corner points 1, 2, 3 on the shell unit. The numbering system is shown in Figure 6.1.

XGC1 YGC1 ZGC1

XGC1, YGC1, ZGC1 (x_g, y_g, z_g) global coordinates of corner point 1

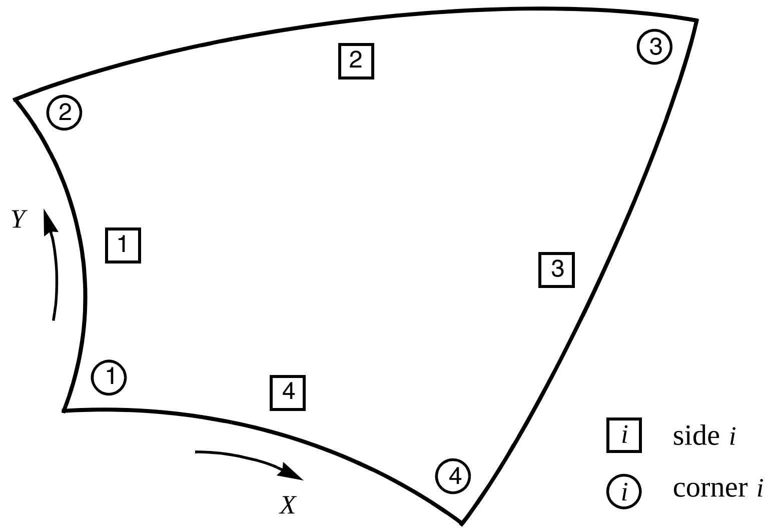


Figure 6.1 Shell-unit boundary- and corner-numbering schemes.

go to M-4b

M-4b Shell Unit Orientation—Corner Point 2

XGC2 YGC2 ZGC2

XGC2, YGC2, ZGC2 (x_g, y_g, z_g) global coordinates of corner point 2

✦ *go to* M-4c

M-4c Shell Unit Orientation—Corner Point 3

XGC3 YGC3 ZGC3

XGC3, YGC3, ZGC3 (x_g, y_g, z_g) global coordinates of corner point 3

go to M-5

M-4d Shell Unit Orientation—Translation

Record M-4d is input if **IGLOBE** $= 4$ or 5 (M-1). These options permit the user to move a shell unit into position manually, even for the case where the corner points lie in a line, as is the case for closed shell units such as complete cylinders or cones. The shell unit is positioned by specifying the global coordinates of a reference point and then applying rotations about axes that are centered at the reference point and parallel to the global axes. Record M-4d provides the global coordinates for the reference point chosen. Record M-4e specifies the Euler angles for rotation.

If **IGLOBE** $= 4$, the reference point is the origin of the (x, y, z) branch coordinate system, shown in “Standard Shell Surfaces” on page 6-2 for each choice of **ISHELL** (M-1). This option has the effect of translating the shell unit in the global coordinate directions, with distances given by $(x_g, y_g, z_g) = (\mathbf{XG}, \mathbf{YG}, \mathbf{ZG})$, since (x, y, z) is initially coincident with (x_g, y_g, z_g), and the shell unit is fixed with respect to the (x, y, z) system.

If **IGLOBE** $= 5$, the reference point is the node belonging to row 1, column 1 (corner point 1, Figure 6.1 on page 6-19). This option has the effect of translating the shell unit to position corner point 1 at the location $(x_g, y_g, z_g) = (\mathbf{XG}, \mathbf{YG}, \mathbf{ZG})$.

XG YG ZG

XG, YG, ZG a position vector in the (x_g, y_g, z_g) global coordinate system, defining the location of the reference point

go to M-4e

M-4e Shell Unit Orientation—Rotation

This record consists of the Euler angles used to rotate the shell unit about the *reference point* (M-4d). If **IGLOBE** $= 4$, the reference point is the origin of the (x, y, z) branch coordinate system, and if **IGLOBE** $= 5$, the reference point is corner point 1. Note that the reference point was positioned in global space by the M-4d record.

The angles input here represent right-handed rotations about axes that are centered at the reference point and parallel to the global axes (x_g, y_g, z_g), in the following order:

- rotate first about the z_g axis, by an amount $\phi°$
- rotate next about the y_g axis, by an amount $\theta°$
- rotate last about the x_g axis, by an amount $\chi°$

CAUTION: Note that the rotations are *order-dependent* and are applied in the *reverse* order of input.

Each rotation is counterclockwise with the viewer looking down along the chosen axis (*i.e.*, in the negative coordinate direction) onto the plane of the remaining two axes. For the **STAGS** right-handed global coordinate system, the convention chosen is called the *space-fixed system of right-hand rotations*, given symbolically by the relation

$$\mathbf{R}(\chi, \theta, \phi) = \mathbf{R}(\chi)\mathbf{R}(\theta)\mathbf{R}(\phi)$$

where each symbol represents a 3×3 orthogonal matrix.

XGROT YGROT ZGROT

XGROT	the angle $\chi°$ (degrees)
YGROT	the angle $\theta°$ (degrees)
ZGROT	the angle $\phi°$ (degrees)

go to M-5

M-5 Shell Wall

Typically, a shell unit defines a two-dimensional reference surface that is subsequently discretized into one- and/or two-dimensional finite elements. The properties of this surface are provided by the Wall Fabrication Table (see the K records, described above), by the GCP Fabrications Table (described in the I records, above), or by a user-written WALL subroutine. The M-5 record contains the necessary data linking a given fabrication to the reference surface. Data input here will also tell **STAGS** whether the strain-displacement relations are linear or nonlinear, whether there is to be nonlinear material behavior, and whether there are initial geometric imperfections defined either as a trigonometric expansion, in a user-written subroutine, or by scaled buckling modes (see records B-2 and B-5). A single M-5 record is always required for such shell units.

A shell unit that is constructed with type **E830, E840** or **E849** sandwich elements requires a separate fabrication identifier for each distinct component in the thickness direction of the shell unit. The simplest **E830**, **E840** or **E849** sandwich construction—which uses one **E330**, **E410** or **E480** thin-shell element for its lower face sheet, a single sandwich-core element for its core, and a second **E330**, **E410** or **E480** thin-shell element for its upper face sheet—requires three fabrication identifiers. The first of these is used for the lower face sheet, the second is used for the core, and the third is used for the upper face sheet. A more complex **E830**, **E840** or **E849** sandwich construction—with **NLAYS** > 1 core components at each station—requires **NLAYS** $+ 3$ fabrication identifiers. The first of these is used for *the lower face sheet*, the second is used for *the lowest core element*, the third is used for *the next core element*, ... and so on, and the next-to-last fabrication is used for *the upper face sheet*. **STAGS** uses the last (**NFABS**th) of these fabrications to construct a “fictitious” **E330**, **E410** or **E480** thin-shell element at each of the interfaces between successive layers of the core-section components. **STAGS** uses the reference surface of the shell unit to define the location of the interface between the lower face sheet and the first (lowest) sandwich-core component of a shell unit that uses **E830**, **E840** or **E849** sandwich elements. **STAGS** then constructs additional layers of nodes by adding the thickness of each successive sandwich-core component—the uppermost such layer defining the interface between the uppermost core element and the upper face sheet of the assembly.

A shell unit that is constructed with type **E881, E882, E883** or **E885** three-dimensional solid elements requires one fabrication identifier specifying the single fabrication to be used for all of those elements, or it requires a separate fabrication identifier for each layer of elements across the thickness of the shell: this is controlled by the **NLAYS** and **NFABS** parameters on the M-1 record, described above. With these types of “standard” solid elements, **STAGS** computes the total thickness of the shell wall by summing the thickness of each layer of the construction. **STAGS** uses half of this total thickness to determine the offset in the normal direction from the shell’s reference surface (which is specified *via* **ISHELL** on M-1 and **PROPS** on M-2) to the “lower” surface of the solid shell, and places the first layer of shell-unit nodes there. Successive additional layers of shell-unit nodes are placed on “parallel” nodal surfaces that are offset from this first surface by the thickness of each successive layer of elements—or by the appropriate whole-number fraction of that thickness, as appropriate. For these types of solid elements, then, the reference surface of the shell is always midway between its lower and upper surfaces.

The principal material axes for individual layers in a fabrication are defined on the K-2 record (**ZETL**) with the traditional **STAGS** definition of shell wall fabrication properties, and on the I-21d record (**ANGSHEL**) with the GCP definition. The user may also rotate the fabrication in the plane tangent to the reference surface by an angle **ZETL (**or **ANGSHL**) so that the angle a principal material axis makes with the shell coordinate lines is the sum of **ZETL (**or **ANGSHL**) and the angle defined for the individual layer in question. The default system for stress output is along the natural shell coordinates. Output can also be specified along an arbitrary direction defined by the user.

It is possible to suppress geometrically nonlinear terms for any particular unit using the **ILIN** parameter. For linear analysis or small vibrations (stress free), **INDIC** = 0 or 2 (B-1), **ILIN** is meaningless. For nonlinear analysis (including bifurcation or vibrations with nonlinear stress state and transient analysis) **INDIC** = 3, 4, 5 or 6, **ILIN** can be used to suppress nonlinear effects in some shell units and thus to expedite execution. For bifurcation buckling from a linear stress state (**INDIC** = 1) **ILIN** can be used to prevent buckling in certain shell units. **ILIN** must be 0 for at least one element or shell unit when performing a bifurcation analysis.

If nonlinear material behavior (plasticity or creep) is desired in a given shell unit, **IPLAS** must be greater than zero. Like **ILIN**, **IPLAS** allows the user to turn plasticity on or off without changing the contents of the material and wall construction libraries. When **IPLAS**=0, all material properties are constructed from the linear elastic data given on the I-2 records. Two options are given for plasticity. If **IPLAS**=1, the material law is satisfied at each element integration point, which for the vast majority of cases gives the most accuracy. If **IPLAS**=2, the material law is enforced only at the element centroid, with the same plastic strain distributed evenly to the integration points. The result is a lower-order, approximate solution requiring only a fraction of the plasticity computations needed when **IPLAS**=1. This option can be used when stresses are slowly varying over the structure. There is one important special case that should be mentioned. Some elements, like the **E410**, have a high-order bending interpolation and a lower-order membrane interpolation. When there is eccentricity in a wall section (the variable **ECZ** on this record) that introduces coupling between the membrane and bending element stiffnesses, the resulting mismatch causes stress overshoot, with the stresses computed at the integration points potentially lying far above and below the average over the element. These oscillations are an artifact of the computation and do not represent real behavior. For elastic response, the displacements will not be adversely affected. For a plastic analysis, however, the path-dependent nature of the material response can cause large errors when significant plastic flow occurs. Since centroidal plasticity avoids these problems, we recommend setting **IPLAS**=2 when **ECZ** $\neq 0$ and when using type **E320**, **E330**, **E410**, **E420** and/or **E430** elements (N-1).

Deterministic imperfections are defined in the form of trigonometric functions on data records if **IWIMP**>0, or in any form in a user-written DIMP subroutine if **IWIMP** = -1. Random imperfections are defined in terms of trigonometric functions if **IRAMP**=1. As they are generated independently for each shell unit, these shell-unit-specfic imperfections may not exhibit continuity across shell unit boundaries. These imperfections are added to the buckling-mode imperfections that are generated when **NIMPFS** is nonzero (on the B-2 record).

As noted previously, there must be at least one M-5 record at this point in the user's input file. If **NFABS** > 1 (M-1), then **NFABS** M-5 records are required.

IWALL IWIMP ZETA ECZ ILIN IPLAS IRAMP

IWALL fabrication identifier:

- 0 – shell wall properties are given in user-written subroutine WALL
- >0 – shell wall configuration number in the Wall Fabrication Table (K-1)
- <0 – shell or solid fabrication identifier in the GCP Fabrications Table (on I-21) for shell elements or on I-22 for solid elements: *this option is **required** for **E830, E840** and **E849** sandwich-core elements*

When **IWALL** $= 0$, data below indicated by ⌘ are defined in user-written subroutine WALL; they are automatically initialized to zero before WALL is called—superseding any nonzero values input here

IWIMP imperfection option

- -1 – initial imperfections are defined in user-written DIMP
- 0 – no initial imperfections
- >0 – number of imperfection components defined on M-6 records; **IWIMP** ≤ 50

⌘ **ZETA** angle ζ between the wall-reference coordinate x_w and the fabrication coordinate $\bar{x}$; ζ is a right-handed rotation about $\bar{z}$. See Figure 6.2 on page 6-28.

⌘ **ECZ** eccentricity in Z' direction. **ECZ** is the Z' coordinate of the middle surface; see Figure 6.2 on page 6-28. Also, see "Effects of Eccentricity" on page 16-6.

⌘ **ILIN** geometric nonlinearity flag:

- 0 – nonlinear strain-displacement relations
- 1 – linear strain-displacement relations

Note that with **ILIN** = 1, bifurcation buckling is suppressed in the shell unit

⌘ **IPLAS** material nonlinearity flag:

- 0 – elastic behavior only
- 1 – plasticity included, with the material law satisfied at each element integration point
- 2 – plasticity included, with the material law satisfied at the element centroid (centroidal plasticity)

IRAMP random imperfections flag:

- 0 – no random imperfection used
- 1 – random imperfections used

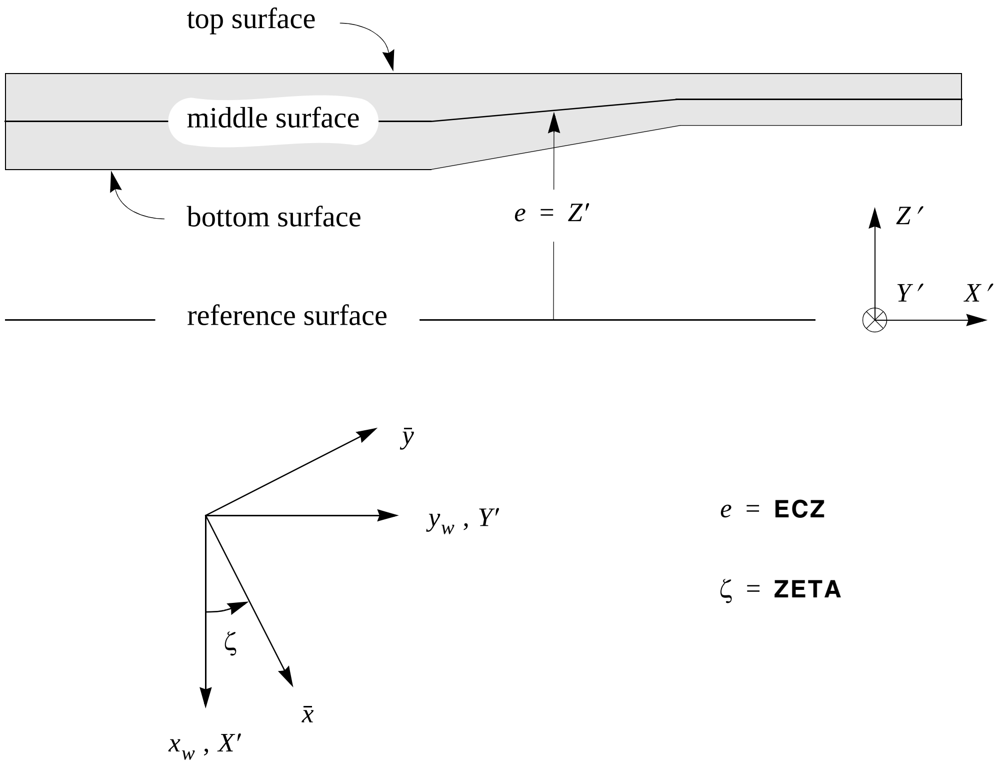


Figure 6.2 Shell wall orientation—eccentricity (top) and reference angle (bottom). Variable wall thickness and eccentricity, shown here, require user-written subroutine WALL (see Chapter 12 “User-Written Subroutines”). Also, see Figure 5.6 on page 5-130.

NFABS (M-1) fabrication-specification parameter

```
if  (fewer than NFABS fabrications have been specified)  then
    continue fabrication specification via additional M-5 record(s)
else
    if       (IWIMP > 0)    then   go to  M-6
    elseif   (IRAMP = 1)    then   go to  M-7a
    else                           go to  N-1
endif
```

M-6 Shell Imperfections

The M-6 records allow the user to define initial geometric imperfections in the shell reference surface. The imperfection consists of a deviation from the ideal geometry in the form of a displacement field (u_0, v_0, w_0). The imperfect shell unit is considered stress-free under zero load. Each record represents one component of the imperfection and the total initial displacement is obtained through addition of all the components. The components are trigonometric functions in the two-dimensional (X, Y) surface coordinate space, with maximum points located at $(X, Y) = (\mathbf{X1}, \mathbf{Y1})$, and with half wavelengths equal to **XL** in the X' direction and **YL** in the Y' direction. Notice that the dimensions of **XL**,**YL** are the same as of (X, Y), which depend upon the specific shell type (see "Standard Shell Surfaces" on page 6-2). For example, in a cylindrical shell, X is length, and Y is degrees.

The amplitude of each imperfection component, W_0, can be expressed as

$$W_0 = \mathbf{WAMP} \cdot \cos\left\{(\mathbf{X} - \mathbf{X1})\frac{\pi}{\mathbf{XL}}\right\} \cdot \cos\left\{(\mathbf{Y} - \mathbf{Y1})\frac{\pi}{\mathbf{YL}}\right\}$$

The record is repeated **IWIMP** times (M-5).

X1 Y1 XL YL WAMP ID

X1, Y1 value of the (X, Y) surface coordinates at one of the maximum points

XL half-wavelength of the imperfection in the X' direction;
if $\mathbf{XL} = 0$, $\mathbf{XL} = \infty$ is set

YL half-wavelength of the imperfection in the Y' direction;
if $\mathbf{YL} = 0$, $\mathbf{YL} = \infty$ is set

WAMP amplitude of imperfection component

ID component identifier:
1 – *u* imperfection
2 – *v* imperfection
0,3 – *w* imperfection

IRAMP (M-5) random imperfections flag

if (**IRAMP** = 1) then *go to* M-7a
else *go to* N-1

M-7a Random Imperfection Shapes

This record is used only if **IRAMP** = 1 (M-5). It defines the shape of a number of components defining randomly-determined initial geometric imperfections. The user defines with the parameters **N1** and **N2** the number of half-wavelengths of a “basic imperfection mode” over the shell unit dimensions in the (X', Y') shell coordinate directions. The program includes imperfections in all modes that are of the form

$$\begin{aligned} N &= \mathbf{N1} + i \cdot \mathbf{NI} \qquad & i &= 1, 2, \ldots \qquad & N &\le \mathbf{N2} \\ M &= \mathbf{M1} + j \cdot \mathbf{MI} \qquad & j &= 1, 2, \ldots \qquad & M &\le \mathbf{M2} \end{aligned}$$

where **N2** and **M2** represent the maximum number of halfwaves over the shell unit dimensions, and where **NI** and **MI** represent increments. The actual size of the imperfections can be printed. The components are harmonics in which both the magnitude and location of the maximum are independently chosen at random. Only transverse (w_0) random imperfections can be defined.

N1 N2 NI M1 M2 MI KTEST

N1 initial wave number in the X' direction

N2 final wave number in the X' direction

NI wave number increment in the X' direction

M1 initial wave number in the Y' direction

M2 final wave number in the Y' direction

MI wave number increment in the Y' direction

KTEST print option:

0 – no print of random imperfections
1 – print random imperfections generated

go to M-7b

M-7b Random Imperfection Amplitudes

This record is included only if **IRAMP** > 0 (M-5). It gives the information on which the amplitudes of random imperfection components are based. The amplitude, W_0, of each component is set equal to

$$W_0 = R(N, M) \cdot \mathbf{GRAMP}\left[\frac{N1 \cdot N2}{N \cdot N}\right]^{\mathbf{EXP}}$$

where **GRAMP** and **EXP** are input variables and *R(N,M)* is a random number with uniform probability in the interval $[-1, 1]$. The values of *R* are chosen independently for the different components. The exponent **EXP** is introduced because the shorter waves in the imperfection pattern are likely to have smaller amplitudes, as in a Fourier expansion of a continuous periodic function. Presently little experience is available on a value for **EXP**. Based on continuity arguments alone, **EXP** should be at least unity for so-called “smooth” imperfections found in most applications. Although in most cases restart executions will not require passing through the model setup phase again, in some situations (such as load and boundary condition changes) the random imperfections will be redefined. To preserve the same random pattern for these restarts, set **RANK** to some nonzero number.

GRAMP RANK EXP

GRAMP general random amplitude factor; random numbers will be chosen in the range [–**GRAMP**, **GRAMP**]

RANK random number initialization constant (seed)

EXP exponent used to scale the amplitude of imperfection components corresponding to higher harmonics

go to N-1

6.2 Discretization

The process of discretizing a shell unit into a number of finite elements is performed in two stages: (1) Grid Generation and (2) Mesh Generation.

Grid Generation

The user defines an “underlying grid” composed of “rows” and “columns,” the intersection of which are called “grid points.” The grid points (or “nodes”) are generated automatically such that rows and columns correspond to lines of constant *X* and *Y*, respectively. The computational freedoms (*dof*) at a grid point are in computational coordinates (x'', y'', z''), which are identical to shell coordinates (X', Y', Z') in a shell unit.

The spacing of rows and columns for either of the above options may be

- uniform
- segmented, *i.e.*, piecewise uniform
- variable

where spacing refers to ΔX or ΔY for the *standard mesh* and to ΔS or ΔT for the *specialized mesh*. The two mesh types are described next.

Mesh Generation

The user introduces an ‘‘overlying mesh’’ of finite elements, utilizing the underlying grid in one of the following ways:

Standard Mesh

Shell or plate elements are automatically introduced utilizing all underlying grid points. The user is required to select a basic “triangular” or “quadrilateral” element type from the element library (Chapter 14 “The Element Library”) to be used throughout the mesh. When quad elements are selected and the shell unit has a pole, **STAGS** substitutes triangles at the pole as and if required. Additionally, a “cutout” may be specified as a range of rows and columns within which no elements will be introduced.

Specialized Mesh — INACTIVE

Shell or plate elements are introduced in user-controlled “patches.” Each patch requires the definition of an element type, grid point connections of the first element, and some repetition parameters. By incorporation of the transition elements (X-ref) it is therefore possible to utilize a uniformly-spaced underlying grid to generate a mesh of variable refinement. Furthermore, it is acceptable to use any of the grid generating options as a basis for the overlying mesh, *i.e.*, for element generation. Grid points which are not utilized by elements remain inactive during the analysis and do not contribute any computational overhead.

Parts of the grid can be left open, *i.e.*, no elements are defined. In that case, these parts will represent cutouts.

Regardless of discretization procedure, the user should be aware of the following restrictions:

- The underlying grids of connected units must match, *i.e.*, have an equal number of grid points, along the juncture line.
- Adjacent elements should be of “consistent” types to achieve best results, *i.e.*, convergence and accuracy of the solution. Consistency, here, means that the elements have identical nodal and midside freedoms.

N-1 Discretization Control

This record establishes the “grid” and “mesh” generating options to be used in the discretization process. Reference will be made to the preceding paragraphs, which define these options, and to Chapter 14 “The Element Library”.

When a standard mesh is employed, the user’s choice for the **KELT** parameter on the N-1 record instructs **STAGS** (in most cases) to generate the element mesh for the shell unit utilizing as many shell, sandwich or solid elements of type **KELT** as may be required. In some cases, the (optional) **KELTX** parameter may also be used to specify an alternate triangular element type or common-side direction information, as described below. In any event, the **KELT** parameter must be specified and must be one of the following values: 320, 330, 410, 411, 420, 430, 480, 830, 840, 849, 881, 882, 883 or 885.

The choice of **KELT**=320 (or **KELT**=330) instructs **STAGS** to use two adjacent **E320** triangular elements (or two adjacent **E330** triangular elements) in each quadrilateral cell and to use a single **E320** element (or a single **E330** element) in each triangular cell of the shell unit being created. The **KELTX** parameter may be used here to specify the orientations of the common sides of these elements, as described below. If **KELTX** is omitted or set equal to zero, **STAGS** *alternates* the common-side direction as shown in sketch (a) in the following figure:

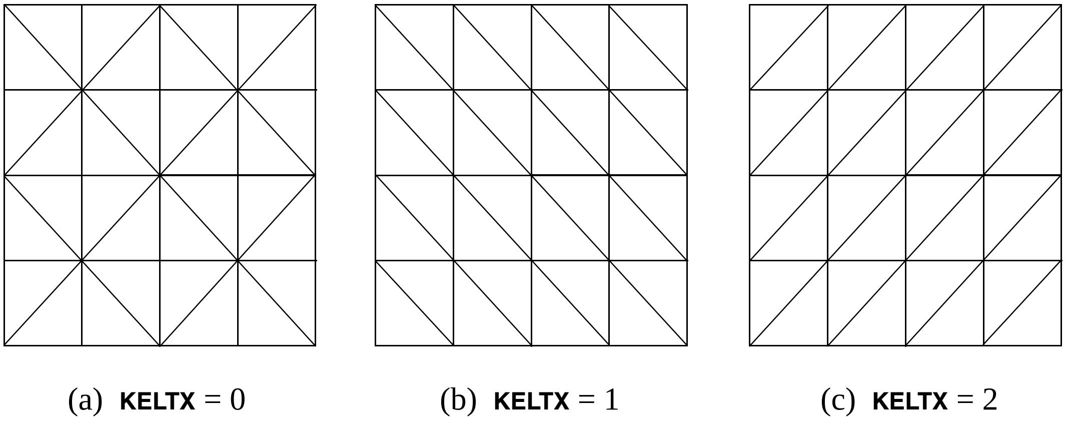


Figure 6.3 Influence of **KELTX** on **E320** or **E330** common-side directions.

The choice of **KELT**=410 (or **KELT**=411) instructs **STAGS** to use a single **E410** (or **E411**) quadrilateral element in each quadrilateral cell of the shell unit and to use a single **E320** or **E330** triangular element in each pole-imposed triangular cell. The **KELTX** parameter may be utilized here to specify the user's choice of **E320** or **E330** for the triangular element(s) to be used here. When transition elements are generated for an **E410**-type shell unit (as described below), the **KELT** parameter specifies the *basic element type* (**E410**) for the shell unit; and connectivity considerations on the boundary (or boundaries) dictate the type(s) of transition elements that are to be used.

The choice of **KELT**=420 (or 430) instructs **STAGS** to use two adjacent **E320** triangular elements (or two adjacent **E330** triangular elements) in each quadrilateral cell and to use a single **E320** (or **E330**) element in each triangular cell of the shell unit being created. Setting **KELT**=420 (or 430) gives exactly the same results as the **KELT**=320 (or **KELT**=330) choices described above.

The choice of **KELT**=480 instructs **STAGS** to use a single **E480** quadrilateral element in each 9-node quadrilateral cell of the shell unit (the nodal mesh for which must therefore have an odd number of rows and an odd number of columns). The current version of **STAGS** does not accommodate *poles* in or *transitions* involving **E480**-type shell units, so the **KELTX** and the **MESH1**, **MESH2**, **MESH3** and **MESH4** parameters should not be used.

The choice of **KELT**=830 instructs **STAGS** to use a single- or multi-layered **E830** *sandwich* construction (of alternating 3-node triangular thin-shell and 6-node triangular sandwich-core elements) for the shell unit in question. **STAGS** does not accommodate mesh transitions with **E830**-type shell units.

The choice of **KELT**=840 instructs **STAGS** to use a single- or multi-layered **E840** *sandwich* construction (of alternating 4-node quadrilateral thin-shell and 8-node sandwich-core elements) for the shell unit in question. The current version of **STAGS** does not accommodate *poles* in **E840**-type shell units, so the **KELTX** parameter should not be used. **STAGS** does accommodate mesh transitions with **E840**-type shell units, however; so **STAGS** does use the **MESH1**, **MESH2**, **MESH3** and **MESH4** parameters to generate type **E845** and/or type **E847** *sandwich transition elements* along the edge(s) of the shell unit, as and if required.

The choice of **KELT**=849 instructs **STAGS** to use a single- or multi-layered **E849** *sandwich* construction (of alternating 9-node thin-shell and 18-node sandwich-core elements) for the shell unit in question. **STAGS** does not accommodate mesh transitions with **E849**-type shell units.

The choice of **KELT**=881 instructs **STAGS** to use one or more **E881** solid elements through the thickness of each multi-layered quadrilateral cell of the shell unit. The current version of **STAGS** does not accommodate *poles* or *transitions* with **E881**-type shell units, so the **KELTX** **MESH1**, **MESH2**, **MESH3** and **MESH4** parameters should not be used.

The choice of **KELT**=882 (or **KELT**=883 or **KELT**=885) instructs **STAGS** to use one or more **E882** (or **E883** or **E885**) solid elements through the thickness of each multi-layered 9-node quadrilateral cell of the shell unit. The current version of **STAGS** does not accommodate *poles* or *transitions* with these types of shell units, so the **KELTX MESH1**, **MESH2**, **MESH3** and **MESH4** parameters should not be used.

With the **E410** element the user has the **INTEG** $= 1$ option to use a modified form of Gaussian integration in which the element centroid is added as the fifth integration point. The added point may, in some situations, suppress spurious strain-free deformation modes (mechanisms) that can crop up in cases involving intersecting free boundaries. In most cases, careful choice of boundary conditions will avoid such difficulties, making unnecessary the extra integration point that increases computational expense and decreases the rate of convergence as the grid is refined. For the **E411** elements, a full 3×3 Gaussian integration is provided to prevent spurious mechanisms. If the boundary conditions are known to prevent strain-free deformation modes, the user should choose the standard reduced 2×2 integration.

In the **E410** and **E411** elements, the bending strain energy is based on a Taylor series with 12 degrees of freedom (corresponding to the two in-plane rotations and the out-of-plane translation at each corner). The series must include two fourth order terms, x^3y and xy^3, which can lead to a small discontinuity between elements along a given edge. The user can essentially eliminate this discontinuity in the lateral displacements by requesting the use of a penalty function (**IPENL** $= 1$), which will make the element stiffer and could be helpful if the strain energy converges from below as the grid is refined.

When, for an **E410**-type shell unit, any of the variables **MESH1–MESH4** is set equal to 1 **STAGS** will flag every other node as *dependent* along the corresponding boundary. **STAGS** will then automatically generate **E510** or **E710** transition elements along that boundary to constrain out the dependent nodes. The **E510** element is used where a single dependent node occurs in an **E410** element. The **E710** element is used in a corner where refinement is requested along two adjacent lines (for example, if **MESH2** and **MESH3** are both set to 1). For more information about this, see “E510 and E710 Quadrilateral mesh-transition shell elements” on page 14-25.

Similarly, when any of the variables **MESH1–MESH4** is set equal to 1 for an **E840**-type shell unit, **STAGS** will flag every other node as *dependent* along the corresponding boundary and will then automatically generate **E845** or **E847** transition sandwich elements along that boundary to constrain out the dependent nodes. The **E845** element is used where a single dependent node occurs in an **E840** element. The **E847** element is used in a corner where refinement is requested along two adjacent lines (for example, if **MESH2** and **MESH3** are both set to 1). For more information about this, see “E845 and E847 mesh-transition sandwich elements” on page 14-46.

KELT NNX NNY IRREG IUGRID INTEG IPENL MESH1 MESH2 MESH3 MESH4 KELTX

KELT element code number (see Chapter 14 “The Element Library”)

>0 – standard mesh:

=	320	**E320** 3-node C^1 triangular shell element
=	330	**E330** 3-node C^0 MIN3 triangular shell element
=	410	**E410** 4-node C^1 quadrilateral shell element
=	411	**E411** 4-node C^1 quadrilateral shell element
=	420	pairs of **E320** 3-node triangular shell elements
=	430	pairs of **E330** 3-node triangular shell elements
=	480	**E480** 9-node C^0 ANS quadrilateral shell element
=	830	**E830** 6-node wedge-shaped sandwich solid/shell element
=	840	**E840** 8-node hexahedral-shaped quadrilateral sandwich solid/shell element
=	849	**E849** 18-node hexahedral-shaped quadrilateral sandwich solid/shell element
=	881	**E881** 8-node ANS hexahedral solid element
=	882	**E882** 18-node ANS hexahedral solid element
=	883	**E883** 27-node ANS hexahedral solid element
=	885	**E885** 20-node displacement-based hexahedral solid element

0 – ~~specialized mesh~~ — INACTIVE

NNX indicates row spacing of underlying grid; refers to the *X* coordinate

0 – uniform spacing in *X* direction

-1 – variable spacing, *X* coordinates defined on N-4 record

>0 – **NNX** defines the number of segments in the *X* direction, each with constant spacing; **NNX** ≤ 30

NNY indicates column spacing of underlying grid; refers to the *Y* coordinate

0 – uniform spacing in *Y* direction

-1 – variable spacing, *Y* coordinates defined on N-7 record

>0 – **NNY** defines the number of segments in the *Y* direction, each with constant spacing; **NNY** ≤ 30

IRREG mesh irregularities

0 – standard mesh with no irregularities

>0 – standard mesh with **IRREG** cutouts (to be defined on N-8 records) *(not operational with sandwich or solid elements)*

IUGRID (X, Y) surface coordinate range flag; relevant only when **ISHELL** = 1 (M-1).

By default, when **ISHELL** = 1, **PROP** (M-2) is used to set the range of (X, Y).

$$\mathbf{PROP(1)} \le X \le \mathbf{PROP(2)} \qquad \mathbf{PROP(3)} \le Y \le \mathbf{PROP(4)}$$

However, when **IUGRID** = 1, the range of (X, Y) is set to

$$0 \le X \le 1 \qquad 0 \le Y \le 1$$

PROP remains intact, but is not used by **STAGS** when **IUGRID** = 1. In that case, the user may assign any values to the **PROP** array, which is available in user-written subroutine LAME, used when **ISHELL** = 1.

Set **IUGRID** = 0 in all other cases

INTEG integration type:

0 **–** standard integration:
2×2 Gauss points, for **E410**, **E411** elements and **E840** face sheets
$2 \times 2 \times 2$ Gauss points (reduced integration), for **E885** elements

1 **–** modified 5-point integration, for **E410** and **E411** elements

2 **–** full 3×3 Gauss integration for **E411** element;

$3 \times 3 \times 3$ Gauss points, for **E885** elements (not recommended)

IPENL penalty option:

0 **–** no penalty function on fourth-order terms in elements **E410** and **E411**

1 **–** penalty function included in elements **E410** and **E411**

MESH1 governs generation of dependent nodes along boundary line 1

0 **–** no dependent nodes generated (the mesh is continuous between shell units along boundary line 1).

1 **–** generate dependent nodes along boundary line 1 (the mesh doubles between shell units along boundary line 1), this facilitates the use of **E510** and/or **E710** quadrilateral shell transition elements on boundary 1.

3 **–** generate dependent nodes along boundary line 1 (the mesh doubles between shell units along boundary line 1), this facilitates the use of **E330** triangular shell transition elements on boundary 1.

MESH2 governs generation of dependent nodes along boundary line 2

0 – no dependent nodes generated (the mesh is continuous between shell units along boundary line 2).

1 – generate dependent nodes along boundary line 2 (the mesh doubles between shell units along boundary line 2), for **E510** and/or **E710** quadrilateral shell transition elements.

3 – generate dependent nodes along boundary line 2 (the mesh doubles between shell units along boundary line 2), for **E330** triangular shell transition elements.

MESH3 governs generation of dependent nodes along boundary line 3

0 – no dependent nodes generated (the mesh is continuous between shell units along boundary line 3).

1 – generate dependent nodes along boundary line 3 (the mesh doubles between shell units along boundary line 3), for **E510** and/or **E710** quadrilateral shell transition elements.

3 – generate dependent nodes along boundary line 3 (the mesh doubles between shell units along boundary line 3), for **E330** triangular shell transition elements.

MESH4 governs generation of dependent nodes along boundary line 4

0 – no dependent nodes generated (the mesh is continuous between shell units along boundary line 4).

1 – generate dependent nodes along boundary line 4 (the mesh doubles between shell units along boundary line 4), for **E510** and/or **E710** quadrilateral shell transition elements.

3 – generate dependent nodes along boundary line 4 (the mesh doubles between shell units along boundary line 4), for **E330** triangular shell transition elements.

KELTX auxiliary element code or adjacent-element direction index:

if **KELT** = 420 or 430, then

KELTX = 320 — use type **E320** element(s) at pole

KELTX = 330 — use type **E330** element(s) at pole

if **KELT** = 320 or 330, then

KELTX = 0 — alternate common-side directions throughout the mesh

KELTX = 1 — constant common-side direction, not intersecting (0,0)

KELTX = 2 — constant common-side direction, intersecting (0,0)

```
if       (NNX > 0)      then  go to  N-2
elseif   (NNX = -1)     then  go to  N-4
elseif   (NNY > 0)      then  go to  N-5
elseif   (NNY = -1)     then  go to  N-7
elseif   (IRREG = 1)    then  go to  N-8
else                    follow instructions at end of  N-8
```

N-2 X–Segment Length

This record is included only if **NNX** > 0 (N-1).

SEGLX(i), i=1,NNX

SEGLX(i) length of segment *i*

Note: Segment lengths are in the user's units except when **ISHELL = 3** (quadrilateral plate); for that case, the coordinates are scaled to the range [0,1], so that **SEGLX(i)** are fractions of the unit interval.

go to N-3

N-3 X–Segment Spacing

This record is included only if **NNX** > 0 (N-1).

NSEGX(i), i=1,NNX

NSEGX(i) number of intervals within segment *i*

✦ *follow instructions at end of* N-4

N-4 X–Coordinate

This record is used to read in a sequence of *X* coordinates. It is included only if **NNX** = –1 (N-1).

X(i), i = 1, NROWS

X(i) *X* value for row *i*; must be monotonically increasing.
NROWS, number of rows, was read on F-1 record.

Note: Coordinate values are in the user's units except when **ISHEL= 3** (quadrilateral plate); for that case, the coordinates are scaled to the range [0,1], so that the **X(i)** are points on the unit interval.

```
if       (NNY > 0)     then  go to  N-5
elseif   (NNY = -1)    then  go to  N-7
elseif   (IRREG = 1)   then  go to  N-8
else                   follow instructions at end of  N-8
```

N-5 Y–Segment Length

This record is included only if **NNY** > 0 (N-1).

SEGLY(j), j = 1, NNY

SEGLY(j) length of segment *j*

Note: Segment lengths are in the user's units except when **ISHELL = 3** (quadrilateral plate); for that case, the coordinates are scaled to the range [0,1], so that **SEGLY(i)** are fractions of the unit interval.

✦ *go to* N-6

N-6 Y–Segment Spacing

This record is included only if **NNY** > 0 (N-1).

NSEGY(j), j = 1, NNY

NSEGY(j) number of intervals within segment *j*

✦ *follow instructions at end of* N-7

N-7 Y–Coordinate

This record is used to read in a sequence of *Y* coordinates. It is included only if **NNY** = –1 (N-1).

Y(j), j = 1, NCOLS

Y(j) *Y* value for column *j*; must be monotonically increasing.
NCOLS, number of columns, was read on an F-1 record.

Note: Coordinate values are in the user's units except when **ISHELL = 3** (quadrilateral plate); for that case, the coordinates are scaled to the range [0,1], so that the **Y(i)** are points on the unit interval.

✦ if (**IRREG** = 1) then *go to* N-8
else *follow instructions at end of* N-8

N-8 Mesh Irregularity

This record is included only if **IRREG** > 0 (N-1). It is used to define the bounding grid lines of cutouts. Figure 6.4 shows a cutout in the shell surface located at boundary line 4 and rectangular in the *X*, *Y* space (*i.e.*, the edge follows two intersecting grid lines). Here, **NRW1**, **NRW2**, **NCL1**, and **NCL2** are row and column numbers corresponding to cutout boundaries. Cutouts of more general shape can be introduced by setting the shell thickness equal to zero inside the cutout with user-written subroutine WALL,

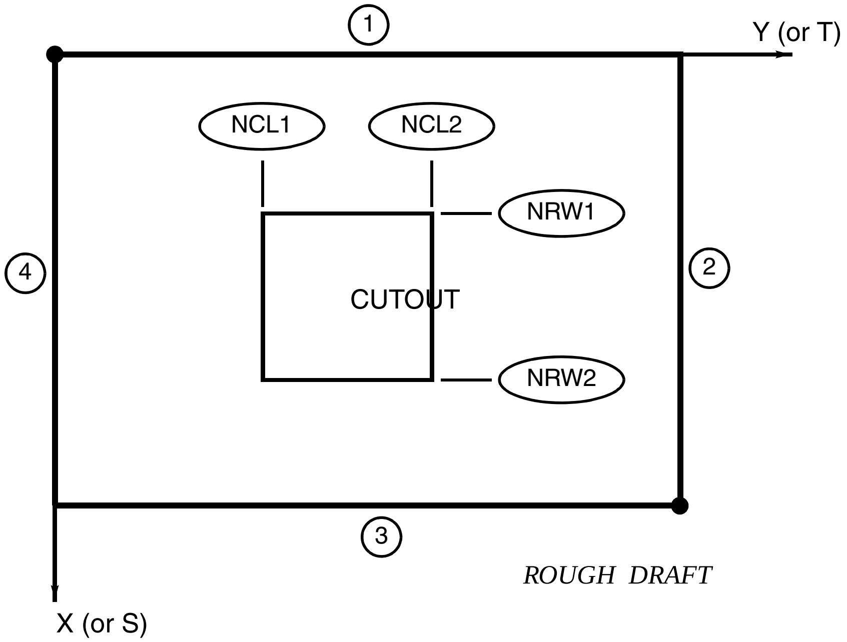


Figure 6.4 Shell unit with cutout.

A total of **IRREG** cutouts may be defined, and the cutouts may overlap, so that the resulting combined cutout is the union of all cutouts. This record is repeated **IRREG** times.

NRW1 NRW2 NCL1 NCL2

NRW1 row number of one edge of cutout

NRW2 row number of opposite edge of cutout; **NRW2** > **NRW1**

NCL1 column number of one edge of cutout

NCL2 column number of opposite edge of cutout; **NCL2** > **NCL1**

NSTFS	(B-2)	number of shell units with discrete stiffeners
IUNIT	(F-2)	unit currently being defined
NRGS	(F-2)	number of rings in **IUNIT**
NSTR	(F-2)	number of stringers in **IUNIT**

```
if       (NRGS > 0)   then  go to O-1a
elseif   (NSTR > 0)   then  go to O-2a
else                        go to P-1
```

6.3 Discrete Stiffeners

Discrete stiffeners may be

- parallel to lines with constant *X*; such stiffeners are sometimes referred to as rings
- parallel to lines with constant *Y*; such stiffeners are sometimes referred to as stringers

Discrete stiffener records (O-1a through O-3b) define the location, eccentricity, and property identification of each stiffener. Cross section properties are specified by reference to the data tables defined on the J records.

Within each shell unit discrete stiffeners are assigned a number given by the order in which they are defined.

If the cross-section number is set to -1, the “moving plane boundary condition” is invoked. Discussed in detail under “B-2 General Model Summary” on page 5-12, this multi-point constraint is like a symmetry boundary, except that the plane of symmetry is allowed to rotate and translate as a rigid body. Each moving plane boundary is treated exactly like a ring or stringer, and counted as such (B-2 and F-2). Moving plane boundaries can be superimposed on real stiffeners, and real stiffeners can be stacked (please note the comments about plasticity and cross-section fabrication under “J-1 Cross-Section” on page 5-118).

O-1a Discrete Ring—Record 1

A ring is a stiffener which runs along a line of constant X'. This record assigns a cross-section to a ring stiffener by reference to the Data Tables (see Section 5.6 “Data Tables” on page 5-57). *Eccentricity* of beam axis and *orientation* of beam cross-section are also specified. *Location* is specified on O-1b. The O-1a/b sequence is repeated **NRGS** times (F-2).

ICROSS XSI ECY ECZ ILIN IPLAS

ICROSS cross-section number, as defined by **ITAB** (J-1) in the Cross Section Table:
ICROSS $= 0$ indicates that the stiffener is defined in user-written CROSS
ICROSS $= -1$ indicates that the stiffener line is a moving plane boundary

When **ICROSS** $= 0$, data below indicated by ⌘ are defined in CROSS. They are automatically initialized to zero before CROSS is called, thereby superseding any nonzero values input here. When **ICROSS** $= -1$, only **ECY** is relevant. Refer to Figure 6.5 on page 6-52 for an illustration of **XSI**, **ECY**, and **ECZ**.

⌘ **XSI** angle ξ, in degrees, between the shell normal Z' and the cross section $\bar{z}$. ξ is a right-handed rotation about $\bar{x}$, the longitudinal axis of the ring, which is parallel to Y'.

⌘ **ECY** eccentricity in the X' direction. **ECY** is the X' coordinate of the (X', Z') pair which positions the origin of the $(\bar{y}, \bar{z})$ system. For **ICROSS** $= -1$ (moving plane boundary), **ECY** is a scale factor used for the numerical conditioning of Lagrange constraints introduced by the multi-point constraint. In that case, **ECY** should be of the same order of magnitude as entries in the stiffness matrix. A good guess is the modulus of elasticity of the material.

⌘ **ECZ** eccentricity in the Z' direction. **ECZ** is the Z' coordinate of the (X', Z') pair which positions the origin of the $(\bar{y}, \bar{z})$ system.

⌘ **ILIN** geometric nonlinearity flag:

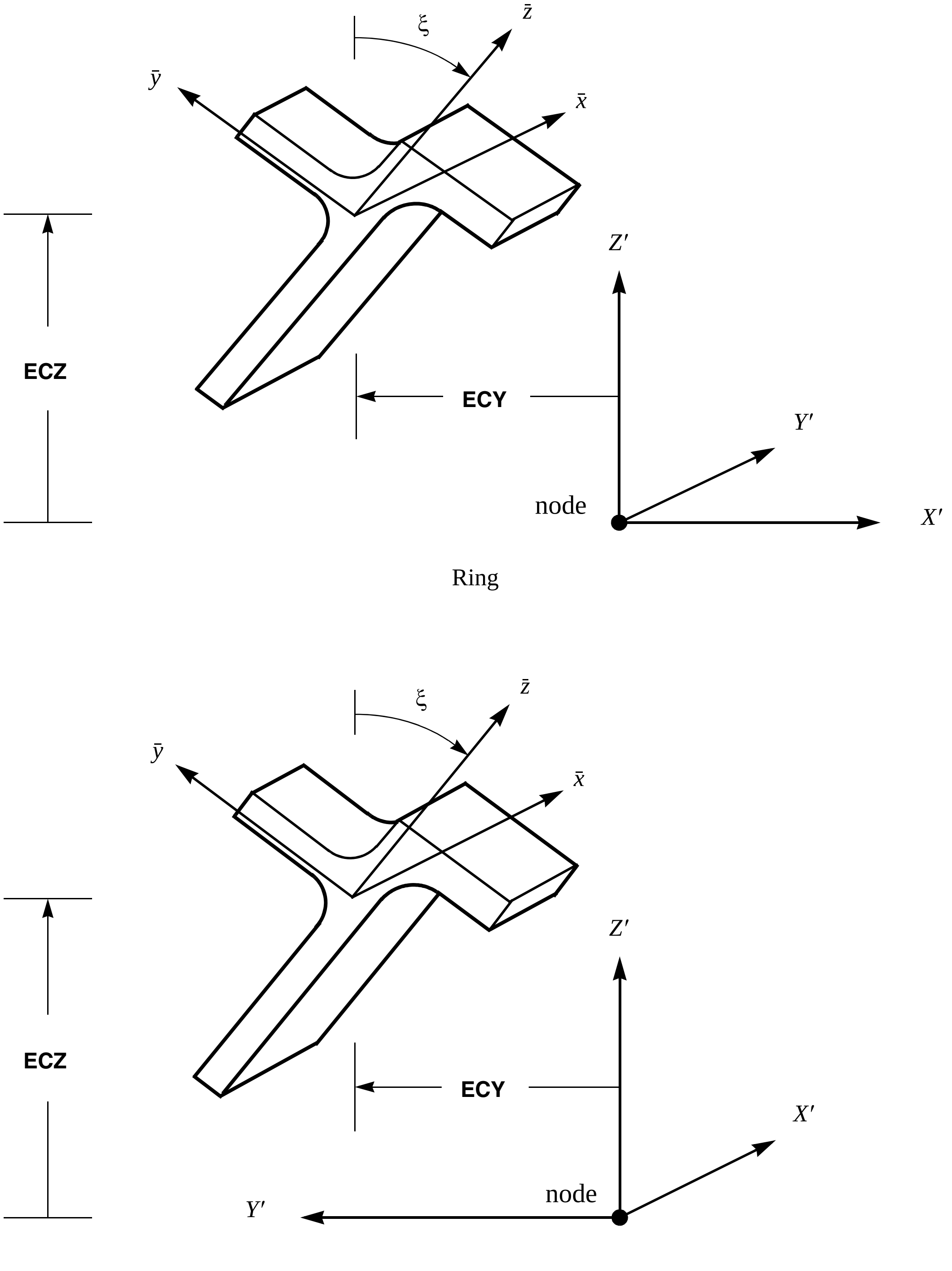
0 – nonlinear strain-displacement relations

1 – linear strain-displacement relations

⌘ **IPLAS** material nonlinearity flag (see M-5):

0 – linear elastic constitutive relations
1 – plasticity included
2 – centroidal plasticity

✦ *go to* O-1b



Ring

Stringer

Figure 6.5 Eccentricity and orientation of stiffener cross sections.

Compare with Figure 5.5 “Beam cross sections.” on page 5-122.
Also, see Section 16.2 “Beam Results” on page 16-8.

O-1b Discrete Ring—Record 2

This record specifies the location on the shell surface of a discrete ring. The stiffener location can be defined either by its row number and the column numbers at its end points or by corresponding surface coordinate values (X, Y). Use of surface coordinates is convenient if the grid is changed in subsequent runs. If the coordinates **(XR, YR1, YR2)** do not coincide with a grid line, **STAGS** will select the closest grid line. **(XR, YR1, YR2)** are ignored unless corresponding row or column numbers **(IR, JR1, JR2)** are set to zero.

IR JR1 JR2 XR YR1 YR2

IR row number of ring; **IR** $= 0$ indicates that the location is given by the coordinate value **XR**

JR1 column number at beginning of ring; **JR1** $= 0$ indicates that this location is given by the coordinate value **YR1**

JR2 column number at end of ring $($**JR2** $>$ **JR1**$)$; **JR2** $= 0$ indicates that this location is given by the coordinate value **YR2**

XR X coordinate of ring; ignored if **IR** > 0

YR1 Y at beginning of ring; ignored if **JR1** > 0

YR2 Y at end of ring; $($**YR2** $>$ **YR1**$)$; ignored if **JR2** > 0

✦

NSTFS	(B-2)	number of shell units with discrete stiffeners
IUNIT	(F-2)	unit currently being defined
NRGS	(F-2)	number of rings in **IUNIT**
NSTR	(F-2)	number of stringers in **IUNIT**

```
if (NRGS rings have been defined) then
    if (NSTR > 0)      then  go to O-2a
    else                     go to P-1
else    continue defining O-1a/b
```

O-2a Discrete Stringer—Record 1

A stringer is a stiffener which runs along a line of constant Y'. This record assigns a cross-section to a stringer by referencing the Data Tables (see Section 5.6 “Data Tables”). *Eccentricity* of beam axis and *orientation* of beam cross-section are also specified. *Location* is specified on O-2b. The O-2a/b sequence is repeated **NSTR** times (F-2).

ICROSS XSI ECY ECZ ILIN IPLAS

ICROSS cross-section number, as defined by **ITAB** (J-1) in the Cross Section Table:

ICROSS $= 0$ indicates that the stiffener is defined in user-written CROSS.
ICROSS $= -1$ indicates that the stiffener line is a moving plane boundary.

When **ICROSS** $= 0$, data below indicated by ⌘ are defined in CROSS. They are automatically initialized to zero before CROSS is called, thereby superseding any nonzero values input here. When **ICROSS** $= -1$, only **ECY** is relevant. Refer to Figure 6.5 on page 6-52 for an illustration of **XSI**, **ECY**, and **ECZ**.

⌘ **XSI** angle ξ, in degrees, between the shell normal Z' and the cross section $\bar{z}$. ξ is a right-handed rotation about $\bar{x}$, the longitudinal axis of the stringer, which is parallel to X'.

⌘ **ECY** eccentricity in the Y' direction. **ECY** is the Y' coordinate of the (Y', Z') pair which positions the origin of the $(\bar{y}, \bar{z})$ system. For **ICROSS** $= -1$ (moving plane boundary), **ECY** is a scale factor used for the numerical conditioning of Lagrange constraints introduced by the multi-point constraint. In that case, **ECY** should be of the same order of magnitude as entries in the stiffness matrix. A good guess is the modulus of elasticity of the material.

⌘ **ECZ** eccentricity in the Z' direction. **ECZ** is the Z' coordinate of the (Y', Z') pair which positions the origin of the $(\bar{y}, \bar{z})$ system.

⌘ **ILIN** geometric nonlinearity flag:

0 – nonlinear strain-displacement relations

1 – linear strain-displacement relations

⌘ **IPLAS** material nonlinearity flag (see M-5):

0 – linear elastic constitutive relations
1 – plasticity included
2 – centroidal plasticity

✦ *go to* O-2b

O-2b Discrete Stringer—Record 2

This record specifies the location on the shell surface of a discrete stringer. The stiffener location can be defined either by its column number and the row numbers at its end points or by corresponding surface coordinate values (X, Y). Use of surface coordinates is convenient if the grid is changed in subsequent runs. If the coordinates **(YS, XS1, XS2)** do not coincide with a grid line, **STAGS** will select the closest grid line. **(YS, XS1, XS2)** are ignored unless corresponding row or column numbers **(JS, IS1, IS2)** are set to zero.

JS IS1 IS2 YS XS1 XS2

JS column number of stringer; **JS** $= 0$ indicates that the location is given by the coordinate value **YS**

IS1 row number at beginning of stringer; **IS1** $= 0$ indicates that this location is given by the coordinate value **XS1**

IS2 row number at end of stringer (**IS2** $>$ **IS1**); **IS2** $= 0$ indicates that this location is given by the coordinate value **XS2**

YS Y coordinate of stringer; ignored if **JS** > 0

XS1 X at beginning of stringer; ignored if **IS1** > 0

XS2 X at end of stringer; (**XS2** $>$ **XS1**); ignored if **IS2** > 0

NSTFS	(B-2)	number of shell units with discrete stiffeners
IUNIT	(F-2)	unit currently being defined
NSTR	(F-2)	number of stringers in **IUNIT**

if (**NSTR** stringers have been defined) then *go to* P-1
else *continue defining* O-2a/b

6.4 Boundary Conditions

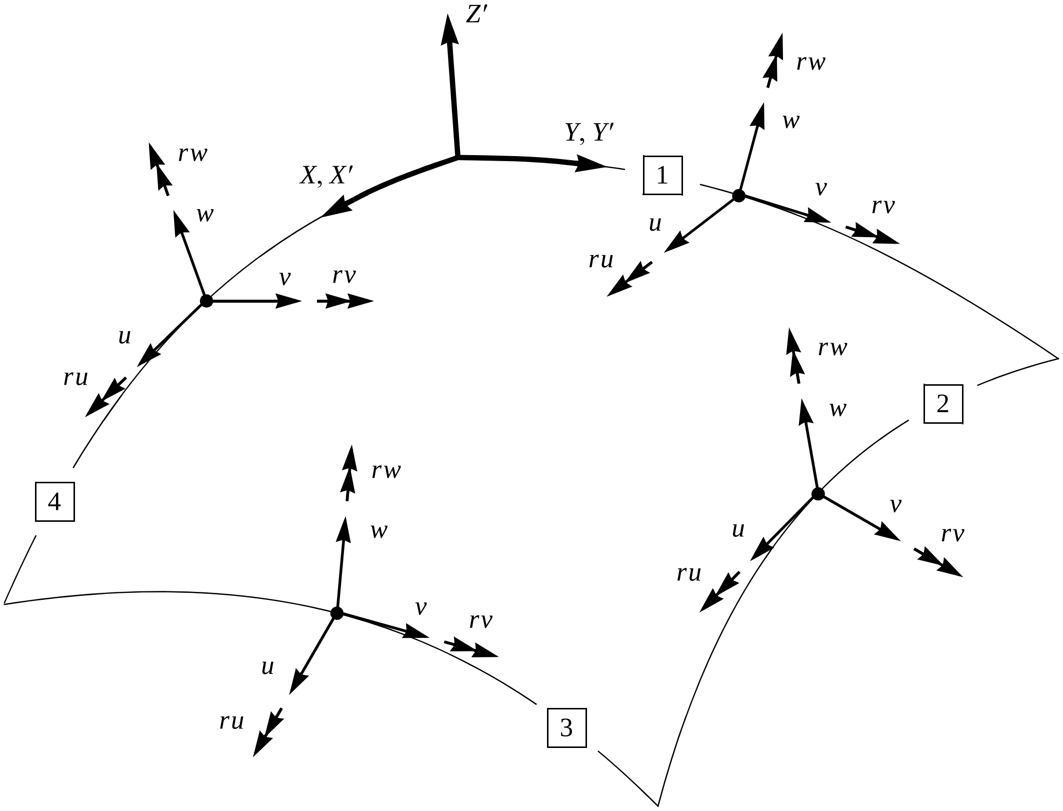
Records P-1 through P-4 are used to define constraints along boundary lines. Certain frequently-occurring boundary conditions may be defined on these records. For other types of constraints such as those applied at interior points, it is sometimes possible to use the load records (Q-1, Q-2, Q-3), defined on pages 6-67, 6-69 and 6-70. For cases with more complicated constraints, a user-written subroutine UCONST is included, or the constraints can be defined on data records as indicated on record B-2 (see, for example, the G-2 and G-3 records).

The unknowns at a juncture line are represented by the displacement components in the direction of the shell coordinates (X', Y', Z') on the shell unit with the lowest number of those involved in the juncture. In general, the constraints are most readily introduced on the shell unit with the lowest number. Some care must be exercised when boundary conditions (P-1 through P-4 records) are introduced on the boundary lines that meet the juncture line to make sure that this does not introduce undue constraints. A case in point involves an annulus with a pole (radius of hole is zero): boundary line 1 (that has zero length) must be left unconstrained, **IBLN**(**1**) = 3, since the single node at the pole already satisfies the boundary conditions imposed along the two intersecting edges 2 and 4.

Boundary lines are numbered 1–4 as shown in Figure 6.6 on page 6-58. This figure also shows the positive directions for displacement components. (u, v) are in the tangent plane of the shell, w is in the direction of the shell normal, and (ru, rv, rw) are the corresponding rotations. (u, v, w) are in the (X', Y', Z') shell coordinate directions. This holds at every node (both interior and boundary nodes) for all shell types, including the user-generated shell unit (**ISHELL** = 1, M-1).

Note that the condition of antisymmetry is identical to the simple support condition. This boundary condition as it stands causes problems for nonlinear executions involving very large rotations; at the time of publication, this boundary condition is being generalized to handle arbitrary response conditions. See Table 6.2 for a summary of boundary condition types.

Do not define constraints that are in conflict with displacements defined on load records. For example, the simple support boundary condition cannot be used together with a specified tangential displacement. A load applied on a clamped edge is ignored. Do not allow rigid body motion in a static analysis. If the boundary conditions as defined here allow rigid body motions, it is usually best to constrain the structure at suitably selected points by use of the load records (Q-1, Q-2, Q-3).



boundary line 1 corresponds to row 1
boundary line 2 corresponds to column **NCOLS** (F-1)
boundary line 3 corresponds to row **NROWS** (F-1)
boundary line 4 corresponds to column 1

Figure 6.6 Sign conventions for displacement components.

It is possible to define different boundary conditions for the pre-critical stress state (*basic* BC) and the incremental state (*incremental* BC) in the case of the bifurcation buckling analysis by setting **INCBC** = 1 (B-1). Incremental BC are meaningful for bifurcation buckling analyses (**INDIC** = 1 or 4, B-1) only.

When incremental BC are included (**INCBC** = 1), the default condition is that they are the same as the basic BC. Default incremental BC may be selectively overridden in two ways—by setting **IBOND** = 1 (P-1), and by defining load system B with specified displacements (**LT** = –1, Q-3).

Table 6.2 Boundary condition (BC) summary; refer to Figure 6.6.
See P-2 record for an explanation of **ITRA**, **IROT**.

BC type	boundary	fixed	free	**ITRA**	**IROT**
simple support	1, 3	*v*, *w*, *ru*	*u*, *rv*, *rw*	100	011
	2, 4	*u*, *w*, *rv*	*v*, *ru*, *rw*	010	101
symmetry	1, 3	*u*, *rv*, *rw*	*v*, *w*, *ru*	011	100
	2, 4	*v*, *ru*, *rw*	*u*, *w*, *rv*	101	010
clamped	all *dof* fixed			000	000
antisymmetry	identical to simple support				

In this situation, the value of the displacement (**P**, on the Q-3 record) is ignored, and a *dof* constraint (*i.e.*, specified zero) is applied to the incremental BC. When different boundary conditions for buckling have been chosen, specified displacements in load system A (Q-1–Q-3) apply to the pre-critical stress state but not to the buckling solution, while specified-zero displacements in load system B apply to the buckling solution only. In such cases, a starting load factor for load system B (**STLD(2)**, C-1) is not needed. This is of particular concern with finite element models using solid and/or sandwich elements.

Lagrangian constraints (G-3/4 or UCONST) and partial compatibility (G-2) apply to both pre-critical and buckling analyses.

In an eigenvalue analysis with a nonlinear stress state, incremental BC are not necessary because it is much more straightforward to perform the nonlinear stress analysis in a separate run and to modify the P-1 and P-2 records in the subsequent eigenvalue analysis. Modifications to boundary conditions and loading are always permitted before restart.

P-1 Boundary Conditions—Record 1

IBLN(i), i = 1, 4 IBOND

IBLN(i) boundary-condition code for boundary line *i, i=1,4*; see Figure 6.6

0 – specified on P-2 records

1 – simple support

2 – clamped

3 – unrestrained

4 – symmetry

5 – antisymmetry

6 – compatibility with displacement on some boundary line (see G-1). This is the same as unrestrained, except that the user is informed that the boundary line is junctured in this case.

WARNING*:* It has been reported that under certain conditions **STAGS** applies erroneous BC at poles when **IBLN(i)** > 0 on a side which degenerates to a pole. (Please see "M-2 Shell Surface Constants" and Table 6.1 on page 6-17 for conditions where poles are generated.) It is recommended that **IBLN(i)** = 0 be set for a side which degenerates to a pole, and that BC be defined using P-2 (see Section 6.4 "Boundary Conditions" and Table 6.2). If this is not done, results should be checked carefully to ensure that proper BC have been applied.

IBOND boundary conditions for incremental and basic (prebuckling, prestress) displacements are:

0 – identical

1 – different; may be used only with **INDIC** = 1 or 4 (B-1)

```
if      (IBLN(i) = 0 for one or more boundaries)  then   go to  P-2
elseif  (IBOND = 1)  then   go to  P-3
else    follow instructions at end of  P-4
```

P-2 Boundary Conditions—Record 2

This record is included only if **IBLN**(**i**) = 0 (P-1) for one or more shell-unit boundaries. A single P-2 record is required for each boundary line for which **IBLN**(**i**) = 0 has been specified. These P-2 records are ordered according to the boundary-line numbering scheme, 1–4, as shown in Figure 6.6 on page 6-58.

ITRA IROT

ITRA a 3-digit binary integer indicating freedom or constraint for each of the three translational displacement components (u, v, w). The significance of each binary digit is as follows:

`0`—fixed `1`—free

The most significant digit corresponds to *u*, and the least significant to *w*. For example, to specify *u* fixed and *v*, *w* free

ITRA = `011`

IROT a 3-digit binary integer indicating freedom or constraint for each of the three rotational displacement components (ru, rv, rw). For example, to specify *rv* fixed, and *ru*, *rw* free

IROT = `101`

For the examples given above (*u*, *rv* fixed; *v*, *w*, *ru*, *rw* free), the P-2 record for the corresponding boundary would be defined as

```
011   101      $ P-2
```

Note that imbedded spaces are not permitted within either **ITRA** or **IROT**; these two 3-digit binary integers must be separated by one or more spaces or by other legal data terminators (see 5.3 “Input Format Conventions” on page 5-4).

Also note that a separate P-2 record is defined for each additional boundary *i*, if any, indicated by **IBLN**(**i**) = 0 (P-1).

✦ **IBOND** (P-1) basic/incremental BC flag

if (**IBOND** = 1) then *go to* P-3
else *follow instructions at end of* P-4

P-3 Boundary Conditions—Record 3

This record is included only if incremental displacements and displacements in the basic stress state are subject to different constraints (**IBOND** = 1, P-1).

JBLN(i), i = 1, 4

JBLN(i) boundary-condition code for boundary line *i*, *i=1,4*; see Figure 6.6

0 – specified on P-4 records
1 – simple support
2 – clamped
3 – unrestrained
4 – symmetry
5 – antisymmetry
6 – compatibility with displacement on some boundary line (see G-1).

if (**JBLN(i)** = 0 for one or more boundaries) then *go to* P-4
else *follow instructions at end of* P-4

P-4 Boundary Conditions—Record 4

This record is included only if **JBLN**(**i**) = 0 (P-3) for one or more shell-unit boundaries. A P-4 record is defined for each boundary line where **JBLN**(**i**) = 0 has been specified. P-4 records are ordered according to the boundary-line numbering scheme, 1 – 4, as shown in Figure 6.6.

JTRA JROT

JTRA a 3-digit binary integer indicating freedom or constraint for each of the three translational displacement components (u, v, w). See **ITRA** (P-2).

JROT a 3-digit binary integer indicating freedom or constraint for each of the three rotational displacement components (ru, rv, rw). See **IROT** (P-2).

✦ *go to* Q-1

6.5 Loads

STAGS utilizes two independent load systems, *load system A* and *load system B*. Loading on the structure is computed as

$$\mathbf{p} = P_A \cdot \mathbf{f_A} + P_B \cdot \mathbf{f_B}$$

where

P_A and P_B are *load factors* for load systems A and B.

$\mathbf{f_A}$ and $\mathbf{f_B}$ are *base loads* for load systems A and B.

$P_A \cdot \mathbf{f_A}$ and $P_B \cdot \mathbf{f_B}$ are *scaled loads* for load systems A and B.

$\mathbf{p}$ represents the *applied loads*.

Load factors, P_A = **PA** and P_B = **PB**, are specified on the C-1 record (in the *case.bin* file) for static analysis and on the E-3/E-4 records for dynamic analysis. User-written subroutine FORCET allows a more generalized load-factor history for transient analysis. For shell units, base loads $\mathbf{f_A}$ and $\mathbf{f_B}$ are defined on the Q-1–Q-3 records. Base loads can also be specified *via*: U-1–U-3 records, for element units; user-written subroutine USRLD, which is an alternative to the Q/U records; and user-written subroutine TEMP, for thermal loading. User-written subroutine UPRESS provides a more generalized pressure-loading feature. Inertial loads defined by the B-6 records are also included in the base load vectors and are scaled by the appropriate load factors.

In addition to forces, base loads include prescribed displacements. We distinguish between *prescribed displacements* and *initial conditions,* both of which are defined on Q-3 when **LT** $= -1$. Prescribed displacements are nonzero displacement constraints which may be specified in both static and dynamic analysis. Initial conditions represent nodal displacements and velocities applied to the structure at time t = **TMIN** (E-1) in a transient analysis. Initial displacements are equivalent to statically-applied prescribed displacements, with the associated constraints removed upon commencement of the transient analysis ($t >$ **TMIN**). Initial conditions are meaningful only when **INDIC** = 6 or 7 (B-1), and for initial velocities, when **IVELO** = 1 (E-2).

It follows that prescribed displacements and initial conditions are mutually exclusive events. Where a nodal degree-of-freedom (*dof*) has been constrained (either fixed or prescribed nonzero), an initial condition applied to that *dof* is ignored, since it no longer is present in the system of equations due to the specified constraint. Similarly, where a *dof* has been fixed by a boundary condition (P records), a prescribed displacement is ignored. Notice the order of precedence where conflicting conditions have been specified: fixity takes precedence over a prescribed displacement, which takes precedence over an initial condition.

For bifurcation buckling, the critical load combination is given by $\lambda P_A \cdot \mathbf{f_A} + P_B \cdot \mathbf{f_B}$, where λ is the computed eignevalue. That is, the B-system represents a set of fixed loads.

Point forces, line loads, and surface tractions are generally assumed to maintain their original direction during loading. The only exception to this is if a normal pressure (on the Q-3 record) is defined as a “live pressure load.” In that case the pressure is applied normal to the deformed shell surface. If the loads thus are allowed to rotate during deformation the system is not necessarily conservative.

If **IUPLDA** or **IUPLDB** (ET-1) is set to unity, the load sets are assumed to rotate with the nodes in question (follower loading). This option can be useful when modeling an endplate with boundary conditions and line loads, since ordinary line loads do not account for the rotation of the plate. Since these loads are not conservative, they should be used with care.

If a nonzero displacement is defined on a Q-3 record, this displacement will be multiplied by the load factor in the same way as a regular load. The option can also be used for introduction of constraints, as discussed under Section 6.4 “Boundary Conditions”. Fixing a displacement to zero introduces a constraint.

The basic loads with fixed direction in any of the load systems can be defined either partially or totally by a user-written subroutine USRLD. A live load that varies with the shell coordinates must be defined in a user-written subroutine UPRESS. In contrast to other forms of loading, the distribution of the live pressures defined in UPRESS can vary with time.

A uniform stress state is defined for bifurcation buckling or vibration analysis in a Q-5 record. Load system records in that case are only meaningful if they apply homogeneous displacement constraints.

As was described under Section 6.4 “Boundary Conditions”, it is possible to specify incremental boundary conditions for a bifurcation analysis (**INDIC** = 1 or 4, B-1) that can be different from those for the pre-critical stress state. For shell units, if **IBOND** = 1 (P-1), specified displacements for load system A apply to the prebuckling state, and specified displacements for load system B become the incremental constraints. It should be noted that only a zero specified displacement may be used in load B for buckling boundary conditions. It should also be noted that a buckling analysis must be requested to make this meaningful. For element units, set **INDIC** = –1 (B-1) to achieve the same effect.

The cable hinge moment and cable hinge restraint are a generalized moment and complementary constraint condition suitable for a large rotation response to moment loading. For linear analysis or when the rotations at a node are small, the cable hinge moment is identical to a torsional moment directed along the axis of a cable, which is usually modeled with standard beam elements like the **E210** beam element (see Chapter 14 “The Element Library”). When rotations become large, the torsional moment is no longer conservative and will produce poor convergence and unanticipated response. A conservative hinge moment that is in agreement with what is expected for a hinged cable under torsional moment loading is

$$\mathbf{m_q} = \frac{\mathbf{q} + \mathbf{e}}{\mathbf{1} + \mathbf{q} \cdot \mathbf{e}} \left| \mathbf{m_e} \right|$$

where $\mathbf{q}$ is the unit vector along the current beam axis at the node being loaded, where $\mathbf{e}$ is the user load direction (the unit vector in the direction of the applied moment), where $\left|\mathbf{m_e}\right|$ is the magnitude of the applied moment, and where $\left|\mathbf{m_q}\right|$ is the point load at the node used by **STAGS**. The cable hinge constraint is the corresponding boundary condition resulting from applying just the right amount of cable moment loading to prevent axial twist. Its small-rotation counterpart is the suppression of axial rotational freedom.

Q-1 Loads Summary

This record summarizes the load data to be defined for the shell unit. It is always included in each of the shell units.

Temperatures are not defined on Q records. See the C-1 record in Chapter 11 and user-written subroutine TEMP in Chapter 12.

NSYS NICS NAMS NUSS NHINGE NMOMNT NLEAST IPRESS

NSYS number of load systems. There are two load systems available—load system A and load system B. Either or both may be included; $\therefore$ **NSYS** ≤ 2

NICS number of sets of initial conditions for a transient analysis (**INDIC** = 6 or 7) (B-1). Two types of initial conditions are permissible—initial velocity and initial displacement. Either or both may be included; $\therefore$ **NICS** ≤ 2. These conditions are prescribed at time t = **TMIN** (E-1). If **INDIC** ≤ 5, initial conditions are irrelevant, though they still may be defined, perhaps in preparation for an anticipated transient analysis.

NAMS number of attached masses

NUSS **NUSS** > 0 indicates that a uniform basic stress state will be defined on Q-5 for vibration or bifurcation buckling

NHINGE number of cable hinge restraint vectors

NMOMNT number of cable hinge moment loading vectors (must be 0, currently)

NLEAST number of least-squares loading sets

IPRESS

0 – no UPRESS

1 – UPRESS is included

User-written subroutine UPRESS defines pressure—surface loading which acts normal to the element surface. The inclusion of UPRESS precludes the definition of pressure loading in the *INP* file. When **IPRESS** = 1, any pressure loads defined on Q-3/U-3 records (**LT** = 4 or 5) are ignored.

```
✦ if      ((NSYS > 0) or (NICS > 0)) then  go to  Q-2
  elseif  (NAMS > 0)                 then  go to  Q-4
  elseif  (NUSS > 0)                 then  go to  Q-5
  elseif  (NHINGE > 0)               then  go to  Q-6
  elseif  (NMOMNT > 0)               then  go to  Q-7
  elseif  (NLEAST > 0)               then  go to  Q-8a
  else                               go to  R-1
```

Q-2 Load Set Summary

The number of loadsets, S_l, is defined as $S_l = \textbf{NSYS} + \textbf{NICS}$ (Q-1), where $\textbf{NSYS} \le 2, \textbf{NICS} \le 2$; therefore $S_l \le 4$. Each of the S_l load sets is defined in a Q-2/3 series. The order in which they are defined is established as:

- load system A
- load system B
- initial displacement
- initial velocity

All four load sets are optional. Each load set which is present must be completely defined *via* a Q-2/3 series before moving on to the next set in the order specified above.

ISYS NN IFLG

ISYS for load systems:

1 – load system A

2 – load system B

for initial conditions:

0 – initial displacements

-1 – initial velocities

NN number of Q-3 records needed to describe the loads or initial conditions

IFLG 0 – no USRLD

1 – loads defined in user-written subroutine USRLD are included

if (**NN** > 0) then *go to* Q-3
else *follow instructions at end of* Q-3

Q-3 Load Definition

This record is included only if **NN** > 0 (Q-2); it is repeated **NN** times. A single Q-3 record is typically used as described in the following three paragraphs to specify loading(s) or displacement(s) at a given point of, along a given row or column of, or over the entire grid of the current shell unit. A convenient *exterior-looping* parameter (**NX**) can also be used to make multiple such definitions with the same Q-3 record, as described after that.

When the row number is entered as zero, the load (or initial condition) is assumed to act at every grid point on the column indicated by the column number. If the column number is entered as zero, the load is assumed to act at every grid point on the row indicated by the row number. If both row and column numbers are zero, then the load is assumed to act at each grid point.

The unknowns at a juncture line are represented by the displacement components in the directions of the shell coordinates (X', Y', Z') associated with the shell unit having the lowest number of those involved in the juncture. This must be observed if displacement constraints are introduced by Q-2 records, by Q-3 records or in user-written UCONST or USRLD subroutines at a juncture line. In general this is most readily achieved by introduction of the constraint on the shell unit with the lowest number. Some care must be exercised when regular boundary conditions (P-1–P-4) are introduced on the lines that meet the juncture line.

Line loads can be applied as uniform along an entire row or column, or they can be applied as constant on a single edge. Refer to Figure 6.7 on page 6-73 for examples of how to specify edges for line loads. To apply a non-uniform variation along a given line, define a separate load value for each edge on that line. Best results will be obtained by specifying centroidal values for each edge on the line.

As noted above, the optional **NX** parameter (and the three incrementation parameters associated with it) may be used in combination with the other information on a Q-3 record to make multiple loading/displacement definitions. This feature can be very useful in situations where similar definitions are required for one or another of the three variables (**LD**, **LI**, or **LJ**) for which FORTRAN-like looping might be appropriate.

P LT LD LI LJ LAX NX INC1 INC2 INC3 ILAY

P magnitude of load, displacement, or velocity; the load type and direction are determined by **LT** and **LD**, respectively

LT
- -1 – prescribed displacement (translation or rotation), or initial condition (initial displacement or initial velocity)
- 1 – point force/moment
- 2 – line load/moment along row
- 3 – line load/moment along column
- 4 – dead pressure—normal to the undeformed element surface
- 5 – live pressure—normal to the deformed element surface throughout geometrically-nonlinear deformations
- 6 – ~~velocity dependent forces~~ (see E-1) — INACTIVE
- 7 – ~~surface traction~~ — INACTIVE

LD load direction; interpretation of (X, Y, Z) is dependent upon **LAX**, below
- 1 – *u*; force/translation in the *X* direction
- 2 – *v*; force/translation in the *Y* direction
- 3 – *w*; force/translation in the *Z* direction
- 4 – *ru*; moment/rotation, right-handed about the *X* axis
- 5 – *rv*; moment/rotation, right-handed about the *Y* axis
- 6 – *rw*; moment/rotation, right-handed about the *Z* axis

LI, **LJ** row and column number of the grid points at which **P** is applied. (**LI**, **LJ** = 0, see above.)

LAX load axes, determining the interpretation of **LD**, above
- 0 – (X, Y, Z) correspond to (X', Y', Z') shell coordinates
- 1 – (X, Y, Z) correspond to $(\bar{x}_g, \bar{y}_g, \bar{z}_g)$ nodal-global coordinates
- 2 – (X, Y, Z) correspond to (x_e, y_e, z_e) element-edge coordinates

LAX = 0 is required for **LT** = -1
LAX = 2 is permitted for line loads only
LAX = 2 is permitted for the 410 and 411 elements only
LAX = 2 is permitted only for the quadrilateral plate (**ISHELL** = 3) or for a user-written shell (**ISHELL** = 1 and user-written subroutine LAME); this option is not necessary for other shell types, since a computational axis will serve as an edge reference in all other shell types

The (z') element normal defines the direction of pressure

NX *exterior-looping* parameter; set equal to unity by **STAGS** if nonpositive or omitted

INC1 incrementation parameter for the **LD** variable, when **NX** > 1

INC2 incrementation parameter for the **LI** variable, when **NX** > 1

INC3 incrementation parameter for the **LJ** variable, when **NX** > 1

ILAY layer- or surface-specification parameter; for non-solid shells, **ILAY** is ignored; for solid shells, **ILAY** designates the nodal layer on which the specified *displacement*, *line* or *point loading* is to be applied—or it designates the element layer to which the specified *pressure loading* is to be applied

NAMS	(Q-1)	number of attached masses
NUSS	(Q-1)	uniform basic stress state option for eigenanalysis
NHINGE	(Q-1)	number of cable hinge restraint vectors
NMOMNT	(Q-1)	number of cable hinge moment loading vectors
NLEAST	(Q-1)	number of least-squares loading sets

```
if      (NAMS > 0)     then  go to  Q-4
elseif  (NUSS > 0)     then  go to  Q-5
elseif  (NHINGE > 0)   then  go to  Q-6
elseif  (NMOMNT > 0)   then  go to  Q-7
elseif  (NLEAST > 0)   then  go to  Q-8a
else                         go to  R-1
```

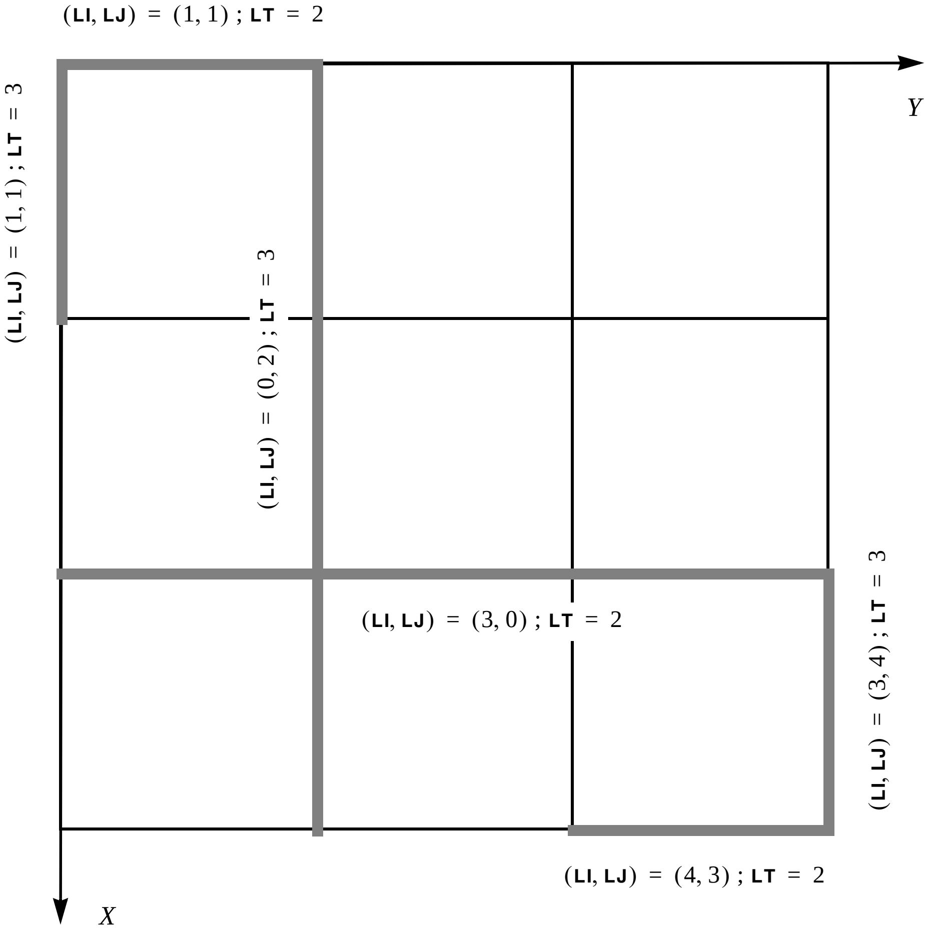

(LI, LJ) = (1, 1) ; LT = 2
(LI, LJ) = (1, 1) ; LT = 3
(LI, LJ) = (0, 2) ; LT = 3
Y
(LI, LJ) = (3, 0) ; LT = 2
(LI, LJ) = (3, 4) ; LT = 3
(LI, LJ) = (4, 3) ; LT = 2
X

Figure 6.7 Shell-unit line loads; examples of how to specify element edges.

Q-4 Attached Mass

The Q-4 records allow the user to define attached masses at node points in the shell unit. The record is repeated **NAMS** (Q-1) times.

GM IRM ICM LAYER NX INC1 INC2 INC3

GM weight of attached mass, in units of *force*

IRM row number of attached mass
ICM column number of attached mass
LAYER nodal layer number for attached mass

NX number of masses to be attached

INC1 incrementation parameter for the **IRM** variable
INC2 incrementation parameter for the **ICM** variable
INC3 incrementation parameter for the **LAYER** variable

NUSS (Q-1) uniform basic stress state option for eigenanalysis
NHINGE (Q-1) number of cable hinge restraint vectors
NMOMNT (Q-1) number of cable hinge moment loading vectors
NLEAST (Q-1) number of least-squares loading sets

```
if   (NAMS attached-mass records have been defined) then
     if      (NUSS > 0)     then   go to  Q-5
     elseif  (NHINGE > 0)   then   go to  Q-6
     elseif  (NMOMNT > 0)   then   go to  Q-7
     elseif  (NLEAST > 0)   then   go to  Q-8a
     else                          go to  R-1
else     continue defining  Q-4
```

Q-5 Uniform Stress State for Eigenanalysis

This record may be used to define the stress resultants in a uniform basic stress state for bifurcation buckling or small vibration analysis. When a Q-5 record is included, the only type of loading allowed is specified homogeneous displacements (**LT** = -1, Q-3). Any other loadings (mechanical or thermal) which may be defined are ignored, not only in the current unit, but in all units. The stress resultants defined on this record are multiplied by the load factors **STLD(1)**,**STLD(2)** (C-1) for load systems A and B, respectively.

PNXA PNYA PNXYA PNXB PNYB PNXYB

PNXA value of the stress resultant in the X' direction, load system A

PNYA value of the stress resultant in the Y' direction, load system A

PNXYA value of the shear resultant, load system A

PNXB value of the stress resultant in the X' direction, load system B

PNYB value of the stress resultant in the Y' direction, load system B

PNXYB value of the shear resultant, load system B

NHINGE (Q-1) number of cable hinge restraint vectors
NMOMNT (Q-1) number of cable hinge moment loading vectors
NLEAST (Q-1) number of least-squares loading sets

```
if      (NHINGE > 0)     then   go to Q-6
elseif  (NMOMNT > 0)     then   go to Q-7
elseif  (NLEAST > 0)     then   go to Q-8a
else                            go to R-1
```

Q-6 Cable Hinge Restraint

This record is included only if **NHINGE** > 0 (Q-1); it is repeated **NHINGE** times.

See discussion of cable hinge restraints under Q-1. The vector described below gives the direction of the constraint in (X', Y', Z') shell coordinates. Although the magnitude of this vector does not theoretically influence the result, this is a multi-point constraint imposed by Lagrange multipliers. The new equation (automatically) produced by this constraint is assembled into the stiffness matrix along with the other freedoms. To avoid numerical problems, the magnitude of this vector is converted to a scaling constant to help the conditioning of the stiffness matrix. See the general discussion of Lagrange constraints under G-3 for more details.

IROW ICOL HRU HRV HRW LAYER NX INC1 INC2 INC3

IROW row number where constraint is applied

ICOL column number where constraint is applied

HRU, HRV, HRW the direction vector, in (X', Y', Z') shell coordinates, along which rotation is prevented; the magnitude of this vector should be of the same order as the element torsional stiffness

LAYER nodal layer on which constraint is applied

NX number of constraints to be attached

INC1 incrementation parameter for the **IROW** variable

INC2 incrementation parameter for the **ICOL** variable

INC3 incrementation parameter for the **LAYER** variable

✦

NHINGE	(Q-1)	number of cable hinge restraint vectors
NMOMNT	(Q-1)	number of cable hinge moment loading vectors
NLEAST	(Q-1)	number of least-squares loading sets

```
if   (NHINGE cable hinge restraint vectors have been defined)  then
     if       (NMOMNT > 0)          then  go to  Q-7
     elseif   (NLEAST > 0)          then  go to  Q-8a
     else                                 go to  R-1
else     continue defining  Q-6
```

Q-7 ~~Cable Hinge Moment~~

NOTE: *This feature is currently disabled, and the user must set* **NMOMNT** = 0 (Q-1). ***STAGS*** *automatically introduces cable moments for all applied moment loadings.*

This record is included only if **NMOMNT** > 0 (Q-1); it is repeated **NMOMNT** times.

See discussion of cable hinge moment loads under Q-1. The vector described below gives the direction and magnitude of the applied moment in (X', Y', Z') shell coordinates.

IROW ICOL MSYS RUM RVM RWM LAYER NX INC1 INC2 INC3

IROW row number where moment is applied

ICOL column number where moment is applied

MSYS
1 – load applies to the A system
2 – load applies to the B system

RUM, RVM, RWM moment vector components in (X', Y', Z') shell coordinates

LAYER nodal layer on which moment is applied

NX number of moments to be applied

INC1 incrementation parameter for the **IROW** variable

INC2 incrementation parameter for the **ICOL** variable

INC3 incrementation parameter for the **LAYER** variable

NMOMNT (Q-1) number of cable hinge moment loading vectors
NLEAST (Q-1) number of least-squares loading sets

```
if   (NMOMNT cable hinge moment loading vectors have been defined)  then
     if   (NLEAST > 0)        then   go to  Q-8a
     else                            go to  R-1
else     continue defining  Q-7
```

Q-8a Least Squares Loading Summary

There are **NLEAST** (Q-1) sets of Q-8 records. Record Q-8a is used to define the number **NSQR** of Q-8b special loading records to follow, to define the reference node for the application of the least-squares summary loads or reactions, and to provide an overall scale factor **SCALE** for the six Lagrange constraints introduced automatically for each least-squares load set. The reference node must have been defined in the current or a previous unit. If any nodes not yet defined are referenced in any Q-8 records, an error will result; to avoid this, postpone the definition of this least-squares set until after all pertinent nodes have been defined. As with all other Lagrange constraints that contribute to the stiffness matrix (see, for example, record G–3 and the ones that follow it), numerical roundoff considerations require that the values of the Lagrange unknowns not differ from other unknowns by too many orders of magnitude. This in turn means that the stiffness contributions should be near the same order as other members, or a **SCALE** value set to about equal to some average thickness times a modulus. The user should remember that this is only an order-of-magnitude estimate for numerical conditioning.

NSQR IUNIT IROW ICOL SCALE

NSQR number of Q-8b data records required to define the edges involved in this least-squares load set

IUNIT unit number for the reference node

IROW row number for the reference node

ICOL column number for the reference node

SCALE scale factor for numerical conditioning. We suggest something of the order of magnitude of the material modulus times a representative shell thickness.

✦ *go to* Q-8b

Q-8b Least Squares Load Definition

A least-squares constraint loading condition is specified by defining the following three components:

- A reference node with section weighting (see Q-8a)
- A curve consisting of one or more arc segments and/or single nodes (Q-8b).
- Loads on the reference node (see Q-1, Q-2, Q-3 records)

Q-8b input records define a curve consisting of one or more arc segments, or alternatively, individual nodes. There are a total of **NSQRS** Q-8b records. A sequence of Q-8b records, all with (**LU**, **LR**, **LC**) defining actual nodes, specifies one arc segment. Additional arc segments may then be defined by adding a Q-8b record with (**LU**, **LR**, **LC**) = 0 followed by more Q-8b records defining the next arc segment. If a segment consists of a single node, the node weight **P** is used unchanged. An individual Q-8b record can specify several nodes at once in two ways:

- For shell units, **LR** = 0 and **LC** > 0 means the entire column **LC**, while **LR** > 0 and **LC** = 0 means the entire row **LR**.
- For either shell or element units, items **LNDA**, **LNDB**, and **LNDINC** may be used to describe a range of nodes.

P LU LR LC LNDA LNDB LNDINC

P nodal weight. For sections of uniform composition, input 1.0. When the defining curve belongs to several distinct wall types, we suggest using 1.0 for the nodes in the stiffest structural areas and choosing other weights so that the set of **P** values are proportional to the modulus times the effective thickness (Eh).

LU unit number of node; any Q-8b records that follow describe a new arc segment to be added to this load set

LR row number of first node

LC column number of first node

LNDA first node of (row if **LR** = 0) or (column if **LC** = 0) in shell unit. If 0, the first node on the row or column is chosen

LNDB last node of (row if **LR** = 0) or (column if **LC** = 0) in shell unit. If 0, the last node on the row or column is chosen. If **LNDB** = **LNDA** > 0, then only one node is specified by this record.

LNDINC increment for nodes from **LNDA** to **LNDB**. Increasing or decreasing ranges are allowed. If **LNDINC** = 0, an increment of +1 is used for increasing ranges, and -1 for decreasing ranges.

NSQR	(Q-8a)	number of Q-8b records
NLEAST	(Q-1)	number of least-squares loading sets

```
if    (NSQR Q-8b records have been defined)then
      if  (NLEAST loading sets have been defined)then    go to  R-1
      else                                               return to  Q-8a
else      continue defining  Q-8b
```

6.6 Least-Squares Distributed Line Loads

Definition of least-squares constraint

Users are often faced with the situation in which a detailed response is required in only part of a structure, such as that shown by the shaded portion of the airplane in Figure 6.7 "Shell-unit line loads; examples of how to specify element edges." on page 6-73. For the rest of the structure, an approximate analysis may be sufficient to provide enough information to define the load path along the boundaries of the area of interest, shown in the lower half of this figure. A very good estimate of the integrated boundary loads can sometimes be computed with simple "stick models" consisting of beams with the appropriate section properties. Unfortunately, with this approach the detailed edge loading (arrows in the figure) is lost. It is time-consuming and error-prone to try to reconstitute these loads by hand; and even when a good approximate initial estimate can be computed, changes in the load path as a function of edge deformation cannot be accounted for. This is a more serious problem when only engineering statically-equivalent forces

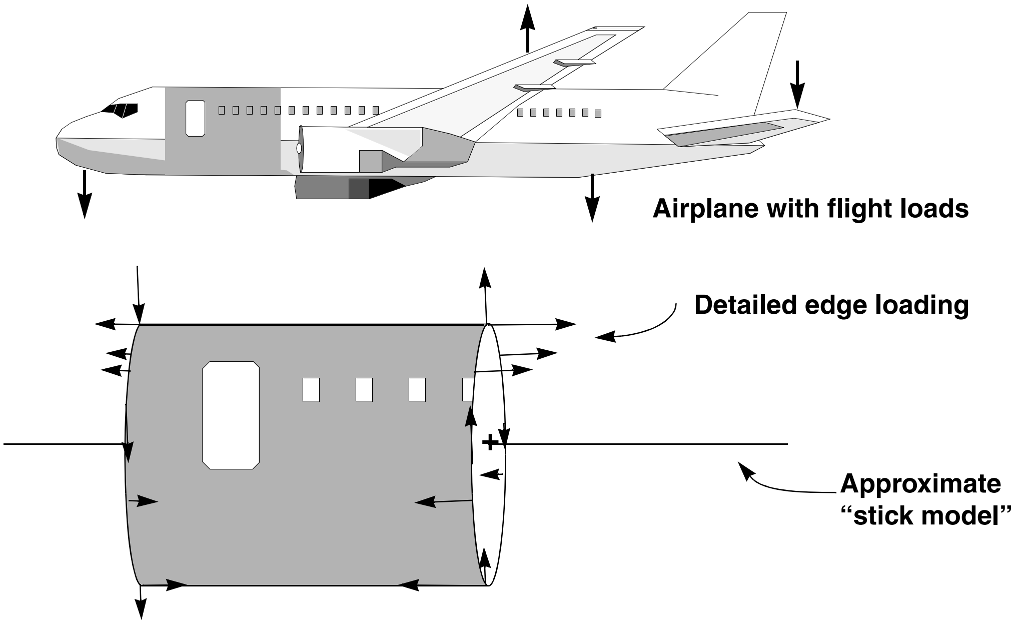


Figure 6.8 Illustration of detailed model taken from larger structure.

and moments acting on the section centroid are available, or when these loads come from unknown reactions generated by an approximate combined model. How, then, can one compute a “best” estimate for the edge loading automatically, one that induces the least spurious deflection, when only the integrated edge force and moment pair acting on the centroid are available?

One plausible solution to this problem is to recognize that the virtual work done by a force **F** and moment **M** directed at a *reference node*—a point in the structure (presumably the centroid of the section, marked by a “+” in the lower half of Figure 6.8)—is

$$\delta W = \mathbf{F}\delta\mathbf{u}_0 + \mathbf{M}\delta\omega_0 \qquad (6.1)$$

where $\delta\mathbf{u}_0$ is the virtual displacement, and $\delta\omega_0$ is the virtual instantaneous rotation. In rigorous language, this means that the force/moment pair is *conjugate* to the rigid translation and rotation of the edge, and that the work done by all of the edge loads is equivalent to equation (6.1), regardless of how the load is distributed over the edge. At this stage of the modeling process, we will have at hand a finite element discretization of the detailed section, with a set of nodes lying on the edge, as illustrated by the dots in the following figure. Imagine that initially we have

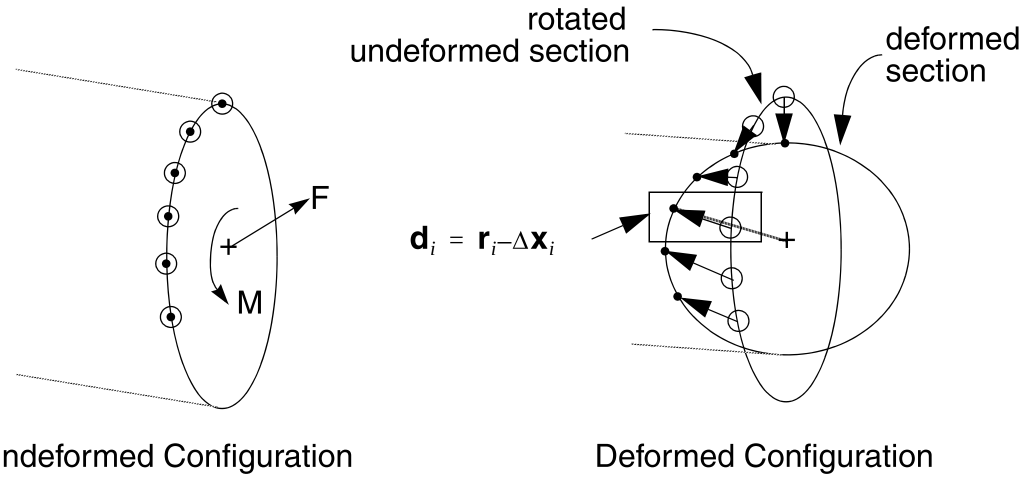


Figure 6.9 Illustration of least-squares loading.

defined a stretch of nodes that are to receive the loads produced by **F** and **M.** The minimum disturbance of the edge is produced by requiring a least-squares error between the actual deflection of the section node and the undeformed section rotating as a rigid body and doing equivalent work on **F** and **M**. We illustrate this in Figure 6.8. On the left side of the figure, we show an undeformed cross section with a number of open circles with dots. Each circle represents a node along the loaded edge, and the + mark represents the loaded reference node. The reference node is an arbitrary structural node, which can be loaded or connected to other parts of the structure. Initially, the undeformed structure and the loaded section are coincident. Later, the structure deforms as shown on the right side of the figure. Here, we have shown the section ovalizing and carrying its nodes with it (dots). We also show an *image* of the undeformed section that has translated and rotated to make the square of the distances $\mathbf{d}_i$ between the deformed node and its rotated undeformed image (open circle) a minimum. One of these deflections (arrows pointing from the image to the deformed node) for node *i* is shown in a box, labeled with its defining equation

$$\begin{aligned}
\mathbf{d}_i &= \mathbf{r}_i - \Delta\mathbf{x}_i \\
\mathbf{r}_i &= \mathbf{T}_0\mathbf{r}_i^0 \\
\mathbf{r}_i^0 &= \boldsymbol{X}_i - \boldsymbol{X}_0 \\
\Delta\mathbf{x}_i &= \mathbf{x}_i - \mathbf{x}_0
\end{aligned} \tag{6.2}$$

where $\boldsymbol{X}_i$ are the undeformed coordinates of node *i*, where *0* refers to the reference node, and where $\mathbf{x}_i$ are the nodal positions after deformation by displacements $\mathbf{u}_i$, (including the reference node):

$$\mathbf{x}_i = \boldsymbol{X}_i + \mathbf{u}_i \tag{6.3}$$

These vectors can be visualized with the help of the following figure. The orthogonal matrix $\mathbf{T}_0$ represents the rigid rotation of the reference node and the section image tied to it. What we want is to rotate and translate the image section to make the least-squares error ε

$$\varepsilon = \sum_i \phi_i \|\mathbf{d}_i\|^2 \tag{6.4}$$

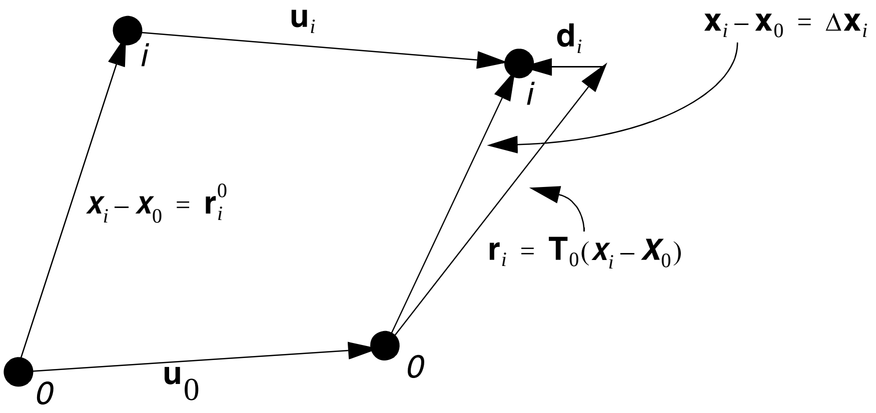

$\mathbf{u}_i$
i
$\mathbf{d}_i$
$\mathbf{x}_i - \mathbf{x}_0 = \Delta\mathbf{x}_i$
i
$\boldsymbol{X}_i - \boldsymbol{X}_0 = \mathbf{r}_i^0$
$\mathbf{r}_i = \mathbf{T}_0(\boldsymbol{X}_i - \boldsymbol{X}_0)$
0
$\mathbf{u}_0$
0

Figure 6.10 Definition of least-squares displacements.

a minimum. If we take the derivative of equation (6.4) and remember that the variation of a vector subjected to a rigid rotation (the second equation in (6.2)) is

$$\delta\mathbf{r}_i = \delta\omega_0 \times \mathbf{r}_i \tag{6.5}$$

the result is six constraint equations expressed as

$$\begin{aligned} \sum_i (\mathbf{r}_i - \Delta\mathbf{x}_i)\phi_i &= 0 \\ -\sum_i (\mathbf{r}_i \times \Delta\mathbf{x}_i)\phi_i &= 0 \end{aligned} \tag{6.6}$$

where ϕ_i are weights chosen by the user. Usually these weights are selected to be proportional to the length of section segments spanned by the nodes. The most straightforward way to introduce these constraints into a finite element code like **STAGS** is to augment the strain energy function U by introducing Lagrange multipliers $\mathbf{f}_0$ and $\mathbf{m}_0$ as follows:

$$\hat{U} = U + \mathbf{f}_0 \cdot \left[\sum_i (\mathbf{r}_i - \Delta\mathbf{x}_i)\right] - \mathbf{m}_0 \cdot \left[\sum_i \mathbf{r}_i \times \Delta\mathbf{x}_i\right] \tag{6.7}$$

The first variation

To obtain contributions to the residual, we take the variation of equation (6.7), the results of which come out to be for each node ***i***

$$\mathbf{f}_i = \begin{bmatrix} \mathbf{r}_i \times \mathbf{m}_0 - \mathbf{f}_0 \\ \mathbf{f}_0 - \mathbf{r}_i \times \mathbf{m}_0 \\ \mathbf{m}_0(\Delta\mathbf{x}_i \cdot \mathbf{r}_i) - \Delta\mathbf{x}_i(\mathbf{r}_i \cdot \mathbf{m}_0) + \mathbf{r}_i \times \mathbf{f}_0 \\ \mathbf{r}_i - \Delta\mathbf{x}_i \\ -\mathbf{r}_i \times \Delta\mathbf{x}_i \end{bmatrix} \phi_i \tag{6.8}$$

where the order of the freedoms is u, v, w for the structural node i; u, v, w, R_u, R_v, R_w for the reference node 0; and the last six for the Lagrange unknowns $\mathbf{f}_0$ and $\mathbf{m}_0$, respectively. There is a contribution to the reference node and the Lagrange freedoms from each $\mathbf{f}_i$, so that one could view the $\mathbf{f}_i$ as being generated by an “element,” shown by the dashed line connecting the reference node and a deformed edge node i in Figure 6.9; there is one such “element” connecting each edge node on the section with the reference node, like spokes on a wheel. Also note that there is no contribution to the rotational freedoms at the edge. If we take the simple case of a reference node unconnected in any way to the structure except for these constraints, and if we assume that the node is loaded by a simple force **F** and moment **M,** then equilibrium requires that

$$\begin{aligned} \mathbf{F} &= W\mathbf{f}_0 - \hat{\mathbf{r}} \times \mathbf{m}_0 \\ \mathbf{M} &= \mathbf{J}_s\mathbf{m}_0 + \hat{\mathbf{r}} \times \mathbf{f}_0 \\ W &= \sum_i \phi_i \\ \hat{\mathbf{r}} &= \sum_i \phi_i \mathbf{r}_i \\ \mathbf{J}_s &= \sum \phi_i[\mathbf{I}(\Delta\mathbf{x}_i \cdot \mathbf{r}_i) - \Delta\mathbf{x}_i\mathbf{r}_i^T] \end{aligned} \tag{6.9}$$

If we simplify the problem further and consider only the case where the reference node is at the center of the section, such that the relative centroid

$$\hat{\mathbf{r}} = 0 \tag{6.10}$$

then from the first of equations (6.6), we see that $\mathbf{f}_o$ times the sum of the weights W equals the total force on the section. Indeed, the first constraint in equation (6.6) is simply a statement that the relative centroid remains unchanged, and the second term in the force equation (6.9) is the correction for the offset of the reference point from the actual centroid. $\mathbf{J}_s$ can be interpreted as a generalized area moment, since from equations (6.6) it is a symmetric matrix and is initially equal to the area moment of the undeformed section. Most importantly, the reader can readily verify that

$$\begin{aligned} \sum_i \mathbf{f}_i &= \sum_i (\mathbf{r}_i \times \mathbf{m}_0 - \mathbf{f}_0)\phi_i = -\mathbf{F} \\ \sum_i \Delta\mathbf{x}_i \times \mathbf{f}_i &= \sum_i \Delta\mathbf{x}_i \times (\mathbf{r}_i \times \mathbf{m}_0 - \mathbf{f}_0)\phi_i = -\mathbf{M} \end{aligned} \tag{6.11}$$

which is clearly required to guarantee that the virtual work done by the edge nodes is equivalent to the work done by the reference node on **F** and **M**. To prove the second equation in (6.11), we use both constraint conditions (equations (6.6)). Finally, for the simple case of a circular cut through a cylinder, the cross product in the first line of equation (6.8) reduces to the familiar cosine distribution derived from an imposed moment.

The stiffness matrix

The second variation is straightforward, so we shall only present the final results here. The lower triangle of the symmetric stiffness matrix $\bar{\mathbf{K}}_i$ looks like

$$\bar{\mathbf{K}}_i = \phi_i \begin{bmatrix} \mathbf{0} & & & & \\ \mathbf{0} & \mathbf{0} & & & \\ \mathbf{K}_{\omega i} & -\mathbf{K}_{\omega i} & \mathbf{K}_{\omega\omega} & & \\ \mathbf{K}_{fi} & -\mathbf{K}_{fi} & \mathbf{K}_{mi} & \mathbf{0} & \\ \mathbf{K}_{mi} & -\mathbf{K}_{mi} & \mathbf{K}_{m\omega} & \mathbf{0} & \mathbf{0} \end{bmatrix} \tag{6.12}$$

where we have ordered the freedoms for each “element” i in the same manner as in equation (6.8), and where ω refers to the rotational components of the reference node. Each of the nonzero 3x3 blocks is defined as follows:

$$
\begin{aligned}
\mathbf{K}_{\omega i} &= \mathbf{r}_i\mathbf{m}_0^T - \mathbf{I}(\mathbf{r}_i \cdot \mathbf{m}_0)\\
\mathbf{K}_{fi} &= -\mathbf{I}\\
\mathbf{K}_{mi} &= \tilde{\mathbf{r}}_i\\
\hat{\mathbf{K}}_{\omega\omega} &= \mathbf{m}_0(\mathbf{r}_i \times \Delta\mathbf{x}_i)^T - \Delta\mathbf{x}_i(\mathbf{r}_i \times \mathbf{m}_0)^T + \mathbf{r}_i\mathbf{f}_0^T - \mathbf{I}(\mathbf{r}_i \cdot \mathbf{f}_0)\\
\mathbf{K}_{\omega\omega} &= \frac{1}{2}(\hat{\mathbf{K}}_{\omega\omega} + \hat{\mathbf{K}}_{\omega\omega}^T)\\
\mathbf{K}_{m\omega} &= \mathbf{I}(\Delta\mathbf{x}_i \cdot \mathbf{r}_i) - \Delta\mathbf{x}_i\mathbf{r}_i^T
\end{aligned}
\tag{6.13}
$$

where $\tilde{\mathbf{r}}_i$ represents the skew-symmetric matrix derived from the vector $\mathbf{r}_i$.

Using least-squares loading in STAGS

We are fortunate that in **STAGS** we are able to use existing software to compute automatically the weights ϕ_i based on the correct internodal distances. The user will be required to provide only a simple overall *scale factor*, and a section *weight factor* to be used to account for changes in thickness or other modeling features he wants to include. As users become accustomed to the least-squares loading feature, their experience will determine optimum weight choice.

STAGS automatically generates a set of local weights equal to the distance between adjacent nodes in a list given by the user. This list, the designation of the reference node, and the section weight factors are provided by a natural extension of the shell-unit Q and U records and the element-unit U and V records in the **STAGS** input stream. The reference node must be defined like any other, either as a part of a previously-defined shell unit, or in an element unit. Of course, this means that an element unit is required if the new node is defined by itself. Loads and boundary conditions for the reference node are defined as usual, including the reference node force and moment that the user wants spread over an edge. The same rules apply to any structural component attached to the reference node: treat the node like any other ordinary **STAGS** node. After all nodes (edge “structural” nodes and the reference node) have been defined, a separate set of Q records must be included for each least-squares loading condition. Provision is made on these records to reference any previously-defined unit that may contain nodes involved in the load set.

6.7 Output Control

Output for any given shell unit to the text-based output file (*casename.out2*, for example) is controlled by input on the R records for that unit. R records are specified independently for each shell unit and do not have to be the same for all units. It may be desirable, at times, to refrain from printing results during the analysis operations—and to use post-processing utilities to print and/or display results of interest, as appropriate. Options are provided for printing all displacements, strains, stresses and/or stress resultants for all grid points and/or elements for every solution step or at specified step-number intervals (see the R-1 record). The R-2 record allows the user to specify a subset of grid points at which displacements are to be printed. The R-3 record (which is disabled at the current time) allows the user to specify elements for which stresses will be printed at each load or time step.

R-1 Output Control—Record 1

This record is always included for each shell unit. The constants governing the output can differ from one unit to another. Output of results within some or all of the units can be suppressed in favor of output in the post-processor. Unnecessary output should be avoided as it leads to unnecessary expense and increase in size of the text-based output file. This is particularly true for stresses since the computer time involved in stress computations is significant.

All displacement and nodal point force output are displayed in (X', Y', Z') shell coordinates. This means that the output of quantities along a juncture belonging to two or more units may not be the same, because these vectors are expressed in different local systems. As an example, where an annular plate is joined to a cylinder, the *w* (radial, or normal) component for the cylinder is the same as the *u* component for the plate. Similarly, the *w* component for the plate is in the plus or minus *u* direction for the cylinder.

Nodal point equilibrium forces are available and may be printed. These internal forces should balance any loads or reactions applied at the node. They can be used to check how well equilibrium is maintained throughout the structural model because internal forces should be zero everywhere except at points of support or mechanical loading. Since the live pressure load contribution is not included in point force output, it is necessary to estimate the value of the pressure when checking for system equilibrium. On shell unit junctures the point forces include the reactions from the adjacent shell units.

Stress, strain, and stress resultant output are in $(\bar{x}, \bar{y})$ fabrication coordinates. Stress output can also be in (ϕ_1, ϕ_2) material coordinates for the layer in question. (See Section 4.1 “Coordinate Systems” on page 4-1 for a description of all **STAGS** coordinate systems.) In principle, for a composite, the stresses on the lower and upper layers can be in different systems; the user therefore should be very careful!

It is possible in nonlinear static or in transient analysis to print displacement components at all load or time steps for selected points, rows, or columns. The total number of records defining selected output in all units cannot exceed 100 times the total number of units.

IPRD IPRR IPRE IPRS IPRP IPRF NSELD NSELS IPRDSP IPRSTR ISL ISS ISD

IPRD
0 – do not print displacements
>0 – displacements are printed at every **IPRD**th load or time step

IPRR
0 – do not print stress resultants
>0 – stress resultants are printed at every **IPRR**th load or time step (elastic analysis only)

IPRE
0 – do not print strains
>0 – strains are printed at every **IPRE**th load or time step

IPRS
0 – do not print stresses
>0 – stresses are printed at every **IPRS**th load or time step

☞ Stress output is obtained only where indicated for the corresponding shell wall or beam cross-section. Please check **LSOL** (K-2), **NSOYZ** (J-1), **ISP** (J-3A), and **ISOC** (J-3B). Also, see **ISL**, **ISS**, and **ISD**, below.

IPRP
0 – no additional stress output for points with yield
>0 – stresses and strains are printed at all points, with yield at every **IPRP**th load or time step

IPRF
0 – do not print nodal point forces (internal force vector)
>0 – nodal point forces are printed at every **IPRF**th load or time step

NSELD number of records defining selected displacements (one record may correspond to a node, a row, or a column)

NSELS ~~number of records defining selected stresses~~ (*disabled*, *set* **NSELS**=0)

IPRDSP
0 – print selected displacements at every load or time step
>0 – print selected displacements at every **IPRDSP**th load or time step

IPRSTR
0 – print selected stresses at every load or time step
>0 – ~~print selected stresses at every **IPRSTR**th load or time step~~ (disabled)

ISL
0 – element results are computed at centroids
1 – element results are computed at integration points

ISS

0 – no transverse shear stresses

1 – ~~compute transverse shear stresses~~ — INACTIVE

ISD

0 – print stress and strain components in $(\bar{x}, \bar{y})$ fabrication coordinates

1 – print stress components in both $(\bar{x}, \bar{y})$ fabrication coordinates and (ϕ_1, ϕ_2) material coordinates

2 – print stress components in both $(\bar{x}, \bar{y})$ fabrication coordinates and the principal directions (includes angle of orientation)

✦

NUNITS (B-2)	number of shell units
NUNITE (B-2)	number of element units

```
if        (NSELD > 0)    then   go to R-2
elseif    (NSELS > 0)    then   go to R-3
elseif    (NUNITS shell units have been defined)  then
    if        (NUNITE = 0)    then   data deck is complete
    else                             follow instructions at end of R-3
else                         return to M-1
```

R-2 Output Control—Record 2

This record defines a number of nodes at which displacements are to be printed at each load or time step.

If **IROWD** is set equal to zero the displacements are printed for each row, (*i.e.*, the entire column). If **ICOLD** is set equal to zero the displacements are printed for each column, (*i.e.*, the entire row).

IROWD ICOLD

IROWD row number at which displacements are to be printed

ICOLD column number at which displacements are to be printed

Note: This selected displacement output option also causes the internal forces for the selected notes to be computed and printed. These forces are also summed. This provides a convenient mechanism for printing the total applied load in cases where only applied displacements are specified, or to check equilibrium at boundaries.

NSELD	(R-1)	number of selected displacements
NSELS	(R-1)	number of selected stresses
NUNITS	(B-2)	number of shell units
NUNITE	(B-2)	number of element units

```
if    (NSELD R-2 records have been defined)  then
      if       (NSELS > 0)    then   go to R-3
      elseif   (NUNITS shell units have been defined)  then
               if       (NUNITE = 0)  then   data deck is complete
               else     follow instructions at end of R-3
      else     return to M-1
else  continue defining R-2
```

R-3 Output Control—Record 3

INACTIVE

This record defines a number of locations at which stresses will be printed at each load or time step. Stress output will be obtained in the directions defined by **ISD** (R-1) or in user-written subroutines. Stresses suppressed in the general output by **LSOL** (K-2) or in user-written subroutines cannot be printed as selected output. The stresses in a given element in the shell unit are referred to by use of the lowest values of the numbers of the rows and columns that bound the element. If selected stress output is requested, all stress components are printed at each selected stress output point.

The record is repeated **NSELS** times (R-1).

IROWS ICOLS

IROWS row number identifying the element for stress output

ICOLS column number identifying the element for stress output

NSELS	(R-1)	number of selected stresses
NUNITS	(B-2)	number of shell units
NUNITE	(B-2)	number of element units
NUPT	(H-1)	number of user points
NT1	(H-1)	number of “spring” elements
NT2	(H-1)	number of “beam” elements
NT3	(H-1)	number of triangular shell elements
NT4	(H-1)	number of quadrilateral shell elements
NT5	(H-1)	other-elements/element-command-mode flag

```
if   (NSELS R-3 records have been defined)  then
     if  (NUNITS shell units have been defined)  then
          if       ( NUNITE  =   0 )   then  data deck is complete
          elseif   ( NUPT    >   0 )   then  go to  S-1
          elseif   ( NUPT    =   0 )   then  go to  S-3
          elseif   ( NUPT    =  -1 )   then  go to  S-3
          elseif   ( NT1     >   0 )   then  go to  T-1
          elseif   ( NT2     >   0 )   then  go to  T-2
          elseif   ( NT3     >   0 )   then  go to  T-3a
          elseif   ( NT4     >   0 )   then  go to  T-4a
          elseif   ( NT5     >   0 )   then  go to  T-5
          else                               go to  U-1
     else          return to  M-1
else      continue defining  R-3
```

7
Model Input—Element Units (1)

Element units are numbered sequentially, in the order in which they are defined, from **NUNITS** + 1 to **NUNITS** + **NUNITE**, where **NUNITS** is the number of shell units and **NUNITE** is the number of element units (B-2) in the model.

The group of records in the S–V series describes the element units. They are defined in serial fashion, completely describing one element unit before proceeding to the next. Thus, when **NUNITE** ≥ 2, the S–V series is defined for the first element unit, then the series is repeated for the second element unit, and so forth, until all of the **NUNITE** element units have been defined. The S–V record sets contain information as summarized below:

• S records:	Nodes and Lines
• T records:	Element specifications
• U records:	Loading specifications
• V records:	Output control specifications

If the model has externally-generated linear-stiffness contributions, W-type records must be included after the all of the S-V records (for all of the element units) have been given.

STAGS input requirements for the S (nodes and lines) records are described in this chapter. Input requirements for the T-x and T-xx (element-definition) records that are used with the historic ***Edef*** *(element-definition)* protocol are described in Chapter 8. Input requirements for the T-xxx (element-definition) records that are used with the newer ***Ecom*** *(element-command)* protocol are described in Chapter 9. Input requirements for the U (loadings), V (output-control) and W (linear-stiffness-contribution) records are described in Chapter 10.

☞ A **STAGS** model may contain any number of shell units, combined with any number of element units.

7.1 User Points

Elements in a **STAGS** element unit are typically connected to node points—some of which may have been defined in one or more shell units and/or in one or more previously-specified element units, and some of which may be unique to that element unit. Nodes that are referenced in any given element unit are called the "user points" for that unit. The current version of **STAGS** gives the user two protocols for defining user points.

If **NUPT** is positive on the H-1 record for the current element unit, **STAGS** expects the user to follow the historic ***upts*** user-point-definition protocol and to identify (and/or create) exactly **NUPT** user points. When this protocol is employed, **STAGS** attempts to read and process one or more S-1/S-1a (and optionally S-2) user-point-definition record sets—all of which are described in this chapter.

If the **NUPT** parameter is zero on H-1, **STAGS** expects the analyst to use the newer ***user–points*** protocol to identify (and/or create) one or more user points for the current unit. When this protocol is used, **STAGS** attempts to read and process one or more S-3/S-3a/S-4 user-point-definition record sets (which are also described in this chapter)—continuing to do this until the analyst tells the program (by setting the user-point-identity parameter to an extraordinarily high value) to stop. With the very first of the record sets for this protocol, the analyst must choose to use either one or the other of the two user-point *numbering* modes, as described in the following two paragraphs:

> If on the very first S-3 record the user assigns a *positive* value to the user-point number, **STAGS** will use that value for the initial user point and will expect (require) that **all** user points be identified explicitly on this and on all subsequent S-3/S-3a record sets. In this case, **STAGS** determines **NUPT** by setting it equal to the highest user-point number specified by any S-3/S-3a record set in the sequence.
>
> If on the very first S-3 record the user assigns a *zero (or any nonpositive)* value to the user-point number, **STAGS** will set the initial user-point number equal to one and will increment each subsequent user-point number (from the first S-3/S-3a record set and from all subsequent S-3/S-3a record sets) by one. In this case, **STAGS** ignores all of the user-point numbers that are given by the user and/or calculated with user-specified incrementations on each and every S-3/S-3a record set. **STAGS** sets **NUPT** equal to the total number of user points that are defined by this process.

If **NUPT**=-1 on the H-1 record for the current element unit, *no* user points are to be defined *via* S-1 or S-3 record groups for this element unit.

In any event, some (or all) of the user points may alternatively be identified (or defined) in a user-written subroutine USRPT, as described in Chapter 12.

S-1 User Points (upts protocol)

The ***upts*** protocol uses records of this type to establish a nodal point list for the element unit. Additional nodes are defined in user-written USRPT if **IUWP**=1 (H-1). If the node point coincides with a node on one of the shell units, its location can be defined through reference to the row and column number for that node. Full displacement compatibility at the node between shell unit and element unit will then be enforced. Other node point locations (auxiliary nodes) are defined by use of their coordinates in the global system.

For nodes that coincide with a node on a shell unit, the directions of the freedoms (displacement and rotation vector components) are identical to those on the shell unit at that node. When more than one shell unit belongs to such a node, the components belong to the shell unit with the lowest number. The same rule applies when two different element units share a node: the components belong to the lowest unit. All shell units have a lower number than any element units. Any node that has not been created before in a lower unit is called an auxiliary node. For auxiliary nodes, the user has a choice regarding the freedom pattern. Often constraints are readily defined if the directions of the freedom coincide with the axes of the global system. For more general cases, auxiliary systems can be defined on an S-2 record.

Constraints on displacements or rotations can be introduced on this record (**IUVW**, **IRUVW**). Attached masses are also permitted. Constraints can also be applied as loads (U-3).

User points may be *defined* in any order, but they must be *numbered* from 1 to **NUPT** (*i.e.*, $1 \le \mathbf{IUPT} \le \mathbf{NUPT}$). If **IUS** > 0, then **IRS** must be > 0. If the node belongs to another shell unit ($\mathbf{IUS} \le \mathbf{NUNITS}$, B-2), then **ICS** must be > 0, giving both the row and column number of the node in the lower unit. If **IUS** > **NUNITS**, the current element unit is joined to another element unit with a lower number; in that case **IRS** is the node number belonging to the lower element unit, defined on a previous S-1 record or in the user-written routine USRPT, and **ICS** = 0. If this is element unit l counted in the order that it is defined, $\mathbf{IUS} = k$, where $k = \mathbf{NUNITS} + l$, where $l \le \mathbf{NUNITE}$ (B-2). If **IUS** = 0, the nodal position must be defined in (x_g, y_g, z_g) global coordinates.

Typically, a single S-1 record (with its associated S-2 record, if required) will be used to define each user point. For some configurations, it is convenient to use the S-1 *looping* feature described below to specify two or more closely-related user points simultaneously. The **NPTS** parameter, on the S-1 record, facilitates that.

In any event, the S-1/S-1a, S-2 sequence must be repeated as many times as necessary to specify **NUPT** (H-1) user points.

IUPT IUS IRS ICS XG YG ZG IUVW IRUVW IAUX NPTS ILAY

IUPT user point (node) number; $1 \le$ **IUPT** $\le$ **NUPT**

IUS, IRS, ICS shell unit number, row number, column number for node on a shell unit

If **IUS** > **NUNITS**, **IUS** $= k =$ **NUNITS** $+ l$, where l is a previously-defined element unit (counted in the order it was defined), and **IRS** is the corresponding node number in that unit. No chaining is allowed. A shared node must be referenced to the unit where it was first defined.

IUS = 0 implies that the user point is an *auxiliary node*; *i.e.*, it is established without reference to an existing node in a previously-defined unit; **IRS** and **ICS** are irrelevant in that case.

☞ The next six entries on this record are relevant for auxiliary nodes only. See Figure 7.1 on page 7-6 for details regarding auxiliary nodes.

XG, YG, ZG (x_g, y_g, z_g) global coordinates

IUVW, IRUVW 3-digit binary integers indicating freedom or constraint for each of the three translational and each of the three rotational displacement components (u, v, w) and (ru, rv, rw), respectively. The significance of each binary digit is as follows:

`0`—fixed `1`—free

The most significant digit corresponds to *u* (or *ru*), and the least significant corresponds to *w* (or *rw*). For example, to specify *u* fixed with *v*, *w* free, and *rv* fixed, with *ru*, *rw* free

IUVW = `011`

IRUVW = `101`

☞ **IUVW** and **IRUVW** are similar to **ITRA** and **IROT** (P-2). See "P-2 Boundary Conditions—Record 2" on page 6-61.

IAUX degree-of-freedom option

0 – the directions of the freedoms are governed by $(\bar{x}_g, \bar{y}_g, \bar{z}_g)$ nodal-global coordinates

1 – the directions of the freedoms are governed by (x_a, y_a, z_a) nodal-auxiliary coordinates

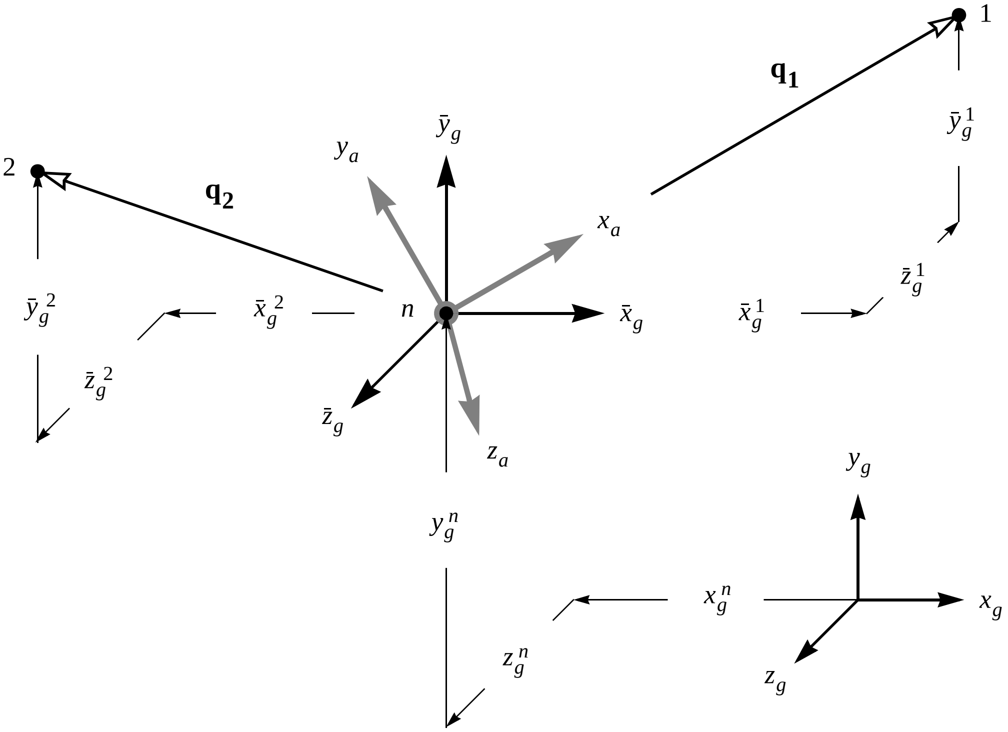
NPTS number of user points specified *via* this S-1 record; set to unity by **STAGS** if nonpositive or omitted

ILAY layer parameter

0 – ignored (this is the preferred value when the user node is not in a shell unit or when it is in a shell unit that is not tessellated with solid elements)

> 0 – the user node is located on surface # **ILAY** of the specified shell unit (this option should only be used when the shell unit is tessellated with solid elements)

✦ if (**NPTS** > 1) then *go to* S-1a
else *follow instructions at end of* S-1a



auxiliary node n: $(x_g^n\ ,\ y_g^n\ ,\ z_g^n\ ) = (\mathsf{XG}, \mathsf{YG}, \mathsf{ZG})$

point 1, on the x_a axis: $\mathbf{q_1} = (\bar{x}_g^1\ ,\ \bar{y}_g^1\ ,\ \bar{z}_g^1\ ) = (\mathsf{YAX}, \mathsf{YAY}, \mathsf{YAZ})$

point 2, in the (x_a, y_a) plane: $\mathbf{q_2} = (\bar{x}_g^2\ ,\ \bar{y}_g^2\ ,\ \bar{z}_g^2\ ) = (\mathsf{YAX}, \mathsf{YAY}, \mathsf{YAZ})$

$$x_a = \frac{\mathbf{q_1}}{|\mathbf{q_1}|} \qquad z_a = \frac{\mathbf{q_1} \times \mathbf{q_2}}{|\mathbf{q_1} \times \mathbf{q_2}|} \qquad y_a = z_a \times x_a$$

if (x_a, y_a, z_a) is specified, then $(x'', y'', z'') \equiv (x_a, y_a, z_a)$

else $(x'', y'', z'') \equiv (\bar{x}_g, \bar{y}_g, \bar{z}_g)$

(x'', y'', z'') computational coordinates (x_g, y_g, z_g) global coordinates

(x_a, y_a, z_a) nodal-auxiliary coordinates $(\bar{x}_g, \bar{y}_g, \bar{z}_g)$ nodal-global coordinates

Figure 7.1 Degree-of-Freedom Directions at an Auxiliary Node

S-1a User Point Incrementations (upts protocol)

A single record of type S-1a must be included immediately after each type S-1 record on which the **NPTS** parameter is greater than unity. Seven incrementation variables are specified here for use with the S-1 record looping function.

JUPT JUS JRS JCS Dxg Dyg Dzg

JUPT incrementation for the **IUPT** (user point number) variable, on S-1

JUS incrementation for the **IUS** (unit number) variable, on S-1

JRS incrementation for the **IRS** (row/element number) variable, on S-1

JCS incrementation for the **ICS** (column number) variable, on S-1

Dxg incrementation for the **XG** (coordinate) variable, on S-1

Dyg incrementation for the **YG** (coordinate) variable, on S-1

Dzg incrementation for the **ZG** (coordinate) variable, on S-1

Any of these incrementation variables can be negative, zero, or positive.

Example: the following S-1/S-1a record combination:

```
1  0  0  0   0.0   0.0   0.0 111  111  0  3    $  S-1
1  0  0  0   0.2   0.4  -0.2                   $  S-1a
```

generates the same three user points as the following three S-1 records:

```
1  0  0  0   0.0   0.0   0.0   111  111  0     $  S-1
2  0  0  0   0.2   0.4  -0.2   111  111  0     $  S-1
3  0  0  0   0.4   0.8  -0.4   111  111  0     $  S-1
```

✦ **IAUX** (S-1) degree-of-freedom option

if (**IAUX** > 0) then *go to* S-2
else *follow instructions at end of* S-2

S-2 Auxiliary Coordinate System (upts protocol)

The S-2 records are used to define auxiliary coordinate systems. These are used for definition of directions of nodal freedoms in element units. Matrices transforming displacements and rotations from (x_a, y_a, z_a) nodal-auxiliary coordinates to $(\bar{x}_g, \bar{y}_g, \bar{z}_g)$ nodal-global coordinates are computed by **STAGS** and can be utilized in user-written subroutines.

For all nodes in an element unit that do not also belong to a shell unit or to another previously-defined element unit, the displacement and rotation components of the freedoms generated at the node will have the directions indicated by the nodal-auxiliary coordinates if such a system is defined. The purpose is to allow displacement and rotational constraints on components other than those given in the nodal-global coordinates. If an S-2 record is not read, the nodal-global coordinates define the (x'', y'', z'') computational coordinates.

The nodal-global coordinate system has its origin at the node point while the coordinate directions coincide with those of the global system. The S-2 record defines the orientation of the auxiliary system by defining two points—$\mathbf{q_1}$, lying on the positive x_a axis, and $\mathbf{q_2}$, lying anywhere in the (x_a, y_a) plane off the x_a axis (for example on the y_a axis). The z_a axis completes a right-handed Cartesian system. Note that the origins of the two systems, $(\bar{x}_g, \bar{y}_g, \bar{z}_g)$ and (x_a, y_a, z_a), coincide. The algorithm for constructing this system is shown in Figure 7.1 on page 7-6. See Section 4.1 “Coordinate Systems” on page 4-1 for a summary of these and all of the other coordinate systems that **STAGS** uses.

The user should be very careful about where in the (x_a, y_a) plane $\mathbf{q_2}$ is chosen, since the signs of the auxiliary coordinate directions depend on this selection. The safest strategy is to put $\mathbf{q_2}$ along the y_a axis itself. Note the similarity of the algorithm for determining the nodal-auxiliary coordinate system here with that for nonlinear mounts (see T-1, for example) and the general algorithm for beams (see T-2, for example). Please refer to Chapter 14 “The Element Library” for more details.

The S-2 record is included only if **IAUX** = 1 (S-1). If multiple user points are defined *via* the S-1/S-1a *looping* function, the default coordinate system or the auxiliary coordinate system defined *via* this S-2 record must be the same for all of these points.

XAX XAY XAZ YAX YAY YAZ

XAX, XAY, XAZ nodal-global coordinates of point $\mathbf{q}_1$, lying on the x_a axis. Refer to Figure 7.1 on page 7-6.

YAX, YAY, YAZ nodal-global coordinates of point $\mathbf{q}_2$, lying anywhere in the (x_a, y_a) plane off the x_a axis; a point on the y_a axis is recommended.

NUPT	(H-1)	number of user points
NS5	(H-1)	number of contact-line records
NT1	(H-1)	number of “spring” elements
NT2	(H-1)	number of “beam” elements
NT3	(H-1)	number of triangular shell elements
NT4	(H-1)	number of quadrilateral shell elements
NT5	(H-1)	other-elements/element-command flag

```
if ( NUPT user points have been defined )  then
     if       ( NS5   > 0 )   then    go to  S-5
     elseif   ( NT1   > 0 )   then    go to  T-1
     elseif   ( NT2   > 0 )   then    go to  T-2
     elseif   ( NT3   > 0 )   then    go to  T-3
     elseif   ( NT4   > 0 )   then    go to  T-4
     elseif   ( NT5   > 0 )   then    go to  T-5
     else                             go to  T-100
else     return to  S-1
```

S-3 User Points (user–points protocol)

The ***user–points*** protocol uses one or more S-3/S-3a/S-4 record sets to establish a nodal point list for the element unit. User-point-definition *via* this protocol is triggered by setting the **NUPT** parameter equal to zero or -1 on H-1; and it is terminated by setting the **N1** parameter (on an S-3 record) equal to 999999. Additional nodes are defined in user-written subroutine USRPT if **IUWP**=1 on H-1. If the node point coincides with a node on one of the shell units, its location can be defined through reference to the row and column number for that node. Full displacement compatibility at the node between shell unit and element unit will then be enforced. Other node point locations (auxiliary nodes) are defined by use of their coordinates in the global system.

For nodes that coincide with a node on a shell unit, the directions of the freedoms (displacement and rotation vector components) are identical to those on the shell unit at that node. When more than one shell unit belongs to such a node, the components belong to the shell unit with the lowest number. The same rule applies when two different element units share a node: the components belong to the lowest unit. All shell units have a lower number than any element units. Any node that has not been created before in a lower unit is called an auxiliary node. For auxiliary nodes, the user has a choice regarding the freedom pattern. Often constraints are readily defined if the directions of the freedom coincide with the axes of the global system. For more general cases, auxiliary systems can be defined on an S-4 record.

Constraints on displacements or rotations can be introduced on this record (**IUVW**, **IRUVW**). Attached masses are also permitted. Constraints can also be applied as loads (U-3).

User points may be numbered explicitly by the analyst, or automatically by the program, as explained in the following two paragraphs.

> If the very first user point that the analyst defines is given a *positive* user-point number (**N1**), then the user-point numbers of all of the user points in the element unit must be specified explicitly. In this case, the user points may be *defined* in any order—but they must be *numbered* from 1 to the total number of user points defined. Here, **STAGS** sets **NUPTS** equal to the highest user-point number that is specified during this process.
>
> If the first user point that the analyst defines is given a *nonpositive* N1 value, **STAGS** ignores that and all subsequent user-point-number specifications, and assigns all user-point numbers sequentially—starting at 1 and incrementing by 1 until the analyst stops the user-point definition process. In this case, **STAGS** sets **NUPT** equal to the total number of user points that are defined.

In either event, after all user-point definitions have been made—and all user points identified and/or created by user-written subroutine USRPT have been processed—**STAGS** checks to ensure that each possible user point **IUPT** in the range $1 \le \textbf{IUPT} \le \textbf{NUPT}$ has been defined.

If **IUS** > 0 for any user point, then **IRS** must be > 0 for that point. If the node belongs to another shell unit ($\textbf{IUS} \le \textbf{NUNITS}$, B-2), then **ICS** must be > 0, giving both the row and column number of the node in the lower unit. If **IUS** > **NUNITS**, the current element unit is joined to another element unit with a lower number; in that case **IRS** is the node number belonging to the lower element unit, defined on a previous S-3 record or in the user-written subroutine USRPT, and **ICS** = 0. If this is element unit *l* counted in the order that it is defined, $\textbf{IUS} = k$, where $k = \textbf{NUNITS} + l$, where $l \le \textbf{NUNITE}$ (B-2). If **IUS** = 0, the nodal position must be defined in (x_g, y_g, z_g) global coordinates.

A single S-3 record (with its associated S-4 record, if required) can be used to define each user point. For some configurations, it is convenient to use the S-3 *looping* feature described below to specify two or more closely-related user points simultaneously. The **NPTS** parameter, on S-3 facilitates that.

In any event, the S-3/S-3a, S-4 sequence may be repeated as many times as necessary to specify user points. This sequence is terminated by setting the **IUPT** parameter equal to 999999.

IUPT IUS IRS ICS XG YG ZG IUVW IRUVW IAUX NPTS ILAY

IUPT user point (node) number (or end-of-sequence signal):

If **IUPT** < 1 on the very first S-3 record, it triggers the *automatic* user-point numbering mode for the *upts* protocol (in which **STAGS** sets the number of the first point defined to 1 and increments the number of each subsequent point by 1); the values of **IUPT** and of its incrementation parameter (**JPNT**, on S-3a) are ignored on the first and on all subsequent S-3/S-3a record sets.

If 0 < **IUPT** < 999999 on the first S-3 record, it triggers the *explicit* user-point numbering mode [in which the initial point defined by this S-3 record is user point number **IUPT**, and the user-point numbers of subsequent points (if any) defined by the first and by subsequent S-3/S-3a records are computed from **IUPT** and **JUPT**].

If **IUPT** = 999999 on any S-3 record, **STAGS** stops defining user points.

IUS, **IRS**, **ICS** shell unit number, row number, column number for node on a shell unit

If **IUS** > **NUNITS**, $\textbf{IUS} = k = \textbf{NUNITS} + l$, where *l* is a previously-defined element unit (counted in the order it was defined), and **IRS** is the corresponding node number in that unit. No chaining is allowed. A shared node must be referenced to the unit where it was first defined.

IUS = 0 implies that the user point is an *auxiliary node*; *i.e.*, that it is established in the current element unit without reference to an existing node in a previously-defined unit; **IRS** and **ICS** are irrelevant in that case.

☞ The next six entries on this record are relevant for auxiliary nodes only. See Figure 7.1 on page 7-6 for details regarding auxiliary nodes.

XG, YG, ZG (x_g, y_g, z_g) global coordinates

IUVW, IRUVW 3-digit binary integers indicating freedom or constraint for each of the three translational and each of the three rotational displacement components (u, v, w) and (ru, rv, rw), respectively. The significance of each binary digit is as follows:

0—fixed 1—free

The most significant digit corresponds to *u* (or *ru*), and the least significant corresponds to *w* (or *rw*). For example, to specify *u* fixed with *v, w* free, and *rv* fixed, with *ru, rw* free

IUVW = 011

IRUVW = 101

☞ **IUVW** and **IRUVW** are similar to **ITRA** and **IROT** (P-2). See "P-2 Boundary Conditions—Record 2" on page 6-61.

IAUX degree-of-freedom option

0 – the directions of the freedoms are governed by $(\bar{x}_g, \bar{y}_g, \bar{z}_g)$ nodal-global coordinates

1 – the directions of the freedoms are governed by (x_a, y_a, z_a) nodal-auxiliary coordinates

NPTS number of user points specified *via* this S-3 record; set to unity by **STAGS** if nonpositive or omitted

ILAY layer parameter

0 – ignored (this is the preferred value when the user node is not in a shell unit or when it is in a shell unit that is not tessellated with solid elements)

> 0 – the user node is located on surface # **ILAY** of the specified shell unit (this option should only be used when the shell unit is tessellated with solid elements)

✦ if (**NPTS** > 1) then *go to* S-3a
else *follow instructions at end of* S-3a

S-3a User Point Incrementations (user–points protocol)

A single record of type S-3a must be included immediately after each type S-3 record on which the **NPTS** parameter is greater than unity. Seven incrementation variables are specified here for use with the S-3 record looping function.

JUPT JUS JRS JCS Dxg Dyg Dzg

JUPT incrementation for the **IUPT** (user point number) variable, on S-3

JUS incrementation for the **IUS** (unit number) variable, on S-3

JRS incrementation for the **IRS** (row/element number) variable, on S-3

JCS incrementation for the **ICS** (column number) variable, on S-3

Dxg incrementation for the **XG** (coordinate) variable, on S-3

Dyg incrementation for the **YG** (coordinate) variable, on S-3

Dzg incrementation for the **ZG** (coordinate) variable, on S-3

Any of these variables can be negative, zero, or positive.

Example: the following S-3/S-3a record combination:

```
1 0 0 0  0.0  0.0  0.0 111 111 0 3   $ S-3
1 0 0 0  0.2  0.4 -0.2               $ S-3a
```

generates the same three user points as the following three S-3 records:

```
1 0 0 0  0.0  0.0  0.0  111 111 0    $ S-3
2 0 0 0  0.2  0.4 -0.2  111 111 0    $ S-3
3 0 0 0  0.4  0.8 -0.4  111 111 0    $ S-3
```

IAUX (S-3) degree-of-freedom option

if (**IAUX** > 0) then *go to* S-4
else *follow instructions at end of* S-4

S-4 Auxiliary Coordinate System (user–points protocol)

The S-4 records are used to define auxiliary coordinate systems. These are used for definition of directions of nodal freedoms in element units. Matrices transforming displacements and rotations from (x_a, y_a, z_a) nodal-auxiliary coordinates to $(\bar{x}_g, \bar{y}_g, \bar{z}_g)$ nodal-global coordinates are computed by **STAGS** and can be utilized in user-written subroutines.

For all nodes in an element unit that do not also belong to a shell unit or to another previously-defined element unit, the displacement and rotation components of the freedoms generated at the node will have the directions indicated by the nodal-auxiliary coordinates if such a system is defined. The purpose is to allow displacement and rotational constraints on components other than those given in the nodal-global coordinates. If an S-4 record is not read, the nodal-global coordinates define the (x'', y'', z'') computational coordinates.

The nodal-global coordinate system has its origin at the node point while the coordinate directions coincide with those of the global system. The S-4 record defines the orientation of the auxiliary system by defining two points—$\mathbf{q_1}$, lying on the positive x_a axis, and $\mathbf{q_2}$, lying anywhere in the (x_a, y_a) plane off the x_a axis (for example on the y_a axis). The z_a axis completes a right-handed Cartesian system. Note that the origins of the two systems, $(\bar{x}_g, \bar{y}_g, \bar{z}_g)$ and (x_a, y_a, z_a), coincide. The algorithm for constructing this system is shown in Figure 7.1 on page 7-6. See Section 4.1 “Coordinate Systems” on page 4-1 for a summary of these and all of the other coordinate systems that **STAGS** uses.

The user should be very careful about where in the (x_a, y_a) plane $\mathbf{q_2}$ is chosen, since the signs of the auxiliary coordinate directions depend on this selection. The safest strategy is to put $\mathbf{q_2}$ along the y_a axis itself. Note the similarity of the algorithm for determining the nodal-auxiliary coordinate system here with that for nonlinear mounts (see T-1, for example) and the general algorithm for beams (see T-2, for example). See Chapter 14 “The Element Library” for more details.

The S-4 record is included only if **IAUX** = 1 (S-3). If multiple user points are defined *via* the S-3/S-3a *looping* function, the default coordinate system or the auxiliary coordinate system defined *via* this S-4 record must be the same for all of these points.

XAX XAY XAZ YAX YAY YAZ

XAX, XAY, XAZ nodal-global coordinates of point $\mathbf{q_1}$, lying on the x_a axis. Refer to Figure 7.1 on page 7-6.

YAX, YAY, YAZ nodal-global coordinates of point $\mathbf{q_2}$, lying anywhere in the (x_a, y_a) plane off the x_a axis; a point on the y_a axis is recommended.

IUPT	(S-3)	initial user point number
NS5	(H-1)	number of contact-line records
NT1	(H-1)	number of “spring” elements
NT2	(H-1)	number of “beam” elements
NT3	(H-1)	number of triangular shell elements
NT4	(H-1)	number of quadrilateral shell elements
NT5	(H-1)	other-elements/element-command flag

```
if ( IUPT < 999999 ) then
    return to S-3
elseif  ( NS5 > 0 ) then    go to S-5
elseif  ( NT1 > 0 ) then    go to T-1
elseif  ( NT2 > 0 ) then    go to T-2
elseif  ( NT3 > 0 ) then    go to T-3
elseif  ( NT4 > 0 ) then    go to T-4
elseif  ( NT5 > 0 ) then    go to T-5
else    go to T-100
```

7.2 Line-to-Line–Contact Specifications

There are situations that arise during the analysis of lightweight structures where the edges of two shells come into contact with each other, as shown in Figure xx, as a result of deformations. Such contacts will most commonly occur along a crack face in a portion of the structure that undergoes compression and local buckling at loads below the ultimate design strength of the structure. Typically, the opposite sides of the crack displace differently; and opposing edges of the crack contact each other obliquely—with no more than one or a few points of contact along the length of the crack. Line-to-line contact capabilities have been implemented in **STAGS** to take this phenomenon into account.*

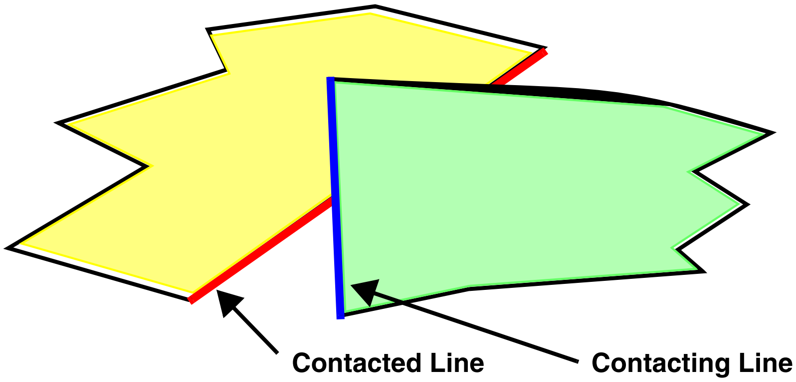


Figure 7.2 Line-to-Line Contact Phenomenon

Lines in a **STAGS** element unit are also typically connected to node points—some of which may have been defined in previously-specified shell units and/or in one or more previously-specified element units, and some of which may be unique to that element unit. Lines are used in line-contact specifications, as described next. Line and line-contact specifications are required and should only be given if the **NS5** parameter is positive on the H-1 record for the current element unit.

* For more information about this, see the "E822 Line contact element" portion of Section 14.8.

S-5 Contact-Line Definition

An S-5 record is used to define a special kind of line on the current element unit (or on a previously-defined shell unit) that *may* experience line-to-line contact with one or more other lines. This record specifies the contact-line identifier to be used for a line, the unit on which the line is defined, and the number of S-5a or S-5b records that are required for that definition. The potential contact-line interactions for a given **STAGS** model are specified later, on one or more T-8 and related records (described on page 8-41). It is important for the user to understand that each such interaction involves two contact lines—one of which is considered to be the *contacting* line and the other of which is considered to be the *contacted* line. The *direction* of a contact line is determined by the order in which the nodes defining that line are specified. This is important if the line is ever used as a *contacted* line, because it uniquely specifies the element(s) that are associated with that line (and which may therefore be contacted by a contacting line).

NS5 (H-1) S-5 records are required.

LINEID UNITID NRECS

LINEID identifier for the current contact line; each contact-line in the model must have a unique **LINEID** identifier

UNITID identifier for the (previously-defined) shell unit on which the contact line is defined, or for the current element unit

NRECS number of S-5a records required to define this contact line (if it is on a shell unit), or the number of S-5b records required to define it (if it is on the current element unit)

```
if ( UNITID identifies a shell unit ) then
    go to S-5a
else
    go to S-5b
endif
```

S-5a Contact Line on a Shell Unit

A *contact line* is a directed line segment that is defined by a sequence of node numbers. When a contact line is on a shell unit, **NRECS** (S-5) records of this type are required to define that line. A contact line on a shell unit can be all or part of an edge, all or part of any row or column, or any set of nodes that are connected *via* an unbroken sequence of node numbers. Contact lines are used by **STAGS** in **E822** line-contact-interaction definitions (T-8), each of which identifies a contact that may occur between two free edges. One of these edges is represented by a *contacted* line, which has elements associated with it; and the other is represented as a *contacting* line, which may or may not have elements associated with it. The theory behind line-to-line contact is given by Rankin *et al*.* and is summarized in Chapter 14.

The order in which the nodes defining a contact line are specified determines its *direction*. This is important because **STAGS** associates with the contact line the elements that are attached to its left side. Any contact line that is ever used as a *contacted* line must have elements associated with it. Any contact line that is only used as a *contacting* line may but need not have elements associated with it. Figure 7.3 shows a typical shell unit in terms of its row and column nodal topology, the shell elements that are defined on that unit, four contact lines, and the elements that are associated with each contact line. Note that line 4 (a *contacting* line) has no elements associated with it.

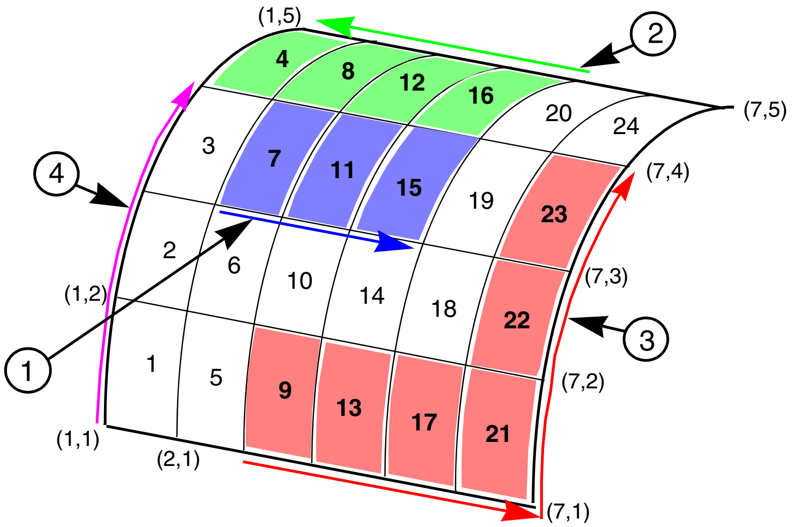


Figure 7.3 Contact Lines on a Typical Shell Unit

* Rankin, C.C., L.S. Chien, W.A. Loden and L.W. Swenson, Jr., *"Line-to-Line Contact Behavior of Shell Structures,"* AIAA Paper No. 99-1237, April 1999.

II JJ NPTS INC

II,JJ (row,col) indices for a node on the shell unit; if **II** = 0, all rows in column **JJ** are included (**STAGS** resetting **NPTS** to **NROWS**, the number of rows in the shell unit); if **JJ** = 0, all columns in row **II** are included (**STAGS** resetting **NPTS** to **NCOLS**, the number of columns in the shell unit); **II** and **JJ** cannot both be zero; each of the row indices specified by **II** and its offspring (*via* **NPTS** and **INC**, as described below) must be in the range $1 \le \mathbf{II} \le \mathbf{NROWS}$; and each of the column indices specified by **JJ** and its offspring (*via* **NPTS** and **INC**) must be in the range $1 \le \mathbf{JJ} \le \mathbf{NCOLS}$.

NPTS number of nodes to be specified with information on this S-5a record

INC direction indicator, used when **II** or **JJ** is 0 or when $\mathbf{NPTS} > 0$:

= +1	increment the row index	**II**	by	+ 1
= –1	increment the row index	**II**	by	– 1
= +2	increment the col index	**JJ**	by	+ 1
= –2	increment the col index	**JJ**	by	– 1

Example 1: The following S-5a record defines contact line 2 on Figure 7.3:

```
2   3   4   1    $ S-5a
```

Example 2: The following S-5a record defines contact line 1 on Figure 7.3:

```
5   5   5  -1    $ S-5a
```

Example 3: The following pair of S-5a records defines defines contact line 3 on Figure 7.3, which starts at node (3,1), proceeds along column 1 to node (7,1) of the shell unit, then makes a left-hand turn and goes along row 7 to node (7,4):

```
3   1   5   1    $ S-5a # 1
7   2   3   2    $ S-5a # 2
```

NS5 (H-1) number of S-5 records for the current element unit
NRECS (S-5) number of S-5a records required to define the current line

```
if      ( fewer than NRECS S-5a records have been processed )  then
        process another S-5a record
elseif  ( fewer than NS5 S-5 records have been processed )  then
        return to  S-5
else
        follow instructions at end of S-5b
endif
```

S-5b Contact Line on an Element Unit

A *contact line* is a directed line segment that is defined by a sequence of node numbers. When a contact line is on an element unit, **NRECS** (S-5) records of this type are required to specify the user nodes that define that line.

As noted in the S-5a description, above, contact lines are used by **STAGS** in **E822** line-contact-interaction definitions (T-8), each of which identifies a possible contact of two free edges. One of the two edges is treated as the *contacted* line, which must have elements associated with it; and the other is treated as the *contacting* line, which may or may not have elements associated with it.

The order in which the nodes defining a contact line are specified determines the *direction* of that contact line—the tail of the line being its first node and the head being its last. In its line-contact operations, **STAGS** uses the elements that are attached to the *left* side of the contacted line, as shown in the following figure:

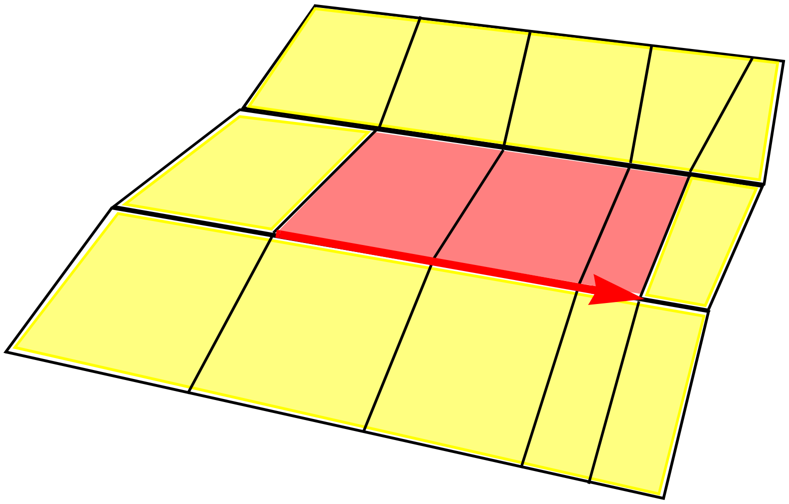


Figure 7.4 Contact Line on a Typical Element Unit

II NPTS INC

II user node number for a node on the contact line

NPTS number of nodes to be specified with information on this S-5a record

INC incrementation, which may be positive or negative

NRECS	(S-5)	number of S-5a records required to define the current line
NS5	(H-1)	number of S-5 records for the current element unit
NT1	(H-1)	number of “spring” elements
NT2	(H-1)	number of “beam” elements
NT3	(H-1)	number of triangular shell elements
NT4	(H-1)	number of quadrilateral shell elements
NT5	(H-1)	other-elements/element-command flag

```
if      ( fewer than NRECS S-5b records have been processed )  then
        process another S-5b record
elseif  ( fewer than NS5 S-5 records have been processed )  then
        return to S-5
else
        if      ( $NT1 > 0$ ) then    go to  T-1
        elseif  ( $NT2 > 0$ ) then    go to  T-2
        elseif  ( $NT3 > 0$ ) then    go to  T-3
        elseif  ( $NT4 > 0$ ) then    go to  T-4
        elseif  ( $NT5 > 0$ ) then    go to  T-5
        else    go to  T-100
endif
```

8
Model Input—Element Units (2)

This chapter describes the historic ***Edef*** protocol for specifying some or all of the elements that are to be used in constructing an element unit in a **STAGS** model. As noted earlier, this protocol is used if and only if one or more of the **NT1**, **NT2**, **NT3**, **NT4** and **NT5** parameters is positive on the H-1 record for the current element unit. If *all* of these five parameters are nonpositive, then **STAGS** expects the analyst to specify *all* of the elements for the element unit *via* the ***Ecom*** protocol, which is described in Chapter 9.

The Edef protocol is a rigorous procedure that begins by using the values of **NT1**, **NT2**, **NT3** and **NT4** (on H-1) to control loops in which appropriate type T-x record sets are processed to make **NT1** *spring* element definitions, then to make **NT2** *beam* element definitions, then to make **NT3** *triangular* element definitions, and finally to make **NT4** *quadrilateral* element definitions. A zero value for any (or all) of these parameters indicates that no elements of that type are to be defined (*via* "regular" input records). After doing that, **STAGS** examines the **NT5** parameter (on H-1) to determine whether or not additional type T-x and/or T-xx record sets are then required to define one or more contact, sandwich and/or solid elements. **STAGS** also checks to determine whether or not the *Ecom* protocol is to be used after that, to define one or more elements of *any* type.

8.1 Definition of "Spring" Elements *via* the Edef Protocol

If and only if **NT1** is positive on H-1, **STAGS** expects the analyst to specify **NT1** "spring" elements at this point in his or her model-definition input file and will attempt to read and process one or more type T-1 record sets to define those elements. Each of these T-1 record sets defines one or more type **E110** (mount), **E120** (rigid-link), **E121** (soft-link) or **E130** (generalized-fastener) spring elements—according to the value of the **KELT** parameter on T-1.

T-1 Spring Element

As noted above, **STAGS** expects **NT1** “spring” element definitions at this point in the model-definition input file if **NT1**>0 on the H-1 record for this element unit. The **NT1** parameter specifies the total number of elements in the four categories that are listed below. Typically, each spring is defined individually on a pair of records, as follows:

• **E110** mount	T-1 / T-1a
• **E120** rigid link	T-1 / T-1b
• **E121** soft link	T-1 / T-1b
• **E130** generalized fastener	T-1 / T-1c

Under some circumstances, the user will find it convenient to employ the *looping* feature provided on record T-1 *via* the **NX** parameter, with increments for one or more of the nodes specified thereon.

In any event, the T-1 series must be repeated as many times as necessary to specify a total of **NT1** “spring” elements. Please refer to “E110 Mount element” on page 14-6, to “E120 Rigid link element” on page 14-7, to “E121 Soft link element” on page 14-7 and/or to Section 14.8 “Contact Elements” on page 14-51 as necessary for explanations of the input data described here.

In the rigid link element (element type **E120**), the third node **N3** is a reference node that is used to enforce rotational compatibility between **N1** and **N2**. If **N3** is zero, the freedoms on **N2** are independent of those on **N1**—a condition that simulates a ball joint at **N2.** If **N3** is nonzero, total rotational compatibility is enforced between **N1** and **N2**—a condition that simulates the ordinary rigid link. If **N3** is positive, the rotational constraint in enforced with a set of three Lagrange multipliers. For this option, computational coordinates for each node in the link are completely independent (at the discretion of the user), affording maximum flexibility. If **N3** is negative, the rotational constraint is enforced using partial compatibility (see record G-2, with **ID1** = -2). A restriction is introduced that forces the computational coordinates of **N2** to be the same as for the master node to which **N1** refers. This can have unforeseen consequences if rigid links cause new master/slave relationships to be defined between other nodes in the model. It is recommended that a negative value for **N3** be used with caution.

In the soft link element (element type **E121**), node **N1** is usually associated with a node in a shell unit; and **N2** and **N3** are usually associated with different layers of a solid.

N1 N2 N3 KELT NX INC1 INC2 INC3 USERELT INC4

N1 node 1

N2 node 2

N3 node 3:

this is a *reference node* for the **E120** element (a positive value enforces rotational compatibility between nodes **N1** and **N2**);

this is an *active soft-link node* for the **E121** element

KELT

110 – **E110** mount element

120 – **E120** rigid link element

121 – **E121** soft link element

130 – **E130** generalized fastener

NX number of “spring” elements specified *via* the current T-1/* series; set equal to unity by **STAGS** if nonpositive or omitted

INC1 incrementation variable for **N1**

INC2 incrementation variable for **N2**

INC3 incrementation variable for **N3**

USERELT user-specified element number (only used if **IUWLE**=1 on H-1)

INC4 incrementation variable for **USERELT**

```
✦  if       ( KELT = 110 ) then   go to  T-1a
   elseif   ( KELT = 120 ) then   go to  T-1b
   elseif   ( KELT = 121 ) then   go to  T-1b
   elseif   ( KELT = 130 ) then   go to  T-1c
```

T-1a Mount

If the *looping* feature on the T-1 record is *not* used, each **E110** mount element is defined individually by a T-1 record followed by a T-1a record. If the *looping* feature *is* used, a series of mount elements is defined by the T-1 record followed by **NX** T-1a records—one for *each* element of the series.

The mount element is a special nonlinear spring capable of modeling a user-defined displacement-velocity-force profile. The mount is discussed in “I-4a Mount Element Table Size” on page 5-64 and in “E110 Mount element” on page 14-6. Please refer to those sections as necessary. As can be seen in Figure 14.1 on page 14-6, rigid links can be introduced. Rigid links provide a method for defining rotational stiffness in addition to axial spring stiffness. Rigid links are expressed in local element coordinate systems, (X_1, Y_1, Z_1) and (X_2, Y_2, Z_2) , as shown in Figure 14.1. The algorithm for determining these systems is very similar to that discussed for record S-2, with the reference node **N3** playing the same role as the point **YAX**, **YAY**, **YAZ** (S-2). Clearly, node **N3** must not lie on the same line as **N1** and **N2**. The coordinate X_1 is in the direction of the line connecting **N1** to **N2**. The Y_1 axis is normal to X_1 and in the plane defined by **N1**, **N2**, and **N3**, pointing “toward” **N3**. Finally, Z_1 is normal to the plane containing **N1**, **N2**, and **N3**, completing a right-handed system. **N3** can be either a structural node or a dummy node, defined only for reference to the mount. Any freedoms defined on dummy nodes are ignored. For rigid link 1, the origin of the (X_1, Y_1, Z_1) system is situated at **N1**, and the distances **RLX1**, **RLY1**, and **RLZ1** are expressed in this system. For rigid link 2, the (X_2, Y_2, Z_2) system, with origin at **N2**, is used to express the distances **RLX2**, **RLY2**, **RLZ2**. These distances can be positive, negative, or zero. When all these distances are zero, no rigid links exist.

IMNT1 IMNT2 RLX1 RLY1 RLZ1 RLX2 RLY2 RLZ2

IMNT1 Mount Element Table identifier (I-4a)

IMNT2 optional additional mount table identifier: if **IMNT2** is not zero, then **IMNT1** and **IMNT2** must refer to tables consisting of a single row (displacement table, **NRV** $= 1$, I-4a) or column (velocity table, **NRD** $= 1$, I-4a). There must be one table of each type, or an error will result. If **IMNT2** > 0, the total mount force is the sum of the force from the displacement table and the force from the velocity table.

RLX1, RLY1, RLZ1 (X_1, Y_1, Z_1) coordinates of point RL1; refer to Figure 14.1 on page 14-6

RLX2, RLY2, RLZ2 (X_2, Y_2, Z_2) coordinates of point RL2

✦ *follow instructions at end of* T-1c

T-1b Rigid or Soft Link

If the *looping* feature on the T-120a record is *not* used, each **E120** rigid link element or **E121** soft link element is defined individually by a T-1 record followed by a T-1b record. If the *looping* feature *is* used, a series of rigid link or soft link elements is defined by the T-1 record, followed by *one* T-1b record on which the **SCALE** variable to be used for *all* of the elements of the series is specified.

The rigid link element is discussed in “E120 Rigid link element” on page 14-7. A rigid link element constrains the distance between two nodes (**N1** and **N2**) to be invariant during an analysis. The displacements of node **N2** are dependent on the displacements and rotations of node **N1** through a rigid-link constraint equation, which is enforced *via* Lagrange multipliers.

The potential energy Π for a rigid link element is given by

$$\Pi = \phi\alpha^T(\boldsymbol{x}_1 + \boldsymbol{r} - \boldsymbol{x}_2)$$

where α is a vector of three Lagrange multipliers, $\boldsymbol{x}_1$ and $\boldsymbol{x}_2$ are the current global positions of nodes **N1** and **N2**, respectively, and $\boldsymbol{r}$ is the directed position of **N2** with respect to **N1**. The magnitude of $\boldsymbol{r}$ is the original distance between nodes **N1** and **N2**. The user-specified element scale factor ϕ is employed to make the magnitude of the stiffness contributions of the rigid link element comparable in size to those of other elements in the configuration—this value is typically on the order of the elastic modulus of the material.

Note that the rotations on **N2** are unaffected unless the reference node **N3** is nonzero, in which case G-2 records are automatically generated to constrain the rotations on **N1** to be the same as **N2**; separate G-2 records can always be generated to constrain the rotational freedoms as the user may desire.

The soft link element is discussed in “E121 Soft link element” on page 14-7. A soft link element constrains the three nodes associated with it to be colinear.

SCALE

SCALE element scale factor

✦ *follow instructions at end of* T-1c

T-1c Generalized Fastener

If the *looping* feature on the T-1 record is *not* used, each **E130** generalized fastener element is defined individually by a T-1 record followed by a T-1c record. If the *looping* feature *is* used, a series of generalized fastener elements is defined by the T-1 record followed by a *single* T-1c record on which the mount-table-identifier and material-code variables to be used for *all* of the elements of the series are specified.

The generalized fastener element is closely related to the **E110** (mount) element, defined on T-1/ T-1a. Please refer to “E121 Soft link element” on page 14-7 for element-formulation details and to Figure 8.1 “Degree-of-Freedom Directions at an Auxiliary Node” on page 8-12.

IMNT1 IMNT2 IMNT3 IMNT4 IMNT5 IMNT6 PLAS1 PLAS2 PLAS3 PLAS4 PLAS5 PLAS6

IMNT1	Mount Table identifier (see I–4a) applied to the relative local x translation
IMNT2	Mount Table identifier (see I–4a) applied to the relative local y translation
IMNT3	Mount Table identifier (see I–4a) applied to the relative local z translation
IMNT4	Mount Table identifier (see I–4a) applied to the relative local θ_x rotation
IMNT5	Mount Table identifier (see I–4a) applied to the relative local θ_y rotation
IMNT6	Mount Table identifier (see I–4a) applied to the relative local θ_z rotation
PLAS1	breakage code for **IMNT1**: see discussion, below, for significance
PLAS2	breakage code for **IMNT2**: see discussion, below, for significance
PLAS3	breakage code for **IMNT3**: see discussion, below, for significance
PLAS4	breakage code for **IMNT4**: see discussion, below, for significance
PLAS5	breakage code for **IMNT5**: see discussion, below, for significance
PLAS6	breakage code for **IMNT6**: see discussion, below, for significance

STAGS uses the six breakage codes, **PLASi**, specified here to control generalized fastener element breakage modes for the associated mount identifiers, **IMNTi** (where $1 \le \mathbf{i} \le 6$). Each breakage code may have one of the following five values:

PLASj = 1 ⇒ fastener **j** behaves elastically; its failure does *not* cause other fasteners to fail
PLASj = 2 ⇒ fastener **j** behaves elastically; its failure causes *all* of the fasteners to fail
PLASj = 3 ⇒ fastener **j** behaves elastically, and is unbreakable, throughout the analysis
PLASj = 4 ⇒ fastener **j** behaves plastically; its failure does *not* cause other fasteners to fail
PLASj = 5 ⇒ fastener **j** behaves plastically; its failure causes *all* of the fasteners to fail

NT1	(H-1)	number of “spring” elements
NT2	(H-1)	number of “beam” elements
NT3	(H-1)	number of triangular shell elements
NT4	(H-1)	number of quadrilateral shell elements
NT5	(H-1)	other-elements/element-command flag

```
if      ( fewer than NT1 spring elements have been defined )return to  T-1
elseif  ( NT2 >  0 )     then  go to  T-2
elseif  ( NT3 >  0 )     then  go to  T-3
elseif  ( NT4 >  0 )     then  go to  T-4
elseif  ( NT5 =  1 )     then  go to  T-5
elseif  ( NT5 =  2 )     then  go to  T-5
elseif  ( NT5 =  3 )     then  go to  T-100
else                           go to  U-1
```

8.2 Definition of “Beam” Elements *via* the Edef Protocol

If and only if **NT2** is positive on H-1, **STAGS** expects the analyst to specify **NT2** “beam” elements at this point in his or her model-definition input file and will attempt to read and process one or more type T-2 record sets to define those elements. Each of these T-2 record sets defines one or more type **E210** (beam), or **E250** (planar boundary conditions) “elements”—according to the value of the **KELT** parameter on T-2.

T-2 Beam

If and only if **NT2** > 0 on the H-1 record for this element unit, **STAGS** expects **NT2** “beam” element definitions at this point in the model-definition input file. In this case, **NT2** specifies the total number of elements in the two categories that are listed below. Typically, each “beam” element is defined individually on one or two records, as follows:

• **E220** standard beam element	T-2 / T-2a
• **E250** planar BC element	T-2

Under some circumstances, the user will find it convenient to employ the *looping* feature provided on record T-2 *via* the **NX** parameter, with increments specified thereon for one or more of the listed nodes. In any event, the T-2 series of records must be repeated as many times as necessary to specify a total of **NT2** “beam” elements.

Beam References

- Section 4.1 “Coordinate Systems” on page 4-1
- Section 14.4 ““Beam” Elements” on page 14-12
- Figure 8.5 on page 8-33

As shown in Figure 14.5 on page 14-13, an (x', y', z') element coordinate system, with its origin located at node 1, is used to define beams. A reference node is required to establish the element coordinate system. The y' coordinate is normal to x' and in the plane defined by **N1**, **N2**, **N3**, pointing “toward” **N3**. Finally, z' is normal to the plane containing **N1**, **N2**, **N3** and completes a right-handed system. **N3** can be either a structural node or a dummy node, defined only for reference to the beam. All freedoms at a dummy node should be suppressed on the S-1 record. Note the similarity of the (x', y', z') system with the system for nonlinear mounts (T-1/T-1a) and the (x_a, y_a, z_a) nodal-auxiliary coordinate system defined on the S-2 record.

Moving-Plane Boundary References

- Section 14.8 “Contact Elements” on page 14-51
- “B-2 General Model Summary” on page 5-12
- “O-1a Discrete Ring—Record 1” on page 6-50

The T-2 record can also be used to define a moving plane boundary which is like a symmetry boundary, except that the symmetry plane itself is allowed to move as a rigid body. In the element unit, beam-like elements are strung along a user-defined space curve forming the boundary. It is the user’s responsibility to make sure that curve initially lies in a plane (if the constraint is violated initially, **STAGS** will complain). The reference node **N3** must also lie in the boundary plane.

Typically, each beam element within an element unit will be defined individually with its own T-2 record, requiring the T-2 record to be repeated **NT2** times (H-1). Under some circumstances, the user will find it convenient to employ the *looping* feature triggered by the **NX** parameter on the T-2 record: in this case, incrementation variables must be specified on a T-2a record following any T-2 record that defines more than one beam; and T-2 records (plus T-2a records, where appropriate) sufficient to define **NT2** beam elements must be supplied.

N1 N2 N3 KELT ICROSS XSI ECY ECZ ILIN IPLAS NX USERELT

N1 node 1; refer to Figure 14.5 on page 14-13

N2 node 2

N3 node 3, the reference node, which is used to generate the (x', y', z') element coordinate system; for the moving plane boundary, **N3** must lie in the boundary plane.

KELT beam element code number; see Section 14.4 ““Beam” Elements” on page 14-12. The only “beam” elements currently available are: **E210** Beam and **E250** Planar Boundary Condition.

ICROSS cross-section number, as defined by **ITAB** (J-1), in the Cross Section Table: **ICROSS** $= 0$ indicates that the stiffener is defined in user-written CROSS. **ICROSS** $= -1$ indicates that the stiffener line is a moving plane boundary.

When **ICROSS** $= 0$, data tagged by ⌘ below are defined in CROSS; they are automatically initialized to zero before CROSS is called, thereby superseding any nonzero values input here; when **ICROSS** $= -1$, only **ECY** is relevant. Refer to Figure 8.5 on page 8-33 for an illustration of **XSI**, **ECY**, and **ECZ**; compare with Figure 6.5 on page 6-52, the shell-unit-stiffener counterpart.

⌘ **XSI** angle ξ, in degrees, between the element normal z' and the cross section $\bar{z}$. ξ is a right-handed rotation about $\bar{x}$, the longitudinal axis of the beam, which is parallel to x'.

⌘ **ECY** eccentricity in the y' direction; **ECY** is the y' coordinate of the (y', z') pair which positions the origin of the $(\bar{y}, \bar{z})$ system.

For **ICROSS** = –1 (moving plane boundary), **ECY** is a scale factor used for the numerical conditioning of Lagrange constraints introduced by the multipoint constraint. In that case, **ECY** should be of the same order of magnitude as entries in the stiffness matrix. A good guess is the modulus of elasticity of the material.

⌘ **ECZ** eccentricity in the z' direction; **ECZ** is the z' coordinate of the (y', z') pair which positions the origin of the $(\bar{y}, \bar{z})$ system.

⌘ **ILIN** geometric nonlinearity flag

0 – nonlinear strain-displacement relations
1 – linear strain-displacement relations

⌘ **IPLAS** material nonlinearity flag (see M-5)

0 – linear elastic constitutive relations

1 – plasticity included

2 – centroidal plasticity

NX number of beam elements to be generated via this T-2 record; set to unity by **STAGS** if nonpositive or omitted

USERELT user-specified element number, used only if **IUWLE** = 1 on H-1

✦ if (**NX** > 1) then *go to* T-2a
else *follow instructions at end of* T-2a

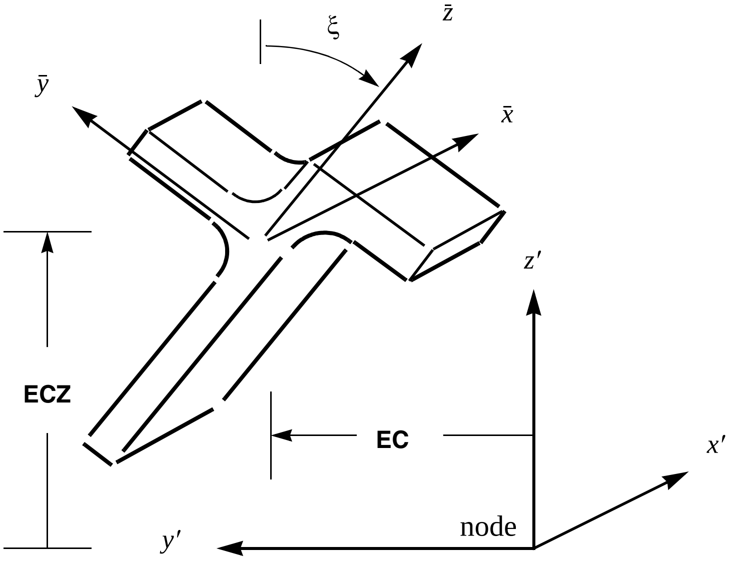


Figure 8.1 Degree-of-Freedom Directions at an Auxiliary Node

Compare with Figure 5.5 “Beam cross sections.” on page 5-122. Also, see 16.2 “Beam Results” on page 16-8.

T-2a Beam Incrementations

A single record of type T-2a must be included immediately after each type T-2 record on which the **NX** parameter is greater than unity. Incrementation variables are specified here for use with the T-2 record looping functions.

INC1 INC2 INC3 INC4

INC1 incrementation variable for use with the **N1** (node 1) variable on T-2

INC2 incrementation variable for use with **N2**

INC3 incrementation variable for use with **N3**

INC4 incrementation variable for use with **USERELT**

Any of these incrementation variables can be negative, zero or positive.

Example: the following T-2/T-2a record combination:

```
20 51 99 210 3 0.0 0.0 0.0 0 0 3    $ T-2  record
 5 10  0                            $ T-2a record
```

generates the same three beams as the following three individual T-2 records:

```
20 51 99 210 3 0.0 0.0 0.0 0 0      $ T-2  record
25 61 99 210 3 0.0 0.0 0.0 0 0      $ T-2  record
30 71 99 210 3 0.0 0.0 0.0 0 0      $ T-2  record
```

NT2 (H-1) number of “beam” elements

NT3 (H-1) number of triangular shell elements

NT4 (H-1) number of quadrilateral shell elements

NT5 (H-1) other-elements/element-command flag

```
if   ( NT2 beams have been defined )  then
     if       ( NT3 > 0 )    then    go to  T-3
     elseif   ( NT4 > 0 )    then    go to  T-4
     elseif   ( NT5 = 1 )    then    go to  T-5
     elseif   ( NT5 = 2 )    then    go to  T-5
     elseif   ( NT5 = 3 )    then    go to  T-100
     else                            go to  U-1
else     continue defining  T-2
```

8.3 Definition of Triangle Elements *via* the Edef Protocol

If and only if **NT3** is positive on H-1, **STAGS** expects the analyst to specify **NT3** triangle elements at this point in his or her model-definition input file and will attempt to read and process one or more type T-3 record sets to define those elements. Each of these T-3 record sets defines one or more **E320** or **E330** triangle elements—according to the value of the **KELT** parameter on T-3.

T-3 Triangular Shell

If and only if **NT3** > 0 on the H-1 record for this element unit, **STAGS** expects **NT3** triangle element definitions at this point in the model-definition input file. In this case, **NT3** specifies the total number of elements in the two categories that are listed below. Typically, each triangle is defined individually by a single T-3 record—or by a T-3/T-3a pair of records, if the **IANG** wall-reference option is exercised—as follows:

• **E320** standard triangle	T-3	or	T-3 / T-3a
• **E330** MIN3 triangle	T-3	or	T-3 / T-3b

Refer to the discussion in “T-4 Quadrilateral Shell” on page 8-17.

N1 N2 N3 KELT IWALL ZETA ECZ ILIN IPLAS IANG USERELT

N1 node 1; see Section 14.5 “Shell and Mesh-Transition Shell Elements” on page 14-19

N2 node 2

N3 node 3

KELT element code number (see Chapter 14 “The Element Library”):

= 320 — type **E320** triangular element
= 330 — type **E330** triangular element

IWALL wall fabrication identifier:

0 – shell wall properties are given in user-written subroutine WALL

>0 – shell wall configuration (fabrication) number in the <u>Wall Fabrication Table</u> (K-1)

<0 – shell fabrication identifier in the <u>GCP Fabrications Table</u> (I-21a): *this option is only available for type **E330** elements*

When **IWALL** = 0, data below indicated by ⌘ are defined in subroutine WALL; they are automatically initialized to zero before WALL is called, thereby superseding any nonzero values input here.

⌘ **ZETA** angle ζ between the wall-reference coordinate x_w and the fabrication coordinate $\bar{x}$; ζ is a right-handed rotation about $\bar{z}$. See Figure 8.2 on page 8-19.

⌘ **ECZ** eccentricity in z' direction. **ECZ** is the z' coordinate of the shell wall middle surface; refer to Figure 6.2 on page 6-28. In element units, (x', y', z') are used in place of (X', Y', Z'), which do not exist in an element unit. See “Effects of Eccentricity” on page 16-6.

⌘ **ILIN** governs geometric nonlinearity

0 – nonlinear strain-displacement relations
1 – linear strain-displacement relations

Note that with **ILIN** = 1, bifurcation buckling is suppressed in the shell unit

⌘ **IPLAS** governs material nonlinearity

0 – elastic behavior only
1 – plasticity included, with the material law satisfied at each element integration point
2 – plasticity included, with the material law satisfied at the element centroid (centroidal plasticity)

IANG wall-reference option; see discussion above

0 – use default strategy of projecting x_g, y_g to establish x_w

1 – input $\mathbf{r_w}$, which is projected to establish x_w

USERELT user-specified element number, used only when **IUWLE** = 1 on H-1

if (**IANG** = 1) then *go to* T-3a
else *follow instructions at end of* T-3a

T-3a Wall Reference Vector

RX RY RZ

RX, RY, RZ wall reference vector, $\mathbf{r_w}$, which is projected onto the element surface to determine the direction of the wall-reference coordinate x_w; $\mathbf{r_w}$ is expressed in (x_g, y_g, z_g) global coordinates

NT3	(H-1)	number of triangular shell elements
NT4	(H-1)	number of quadrilateral shell elements
NT5	(H-1)	other-elements/element-command flag

```
if      ( fewer than NT3 triangles have been defined ) return to  T-3
elseif  ( NT4 > 0 )     then   go to  T-4
elseif  ( NT5 = 1 )     then   go to  T-5
elseif  ( NT5 = 2 )     then   go to  T-5
elseif  ( NT5 = 3 )     then   go to  T-100
else    go to  U-1
```

8.4 Definition of “Quadrilateral” Elements *via* the Edef Protocol

If and only if **NT4** is positive on H-1, **STAGS** expects the analyst to specify **NT4** “quadrilateral” elements next and will attempt to read and process one or more type T-4 record sets to define those elements. Each of these T-4 record sets defines one or more type **E410**, **E411** or **E480** quad elements, one or more **E510** or **E710** quad transition elements, or one or more **E420** or **E430** pairs of **E320** or **E330** triangular elements—according to the value of the **KELT** parameter on T-4.

T-4 Quadrilateral Shell

If and only if **NT4** > 0 on the H-1 record for this element unit, **STAGS** expects **NT4** “quadrilateral” element specifications at this point in the model-definition input file. In this case, **NT4** specifies the total number of elements in the three categories that are listed below. Each quadrilateral is defined individually *via* a single T-4 record or (for the **E480** 9-node quadrilateral element) *via* a T-4/T-4a pair of records—followed by a T-4b record if the **IANG** wall-reference option is exercised—as follows:

• **E410** 4-node quadrilateral element	T-4	or	T-4 / T-4b
• **E411** 4-node quadrilateral element	T-4	or	T-4 / T-4b
• **E480** 9-node quadrilateral element	T-4 / T-4a	or	T-4 / T-4a / T-4b

NT4 (H-1) is the total number of quadrilateral shell elements in the current element unit.

Quadrilateral Shell References

- Section 4.1 “Coordinate Systems” on page 4-1
- Section 14.2 “Algorithm for Determining the Element Frame” on page 14-2
- Section 14.5 “Shell and Mesh-Transition Shell Elements” on page 14-19
- “K-1 Shell Wall Properties” on page 5-129
- “M-5 Shell Wall” on page 6-24

A quadrilateral shell element is defined by specifying the four corner nodes in counterclockwise order as viewed from above. In this context, “viewed from above” means looking down onto the *top surface* of the element. As shown in Figure 6.2 on page 6-28, the top surface corresponds to $Z' = Z'_{max}$ $(z' = z'_{max}$ in an element unit). These four nodes, input on T-4, determine the (x', y', z') element coordinate system. Refer to 14.2 and 14.5 for details.

For elements having more than four nodes, nodes 5–n, where n is the total number of nodes in the element, are specified on T-4a. The order in which the nodes are given is according to the numbering shown in the sketches in Section 14.5 “Shell and Mesh-Transition Shell Elements”. Some 4-node elements, like **E411**, contain midside deviational nodes that are added automatically, without user input. Currently, only the 9-node **E480** element requires a T-4a record.

> ☞ The z' axis defines the direction in which pressure acts—a positive pressure value acts in the positive z' direction, and a negative pressure value acts in the negative z' direction.

In shell units, the wall-fabrication orientation is determined by **ZETA** & **ECZ** (M-5). Figure 6.2 shows how **ECZ** defines the eccentricity and how **ZETA** rotates the $(\bar{x}, \bar{y})$ fabrication coordinates to establish their directions relative to the (x_w, y_w) wall-reference coordinates. Implicit in Figure 6.2 is the shell-unit convention that the (x_w, y_w) wall-reference coordinates are defined to be coincident with the (X', Y') shell coordinates. In element units, shell coordinate systems do not exist. Instead, the user is given two options for establishing wall-reference coordinates.

In the default option, **STAGS** determines whether the x_g or y_g axis lies closer to the element plane. If x_g lies closer, it is projected onto the element surface to establish the x_w axis. If y_g lies closer, it is projected to establish the y_w axis. This means that when x_g and y_g both lie in the plane of the element, the result will be the same regardless of which is chosen to be projected.

The other option is to input a wall reference vector, $\mathbf{r_w}$, that determines the direction of x_w. Although the user will in most cases try to make sure that this vector is tangent to the surface he has in mind, the code makes no such assumption. **STAGS** will project this vector onto the element surface to establish the x_w axis.

After the x_w axis is established, using either of the two options, the wall orientation is then determined just as it is for shell units. Compare Figure 8.2 with Figure 6.2. **ZETA** has the same meaning in both instances. The only difference is that for shell units, the (x_w, y_w) wall-reference coordinates are uniquely defined by the (X', Y') shell coordinates, and for element units, one of two user-selected options (**IANG**, on the T-4, T-9, T-10, T-11, T-12 and T-13 records) is used to establish the wall-reference system.

The process outlined here often allows the user to specify all the wall angles with very simple input. For example, some standard geometries such as cylinders or cones have an axis of revolution (the generator) whose projection onto the element surface lies along the same direction, independent of the element location. If user input specifies the generator as $\mathbf{r_w}$, or if the default is used (for cone angles less than $45°$), a unique angle **ZETA** gives the proper offset

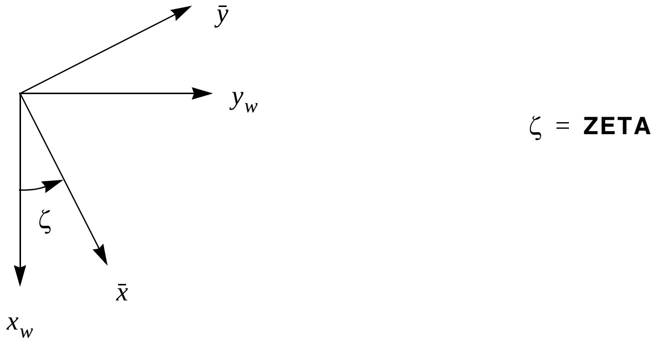


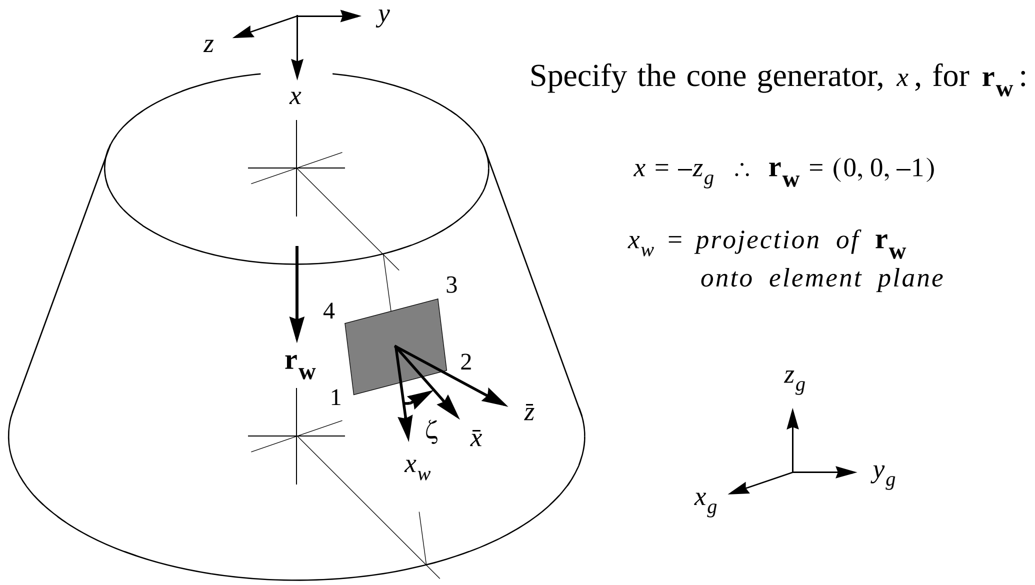
Figure 8.2 Shell Wall Orientation for Element Units

for all elements in the geometry. Figure 8.3 on page 8-20 shows an example where the generator of a cone is specified as $\mathbf{r_w}$. It is usually straightforward to specify the global coordinates of a vector parallel to a shell-of-revolution generator. The user should be careful for more complex geometries. It should also be noted that the user need not know the (x', y', z') shell element coordinate system.

For all quadrilaterals, regardless of the number of nodes or the order of the element, the plane of the element is determined by the procedure outlined in Section 14.2 “Algorithm for Determining the Element Frame”. The result of this procedure is an element reference plane that is the “best fit” to the four corner nodes. (x_w, y_w) wall-reference coordinates, and hence $(\bar{x}, \bar{y})$ fabrication coordinates and (ϕ_1, ϕ_2) material coordinates, all lie in this “average” plane.

☞ Note that the fabrication coordinate system is oriented by rotating the wall-reference system through the angle **ZETA**. The material coordinate system for each layer in a laminate is then determined by rotating the fabrication system through a unique angle **ZETL** (K-2)—or **ANGSHL** (I-21d), for GCP input—for the corresponding layer.

T-4 is repeated **NT4** times (H-1).


Specify the cone generator, x, for $\mathbf{r_w}$:

$x = -z_g \;\; \therefore \;\; \mathbf{r_w} = (0, 0, -1)$

x_w = *projection of* $\mathbf{r_w}$ *onto element plane*

ζ = **ZETA** is a right-handed rotation about $\bar{z}$, the fabrication normal.

Figure 8.3 Specifying the Wall-Reference Vector, $\mathbf{r_w}$, in an Element Unit: example showing use of a conical-shell generator

N1 N2 N3 N4 KELT IWALL ZETA ECZ ILIN IPLAS INTEG IPENL IANG USERELT

N1 node 1; see Section 14.5 “Shell and Mesh-Transition Shell Elements” on page 14-19

N2 node 2

N3 node 3

N4 node 4

KELT element code number (see Chapter 14 “The Element Library”)

IWALL wall fabrication identifier:

- 0 – shell wall properties are given in user-written subroutine WALL
- >0 – shell wall configuration (fabrication) number in the Wall Fabrication Table (K-1)
- <0 – shell wall fabrication identifier in the GCP Fabrications Table (I-21a)

When **IWALL** = 0, data below indicated by ⌘ are defined in subroutine WALL; they are automatically initialized to zero before WALL is called, thereby superseding any nonzero values input here

⌘ **ZETA** angle ζ between the wall-reference coordinate x_w and the fabrication coordinate $\bar{x}$; ζ is a right-handed rotation about $\bar{z}$; see Figure 8.2 on page 8-19

⌘ **ECZ** eccentricity in z' direction. **ECZ** is the z' coordinate of the shell wall middle surface; refer to Figure 6.2 on page 6-28; in element units, (x', y', z') are used in place of (X', Y', Z'), which do not exist in an element unit; see “Effects of Eccentricity” on page 16-6

⌘ **ILIN** governs geometric nonlinearity

- 0 – nonlinear strain-displacement relations
- 1 – linear strain-displacement relations

Note that with **ILIN** = 1, bifurcation buckling is suppressed in the shell unit

⌘ **IPLAS** governs material nonlinearity

- 0 – elastic behavior only
- 1 – plasticity included, with the material law satisfied at each element integration point
- 2 – plasticity included, with the material law satisfied at the element centroid (centroidal plasticity)

INTEG integration type (see N-1)

0 – standard integration, or 2×2 Gauss points for elements **E410** & **E411**

1 – modified 5-point integration, previously referred to as full integration

2 – full 3×3 Gauss integration for **E411** element

IPENL penalty option (see N-1)

0 – no penalty function on fourth-order terms in elements **E410** and **E411**

1 – penalty function included in elements **E410** and **E411**

IANG wall-reference option; see discussion on page 8-18

0 – use default strategy of projecting x_g, y_g to establish x_w

1 – input $\mathbf{r_w}$, which is projected to establish x_w; see (T-4b)

USERELT user-specified element number, used only when **IUWLE** = 1 on H-1

```
✦  if      ( KELT references an element with > 4 nodes )then  go to  T-4a
   elseif  ( IANG = 1 )     then   go to  T-4b
   else    follow instructions at end of  T-4c
```

T-4a Extra Nodes

This record is provided only for elements having more than four nodes, and is used to input nodes 5–*n*, where *n* is the total number of nodes in the element. The order in which the nodes are given is according to the numbering shown in the sketches in Section 14.5 “Shell and Mesh-Transition Shell Elements”. Some 4-node elements, like the **E411**, contain midside deviational nodes that are added automatically without user input. Currently, only the 9-node **E480** element requires a T-4a record.

NODE(i), i=5,n

NODE(i) node *i*; see above

IANG (T-4) wall-reference option

if (**IANG** = 1) then *go to* T-4b
else *follow instructions at end of* T-4b

T-4b Wall Reference Vector

RX RY RZ

RX, RY, RZ wall reference vector, $\mathbf{r_w}$, which is projected onto the element surface to determine the direction of the wall-reference coordinate x_w; $\mathbf{r_w}$ is expressed in (x_g, y_g, z_g) global coordinates

NT4 (H-1) number of quadrilateral shell elements
NT5 (H-1) element-command flag

```
if      ( fewer than NT4 quadrilaterals defined )return to  T-4
elseif  ( NT5 = 1 ) then  go to  T-5
elseif  ( NT5 = 2 ) then  go to  T-5
elseif  ( NT5 = 3 ) then  go to  T-100
else                      go to  U-1
```

8.5 Definition of “Other” Elements *via* the Edef Protocol

If and only if the **NT5** parameter is 1 or 2 on the H-1 record for the current element unit, **STAGS** expects the analyst to continue using the Edef protocol to define zero or more type **E810**, **E820** and/or **E822** *contact* elements, then to define zero or more type **E830**, **E840**, **E845**, **E847** and/or **E849** *sandwich* elements, and then to define zero or more **E880**-family *solid* elements *via* additional type T-x and/or T-xx “regular” input records, as described below. A type T-5 control record is required next to specify how many definitions are to be made for each of these types or classes of elements.

T-5 Contact, Sandwich, and Solid Element Flags

This record is required next (with the Edef protocol) for specification of the number of “regular” input *definitions* that **STAGS** must process to generate zero or more **E810** (PAD) elements, then to generate zero or more **E820** (generalized contact) elements, then to generate zero or more **E822** (line-contact-interaction) definitions, then to generate zero or more **E830**, **E840**, **E845**, **E847** and/or **E849** (sandwich) elements, and finally to generate zero or more **E880**-family (ANS-type solid) elements.

Each type **E810** PAD element to be generated may be defined explicitly with a single T-6 record, which references eight user points that must have been defined with S-1/S-1a/S-2 or S-3/S-3a/S-4 user point records within that element unit. Multiple PAD elements can be defined explicitly with a T-6 record on which the PAD-element *looping* parameter (described below) is invoked, using nodal incrementations specified on a companion T-6b record.

Specific type **E820** *“general-contact”* elements in an element unit are constructed *on-the-fly* by the **STAGS** program when contact occurs during the course of an analysis—utilizing *“contact-definition”* information supplied here. Each *contact definition* identifies a set of one or more *contact points* on one structural component that *may* come into contact with a specific *contact surface* on another. Each such *contact definition* is specified with a single T-7 record set (consisting of a T-7a record followed by as many T-7b or T-7c *contact-surface-element-specification* records and by as many T-7d or T-7e *contact-point-specification* records as may be required), as described below.

Similarly, specific line-contact elements are constructed *on-the-fly* by **STAGS** when edge-to-edge contact occurs during the course of an analysis—using *contact lines* that have been specified as described earlier (with the S-5 and related records) and utilizing *“line-contact-interaction-definition”* information that the analyst must supply here. Each line-contact-interaction definition identifies a specific line on one structural component that *may* be *contacted* by a specific *contacting* line on another. Each such line-contact-interaction definition is specified with a single T-8 record.

Each **E810**-element-, each **E820**-element- and each **E822**-element specification references a stiffness/displacement (penalty) function table that must have been defined *via* I-4a, I-4b, I-4c and I-4d records.

Each individual **E830** sandwich element in a **STAGS** element unit may be defined *via* its own T-9/T-9a/T-9c/T-9e record set (plus T-9b, T-9d and/or T-9f records, if material-angle transformations are required). Multiple **E830** sandwich elements can be defined using the two looping parameters on the T-9 record, with nodal incrementations specified on the T-9g and T-9h companion records.

Each individual **E840** sandwich element in a **STAGS** element unit may be defined *via* its own T-10/T-10a/T-10c/T-10e record set (plus T-10b, T-10d and/or T-10f records, if material-angle transformations are required). Multiple **E840** sandwich elements can be defined *via* the two looping parameters on T-10, with nodal incrementations specified on T-10g and T-10h.

Each individual **E845** sandwich transition element in a **STAGS** element unit may be defined *via* its own T-11/T-11a/T-11c/T-11e record set (plus T-11b, T-11d and/or T-11f records, if material-angle transformations are required). Multiple **E845** elements can be defined *via* the two looping parameters on T-11, with nodal incrementations specified on T-11g and T-11h.

Each individual **E847** sandwich transition element in a **STAGS** element unit may be defined *via* its own T-12/T-12a/T-12c/T-12e record set (plus T-12b, T-12d and/or T-12f records, if material-angle transformations are required). Multiple **E847** elements can be defined *via* the two looping parameters on T-12, with nodal incrementations specified on T-12g and T-12h.

Each individual **E849** sandwich element in a **STAGS** element unit may be defined *via* its own T-13/T-13a/T-13c/T-13e record set (plus T-13b, T-13d and/or T-13f records, if material-angle transformations are required). Multiple **E849** elements can be defined *via* the two looping parameters on T-13, with nodal incrementations specified on T-13g and T-13h.

Each individual **E880**-family solid element in a **STAGS** element unit may be defined explicitly *via* its own T-14/T-14a record set (plus a T-14b record, if a material-angle transformation is required). Multiple **E880**-family solid elements can be defined via the two looping parameters on T-14, with nodal incrementations specified on T-14c and T-14d.

The T-5 record contains three contact-element-definition flags (**N810**, **N820** and **N822**), five sandwich-element-definition flags (**N830**, **N840**, **N845**, **N847** and **N849**), and one solid-element-definition flag (**N880**):

N810 N820 N822 N830 N840 N845 N847 N849 N880

N810 number of *PAD-element-definition* records for the current element unit

N820 number of *general-contact-definition* records

N822 number of *line-contact-interaction definition* records

N830 number of *6-node-sandwich-element-definition* records

N840 number of *8-node-sandwich-element-definition* records

N845 number of *10-node-sandwich-transition-element-definition* records

N847 number of *14-node-sandwich-transition-element-definition* records

N849 number of *18-node-sandwich-element-definition* records

N880 number of *solid-element-definition* records

```
if      ( N810 > 0 )   then   go to T-6
elseif  ( N820 > 0 )   then   go to T-7
elseif  ( N822 > 0 )   then   go to T-8
elseif  ( N830 > 0 )   then   go to T-9
elseif  ( N840 > 0 )   then   go to T-10
elseif  ( N845 > 0 )   then   go to T-11
elseif  ( N847 > 0 )   then   go to T-12
elseif  ( N849 > 0 )   then   go to T-13
elseif  ( N880 > 0 )   then   go to T-14
else                          go to U-1
```

Contact elements

The current version of **STAGS** has three “elements” that enable the user to perform analyses in which three types of contact might occur.

The **E810** PAD surface/surface contact “element” is designed to treat situations in which one surface may come into contact with another, when the specific elements on one surface that may come into contact with specific elements on the other surface are known *a priori*.

The **E820** generalized contact “element” is designed to treat situations in which one surface may come into contact with another surface, but where the specific elements that may come into contact with each other are *not* known in advance and/or when they may change during the course of the analysis to be performed. The **E820** approach considers contact to be point/surface phenomenon. Here, the user specifies a set of points on one surface and a set of elements on the other, telling **STAGS** that one or more of the identified points *may* come into contact one or more of the identified elements. **STAGS** digests this information and uses it to determine whether or not point/surface contact has started (or is continuing) at each step of the analysis, and generates one or more point/surface contact elements as and if required, for the specific points and surfaces that are involved with that contact.

The **E830** line/line contact “element” is designed to treat situations in which one line (edge) may come into contact with another line (edge), but where the exact location at which that contact may occur is not known in advance and/or when it may change during the course of the analysis. The **E830** approach considers this type of contact to be line/line phenomenon. Here, the user specifies a set of two or more line segments in the model—and uses an **E830** line/line contact “element” to identify one line that *may* come into contact with another, for each line/line contact situation that might occur. **STAGS** digests this information and uses it to determine whether or not line/line contact has started (or is continuing) at each step of the analysis, and generates one or more line/line contact elements as and if required.

The theoretical foundations of these three types of contact “elements” are described in Section 14.8 of this document and in the ***STAGS** Elements Manual* document. The input requirements for these elements are described next.

T-6 E810 PAD Contact Element

The **E810** 8-node *PAD* contact element is basically a set of four independent nonlinear springs connecting the nodes defining one **E410** shell element to the corresponding nodes of a second **E410** element. It is intended for use in situations where those two PAD-connected elements—which may be in the same or in different shell or element units—*may* come into contact with each other. The **E810** PAD element is suitable for use only in situations where the contact region is known *a priori*, where the individual elements coming into contact with each other can be readily identified and paired, and where no *sliding* along the contact surface occurs. The PAD element can be used to treat (some) lap-joint and Hertzian impact problems, but it is *not* designed for use in more general situations where the contact regions are not known *a priori* or when sliding occurs or when friction is present. **STAGS**' more general (**E820**) contact capabilities must be used in those situations.

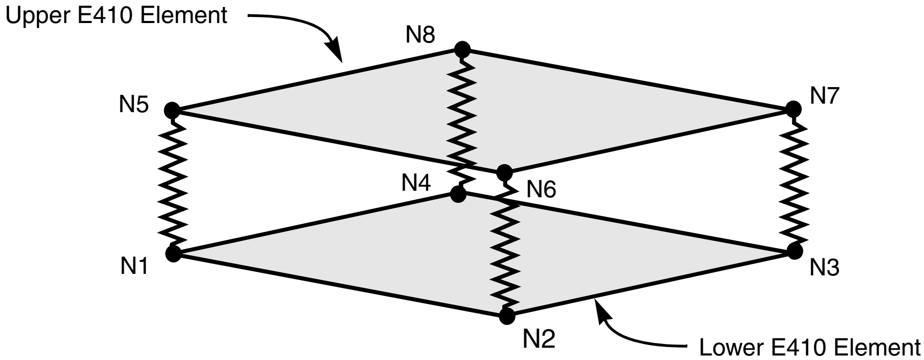


Figure 8.4 **E810** *PAD* Element

The nonlinear spring connecting each pair of nodes typically has a very low stiffness when the *gap* separating the two nodes is positive (where the gap is defined as the distance of the upper-element node from the lower-element reference plane) and to be very stiff when the gap is extremely small or negative (indicating that at least some portions of the two parent elements are in contact with each other): the large forces and stiffnesses that are produced by stiff PAD-element springs helps to enforce the displacement compatibility constraints for the contact problem.

Stiffness properties for PAD-element springs must be specified *via* one or more stiffness-displacement tables (type I-4a through I-4d records). These stiffness profiles, each of which is identified by its *profile-definition table number*, are currently assumed to be independent of velocity (any velocity dependencies specified are ignored by the program).

Element-unit *user point* nodes employed in defining PAD elements are defined *via* type S-1 or S-3 records (and type S-2 or S-4 records, if necessary): these *user points* are generally slaved to nodes defining the **E410** shell elements that are expected to come in contact with each other. An additional **OFFSET** parameter can be used to account for thickness effects when the user point nodes lie on parent-node reference surfaces within (rather than on the surfaces of) those parent elements.

The T-6 record defines one or more **E810** elements to be included in the current element unit. The *looping* capabilities provided here, *via* **NX** and on T-6 and the incrementation parameters on T-6a, can be used effectively in many situations.

N1 N2 N3 N4 N5 N6 N7 N8 KELT ITAB OFFSET NX USERELT

N1	first lower-surface pad-element node point
N2	second lower-surface pad-element node point
N3	third lower-surface pad-element node point
N4	fourth lower-surface pad-element node point
N5	first upper-surface pad-element node point, connected to **N1**
N6	second upper-surface pad-element node, connected to **N2**
N7	third upper-surface pad-element node, connected to **N3**
N8	fourth upper-surface pad-element node, connected to **N4**
KELT	element code number 810 defines an 8-node PAD element
ITAB	spring stiffness-displacement-table identifier (see record I–4a)
OFFSET	offset parameter, to account for element thicknesses
NX	looping parameter, set equal to unity by **STAGS** if omitted or nonpositive
USERELT	user-specified element number, used only if **IUWLE** = 1 on H-1

if (**NX** > 1) *go to* T-6a
else *follow instructions at the end of* T-6a

T-6a PAD Element Incrementations

If the **NX** looping parameter is greater than 1 on T-6, a T-6a record is required to specify nine incrementation variables to be used with the T-6 looping function.

I1 I2 I3 I4 I5 I6 I7 I8 I9

I1	incrementation for the **N1** (PAD node) variable on the parent T-6 record
I2	incrementation for the **N2** (PAD node) variable on the parent T-6 record
I3	incrementation for the **N3** (PAD node) variable on the parent T-6 record
I4	incrementation for the **N4** (PAD node) variable on the parent T-6 record
I5	incrementation for the **N5** (PAD node) variable on the parent T-6 record
I6	incrementation for the **N6** (PAD node) variable on the parent T-6 record
I7	incrementation for the **N7** (PAD node) variable on the parent T-6 record
I8	incrementation for the **N8** (PAD node) variable on the parent T-6 record
I9	incrementation for **IUWLE**

Any of these incrementation variables can be negative, zero, or positive, as required.

Example: the following T-6/T-6a record combination:

```
10 20 30 40 50 60 70 80  810  7 0.0  3
 1  1  1  1  1  1  1  1
```

generates the same three PAD elements as the following three individual T-6 records:

```
10 20 30 40 50 60 70 80  810  7 0.0
11 21 31 41 51 61 71 81  810  7 0.0
12 22 32 42 52 62 72 82  810  7 0.0 1
```

N810 (T-5) number of **E810** definitions
N820 (T-5) number of **E820** definitions
N822 (T-5) number of **E822** definitions
N830 (T-5) number of **E830** definitions
N840 (T-5) number of **E840** definitions
N845 (T-5) number of **E845** definitions
N847 (T-5) number of **E847** definitions
N849 (T-5) number of **E849** definitions
N880 (T-5) number of **E880** definitions

```
if     ( N810 E810 definitions have been processed )return to  T-6
elseif ( N820 > 0 )   then   go to  T-7
elseif ( N822 > 0 )   then   go to  T-8
elseif ( N830 > 0 )   then   go to  T-9
elseif ( N840 > 0 )   then   go to  T-10
elseif ( N845 > 0 )   then   go to  T-11
elseif ( N847 > 0 )   then   go to  T-12
elseif ( N849 > 0 )   then   go to  T-13
elseif ( N880 > 0 )   then   go to  T-14
else                         go to  U-1
```

T-7 General Contact Definition

As noted in the preceding description, **E810** PAD elements are defined *explicitly* and should only be used in situations where particular **E410** elements that may contact each other are known *a priori* and can be paired, and where the contact regions (and **E410**-element pairings) do not change during an analysis. **STAGS**’ more general point/surface contact capabilities must be used in situations where contact is anticipated but it is not known where the contact will occur and/or how the contact region changes as the analysis progresses.

It is convenient, here, for the analyst to view the contact problem as one in which one structure is (perhaps arbitrarily) designated as the *contacting* structure and the other is considered to be the *contacted* one. The current approach in **STAGS** to the general contact problem avoids many of the complexities and inefficiencies of general surface-on-surface interactions by considering *one or more specific points* on one structure that *may* come into contact with *one or more shell elements* on the other structure—as shown schematically in Figure 8.5.

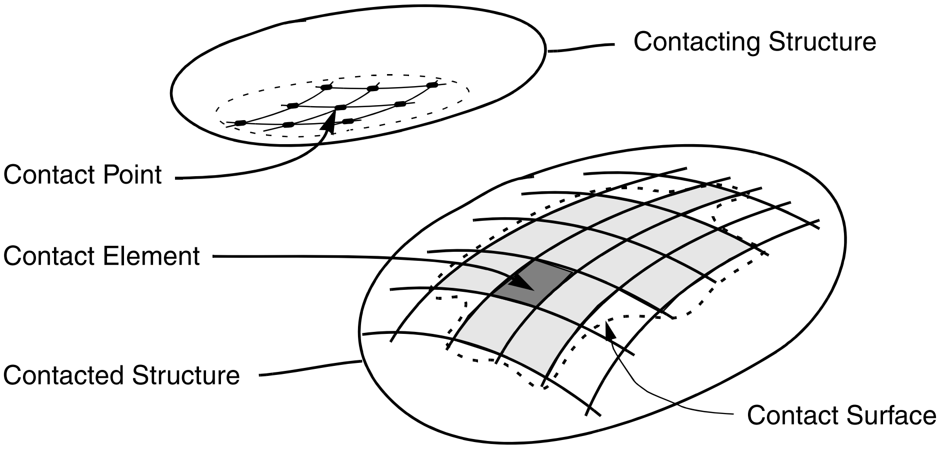


Figure 8.5 Contact-Definition Specification in **STAGS**

The general-contact capabilities in **STAGS** are invoked when the analyst, anticipating the possibility that contact between two structural components may occur, includes one or more **E820** *contact-definition* specifications in an element unit of the **STAGS** model. Each *contact definition* identifies a set of *contact points* on the contacting structure that *may* experience contact with a particular *contact surface* on the contacted structure—where the *contact surface* is a set of contiguous shell elements forming a convex region on the surface of the latter body.

STAGS uses these *contact-definitions* to check for contact and to construct actual contact elements coupling contacting points with contacted shell elements on-the-fly, as and if required, as the analysis progresses. In doing this, **STAGS** attempts to use penalty functions to enforce displacement-compatibility constraints between each contacting point and each element with which it is in contact—utilizing analyst-supplied *stiffness-vs.-displacement* information to compute the forces and stiffnesses resulting from the (necessarily) small contact-surface penetrations that occur.

An actual contact element is (conceptually) a nonlinear spring connecting the contacting point to the surface of the contacted element. This nonlinear spring typically has a very low stiffness and generates a small force when the *contact-surface* penetration is small, but it gets progressively stiffer and generates a larger force as the penetration increases. Stiffness properties for these springs must be specified *via* one or more stiffness-displacement tables (type I-4a through I-4d records). These stiffness-displacement functions each of which is identified by its *table number*, are currently assumed to be independent of velocity (any velocity dependencies specified are ignored by the program).

The T-7 record defines a single **E820** definition to be included in the current element unit. An **E820** *contact-definition* is made *via* a T-7 record (described immediately below) that is followed first by as many T-7a or T-7b *contact-surface-element-specification* records, and then by as many T-7c or T-7d *contact-point-specification* records as may be required—as described farther below. Each of these *contact-surface-specifications* references a specific stiffness-displacement (penalty) function table.

KELT NSRF NPTS

KELT element code number 820 identifies a contact-definition specification

NSRF parameter indicating the method to be used to identify the contiguous shell elements that comprise the *contact surface*: set **NSRF** ≥ 0 to use the *row & column* method (to identify one or more elements in one or more shell units), or set **NSRF** < 0 to use the *element-number* method (to identify one or more elements in one or more shell units and/or one or more elements in the current or previously-defined element units)

NPTS parameter indicating the method to be used to identify the specific points that *may* come into contact with the *contact surface*: set **NPTS** ≥ 0 to use the *row & column* method (to identify one or more nodes in one or more shell units), or set **NPTS** < 0 to use the *point-number* method (to identify one or more nodes in one or more shell units and/or one or more nodes in the current or previously-defined element units)

```
if    ( NSRF ≥ 0 )    then
        go to T-7a
else    go to T-7b
```

T-7a E820 Row & Column Contact-Element Specifications

NSRF ≥ 0 (T-7) indicates that the *row & column method* is to be used to identify the contiguous shell elements that comprise the *contact surface*. This method clearly can only be used to identify contact elements that are associated with one or more *shell* units, because there are no row or column associations for elements in element units. With this method, the value of the **NSRF** parameter indicates the *minimum number* of contact elements to be identified with the set of one or more T-7a records included for the current *contact-definition*. The number of contact elements identified by any given T-7a depends on the parameters on that record—as described below:

USRF TYPE LI LJ ID NI NJ

USRF identifies the *shell unit* within which the element(s) identified by the **LI** and **LJ** row & column parameters are defined; the element grid for this *shell unit* has **NROWS** rows and **NCOLS** columns of quadrilateral domains—each of which contains one **E410** quadrilateral element or two **E320** triangular elements

TYPE specifies the element type for this (or these) element(s): **TYPE** must currently be either **E410** or **E320**

LI,LJ row and column numbers identifying one or more elements: **LI** $=$ **LJ** $= 0$ indicates that *all* type **TYPE** elements of shell unit **USRF** are to be included; **LI** > 0 with **LJ** $= 0$ identifies (and includes) all of the elements in row # **LI** of the element grid; **LJ** > 0 with **LI** $= 0$ identifies all of the elements in column **LJ**; and **LI** > 0 with **LJ** > 0 identifies one or more **E410** element or the one or more pairs of **E320** elements, starting at row **LI** and column **LJ** of the unit: if **NI** and **NJ** are absent, zero or unity, a single element (or pair of elements) is defined; if **NI** and **NJ** are both positive, then **NI**x**NJ** elements (or pairs of elements) are identified in a double FORTRAN-like loop, starting with the element (or pair of elements) at (**LI**,**LJ**).

ID spring stiffness-displacement table identifier (see record I–4a)

NI,NJ element-identification looping parameters, as discussed in **LI,LJ**, above

NSRF	(T-7)	surface-method parameter
NPTS	(T-7)	point-method parameter

```
if     ( fewer than NSRF contact-surface elements have been identified )return to  T-7a
elseif( NPTS > 0 )  then   go to  T-7c
else                       go to  T-7d
```

T-7b E820 Element-Number Contact-Element Specifications

NSRF $<$ 0 (T-7) indicates that the *element-number method* is to be used to identify the contiguous shell elements that comprise the *contact surface*. This method can (but generally should not) be used to identify contact elements that are associated with *shell units*, and it *must* be used to identify elements that are defined in **STAGS** *element units*. With this method, the *magnitude* of the **NSRF** parameter indicates the *minimum number* of contact elements to be identified with the set of one or more T-7b records included for the current *contact-definition*.

The number of contact elements identified by any given T-7b depends on the parameters on that record—as described below.

USRF TYPE I1 I2 INC ID

USRF identifies the *shell or element unit* within which the element(s) identified by the **I1**, **I2** and **INC** parameters are defined

TYPE specifies the element type for this (or these) element(s): **TYPE** must currently be either **E410** or **E320**

I1,I2,INC element identifiers: **I1** > 0, with **I2** $= 0$ and **INC** $= 0$ identifies element # **I1** (in unit **USRF**) as part of the contact surface for the current contact-definition; **I1**, **I2**, **INC** $>$ 0 identifies **I2** elements—starting with element **I1** and incrementing by **INC** until **I2** elements have been indicated (in unit **USRF**) as part of the *contact surface* for the current *contact-definition*

ID spring stiffness-displacement table identifier (see record I–4a)

NSRF	(T-7)	surface-method parameter
NPTS	(T-7)	point-method parameter

```
if     ( fewer than NSRF contact-surface elements have been identified ) return to  T-7b
elseif ( NPTS > 0 )   then   go to  T-7c
else                         go to  T-7d
```

T-7c Row & Column Contact-Point Specifications

NPTS ≥ 0 (T-7) indicates that the *row & column method* is to be used to identify the points that may come into contact with the *contact surface* specified for the current *contact-definition*. This method clearly can only be used to identify nodes that are associated with one or more *shell* units, because there are no row or column associations for nodal points in element units. With this method, the value of the **NPTS** parameter indicates the *minimum number* of contact points to be identified with the set of one or more T-7c records included for the current *contact-definition*. The number of contact points identified by any given T-7c depends on the parameters on that record—as described below:

UNITP LI LJ RADIUS TOUCHE NI NJ

UNITP identifies the *shell unit* within which the contact point(s) identified by the **LI** and **LJ** row & column parameters are defined; the nodal mesh for this shell unit has **NROWS** rows and **NCOLS** columns of nodal points

LI,LJ row and column numbers identifying one or more contact points: **LI** $=$ **LJ** $= 0$ indicates that *all* of the node points of shell unit **UNITP** are to be considered as *contact points*; **LI** > 0 with **LJ** $= 0$ identifies all of the nodes in row **LI** of the nodal grid; **LJ** > 0 with **LI** $= 0$ identifies all of the nodes in column **LJ**; and **LI** > 0 with **LJ** > 0 identifies one or more nodes, starting at row **LI** and column **LJ of the unit:** if **NI** and **NJ** are absent, zero or unity, a single point (**LI**,**LJ**) is defined; if **NI** and **NJ** are both positive, then **NI**x**NJ** points are identified in a double FORTRAN-like loop, starting with the point at (**LI**,**LJ**).

RADIUS specifies a radial offset parameter to be used in determining whether or not the point(s) identified by the current T-7c are in contact with the *contact surface*: this parameter can be used to account for the thickness of material surrounding the contact point(s) in much the same way as the thicknesses of contact elements on the *contact surface* are taken into account

TOUCHE provides information required if the identified *contact point(s)* are in contact with the *contact surface* at the outset of the problem: set **TOUCHE** $= 0$ if not; or set **TOUCHE** $= 1$ if the point(s) are contacting the surface from its *positive* side; or set **TOUCHE** $= -1$ if the point(s) are contacting the surface from its *negative* side—where the normal vector for the *contact surface* points out of the *positive* side of the surface and away from the *negative* side

NI,NJ point-identification looping parameters, as discussed in **LI**,**LJ**, above

✦ if (fewer than **NPTS** contact-points have been identified)*go to* T-7c
else *follow instructions at the end of* T-7d

T-7d Point-Number Contact-Point Specifications

NPTS < 0 (on T-7) indicates that the *point-number method* is to be used to identify the nodal points that may come into contact with the *contact surface*. This method can (but generally should not) be used to identify nodes that are associated with *shell units*, and it *must* be used to identify points that are defined in **STAGS** *element units*. With this method, the *magnitude* of the **NPTS** parameter indicates the *minimum number* of contact points to be identified with the set of one or more T-7d records included for the current *contact-definition*. The number of *contact points* identified by any given T-7d depends on the parameters on that record—as described below.

UNITP I1 I2 INC RADIUS TOUCHE

UNITP identifies the *shell or element unit* within which the *contact point(s)* identified by the **I1**, **I2** and **INC** parameters are defined; the nodal mesh for this shell unit has **NROWS** rows and **NCOLS** columns of node points

I1,I2,INC point identifiers: **I1** > 0, with **I2** $=$ **INC** $= 0$ identifies point # **I1** (in unit **UNITP**) as a *contact point* for the current *contact-definition*; **I1**, **I2**, **INC** > 0 identifies **I2** points—starting with point **I1** and incrementing by **INC** until **I2** points have been indicated (in unit **UNITP**) as *contact points* for the current *contact-definition*

RADIUS specifies a radial offset parameter to be used in determining whether or not the point(s) identified by the current T-7 definition are in contact with the *contact surface*: this parameter can be used to account for the thickness of material surrounding the *contact point(s)* in much the same way as the thicknesses of contact elements on the *contact surface* are taken into account

TOUCHE provides information required if the identified *contact point(s)* are in contact with the *contact surface* at the outset of the problem: set **TOUCHE** $= 0$ if not; or set **TOUCHE** $= 1$ if the point(s) are contacting the surface from its *positive* side; or set **TOUCHE** $= -1$ if the point(s) are contacting the surface from its *negative* side—where the normal vector for the *contact surface* points out of the *positive* side of the surface and away from the *negative* side

N820	(T-5)	number of **E820** definitions
N822	(T-5)	number of **E822** definitions
N830	(T-5)	number of **E830** definitions
N840	(T-5)	number of **E840** definitions
N845	(T-5)	number of **E845** definitions
N847	(T-5)	number of **E847** definitions
N849	(T-5)	number of **E849** definitions
N880	(T-5)	number of **E880** definitions

```
if     ( fewer than NPTS contact-points have been identified ) return to T-7d
elseif ( fewer than N820 E820 definitions have been processed ) return to T-7
elseif ( N822 > 0 )  then  go to  T-8
elseif ( N830 > 0 )  then  go to  T-9
elseif ( N840 > 0 )  then  go to  T-10
elseif ( N845 > 0 )  then  go to  T-11
elseif ( N847 > 0 )  then  go to  T-12
elseif ( N849 > 0 )  then  go to  T-13
elseif ( N880 > 0 )  then  go to  T-14
else                       go to  U-1
```

T-8 Line-Contact Interaction Definition

The T-8 record specifies a pair of “contact” lines (which must have been defined *via* S-5 records, as described on page 7-17) that *may* experience line-to-line contact with each other during the course of the analysis that **STAGS** is to perform. The first line of each such pair must have one or more type **E410** elements associated with it (qualifying it to be a *contacted* line), as described earlier. The second line, which may but does not need to have elements associated with it, is treated as the *contacting* line. When contact occurs at one or more points along the two lines, **STAGS** uses penalty information supplied by the analyst to generate stiffnesses and forces on the fly to treat that contact.

LINE1 LINE2 IPEN NX INC1 INC2 INC3

LINE1 identifies the *contacted* line, which must have one or more elements associated with it; this line must have been specified *via* an S-5 record, as described on page 7-17

LINE2 identifies the *contacting* line, which may (but is not required to) have one or more elements associated with it; this line must also have been specified *via* an S-5 record

IPEN identifies the penalty function table (of stiffness as a function of penetration) that **STAGS** is to use in calculating stiffnesses and forces that arise when contact occurs between these two lines; the table identified must have been specified *via* an I-4 record set, as described above

NX indicates the number of line contact interactions that are to be specified with information on this T-8 record; **STAGS** sets **NX** = 1 if it is not positive

INC1 incrementation parameter for **LINE1** (used only when **NX** > 0)

NC2 incrementation parameter for **LINE2** (used only when **NX** > 0)

NC3 incrementation parameter for **IPEN** (used only when **NX** > 0)

N822	(T-5)	number of **E822** definitions
N830	(T-5)	number of **E830** definitions
N840	(T-5)	number of **E840** definitions
N845	(T-5)	number of **E845** definitions
N847	(T-5)	number of **E847** definitions
N849	(T-5)	number of **E849** definitions
N880	(T-5)	number of **E880** definitions

```
if     ( fewer than N822 E822 definitions have been processed )return to  T-8
elseif   ( N830 > 0 )    then  go to  T-9
elseif   ( N840 > 0 )    then  go to  T-10
elseif   ( N845 > 0 )    then  go to  T-11
elseif   ( N847 > 0 )    then  go to  T-12
elseif   ( N849 > 0 )    then  go to  T-13
elseif   ( N880 > 0 )    then  go to  T-14
else                           go to  U-1
```

Sandwich elements

Sandwiche structures play such an important role in the design of many aerospace structures, so it is necessary that their behavior be determined adequately. The classical approach to the modeling of sandwiches is an extension of thin-shell-theory, in which the behavior of a three-dimensional sandwich object is reduced to the behavior of a two-dimensional surface with in- and out-of-plane stiffness properties. In some programs, a sandwich construction is idealized as a pair of membranes that are held apart by a core that has a relatively large resistance against transverse shear, is virtually inextensional in the transverse direction, and has virtually no stiffness in the middle-surface plane. This type of model is called a sandwich of the first kind. Finite element discretizations of this kind of classical model have been made in the past, but successful applications have been confined primarily to linear or moderately nonlinear analyses. A more general sandwich model emerges by considering the two faces to be shells (with bending as well as the usual membrane stiffness) that are held apart by a lightweight core. The core may have three dimensional elastic properties. This type of model is called a sandwich of the second kind, and is the model that is implemented in **STAGS**.* A good example of a problem requiring this model would be one with structural walls made of glass fiber faces and using polyurethane foam as the core material.

The current version of **STAGS** has three “standard” sandwich elements (element types **E830**, **E840** and **E849**) and two mesh-transition sandwich elements (**E845** and **E847**). **STAGS** input requirements for each of these are described next.

* See, for example:
Riks, E. and C. C. Rankin, “*Sandwich Modeling with an Application to the Residual Strength Analysis of a Damaged Composite Compression Panel,*” International Journal of Non-Linear Mechanics, Vol. 37, No. 4-5, June–July 2002, pp. 897–908 (also available as AIAA Paper No. 2001-1232, April 2001), and
Rose, C.A., D.F. Moore, N.F. Knight, Jr. and C.C. Rankin, “Finite Element Modeling of the Buckling Response of Sandwich Panels,” AIAA Paper No. 2202-1517, April 2002

T-9 E830 6-Node Sandwich Element Definition

The 6–node **E830** sandwich element in **STAGS** is a construction of two triangular-shell face elements that are held apart by a lightweight core, as shown in Figure 8.6. The core may have three dimensional elastic properties.

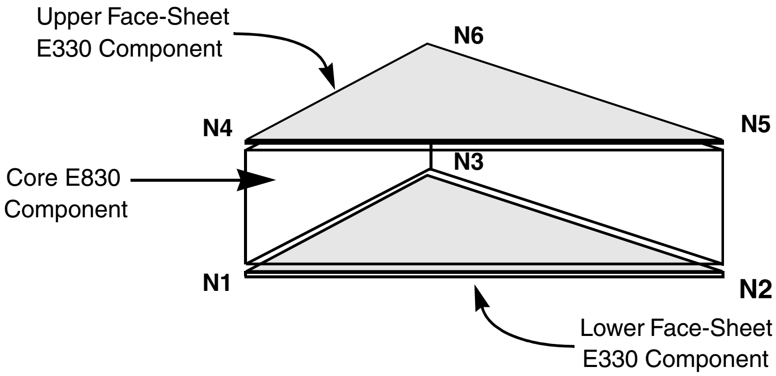


Figure 8.6 **E830** 6-Node Sandwich Element

Definition of one or more 6–node **E830** sandwich elements is accomplished with the following set of records:

T-9	to specify parameters used for all parts of the element
T-9a	to specify information for the lower face sheet of the element
T-9b	to specify lower face sheet transformation angles (optional)
T-9c	to specify information for the upper face sheet
T-9d	to specify upper face sheet transformation angles (optional)
T-9e	to specify core parameters
T-9f	to specify core transformation angles (optional)
T-9g	for “x-direction” incrementation parameters
T-9h	for “y-direction” incrementation parameters

These are described sequentially in the following text.

KELT ILIN INTEG IPEN NX NY USERC USER1 USER2

KELT element code number (must be 830)

ILIN geometric-linearity flag:

0 – nonlinear strain-displacement relations

1 – linear strain-displacement relations

INTEG number of surface-integration points: set **INTEG** = 1, 3, 4 or 7; if **INTEG** = 0, **STAGS** sets **INTEG** = 3

IPEN penalty option (see N-1)

0 – no penalty function on fourth-order terms in **E330** elements

1 – penalty function included in **E330** elements

NX x-direction looping parameter, set equal to unity by **STAGS** if omitted or nonpositive; **NX** > 1 instructs **STAGS** to generate a set of **NX** type **E830** elements in the x direction, using nodal incrementation information given on the T-9g record

NY y-direction looping parameter, set equal to unity by **STAGS** if omitted or nonpositive; **NY** > 1 instructs **STAGS** to generate a set of **NY** type **E830** elements in the y direction for each of the **NX** elements generated in the x-direction in the current definition, using nodal incrementation information given on the T-9h record

USERC user-specified element number for core component (used only if **IUWLE** = 1 on H-1)

USER1 user-specified element number for **lower face sheet**, (if **IUWLE** = 1 on H-1)

USER2 user-specified element number for **upper face sheet**, (if **IUWLE** = 1 on H-1)

go to T-9a

T-9a E830 Lower Face-Sheet Properties

A single T-9a record must be included immediately following the T-9 record, to specify the nodes for the lower face sheet of the first **E830** element and to specify other parameters for the lower face sheet of each of the element(s) specified in the current definition.

N1 N2 N3 IFABL ZETAL ECZL IPLASL IANGL

N1 first lower face sheet node point

N2 second lower face sheet node point

N3 third lower face sheet node point

IFABL fabrication identifier for the lower face sheet element(s); this is equivalent to the **WALL** parameter for **E330** triangular elements:

>0 – wall configuration number in the Wall Fabrication Table (K-1)

0 – shell wall properties are given in user-written subroutine WALL (See the T-4 record description for more information about this)

<0 – shell fabrication identifier in the GCP Fabrication Table (I-21a)

ZETAL angle ζ between the wall-reference coordinate x_w and the fabrication coordinate $\bar{x}$, for the lower face sheet; ζ is a right-handed rotation about $\bar{z}$; see Figure 8.2 on page 8-19.

ECZL eccentricity in z' direction, for the lower face sheet; **ECZL** is the z' coordinate of the shell wall middle surface; please refer to Figure 6.2 on page 6-28; in element units, (x', y', z') are used in place of (X', Y', Z'), which do not exist in an element unit; see “Effects of Eccentricity” on page 16-6.

IPLASL lower face sheet material-nonlinearity flag:

0 – elastic behavior only

1 – plasticity included, with the material law satisfied at each element integration point

2 – plasticity included, with the material law satisfied at the element centroid (centroidal plasticity)

IANGL lower face sheet wall-reference option; see discussion on page 8-18

0 – use default strategy of projecting x_g, y_g to establish x_w

1 – input $\mathbf{r_w}$, which is projected to establish x_w; see (T-9b)

```
if  ( IANGL > 0 )  then
                   go to T-9b
else               go to T-9c
```

T-9b E830 Lower Face-Sheet Wall Reference Vector

RXL RYL RZL

RXL,RYL,RZL lower face sheet wall reference vector, $\mathbf{r_w}$, which is projected onto the element surface to determine the direction of the wall-reference coordinate x_w; $\mathbf{r_w}$ is expressed in (x_g, y_g, z_g) global coordinates

go to T-9c

T-9c E830 Upper Face-Sheet Properties

A single T-9c record must be included immediately following the T-9a (or T-9b) record, to specify the nodes for the upper face sheet of the first **E830** element and to specify other parameters for the upper face sheet of each of the element(s) specified in the current definition.

N4 N5 N6 IFABU ZETAU ECZU IPLASU IANGU

N4 first upper face sheet node point

N5 second upper face sheet node point

N6 third upper face sheet node point

IFABU fabrication identifier for the upper face sheet element(s); this is equivalent to the **WALL** parameter for **E330** quadrilateral elements:

>0 – wall configuration number in the Wall Fabrication Table (K-1)
0 – shell wall properties are given in user-written subroutine WALL
<0 – shell fabrication identifier in the GCP Fabrication Table (I-21a)

ZETAU angle ζ between the wall-reference coordinate x_w and the fabrication coordinate $\bar{x}$, for the upper face sheet; ζ is a right-handed rotation about $\bar{z}$

ECZU eccentricity in z' direction, for the upper face sheet; **ECZL** is the z' coordinate of the shell wall middle surface

IPLASU upper face sheet material-nonlinearity flag:

0 – elastic behavior only
1 – plasticity included, with the material law satisfied at each element integration point
2 – plasticity included, with the material law satisfied at the element centroid (centroidal plasticity)

IANGL upper face sheet wall-reference option; see discussion on page 8-18

0 – use default strategy of projecting x_g, y_g to establish x_w
1 – input $\mathbf{r_w}$, which is projected to establish x_w; see (T-9b)

if (**IANGU** > 0) then *go to* T-9d
else *go to* T-9e

T-9d E830 Upper Face-Sheet Wall Reference Vector

RXU RYU RZU

RXU, RYU, RZU upper face sheet wall reference vector, $\mathbf{r_w}$, which is projected onto the element surface to determine the direction of the wall-reference coordinate x_w; $\mathbf{r_w}$ is expressed in (x_g, y_g, z_g) global coordinates

✦ *go to* T-9e

T-9e E830 Core Properties

A single T-9e record must be included immediately following the T-9c (or T-9d) record, to specify parameters for the core component of the element(s) specified in the current definition.

IFABC ZETAC IPLASC IANGC

IFABC core fabrication identifier:

>0 – wall configuration number in the Wall Fabrication Table (K-1)

<0 – solid fabrication identifier in the GCP Fabrication Table (I-22a)

ZETAC angle ζ between the wall-reference coordinate x_w and the fabrication coordinate $\bar{x}$, for the core component; ζ is a right-handed rotation about $\bar{z}$

IPLASC core material-nonlinearity flag:

0 – elastic behavior only

1 – plasticity included *(not operational with GCP fabrications, yet)*

IANGC core wall-reference option; see discussion on page 8-18

0 – use default strategy of projecting x_g, y_g to establish x_w

1 – input $\mathbf{r_w}$, which is projected to establish x_w; see (T-9b)

NX	(T-9)	x-direction looping parameter
NY	(T-9)	y-direction looping parameter

```
if      ( IANGC > 0 )  then   go to T-9f
elseif  ( NX > 0 )     then   go to T-9g
elseif  ( NY > 0 )     then   go to T-9h
else    follow instructions at end of T-9h
```

T-9f E830 Core Reference Vector

RXC RYC RZC

RXC, RYC, RZC core reference vector, $\mathbf{r_w}$, which is projected onto the element surface to determine the direction of the core-reference coordinate x_w; $\mathbf{r_w}$ is expressed in (x_g, y_g, z_g) global coordinates

✦	**NX**	(T-9)	x-direction looping parameter
	NY	(T-9)	y-direction looping parameter

```
if      ( NX > 0 ) then    go to T-9g
elseif  ( NY > 0 ) then    go to T-9h
else    follow instructions at end of T-9h
```

T-9g E830 X-Direction Incrementations

A single record of type T-9g must be included immediately after the T-9e or T-9f record when the **NX** *“x-direction” looping parameter* (T-9) is greater than unity. Eight nodal incrementation variables are specified here for use with the “x-direction” looping function on the T-9 record. **NX** **E830** sandwich elements are generated in the “x-direction” with this information. Three incrementation variables are also specified here for “x-direction” looping with the user-element-number parameters on T-9.

I1 I2 I3 I4 I5 I6 I7 I8 I9

I1 incrementation for the **N1** lower face sheet node on the T-9a record

I2 incrementation for the **N2** lower face sheet node on the T-9a record

I3 incrementation for the **N3** lower face sheet node on the T-9a record

I4 incrementation for the **N4** upper face sheet node on the T-9c record

I5 incrementation for the **N5** upper face sheet node on the T-9c record

I6 incrementation for the **N6** upper face sheet node on the T-9c record

I7 incrementation for **USERC** on the T-9 record

I8 incrementation for **USER1** on the T-9 record

I9 incrementation for **USER2** on the T-9 record

Any of these incrementation variables can be negative, zero, or positive, as required.

Example: the following T-9 / T-9a / T-9c / T-9g record combination:

```
830 1 0 0 3            $ T-9 with NX=3
10 20 30 ...           $ T-9a lower face nodes
50 60 70 ...           $ T-9c upper face nodes
...
1 1 1 2 2 2            $ T-9g increments
```

generates three **E830** elements, with the following nodes:

```
10 20 30 50 60 70           Element #1
11 21 31 52 62 72           Element #2
12 22 32 54 64 74           Element #3
```

✦ **NY** (T-9) y-direction looping parameter

if (**NY** > 0) then *go to* T-9h

else *follow instructions at end of* T-9h

T-9h E830 Y-Direction Incrementations

A single type T-9h record must be included immediately after the T-9e or T-9f or T-9g record when the **NY** *“y-direction” looping parameter* is greater than unity (T-9). Eight nodal incrementation variables are specified here for use with the T-9 record “y-direction” looping function. **NY** **E830** sandwich elements are generated in the “y-direction”, for each **E830** element generated in the x-direction, with this information. The **NX** and **NY** looping parameters are usually employed together to specify **NX** × **NY** **E830** elements in a single stroke.

J1 J2 J3 J4 J5 J6 J7 J8 J9

J1 incrementation for the **N1** lower face sheet node on the T-9a record

J2 incrementation for the **N2** lower face sheet node on the T-9a record

J3 incrementation for the **N3** lower face sheet node on the T-9a record

J4 incrementation for the **N4** upper face sheet node on the T-9c record

J5 incrementation for the **N5** upper face sheet node on the T-9c record

J6 incrementation for the **N6** upper face sheet node on the T-9c record

J7 incrementation for **USERC** on the T-9 record

J8 incrementation for **USER1** on the T-9 record

J9 incrementation for **USER2** on the T-9 record

Any of these incrementation variables can be negative, zero, or positive, as required.

Example: the following T-9 / T-9a / T-9c / T-9g / T-9h record combination:

```
830 1 0 0 3 2          $ T-9 NX=3, NY=2
10 20 30 ...           $ T-9a (lower face nodes)
50 60 70 ...           $ T-9c (upper face nodes)
...
1 1 1 1 1 1            $ T-9g (x increments)
5 5 5 5 5 5            $ T-9h (y increments)
```

generates six **E830** elements, with the following nodes:

```
10 20 30 50 60 70           Element #1
11 21 31 51 61 71           Element #2
12 22 32 52 62 72           Element #3
15 25 35 55 65 75           Element #4
16 26 36 56 66 76           Element #5
17 27 37 57 67 77           Element #6
```

N830 (T-5) number of **E830** definitions
N840 (T-5) number of **E840** definitions
N845 (T-5) number of **E845** definitions
N847 (T-5) number of **E847** definitions
N849 (T-5) number of **E849** definitions
N880 (T-5) number of **E880** definitions

```
if     ( fewer than N830 E830 definitions have been processed )return to  T-9
elseif  ( N840 > 0 )   then  go to  T-10
elseif  ( N845 > 0 )   then  go to  T-11
elseif  ( N847 > 0 )   then  go to  T-12
elseif  ( N849 > 0 )   then  go to  T-13
elseif  ( N880 > 0 )   then  go to  T-14
else                         go to  U-1
```

T-10 E840 8-Node Sandwich Element Definition

The 8–node **E840** sandwich element in **STAGS** is constructed with a pair of **E410** quadrilateral shells (with bending as well as the usual membrane stiffness) that are held apart by a lightweight core that has three-dimensional elastic properties—as shown in Figure 8.7.

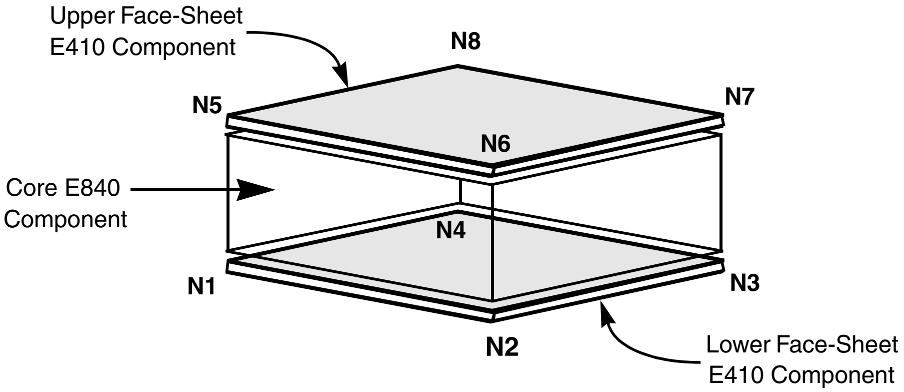


Figure 8.7 **E840** 8-Node Sandwich Element

Definition of one or more 8–node **E840** sandwich elements is accomplished with the following set of records:

T-10 to specify parameters used for all parts of the element
T-10a to specify information for the lower face sheet of the element
T-10b to specify lower face sheet transformation angles (optional)
T-10c to specify information for the upper face sheet
T-10d to specify upper face sheet transformation angles (optional)
T-10e to specify core parameters
T-10f to specify core transformation angles (optional)
T-10g for “x-direction” incrementation parameters
T-10h for “y-direction” incrementation parameters

These are described sequentially in the following text.

KELT ILIN INTEG IPEN NX NY USERC USER1 USER2

KELT element code number (must be 840)

ILIN geometric-linearity flag:

0 – nonlinear strain-displacement relations

1 – linear strain-displacement relations

INTEG integration-type flag (see N-1):

0 – standard integration, or 2×2 Gauss points for **E410** elements

1 – modified 5-point integration, previously referred to as full integration

IPEN penalty option (see N-1)

0 – no penalty function on fourth-order terms in **E410** elements

1 – penalty function included in **E410** elements

NX x-direction looping parameter, set equal to unity by **STAGS** if omitted or nonpositive; **NX** > 1 instructs **STAGS** to generate a set of **NX** type **E840** elements in the x direction, using nodal incrementation information given on the T-10g record described below

NY y-direction looping parameter, set equal to unity by **STAGS** if omitted or nonpositive; **NY** > 1 instructs **STAGS** to generate a set of **NY** type **E840** elements in the y direction for each of the **NX** elements generated in the x-direction in the current definition, using nodal incrementation information given on the T-10h record described below

USERC user-specified element number for core component (used only if **IUWLE** = 1 on H-1)

USER1 user-specified element number for **lower face sheet**, (if **IUWLE** = 1 on H-1)

USER2 user-specified element number for **upper face sheet**, (if **IUWLE** = 1 on H-1)

go to T-10a

T-10a E840 Lower Face-Sheet Properties

A single T-10a record must be included immediately following the T-10 record, to specify the nodes for the lower face sheet of the first **E840** element and to specify other parameters for the lower face sheet of each of the element(s) specified in the current definition.

N1 N2 N3 N4 IFABL ZETAL ECZL IPLASL IANGL

N1	first lower face sheet node point
N2	second lower face sheet node point
N3	third lower face sheet node point
N4	fourth lower face sheet node point

IFABL fabrication identifier for the lower face sheet element(s); this is equivalent to the **WALL** parameter for **E410** quadrilateral elements:

- >0 – wall configuration number in the Wall Fabrication Table (K-1)
- 0 – shell wall properties are given in user-written subroutine WALL (See the T-4 record description for more information about this)
- <0 – shell fabrication identifier in the GCP Fabrication Table (I-21a)

ZETAL angle ζ between the wall-reference coordinate x_w and the fabrication coordinate $\bar{x}$, for the lower face sheet; ζ is a right-handed rotation about $\bar{z}$; see Figure 8.2 on page 8-19.

ECZL eccentricity in z' direction, for the lower face sheet; **ECZL** is the z' coordinate of the shell wall middle surface; please refer to Figure 6.2 on page 6-28; in element units, (x', y', z') are used in place of (X', Y', Z'), which do not exist in an element unit; see “Effects of Eccentricity” on page 16-6.

IPLASL lower face sheet material-nonlinearity flag:

- 0 – elastic behavior only
- 1 – plasticity included, with the material law satisfied at each element integration point
- 2 – plasticity included, with the material law satisfied at the element centroid (centroidal plasticity)

IANGL lower face sheet wall-reference option; see discussion on page 8-18

0 – use default strategy of projecting x_g, y_g to establish x_w

1 – input $\mathbf{r_w}$, which is projected to establish x_w; see (T-10b)

```
if ( IANGL > 0 ) then
                    go to T-10b
else                go to T-10c
```

T-10b E840 Lower Face-Sheet Wall Reference Vector

RXL RYL RZL

RXL,RYL,RZL lower face sheet wall reference vector, $\mathbf{r_w}$, which is projected onto the element surface to determine the direction of the wall-reference coordinate x_w; $\mathbf{r_w}$ is expressed in (x_g, y_g, z_g) global coordinates

✦ *go to* T-10c

T-10c E840 Upper Face-Sheet Properties

A single T-10c record must be included immediately following the T-10a (or T-10b) record, to specify the nodes for the upper face sheet of the first **E840** element and to specify other parameters for the upper face sheet of each of the element(s) specified in the current definition.

N5 N6 N7 N8 IFABU ZETAU ECZU IPLASU IANGU

N5 first upper face sheet node point

N6 second upper face sheet node point

N7 third upper face sheet node point

N8 fourth upper face sheet node point

IFABU fabrication identifier for the upper face sheet element(s); this is equivalent to the **WALL** parameter for **E410** quadrilateral elements:

- >0 – wall configuration number in the Wall Fabrication Table (K-1)
- 0 – shell wall properties are given in user-written subroutine WALL
- <0 – shell fabrication identifier in the GCP Fabrication Table (I-21a)

ZETAU angle ζ between the wall-reference coordinate x_w and the fabrication coordinate $\bar{x}$, for the upper face sheet; ζ is a right-handed rotation about $\bar{z}$

ECZU eccentricity in z' direction, for the upper face sheet; **ECZL** is the z' coordinate of the shell wall middle surface

IPLASU upper face sheet material-nonlinearity flag:

- 0 – elastic behavior only
- 1 – plasticity included, with the material law satisfied at each element integration point
- 2 – plasticity included, with the material law satisfied at the element centroid (centroidal plasticity)

IANGL upper face sheet wall-reference option; see discussion on page 8-18

- 0 – use default strategy of projecting x_g, y_g to establish x_w
- 1 – input $\mathbf{r_w}$, which is projected to establish x_w; see (T-10b)

✦ if (**IANGU** > 0) then *go to* T-10d
else *go to* T-10e

T-10d E840 Upper Face-Sheet Wall Reference Vector

RXU RYU RZU

RXU, RYU, RZU upper face sheet wall reference vector, $\mathbf{r_w}$, which is projected onto the element surface to determine the direction of the wall-reference coordinate x_w; $\mathbf{r_w}$ is expressed in (x_g, y_g, z_g) global coordinates

✦ *go to* T-10e

T-10e E840 Core Properties

A single T-10e record must be included immediately following the T-10c (or T-10d) record, to specify parameters for the core component of the element(s) specified in the current definition.

IFABC ZETAC IPLASC IANGC

IFABC core fabrication identifier:

>0 – wall configuration number in the Wall Fabrication Table (K-1)

<0 – solid fabrication identifier in the GCP Fabrication Table (I-22a)

ZETAC angle ζ between the wall-reference coordinate x_w and the fabrication coordinate $\bar{x}$, for the core component; ζ is a right-handed rotation about $\bar{z}$

IPLASC core material-nonlinearity flag:

0 – elastic behavior only

1 – plasticity included *(not operational with GCP fabrications, yet)*

IANGC core wall-reference option; see discussion on page 8-18

0 – use default strategy of projecting x_g, y_g to establish x_w

1 – input $\mathbf{r}_w$, which is projected to establish x_w; see (T-10b)

NX	(T-10)	x-direction looping parameter
NY	(T-10)	y-direction looping parameter

```
if      ( IANGC > 0 )  then   go to T-10f
elseif  ( NX > 0 )     then   go to T-10g
elseif  ( NY > 0 )     then   go to T-10h
else    follow instructions at end of T-10h
```

T-10f E840 Core Reference Vector

RXC RYC RZC

RXC, RYC, RZC core reference vector, $\mathbf{r_w}$, which is projected onto the element surface to determine the direction of the core-reference coordinate x_w; $\mathbf{r_w}$ is expressed in (x_g, y_g, z_g) global coordinates

NX	(T-10)	x-direction looping parameter
NY	(T-10)	y-direction looping parameter

```
if      ( NX > 0 ) then    go to T-10g
elseif  ( NY > 0 ) then    go to T-10h
else    return to T-10
```

T-10g E840 X-Direction Incrementations

A single record of type T-10g must be included immediately after the T-10e or T-10f record when the **NX** *“x-direction” looping parameter* (T-10) is greater than unity. Eight nodal incrementation variables are specified here for use with the “x-direction” looping function on the T-10 record. **NX** **E840** sandwich elements are generated in the “x-direction” with this information. Three incrementation variables are also specified here for “x-direction” looping with the user-element-number parameters on T-10.

I1 I2 I3 I4 I5 I6 I7 I8 I9 I10 I11

I1 incrementation for the **N1** lower face sheet node on the T-10a record

I2 incrementation for the **N2** lower face sheet node on the T-10a record

I3 incrementation for the **N3** lower face sheet node on the T-10a record

I4 incrementation for the **N4** lower face sheet node on the T-10a record

I5 incrementation for the **N5** upper face sheet node on the T-10c record

I6 incrementation for the **N6** upper face sheet node on the T-10c record

I7 incrementation for the **N7** upper face sheet node on the T-10c record

I8 incrementation for the **N8** upper face sheet node on the T-10c record

I9 incrementation for **USERC** on the T-10 record

I10 incrementation for **USER1** on the T-10 record

I11 incrementation for **USER2** on the T-10 record

Any of these incrementation variables can be negative, zero, or positive, as required.

Example: the following T-10 / T-10a / T-10c / T-10g record combination:

```
840 1 0 0 3            $ T-10 with NX=3
10 20 30 40 ...        $ T-10a lower face nodes
50 60 70 80 ...        $ T-10c upper face nodes
...
1 1 1 1 2 2 2 2        $ T-10g increments
```

generates three **E840** elements, with the following nodes:

```
10 20 30 40 50 60 70 80    Element #1
11 21 31 41 52 62 72 82    Element #2
12 22 32 42 54 64 74 84    Element #3
```

NY (T-10) y-direction looping parameter

if (**NY** > 0) then *go to* T-10h
else *follow instructions at end of* T-10h

T-10h E840 Y-Direction Incrementations

A single type T-10h record must be included immediately after the T-10e or T-10f or T-10g record when the **NY** *“y-direction” looping parameter* is greater than unity (T-10). Eight nodal incrementation variables are specified here for use with the T-10 record “y-direction” looping function. **NY** **E840** sandwich elements are generated in the “y-direction”, for each **E840** element generated in the x-direction, with this information. The **NX** and **NY** looping parameters are usually employed together to specify **NX** × **NY** **E840** elements in a single stroke.

J1 J2 J3 J4 J5 J6 J7 J8 J9 J10 J11

J1	incrementation for the **N1** lower face sheet node on the T-10a record
J2	incrementation for the **N2** lower face sheet node on the T-10a record
J3	incrementation for the **N3** lower face sheet node on the T-10a record
J4	incrementation for the **N4** lower face sheet node on the T-10a record
J5	incrementation for the **N5** upper face sheet node on the T-10c record
J6	incrementation for the **N6** upper face sheet node on the T-10c record
J7	incrementation for the **N7** upper face sheet node on the T-10c record
J8	incrementation for the **N8** upper face sheet node on the T-10c record
J9	incrementation for **USERC** on the T-10 record
J10	incrementation for **USER1** on the T-10 record
J11	incrementation for **USER2** on the T-10 record

Any of these incrementation variables can be negative, zero, or positive, as required.

Example: the following T-10 / T-10a / T-10c / T-10g / T-10h record combination:

```
840 1 0 0 3 2          $ T-10 NX=3, NY=2
10 20 30 40 ...        $ T-10a (lower face nodes)
50 60 70 80 ...        $ T-10c (upper face nodes)
...
1 1 1 1 1 1 1 1        $ T-10g (x increments)
5 5 5 5 5 5 5 5        $ T-10h (y increments)
```

generates six **E840** elements, with the following nodes:

```
10 20 30 40 50 60 70 80    Element #1
11 21 31 41 51 61 71 81    Element #2
12 22 32 42 52 62 72 82    Element #3
15 25 35 45 55 65 75 85    Element #4
16 26 36 46 56 66 76 86    Element #5
17 27 37 47 57 67 77 87    Element #6
```

N840	(T-5)	number of **E840** definitions
N845	(T-5)	number of **E845** definitions
N847	(T-5)	number of **E847** definitions
N849	(T-5)	number of **E849** definitions
N880	(T-5)	number of **E880** definitions

```
if     ( fewer than N830 E840 definitions have been processed )return to  T-10
elseif    ( N845 > 0 )      then   go to  T-11
elseif    ( N847 > 0 )      then   go to  T-12
elseif    ( N849 > 0 )      then   go to  T-13
elseif    ( N880 > 0 )      then   go to  T-14
else                               go to  U-1
```

T-11 E845 10-Node Sandwich Transition Element Definition

The 10–node **E845** sandwich-transition element, shown in Figure 8.8, is used in shell units to make a transition between one mesh of **E840** elements and another mesh of **E840** elements that has nodes that are exactly half as far apart as the one in which the **E845** element “resides.” It can be used to accomplish the same objective in an element unit. A single T-11 definition may specify one or more **E845** sandwich transition elements, as described below.

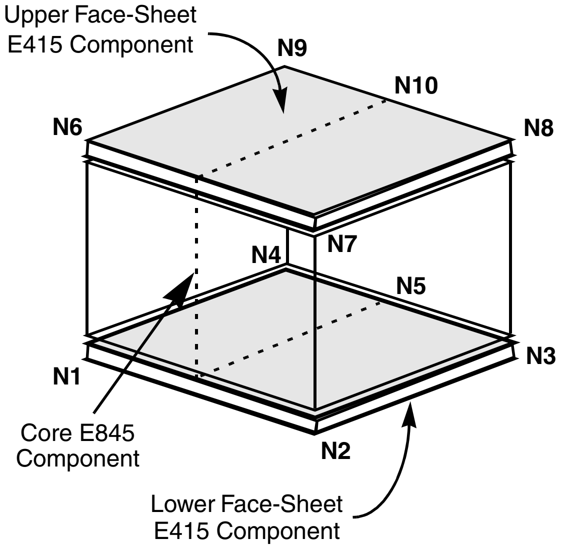


Figure 8.8 **E845** 10-Node Sandwich Transition Elements

Definition of one or more 10–node **E845** sandwich transition elements is accomplished with the following set of records:

T-11	to specify parameters used for all parts of the element
T-11a	to specify information for the lower face sheet of the element
T-11b	to specify lower face sheet transformation angles (optional)
T-11c	to specify information for the upper face sheet
T-11d	to specify upper face sheet transformation angles (optional)
T-11e	to specify core parameters
T-11f	to specify core transformation angles (optional)
T-11g	for “x-direction” incrementation parameters
T-11h	for “y-direction” incrementation parameters

These are described sequentially in the following text.

KELT ILIN INTEG IPEN IEDGE NX NY USER

KELT element code number (must be 845)

ILIN geometric-linearity flag:

0 – nonlinear strain-displacement relations
1 – linear strain-displacement relations

INTEG integration-type flag (see N-1):

0 – standard integration, or 2×2 Gauss points for **E410** elements
1 – modified 5-point integration, previously referred to as full integration

IPEN penalty option (see N-1)

0 – no penalty function on fourth-order terms in **E410** elements
1 – penalty function included in **E410** elements

IEDGE identifies the **E845** edge on which node **N5** is located (**N10** is above **N5**):

1 – node **N5** is between **N3** and **N4**
2 – node **N5** is between **N4** and **N1**
3 – node **N5** is between **N1** and **N2**
4 – node **N5** is between **N2** and **N3**

NX x-direction looping parameter, set equal to unity by **STAGS** if omitted or nonpositive; **NX** > 1 instructs **STAGS** to generate a set of **NX** type **E845** elements in the x direction, using the increments given on the T-11g record described below

NY y-direction looping parameter, set equal to unity by **STAGS** if omitted or nonpositive; **NY** > 1 instructs **STAGS** to generate a set of **NY** type **E845** elements in the y direction for each of the **NX** elements generated in the x-direction in the current definition, using the increments given on the T-11h record described below

USER user-specified element number for the first **E845** element generated here (used only if **IUWLE** = 1 on H-1)

go to T-11a

T-11a E845 Lower Face-Sheet Properties

A single T-11a record must be included immediately following the T-11 record, to specify the nodes for the lower face sheet of the first **E845** element and to specify other parameters for the lower face sheet of each of the element(s) specified in the current definition.

N1 N2 N3 N4 N5 IFABL ZETAL ECZL IPLASL IANGL

N1 first lower face sheet node point

N2 second lower face sheet node point

N3 third lower face sheet node point

N4 fourth lower face sheet node point

N5 fifth lower face sheet node point

IFABL fabrication identifier for the lower face sheet element(s); this is equivalent to the **WALL** parameter for **E410** quadrilateral elements:

>0 – wall configuration number in the Wall Fabrication Table (K-1)

0 – shell wall properties are given in user-written subroutine WALL (See the T-4 record description for more information about this)

<0 – shell fabrication identifier in the GCP Fabrication Table (I-21a) *(this option is not operational yet and should not be used)*

ZETAL angle ζ between the wall-reference coordinate x_w and the fabrication coordinate $\bar{x}$, for the lower face sheet; ζ is a right-handed rotation about $\bar{z}$; see Figure 8.2 on page 8-19.

ECZL eccentricity in z' direction, for the lower face sheet; **ECZL** is the z' coordinate of the shell wall middle surface; please refer to Figure 6.2 on page 6-28; in element units, (x', y', z') are used in place of (X', Y', Z'), which do not exist in an element unit; see “Effects of Eccentricity” on page 16-6.

IPLASL lower face sheet material-nonlinearity flag:

0 – elastic behavior only

1 – plasticity included, with the material law satisfied at each element integration point

2 – plasticity included, with the material law satisfied at the element centroid (centroidal plasticity)

IANGL lower face sheet wall-reference option; see discussion on page 8-18

0 – use default strategy of projecting x_g, y_g to establish x_w

1 – input $\mathbf{r_w}$, which is projected to establish x_w; see (T-11b)

```
if ( IANGL > 0 ) then
                    go to T-11b
else                go to T-11c
```

T-11b E845 Lower Face-Sheet Wall Reference Vector

RXL RYL RZL

RXL,RYL,RZL lower face sheet wall reference vector, $\mathbf{r_w}$, which is projected onto the element surface to determine the direction of the wall-reference coordinate x_w; $\mathbf{r_w}$ is expressed in (x_g, y_g, z_g) global coordinates

✦ *go to* T-11c

T-11c E845 Upper Face-Sheet Properties

A single T-11c record must be included immediately following the T-11a (or T-11b) record, to specify the nodes for the upper face sheet of the first **E845** element and to specify other parameters for the upper face sheet of each of the element(s) specified in the current definition.

N6 N7 N8 N9 N10 IFABU ZETAU ECZU IPLASU IANGU

N6 first upper face sheet node point

N7 second upper face sheet node point

N8 third upper face sheet node point

N9 fourth upper face sheet node point

N10 fifth upper face sheet node point

IFABU fabrication identifier for the upper face sheet element(s); this is equivalent to the **WALL** parameter for **E410** quadrilateral elements:

>0 – wall configuration number in the Wall Fabrication Table (K-1)
0 – shell wall properties are given in user-written subroutine WALL
<0 – shell fabrication identifier in the GCP Fabrication Table (I-21a)

ZETAU angle ζ between the wall-reference coordinate x_w and the fabrication coordinate $\bar{x}$, for the upper face sheet; ζ is a right-handed rotation about $\bar{z}$

ECZU eccentricity in z' direction, for the upper face sheet; **ECZL** is the z' coordinate of the shell wall middle surface

IPLASU upper face sheet material-nonlinearity flag:

0 – elastic behavior only
1 – plasticity included, with the material law satisfied at each element integration point
2 – plasticity included, with the material law satisfied at the element centroid (centroidal plasticity)

IANGL upper face sheet wall-reference option; see discussion on page 8-18

0 – use default strategy of projecting x_g, y_g to establish x_w
1 – input $\mathbf{r_w}$, which is projected to establish x_w; see (T-11b)

if (**IANGU** > 0) then *go to* T-11d
else *go to* T-11e

T-11d E845 Upper Face-Sheet Wall Reference Vector

RXU RYU RZU

RXU, RYU, RZU upper face sheet wall reference vector, $\mathbf{r_w}$, which is projected onto the element surface to determine the direction of the wall-reference coordinate x_w; $\mathbf{r_w}$ is expressed in (x_g, y_g, z_g) global coordinates

go to T-11e

T-11e E845 Core Properties

A single T-11e record must be included immediately following the T-11c (or T-11d) record, to specify parameters for the core component of the element(s) specified in the current definition.

IFABC ZETAC IPLASC IANGC

IFABC core fabrication identifier:

>0 – wall configuration number in the Wall Fabrication Table (K-1)

<0 – solid fabrication identifier in the GCP Fabrication Table (I-22a)

ZETAC angle ζ between the wall-reference coordinate x_w and the fabrication coordinate $\bar{x}$, for the core component; ζ is a right-handed rotation about $\bar{z}$

IPLASC core material-nonlinearity flag:

0 – elastic behavior only

1 – plasticity included *(not operational with GCP fabrications, yet)*

IANGC core wall-reference option; see discussion on page 8-18

0 – use default strategy of projecting x_g, y_g to establish x_w

1 – input $\mathbf{r_w}$, which is projected to establish x_w; see (T-11b)

✦			
	NX	(T-11)	x-direction looping parameter
	NY	(T-11)	y-direction looping parameter

```
if      ( IANGC $> 0$ ) then    go to T-11f
elseif  ( NX $> 0$ )    then    go to T-11g
elseif  ( NY $> 0$ )    then    go to T-11h
else    follow instructions at end of T-10h
```

T-11f E845 Core Reference Vector

RXC RYC RZC

RXC, RYC, RZC core reference vector, $\mathbf{r_w}$, which is projected onto the element surface to determine the direction of the core-reference coordinate x_w; $\mathbf{r_w}$ is expressed in (x_g, y_g, z_g) global coordinates

NX	(T-11)	x-direction looping parameter
NY	(T-11)	y-direction looping parameter

```
if      ( NX > 0 )    then    go to T-11g
elseif  ( NY > 0 )    then    go to T-11h
else    follow instructions at end of T-11h
```

T-11g E845 X-Direction Incrementations

A single record of type T-11g must be included immediately after the T-11e or T-11f record when the **NX** *“x-direction” looping parameter* (T-11) is greater than unity. Ten nodal incrementation variables are specified here for use with the “x-direction” looping function on the T-11 record. **NX** **E845** sandwich transition elements are generated in the “x-direction” with this information. One incrementation variable is also specified here for “x-direction” looping with the user-element-number parameter on T-11.

I1 I2 I3 I4 I5 I6 I7 I8 I9 I10 I11

I1 incrementation for the **N1** lower face sheet node on the T-11a record
I2 incrementation for the **N2** lower face sheet node on the T-11a record
I3 incrementation for the **N3** lower face sheet node on the T-11a record
I4 incrementation for the **N4** lower face sheet node on the T-11a record
I5 incrementation for the **N5** lower face sheet node on the T-11a record
I6 incrementation for the **N6** upper face sheet node on the T-11c record
I7 incrementation for the **N7** upper face sheet node on the T-11c record
I8 incrementation for the **N8** upper face sheet node on the T-11c record
I9 incrementation for the **N9** upper face sheet node on the T-11c record
I10 incrementation for the **N10** upper face sheet node on the T-11c record
I11 incrementation for **USER** on the T-11 record

Any of these incrementation variables can be negative, zero, or positive, as required.

Example: the following T-11 / T-11a / T-11c / T-11g record combination:

```
845 1 0 0 1 3                 $ T-11 with NX=3
10 20 30 40  50 ...           $ T-11a lower face nodes
60 70 80 90 100 ...           $ T-11c upper face nodes
...
1 1 1 1 1 2 2 2 2 2           $ T-11g increments
```

generates three **E845** elements, with the following nodes:

```
10 20 30 40 50  60 70 80 90 100Element #1
11 21 31 41 51  62 72 82 92 102Element #2
12 22 32 42 52  64 74 84 94 104Element #3
```

✦ **NY** (T-11) y-direction looping parameter

if (**NY** > 0) then *go to* T-11h
else *follow instructions at end of* T-11h

T-11h E845 Y-Direction Incrementations

A type T-11h record must be included immediately after the T-11e or T-11f or T-11g record when the **NY** *“y-direction” looping parameter* is greater than unity (T-11). Ten nodal incrementation variables are specified here for use with the T-11 record “y-direction” looping function. **NY** **E845** sandwich transition elements are generated in the “y-direction”, for each **E845** element generated in the x-direction, with this information. The **NX** and **NY** looping parameters are usually employed together to specify **NX** × **NY** **E845** elements in a single stroke.

J1 J2 J3 J4 J5 J6 J7 J8 J9 J10 J11

J1 incrementation for the **N1** lower face sheet node on the T-11a record

J2 incrementation for the **N2** lower face sheet node on the T-11a record

J3 incrementation for the **N3** lower face sheet node on the T-11a record

J4 incrementation for the **N4** lower face sheet node on the T-11a record

J5 incrementation for the **N5** lower face sheet node on the T-11a record

J6 incrementation for the **N6** upper face sheet node on the T-11c record

J7 incrementation for the **N7** upper face sheet node on the T-11c record

J8 incrementation for the **N8** upper face sheet node on the T-11c record

J9 incrementation for the **N9** upper face sheet node on the T-11c record

J10 incrementation for the **N10** upper face sheet node on the T-11c record

J11 incrementation for **USER** on the T-11 record

Any of these incrementation variables can be negative, zero, or positive, as required.

Example: the following T-11 / T-11a / T-11c / T-11g / T-11h record combination:

```
845 1 0 0 1 3 2         $ T-11 NX=3, NY=2
10 20 30 40  50 ...     $ T-11a (lower face nodes)
60 70 80 90 100 ...     $ T-11c (upper face nodes)
...
1 1 1 1 1 1 1 1 1 1     $ T-11g (x increments)
5 5 5 5 5 5 5 5 5 5     $ T-11h (y increments)
```

generates six **E845** elements, with the following nodes:

```
10 20 30 40 50  60 70 80 90 100  Element #1
11 21 31 41 51  61 71 81 91 101  Element #2
12 22 32 42 52  62 72 82 92 102  Element #3
15 25 35 45 55  65 75 85 95 105  Element #4
16 26 36 46 56  66 76 86 96 106  Element #5
17 27 37 47 57  67 77 87 97 107  Element #6
```

N845 (T-5) number of **E845** definitions
N847 (T-5) number of **E847** definitions
N849 (T-5) number of **E849** definitions
N880 (T-5) number of **E880** definitions

```
if     ( fewer than N845 E845 definitions have been processed ) return to  T-11
elseif    ( N847 > 0 )     then  go to  T-12
elseif    ( N849 > 0 )     then  go to  T-13
elseif    ( N880 > 0 )     then  go to  T-14
else                             go to  U-1
```

T-12 E847 14-Node Sandwich Transition Element Definition

The 14–node **E847** sandwich-transition element, shown in Figure 8.9, is used in shell units to make a transition between one mesh of **E840** elements and two other meshes of **E840** elements that have nodes that are exactly half as far apart as the one in which the **E847** element “resides.” It can be used to accomplish the same objective in an element unit. A single T-12 definition may specify one or more **E847** sandwich transition elements, as described below.

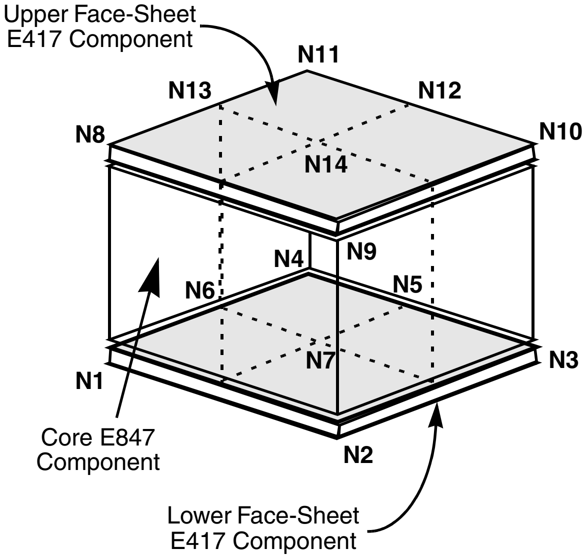


Figure 8.9 **E847** 14-Node Sandwich Transition Elements

Definition of one or more 14–node **E847** sandwich transition elements is accomplished with the following set of records:

T-12 to specify parameters used for all parts of the element
T-12a to specify information for the lower face sheet of the element
T-12b to specify lower face sheet transformation angles (optional)
T-12c to specify information for the upper face sheet
T-12d to specify upper face sheet transformation angles (optional)
T-12e to specify core parameters
T-12f to specify core transformation angles (optional)
T-12g for “x-direction” incrementation parameters
T-12h for “y-direction” incrementation parameters

These are described sequentially in the following text.

KELT ILIN INTEG IPEN IEDGE NX NY USER

ILIN geometric-linearity flag:

0 – nonlinear strain-displacement relations
1 – linear strain-displacement relations

INTEG integration-type flag (see N-1):

0 – standard integration, or 2×2 Gauss points for **E410** elements
1 – modified 5-point integration, previously referred to as full integration

IPEN penalty option (see N-1)

0 – no penalty function on fourth-order terms in **E410** elements
1 – penalty function included in **E410** elements

IEDGE identifies the **E847** edges on which nodes **N5** and **N6** are located nodes **N12** and **N13** are above **N5** and **N6**, respectively:

1 – node **N5** is between **N3** and **N4**; node **N6** is between **N4** and **N1**
2 – node **N5** is between **N4** and **N1**; node **N6** is between **N1** and **N2**
3 – node **N5** is between **N1** and **N2**; node **N6** is between **N2** and **N3**
4 – node **N5** is between **N2** and **N3**; node **N6** is between **N3** and **N4**

NX x-direction looping parameter, set equal to unity by **STAGS** if omitted or nonpositive; **NX** > 1 instructs **STAGS** to generate a set of **NX** type **E847** elements in the x direction, using the increments given on the T-12g record described below

NY y-direction looping parameter, set equal to unity by **STAGS** if omitted or nonpositive; **NY** > 1 instructs **STAGS** to generate a set of **NY** type **E847** elements in the y direction for each of the **NX** elements generated in the x-direction in the current definition, using the increments given on the T-12h record described below

USER user-specified element number for the first **E847** element generated here (used only if **IUWLE** = 1 on H-1)

go to T-12a

T-12a E847 Lower Face-Sheet Properties

A single T-12a record must be included immediately following the T-12 record, to specify the nodes for the lower face sheet of the first **E847** element and to specify other parameters for the lower face sheet of each of the element(s) specified in the current definition.

N1 N2 N3 N4 N5 N6 N7 IFABL ZETAL ECZL IPLASL IANGL

N1	first lower face sheet node point
N2	second lower face sheet node point
N3	third lower face sheet node point
N4	fourth lower face sheet node point
N5	fifth lower face sheet node point
N6	sixth lower face sheet node point
N7	seventh lower face sheet node point

IFABL fabrication identifier for the lower face sheet element(s); this is equivalent to the **WALL** parameter for **E410** quadrilateral elements:

>0 – wall configuration number in the Wall Fabrication Table (K-1)

0 – shell wall properties are given in user-written subroutine WALL (See the T-4 record description for more information about this)

<0 – shell fabrication identifier in the GCP Fabrication Table (I-21a)

ZETAL angle ζ between the wall-reference coordinate x_w and the fabrication coordinate $\bar{x}$, for the lower face sheet; ζ is a right-handed rotation about $\bar{z}$; see Figure 8.2 on page 8-19.

ECZL eccentricity in z' direction, for the lower face sheet; **ECZL** is the z' coordinate of the shell wall middle surface; please refer to Figure 6.2 on page 6-28; in element units, (x', y', z') are used in place of (X', Y', Z'), which do not exist in an element unit; see “Effects of Eccentricity” on page 16-6.

IPLASL lower face sheet material-nonlinearity flag:

0 – elastic behavior only

1 – plasticity included, with the material law satisfied at each element integration point

2 – plasticity included, with the material law satisfied at the element centroid (centroidal plasticity)

IANGL lower face sheet wall-reference option; see discussion on page 8-18

0 – use default strategy of projecting x_g, y_g to establish x_w

1 – input $\mathbf{r_w}$, which is projected to establish x_w; see (T-12b)

```
✦ if ( IANGL > 0 ) then
                      go to T-12b
  else                go to T-12c
```

T-12b E847 Lower Face-Sheet Wall Reference Vector

RXL RYL RZL

RXL,RYL,RZL lower face sheet wall reference vector, $\mathbf{r_w}$, which is projected onto the element surface to determine the direction of the wall-reference coordinate x_w; $\mathbf{r_w}$ is expressed in (x_g, y_g, z_g) global coordinates

✦ *go to* T-12c

T-12c E847 Upper Face-Sheet Properties

A single T-12c record must be included immediately following the T-12a (or T-12b) record, to specify the nodes for the upper face sheet of the first **E847** element and to specify other parameters for the upper face sheet of each of the element(s) specified in the current definition.

N8 N9 N10 N11 N12 N13 N14 IFABU ZETAU ECZU IPLASU IANGU

N8 first upper face sheet node point

N9 second upper face sheet node point

N10 third upper face sheet node point

N11 fourth upper face sheet node point

N12 fifth upper face sheet node point

N13 sixth upper face sheet node point

N14 seventh upper face sheet node point

IFABU fabrication identifier for the upper face sheet element(s); this is equivalent to the **WALL** parameter for **E410** quadrilateral elements:

- >0 – wall configuration number in the Wall Fabrication Table (K-1)
- 0 – shell wall properties are given in user-written subroutine WALL
- <0 – shell fabrication identifier in the GCP Fabrication Table (I-21a)

ZETAU angle ζ between the wall-reference coordinate x_w and the fabrication coordinate $\bar{x}$, for the upper face sheet; ζ is a right-handed rotation about $\bar{z}$

ECZU eccentricity in z' direction, for the upper face sheet; **ECZL** is the z' coordinate of the shell wall middle surface

IPLASU upper face sheet material-nonlinearity flag:

- 0 – elastic behavior only
- 1 – plasticity included, with the material law satisfied at each element integration point
- 2 – plasticity included, with the material law satisfied at the element centroid (centroidal plasticity)

IANGL upper face sheet wall-reference option; see discussion on page 8-18

0 – use default strategy of projecting x_g, y_g to establish x_w

1 – input $\mathbf{r_w}$, which is projected to establish x_w; see (T-12b)

if (**IANGU** > 0) then *go to* T-12d
else *go to* T-12e

T-12d E847 Upper Face-Sheet Wall Reference Vector

RXU RYU RZU

RXU, RYU, RZU upper face sheet wall reference vector, $\mathbf{r_w}$, which is projected onto the element surface to determine the direction of the wall-reference coordinate x_w; $\mathbf{r_w}$ is expressed in (x_g, y_g, z_g) global coordinates

✦ *go to* T-12e

T-12e E847 Core Properties

A single T-12e record must be included immediately following the T-12c (or T-12d) record, to specify parameters for the core component of the element(s) specified in the current definition.

IFABC ZETAC IPLASC IANGC

IFABC core fabrication identifier:

- >0 – wall configuration number in the Wall Fabrication Table (K-1)
- <0 – solid fabrication identifier in the GCP Fabrication Table (I-22a)

ZETAC angle ζ between the wall-reference coordinate x_w and the fabrication coordinate $\bar{x}$, for the core component; ζ is a right-handed rotation about $\bar{z}$

IPLASC core material-nonlinearity flag:

- 0 – elastic behavior only
- 1 – plasticity included *(not operational with GCP fabrications, yet)*

IANGC core wall-reference option; see discussion on page 8-18

- 0 – use default strategy of projecting x_g, y_g to establish x_w
- 1 – input $\mathbf{r_w}$, which is projected to establish x_w; see (T-12b)

NX	(T-12)	x-direction looping parameter
NY	(T-12)	y-direction looping parameter

```
if      ( $\textbf{IANGC} > 0$ )   then   go to T-12f
elseif  ( $\textbf{NX} > 0$ )      then   go to T-12g
elseif  ( $\textbf{NY} > 0$ )      then   go to T-12h
else    follow instructions at end of T-12h
```

T-12f E847 Core Reference Vector

RXC RYC RZC

RXC, RYC, RZC core reference vector, $\mathbf{r_w}$, which is projected onto the element surface to determine the direction of the core-reference coordinate x_w; $\mathbf{r_w}$ is expressed in (x_g, y_g, z_g) global coordinates

✦	**NX**	(T-12)	x-direction looping parameter
	NY	(T-12)	y-direction looping parameter

```
if      ( NX > 0 )     then   go to T-12g
elseif  ( NY > 0 )     then   go to T-12h
else    follow instructions at end of T-12h
```

T-12g E847 X-Direction Incrementations

A single record of type T-12g must be included immediately after the T-12e or T-12f record when the **NX** *“x-direction” looping parameter* (T-12) is greater than unity. Fourteen nodal incrementation variables are specified here for use with the “x-direction” looping function on the T-12 record. **NX** **E847** sandwich elements are generated in the “x-direction” with this information. One incrementation variable is also specified here for “x-direction” looping with the user-element-number parameter on T-12.

I1 I2 I3 I4 I5 I6 I7 I8 I9 I10 I11 I12 I13 I14 I15

I1 incrementation for the **N1** lower face sheet node on the T-12a record

I2 incrementation for the **N2** lower face sheet node on the T-12a record

I3 incrementation for the **N3** lower face sheet node on the T-12a record

I4 incrementation for the **N4** lower face sheet node on the T-12a record

I5 incrementation for the **N5** lower face sheet node on the T-12a record

I6 incrementation for the **N6** lower face sheet node on the T-12a record

I7 incrementation for the **N7** lower face sheet node on the T-12a record

I8 incrementation for the **N8** upper face sheet node on the T-12c record

I9 incrementation for the **N9** upper face sheet node on the T-12c record

I10 incrementation for the **N10** upper face sheet node on the T-12c record

I11 incrementation for the **N11** upper face sheet node on the T-12c record

I12 incrementation for the **N12** upper face sheet node on the T-12c record

I13 incrementation for the **N13** upper face sheet node on the T-12c record

I14 incrementation for the **N14** upper face sheet node on the T-12c record

I15 incrementation for **USER** on the T-12 record

Any of these incrementation variables can be negative, zero, or positive, as required.

✦ **NY** (T-12) y-direction looping parameter

if (**NY** > 0) then *go to* T-12h
else *follow instructions at end of* T-12h

T-12h E847 Y-Direction Incrementations

A type T-12h record must be included immediately after the T-12e or T-12f or T-12g record when the **NY** *“y-direction” looping parameter* is greater than unity (T-12). Fourteen nodal incrementation variables are specified here for use with the T-12 record “y-direction” looping function. **NY** **E847** sandwich elements are generated in the “y-direction”, for each **E847** element generated in the x-direction, with this information. The **NX** and **NY** looping parameters are usually employed together to specify **NX** × **NY** **E847** elements in a single stroke.

J1 J2 J3 J4 J5 J6 J7 J8 J9 J10 J11 J12 J13 J14 J15

J1 incrementation for the **N1** lower face sheet node on the T-12a record
J2 incrementation for the **N2** lower face sheet node on the T-12a record
J3 incrementation for the **N3** lower face sheet node on the T-12a record
J4 incrementation for the **N4** lower face sheet node on the T-12a record
J5 incrementation for the **N5** lower face sheet node on the T-12a record
J6 incrementation for the **N6** lower face sheet node on the T-12a record
J7 incrementation for the **N7** lower face sheet node on the T-12a record
J8 incrementation for the **N8** upper face sheet node on the T-12c record
J9 incrementation for the **N9** upper face sheet node on the T-12c record
J10 incrementation for the **N10** upper face sheet node on the T-12c record
J11 incrementation for the **N11** upper face sheet node on the T-12c record
J12 incrementation for the **N12** upper face sheet node on the T-12c record
J13 incrementation for the **N13** upper face sheet node on the T-12c record
J14 incrementation for the **N14** upper face sheet node on the T-12c record
J15 incrementation for **USER** on the T-12 record

Any of these incrementation variables can be negative, zero, or positive, as required.

N847 (T-5) number of **E847** definitions
N849 (T-5) number of **E849** definitions
N880 (T-5) number of **E880** definitions

```
if     ( fewer than N847 E847 definitions have been processed ) return to  T-12
elseif   ( N849 > 0 )     then     go to  T-13
elseif   ( N880 > 0 )     then     go to  T-14
else                               go to  U-1
```

T-13 E849 18-Node Sandwich Element Definition

The 18–node **E849** sandwich element in **STAGS**, shown in Figure 8.10, is constructed with a pair of 9–node **E480** quadrilateral shells (with bending as well as the usual membrane stiffness) that are held apart by a lightweight core that has three-dimensional elastic properties. This type of model is called a sandwich of the second kind. A good example of a problem requiring this model would be one with structural walls made of glass fiber faces and using polyurethane foam as the core material.

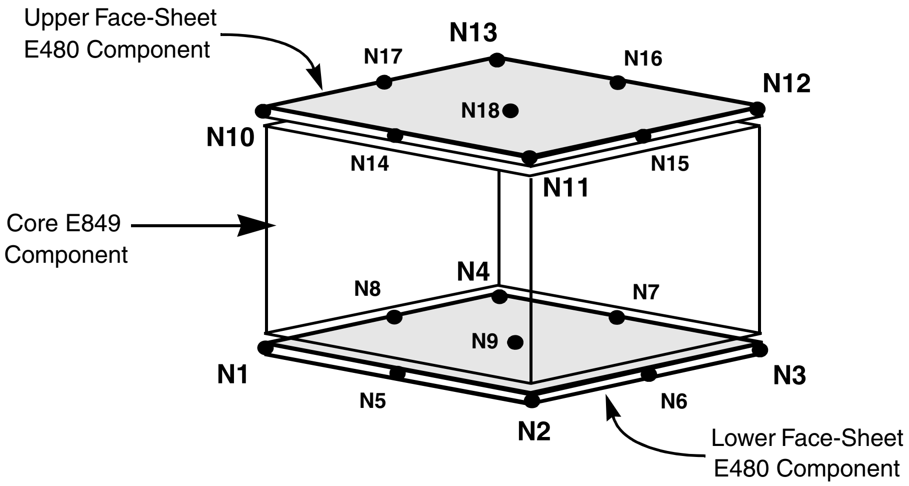


Figure 8.10 **E849** 18-Node Sandwich Element

Definition of one or more 18–node **E849** sandwich elements is accomplished with the following set of records:

T-13 to specify parameters used for all parts of the element
T-13a to specify information for the lower face sheet of the element
T-13b to specify lower face sheet transformation angles (optional)
T-13c to specify information for the upper face sheet
T-13d to specify upper face sheet transformation angles (optional)
T-13e to specify core parameters
T-13f to specify core transformation angles (optional)
T-13g for “x-direction” incrementation parameters
T-13h for “y-direction” incrementation parameters

These are described sequentially in the following text.

KELT ILIN INTEG IPEN NX NY USERC USER1 USER2

KELT element code number (must be 849)

ILIN geometric-linearity flag:

0 – nonlinear strain-displacement relations
1 – linear strain-displacement relations

INTEG integration-type flag: not used for this element; set **INTEG** = 0

IPEN penalty option: not used for this element; set **IPEN** = 0

NX x-direction looping parameter, set equal to unity by **STAGS** if omitted or nonpositive; $\mathbf{NX} > 1$ instructs **STAGS** to generate a set of **NX** type **E849** elements in the x direction, using nodal incrementation information given on the T-13g record described below

NY y-direction looping parameter, set equal to unity by **STAGS** if omitted or nonpositive; $\mathbf{NY} > 1$ instructs **STAGS** to generate a set of **NY** type **E849** elements in the y direction for each of the **NX** elements generated in the x-direction in the current definition, using nodal incrementation information given on the T-13h record described below

USERC user-specified element number for core component
(used only if **IUWLE** = 1 on H-1)

USER1 user-specified element number for **lower face sheet**, (if **IUWLE** = 1 on H-1)

USER2 user-specified element number for **upper face sheet**, (if **IUWLE** = 1 on H-1)

go to T-13a

T-13a E849 Lower Face-Sheet Properties

A single T-13a record must be included immediately following the T-13 record, to specify the nodes for the lower face sheet of the first **E849** element (see Figure 8.10 on page 8-92) and to specify other parameters for the lower face sheet of each of the element(s) specified in the current definition.

N1 N2 N3 N4 N5 N6 N7 N8 N9 IFABL ZETAL ECZL IPLASL IANGL

N1	node # 1 of the lower face sheet
N2	node # 2 of the lower face sheet
N3	node # 3 of the lower face sheet
N4	node # 4 of the lower face sheet
N5	node # 5 of the lower face sheet
N6	node # 6 of the lower face sheet
N7	node # 7 of the lower face sheet
N8	node # 8 of the lower face sheet
N9	node # 9 of the lower face sheet

IFABL fabrication identifier for the lower face sheet element(s); this is equivalent to the **WALL** parameter for **E480** quadrilateral elements:

- >0 – wall configuration number in the Wall Fabrication Table (K-1)
- 0 – shell wall properties are given in user-written subroutine WALL (See the T-4 record description for more information about this)
- <0 – shell fabrication identifier in the GCP Fabrication Table (I-21a)

ZETAL angle ζ between the wall-reference coordinate x_w and the fabrication coordinate $\bar{x}$, for the lower face sheet; ζ is a right-handed rotation about $\bar{z}$; see Figure 8.2 on page 8-19.

ECZL eccentricity in z' direction, for the lower face sheet; **ECZL** is the z' coordinate of the shell wall middle surface; please refer to Figure 6.2 on page 6-28; in element units, (x', y', z') are used in place of (X', Y', Z'), which do not exist in an element unit; see “Effects of Eccentricity” on page 16-6.

IPLASL lower face sheet material-nonlinearity flag:

- 0 – elastic behavior only
- 1 – plasticity included, with the material law satisfied at each element integration point
- 2 – plasticity included, with the material law satisfied at the element centroid (centroidal plasticity)

IANGL lower face sheet wall-reference option; see discussion on page 8-18

0 – use default strategy of projecting x_g, y_g to establish x_w

1 – input $\mathbf{r_w}$, which is projected to establish x_w; see (T-13b)

```
if ( IANGL $> 0$ ) then
                        go to T-13b
else                    go to T-13c
```

T-13b E849 Lower Face-Sheet Wall Reference Vector

RXL RYL RZL

RXL,RYL,RZL lower face sheet wall reference vector, $\mathbf{r_w}$, which is projected onto the element surface to determine the direction of the wall-reference coordinate x_w; $\mathbf{r_w}$ is expressed in (x_g, y_g, z_g) global coordinates

✦ *go to* T-13c

T-13c E849 Upper Face-Sheet Properties

A single T-13c record must be included immediately following the T-13a (or T-13b) record, to specify the nodes for the upper face sheet of the first **E849** element (see Figure 8.10 on page 8-92) and to specify other parameters for the upper face sheet of each of the element(s) specified in the current definition.

N10 N11 N12 N13 N14 N15 N16 N17 N18 IFABU ZETAU ECZU IPLASU IANGU

N10 node # 1 of the upper face sheet

N11 node # 2 of the upper face sheet

N12 node # 3 of the upper face sheet

N13 node # 4 of the upper face sheet

N14 node # 5 of the upper face sheet

N15 node # 6 of the upper face sheet

N16 node # 7 of the upper face sheet

N17 node # 8 of the upper face sheet

N18 node # 9 of the upper face sheet

IFABU fabrication identifier for the upper face sheet element(s); this is equivalent to the **WALL** parameter for **E410** quadrilateral elements:

>0 – wall configuration number in the Wall Fabrication Table (K-1)
0 – shell wall properties are given in user-written subroutine WALL
<0 – shell fabrication identifier in the GCP Fabrication Table (I-21a)

ZETAU angle ζ between the wall-reference coordinate x_w and the fabrication coordinate $\bar{x}$, for the upper face sheet; ζ is a right-handed rotation about $\bar{z}$

ECZU eccentricity in z' direction, for the upper face sheet; **ECZL** is the z' coordinate of the shell wall middle surface

IPLASU upper face sheet material-nonlinearity flag:

0 – elastic behavior only
1 – plasticity included, with the material law satisfied at each element integration point
2 – plasticity included, with the material law satisfied at the element centroid (centroidal plasticity)

IANGL upper face sheet wall-reference option; see discussion on page 8-18

0 – use default strategy of projecting x_g, y_g to establish x_w
1 – input $\mathbf{r_w}$, which is projected to establish x_w; see (T-13b)

if (**IANGU** > 0) then *go to* T-13d
else *go to* T-13e

T-13d E849 Upper Face-Sheet Wall Reference Vector

RXU RYU RZU

RXU, RYU, RZU upper face sheet wall reference vector, $\mathbf{r_w}$, which is projected onto the element surface to determine the direction of the wall-reference coordinate x_w; $\mathbf{r_w}$ is expressed in (x_g, y_g, z_g) global coordinates

✦ *go to* T-13e

T-13e E849 Core Properties

A single T-13e record must be included immediately following the T-13c (or T-13d) record, to specify parameters for the core component of the element(s) specified in the current definition.

IFABC ZETAC IPLASC IANGC

IFABC core fabrication identifier:

>0 – wall configuration number in the Wall Fabrication Table (K-1)

<0 – solid fabrication identifier in the GCP Fabrication Table (I-22a)

ZETAC angle ζ between the wall-reference coordinate x_w and the fabrication coordinate $\bar{x}$, for the core component; ζ is a right-handed rotation about $\bar{z}$

IPLASC core material-nonlinearity flag:

0 – elastic behavior only

1 – plasticity included *(not operational with GCP fabrications, yet)*

IANGC core wall-reference option; see discussion on page 8-18

0 – use default strategy of projecting x_g, y_g to establish x_w

1 – input $\mathbf{r_w}$, which is projected to establish x_w; see (T-13b)

NX	(T-13)	x-direction looping parameter
NY	(T-13)	y-direction looping parameter

```
if      ( IANGC > 0 ) then   go to T-13f
elseif  ( NX > 0 )    then   go to T-13g
elseif  ( NY > 0 )    then   go to T-13h
else    follow instructions at end of T-13h
```

T-13f E849 Core Reference Vector

RXC RYC RZC

RXC, RYC, RZC core reference vector, $\mathbf{r_w}$, which is projected onto the element surface to determine the direction of the core-reference coordinate x_w; $\mathbf{r_w}$ is expressed in (x_g, y_g, z_g) global coordinates

NX	(T-13)	x-direction looping parameter
NY	(T-13)	y-direction looping parameter

```
if      ( NX > 0 )  then    go to T-13g
elseif  ( NY > 0 )  then    go to T-13h
else    follow instructions at end of T-13h
```

T-13g E849 X-Direction Incrementations

A single record of type T-13g must be included immediately after the T-13e or T-13f record when the **NX** “*x-direction” looping parameter* (T-13) is greater than unity. Eighteen nodal incrementation variables are specified here for use with the “x-direction” looping function on the T-13 record. **NX E849** sandwich elements are generated in the “x-direction” with this information. Three incrementation variables are also specified here for “x-direction” looping with the user-element-number parameters on T-13.

(IX(k), k=1,18) iXC iX1 iX2

IX(k) *x*-direction incrementation for the kth node,which is on the T-13a record (when $1 \le \mathbf{k} \le 9$), or on the T-13c record (when $10 \le \mathbf{k} \le 18$)

IXC *x*-direction incrementation for **USERC** on the T-13 record

IX1 *x*-direction incrementation for **USER1** on the T-13 record

IX2 *x*-direction incrementation for **USER2** on the T-13 record

Any of these incrementation variables can be negative, zero, or positive, as required.

Example: the following T-13 / T-13a / T-13c / T-13g record combination:

```
849 1 0 0 3                          $ T-13 with NX=3
10 20 30 40 50 60 70 80 90 ...       $ T-13a lower face nodes
15 25 35 45 55 65 75 85 95 ...       $ T-13c upper face nodes
...
1 1 1 1 1 1 1 1 1    9*2             $ T-13g increments
```

generates three **E849** elements, with the following nodes:

```
10 20 30 40 50 60 70 80 90   15 25 35 45 55 65 75 85 95Element #1
11 21 31 41 51 61 71 81 91   17 27 37 47 57 67 77 87 97Element #2
12 22 32 42 52 62 72 82 92   19 29 39 49 59 69 79 89 99Element #3
```

NY (T-13) y-direction looping parameter

if (**NY** > 0) then *go to* T-13h
else *follow instructions at end of* T-13h

T-13h E849 Y-Direction Incrementations

A single type T-13h record must be included immediately after the T-13e or T-13f or T-13g record when the **NY** *“y-direction” looping parameter* is greater than unity (T-13). Eighteen nodal incrementation variables are specified here for use with the T-13 record “y-direction” looping function. **NY** **E849** sandwich elements are generated in the “y-direction”, for each **E849** element generated in the x-direction, with this information. The **NX** and **NY** looping parameters are usually employed together to specify **NX** × **NY** **E849** elements in a single stroke.

(IY(k), k=1,18) IYC IY1 IY2

IY(k) *y*-direction incrementation for the kth node,which is
on the T-13a record (when $1 \le \mathbf{k} \le 9$), or
on the T-13c record (when $10 \le \mathbf{k} \le 18$)

IYC *y*-direction incrementation for **USERC** on the T-13 record

IY1 *y*-direction incrementation for **USER1** on the T-13 record

IY2 *y*-direction incrementation for **USER2** on the T-13 record

Any of these incrementation variables can be negative, zero, or positive, as required.

N849 (T-5) number of **E849** definitions
N880 (T-5) number of **E880** definitions

```
if       ( fewer than N849 E849 definitions have been processed )return to  T-13
elseif   ( N880 > 0 )      then  go to  T-14
else                             go to  U-1
```

Solid elements

The current version of **STAGS** gives the analyst a choice of four solid elements:

- E881 — an 8-node ANS solid element
- E882 — an 18-node ANS solid element
- E883 — a 27-node ANS solid element
- E885 — a 20-node BR20 displacement-based solid element

The elements and their node-numbering patterns are shown in Figure 8.11:

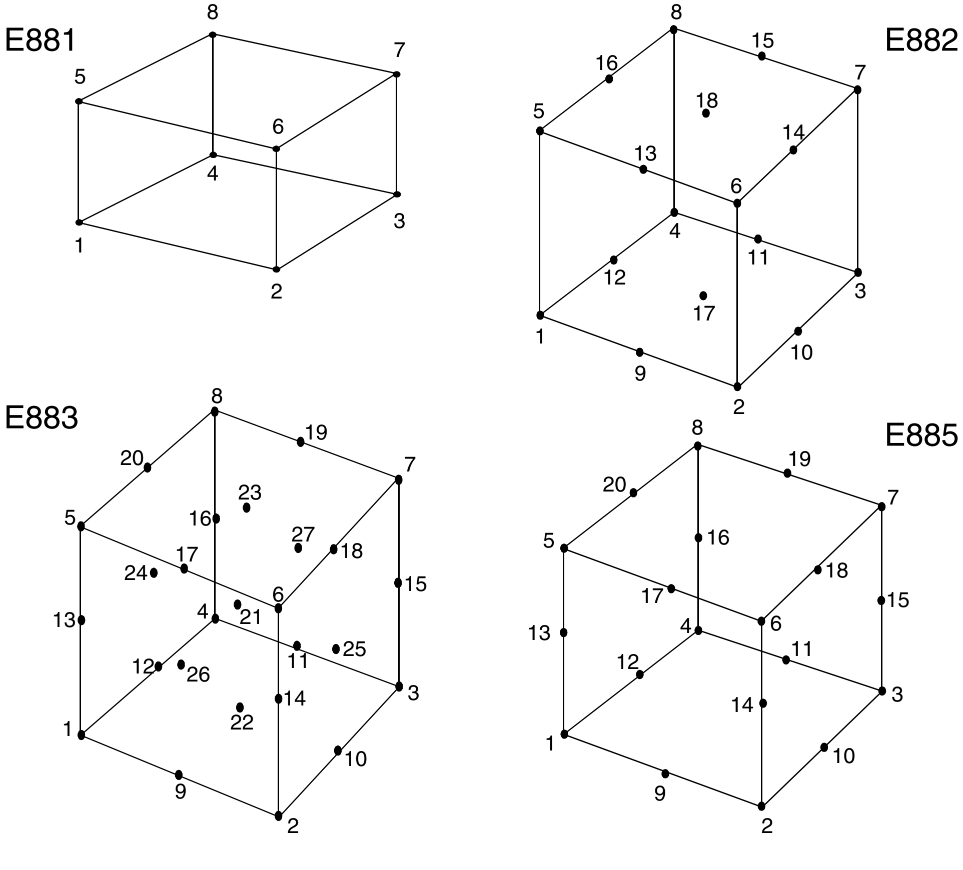


Figure 8.11 The **E880** Family of Solid Elements

T-14 E880-Family Solid Element

The **N880** parameter, on T-5, specifies the number of *definitions* that the analyst wishes to make to include one or more of the **E880**-family solid elements in the current element unit. Each of these definitions begins with a T-14 record, on which the **KELT** parameter, indicates which *one* of these element types is being specified with any given solid-element definition:

KELT IFAB IANG ILIN IPLAS NX NY

KELT solid element type:

KELT = 881 – 8-node ANS solid element
KELT = 882 – 18-node ANS solid element
KELT = 883 – 27-node ANS solid element
KELT = 885 – 20-node BR20 displacement-based solid element

IFAB fabrication identifier for the element; this is equivalent to the **WALL** parameter for **E410** quadrilateral elements:

>0 – wall configuration number in the Wall Fabrication Table (K-1)
0 – wall properties are given in user-written subroutine WALL
<0 – fabrication identifier in the GCP Fabrication Table (I-22a)

IANG wall-reference option:

0 – use default strategy of projecting x_g, y_g to establish x_w
1 – input $\mathbf{r_w}$, which is projected to establish x_w

IPLAS material-nonlinearity flag:

0 – elastic behavior only
1 – plasticity included, with the material law satisfied at each element integration point
2 – plasticity included, with the material law satisfied at the element centroid (centroidal plasticity)

NX number of elements to be generated in the x-direction; **STAGS** sets **NX** = 1 if it is nonpositive

NY number of elements to be generated in the y-direction; **STAGS** sets **NY** = 1 if it is nonpositive

✦ *go to* T-14a

T-14a E880 Solid Element Nodes

A single T-14a record must follow the T-14 record, to identify the user points that define the first solid element of the set to be generated here. The number **NPTS** of user points required is 8 for an **E881** element, 18 for an **E882** element, 27 for an **E883** element, or 20 for an **E885** element. These user points must have been defined by appropriate S-1/S-1a/S-2 or S-3/S-3a/S-4 records, as described in Chapter 7.

(NODE(k), k=1,NPTS)   USERELT

NODE(k) k^{th} of **NPTS** node points for the initial **E881**, **E882**, **E883 or E884** solid element

USERELT user-specified element number, used only if **IUWLE** = 1 on H-1

The nodal orderings for **E880**-family elements correspond exactly to the nodal orderings that are used in the ***PATRAN*** program.

NX	(T-14)	x-direction incrementation flag
NY	(T-14)	y-direction incrementation flag
IANG	(T-14)	wall-reference option

```
if      ( NX > 1)      then   go to T-14b
elseif  ( NY > 1)      then   go to T-14c
elseif  ( IANG > 0 )   then   go to T-14d
else    follow instructions at end of T-14d
```

T-14b E880 X-Direction Incrementations

Nine x-direction incrementation variables are specified here for use with the **NX** looping function invoked on the T-14 record and the initial node points established on T-14a.

IX1 IX2 IX3 IX4 IX5 IX6 IX7 IX8 IUX

IX1 x-direction incrementation variable for node **N1** on T-14a

IX2 x-direction incrementation variable for node **N2** on T-14a

IX3 x-direction incrementation variable for node **N3** on T-14a

IX4 x-direction incrementation variable for node **N4** on T-14a

IX5 x-direction incrementation variable for node **N5** on T-14a

IX6 x-direction incrementation variable for node **N6** on T-14a

IX7 x-direction incrementation variable for node **N7** on T-14a

IX8 x-direction incrementation variable for node **N8** on T-14a

IUX x-direction incrementation variable for use with **USERELT**

Any of these incrementation variables can be negative, zero or positive.

✦ if (**NY** > 1) then *go to* T-14c
elseif (**IANG** = 1) then *go to* T-14d
else *follow instructions at end of* T-14d

T-14c E880 Y-Direction Incrementations

Nine y-direction incrementation variables are specified here for use with the **NY** looping function invoked on the T-14 record and the initial node points established on T-880a.

IY1 IY2 IY3 IY4 IY5 IY6 IY7 IY8 IUY

IY1 y-direction incrementation variable for node **N1** on T-14a

IY2 y-direction incrementation variable for node **N2** on T-14a

IY3 y-direction incrementation variable for node **N3** on T-14a

IY4 y-direction incrementation variable for node **N4** on T-14a

IY5 y-direction incrementation variable for node **N5** on T-14a

IY6 y-direction incrementation variable for node **N6** on T-14a

IY7 y-direction incrementation variable for node **N7** on T-14a

IY8 y-direction incrementation variable for node **N8** on T-14a

IUY y-direction incrementation variable for use with **USERELT**

Any of these incrementation variables can be negative, zero or positive.

if (**IANG** = 1) then *go to* T-14d
else *follow instructions at end of* T-14d

T-14d E880 Material Orientation Record

If **IANG** > 0 (T-14), a single T-14d record must follow the T-14a record (or T-880b or T-880c record, if applicable) for the current **E880** solid element. T-14d specifies the material orientation for each of the **E880** elements that are to be generated by the current T-14 element-definition set.

XFX XFY XFZ YFX YFY YFZ

XFX,XFY,XFZ	vector components establishing the x orientation of the material
YFX,YFY,YFZ	vector components establishing the x orientation of the material

N880 (T-5) number of **E880** definitions

```
if      ( fewer than N880 E880 definitions have been processed )return to  T-14
else    go to  U-1
```

9
Model Input—Element Units (3)

This chapter describes the ***Ecom*** *(element-command)* protocol for specifying some or all of the elements that are to be used in constructing an element unit in a **STAGS** model. As noted earlier, this protocol is used if and only if the **NT1**, **NT2**, **NT3**, **NT4** and **NT5** parameters are *all* set equal to 0 on the H-1 record for the current element unit—or if one or more of the **NT1**, **NT2**, **NT3** and/or **NT4** parameters is positive and the **NT5** parameter is 3. The Ecom protocol can be used by itself to define *all* of the elements in the element unit, or in combination with the (older) Edef protocol to define one or more *additional* elements after other elements have been defined *via* T-x and/or T-xx records, as described in Chapter 8.

The Ecom protocol, as its name suggests, is a *command-driven* procedure (like the GCP facility described in Chapter 5). **STAGS** responds to command and control information on the following T-100 record, to read and process element-definition input or to stop doing so. The analyst uses a typical command, here, to tell **STAGS** to process one or more record sets that define one or more spring, beam, triangle, quadrilateral, contact, sandwich, solid or user-defined elements—as described in this chapter. The analyst terminates Ecom-controlled element definitions with a simple ‘END’ command.

After all Edef and Ecom protocol element definitions have been processed, **STAGS** calls user-written subroutines to generate one or more *additional* elements (if **IUELT** is positive on H-1)—and then moves forward to process loading and other input information, as required.

T-100 Ecom Control or Element-Specification Record

STAGS examines each T-100 record that it encounters to determine if it begins with a character string (in which case **STAGS** interprets it as an *Ecom control record*) or if it begins with numeric data (in which case **STAGS** interprets it as an *Ecom element-specification record*). For reasons that will become clear as this narrative continues, the very first and the very last T-100 records for any given element unit must be Ecom control records. One or more T-100 records of either type can appear in any order between the first and last T-100 records for each element unit.

When the analyst's current T-100 record is an Ecom control record (starting with a character string called **COMMAND**), **STAGS** examines the first four "active" characters in **COMMAND**—starting with the first non-blank character and continuing with the next three characters following it—to determine whether or not they uniquely identify one or another of the following thirty case-insensitive Ecom commands that **STAGS** recognizes:

Ecom command	Action instruction
`E110_Elements`	– specify one or more additional **E110** spring element(s)
`E120_Elements`	– specify one or more additional **E120** rigid link element(s)
`E121_Elements`	– specify one or more additional **E121** soft link element(s)
`E130_Elements`	– specify one or more additional **E130** generalized fastener element(s)
`E210_Elements`	– specify one or more additional **E210** beam element(s)
`E250_Elements`	– specify one or more additional **E250** planar BC element(s)
`E320_Elements`	– specify one or more additional **E320** standard triangle element(s)
`E330_Elements`	– specify one or more additional **E330** MIN3 triangle element(s)
`E410_Elements`	– specify one or more additional **E410** 4-node quadrilateral element(s)
`E411_Elements`	– specify one or more additional **E411** quadrilateral element(s)
`E480_Elements`	– specify one or more additional **E480** 9-node quadrilateral element(s)
`E510_Elements`	– specify one or more additional **E510** 5-node quad mesh transition element(s)
`E710_Elements`	– specify one or more additional **E710** 7-node quad mesh transition element(s)
`E810_Elements`	– specify one or more additional **E810** PAD surface/surface contact element(s)
`E820_Elements`	– specify one or more additional **E820** generalized point/surface contact element(s)
`E822_Elements`	– specify one or more additional **E822** line/line contact element(s)
`E830_Elements`	– specify one or more additional **E830** 6-node sandwich element(s)
`E840_Elements`	– specify one or more additional **E840** 8-node sandwich element(s)
`E845_Elements`	– specify one or more additional **E845** 10-node sandwich transition element(s)
`E847_Elements`	– specify one or more additional **E847** 14-node sandwich transition element(s)
`E849_Elements`	– specify one or more additional **E849** 18-node sandwich element(s)
`E881_Elements`	– specify one or more additional **E881** 8-node ANS brick element(s)
`E882_Elements`	– specify one or more additional **E882** 18-node ANS solid element(s)
`E883_Elements`	– specify one or more additional **E883** 27-node ANS solid element(s)
`E885_Elements`	– specify one or more additional **E885** 20-node displacement-based solid element(s)
`E900_Elements`	– specify one or more additional **E900** user-defined element(s)
`E928_Elements`	– specify one or more additional **E928** "built-in" 3-node curved-beam **UEL**(s)
`E940_Elements`	– specify one or more additional **E940** "built-in" MIN4 quadrilateral **UEL**(s)
`E9XX_Elements`	– specify one or more additional **E9xx** **UEL**(s)

and

`End`	– stop specifying elements!

STAGS ignores the `'_'` character in the user's **COMMAND** string and the program's matrix of recognizable keywords, and everything after that character in both places, so the user can abbreviate any of these keywords to four characters as and if he wishes to do so—except for the 3-character `'End'` keyword, which he cannot abbreviate.

When the "active" part of the **COMMAND** string on the user's current T-100 record "matches" the first four characters of one of the twenty nine `'Ennn_Elements'` Ecom commands that **STAGS** recognizes and supports, **STAGS** understands that the analyst wants to add one or more type `'nnn'` elements to the current element unit. Under these circumstances, the `'nnn'` part of the user's **COMMAND** must be one or another of the twenty nine 3-digit element-type codes that the current version of the **STAGS** program supports—one or another of the **KELT** values that are specified in the nine element-type "groups" that are shown in the following Table:

Group	Element-type code (KELT = nnn value)				
100	110	120	121	130	
200	210	250			
300	320	330			
400	410	411	480	510	710
800	810	820	822		
830	830				
840	840	845	847	849	
880	881	882	883	885	
900	900	928	940	9xx	

These twenty nine element-type codes are arranged in "groups" like this because element-specification input requirements tend to be similar from one type of element to another when the elements are in the same group, and because they tend to be very different from each other when the elements are in different element-type groups. It takes more input (of different kinds) for the user to specify an **E410** quadrilateral element, for example, than it does for him to specify any type of "spring" element. It also takes more input to specify a set of 18-node **E885** elements than it does to specify a set of **E881**s.

The "real" reason for arranging these element-type codes in nine "groups" like this is to make it easier for the user to specify the elements that he wants to add to his current element unit—by relaxing the old rule that he had to warn **STAGS** each time he stopped specifying elements of one type and started specifying elements of a different type (with a T-100 record specifying the new type and the number of record sets needed to define those elements). The current version of **STAGS** lets the user switch from one type of element to any other type of element in the same element-type group—without using an Ecom record to specify the new type and without counting the number of record sets to be used to define them.

With the previous version of **STAGS**, the Ecom-controlled part of the user's element-specification input stream might have looked like this (for example):

```
:
E220_Elements 1
     T-220 record set # 1 (T-220/T-220a)
E221_Elements 1
     T-221 record set # 1 (T-221/T-221a)
E410_Elements 2
     T-410 record set # 1 (T-410/T-410a/T-410b/T-410c)
     T-410 record set # 2 (T-410/T-410a/T-410b/T-410c)
E510_Elements 1
     T-510 record set # 1 (T-510/T-510a/T-510b/T-510c)
E710_Elements 1
     T-710 record set # 1 (T-710/T-710a/T-710b/T-710c)
E410_Elements 2
     T-410 record set # 3 (T-410/T-410a/T-410b/T-410c)
     T-410 record set # 4 (T-410/T-410a/T-410b/T-410c)
End
```

With the current version of **STAGS**, this user might want to take advantage of this new flexibility by removing the "optional" `'Ennn_Elements'` commands in his input stream and restraining himself from counting the number of element-specification record sets that he needs to do the job at hand—thusly:

```
:
E410_Elements
     T-410 record set # 1 (T-410/T-410a/T-410b/T-410c)
     T-410 record set # 2 (T-410/T-410a/T-410b/T-410c)
     T-410 record set # 3 (T-410/T-410a/T-410b/T-410c)
     T-410 record set # 4 (T-410/T-410a/T-410b/T-410c)
     T-510 record set # 1 (T-510/T-510a/T-510b/T-510c)
     T-710 record set # 1 (T-710/T-710a/T-710b/T-710c)
E120_Elements
     T-220 record set # 1 (T-220/T-220a)
     T-221 record set # 1 (T-221/T-221a)
End
```

In any event, the reader should take pains to note that the first record in both of these element-specification streams must be an Ecom command that identifies the first type of element that the user wants to add to the current element unit—and that the last Ecom record in both of these element-specification streams must be the `'END'` command, to stop specifying more elements for that unit. It's no big deal for the user to cut out four element-type Ecom commands in this small and simple example, but it might make life much simpler and easier for him to do so (without having to count his record sets) for larger and/or more complex cases.

This is a good point for us to remind the reader (again) that when the character string on the analyst's T-100 (Ecom) record gives **STAGS** the `'END'` instruction, the program stops reading element specifications for the current unit and starts reading the user's U-1 (Loads Summary) input.

This is also a good point for us to tell (or remind) the reader that when the current T-100 record starts with numeric data, **STAGS** considers that T-100 record to be the first record in the record set that is needed to specify type-nnn elements. Initially (and typically), nnn is the **KELT**-specification part of the user's most recent Ecom control command. It will be different from that, however, if the user has switched to a different type of element in the same element-type group. **STAGS** expects to continue reading and processing one T-nnn record set after another—as described below and in the remainder of this chapter—until the user gives it a new Ecom control record that directs it to do otherwise.

The following "overview" navigation diagram describes that more succinctly than more paragraphs in this "Model Input—Element Units" chapter can:

```
if       ( the T-100 record contains an Ecom control command )  then
         if       ( COMMAND := 'Ennn' --> valid STAGS element type )  then
                  go to T-nnn   to specify one or more type nnn elements to be
                                added to the current element unit
         elseif   ( COMMAND := 'End' )  then
                  go to U-1     (stop specifying elements)
         else
                  STOP gracefully (unrecognized command)
         endif
elseif   ( the T-100 record contains numerical data )  then
                  go to T-nnn and follow instructions there
endif
```

The following navigation diagram describes more precisely what **STAGS** expects the user to "do" when he reaches (or returns to) this point in preparing his *case.inp* input file for the **s1** program:

```
if    ( T-100 contains an Ecom control command )  then

    if   ( COMMAND := ‘Ennn’ --> valid STAGS element type )  then

        if       ( COMMAND  = ’E110_Elements’ )  then     go to T-110
        elseif   ( COMMAND  = ’E120_Elements’ )  then     go to T-120
        elseif   ( COMMAND  = ’E121_Elements’ )  then     go to T-121
        elseif   ( COMMAND  = ’E130_Elements’ )  then     go to T-130
        elseif   ( COMMAND  = ’E210_Elements’ )  then     go to T-210
        elseif   ( COMMAND  = ’E250_Elements’ )  then     go to T-250
        elseif   ( COMMAND  = ’E320_Elements’ )  then     go to T-320
        elseif   ( COMMAND  = ’E330_Elements’ )  then     go to T-330
        elseif   ( COMMAND  = ’E410_Elements’ )  then     go to T-410
        elseif   ( COMMAND  = ’E411_Elements’ )  then     go to T-411
        elseif   ( COMMAND  = ’E480_Elements’ )  then     go to T-480
        elseif   ( COMMAND  = ’E510_Elements’ )  then     go to T-510
        elseif   ( COMMAND  = ’E710_Elements’ )  then     go to T-710
        elseif   ( COMMAND  = ’E810_Elements’ )  then     go to T-810
        elseif   ( COMMAND  = ’E820_Elements’ )  then     go to T-820
        elseif   ( COMMAND  = ’E822_Elements’ )  then     go to T-822
        elseif   ( COMMAND  = ’E830_Elements’ )  then     go to T-830
        elseif   ( COMMAND  = ’E840_Elements’ )  then     go to T-840
        elseif   ( COMMAND  = ’E845_Elements’ )  then     go to T-845
        elseif   ( COMMAND  = ’E847_Elements’ )  then     go to T-847
        elseif   ( COMMAND  = ’E849_Elements’ )  then     go to T-849
        elseif   ( COMMAND  = ’E881_Elements’ )  then     go to T-881
        elseif   ( COMMAND  = ’E882_Elements’ )  then     go to T-882
        elseif   ( COMMAND  = ’E883_Elements’ )  then     go to T-883
        elseif   ( COMMAND  = ’E885_Elements’ )  then     go to T-885
        elseif   ( COMMAND  = ’E900_Elements’ )  then     go to T-900
        elseif   ( COMMAND  = ’E928_Elements’ )  then     go to T-928
        elseif   ( COMMAND  = ’E940_Elements’ )  then     go to T-940
        elseif   ( COMMAND  = ’E9XX_Elements’ )  then     go to T-900

    elseif   ( COMMAND := ‘End’ )  then

            go to U-1        (stop specifying elements)

    endif

elseif    ( T-100 contains numerical data )      then

go to T-100

endif
```

9.1 Definition of “Spring” Elements *via* the Ecom Protocol

There are four so-called “spring” elements available in the current version of the **STAGS** program.

The 2-node **E110** Mount element is a special-purpose function (disguised as an element) that is designed to model a user-specified displacement-velocity-force profile. One or more **E110** elements (or additional **E110** elements) can be defined with the T-110 record set. For more information about the **E110** element, see “I-4a Mount Element Table Size” on page 5-64 and “E110 Mount element” on page 14-6.

The 2-node **E120** rigid link element constrains the distance between two nodes to be invariant during an analysis and the rotations at the two nodes to be equal. It is a *traditional* rigid link. One or more **E120** elements (or additional **E120** elements) can be defined with the T-120 record set. For more information about the **E120** element, see “E120 Rigid link element” on page 14-7.

The 3-node **E121** soft link element constrains three nodes to be colinear. The **E121** element is most useful in connecting shell units that are modeled with three-dimensional solid elements to other shell units that are modeled with two-dimensional shell elements. One or more **E121** elements (or additional **E121** elements) can be defined with the T-121 record set. For more information about the **E121** element, see “E121 Soft link element” on page 14-7 and the ***STAGS*** *Elements Manual*.

The 2-node **E130** element is a special-purpose element that uses Mount Element Table and other user-supplied information to model breakable fasteners. One or more **E130** elements (or additional **E130** elements) can be defined with the T-130 record set. For more information about the **E130** element, see “E130 Generalized fastener element” on page 14-8.

T-110 Additional E110 Elements

This is the first record of the two-record T-110/T-110a Ecom protocol counterpart of the T-1/T-1a record set that also defines one or more **E110** mount elements. With this T-110 record (and its T-110a companion), the user can specify one or more additional mount elements to be included in the current element unit. The *looping* capability provided here *via* **NX**, **INC1**, **INC2** and **INC3** can be used effectively in many situations.

N1 N2 N3 KELT NX INC1 INC2 INC3 USERELT INC4

N1	node 1
N2	node 2
N3	node 3
KELT	must = 110
NX	number of mount elements to be specified; **STAGS** sets **NX** = 1 if it is nonpositive or omitted
INC1	incrementation variable for **N1**
INC2	incrementation variable for **N2**
INC3	incrementation variable for **N3**
USERELT	user-specified element number (only used if **IUWLE**=1 on H-1)
INC4	incrementation variable for **USERELT**

go to T-110a

T-110a E110 Element Data

The mount element is described fully in “E110 Mount element” on page 14-6 and in Chapter 8, in connection with the T-1/T-1a record set. As noted there, it is a special nonlinear spring capable of modeling a user-defined displacement-velocity-force profile. Rigid links with this element provide a method for defining rotational stiffness in addition to axial spring stiffness.

IMNT1 IMNT2 RLX1 RLY1 RLZ1 RLX2 RLY2 RLZ2

IMNT1 required Mount Element Table identifier (I-4a)

IMNT2 optional additional mount table identifier: if **IMNT2** is not zero, then **IMNT1** and **IMNT2** must refer to tables consisting of a single row (displacement table, **NRV** $= 1$, I-4a) or column (velocity table, **NRD** $= 1$, I-4a). There must be one table of each type, or an error will result. If **IMNT2** > 0, the total mount force is the sum of the force from the displacement table and the force from the velocity table.

RLX1, RLY1, RLZ1 (X_1, Y_1, Z_1) coordinates of point RL1; see Figure 14.1 on page 14-6

RLX2, RLY2, RLZ2 (X_2, Y_2, Z_2) coordinates of point RL2

```
if     ( the user wants to add another set of E110 elements )  then
         go to T-110
elseif ( the user wants to add a set of E120 elements )  then
         go to T-120
elseif ( the user wants to add a set of E121 elements )  then
         go to T-121
elseif ( the user wants to add a set of E130 elements )  then
         go to T-130
else
         return to T-100
endif
```

T-120 Additional E120 Elements

This is the first record of the two-record T-120/T-120a Ecom protocol counterpart of the T-1/ T-1b record set that also defines one or more **E120** rigid link elements. With this record (and T-120a), the user can specify one or more additional rigid link elements to be included in the current element unit. The *looping* capability provided here *via* **NX**, **INC1**, **INC2** and **INC3** can be used effectively in many situations.

N1 N2 N3 KELT NX INC1 INC2 INC3 USERELT INC4

N1 node 1

N2 node 2

N3 node 3 — a reference node; a positive value enforces rotational compatibility between **N1** and **N2**)

KELT must = 120

NX number of rigid link elements to be specified; **STAGS** sets **NX** = 1 if it is nonpositive or omitted

INC1 incrementation variable for **N1**

INC2 incrementation variable for **N2**

INC3 incrementation variable for **N3**

USERELT user-specified element number (only used if **IUWLE**=1 on H-1)

INC4 incrementation variable for **USERELT**

The third node, **N3**, is a reference node that is used to enforce rotational compatibility between **N1** and **N2**. If **N3** is zero, the freedoms on **N2** are independent of those on **N1**—a condition that simulates a ball joint at **N2.** If **N3** is nonzero, total rotational compatibility is enforced between **N1** and **N2**—a condition that simulates the ordinary rigid link. If **N3** is positive, the rotational constraint in enforced with a set of three Lagrange multipliers. For this option, computational coordinates for each node in the link are completely independent (at the discretion of the user), affording maximum flexibility. If **N3** is negative, the rotational constraint is enforced using partial compatibility (see G-2, with **ID1** = -2). A restriction is introduced that forces the computational coordinates of **N2** to be the same as for the master node to which **N1** refers. This can have unforeseen consequences if rigid links cause new master/slave relationships to be defined between other nodes in the model. It is recommended that a negative value for **N3** be used with caution.

go to T-120a

T-120a E120 Element Data

The rigid link element is discussed in the ***STAGS** Elements Manual*. A rigid link element constrains the distance between two nodes (**N1** and **N2**) to be invariant during an analysis. The displacements of node **N2** are dependent on the displacements and rotations of node **N1** through a rigid-link constraint equation, which is enforced *via* Lagrange multipliers.

The potential energy Π for a rigid link element is given by

$$\Pi = \phi\alpha^T(\boldsymbol{x}_1 + \boldsymbol{r} - \boldsymbol{x}_2)$$

where α is a vector of three Lagrange multipliers, $\boldsymbol{x}_1$ and $\boldsymbol{x}_2$ are the current global positions of nodes **N1** and **N2**, respectively, and $\boldsymbol{r}$ is the directed position of **N2** with respect to **N1**. The magnitude of $\boldsymbol{r}$ is the original distance between nodes **N1** and **N2**. The user-specified element scale factor ϕ is employed to make the magnitude of the stiffness contributions of the rigid link element comparable in size to those of other elements in the configuration—this value is typically on the order of the elastic modulus of the material.

Note that the rotations on **N2** are unaffected unless the reference node **N3** is nonzero, in which case G-2 records are automatically generated to constrain the rotations on **N1** to be the same as on **N2**; separate G-2 records can always be generated to constrain the rotational freedoms as the user may desire.

SCALE

SCALE	element scale factor

```
if     ( the user wants to add another set of E120 elements )  then
        go to T-120
elseif ( the user wants to add a set of E110 elements )  then
        go to T-110
elseif ( the user wants to add a set of E121 elements )  then
        go to T-121
elseif ( the user wants to add a set of E130 elements )  then
        go to T-130
else
        return to T-100
endif
```

T-121 Additional E121 Elements

The soft link element, which is described fully in the ***STAGS** Elements Manual*, uses Lagrange multipliers to constrain the three nodes that are associated with it to be colinear.

T-121 is the first record of the two-record T-121/T-121a Ecom protocol counterpart of the T-1/T-1b record set that also defines one or more **E121** soft link elements. With this record (and T-121a), the user can specify one or more additional soft link elements to be included in the current element unit. The *looping* capability provided here *via* **NX**, **INC1**, **INC2** and **INC3** can be used effectively in many situations.

N1 N2 N3 KELT NX INC1 INC2 INC3 USERELT INC4

N1 active soft-link node # 1
N2 active soft-link node # 2
N3 active soft-link node # 3

KELT must = 121

NX number of soft link elements to be specified; **STAGS** sets **NX** = 1 if it is nonpositive or omitted

INC1 incrementation variable for **N1**
INC2 incrementation variable for **N2**
INC3 incrementation variable for **N3**

USERELT user-specified element number (only used if **IUWLE**=1 on H-1)

INC4 incrementation variable for **USERELT**

✦ *go to* T-121a

T-121a E121 Element Data

The basic scale factor for the Lagrange multipliers generated by the soft link element(s) defined here is specified on this record.

SCALE

SCALE basic Lagrange multiplier scale factor

```
if     ( the user wants to add another set of E121 elements )  then
          go to T-121
elseif ( the user wants to add a set of E110 elements )  then
          go to T-110
elseif ( the user wants to add a set of E120 elements )  then
          go to T-120
elseif ( the user wants to add a set of E130 elements )  then
          go to T-130
else
          return to T-100
endif
```

T-130 Additional E130 Elements

The generalized fastener element is described fully in the ***STAGS** Elements Manual*.

T-130 is the first record of the two-record T-130/T-130a Ecom protocol counterpart of the T-1/ T-1c record set that also defines one or more **E130** generalized fastener elements. With this record (and T-130a), the user can specify one or more additional generalized fastener elements to be included in the current element unit. The *looping* capability provided here *via* **NX**, **INC1**, **INC2** and **INC3** can be used effectively in many situations.

N1 N2 N3 KELT NX INC1 INC2 INC3 USERELT INC4

N1 active soft-link node # 1

N2 active soft-link node # 2

N3 active soft-link node # 3

KELT must = 130

NX number of soft link elements to be specified; **STAGS** sets **NX** = 1 if it is nonpositive or omitted

INC1 incrementation variable for **N1**

INC2 incrementation variable for **N2**

INC3 incrementation variable for **N3**

USERELT user-specified element number (only used if **IUWLE**=1 on H-1)

INC4 incrementation variable for **USERELT**

go to T-130a

T-130a E130 Element Data

The T-130a record identifies all of the Mount tables and breakage codes that are to be used for *all* of the **E130** mount element(s) that are defined on the current T-130 record.

IMNT1 IMNT2 IMNT3 IMNT4 IMNT5 IMNT6 PLAS1 PLAS2 PLAS3 PLAS4 PLAS5 PLAS6

IMNT1 Mount Table identifier (see I–4a) applied to the relative local x translation

IMNT2 Mount Table identifier (see I–4a) applied to the relative local y translation

IMNT3 Mount Table identifier (see I–4a) applied to the relative local z translation

IMNT4 Mount Table identifier (see I–4a) applied to the relative local θ_x rotation

IMNT5 Mount Table identifier (see I–4a) applied to the relative local θ_y rotation

IMNT6 Mount Table identifier (see I–4a) applied to the relative local θ_z rotation

PLAS1 breakage code for **IMNT1**: see discussion, below, for significance

PLAS2 breakage code for **IMNT2**: see discussion, below, for significance

PLAS3 breakage code for **IMNT3**: see discussion, below, for significance

PLAS4 breakage code for **IMNT4**: see discussion, below, for significance

PLAS5 breakage code for **IMNT5**: see discussion, below, for significance

PLAS6 breakage code for **IMNT6**: see discussion, below, for significance

The six breakage codes specified here control generalized fastener breakage modes for the associated mount identifiers. Each breakage code may have one of the following five values:

PLASj = 1 ⇒ fastener **j** behaves elastically; its failure does *not* cause other fasteners to fail
PLASj = 2 ⇒ fastener **j** behaves elastically; its failure causes *all* of the fasteners to fail
PLASj = 3 ⇒ fastener **j** behaves elastically, and is unbreakable, throughout the analysis
PLASj = 4 ⇒ fastener **j** behaves plastically; its failure does *not* cause other fasteners to fail
PLASj = 5 ⇒ fastener **j** behaves plastically; its failure causes *all* of the fasteners to fail

```
if     ( the user wants to add another set of E130 elements )  then
         go to T-130
elseif ( the user wants to add a set of E110 elements )  then
         go to T-110
elseif ( the user wants to add a set of E120 elements )  then
         go to T-120
elseif ( the user wants to add a set of E121 elements )  then
         go to T-121
else
         return to T-100
endif
```

9.2 Definition of “Beam” Elements *via* the Ecom Protocol

There are two standard “beam” elements in the current version of **STAGS**.

The standard 2-node **E210** element is a multi-sectional straight beam that was implemented in the earliest versions of **STAGS** several decades ago using traditional element-implementation methodologies. One or more **E210** elements (or additional **E210** elements) can be defined with the T-210 record set—as described on the following two pages. For more information about the **E210** element, please see “E210 Beam element” on page 14-13.

The standard 3-node **E250** element is a special-purpose function (that is disguised as a “beam element”) that can be used (in groups) to enforce planar boundary conditions. This “element” was implemented in **STAGS** several lustra ago using traditional methodologies. One or more **E250** elements (or additional **E250** elements) can be defined with the T-250 record set—as described later in this section. For more information about the **E250** element, see the ***STAGS*** *Elements Manual*.

There is one user-developed “beam” element in the current version of **STAGS**.

The 3-node **E928** curved beam element was originally implemented as a User-Defined **STAGS** element using the **STAGS UEL** methodologies and standards that are described in Section 9.8 of this chapter and in Chapter 13 of this document. In 2008, this **E928** element was integrated into the current version of **STAGS** as a “built-in” **UEL** that can be used by anyone who needs a curved beam element that is compatible with **STAGS**’ standard 9-node **E480** quad element. One or more **E928** elements can be defined with the T-900 record and the T-928 record set that are also described in Section 9.8 of this chapter. For more information about the **E928** element, please see ~~Chapter 14 in this document, the~~ ~~***STAGS*** *Elements Manual*, and the~~ ~~***STAGS*** *Test Cases Manual*~~.

T-210 Additional E210 Elements

T-210 is the first record of the two-record T-210/T-210a Ecom protocol counterpart of the T-2/ T-2a record set that also defines one or more **E210** beam elements. With this record (and T-210a), the user can specify one or more additional generalized fastener elements to be included in the current element unit. The *looping* capability provided here, *via* **NX** and the four incrementation parameters on T-210a, can be used effectively in many situations.

N1 N2 N3 KELT ICROSS XSI ECY ECZ ILIN IPLAS NX USERELT

N1 active beam node # 1

N2 active beam node # 2

N3 node # 3 — a reference node used to generate the element coordinate system

KELT must = 210

ICROSS cross-section identifier, in the Cross Section Table: see the T-2 description, in Chapter 8, for important information about **ICROSS**

⌘ **XSI** angle ξ, in degrees, between the element normal z' and the cross section $\bar{z}$. ξ is a right-handed rotation about $\bar{x}$, the longitudinal axis of the beam, which is parallel to x'.

⌘ **ECY** eccentricity in the y' direction. **ECY** is the y' coordinate of the (y', z') pair which positions the origin of the $(\bar{y}, \bar{z})$ system.

⌘ **ECZ** eccentricity in the z' direction. **ECZ** is the z' coordinate of the (y', z') pair which positions the origin of the $(\bar{y}, \bar{z})$ system.

⌘ **ILIN** geometric nonlinearity flag

0 – nonlinear strain-displacement relations
1 – linear strain-displacement relations

⌘ **IPLAS** material nonlinearity flag (see M-5)

0 – linear elastic constitutive relations
1 – plasticity included
2 – centroidal plasticity

NX number of beam elements to be generated *via* this T-210 record; set to unity by **STAGS** if nonpositive or omitted

USERELT user-specified element number, used only if **IUWLE** = 1 on H-1

✦ if (**NX** > 1) then *go to* T-210a
else *follow the instructions at the end of* T-210a

T-210a E210 Incrementations

Four incrementation variables are specified here for use with the T-210 record looping functions.

INC1 INC2 INC3 INC4

INC1 incrementation variable for use with the **N1** (node 1) variable on T-210

INC2 incrementation variable for use with the **N2** (node 2) variable on T-210

INC3 incrementation variable for use with the **N3** (node 3) variable on T-210

INC4 incrementation variable for use with **USERELT**

Any of these incrementation variables can be negative, zero or positive.

```
if     ( the user wants to add another set of E210 elements )  then
          go to T-210
elseif ( the user wants to add a set of E250 elements )  then
          go to T-250
else
          return to T-100
endif
```

T-250 Additional E250 Elements

T-250 is the first record of the two-record T-250/T-250a Ecom protocol extension of the T-2 record that also defines an **E250** planar boundary condition element. With this record (and T-250a), the user can specify one or more additional planar boundary condition elements to be included in the current element unit. The *looping* capability provided here, *via* **NX** and the four incrementation parameters on T-250a, can be used effectively in many situations.

A moving plane boundary—which is like a symmetry boundary, except that the symmetry plane itself is allowed to move as a rigid body—is defined in a **STAGS** element unit with a set of T-250 planar boundary condition elements that are modeled with “beams” that are strung along a user-defined space curve forming the boundary. It is the user’s responsibility to make sure that curve initially lies in a plane. If the constraint is violated initially, **STAGS** will complain. The reference node **N3** must also lie in the boundary plane.

N1 N2 N3 KELT ICROSS XSI ECY ECZ ILIN IPLAS NX USERELT

N1 active beam node # 1

N2 active beam node # 2

N3 node # 3 — reference node used to generate the element coordinate system; **N3** must lie in the boundary plane

KELT must = 250

ICROSS must = -1

XSI ignored

ECY scale factor used for the numerical conditioning of Lagrange constraints introduced by the multipoint constraint; should be of the same order of magnitude as entries in the stiffness matrix; a good guess is the modulus of elasticity of the material

ECZ ignored

ILIN ignored

IPLAS ignored

NX number of planar boundary condition elements to be generated *via* this T-250 record; set to unity by **STAGS** if nonpositive or omitted

USERELT user-specified element number, used only if **IUWLE** = 1 on H-1

if (**NX** > 1) then *go to* T-250a
else *follow the instructions at the end of* T-250a

T-250a E250 Incrementations

Four incrementation variables are specified here for use with the T-250 record looping functions.

INC1 INC2 INC3 INC4

INC1 incrementation variable for use with the **N1** (node 1) variable on T-250

INC2 incrementation variable for use with the **N2** (node 2) variable on T-250

INC3 incrementation variable for use with the **N3** (node 3) variable on T-250

INC4 incrementation variable for use with **USERELT**

Any of these incrementation variables can be negative, zero or positive.

```
if     ( the user wants to add another set of E250 elements )  then
          go to T-250
elseif ( the user wants to add a set of E210 elements )  then
          go to T-210
else
          return to T-100
endif
```

9.3 Definition of Triangular Elements *via* the Ecom Protocol

There are two triangular thin shell elements available in the current version of **STAGS**.

The 3-node **E320** element is a traditional triangular thin shell element. One or more **E320** elements (or additional **E320** elements) can be defined with the T-320 record set. For more information about the **E320** element, see “E320 Triangular shell element” on page 14-20.

The 3-node **E330** element is **STAGS**’ implementation of the MIN3 triangle element in the **COMET** program. One or more **E330** elements (or additional **E330** elements) can be defined with the T-330 record set. For more information about the **E330** element, see “E330 Triangular shell element” on page 14-21.

T-320 Additional E320 Elements

T-320 is the first record of the multi-record Ecom protocol extension of the T-3/T-3a record set that also defines an **E320** triangular shell element. With this record (and T-320a, T-320b and/or T-320c companion records, as required), the user can specify one or more additional **E320** triangular shell elements to be included in the current element unit. The *looping* capabilities provided here, *via* **NX**, **NY**, and the incrementation parameters on T-320a and T-320b, can be used effectively in many situations.

N1 N2 N3 KELT IWALL ZETA ECZ ILIN IPLAS IANG USERELT NX NY

N1 node 1

N2 node 2

N3 node 3

KELT must = 320

IWALL wall fabrication identifier:

0 – shell wall properties are given in user-written subroutine WALL

>0 – wall fabrication number, in the Wall Fabrication Table (K-1)

When **IWALL** = 0, data below indicated by ⌘ are defined in WALL and are initialized to zero before WALL is called, superseding any values input here

⌘ **ZETA** angle ζ between the wall-reference coordinate x_w and the fabrication coordinate $\bar{x}$; ζ is a right-handed rotation about $\bar{z}$. see Figure 8.2 on page 8-19.

⌘ **ECZ** eccentricity in z' direction. **ECZ** is the z' coordinate of the shell wall middle surface; see Figure 6.2 on page 6-28. In element units, (x', y', z') are used in place of (X', Y', Z'), which do not exist in an element unit. See "Effects of Eccentricity" on page 16-6.

⌘ **ILIN** governs geometric nonlinearity

0 – nonlinear strain-displacement relations

1 – linear strain-displacement relations

⌘ **IPLAS** governs material nonlinearity

0 – elastic behavior only
1 – plasticity included, with the material law satisfied at each element integration point
2 – plasticity included, with the material law satisfied at the element centroid (centroidal plasticity)

IANG wall-reference option; see discussion on page 8-18

0 – use default strategy of projecting x_g, y_g to establish x_w
1 – input $\mathbf{r_w}$, which is projected to establish x_w; see (T-320c)

USERELT user-specified element number, used only when **IUWLE**=1 on H-1

✦

```
if       ( NX > 1 )      then   go to  T-320a
elseif   ( NY > 1 )      then   go to  T-320b
elseif   ( IANG = 1 )    then   go to  T-320c
else     follow the instructions at the end of  T-320c
```

T-320a E320 X-Direction Incrementations

Four x-direction incrementation variables are specified here for use with the T-320 record looping functions.

IX1 IX2 IX3 IX4

IX1 x-direction incrementation variable for node **N1** on T-320

IX2 x-direction incrementation variable for node **N2** on T-320

IX3 x-direction incrementation variable for node **N3** on T-320

IX4 x-direction incrementation variable for use with **USERELT**

Any of these incrementation variables can be negative, zero or positive.

```
if       ( NY > 1 )      then   go to  T-320b
elseif   ( IANG = 1 )    then   go to  T-320c
else     follow the instructions at the end of  T-320c
```

T-320b E320 Y-Direction Incrementations

Four y-direction incrementation variables are specified here for use with the T-320 record looping functions.

IY1 IY2 IY3 IY4

IY1 y-direction incrementation variable for node **N1** on T-320
IY2 y-direction incrementation variable for node **N2** on T-320
IY3 y-direction incrementation variable for node **N3** on T-320
IY4 y-direction incrementation variable for use with **USERELT**

Any of these incrementation variables can be negative, zero or positive.

if (**IANG** = 1) then *go to* T-320c
else *follow the instructions at the end of* T-320c

T-320c E320 Wall Reference Vector

RX RY RZ

RX, RY, RZ wall reference vector, $\mathbf{r_w}$, which is projected onto the element surface to determine the direction of the wall-reference coordinate x_w; $\mathbf{r_w}$ is expressed in (x_g, y_g, z_g) global coordinates.

```
if      ( the user wants to add another set of E320 elements )  then
        go to T-320
elseif ( the user wants to add a set of E330 elements )  then
        go to T-330
else
        return to T-100
endif
```

T-330 Additional E330 Elements

T-330 is the first record of the multi-record Ecom protocol extension of the T-3/T-3a record set that also defines an **E330** triangular shell element. With this record (and T-330a, T-330b and/or T-330c companion records, as required), the user can specify one or more additional **E330** shell elements to be included in the current element unit. The *looping* capabilities provided here, *via* **NX**, **NY**, and the incrementation parameters on T-330a and T-330b, can be used effectively in many situations.

N1 N2 N3 KELT IWALL ZETA ECZ ILIN IPLAS IANG USERELT NX NY

N1 node 1

N2 node 2

N3 node 3

KELT must = 330

IWALL wall fabrication identifier:

0 – shell wall properties are given in user-written subroutine WALL

>0 – wall fabrication number, in the Wall Fabrication Table (K-1)

<0 – shell fabrication identifier in the GCP Fabrications Table (I-21a)

When **IWALL** = 0, data below indicated by ⌘ are defined in subroutine WALL and are set to zero before WALL is called, superseding any values input here

⌘ **ZETA** angle ζ between the wall-reference coordinate x_w and the fabrication coordinate $\bar{x}$; ζ is a right-handed rotation about $\bar{z}$. see Figure 8.2 on page 8-19.

⌘ **ECZ** eccentricity in z' direction. **ECZ** is the z' coordinate of the shell wall middle surface; see Figure 6.2 on page 6-28. In element units, (x', y', z') are used in place of (X', Y', Z'), which do not exist in an element unit.

⌘ **ILIN** governs geometric nonlinearity

0 – nonlinear strain-displacement relations

1 – linear strain-displacement relations

⌘ **IPLAS** governs material nonlinearity

0 – elastic behavior only

1 – plasticity included, with the material law satisfied at each element integration point

2 – plasticity included, with the material law satisfied at the element centroid (centroidal plasticity)

IANG wall-reference option; see discussion on page 8-18

0 – use default strategy of projecting x_g, y_g to establish x_w

1 – input $\mathbf{r_w}$, which is projected to establish x_w; see (T-330c)

USERELT user-specified element number, used only when **IUWLE** = 1 on H-1

✦
```
if      ( NX > 1 )     then  go to  T-330a
elseif  ( NY > 1 )     then  go to  T-330b
elseif  ( IANG = 1 )   then  go to  T-330c
else    follow the instructions at the end of  T-330c
```

T-330a E330 X-Direction Incrementations

Four x-direction incrementation variables are specified here for use with the T-330 record looping functions.

IX1 IX2 IX3 IX4

IX1 x-direction incrementation variable for node **N1** on T-330

IX2 x-direction incrementation variable for node **N2** on T-330

IX3 x-direction incrementation variable for node **N3** on T-330

IX4 x-direction incrementation variable for use with **USERELT**

Any of these incrementation variables can be negative, zero or positive.

```
if       ( NY > 1 )     then   go to  T-330b
elseif   ( IANG = 1 )   then   go to  T-330c
else     follow the instructions at the end of  T-330c
```

T-330b E330 Y-Direction Incrementations

Four y-direction incrementation variables are specified here for use with the T-330 record looping functions.

IY1 IY2 IY3 IY4

IY1	y-direction incrementation variable for node **N1** on T-330
IY2	y-direction incrementation variable for node **N2** on T-330
IY3	y-direction incrementation variable for node **N3** on T-330
IY4	y-direction incrementation variable for use with **USERELT**

Any of these incrementation variables can be negative, zero or positive.

if (**IANG** = 1) then *go to* T-330c
else *follow the instructions at the end of* T-330c

T-330c E330 Wall Reference Vector

RX RY RZ

RX, RY, RZ wall reference vector, $\mathbf{r_w}$, which is projected onto the element surface to determine the direction of the wall-reference coordinate x_w; $\mathbf{r_w}$ is expressed in (x_g, y_g, z_g) global coordinates.

```
✦ if     ( the user wants to add another set of **E330** elements )  then
         go to T-330
  elseif ( the user wants to add a set of **E320** elements )  then
         go to T-320
  else
         return to T-100
  endif
```

9.4 Definition of Quad Elements *via* the Ecom Protocol

There are five “standard” quadrilateral thin shell elements available in the current version of **STAGS**. Three of these (**E410**, **E411** and **E480**) are traditional 4- and 9-node quadrilateral elements. The other two (**E510** and **E710**) are 5- and 7-node *constructions* (of two and four **E410**s, respectively) that are most appropriately used in modeling transition zones where mesh refinements are required.

The “standard” 4-node **E410** element is a traditional thin shell quadrilateral element. One or more **E410** elements (or additional **E410** elements) can be defined with the T-410 record set—as described on the pages immediately following these introductory remarks. For more information about the **E410** element, please see “E410 4–Node quadrilateral shell element” on page 14-22.

The “standard” **E411** element is a thin shell quad element that is defined by its four corner node points but which has additional (program-generated) mid-side nodes with supplementary (program-generated) degrees of freedom. One or more **E411** elements (or additional **E411** elements) can be defined with the T-411 record set—as described later in this section. For more information about the **E411** element, please see “E411 4–Node quadrilateral shell element” on page 14-23.

The “standard” 9-node **E480** element is a traditional higher-order thin shell quadrilateral element. One or more **E480** elements (or additional **E480** elements) can be defined with the T-480 record set—as described later in this section. For more information about the **E480** element, please see “E480 9–Node quadrilateral shell element” on page 14-24.

The “standard” 5-node **E510** “quadrilateral” element has a (user-defined) mid-side node on one of its four edges. It is typically used to connect two 4-node quadrilateral shell elements in a finely-meshed region to a single 4-node quad shell element in another (more-coarsely-meshed) region. One or more **E510** elements (or additional **E510** elements) can be defined with the T-510 record set—as described later in this section.

The “standard” 7-node **E510** “quadrilateral” element has one (user-defined) mid-side node on each of two adjacent edges and an extra (user-defined) internal node. It is typically used to connect 4-node quads in a finely-meshed region to 4-node quads in two or three other (more-coarsely-meshed) regions—at a corner where all of these regions come together. One or more **E710** elements (or additional **E710** elements) can be defined with the T-710 record set—as described later in this section.

There is one user-developed quadrilateral element in the current version of **STAGS**.

The 4-node **E940** MIN4 quad element was originally implemented as a User-Defined **STAGS** element using the **STAGS UEL** methodologies and standards that are described in Section 9.8 of this chapter and in Chapter 13 of this document. In 2008, this **E940** element was integrated into the current version of **STAGS** as a "built-in" **UEL** that can be used by anyone who needs or wants to use that element. One or more **E940** elements can be defined with the T-900 record and the T-940 record set that are also described in Section 9.8 of this chapter. For more information about the **E940** element, please see ~~Chapter 14 in this document, the ***STAGS** Elements Manual*, and the ***STAGS** Test Cases Manual*~~.

T-410 Additional E410 Elements

T-410 is the first record of the multi-record Ecom protocol extension of the T-4/T-4b record set that also defines an **E410** 4-node quadrilateral shell element. With this record (and T-410a, T-410b and/or T-410c companion records, as required), the user can specify one or more additional **E410** shell elements to be included in the current element unit. The *looping* capabilities provided here, *via* **NX**, **NY**, and the incrementation parameters on T-410a and T-410b, can be used effectively in many situations.

A quadrilateral shell element is defined by specifying the four corner nodes in counterclockwise order as viewed from above. In this context, “viewed from above” means looking down onto the *top surface* of the element. As shown in Figure 6.2 on page 6-28, the top surface corresponds to $Z' = Z'_{max}$ ($z' = z'_{max}$ in an element unit). The four nodes that are input on T-410 determine the (x', y', z') element coordinate system.

> ☞ The z' axis defines the direction in which pressure acts—a positive pressure value acts in the positive z' direction, and a negative pressure value acts in the negative z' direction.

In shell units, the wall-fabrication orientation is determined by **ZETA** & **ECZ** (M-5). Figure 6.2 shows how **ECZ** defines the eccentricity and how **ZETA** rotates the $(\bar{x}, \bar{y})$ fabrication coordinates to establish their directions relative to the (x_w, y_w) wall-reference coordinates. Implicit in Figure 6.2 is the shell-unit convention that the (x_w, y_w) wall-reference coordinates are defined to be coincident with the (X', Y') shell coordinates. In element units, shell coordinate systems do not exist. Instead, the user is given two options for establishing wall-reference coordinates.

In the default option, **STAGS** determines whether the x_g or y_g axis lies closer to the element plane. If x_g lies closer, it is projected onto the element surface to establish the x_w axis. If y_g lies closer, it is projected to establish the y_w axis. This means that when x_g and y_g both lie in the plane of the element, the result will be the same regardless of which is chosen to be projected.

The other option is to input a wall reference vector, $\mathbf{r_w}$, that determines the direction of x_w. Although the user will in most cases try to make sure that this vector is tangent to the surface he has in mind, the code makes no such assumption. **STAGS** will project this vector onto the element surface to establish the x_w axis.

After the x_w axis is established, using either of the two options, the wall orientation is then determined just as it is for shell units. Compare Figure 8.2 with Figure 6.2. **ZETA** has the same meaning in both instances. The only difference is that for shell units, the (x_w, y_w) wall-reference coordinates are uniquely defined by the (X', Y') shell coordinates, and for element units, one of two user-selected options (**IANG**) is used to establish the wall-reference system.

This process often allows the user to specify all the wall angles with very simple input. For example, some standard geometries such as cylinders or cones have an axis of revolution (the generator) whose projection onto the element surface lies along the same direction, independent of the element location. If user input specifies the generator as $\mathbf{r_w}$, or if the default is used (for cone angles less than $45°$), a unique angle **ZETA** gives the proper offset for all elements in the geometry. Figure 8.3 on page 8-20 shows an example where the generator of a cone is specified as $\mathbf{r_w}$. It is usually straightforward to specify the global coordinates of a vector parallel to a shell-of-revolution generator. The user should be careful for more complex geometries. It should also be noted that the user need not know the (x', y', z') shell element coordinate system.

For all quadrilaterals, the plane of the element is determined by the procedure outlined in Section 14.2 “Algorithm for Determining the Element Frame”. The result of this procedure is an element reference plane that is the “best fit” to the four corner nodes. (x_w, y_w) wall-reference coordinates, and hence $(\bar{x}, \bar{y})$ fabrication coordinates and (ϕ_1, ϕ_2) material coordinates, all lie in this “average” plane.

☞ Note that the fabrication coordinate system is oriented by rotating the wall-reference system through the angle **ZETA**. The material coordinate system for each layer in a laminate is then determined by rotating the fabrication system through a unique angle **ZETL** (K-2) (or **ANGSHL** (I-21d) for GCP input) for the corresponding layer.

N1 N2 N3 N4 KELT IWALL ZETA ECZ ILIN IPLAS INTEG IPENL IANG USERELT NX NY

N1 node 1

N2 node 2

N3 node 3

N4 node 4

KELT must = 410

IWALL wall fabrication identifier:

0 – shell wall properties are given in user-written subroutine WALL

>0 – shell wall fabrication number in the Wall Fabrication Table (K-1)

<0 – shell wall fabrication identifier in the GCP Fabrications Table (I-21a)

When **IWALL** $= 0$, data below indicated by ⌘ are defined in WALL; they are automatically initialized to zero before WALL is called, thereby superseding any nonzero values input here.

⌘ **ZETA** angle ζ between the wall-reference coordinate x_w and the fabrication coordinate $\bar{x}$; ζ is a right-handed rotation about $\bar{z}$; see Figure 8.2 on page 8-19

⌘ **ECZ** eccentricity in z' direction. **ECZ** is the z' coordinate of the shell wall middle surface; refer to Figure 6.2 on page 6-28; in element units, (x', y', z') are used in place of (X', Y', Z'), which do not exist in an element unit; see "Effects of Eccentricity" on page 16-6

⌘ **ILIN** governs geometric nonlinearity

0 – nonlinear strain-displacement relations

1 – linear strain-displacement relations

Note that with **ILIN** = 1, bifurcation buckling is suppressed in the shell unit

⌘ **IPLAS** governs material nonlinearity

0 – elastic behavior only

1 – plasticity included, with the material law satisfied at each element integration point

2 – plasticity included, with the material law satisfied at the element centroid (centroidal plasticity)

INTEG integration type (see N-1)

0 – standard integration, or 2×2 Gauss points

1 – modified 5-point integration, previously referred to as full integration

IPENL penalty option (see N-1)

0 – no penalty function on fourth-order terms

1 – penalty function included in elements

IANG wall-reference option; see discussion on page 8-18

0 – use default strategy of projecting x_g, y_g to establish x_w

1 – input $\mathbf{r_w}$, which is projected to establish x_w; see (T-410c)

USERELT user-specified element number, used only when **IUWLE** = 1 on H-1

✦ if (**NX** > 0) then *go to* T-410a
elseif (**NY** > 0) then *go to* T-410b
elseif (**IANG** = 1) then *go to* T-410c
else *follow the instructions at the end of* T-410c

T-410a E410 X-Direction Incrementations

Five x-direction incrementation variables are specified here for use with the T-410 record looping functions (if and only if **NX** > 0 on T-410).

IX1 IX2 IX3 IX4 IX5

IX1 x-direction incrementation variable for node **N1** on T-410
IX2 x-direction incrementation variable for node **N2** on T-410
IX3 x-direction incrementation variable for node **N3** on T-410
IX4 x-direction incrementation variable for node **N4** on T-410
IX5 x-direction incrementation variable for use with **USERELT**

Any of these incrementation variables can be negative, zero or positive.

```
if       ( NY > 1 )      then   go to T-410b
elseif   ( IANG = 1 )    then   go to T-410c
else     follow the instructions at the end of  T-410c
```

T-410b E410 Y-Direction Incrementations

Five y-direction incrementation variables are specified here for use with the T-410 record looping functions (if and only if **NY** > 0 on T-410).

IY1 IY2 IY3 IY4 IY5

IY1 y-direction incrementation variable for node **N1** on T-410

IY2 y-direction incrementation variable for node **N2** on T-410

IY3 y-direction incrementation variable for node **N3** on T-410

IY4 y-direction incrementation variable for node **N4** on T-410

IY5 y-direction incrementation variable for use with **USERELT**

Any of these incrementation variables can be negative, zero or positive.

if (**IANG** = 1) then *go to* T-410c
else *follow the instructions at the end of* T-410c

T-410c E410 Wall Reference Vector

RX RY RZ

RX, RY, RZ wall reference vector, $\mathbf{r_w}$, which is projected onto the element surface to determine the direction of the wall-reference coordinate x_w; $\mathbf{r_w}$ is expressed in (x_g, y_g, z_g) global coordinates.

```
if     ( the user wants to add another set of E410 elements )  then
       go to T-410
elseif ( the user wants to add a set of E411 elements )  then
       go to T-411
elseif ( the user wants to add a set of E480 elements )  then
       go to T-480
elseif ( the user wants to add a set of E510 elements )  then
       go to T-510
elseif ( the user wants to add a set of E710 elements )  then
       go to T-710
else
       return to T-100
endif
```

T-411 Additional E411 Elements

T-411 is the first record of the multi-record Ecom protocol extension of the T-4/T-4b/T-4c record set that also defines an **E411** quadrilateral shell element. With this record (and T-411a, T-411b and/or T-411c companion records, as required), the user can specify one or more additional **E411** shell elements to be included in the current element unit. The *looping* capabilities provided here, *via* **NX**, **NY**, and the incrementation parameters on T-411a and T-411b, can be used effectively in many situations.

For definition purposes, the **E411** element is considered to be a 4-node quadrilateral, similar to the **E410** element. **STAGS** adds midside deviational nodes to the **E411** element automatically, without user input.

The methods that **STAGS** uses for determining the element coordinate system for this and other quadrilateral elements are described earlier in this document, in connection with the T-4 and T-410 element-definition records, and will not be repeated here.

N1 N2 N3 N4 KELT IWALL ZETA ECZ ILIN IPLAS INTEG IPENL IANG USERELT NX NY

N1 node 1
N2 node 2
N3 node 3
N4 node 4

KELT must = 411

IWALL wall fabrication identifier:

0 – shell wall properties are given in user-written subroutine WALL
>0 – shell wall fabrication number in the Wall Fabrication Table (K-1)

When **IWALL** = 0, data below indicated by ⌘ are defined in WALL; they are automatically initialized to zero before WALL is called, thereby superseding any nonzero values input here.

⌘ **ZETA** angle ζ between the wall-reference coordinate x_w and the fabrication coordinate $\bar{x}$; ζ is a right-handed rotation about $\bar{z}$; see Figure 8.2 on page 8-19

⌘ **ECZ** eccentricity in z' direction; **ECZ** is the z' coordinate of the shell wall middle surface; refer to Figure 6.2 on page 6-28; in element units, (x', y', z') are used in place of (X', Y', Z'), which do not exist in an element unit.

⌘ **ILIN** governs geometric nonlinearity

0 – nonlinear strain-displacement relations
1 – linear strain-displacement relations

Note that with **ILIN** = 1, bifurcation buckling is suppressed in the shell unit

⌘ **IPLAS** governs material nonlinearity

- 0 – elastic behavior only
- 1 – plasticity included, with the material law satisfied at each element integration point
- 2 – plasticity included, with the material law satisfied at the element centroid (centroidal plasticity)

INTEG integration type (see N-1)

- 0 – standard integration, or 2×2 Gauss points
- 1 – modified 5-point integration, previously referred to as full integration

IPENL penalty option (see N-1)

- 0 – no penalty function on fourth-order terms
- 1 – penalty function included in elements

IANG wall-reference option; see discussion on page 8-18

- 0 – use default strategy of projecting x_g, y_g to establish x_w
- 1 – input $\mathbf{r_w}$, which is projected to establish x_w; see (T-411c)

USERELT user-specified element number, used only when **IUWLE** = 1 on H-1

```
✦  if      ( NX > 0 )      then  go to  T-411a
   elseif  ( NY > 0 )      then  go to  T-411b
   elseif  ( IANG = 1 )    then  go to  T-411c
   else    follow the instructions at the end of  T-411c
```

T-411a E411 X-Direction Incrementations

Five x-direction incrementation variables are specified here for use with the T-411 record looping functions (if and only if **NX** > 0 on T-411).

IX1 IX2 IX3 IX4 IX5

IX1 x-direction incrementation variable for node **N1** on T-411

IX2 x-direction incrementation variable for node **N2** on T-411

IX3 x-direction incrementation variable for node **N3** on T-411

IX4 x-direction incrementation variable for node **N4** on T-411

IX5 x-direction incrementation variable for use with **USERELT**

Any of these incrementation variables can be negative, zero or positive.

```
if       ( NY > 1 )     then  go to T-411b
elseif   ( IANG = 1 )   then  go to T-411c
else     follow the instructions at the end of  T-411c
```

T-411b E411 Y-Direction Incrementations

Five y-direction incrementation variables are specified here for use with the T-411 record looping functions (if and only if **NY** > 0 on T-411).

IY1 IY2 IY3 IY4 IY5

IY1 y-direction incrementation variable for node **N1** on T-411
IY2 y-direction incrementation variable for node **N2** on T-411
IY3 y-direction incrementation variable for node **N3** on T-411
IY4 y-direction incrementation variable for node **N4** on T-411
IY5 y-direction incrementation variable for use with **USERELT**

Any of these incrementation variables can be negative, zero or positive.

if (**IANG** = 1) then *go to* T-411c
else *follow the instructions at the end of* T-411c

T-411c E411 Wall Reference Vector

RX RY RZ

RX, RY, RZ wall reference vector, $\mathbf{r_w}$, which is projected onto the element surface to determine the direction of the wall-reference coordinate x_w. $\mathbf{r_w}$ is expressed in (x_g, y_g, z_g) global coordinates.

```
if     ( the user wants to add another set of **E411** elements )  then
       *go to* T-411
elseif ( the user wants to add a set of **E410** elements )  then
       *go to* T-410
elseif ( the user wants to add a set of **E480** elements )  then
       *go to* T-480
elseif ( the user wants to add a set of **E510** elements )  then
       *go to* T-510
elseif ( the user wants to add a set of **E710** elements )  then
       *go to* T-710
else
       *return to* T-100
endif
```

T-480 Additional E480 Elements

T-480 is the first record of the multi-record Ecom protocol extension of the T-4/T-4b/T-4c record set that also defines an **E480** 9-node quadrilateral shell element. With this record and T-480a (and T-480b, T-480c and/or T-480d companion records, as required), the user can specify one or more additional **E480** 9-node quadrilateral elements to be included in the current element unit. The *looping* capabilities provided here, *via* **NX**, **NY** and the incrementation parameters on T-480b and T-480c, can be used effectively in many situations.

The methods that **STAGS** uses for determining the element coordinate system for this and other quadrilateral elements are described earlier in this document, in connection with the T-4 and T-410 element-definition records, and will not be repeated here.

N1 N2 N3 N4 KELT IWALL ZETA ECZ ILIN IPLAS INTEG IPENL IANG USERELT NX NY

N1 node 1

N2 node 2

N3 node 3

N4 node 4

KELT must = 480

IWALL wall fabrication identifier:

0 – shell wall properties are given in user-written subroutine WALL
>0 – shell wall fabrication number in the Wall Fabrication Table (K-1)
<0 – shell wall fabrication identifier in the GCP Fabrications Table (I-21a)

When **IWALL** = 0, data below indicated by ⌘ are defined in WALL; they are automatically initialized to zero before WALL is called, thereby superseding any nonzero values input here.

⌘ **ZETA** angle ζ between the wall-reference coordinate x_w and the fabrication coordinate $\bar{x}$; ζ is a right-handed rotation about $\bar{z}$.

⌘ **ECZ** eccentricity in z' direction. **ECZ** is the z' coordinate of the shell wall middle surface; in element units, (x', y', z') are used in place of (X', Y', Z'), which do not exist in an element unit.

⌘ **ILIN** governs geometric nonlinearity

0 – nonlinear strain-displacement relations
1 – linear strain-displacement relations

Note that with **ILIN** = 1, bifurcation buckling is suppressed in the shell unit

⌘ **IPLAS** governs material nonlinearity

0 – elastic behavior only

1 – plasticity included, with the material law satisfied at each element integration point

2 – plasticity included, with the material law satisfied at the element centroid (centroidal plasticity)

INTEG integration type: not used for this element; set **INTEG** = 0

IPENL penalty option: not used for this element; set **IPENL** = 0

IANG wall-reference option; see discussion on page 8-18

0 – use default strategy of projecting x_g, y_g to establish x_w

1 – input $\mathbf{r_w}$, which is projected to establish x_w; see (T-480d)

USERELT user-specified element number, used only when **IUWLE** = 1 on H-1

go to T-480a

T-480a E480 Extra Nodes Specification

This record is required to specify the fifth, sixth, seventh, eighth and ninth nodes of the (first) **E480** element that is defined *via* the current T-480 record.

N5 N6 N7 N8 N9

N5	node 5
N6	node 6
N7	node 7
N8	node 8
N9	node 9

```
✦   if       ( NX > 0 )      then  go to  T-480b
    elseif   ( NY > 0 )      then  go to  T-480c
    elseif   ( IANG = 1 )    then  go to  T-480d
    else     follow the instructions at the end of  T-480d
```

T-480b E480 X-Direction Incrementations

Ten x-direction incrementation variables are specified here for use with the T-480 record looping functions (if and only if **NX** > 0 on T-480).

IX1 IX2 IX3 IX4 IX5 IX6 IX7 IX8 IX9 IXU

IX1 x-direction incrementation variable for node **N1** on T-480
IX2 x-direction incrementation variable for node **N2** on T-480
IX3 x-direction incrementation variable for node **N3** on T-480
IX4 x-direction incrementation variable for node **N4** on T-480
IX5 x-direction incrementation variable for node **N5** on T-480a
IX6 x-direction incrementation variable for node **N6** on T-480a
IX7 x-direction incrementation variable for node **N7** on T-480a
IX8 x-direction incrementation variable for node **N8** on T-480a
IX9 x-direction incrementation variable for node **N9** on T-480a
IXU x-direction incrementation variable for use with **USERELT**

Any of these incrementation variables can be negative, zero or positive.

if (**NY** > 1) then *go to* T-480c
elseif (**IANG** = 1) then *go to* T-480d
else *follow the instructions at the end of* T-480d

T-480c E480 Y-Direction Incrementations

Ten y-direction incrementation variables are specified here for use with the T-480 record looping functions (if and only if **NY** > 0 on T-480).

IY1 IY2 IY3 IY4 IY5 IY6 IY7 IY8 IX9 IYU

IY1 x-direction incrementation variable for node **N1** on T-480

IY2 x-direction incrementation variable for node **N2** on T-480

IY3 x-direction incrementation variable for node **N3** on T-480

IY4 x-direction incrementation variable for node **N4** on T-480

IY5 x-direction incrementation variable for node **N5** on T-480a

IY6 x-direction incrementation variable for node **N6** on T-480a

IY7 x-direction incrementation variable for node **N7** on T-480a

IY8 x-direction incrementation variable for node **N8** on T-480a

IY9 x-direction incrementation variable for node **N9** on T-480a

IYU x-direction incrementation variable for use with **USERELT**

Any of these incrementation variables can be negative, zero or positive.

✦ if (**IANG** = 1) then *go to* T-480d
else *follow the instructions at the end of* T-411d

T-480d E480 Wall Reference Vector

RX RY RZ

RX, RY, RZ wall reference vector, $\mathbf{r_w}$, which is projected onto the element surface to determine the direction of the wall-reference coordinate x_w; $\mathbf{r_w}$ is expressed in (x_g, y_g, z_g) global coordinates.

```
if      ( the user wants to add another set of E480 elements )  then
        go to T-480
elseif ( the user wants to add a set of E410 elements )  then
        go to T-410
elseif ( the user wants to add a set of E411 elements )  then
        go to T-411
elseif ( the user wants to add a set of E510 elements )  then
        go to T-510
elseif ( the user wants to add a set of E710 elements )  then
        go to T-710
else
        return to T-100
endif
```

T-510 Additional E510 Elements

T-510 is the first record of the multi-record Ecom protocol extension of the T-4/T-4b/T-4c record set that also defines an **E510** 5-node quadrilateral mesh transition element. With this record and T-510a (and with T-510b and/or T-510c companion records, as required), the user can specify one or more additional **E510** 5-node quadrilateral mesh transition elements to be included in the current element unit. The *looping* capabilities provided here, *via* **NX** and the six incrementation parameters on T-510b, can be used effectively in many situations.

The methods that **STAGS** uses for determining the element coordinate system for this and other quadrilateral elements are described earlier in this document, in connection with the T-4 and T-410 element-definition records, and will not be repeated here.

N1 N2 N3 N4 KELT IWALL ZETA ECZ ILIN IPLAS INTEG IPENL IANG USERELT NX

N1 node 1

N2 node 2

N3 node 3

N4 node 4

KELT must = 510

IWALL wall fabrication identifier:

0 – shell wall properties are given in user-written subroutine WALL
>0 – shell wall fabrication number in the Wall Fabrication Table (K-1)
<0 – shell wall fabrication identifier in the GCP Fabrications Table (I-21a)

When **IWALL** = 0, data below indicated by ⌘ are defined in WALL; they are automatically initialized to zero before WALL is called, thereby superseding any nonzero values input here.

⌘ **ZETA** angle ζ between the wall-reference coordinate x_w and the fabrication coordinate $\bar{x}$; ζ is a right-handed rotation about $\bar{z}$.

⌘ **ECZ** eccentricity in z' direction. **ECZ** is the z' coordinate of the shell wall middle surface; in element units, (x', y', z') are used in place of (X', Y', Z'), which do not exist in an element unit.

⌘ **ILIN** governs geometric nonlinearity

0 – nonlinear strain-displacement relations
1 – linear strain-displacement relations

Note that with **ILIN** = 1, bifurcation buckling is suppressed in the shell unit

IPLAS governs material nonlinearity
0 – elastic behavior only
1 – plasticity included, with the material law satisfied at each element integration point
2 – plasticity included, with the material law satisfied at the element centroid (centroidal plasticity)

INTEG integration type (see N-1)
0 – standard integration, or 2×2 Gauss points
1 – modified 5-point integration, previously referred to as full integration

IPENL penalty option (see N-1)
0 – no penalty function on fourth-order terms
1 – penalty function included in elements

IANG wall-reference option; see discussion on page 8-18
0 – use default strategy of projecting x_g, y_g to establish x_w
1 – input $\mathbf{r_w}$, which is projected to establish x_w; see (T-510c)

USERELT user-specified element number, used only when **IUWLE** = 1 on H-1

go to T-510a

T-510a E510 Extra Node Specification

This record is required to specify the fifth node of the first **E510** element that is defined *via* the current T-510 record (which defines **NX** **E510** elements if **NX** > 0).

N5

N5 node 5

```
if      ( NX > 0 )     then  go to T-510b
elseif  ( IANG = 1 )   then  go to T-510c
else    follow the instructions at the end of T-510c
```

T-510b E510 Incrementations

Six incrementation variables are specified here for use with the T-510 record looping functions (if and only if **NX** > 0 on T-510).

IX1 IX2 IX3 IX4 IX5 IXU

IX1	incrementation variable for node **N1** on T-510
IX2	incrementation variable for node **N2** on T-510
IX3	incrementation variable for node **N3** on T-510
IX4	incrementation variable for node **N4** on T-510
IX5	incrementation variable for node **N5** on T-510a
IXU	incrementation variable for use with **USERELT**

Any of these incrementation variables can be negative, zero or positive.

if (**IANG** = 1) then *go to* T-510c
else *follow the instructions at the end of* T-510c

T-510c E510 Wall Reference Vector

RX RY RZ

RX, RY, RZ wall reference vector, $\mathbf{r}_\mathbf{w}$, which is projected onto the element surface to determine the direction of the wall-reference coordinate x_w; $\mathbf{r}_\mathbf{w}$ is expressed in (x_g, y_g, z_g) global coordinates.

```
if     ( the user wants to add another set of E510 elements )  then
          go to T-510
elseif ( the user wants to add a set of E410 elements )  then
          go to T-410
elseif ( the user wants to add a set of E411 elements )  then
          go to T-411
elseif ( the user wants to add a set of E490 elements )  then
          go to T-480
elseif ( the user wants to add a set of E710 elements )  then
          go to T-710
else
          return to T-100
endif
```

T-710 Additional E710 Elements

T-710 is the first record of the multi-record Ecom protocol extension of the T-4/T-4b/T-4c record set that also defines an **E710** 7-node quadrilateral mesh transition element. With this record and T-710a (and with T-710b and/or T-710c companion records, as required), the user can specify one or more additional **E710** 7-node quadrilateral mesh transition elements to be included in the current element unit. The *looping* capabilities provided here, *via* **NX** and the eight incrementation parameters on T-710b, can be used effectively in many situations.

The methods that **STAGS** uses for determining the element coordinate system for this and other quadrilateral elements are described earlier in this document, in connection with the T-4 and T-410 element-definition records, and will not be repeated here.

N1 N2 N3 N4 KELT IWALL ZETA ECZ ILIN IPLAS INTEG IPENL IANG USERELT NX

N1 node 1

N2 node 2

N3 node 3

N4 node 4

KELT must = 710

IWALL wall fabrication identifier:

0 – shell wall properties are given in user-written subroutine WALL
>0 – shell wall fabrication number in the Wall Fabrication Table (K-1)
<0 – shell wall fabrication identifier in the GCP Fabrications Table (I-21a)

When **IWALL** = 0, data below indicated by ⌘ are defined in WALL; they are automatically initialized to zero before WALL is called, thereby superseding any nonzero values input here.

⌘ **ZETA** angle ζ between the wall-reference coordinate x_w and the fabrication coordinate $\bar{x}$; ζ is a right-handed rotation about $\bar{z}$.

⌘ **ECZ** eccentricity in z' direction. **ECZ** is the z' coordinate of the shell wall middle surface; in element units, (x', y', z') are used in place of (X', Y', Z'), which do not exist in an element unit.

⌘ **ILIN** governs geometric nonlinearity

0 – nonlinear strain-displacement relations
1 – linear strain-displacement relations

Note that with **ILIN** = 1, bifurcation buckling is suppressed in the shell unit

⌘ **IPLAS** governs material nonlinearity

- 0 – elastic behavior only
- 1 – plasticity included, with the material law satisfied at each element integration point
- 2 – plasticity included, with the material law satisfied at the element centroid (centroidal plasticity)

INTEG integration type (see N-1)

- 0 – standard integration, or 2×2 Gauss points
- 1 – modified 5-point integration, previously referred to as full integration

IPENL penalty option (see N-1)

- 0 – no penalty function on fourth-order terms
- 1 – penalty function included in elements

IANG wall-reference option; see discussion on page 8-18

- 0 – use default strategy of projecting x_g, y_g to establish x_w
- 1 – input $\mathbf{r_w}$, which is projected to establish x_w; see (T-710c)

USERELT user-specified element number, used only when **IUWLE** = 1 on H-1

✦ *go to* T-710a

T-710a E710 Extra Nodes Specification

This record is required to specify the fifth, six and seventh nodes of the first **E710** element that is defined *via* the current T-710 record (which defines **NX** **E710** elements if **NX** > 0).

N5 N6 N7

N5	node 5
N6	node 6
N7	node 7

if (**NX** > 0) then *go to* T-710b
elseif (**IANG** = 1) then *go to* T-710c
else *follow the instructions at the end of* T-710c

T-710b E710 Incrementations

Eight incrementation variables are specified here for use with the T-710 record looping functions (if and only if **NX** > 0 on T-710).

IX1 IX2 IX3 IX4 IX5 IX6 IX7 IXU

IX1 incrementation variable for node **N1** on T-710
IX2 incrementation variable for node **N2** on T-710
IX3 incrementation variable for node **N3** on T-710
IX4 incrementation variable for node **N4** on T-710
IX5 incrementation variable for node **N5** on T-710a
IX6 incrementation variable for node **N6** on T-710a
IX7 incrementation variable for node **N7** on T-710a
IXU incrementation variable for use with **USERELT**

Any of these incrementation variables can be negative, zero or positive.

✦ if (**IANG** = 1) then *go to* T-710c
else *follow the instructions at the end of* T-710c

T-710c E710 Wall Reference Vector

RX RY RZ

RX, RY, RZ wall reference vector, $\mathbf{r_w}$, which is projected onto the element surface to determine the direction of the wall-reference coordinate x_w; $\mathbf{r_w}$ is expressed in (x_g, y_g, z_g) global coordinates.

```
if     ( the user wants to add another set of **E710** elements )  then
       *go to* T-710
elseif ( the user wants to add a set of **E410** elements )  then
       *go to* T-410
elseif ( the user wants to add a set of **E411** elements )  then
       *go to* T-411
elseif ( the user wants to add a set of **E480** elements )  then
       *go to* T-480
elseif ( the user wants to add a set of **E510** elements )  then
       *go to* T-510
else
       *return to* T-100
endif
```

9.5 Definition of Contact Elements *via* the Ecom Protocol

The current version of **STAGS** has three “elements” that enable the user to perform analyses in which three types of contact might occur.

The **E810 PAD** surface/surface contact element is designed to treat situations in which one surface may come into contact with another, when the specific elements on one surface that may come into contact with specific elements on the other surface are known *a priori*.

The **E820** generalized contact “element” is designed to treat situations in which one surface may come into contact with another surface, but where the specific elements that may come into contact with each other are *not* known in advance and/or when they may change during the course of the analysis to be performed. The **E820** approach considers contact to be point/surface phenomenon. Here, the user specifies a set of points on one surface and a set of elements on the other, telling **STAGS** that one or more of the identified points *may* come into contact one or more of the identified elements. **STAGS** digests this information and uses it to determine whether or not point/surface contact has started (or is continuing) at each step of the analysis, and generates one or more point/surface contact elements as and if required, for the specific points and surfaces that are involved with that contact.

The **E822** line/line contact “element” is designed to treat situations in which one line (edge) may come into contact with another line (edge), but where the exact location at which that contact may occur is not known in advance and/or when it may change during the course of the analysis. The **E822** approach considers this type of contact to be line/line phenomenon. Here, the user specifies a set of two or more line segments in the model—and uses an **E822** line/line contact “element” to identify one line that *may* come into contact with another, for each line/line contact situation that might occur. **STAGS** digests this information and uses it to determine whether or not line/line contact has started (or is continuing) at each step of the analysis, and generates one or more line/line contact elements as and if required.

The theoretical foundations of these three types of contact “elements” are described in agonizing detail in the ***STAGS** Elements Manual* document. The input requirements for these elements are described next.

T-810 E810 PAD Contact Element

The **E810** 8-node ***PAD*** contact element is basically a set of four independent nonlinear springs connecting the nodes defining one **E410** shell element to the corresponding nodes of a second **E410** element. It is intended for use in situations where those two **PAD**-connected elements—which may be in the same or in different shell or element units—*may* come into contact with each other. The **E810 PAD** element is suitable for use only in situations where the contact region is known *a priori*, where the individual elements coming into contact with each other can be readily identified and paired, and where no *sliding* along the contact surface occurs. The **PAD** element can be used to treat (some) lap-joint and Hertzian impact problems, but it is *not* designed for use in more general situations where the contact regions are not known *a priori* or when sliding occurs or when friction is present. **STAGS**' more general (**E820**) contact capabilities must be used in those situations.

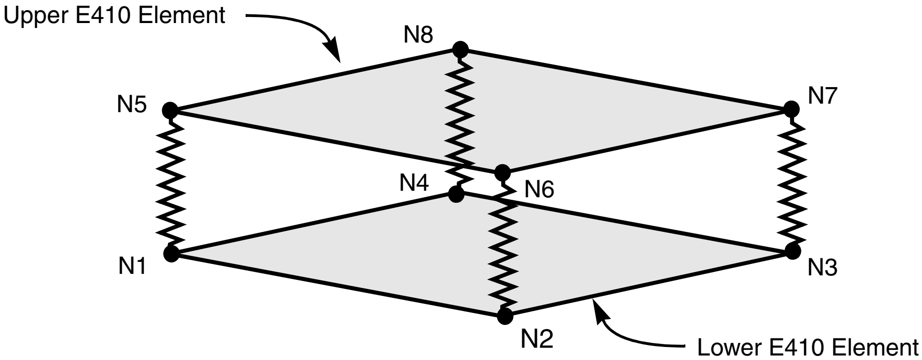


Figure 9.1 **E810** *PAD* Element

The nonlinear spring connecting each pair of nodes typically has a very low stiffness when the *gap* separating the two nodes is positive (where the gap is defined as the distance of the upper-element node from the lower-element reference plane) and to be very stiff when the gap is extremely small or negative (indicating that at least some portions of the two parent elements are in contact with each other): the large forces and stiffnesses that are produced by stiff **PAD**-element springs helps to enforce the displacement compatibility constraints for the contact problem.

Stiffness properties for **PAD**-element springs must be specified *via* one or more stiffness-displacement tables (type I-4a through I-4d records). These stiffness profiles, each of which is identified by its *profile-definition table number*, are currently assumed to be independent of velocity (any velocity dependencies specified are ignored by the program).

The *user point* nodes that are employed in defining **PAD** elements are defined *via* type S-1/S-1a/S-2 record sets (or *via* type S-3/S-3a/S4 record sets): these user points are generally slaved to nodes defining the **E410** shell elements that are expected to come in contact with each other. An additional **OFFSET** parameter can be used to account for thickness effects when the user point nodes lie on parent-node reference surfaces within (rather than on the surfaces of) those parent elements.

The T-810 record defines one or more **E810** elements to be included in the current element unit. The *looping* capabilities provided here, *via* **NX** and on T-810 and the incrementation parameters on T-810a, can be used effectively in many situations.

N1 N2 N3 N4 N5 N6 N7 N8 KELT ITAB OFFSET NX USERELT

N1 first lower-surface **PAD**-element node point

N2 second lower-surface **PAD**-element node point

N3 third lower-surface **PAD**-element node point

N4 fourth lower-surface **PAD**-element node point

N5 first upper-surface **PAD**-element node point, connected to **N1**

N6 second upper-surface **PAD**-element node, connected to **N2**

N7 third upper-surface **PAD**-element node, connected to **N3**

N8 fourth upper-surface **PAD**-element node, connected to **N4**

KELT element code number 810 defines an 8-node **PAD** element

ITAB spring stiffness-displacement-table identifier (see record I–4a)

OFFSET offset parameter, to account for element thicknesses

NX looping parameter, set equal to unity by **STAGS** if omitted or nonpositive

USERELT user-specified element number, used only if **IUWLE** =1 on H-1

if (**NX** > 1) *go to* T-810a
else *return to* T-100

T-810a PAD Element Incrementations

If the **NX** looping parameter is greater than 1 on T-810, a T-810a record is required to specify nine incrementation variables to be used with the T-810 looping function.

I1 I2 I3 I4 I5 I6 I7 I8 I9

I1 incrementation for the **N1** (**PAD** node) variable on the parent T-810 record
I2 incrementation for the **N2** (**PAD** node) variable on the parent T-810 record
I3 incrementation for the **N3** (**PAD** node) variable on the parent T-810 record
I4 incrementation for the **N4** (**PAD** node) variable on the parent T-810 record
I5 incrementation for the **N5** (**PAD** node) variable on the parent T-810 record
I6 incrementation for the **N6** (**PAD** node) variable on the parent T-810 record
I7 incrementation for the **N7** (**PAD** node) variable on the parent T-810 record
I8 incrementation for the **N8** (**PAD** node) variable on the parent T-810 record
I9 incrementation for **IUWLE**

Any of these incrementation variables can be negative, zero, or positive, as required.

Example: the following T-810/T-810a record combination:

```
10 20 30 40 50 60 70 80  810  7 0.0  3
 1  1  1  1  1  1  1  1
```

generates the same three **PAD** elements as the following three individual T-810 records:

```
10 20 30 40 50 60 70 80  810  7 0.0
11 21 31 41 51 61 71 81  810  7 0.0
12 22 32 42 52 62 72 82  810  7 0.0 1
```

return to T-100

T-820 General Contact Definition

As noted in the preceding description, **E810 PAD** elements are defined *explicitly* and should only be used in situations where particular **E410** elements that may contact each other are known *a priori* and can be paired, and where the contact regions (and **E410**-element pairings) do not change during an analysis. **STAGS**' more general point/surface contact capabilities must be used in situations where contact is anticipated but it is not known where the contact will occur and/or how the contact region changes as the analysis progresses.

It is convenient, here, for the analyst to view the contact problem as one in which one structure is (perhaps arbitrarily) designated as the *contacting* structure and the other is considered to be the *contacted* one. The current approach in **STAGS** to the general contact problem avoids many of the complexities and inefficiencies of general surface-on-surface interactions by considering *one or more specific points* on one structure that *may* come into contact with *one or more shell elements* on the other structure—as shown schematically in Figure 9.1:

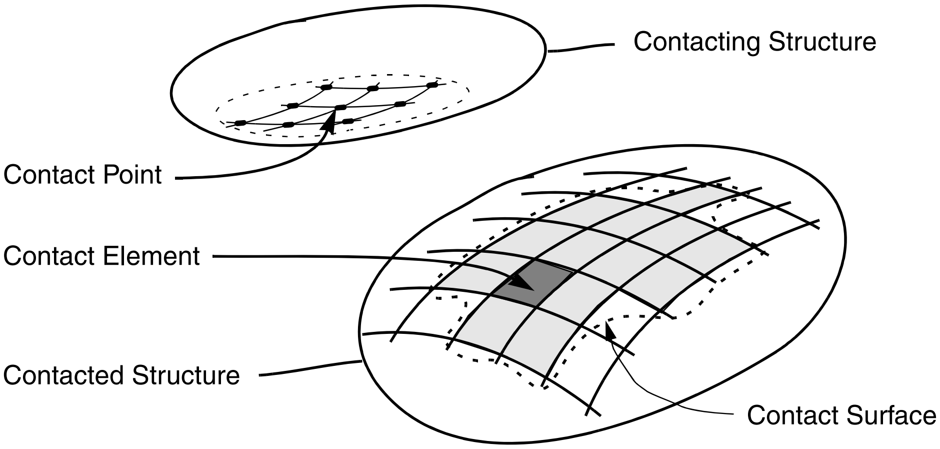


Figure 9.2 Contact-Definition Specification in **STAGS**

The general-contact capabilities in **STAGS** are invoked when the analyst, anticipating the possibility that contact between two structural components may occur, includes one or more **E820** *contact-definition* specifications in an element unit of the **STAGS** model. Each *contact definition* identifies a set of *contact points* on the contacting structure that *may* experience contact with a particular *contact surface* on the contacted structure—where the *contact surface* is a set of contiguous shell elements forming a convex region on the surface of the latter body.

STAGS uses these *contact-definitions* to check for contact and to construct actual contact elements coupling contacting points with contacted shell elements on-the-fly, as and if required, as the analysis progresses. In doing this, **STAGS** attempts to use penalty functions to enforce displacement-compatibility constraints between each contacting point and each element with which it is in contact—utilizing analyst-supplied *stiffness-vs.-displacement* information to compute the forces and stiffnesses resulting from the (necessarily) small contact-surface penetrations that occur.

An actual contact element is (conceptually) a nonlinear spring connecting the contacting point to the surface of the contacted element. This nonlinear spring typically has a very low stiffness and generates a small force when the *contact-surface* penetration is small, but it gets progressively stiffer and generates a larger force as the penetration increases. Stiffness properties for these springs must be specified *via* one or more stiffness-displacement tables (type I-4a through I-4d records). These stiffness-displacement functions each of which is identified by its *table number*, are currently assumed to be independent of velocity (any velocity dependencies specified are ignored by the program).

The T-820 record defines a single **E820** definition to be included in the current element unit. An **E820** *contact-definition* is made *via* a T-820 record (described next) that is followed first by as many T-820a or T-820b *contact-surface-element-specification* records, and then by as many T-820c or T-820d *contact-point-specification* records as may be required. Each of these *contact-surface-specifications* references a specific stiffness-displacement (penalty) function table.

KELT NSRF NPTS

KELT element code number 820 identifies a contact-definition specification

NSRF parameter selecting the method that is to be used to identify the contiguous shell elements defining the contact surface, and (optionally) to specify the minimum number of elements required to define that surface (see Note 1, below):

NSRF ≥ 0 — use the *row & column* method to identify one or more elements in one or more shell units, or

NSRF < 0 — use the *element-number* method to identify one or more elements in one or more shell units and/or one or more elements in the current or previously-defined element units

NPTS parameter selecting the method that is to be used to identify the specific points that *may* come into contact with the contact surface, and (optionally) to specify the minimum number of points that are to be specified (see Note 2, below):

NPTS ≥ 0 — use the *row & column* method to identify one or more nodes in one or more shell units, or

NPTS < 0 — use the *point-number* method to identify one or more nodes in one or more shell units and/or in the current or previously-defined element units

Note 1: In the *row & column* method of defining contact elements, **STAGS** reads one or more type T-820a records—each of which specifies one or more elements of the contact surface. **STAGS** keeps a running count of the number of elements specified by each T-820a record—and stops processing T-820a records as soon as **NSRF** or more elements have been specified. In the *element-number* method of defining contact elements, **STAGS** reads one or more type T-820b records—each of which specifies one or more elements of the contact surface. **STAGS** keeps a running count of the number of elements specified by each T-820b record—and stops processing T-820b records as soon as | **NSRF** | or more elements have been specified.

Note 2: In the *row & column* method of defining contact points, **STAGS** reads one or more type T-820c records—each of which specifies one or more contact points. **STAGS** keeps a running count of the number of points specified by each T-820c record—and stops processing T-820c records as soon as **NPTS** or more points have been specified. In the *element-number* method of defining contact points, **STAGS** reads one or more type T-820d records—each of which specifies one or more contact points. **STAGS** keeps a running count of the number of points specified by each T-820d record—and stops processing T-820d records as soon as | **NPTS** | or more points have been specified.

```
if   ( NSRF ≥ 0 )   then
          go to T-820a
else      go to T-820b
```

T-820a E820 Row & Column Contact-Element Specifications

NSRF ≥ 0 (T-820) indicates that the *row & column method* is to be used to identify the contiguous shell elements that comprise the *contact surface*. This method clearly can only be used to identify contact elements that are associated with one or more *shell* units, because there are no row or column associations for elements in element units. With this method, the value of the **NSRF** parameter indicates the *minimum number* of contact elements to be identified with the set of one or more T-820a records included for the current *contact-definition* (see Note 1 for the T-820 record). The number of contact elements identified by any given T-820a depends on the parameters on that record.

USRF TYPE LI LJ ID NI NJ

USRF identifies the *shell unit* within which the element(s) identified by the **LI** and **LJ** row & column parameters are defined; the element grid for this *shell unit* has **NROWS** rows and **NCOLS** columns of quadrilateral domains—each of which contains one **E410** quadrilateral element or two **E320** triangular elements

TYPE specifies the element type for this (or these) element(s): **TYPE** must currently be either **E410** or **E320**

LI,LJ row and column numbers identifying one or more elements: **LI** = **LJ** = 0 indicates that *all* type **TYPE** elements of shell unit **USRF** are to be included; **LI** > 0 with **LJ** = 0 identifies (and includes) all of the elements in row # **LI** of the element grid; **LJ** > 0 with **LI** = 0 identifies all of the elements in column **LJ**; and **LI** > 0 with **LJ** > 0 identifies one or more **E410** element or the one or more pairs of **E320** elements, starting at row **LI** and column **LJ** of the unit: if **NI** and **NJ** are absent, zero or unity, a single element (or pair of elements) is defined; if **NI** and **NJ** are both positive, then **NI**x**NJ** elements (or pairs of elements) are identified in a double FORTRAN-like loop, starting with the element (or pair of elements) at (**LI**,**LJ**).

ID spring stiffness-displacement table identifier (see record I–4a)

NI,NJ element-identification looping parameters, as discussed in **LI**,**LJ**, above

NSRF	(T-820)	surface-method parameter
NPTS	(T-820)	point-method parameter

```
if  ( NSRF contact-surface elements have been identified ) then
    if ( NPTS > 0 )      then     go to  T-820c
    else                          go to  T-820d
else                              return to  T-820a
```

T-820b E820 Element-Number Contact-Element Specifications

NSRF <0 (T-820) indicates that the *element-number method* is to be used to identify the contiguous shell elements that comprise the *contact surface*. This method can (but generally should not) be used to identify contact elements that are associated with *shell units*, and it *must* be used to identify elements that are defined in **STAGS** *element units* (see Note 1 for the T-820 record). With this method, the *magnitude* of the **NSRF** parameter indicates the *minimum number* of contact elements to be identified with the set of one or more T-820b records included for the current *contact-definition*. The number of contact elements identified by any given T-820b depends on the parameters on that record.

USRF TYPE I1 I2 INC ID

USRF identifies the *shell or element unit* within which the element(s) identified by the **I1**, **I2** and **INC** parameters are defined

TYPE specifies the element type for this (or these) element(s): **TYPE** must currently be either **E410** or **E320**

I1,I2,INC element identifiers: **I1** >0, with **I2** $=0$ and **INC** $=0$ identifies element # **I1** (in unit **USRF**) as part of the contact surface for the current contact-definition; **I1**, **I2**, **INC** $>$ 0 identifies **I2** elements—starting with element **I1** and incrementing by **INC** until **I2** elements have been indicated (in unit **USRF**) as part of the *contact surface* for the current *contact-definition*

ID spring stiffness-displacement table identifier (see record I–4a)

NSRF	(T-820)	surface-method parameter
NPTS	(T-820)	point-method parameter

```
if     ( fewer than NSRF contact-surface elements have been identified )   then
                                          return to  T-820b
elseif   ( NPTS > 0 )      then          go to  T-820c
else                                     go to  T-820d
```

T-820c Row & Column Contact-Point Specifications

NPTS ≥ 0 (T-820) indicates that the *row & column method* is to be used to identify the points that may come into contact with the *contact surface* specified for the current *contact-definition*. This method clearly can only be used to identify nodes that are associated with one or more *shell* units, because there are no row or column associations for nodal points in element units. With this method, the value of the **NPTS** parameter indicates the *minimum number* of contact points to be identified with the set of one or more T-820c records included for the current *contact-definition* (see Note 2 for T-820). The number of contact points identified by any given T-820c depends on the parameters on that record.

UNITP LI LJ RADIUS TOUCHE NI NJ

UNITP identifies the *shell unit* within which the contact point(s) identified by the **LI** and **LJ** row & column parameters are defined; the nodal mesh for this shell unit has **NROWS** rows and **NCOLS** columns of nodal points

LI,LJ row and column numbers identifying one or more contact points: **LI** = **LJ** = 0 indicates that *all* of the node points of shell unit **UNITP** are to be considered as *contact points*; **LI** > 0 with **LJ** = 0 identifies all of the nodes in row **LI** of the nodal grid; **LJ** > 0 with **LI** = 0 identifies all of the nodes in column **LJ**; and **LI** > 0 with **LJ** > 0 identifies one or more nodes, starting at row **LI** and column **LJ of the unit:** if **NI** and **NJ** are absent, zero or unity, a single point (**LI**,**LJ**) is defined; if **NI** and **NJ** are both positive, then **NI**x**NJ** points are identified in a double FORTRAN-like loop, starting with the point at (**LI**,**LJ**).

RADIUS specifies a radial offset parameter to be used in determining whether or not the point(s) identified by the current T-820c are in contact with the *contact surface*: this parameter can be used to account for the thickness of material surrounding the contact point(s) in much the same way as the thicknesses of contact elements on the *contact surface* are taken into account

TOUCHE provides information required if the identified *contact point(s)* are in contact with the *contact surface* at the outset of the problem: set **TOUCHE** = 0 if not; or set **TOUCHE** = 1 if the point(s) are contacting the surface from its *positive* side; or set **TOUCHE** = –1 if the point(s) are contacting the surface from its *negative* side—where the normal vector for the *contact surface* points out of the *positive* side of the surface and away from the *negative* side

NI,NJ point-identification looping parameters, as discussed in **LI,LJ**, above

```
if    ( fewer than NPTS contact-points have been identified )  then
          go to T-820c
else      return to T-100
```

T-820d Point-Number Contact-Point Specifications

NPTS < 0 (on T-820) indicates that the *point-number method* is to be used to identify the nodal points that may come into contact with the *contact surface*. This method can (but generally should not) be used to identify nodes that are associated with *shell units*, and it *must* be used to identify points that are defined in **STAGS** *element units*. With this method, the *magnitude* of the **NPTS** parameter indicates the *minimum number* of contact points to be identified with the set of one or more T-820d records included for the current *contact-definition* (see Note 2 for the T-820 record). The number of *contact points* identified by any given T-820d depends on the parameters on that record.

UNITP I1 I2 INC RADIUS TOUCHE

UNITP identifies the *shell or element unit* within which the *contact point(s)* identified by the **I1**, **I2** and **INC** parameters are defined; the nodal mesh for this shell unit has **NROWS** rows and **NCOLS** columns of node points

I1,I2,INC point identifiers: **I1** > 0, with **I2** $=$ **INC** $= 0$ identifies point # **I1** (in unit **UNITP**) as a *contact point* for the current *contact-definition*; **I1**, **I2**, **INC** > 0 identifies **I2** points—starting with point **I1** and incrementing by **INC** until **I2** points have been indicated (in unit **UNITP**) as *contact points* for the current *contact-definition*

RADIUS specifies a radial offset parameter to be used in determining whether or not the point(s) identified by the current T-820d are in contact with the *contact surface*: this parameter can be used to account for the thickness of material surrounding the *contact point(s)* in much the same way as the thicknesses of contact elements on the *contact surface* are taken into account

TOUCHE provides information required if the identified *contact point(s)* are in contact with the *contact surface* at the outset of the problem: set **TOUCHE** $= 0$ if not; or set **TOUCHE** $= 1$ if the point(s) are contacting the surface from its *positive* side; or set **TOUCHE** $= -1$ if the point(s) are contacting the surface from its *negative* side—where the normal vector for the *contact surface* points out of the *positive* side of the surface and away from the *negative* side

```
if    ( fewer than NPTS contact-points have been identified )  then
          return to T-820d
else      return to T-100
```

T-822 Line-Contact Interaction Definition

The T-822 record specifies a pair of "contact" lines (which must have been defined *via* S-5 records, as described on page 7-17) that *may* experience line-to-line contact with each other during the course of the analysis that **STAGS** is to perform. The first line of each such pair must have one or more type **E410** elements associated with it (qualifying it to be a *contacted* line), as described earlier. The second line, which may but does not need to have elements associated with it, is treated as the *contacting* line. When contact occurs at one or more points along the two lines, **STAGS** uses penalty information supplied by the analyst to generate stiffnesses and forces on the fly to treat that contact.

LINE1 LINE2 IPEN NX INC1 INC2 INC3

LINE1 identifies the *contacted* line, which must have one or more elements associated with it; this line must have been specified *via* an S-5 record, as described on page 7-17

LINE2 identifies the *contacting* line, which may (but is not required to) have one or more elements associated with it; this line must also have been specified *via* an S-5 record

IPEN identifies the penalty function table (of stiffness as a function of penetration) that **STAGS** is to use in calculating stiffnesses and forces that arise when contact occurs between these two lines; the table identified must have been specified *via* an I-4 record set, as described above.

NX indicates the number of line contact interactions that are to be specified with information on this T-822 record; **STAGS** sets **NX** = 1 if it is not positive

INC1 incrementation parameter for **LINE1** (used only when **NX** > 0)

NC2 incrementation parameter for **LINE2** (used only when **NX** > 0)

NC3 incrementation parameter for **IPEN** (used only when **NX** > 0)

return to T-100

9.6 Definition of Sandwich Elements *via* the Ecom Protocol

Sandwich structures play such an important role in the design of many aerospace structures, so it is necessary that their behavior be determined adequately. The classical approach to the modeling of sandwiches is an extension of thin-shell-theory, in which the behavior of a three-dimensional sandwich object is reduced to the behavior of a two-dimensional surface with in- and out-of-plane stiffness properties. Here, the sandwich construction is idealized as a pair of membranes that are held apart by a core that has a relatively large resistance against transverse shear. The core is virtually inextensional in the transverse direction, with virtually no stiffness in the middle-surface plane. This type of model is called a sandwich of the first kind. Finite element discretizations of this kind of classical model have been made in the past, but successful applications have been confined primarily to linear or moderately nonlinear analyses. A more general sandwich model emerges by considering the two faces to be shells (with bending as well as the usual membrane stiffness) that are held apart by a lightweight core. The core may have three dimensional elastic properties. This type of model is called a sandwich of the second kind, and is the model that is implemented in STAGS.* A good example of a problem requiring this model would be one with structural walls made of glass fiber faces and using polyurethane foam as the core material.

There are five sandwich elements in the current version of STAGS. Three of these (**E830**, **E840** and **E849**) are “standard” 6-, 8- and 18-node 3-layered (shell/solid/shell) counterparts of the **E330**, **E410** and **E480** thin shell elements, respectively. The other two (**E845** and **E847**) are 10- and 14-node 3-layered counterparts of the **E510** and **E710** shell elements—most appropriately used in modeling transition zones where **E840** mesh refinements are required.

The 6-node **E830** element is a “standard” sandwich element that is constructed with a pair of **E330** triangular thin shell elements that are held apart by a 6-node pentahedral solid core component. One or more **E830** elements (or additional **E830** elements) can be defined with the T-830 record set. For more information about the **E830** element, see “E830 6–Node sandwich element” on page 14-36.

The 8-node **E840** element is a “standard” sandwich element that is constructed with a pair of 4-node **E410** quadrilateral thin shell elements that are held apart by an 8-node hexahedral solid

* See, for example:
Riks, E. and C. C. Rankin, “*Sandwich Modeling with an Application to the Residual Strength Analysis of a Damaged Composite Compression Panel,*” International Journal of Non-Linear Mechanics, Vol. 37, No. 4-5, June–July 2002, pp. 897–908 (also available as AIAA Paper No. 2001-1232, April 2001), and
Rose, C.A., D.F. Moore, N.F. Knight, Jr. and C.C. Rankin, “Finite Element Modeling of the Buckling Response of Sandwich Panels,” AIAA Paper No. 2202-1517, April 2002

core component. One or more **E840** elements (or additional **E840** elements) can be defined with the T-840 record set. For more information about the **E840** element, see “E840 8–Node sandwich element” on page 14-44.

The 10-node **E845** element is the sandwich-element counterpart of the **E510** thin-shell mesh-transition “quadrilateral” element. An **E845** element is constructed with a pair of 5-node **E510** transition elements that are held apart by a 10-node solid-core mesh-transition component. One or more **E845** elements (or additional **E845** elements) can be defined with the T-845 record set. For more information about the **E845** element, see “E845 and E847 mesh-transition sandwich elements” on page 14-46.

The 14-node **E847** element is the sandwich-element counterpart of the **E710** thin-shell mesh-transition “quadrilateral” element. An **E847** element is constructed with a pair of 7-node **E710** transition elements that are held apart by a 14-node solid-core mesh-transition component. One or more **E847** elements (or additional **E847** elements) can be defined with the T-847 record set. For more information about the **E847** element, see “E845 and E847 mesh-transition sandwich elements” on page 14-46.

The 18-node **E849** element is a “standard” sandwich element that is constructed with a pair of 9-node **E480** quadrilateral thin shell elements that are held apart by an 18-node hexahedral solid core component. One or more **E849** elements (or additional **E849** elements) can be defined with the T-849 record set. For more information about the **E849** element, see “E849 18–Node sandwich element” on page 14-45.

T-830 E830 6-Node Sandwich Element Definition

The **E830** 6-node sandwich element in **STAGS** is constructed with a pair of **E330** triangular shells (with bending as well as the usual membrane stiffness) that are held apart by a lightweight core that has three-dimensional elastic properties.

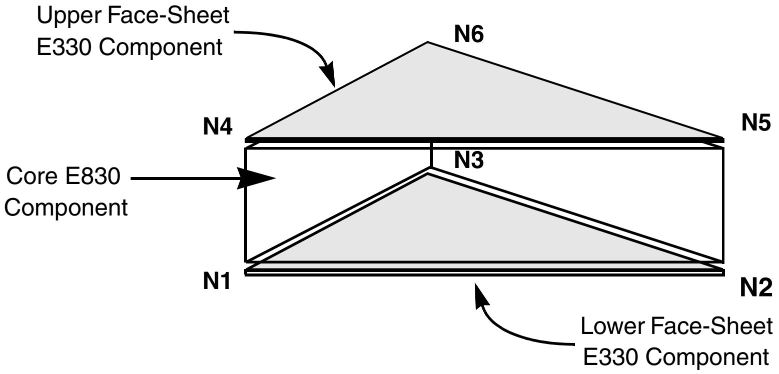


Figure 9.3 **E830** 6-Node Sandwich Element

Definition of one or more **E830** 6-node sandwich elements is accomplished with the following set of records:

T-830 to specify parameters used for all parts of the element
T-830a to specify information for the lower face sheet of the element
T-830b to specify lower face sheet transformation angles (optional)
T-830c to specify information for the upper face sheet
T-830d to specify upper face sheet transformation angles (optional)
T-830e to specify core parameters
T-830f to specify core transformation angles (optional)
T-830g for “x-direction” incrementation parameters
T-830h for “y-direction” incrementation parameters

These are described sequentially in the following text.

KELT ILIN INTEG IPEN NX NY USERC USER1 USER2

KELT element code number (must be 830)

ILIN geometric-linearity flag:

- 0 – nonlinear strain-displacement relations
- 1 – linear strain-displacement relations

INTEG number of surface-integration points: set **INTEG** = 1, 3, 4 or 7;
if **INTEG** = 0, **STAGS** sets **INTEG** = 3

IPEN penalty option (see N-1)

- 0 – no penalty function on fourth-order terms in **E330** elements
- 1 – penalty function included in **E330** elements

NX x-direction looping parameter, set equal to unity by **STAGS** if omitted or nonpositive; **NX** > 1 instructs **STAGS** to generate a set of **NX** type **E830** elements in the x direction, using nodal incrementation information given on T-830g

NY y-direction looping parameter, set equal to unity by **STAGS** if omitted or nonpositive; **NY** > 1 instructs **STAGS** to generate a set of **NY** type **E830** elements in the *y* direction for each of the **NX** elements generated in the *x* direction in the current definition, using nodal incrementation information given on T-830h

USERC user-specified element number for core component
(used only if **IUWLE** = 1 on H-1)

USER1 user-specified element number for **lower face sheet**, (if **IUWLE** = 1 on H-1)

USER2 user-specified element number for **upper face sheet**, (if **IUWLE** = 1 on H-1)

✦ *go to* T-830a

T-830a E830 Lower Face-Sheet Properties

A single T-830a record must be included immediately following the T-830 record, to specify the nodes for the lower face sheet of the first **E830** element and to specify other parameters for the lower face sheet of each of the element(s) specified in the current definition.

N1 N2 N3 IFABL ZETAL ECZL IPLASL IANGL

N1 first node point on lower face sheet

N2 second node point on lower face sheet

N3 third node point on lower face sheet

IFABL fabrication identifier for the lower face sheet element(s); this is equivalent to the **WALL** parameter for **E330** triangular elements:

>0 – wall configuration number in the Wall Fabrication Table (K-1)

0 – shell wall properties are given in user-written subroutine WALL (See the T-4 record description for more information about this)

<0 – shell fabrication identifier in the GCP Fabrication Table (I-21a)

ZETAL angle ζ between the wall-reference coordinate x_w and the fabrication coordinate $\bar{x}$, for the lower face sheet; ζ is a right-handed rotation about $\bar{z}$; see Figure 8.2 on page 8-19.

ECZL eccentricity in z' direction, for the lower face sheet; **ECZL** is the z' coordinate of the shell wall middle surface; please refer to Figure 6.2 on page 6-28; in element units, (x', y', z') are used in place of (X', Y', Z'), which do not exist in an element unit; see "Effects of Eccentricity" on page 16-6.

IPLASL lower face sheet material-nonlinearity flag:

0 – elastic behavior only

1 – plasticity included, with the material law satisfied at each element integration point

2 – plasticity included, with the material law satisfied at the element centroid (centroidal plasticity)

IANGL lower face sheet wall-reference option; see the discussion on page 8-18

0 – use default strategy of projecting x_g, y_g to establish x_w

1 – input $\mathbf{r_w}$, which is projected to establish x_w; see (T-830b)

```
if ( IANGL > 0 ) then
                      go to T-830b
else                  go to T-830c
```

T-830b E830 Lower Face-Sheet Wall Reference Vector

RXL RYL RZL

RXL, RYL, RZL lower face sheet wall reference vector, $\mathbf{r_w}$, which is projected onto the element surface to determine the direction of the wall-reference coordinate x_w; $\mathbf{r_w}$ is expressed in (x_g, y_g, z_g) global coordinates

go to T-830c

T-830c E830 Upper Face-Sheet Properties

A single T-830c record must be included immediately following the T-830a (or T-830b) record, to specify the nodes for the upper face sheet of the first **E830** element and to specify other parameters for the upper face sheet of each of the element(s) specified in the current definition.

N4 N5 N6 IFABU ZETAU ECZU IPLASU IANGU

N4 first node point on upper face sheet

N5 second node point on upper face sheet

N6 third node point on upper face sheet

IFABU fabrication identifier for the upper face sheet element(s); this is equivalent to the **WALL** parameter for **E330** quadrilateral elements:

- >0 – wall configuration number in the Wall Fabrication Table (K-1)
- 0 – shell wall properties are given in user-written subroutine WALL
- <0 – shell fabrication identifier in the GCP Fabrication Table (I-21a)

ZETAU angle ζ between the wall-reference coordinate x_w and the fabrication coordinate $\bar{x}$, for the upper face sheet; ζ is a right-handed rotation about $\bar{z}$

ECZU eccentricity in z' direction, for the upper face sheet; **ECZL** is the z' coordinate of the shell wall middle surface

IPLASU upper face sheet material-nonlinearity flag:

- 0 – elastic behavior only
- 1 – plasticity included, with the material law satisfied at each element integration point
- 2 – plasticity included, with the material law satisfied at the element centroid (centroidal plasticity)

IANGL upper face sheet wall-reference option; see discussion on page 8-18

- 0 – use default strategy of projecting x_g, y_g to establish x_w
- 1 – input $\mathbf{r_w}$, which is projected to establish x_w; see (T-830d)

if (**IANGU** > 0) then *go to* T-830d
else *go to* T-830e

T-830d E830 Upper Face-Sheet Wall Reference Vector

RXU RYU RZU

RXU, RYU, RZU upper face sheet wall reference vector, $\mathbf{r_w}$, which is projected onto the element surface to determine the direction of the wall-reference coordinate x_w; $\mathbf{r_w}$ is expressed in (x_g, y_g, z_g) global coordinates

✦ *go to* T-830e

T-830e E830 Core Properties

A single T-830e record must be included immediately following the T-830c (or T-830d) record, to specify parameters for the core component of the element(s) specified in the current definition.

IFABC ZETAC IPLASC IANGC

IFABC core fabrication identifier:

- >0 – wall configuration number in the Wall Fabrication Table (K-1)
- <0 – solid fabrication identifier in the GCP Fabrication Table (I-22a)

ZETAC angle ζ between the wall-reference coordinate x_w and the fabrication coordinate $\bar{x}$, for the core component; ζ is a right-handed rotation about $\bar{z}$

IPLASC core material-nonlinearity flag:

- 0 – elastic behavior only
- 1 – plasticity included *(not operational with GCP fabrications, yet)*

IANGC core wall-reference option; see discussion on page 8-18

- 0 – use default strategy of projecting x_g, y_g to establish x_w
- 1 – input $\mathbf{r}_w$, which is projected to establish x_w; see (T-830f)

✦

NX	(T-830)	x-direction looping parameter
NY	(T-830)	y-direction looping parameter

```
if      ( IANGC > 0 )  then   go to T-830f
elseif  ( NX > 0 )     then   go to T-830g
elseif  ( NY > 0 )     then   go to T-830h
else    return to T-100
```

T-830f E830 Core Reference Vector

RXC RYC RZC

RXC, RYC, RZC core reference vector, $\mathbf{r_w}$, which is projected onto the element surface to determine the direction of the core-reference coordinate x_w; $\mathbf{r_w}$ is expressed in (x_g, y_g, z_g) global coordinates

✦

NX	(T-830)	x-direction looping parameter
NY	(T-830)	y-direction looping parameter

```
if       ( NX > 0 )  then  go to T-830g
elseif   ( NY > 0 )  then  go to T-830h
else     return to T-100
```

T-830g X-Direction Incrementations

A single record of type T-830g must be included immediately after the T-830e or T-830f record when the **NX** "x-direction" *looping parameter* (T-830) is greater than unity. Eight nodal incrementation variables are specified here for use with the "x-direction" looping function on the T-830 record. **NX** **E830** sandwich elements are generated in the "x-direction" with this information. Three incrementation variables are also specified here for "x-direction" looping with the user-element-number parameters on T-830.

I1 I2 I3 I4 I5 I6 I7 I8 I9

I1 incrementation for the **N1** lower face sheet node on the T-830a record

I2 incrementation for the **N2** lower face sheet node on the T-830a record

I3 incrementation for the **N3** lower face sheet node on the T-830a record

I4 incrementation for the **N4** upper face sheet node on the T-830c record

I5 incrementation for the **N5** upper face sheet node on the T-830c record

I6 incrementation for the **N6** upper face sheet node on the T-830c record

I7 incrementation for **USERC** on the T-830 record

I8 incrementation for **USER1** on the T-830 record

I9 incrementation for **USER2** on the T-830 record

Any of these incrementation variables can be negative, zero, or positive, as required.

Example: the following T-830 / T-830a / T-830c / T-830g record combination:

```
830 1 0 0 3            $ T-830 with NX=3
10 20 30 ...           $ T-830a lower face nodes
50 60 70 ...           $ T-830c upper face nodes
...
1 1 1 2 2 2            $ T-830g increments
```

generates three **E830** elements, with the following nodes:

```
10 20 30 50 60 70           Element #1
11 21 31 52 62 72           Element #2
12 22 32 54 64 74           Element #3
```

NY (T-830) y-direction looping parameter

if (**NY** > 0) then *go to* T-830h
else *return to* T-100

T-830h Y-Direction Incrementations

A single type T-830h record must be included immediately after the T-830e or T-830f or T-830g record when the **NY** "y-direction" *looping parameter* is greater than unity (T-830). Eight nodal incrementation variables are specified here for use with the T-830 record "y-direction" looping function. **NY E830** sandwich elements are generated in the "y-direction", for each **E830** element generated in the *x* direction, with this information. The **NX** and **NY** looping parameters are usually employed together to specify **NX** × **NY** **E830** elements in a single stroke.

J1 J2 J3 J4 J5 J6 J7 J8 J9

J1 incrementation for the **N1** lower face sheet node on the T-830a record
J2 incrementation for the **N2** lower face sheet node on the T-830a record
J3 incrementation for the **N3** lower face sheet node on the T-830a record
J4 incrementation for the **N4** upper face sheet node on the T-830c record
J5 incrementation for the **N5** upper face sheet node on the T-830c record
J6 incrementation for the **N6** upper face sheet node on the T-830c record
J7 incrementation for **USERC** on the T-830 record
J8 incrementation for **USER1** on the T-830 record
J9 incrementation for **USER2** on the T-830 record

Any of these incrementation variables can be negative, zero, or positive, as required.

Example: the following T-830 / T-830a / T-830c / T-830g / T-830h record combination:

```
830 1 0 0 3 2          $ T-830 NX=3, NY=2
10 20 30 ...           $ T-830a (lower face nodes)
50 60 70 ...           $ T-830c (upper face nodes)
...
1 1 1 1 1 1            $ T-830g (x increments)
5 5 5 5 5 5            $ T-830h (y increments)
```

generates six **E830** elements, with the following nodes:

```
10 20 30 50 60 70          Element #1
11 21 31 51 61 71          Element #2
12 22 32 52 62 72          Element #3
15 25 35 55 65 75          Element #4
16 26 36 56 66 76          Element #5
17 27 37 57 67 77          Element #6
```

return to T-100

T-840 E840 8-Node Sandwich Element Definition

The **E840** 8-node sandwich element in **STAGS**, shown in Figure 9.4, is constructed with a pair of **E410** quadrilateral shells (with bending as well as the usual membrane stiffness) that are held apart by a lightweight core that has three-dimensional elastic properties.

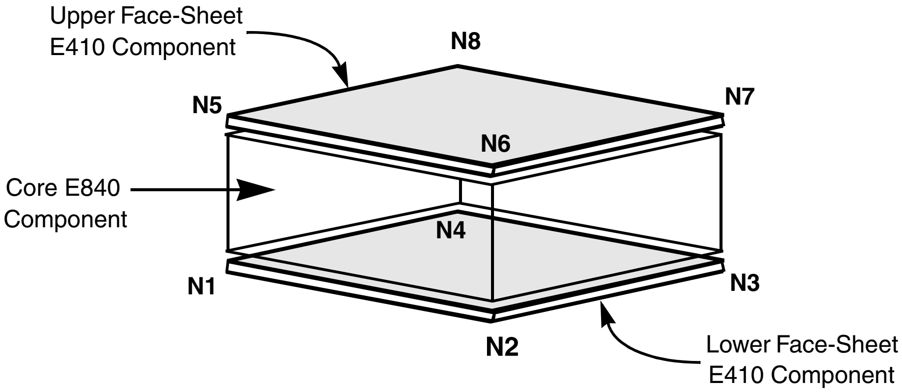


Figure 9.4 **E840** 8-Node Sandwich Element

Definition of one or more **E840** 8-node sandwich elements is accomplished with the following set of records:

T-840	to specify parameters used for all parts of the element
T-840a	to specify information for the lower face sheet of the element
T-840b	to specify lower face sheet transformation angles (optional)
T-840c	to specify information for the upper face sheet
T-840d	to specify upper face sheet transformation angles (optional)
T-840e	to specify core parameters
T-840f	to specify core transformation angles (optional)
T-840g	for “x-direction” incrementation parameters
T-840h	for “y-direction” incrementation parameters

These are described sequentially in the following text.

KELT ILIN INTEG IPEN NX NY USERC USER1 USER2

KELT element code number (must be 840)

ILIN geometric-linearity flag:

0 – nonlinear strain-displacement relations

1 – linear strain-displacement relations

INTEG integration-type flag (see N-1):

0 – standard integration, or 2×2 Gauss points for **E410** elements

1 – modified 5-point integration, previously referred to as full integration

IPEN penalty option (see N-1)

0 – no penalty function on fourth-order terms in **E410** elements

1 – penalty function included in **E410** elements

NX x-direction looping parameter, set equal to unity by **STAGS** if omitted or nonpositive; **NX** > 1 instructs **STAGS** to generate a set of **NX** type **E840** elements in the x direction, using nodal incrementation information given on T-840g

NY y-direction looping parameter, set equal to unity by **STAGS** if omitted or nonpositive; **NY** > 1 instructs **STAGS** to generate a set of **NY** type **E840** elements in the *y* direction for each of the **NX** elements generated in the *x* direction in the current definition, using nodal incrementation information given on T-840h

USERC user-specified element number for core component (used only if **IUWLE** = 1 on H-1)

USER1 user-specified element number for **lower face sheet**, (if **IUWLE** = 1 on H-1)

USER2 user-specified element number for **upper face sheet**, (if **IUWLE** = 1 on H-1)

✦ *go to* T-840a

T-840a E840 Lower Face-Sheet Properties

A single T-840a record must be included immediately following the T-840 record, to specify the nodes for the lower face sheet of the first **E840** element and to specify other parameters for the lower face sheet of each of the element(s) specified in the current definition.

N1 N2 N3 N4 IFABL ZETAL ECZL IPLASL IANGL

N1	first node point on lower face sheet
N2	second node point on lower face sheet
N3	third node point on lower face sheet
N4	fourth node point on lower face sheet

IFABL fabrication identifier for the lower face sheet element(s); this is equivalent to the **WALL** parameter for **E410** quadrilateral elements:

>0 – wall configuration number in the Wall Fabrication Table (K-1)

0 – shell wall properties are given in user-written subroutine WALL (See the T-4 record description for more information about this)

<0 – shell fabrication identifier in the GCP Fabrication Table (I-21a)

ZETAL angle ζ between the wall-reference coordinate x_w and the fabrication coordinate $\bar{x}$, for the lower face sheet; ζ is a right-handed rotation about $\bar{z}$; see Figure 8.2 on page 8-19.

ECZL eccentricity in z' direction, for the lower face sheet; **ECZL** is the z' coordinate of the shell wall middle surface; please refer to Figure 6.2 on page 6-28; in element units, (x', y', z') are used in place of (X', Y', Z'), which do not exist in an element unit; see "Effects of Eccentricity" on page 16-6.

IPLASL lower face sheet material-nonlinearity flag:

0 – elastic behavior only

1 – plasticity included, with the material law satisfied at each element integration point

2 – plasticity included, with the material law satisfied at the element centroid (centroidal plasticity)

IANGL lower face sheet wall-reference option; see discussion on page 8-18

0 – use default strategy of projecting x_g, y_g to establish x_w

1 – input $\mathbf{r_w}$, which is projected to establish x_w; see (T-840b)

```
if  ( IANGL > 0 )  then
                    go to T-840b
else                go to T-840c
```

T-840b E840 Lower Face-Sheet Wall Reference Vector

RXL RYL RZL

RXL, RYL, RZL lower face sheet wall reference vector, $\mathbf{r_w}$, which is projected onto the element surface to determine the direction of the wall-reference coordinate x_w; $\mathbf{r_w}$ is expressed in (x_g, y_g, z_g) global coordinates

✦ *go to* T-840c

T-840c E840 Upper Face-Sheet Properties

A single T-840c record must be included immediately following the T-840a (or T-840b) record, to specify the nodes for the upper face sheet of the first **E840** element and to specify other parameters for the upper face sheet of each of the element(s) specified in the current definition.

N5 N6 N7 N8 IFABU ZETAU ECZU IPLASU IANGU

N5 first node point on upper face sheet

N6 second node point on upper face sheet

N7 third node point on upper face sheet

N8 fourth node point on upper face sheet

IFABU fabrication identifier for the upper face sheet element(s); this is equivalent to the **WALL** parameter for **E410** quadrilateral elements:

- >0 – wall configuration number in the Wall Fabrication Table (K-1)
- 0 – shell wall properties are given in user-written subroutine WALL
- <0 – shell fabrication identifier in the GCP Fabrication Table (I-21a)

ZETAU angle ζ between the wall-reference coordinate x_w and the fabrication coordinate $\bar{x}$, for the upper face sheet; ζ is a right-handed rotation about $\bar{z}$

ECZU eccentricity in z' direction, for the upper face sheet; **ECZL** is the z' coordinate of the shell wall middle surface

IPLASU upper face sheet material-nonlinearity flag:

- 0 – elastic behavior only
- 1 – plasticity included, with the material law satisfied at each element integration point
- 2 – plasticity included, with the material law satisfied at the element centroid (centroidal plasticity)

IANGL upper face sheet wall-reference option; see discussion on page 8-18

- 0 – use default strategy of projecting x_g, y_g to establish x_w
- 1 – input $\mathbf{r_w}$, which is projected to establish x_w; see (T-840d)

```
if ( IANGU > 0 ) then    go to T-840d
else                     go to T-840e
```

T-840d E840 Upper Face-Sheet Wall Reference Vector

RXU RYU RZU

RXU, RYU, RZU upper face sheet wall reference vector, $\mathbf{r_w}$, which is projected onto the element surface to determine the direction of the wall-reference coordinate x_w; $\mathbf{r_w}$ is expressed in (x_g, y_g, z_g) global coordinates

✦ *go to* T-840e

T-840e E840 Core Properties

A single T-840e record must be included immediately following the T-840c (or T-840d) record, to specify parameters for the core component of the element(s) specified in the current definition.

IFABC ZETAC IPLASC IANGC

IFABC core fabrication identifier:

>0 – wall configuration number in the Wall Fabrication Table (K-1)

<0 – solid fabrication identifier in the GCP Fabrication Table (I-22a)

ZETAC angle ζ between the wall-reference coordinate x_w and the fabrication coordinate $\bar{x}$, for the core component; ζ is a right-handed rotation about $\bar{z}$

IPLASC core material-nonlinearity flag:

0 – elastic behavior only

1 – plasticity included *(not operational with GCP fabrications, yet)*

IANGC core wall-reference option; see discussion on page 8-18

0 – use default strategy of projecting x_g, y_g to establish x_w

1 – input $\mathbf{r_w}$, which is projected to establish x_w; see (T-840f)

NX	(T-840)	x-direction looping parameter
NY	(T-840)	y-direction looping parameter

```
if      ( $\textbf{IANGC} > 0$ )  then  go to T-840f
elseif  ( $\textbf{NX} > 0$ )     then  go to T-840g
elseif  ( $\textbf{NY} > 0$ )     then  go to T-840h
else    return to T-100
```

T-840f E840 Core Reference Vector

RXC RYC RZC

RXC, RYC, RZC core reference vector, $\mathbf{r_w}$, which is projected onto the element surface to determine the direction of the core-reference coordinate x_w; $\mathbf{r_w}$ is expressed in (x_g, y_g, z_g) global coordinates

✧

NX	(T-840)	x-direction looping parameter
NY	(T-840)	y-direction looping parameter

```
if       ( NX > 0 )  then  go to T-840g
elseif   ( NY > 0 )  then  go to T-840h
else     return to T-840
```

T-840g X-Direction Incrementations

A single record of type T-840g must be included immediately after the T-840e or T-840f record when the **NX** “x-direction” *looping parameter* (T-840) is greater than unity. Eight nodal incrementation variables are specified here for use with the “x-direction” looping function on the T-840 record. **NX** **E840** sandwich elements are generated in the “x-direction” with this information. Three incrementation variables are also specified here for “x-direction” looping with the user-element-number parameters on T-840.

I1 I2 I3 I4 I5 I6 I7 I8 I9 I10 I11

I1 incrementation for the **N1** lower face sheet node on the T-840a record

I2 incrementation for the **N2** lower face sheet node on the T-840a record

I3 incrementation for the **N3** lower face sheet node on the T-840a record

I4 incrementation for the **N4** lower face sheet node on the T-840a record

I5 incrementation for the **N5** upper face sheet node on the T-840c record

I6 incrementation for the **N6** upper face sheet node on the T-840c record

I7 incrementation for the **N7** upper face sheet node on the T-840c record

I8 incrementation for the **N8** upper face sheet node on the T-840c record

I9 incrementation for **USERC** on the T-840 record

I10 incrementation for **USER1** on the T-840 record

I11 incrementation for **USER2** on the T-840 record

Any of these incrementation variables can be negative, zero, or positive, as required.

Example: the following T-840 / T-840a / T-840c / T-840g record combination:

```
840 1 0 0 3            $ T-840 with NX=3
10 20 30 40 ...        $ T-840a lower face nodes
50 60 70 80 ...        $ T-840c upper face nodes
...
1 1 1 1 2 2 2 2        $ T-840g increments
```

generates three **E840** elements, with the following nodes:

```
10 20 30 40 50 60 70 80     Element #1
11 21 31 41 52 62 72 82     Element #2
12 22 32 42 54 64 74 84     Element #3
```

NY (T-840) y-direction looping parameter

if (**NY** > 0) then *go to* T-840h
else *return to* T-100

T-840h Y-Direction Incrementations

A single type T-840h record must be included immediately after the T-840e or T-840f or T-840g record when the **NY** "y-direction" *looping parameter* is greater than unity (T-840). Eight nodal incrementation variables are specified here for use with the T-840 record "y-direction" looping function. **NY** **E840** sandwich elements are generated in the *y* direction, for each **E840** element generated in the *x* direction, with this information. The **NX** and **NY** looping parameters are usually employed together to specify **NX** × **NY** **E840** elements in a single stroke.

J1 J2 J3 J4 J5 J6 J7 J8 J9 J10 J11

J1 incrementation for the **N1** lower face sheet node on the T-840a record

J2 incrementation for the **N2** lower face sheet node on the T-840a record

J3 incrementation for the **N3** lower face sheet node on the T-840a record

J4 incrementation for the **N4** lower face sheet node on the T-840a record

J5 incrementation for the **N5** upper face sheet node on the T-840c record

J6 incrementation for the **N6** upper face sheet node on the T-840c record

J7 incrementation for the **N7** upper face sheet node on the T-840c record

J8 incrementation for the **N8** upper face sheet node on the T-840c record

J9 incrementation for **USERC** on the T-840 record

J10 incrementation for **USER1** on the T-840 record

J11 incrementation for **USER2** on the T-840 record

Any of these incrementation variables can be negative, zero, or positive, as required.

Example: the following T-840 / T-840a / T-840c / T-840g / T-840h record combination:

```
840 1 0 0 3 2          $ T-840 NX=3, NY=2
10 20 30 40 ...        $ T-840a (lower face nodes)
50 60 70 80 ...        $ T-840c (upper face nodes)
...
1 1 1 1 1 1 1 1        $ T-840g (x increments)
5 5 5 5 5 5 5 5        $ T-840h (y increments)
```

generates six **E840** elements, with the following nodes:

```
10 20 30 40 50 60 70 80     Element #1
11 21 31 41 51 61 71 81     Element #2
12 22 32 42 52 62 72 82     Element #3
15 25 35 45 55 65 75 85     Element #4
16 26 36 46 56 66 76 86     Element #5
17 27 37 47 57 67 77 87     Element #6
```

return to T-100

T-845 E845 10-Node Sandwich Transition Element Definition

The **E845** 10-node sandwich-transition element, shown in Figure 9.5, is used in sandwich shell units to make a transition between one mesh and another that has nodes that are exactly half as far apart as the one in which the **E845** element "resides." It can be used to accomplish the same objective in an element unit. A single T-845 definition may specify one or more **E845** sandwich transition elements.

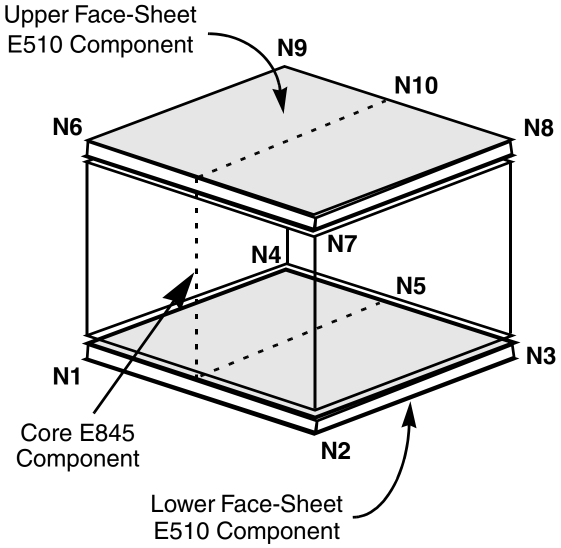


Figure 9.5 **E845** 10-Node Sandwich Transition Elements

Definition of one or more **E845** 10-node sandwich transition elements is accomplished with the following set of records:

T-845	to specify parameters used for all parts of the element
T-845a	to specify information for the lower face sheet of the element
T-845b	to specify lower face sheet transformation angles (optional)
T-845c	to specify information for the upper face sheet
T-845d	to specify upper face sheet transformation angles (optional)
T-845e	to specify core parameters
T-845f	to specify core transformation angles (optional)
T-845g	for "x-direction" incrementation parameters
T-845h	for "y-direction" incrementation parameters

These are described sequentially in the following text.

KELT ILIN INTEG IPEN IEDGE NX NY USER

KELT element code number (must be 845)

ILIN geometric-linearity flag:

- 0 – nonlinear strain-displacement relations
- 1 – linear strain-displacement relations

INTEG integration-type flag (see N-1):

- 0 – standard integration, or 2×2 Gauss points for **E410** elements
- 1 – modified 5-point integration, previously referred to as full integration

IPEN penalty option (see N-1)

- 0 – no penalty function on fourth-order terms in **E410** elements
- 1 – penalty function included in **E410** elements

IEDGE identifies the **E845** edge on which node **N5** is located (**N10** is above **N5**):

- 1 – node **N5** is between **N3** and **N4**
- 2 – node **N5** is between **N4** and **N1**
- 3 – node **N5** is between **N1** and **N2**
- 4 – node **N5** is between **N2** and **N3**

NX x-direction looping parameter, set equal to unity by **STAGS** if omitted or nonpositive; **NX** > 1 instructs **STAGS** to generate a set of **NX** type **E845** elements in the x direction, using the increments given on the T-845g record

NY y-direction looping parameter, set equal to unity by **STAGS** if omitted or nonpositive; **NY** > 1 instructs **STAGS** to generate a set of **NY** type **E845** elements in the *y* direction for each of the **NX** elements generated in the *x* direction in the current definition, using the increments given on the T-845h record

USER user-specified element number for the first **E845** element generated here (used only if **IUWLE** = 1 on H-1)

✦ *go to* T-845a

T-845a E845 Lower Face-Sheet Properties

A single T-845a record must be included immediately following the T-845 record, to specify the nodes for the lower face sheet of the first **E845** element and to specify other parameters for the lower face sheet of each of the element(s) specified in the current definition.

N1 N2 N3 N4 N5 IFABL ZETAL ECZL IPLASL IANGL

N1	first node point on lower face sheet
N2	second node point on lower face sheet
N3	third node point on lower face sheet
N4	fourth node point on lower face sheet
N5	fifth node point on lower face sheet

IFABL fabrication identifier for the lower face sheet element(s); this is equivalent to the **WALL** parameter for **E410** quadrilateral elements:

>0 – wall configuration number in the Wall Fabrication Table (K-1)

0 – shell wall properties are given in user-written subroutine WALL (See the T-4 record description for more information about this)

<0 – shell fabrication identifier in the GCP Fabrication Table (I-21a) *(this option is not operational yet and should not be used)*

ZETAL angle ζ between the wall-reference coordinate x_w and the fabrication coordinate $\bar{x}$, for the lower face sheet; ζ is a right-handed rotation about $\bar{z}$; see Figure 8.2 on page 8-19

ECZL eccentricity in z' direction, for the lower face sheet; **ECZL** is the z' coordinate of the shell wall middle surface; please refer to Figure 6.2 on page 6-28; in element units, (x', y', z') are used in place of (X', Y', Z'), which do not exist in an element unit; see "Effects of Eccentricity" on page 16-6

IPLASL lower face sheet material-nonlinearity flag:

0 – elastic behavior only

1 – plasticity included, with the material law satisfied at each element integration point

2 – plasticity included, with the material law satisfied at the element centroid (centroidal plasticity)

IANGL lower face sheet wall-reference option; see discussion on page 8-18

0 – use default strategy of projecting x_g, y_g to establish x_w

1 – input $\mathbf{r_w}$, which is projected to establish x_w; see (T-845b)

```
if ( IANGL > 0 ) then
                         go to T-845b
else                     go to T-845c
```

T-845b E845 Lower Face-Sheet Wall Reference Vector

RXL RYL RZL

RXL, RYL, RZL lower face sheet wall reference vector, $\mathbf{r_w}$, which is projected onto the element surface to determine the direction of the wall-reference coordinate x_w; $\mathbf{r_w}$ is expressed in (x_g, y_g, z_g) global coordinates

✦ *go to* T-845c

T-845c E845 Upper Face-Sheet Properties

A single T-845c record must be included immediately following the T-845a (or T-845b) record, to specify the nodes for the upper face sheet of the first **E845** element and to specify other parameters for the upper face sheet of each of the element(s) specified in the current definition.

N6 N7 N8 N9 N10 IFABU ZETAU ECZU IPLASU IANGU

N6 first node point on upper face sheet

N7 second node point on upper face sheet

N8 third node point on upper face sheet

N9 fourth node point on upper face sheet

N10 fifth node point on upper face sheet

IFABU fabrication identifier for the upper face sheet element(s); this is equivalent to the **WALL** parameter for **E410** quadrilateral elements:

>0 – wall configuration number in the Wall Fabrication Table (K-1)
0 – shell wall properties are given in user-written subroutine WALL
<0 – shell fabrication identifier in the GCP Fabrication Table (I-21a)

ZETAU angle ζ between the wall-reference coordinate x_w and the fabrication coordinate $\bar{x}$, for the upper face sheet; ζ is a right-handed rotation about $\bar{z}$

ECZU eccentricity in z' direction, for the upper face sheet; **ECZL** is the z' coordinate of the shell wall middle surface

IPLASU upper face sheet material-nonlinearity flag:

0 – elastic behavior only
1 – plasticity included, with the material law satisfied at each element integration point
2 – plasticity included, with the material law satisfied at the element centroid (centroidal plasticity)

IANGL upper face sheet wall-reference option; see discussion on page 8-18

0 – use default strategy of projecting x_g, y_g to establish x_w
1 – input $\mathbf{r}_w$, which is projected to establish x_w; see (T-845d)

```
if ( IANGU > 0 ) then    go to T-845d
else                     go to T-845e
```

T-845d E845 Upper Face-Sheet Wall Reference Vector

RXU RYU RZU

RXU, RYU, RZU upper face sheet wall reference vector, $\mathbf{r_w}$, which is projected onto the element surface to determine the direction of the wall-reference coordinate x_w; $\mathbf{r_w}$ is expressed in (x_g, y_g, z_g) global coordinates

✦ *go to* T-845e

T-845e E845 Core Properties

A single T-845e record must be included immediately following the T-845c (or T-845d) record, to specify parameters for the core component of the element(s) specified in the current definition.

IFABC ZETAC IPLASC IANGC

IFABC core fabrication identifier:

>0 – wall configuration number in the Wall Fabrication Table (K-1)

<0 – solid fabrication identifier in the GCP Fabrication Table (I-22a)

ZETAC angle ζ between the wall-reference coordinate x_w and the fabrication coordinate $\bar{x}$, for the core component; ζ is a right-handed rotation about $\bar{z}$

IPLASC core material-nonlinearity flag:

0 – elastic behavior only

1 – plasticity included *(not operational with GCP fabrications, yet)*

IANGC core wall-reference option; see discussion on page 8-18

0 – use default strategy of projecting x_g, y_g to establish x_w

1 – input $\mathbf{r_w}$, which is projected to establish x_w; see (T-845f)

✦	**NX**	(T-845)	x-direction looping parameter
	NY	(T-845)	y-direction looping parameter

```
if      ( IANGC > 0 ) then go to T-845f
elseif  ( NX > 0 )    then go to T-845g
elseif  ( NY > 0 )    then go to T-845h
else    return to T-100
```

T-845f E845 Core Reference Vector

RXC RYC RZC

RXC, RYC, RZC core reference vector, $\mathbf{r_w}$, which is projected onto the element surface to determine the direction of the core-reference coordinate x_w; $\mathbf{r_w}$ is expressed in (x_g, y_g, z_g) global coordinates

NX	(T-845)	x-direction looping parameter
NY	(T-845)	y-direction looping parameter

```
if      ( NX $> 0$ )    then  go to T-845g
elseif  ( NY $> 0$ )    then  go to T-845h
else    return to T-100
```

T-845g E845 X-Direction Incrementations

A single record of type T-845g must be included immediately after the T-845e or T-845f record when the **NX** "x-direction" *looping parameter* (T-845) is greater than unity. Ten nodal incrementation variables are specified here for use with the "x-direction" looping function on the T-845 record. **NX** **E845** sandwich transition elements are generated in the *x* direction with this information. One incrementation variable is also specified here for "x-direction" looping with the user-element-number parameter on T-845.

I1 I2 I3 I4 I5 I6 I7 I8 I9 I10 I11

I1 incrementation for the **N1** lower face sheet node on the T-845a record
I2 incrementation for the **N2** lower face sheet node on the T-845a record
I3 incrementation for the **N3** lower face sheet node on the T-845a record
I4 incrementation for the **N4** lower face sheet node on the T-845a record
I5 incrementation for the **N5** lower face sheet node on the T-845a record
I6 incrementation for the **N6** upper face sheet node on the T-845c record
I7 incrementation for the **N7** upper face sheet node on the T-845c record
I8 incrementation for the **N8** upper face sheet node on the T-845c record
I9 incrementation for the **N9** upper face sheet node on the T-845c record
I10 incrementation for the **N10** upper face sheet node on the T-845c record
I11 incrementation for **USER** on the T-845 record

Any of these incrementation variables can be negative, zero, or positive, as required.

Example: the following T-845 / T-845a / T-845c / T-845g record combination:

```
845 1 0 0 1 3                $ T-845 with NX=3
10 20 30 40  50 ...          $ T-845a lower face nodes
60 70 80 90 100 ...          $ T-845c upper face nodes
...
1 1 1 1 1 2 2 2 2 2          $ T-845g increments
```

generates three **E845** elements, with the following nodes:

```
10 20 30 40 50  60 70 80 90 100Element #1
11 21 31 41 51  62 72 82 92 102Element #2
12 22 32 42 52  64 74 84 94 104Element #3
```

NY (T-845) y-direction looping parameter

if (**NY** > 0) then *go to* T-845h
else *return to* T-100

T-845h Y-Direction Incrementations

A type T-845h record must be included immediately after the T-845e or T-845f or T-845g record when the **NY** “y-direction” *looping parameter* is greater than unity (T-845). Ten nodal incrementation variables are specified here for use with the T-845 record “y-direction” looping function. **NY** **E845** sandwich transition elements are generated in the “y-direction”, for each **E845** element generated in the *x* direction, with this information. The **NX** and **NY** looping parameters are usually employed together to specify **NX** × **NY** **E845** elements in a single stroke.

J1 J2 J3 J4 J5 J6 J7 J8 J9 J10 J11

J1 incrementation for the **N1** lower face sheet node on the T-845a record

J2 incrementation for the **N2** lower face sheet node on the T-845a record

J3 incrementation for the **N3** lower face sheet node on the T-845a record

J4 incrementation for the **N4** lower face sheet node on the T-845a record

J5 incrementation for the **N5** lower face sheet node on the T-845a record

J6 incrementation for the **N6** upper face sheet node on the T-845c record

J7 incrementation for the **N7** upper face sheet node on the T-845c record

J8 incrementation for the **N8** upper face sheet node on the T-845c record

J9 incrementation for the **N9** upper face sheet node on the T-845c record

J10 incrementation for the **N10** upper face sheet node on the T-845c record

J11 incrementation for **USER** on the T-845 record

Any of these incrementation variables can be negative, zero, or positive, as required.

Example: the following T-845 / T-845a / T-845c / T-845g / T-845h record combination:

```
845 1 0 0 1 3 2        $ T-845 NX=3, NY=2
10 20 30 40  50 ...    $ T-845a (lower face nodes)
60 70 80 90 100 ...    $ T-845c (upper face nodes)
...
1 1 1 1 1 1 1 1 1 1    $ T-845g (x increments)
5 5 5 5 5 5 5 5 5 5    $ T-845h (y increments)
```

generates six **E845** elements, with the following nodes:

```
10 20 30 40 50  60 70 80 90 100  Element #1
11 21 31 41 51  61 71 81 91 101  Element #2
12 22 32 42 52  62 72 82 92 102  Element #3
15 25 35 45 55  65 75 85 95 105  Element #4
16 26 36 46 56  66 76 86 96 106  Element #5
17 27 37 47 57  67 77 87 97 107  Element #6
```

return to T-100

T-847 14-Node Sandwich Transition Element Definition

The **E847** 14-node sandwich-transition element, shown in Figure 9.6, is used in sandwich shell units to make a transition between one mesh and two other meshes that have nodes that are exactly half as far apart as the one in which the **E847** element “resides.” It can be used to accomplish the same objective in an element unit. A single T-847 definition may specify one or more **E847** sandwich transition elements.

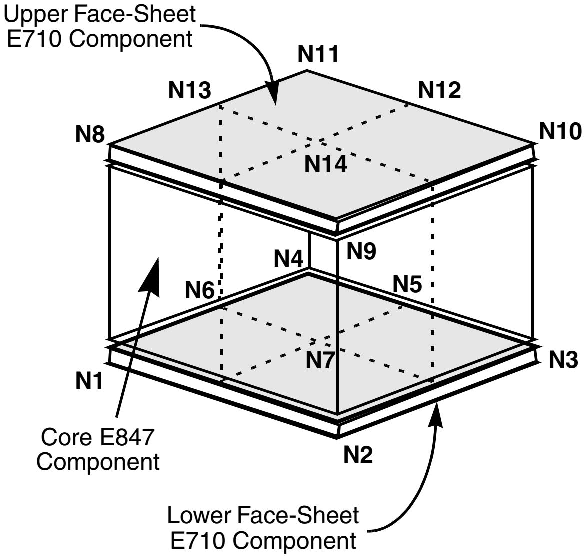


Figure 9.6 **E847** 14-Node Sandwich Transition Elements

Definition of one or more **E847** 14-node sandwich transition elements is accomplished with the following set of records:

T-847	to specify parameters used for all parts of the element
T-847a	to specify information for the lower face sheet of the element
T-847b	to specify lower face sheet transformation angles (optional)
T-847c	to specify information for the upper face sheet
T-847d	to specify upper face sheet transformation angles (optional)
T-847e	to specify core parameters
T-847f	to specify core transformation angles (optional)
T-847g	for “x-direction” incrementation parameters
T-847h	for “y-direction” incrementation parameters

These are described sequentially in the following text.

KELT ILIN INTEG IPEN IEDGE NX NY USER

ILIN geometric-linearity flag:

0 – nonlinear strain-displacement relations
1 – linear strain-displacement relations

INTEG integration-type flag (see N-1):

0 – standard integration, or 2×2 Gauss points for **E410** elements
1 – modified 5-point integration, previously referred to as full integration

IPEN penalty option (see N-1)

0 – no penalty function on fourth-order terms in **E410** elements
1 – penalty function included in **E410** elements

IEDGE identifies the **E847** edges on which nodes **N5** and **N6** are located nodes **N12** and **N13** are above **N5** and **N6**, respectively:

1 – node **N5** is between **N3** and **N4**; node **N6** is between **N4** and **N1**
2 – node **N5** is between **N4** and **N1**; node **N6** is between **N1** and **N2**
3 – node **N5** is between **N1** and **N2**; node **N6** is between **N2** and **N3**
4 – node **N5** is between **N2** and **N3**; node **N6** is between **N3** and **N4**

NX x-direction looping parameter, set equal to unity by **STAGS** if omitted or nonpositive; **NX** > 1 instructs **STAGS** to generate a set of **NX** type **E847** elements in the *x* direction, using the increments given on T-847g

NY y-direction looping parameter, set equal to unity by **STAGS** if omitted or nonpositive; **NY** > 1 instructs **STAGS** to generate a set of **NY** type **E847** elements in the *y* direction for each of the **NX** elements generated in the *x* direction in the current definition, using the increments given on T-847h

USER user-specified element number for the first **E847** element generated here (used only if **IUWLE** = 1 on H-1)

✦ *go to* T-847a

T-847a E847 Lower Face-Sheet Properties

A single T-847a record must be included immediately following the T-847 record, to specify the nodes for the lower face sheet of the first **E847** element and to specify other parameters for the lower face sheet of each of the element(s) specified in the current definition.

N1 N2 N3 N4 N5 N6 N7 IFABL ZETAL ECZL IPLASL IANGL

N1	first node point on lower face sheet
N2	second node point on lower face sheet
N3	third node point on lower face sheet
N4	fourth node point on lower face sheet
N5	fifth node point on lower face sheet
N6	sixth node point on lower face sheet
N7	seventh node point on lower face sheet

IFABL fabrication identifier for the lower face sheet element(s); this is equivalent to the **WALL** parameter for **E410** quadrilateral elements:

>0 – wall configuration number in the Wall Fabrication Table (K-1)

0 – shell wall properties are given in user-written subroutine WALL (See the T-4 record description for more information about this)

<0 – shell fabrication identifier in the GCP Fabrication Table (I-21a)

ZETAL angle ζ between the wall-reference coordinate x_w and the fabrication coordinate $\bar{x}$, for the lower face sheet; ζ is a right-handed rotation about $\bar{z}$; see Figure 8.2 on page 8-19.

ECZL eccentricity in z' direction, for the lower face sheet; **ECZL** is the z' coordinate of the shell wall middle surface; please refer to Figure 6.2 on page 6-28; in element units, (x', y', z') are used in place of (X', Y', Z'), which do not exist in an element unit; see "Effects of Eccentricity" on page 16-6.

IPLASL lower face sheet material-nonlinearity flag:

0 – elastic behavior only

1 – plasticity included, with the material law satisfied at each element integration point

2 – plasticity included, with the material law satisfied at the element centroid (centroidal plasticity)

IANGL lower face sheet wall-reference option; see discussion on page 8-18

0 – use default strategy of projecting x_g, y_g to establish x_w

1 – input $\mathbf{r_w}$, which is projected to establish x_w; see (T-847b)

```
if   ( IANGL > 0 )  then
                        go to T-847b
else                    go to T-847c
```

T-847b E847 Lower Face-Sheet Wall Reference Vector

RXL RYL RZL

RXL, RYL, RZL lower face sheet wall reference vector, $\mathbf{r_w}$, which is projected onto the element surface to determine the direction of the wall-reference coordinate x_w; $\mathbf{r_w}$ is expressed in (x_g, y_g, z_g) global coordinates

✦ *go to* T-847c

T-847c E847 Upper Face-Sheet Properties

A single T-847c record must be included immediately following the T-847a (or T-847b) record, to specify the nodes for the upper face sheet of the first **E847** element and to specify other parameters for the upper face sheet of each of the element(s) specified in the current definition.

N8 N9 N10 N11 N12 N13 N14 IFABU ZETAU ECZU IPLASU IANGU

N8	first node point on upper face sheet
N9	second node point on upper face sheet
N10	third node point on upper face sheet
N11	fourth node point on upper face sheet
N12	fifth node point on upper face sheet
N13	sixth node point on upper face sheet
N14	seventh node point on upper face sheet

IFABU fabrication identifier for the upper face sheet element(s); this is equivalent to the **WALL** parameter for **E410** quadrilateral elements:

>0 – wall configuration number in the Wall Fabrication Table (K-1)

0 – shell wall properties are given in user-written subroutine WALL

<0 – shell fabrication identifier in the GCP Fabrication Table (I-21a)

ZETAU angle ζ between the wall-reference coordinate x_w and the fabrication coordinate $\bar{x}$, for the upper face sheet; ζ is a right-handed rotation about $\bar{z}$

ECZU eccentricity in z' direction, for the upper face sheet; **ECZL** is the z' coordinate of the shell wall middle surface

IPLASU upper face sheet material-nonlinearity flag:

0 – elastic behavior only

1 – plasticity included, with the material law satisfied at each element integration point

2 – plasticity included, with the material law satisfied at the element centroid (centroidal plasticity)

IANGL upper face sheet wall-reference option; see discussion on page 8-18

0 – use default strategy of projecting x_g, y_g to establish x_w

1 – input $\mathbf{r_w}$, which is projected to establish x_w; see (T-847d)

✦ if (**IANGU** > 0) then *go to* T-847d
else *go to* T-847e

T-847d E847 Upper Face-Sheet Wall Reference Vector

RXU RYU RZU

RXU, RYU, RZU upper face sheet wall reference vector, $\mathbf{r_w}$, which is projected onto the element surface to determine the direction of the wall-reference coordinate x_w; $\mathbf{r_w}$ is expressed in (x_g, y_g, z_g) global coordinates

go to T-847e

T-847e E847 Core Properties

A single T-847e record must be included immediately following the T-847c (or T-847d) record, to specify parameters for the core component of the element(s) specified in the current definition.

IFABC ZETAC IPLASC IANGC

IFABC core fabrication identifier:

>0 – wall configuration number in the Wall Fabrication Table (K-1)
<0 – solid fabrication identifier in the GCP Fabrication Table (I-22a)

ZETAC angle ζ between the wall-reference coordinate x_w and the fabrication coordinate $\bar{x}$, for the core component; ζ is a right-handed rotation about $\bar{z}$

IPLASC core material-nonlinearity flag:

0 – elastic behavior only
1 – plasticity included *(not operational with GCP fabrications, yet)*

IANGC core wall-reference option; see discussion on page 8-18

0 – use default strategy of projecting x_g, y_g to establish x_w
1 – input $\mathbf{r_w}$, which is projected to establish x_w; see (T-847f)

NX	(T-847)	x-direction looping parameter
NY	(T-847)	y-direction looping parameter

```
if       ( IANGC > 0 )    then  go to T-847f
elseif   ( NX > 0 )       then  go to T-847g
elseif   ( NY > 0 )       then  go to T-847h
else     return to T-100
```

T-847f E847 Core Reference Vector

RXC RYC RZC

RXC, RYC, RZC core reference vector, $\mathbf{r_w}$, which is projected onto the element surface to determine the direction of the core-reference coordinate x_w; $\mathbf{r_w}$ is expressed in (x_g, y_g, z_g) global coordinates

NX	(T-847)	x-direction looping parameter
NY	(T-847)	y-direction looping parameter

```
if      ( $NX > 0$ )     then  go to T-847g
elseif  ( $NY > 0$ )     then  go to T-847h
else    return to T-100
```

T-847g X-Direction Incrementations

A single record of type T-847g must be included immediately after the T-847e or T-847f record when the **NX** “x-direction” *looping parameter* (T-847) is greater than unity. Fourteen nodal incrementation variables are specified here for use with the “x-direction” looping function on the T-847 record. **NX** **E847** sandwich elements are generated in the *x* direction with this information. One incrementation variable is also specified here for “x-direction” looping with the user-element-number parameter on T-847.

I1 I2 I3 I4 I5 I6 I7 I8 I9 I10 I11 I12 I13 I14 I15

I1 incrementation for the **N1** lower face sheet node on the T-847a record

I2 incrementation for the **N2** lower face sheet node on the T-847a record

I3 incrementation for the **N3** lower face sheet node on the T-847a record

I4 incrementation for the **N4** lower face sheet node on the T-847a record

I5 incrementation for the **N5** lower face sheet node on the T-847a record

I6 incrementation for the **N6** lower face sheet node on the T-847a record

I7 incrementation for the **N7** lower face sheet node on the T-847a record

I8 incrementation for the **N8** upper face sheet node on the T-847c record

I9 incrementation for the **N9** upper face sheet node on the T-847c record

I10 incrementation for the **N10** upper face sheet node on the T-847c record

I11 incrementation for the **N11** upper face sheet node on the T-847c record

I12 incrementation for the **N12** upper face sheet node on the T-847c record

I13 incrementation for the **N13** upper face sheet node on the T-847c record

I14 incrementation for the **N14** upper face sheet node on the T-847c record

I15 incrementation for **USER** on the T-847 record

Any of these incrementation variables can be negative, zero, or positive, as required.

NY (T-847) y-direction looping parameter

if (**NY** > 0) then *go to* T-847h
else *return to* T-100

T-847h E847 Y-Direction Incrementations

A type T-847h record must be included immediately after the T-847e or T-847f or T-847g record when the **NY** “y-direction” *looping parameter* is greater than unity (T-847). Fourteen nodal incrementation variables are specified here for use with the T-847 record “y-direction” looping function. **NY** **E847** sandwich elements are generated in the *y* direction, for each **E847** element generated in the *x* direction, with this information. The **NX** and **NY** looping parameters are usually employed together to specify **NX** × **NY** **E847** elements in a single stroke.

J1 J2 J3 J4 J5 J6 J7 J8 J9 J10 J11 J12 J13 J14 J15

J1 incrementation for the **N1** lower face sheet node on the T-847a record

J2 incrementation for the **N2** lower face sheet node on the T-847a record

J3 incrementation for the **N3** lower face sheet node on the T-847a record

J4 incrementation for the **N4** lower face sheet node on the T-847a record

J5 incrementation for the **N5** lower face sheet node on the T-847a record

J6 incrementation for the **N6** lower face sheet node on the T-847a record

J7 incrementation for the **N7** lower face sheet node on the T-847a record

J8 incrementation for the **N8** upper face sheet node on the T-847c record

J9 incrementation for the **N9** upper face sheet node on the T-847c record

J10 incrementation for the **N10** upper face sheet node on the T-847c record

J11 incrementation for the **N11** upper face sheet node on the T-847c record

J12 incrementation for the **N12** upper face sheet node on the T-847c record

J13 incrementation for the **N13** upper face sheet node on the T-847c record

J14 incrementation for the **N14** upper face sheet node on the T-847c record

J15 incrementation for **USER** on the T-847 record

Any of these incrementation variables can be negative, zero, or positive, as required.

return to T-100

T-849 E849 18-Node Sandwich Element Definition

The **E849** 18-node sandwich element in STAGS, shown in Figure 9.7, is constructed with a pair of **E480** 9–node quadrilateral shells (with bending as well as the usual membrane stiffness) that are held apart by a lightweight core that has three-dimensional elastic properties.

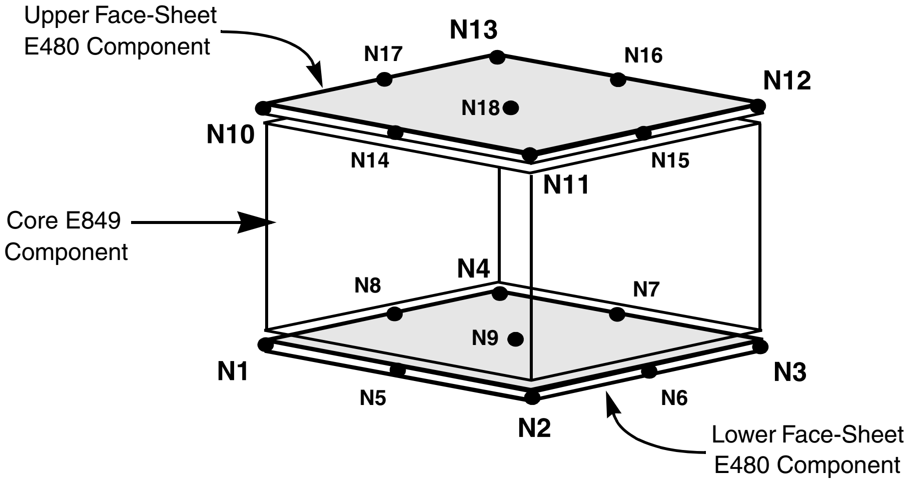


Figure 9.7 **E849** 18-Node Sandwich Element

Definition of one or more **E849** 18-node sandwich elements is accomplished with the following set of records:

T-849	to specify parameters used for all parts of the element
T-849a	to specify information for the lower face sheet of the element
T-849b	to specify lower face sheet transformation angles (optional)
T-849c	to specify information for the upper face sheet
T-849d	to specify upper face sheet transformation angles (optional)
T-849e	to specify core parameters
T-849f	to specify core transformation angles (optional)
T-849g	for “x-direction” incrementation parameters
T-849h	for “y-direction” incrementation parameters

These are described sequentially in the following text.

KELT ILIN INTEG IPEN NX NY USERC USER1 USER2

KELT element code number (must be 849)

ILIN geometric-linearity flag:

0 – nonlinear strain-displacement relations
1 – linear strain-displacement relations

INTEG integration-type flag: not used for this element; set **INTEG** = 0

IPEN penalty option: not used for this element; set **IPEN** = 0

NX x-direction looping parameter, set equal to unity by **STAGS** if omitted or nonpositive; **NX** > 1 instructs **STAGS** to generate a set of **NX** type **E849** elements in the *x* direction, using nodal incrementation information given on T-849g

NY y-direction looping parameter, set equal to unity by **STAGS** if omitted or nonpositive; **NY** > 1 instructs **STAGS** to generate a set of **NY** type **E849** elements in the *y* direction for each of the **NX** elements generated in the *x* direction in the current definition, using nodal incrementation information given on T-849h

USERC user-specified element number for core component
(used only if **IUWLE** = 1 on H-1)

USER1 user-specified element number for **lower face sheet**, (if **IUWLE** = 1 on H-1)

USER2 user-specified element number for **upper face sheet**, (if **IUWLE** = 1 on H-1)

go to T-849a

T-849a E849 Lower Face-Sheet Properties

A single T-849a record must be included immediately following the T-849 record, to specify the nodes for the lower face sheet of the first **E849** element (see Figure 9.7 on page 9-120) and to specify other parameters for the lower face sheet of each element that is specified in the current definition.

N1 N2 N3 N4 N5 N6 N7 N8 N9 IFABL ZETAL ECZL IPLASL IANGL

N1	node # 1 on the lower face sheet
N2	node # 2 on the lower face sheet
N3	node # 3 on the lower face sheet
N4	node # 4 on the lower face sheet
N5	node # 5 on the lower face sheet
N6	node # 6 on the lower face sheet
N7	node # 7 on the lower face sheet
N8	node # 8 on the lower face sheet
N9	node # 9 on the lower face sheet

IFABL fabrication identifier for the lower face sheet element(s); this is equivalent to the **WALL** parameter for **E480** quadrilateral elements:

>0 – wall configuration number in the Wall Fabrication Table (K-1)
0 – shell wall properties are given in user-written subroutine WALL (See the T-4 record description for more information about this)
<0 – shell fabrication identifier in the GCP Fabrication Table (I-21a)

ZETAL angle ζ between the wall-reference coordinate x_w and the fabrication coordinate $\bar{x}$, for the lower face sheet; ζ is a right-handed rotation about $\bar{z}$; see Figure 8.2 on page 8-19.

ECZL eccentricity in z' direction, for the lower face sheet; **ECZL** is the z' coordinate of the shell wall middle surface; please refer to Figure 6.2 on page 6-28; in element units, (x', y', z') are used in place of (X', Y', Z'), which do not exist in an element unit; see "Effects of Eccentricity" on page 16-6.

IPLASL lower face sheet material-nonlinearity flag:

0 – elastic behavior only
1 – plasticity included, with the material law satisfied at each element integration point
2 – plasticity included, with the material law satisfied at the element centroid (centroidal plasticity)

IANGL lower face sheet wall-reference option; see discussion on page 8-18

0 – use default strategy of projecting x_g, y_g to establish x_w

1 – input $\mathbf{r_w}$, which is projected to establish x_w; see (T-849b)

```
if  ( IANGL $> 0$ )  then
                     go to T-849b
else                 go to T-849c
```

T-849b E849 Lower Face-Sheet Wall Reference Vector

RXL RYL RZL

RXL, RYL, RZL lower face sheet wall reference vector, $\mathbf{r_w}$, which is projected onto the element surface to determine the direction of the wall-reference coordinate x_w; $\mathbf{r_w}$ is expressed in (x_g, y_g, z_g) global coordinates

✦ *go to* T-849c

T-849c E849 Upper Face-Sheet Properties

A single T-849c record must be included immediately following the T-849a (or T-849b) record, to specify the nodes for the upper face sheet of the first **E849** element (see Figure 9.7 on page 9-120) and to specify other parameters for the upper face sheet of each element that is specified in the current definition.

N10 N11 N12 N13 N14 N15 N16 N17 N18 IFABU ZETAU ECZU IPLASU IANGU

N10 node # 1 on the upper face sheet

N11 node # 2 on the upper face sheet

N12 node # 3 on the upper face sheet

N13 node # 4 on the upper face sheet

N14 node # 5 on the upper face sheet

N15 node # 6 on the upper face sheet

N16 node # 7 on the upper face sheet

N17 node # 8 on the upper face sheet

N18 node # 9 on the upper face sheet

IFABU fabrication identifier for the upper face sheet element(s); this is equivalent to the **WALL** parameter for **E410** quadrilateral elements:

>0 – wall configuration number in the Wall Fabrication Table (K-1)
0 – shell wall properties are given in user-written subroutine WALL
<0 – shell fabrication identifier in the GCP Fabrication Table (I-21a)

ZETAU angle ζ between the wall-reference coordinate x_w and the fabrication coordinate $\bar{x}$, for the upper face sheet; ζ is a right-handed rotation about $\bar{z}$

ECZU eccentricity in z' direction, for the upper face sheet; **ECZL** is the z' coordinate of the shell wall middle surface

IPLASU upper face sheet material-nonlinearity flag:

0 – elastic behavior only
1 – plasticity included, with the material law satisfied at each element integration point
2 – plasticity included, with the material law satisfied at the element centroid (centroidal plasticity)

IANGL upper face sheet wall-reference option; see discussion on page 8-18

0 – use default strategy of projecting x_g, y_g to establish x_w
1 – input $\mathbf{r_w}$, which is projected to establish x_w; see (T-849d)

```
if ( IANGU > 0 ) then    go to T-849d
else                     go to T-849e
```

T-849d E849 Upper Face-Sheet Wall Reference Vector

RXU RYU RZU

RXU, RYU, RZU upper face sheet wall reference vector, $\mathbf{r_w}$, which is projected onto the element surface to determine the direction of the wall-reference coordinate x_w; $\mathbf{r_w}$ is expressed in (x_g, y_g, z_g) global coordinates

go to T-849e

T-849e E849 Core Properties

A single T-849e record must be included immediately following the T-849c (or T-849d) record, to specify parameters for the core component of the element(s) specified in the current definition.

IFABC ZETAC IPLASC IANGC

IFABC core fabrication identifier:

- >0 – wall configuration number in the Wall Fabrication Table (K-1)
- <0 – solid fabrication identifier in the GCP Fabrication Table (I-22a)

ZETAC angle ζ between the wall-reference coordinate x_w and the fabrication coordinate $\bar{x}$, for the core component; ζ is a right-handed rotation about $\bar{z}$

IPLASC core material-nonlinearity flag:

- 0 – elastic behavior only
- 1 – plasticity included *(not operational with GCP fabrications, yet)*

IANGC core wall-reference option; see discussion on page 8-18

- 0 – use default strategy of projecting x_g, y_g to establish x_w
- 1 – input $\mathbf{r_w}$, which is projected to establish x_w; see (T-849f)

NX	(T-849)	x-direction looping parameter
NY	(T-849)	y-direction looping parameter

```
if       ( IANGC > 0 )  then  go to T-849f
elseif   ( NX > 0 )     then  go to T-849g
elseif   ( NY > 0 )     then  go to T-849h
else     return to T-100
```

T-849f E849 Core Reference Vector

RXC RYC RZC

RXC, RYC, RZC core reference vector, $\mathbf{r_w}$, which is projected onto the element surface to determine the direction of the core-reference coordinate x_w; $\mathbf{r_w}$ is expressed in (x_g, y_g, z_g) global coordinates

NX	(T-849)	x-direction looping parameter
NY	(T-849)	y-direction looping parameter

```
if      ( NX $> 0$ ) then  go to T-849g
elseif  ( NY $> 0$ ) then  go to T-849h
else    return to T-100
```

T-849g X-Direction Incrementations

A single record of type T-849g must be included immediately after the T-849e or T-849f record when the **NX** “x-direction” *looping parameter* (T-849) is greater than unity. Eighteen nodal incrementation variables are specified here for use with the “x-direction” looping function on the T-849 record. **NX** **E849** sandwich elements are generated in the *x* direction with this information. Three incrementation variables are also specified here for “x-direction” looping with the user-element-number parameters on T-849.

(IX(k), k=1,18) IXC IX1 IX2

IX(k) *x*-direction incrementation for the kth node,which is
on the T-849a record (when 1 ≤ **k** ≤ 9), or
on the T-849c record (when 10 ≤ **k** ≤ 18)

IXC *x*-direction incrementation for **USERC** on the T-849 record

IX1 *x*-direction incrementation for **USER1** on the T-849 record

IX2 *x*-direction incrementation for **USER2** on the T-849 record

Any of these incrementation variables can be negative, zero, or positive, as required.

Example: the following T-849 / T-849a / T-849c / T-849g record combination:

```
849 1 0 0 3                          $ T-849 with NX=3
10 20 30 40 50 60 70 80 90 ...       $ T-849a lower face nodes
15 25 35 45 55 65 75 85 95 ...       $ T-849c upper face nodes
...
1 1 1 1 1 1 1 1 1    9*2             $ T-849g increments
```

generates three **E849** elements, with the following nodes:

```
10 20 30 40 50 60 70 80 90   15 25 35 45 55 65 75 85 95Element #1
11 21 31 41 51 61 71 81 91   17 27 37 47 57 67 77 87 97Element #2
12 22 32 42 52 62 72 82 92   19 29 39 49 59 69 79 89 99Element #3
```

NY (T-849) y-direction looping parameter

if (**NY** > 0) then *go to* T-849h
else *return to* T-100

T-849h Y-Direction Incrementations

A single type T-849h record must be included immediately after the T-849e or T-849f or T-849g record when the **NY** "y-direction" *looping parameter* is greater than unity (T-849). Eighteen nodal incrementation variables are specified here for use with the T-849 record "y-direction" looping function. **NY** **E849** sandwich elements are generated in the *y* direction, for each **E849** element generated in the *x* direction, with this information. The **NX** and **NY** looping parameters are usually employed together to specify **NX** × **NY** **E849** elements in a single stroke.

(IY(k), k=1,18) IYC IY1 IY2

IY(k) *y*-direction incrementation for the kth node,which is
on the T-849a record (when $1 \leq \mathbf{k} \leq 9$), or
on the T-849c record (when $10 \leq \mathbf{k} \leq 18$)

IYC *y*-direction incrementation for **USERC** on the T-849 record

IY1 *y*-direction incrementation for **USER1** on the T-849 record

IY2 *y*-direction incrementation for **USER2** on the T-849 record

Any of these incrementation variables can be negative, zero, or positive, as required.

return to T-100

9.7 Definition of Solid Elements *via* the Ecom Protocol

The current version of **STAGS** has four conventional solid elements that are fully operational and "hooks" for an as-yet-undetermined number of unconventional solid elements that are not "ready for prime time" yet. The four operational solid elements—members of the **E880** "family" of elements—are shown in Figure 9.8. The other solid elements—members of the **E860** family—were originally implemented in and are being transferred into **STAGS** from the tetrahedral, pentahedral and hexahedral constructions in the ORACLE program.

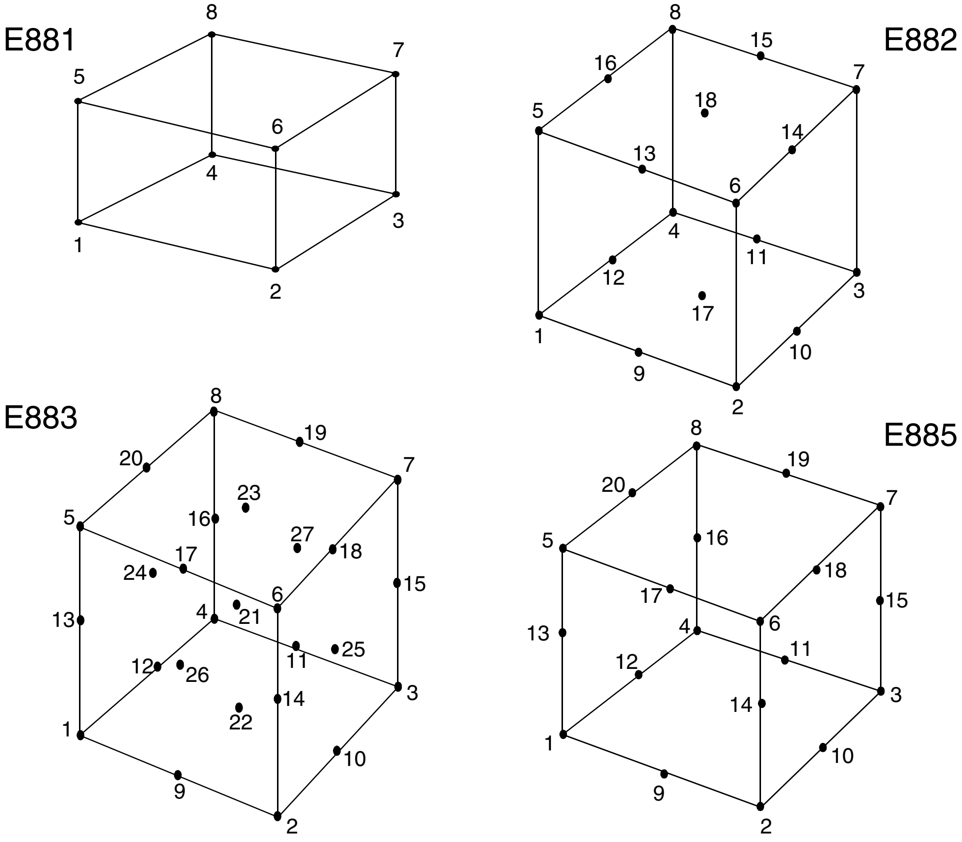


Figure 9.8 The **E880** Family of Solid Elements

In the Edef protocol (which was described in Chapter 8), the number of **E880**-element-family *definitions* to be made for the current element unit was specified *via* the **N880** parameter on the T-5 record and that the element *type* for any given definition was specified by the value of **KELT** in that definition. In the Ecom protocol (which is being described here), the command keyword (on T-100) specifies the element type explicitly.

The 8-node **E881** ANS solid element has 4 nodes on its lower face and 4 nodes on its upper face. One or more **E881** elements (or additional **E881** elements) can be defined with the T-881 record set. For more information about the **E881** element, see “E881 8-Node ANS solid element” on page 14-47.

The 18-node **E882** ANS solid element has 9 nodes on its lower face and 9 nodes on its upper face. One or more **E882** elements (or additional **E882** elements) can be defined with the T-882 record set. For more information about the **E882** element, see “E882 18-Node solid element” on page 14-48.

The 27-node **E883** ANS solid element, has 9 nodes on its lower face, 9 nodes on its mid-surface, and 9 nodes on its upper face. One or more **E883** elements (or additional **E883** elements) can be defined with the T-883 record set. For more information about the **E883** element, see “E883 27-Node solid element” on page 14-49.

The 20-node **E885** displacement-based solid element has 8 nodes on its lower face, 4 nodes on its mid-surface, and 8 nodes on its upper face. One or more **E885** elements (or additional **E885** elements) can be defined with the T-885 record set. For more information about the **E885** element, see “E885 20-Node displacement-based solid element” on page 14-50.

T-860 ~~E860 ORACLE Solid Element~~

The **E860** (ORACLE solid) element in **STAGS,** shown in Figure 9.9, is based on the general tetrahedral, pentahedral, or hexahedral element that was implemented in the **ORACLE** program.

Figure 9.9 E860 ORACLE Solid Element

The T-860 record is the first record of a multi-record set that defines one or more **E860** solid elements to be included in the current element unit. The *looping* capabilities provided here, *via* **NX** and **NY** on T-860 and the incrementation parameters on T-860b and T-860c, can be used effectively in many situations.

KELT NNODES IFAB IANG ILIN IPLAS NX NY

KELT must = 860

NNODES number of node points required to define the current **E860** element(s);
NNODES must be greater than or equal to 4

IFAB fabrication identifier for the element:

<0 – fabrication identifier in the GCP Fabrication Table (I-22a)

IANG wall-reference option:

0 – use default strategy of projecting x_g, y_g to establish x_w
1 – input $\mathbf{r_w}$, which is projected to establish x_w

ILIN geometric-nonlinearity flag:

0 – use nonlinear strain-displacement relations
1 – use linear strain-displacement relations

IPLAS material-nonlinearity flag:

0 – elastic behavior only
1 – plasticity included, with the material law satisfied at each element integration point
2 – plasticity included, with the material law satisfied at the element centroid (centroidal plasticity)

NX number of elements to be generated in the x direction;
STAGS sets **NX** = 1 if it is nonpositive

NY number of elements to be generated in the y direction;
STAGS sets **NY** = 1 if it is nonpositive

go to T-860b

~~T-860a E860 Solid Element Nodes~~

A single T-860a record must follow the T-860 record, to identify the **NNODES** (T-860) nodes (S-1) that define the first ORACLE solid element of the set to be generated here.

(NODE(k), k=1,NNODES)   USERELT

NODE(k) k^{th} of **NNODES** node points for the initial **E860** solid element

USERELT user-specified element number, used only if **IUWLE** = 1 on H-1

NX (T-860) x-direction incrementation flag
NY (T-860) y-direction incrementation flag
IANG (T-860) wall-reference option

```
if       ( NX > 1)      then    go to T-860b
elseif   ( NY > 1)      then    go to T-860c
elseif   ( IANG > 0 )   then    go to T-860d
else     return to  T-100
```

T-860b E860 X-Direction Incrementations

NNODES+1 (T-860) x-direction incrementation variables are specified here for use with the **NX** looping function invoked on the T-860 record and the initial node points established on T-860a.

(IX(k), k=1,NNODES) IXU

IX(k) x-direction incrementation variable for node **NODE(k)** on T-883a

IXU x-direction incrementation variable for use with **USERELT**

Any of these incrementation variables can be negative, zero or positive.

```
if ( NY > 1)          then  go to T-860c
elseif ( IANG = 1 )   then  go to T-860d
else  return to T-100
```

~~T-860c E860 Y-Direction Incrementations~~

NNODES+1 (T-860) y-direction incrementation variables are specified here for use with the **NY** looping function invoked on the T-860 record and the initial node points established on T-860a.

(IY(k), k=1,NNODES) IYU

IY(k) y-direction incrementation variable for node **NODE(k)** on T-883a

IYU y-direction incrementation variable for use with **USERELT**

Any of these incrementation variables can be negative, zero or positive.

```
if ( IANG = 1 )     then  go to T-860d
else  return to T-100
```

~~T-860d E860 Material Orientation Record~~

If **IANG** > 0 (T-860), a single T-860d record must follow the T-860a record (or T-860b or T-860c record, if applicable) for the current **E860** solid element. T-860d specifies the material orientation for each of the **E860** elements that are to be generated by the current T-860 element-definition set.

XFX XFY XFZ YFX YFY YFZ

XFX, **XFY**, **XFZ** vector components establishing the x orientation of the material

YFX, **YFY**, **YFZ** vector components establishing the y orientation of the material

return to T-100

T-881 E881 8-Node Solid Element

The **E881** 8-node ANS solid element, in **STAGS**, is shown in Figure 9.10:

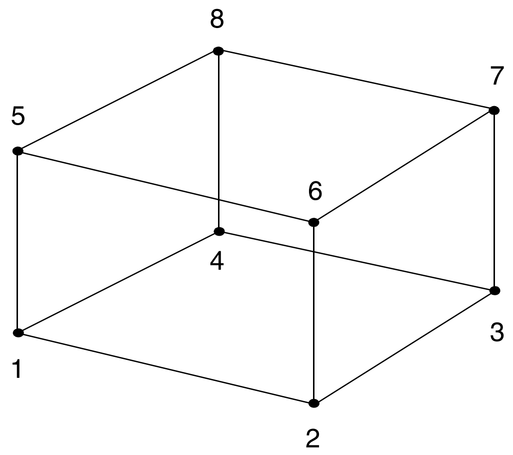


Figure 9.10 E881 8-Node ANS Solid Element

The nodal ordering for **E881** corresponds exactly to the ordering used in the **PATRAN** program.

The T-881 record is the first record of a multi-record set that defines one or more **E881** 8-node solid elements to be included in the current element unit. The *looping* capabilities provided here, *via* **NX** and **NY** on T-881 and the incrementation parameters on T-881b and T-881c, can be used effectively in many situations.

KELT IFAB IANG ILIN IPLAS NX NY

KELT must = 881

IFAB fabrication identifier for the element; this is equivalent to the **WALL** parameter for **E410** quadrilateral elements:

- >0 – wall configuration number in the Wall Fabrication Table (K-1)
- 0 – wall properties are given in user-written subroutine WALL
- <0 – fabrication identifier in the GCP Fabrication Table (I-22a)

IANG wall-reference option:

- 0 – use default strategy of projecting x_g, y_g to establish x_w
- 1 – input $\mathbf{r_w}$, which is projected to establish x_w

ILIN geometric-nonlinearity flag:

- 0 – use nonlinear strain-displacement relations
- 1 – use linear strain-displacement relations

IPLAS material-nonlinearity flag:

- 0 – elastic behavior only
- 1 – plasticity included, with the material law satisfied at each element integration point
- 2 – plasticity included, with the material law satisfied at the element centroid (centroidal plasticity)

NX number of elements to be generated in the x direction; **STAGS** sets **NX** = 1 if it is nonpositive

NY number of elements to be generated in the y direction; **STAGS** sets **NY** = 1 if it is nonpositive

go to T-881b

T-881a E881 Solid Element Nodes

A single T-881a record must follow the T-881 record, to identify the 8 user nodes (S-1) that define the first solid element of the set to be generated here.

(NODE(k), k=1,8)   USERELT

NODE(k) k^{th} of 8 node points for the initial **E881** solid element

USERELT user-specified element number, used only if **IUWLE** = 1 on H-1

NX	(T-881)	x-direction incrementation flag
NY	(T-881)	y-direction incrementation flag
IANG	(T-881)	wall-reference option

```
if      ( NX > 1)      then  go to T-881b
elseif  ( NY > 1)      then  go to T-881c
elseif  ( IANG > 0 )   then  go to T-881d
else    return to  T-100
```

T-881b E881 X-Direction Incrementations

Nine x-direction incrementation variables are specified here for use with the **NX** looping function invoked on the T-881 record and the initial node points established on T-881a.

IX1 IX2 IX3 IX4 IX5 IX6 IX7 IX8 IUX

IX1 x-direction incrementation variable for node **N1** on T-881a

IX2 x-direction incrementation variable for node **N2** on T-881a

IX3 x-direction incrementation variable for node **N3** on T-881a

IX4 x-direction incrementation variable for node **N4** on T-881a

IX5 x-direction incrementation variable for node **N5** on T-881a

IX6 x-direction incrementation variable for node **N6** on T-881a

IX7 x-direction incrementation variable for node **N7** on T-881a

IX8 x-direction incrementation variable for node **N8** on T-881a

IUX x-direction incrementation variable for use with **USERELT**

Any of these incrementation variables can be negative, zero or positive.

```
if       ( NY > 1 )     then   go to  T-881c
elseif   ( IANG = 1 )   then   go to  T-881d
else     return to  T-100
```

T-881c E881 Y-Direction Incrementations

Nine y-direction incrementation variables are specified here for use with the **NY** looping function invoked on the T-881 record and the initial node points established on T-881a.

IY1 IY2 IY3 IY4 IY5 IY6 IY7 IY8 IUY

IY1 y-direction incrementation variable for node **N1** on T-881a

IY2 y-direction incrementation variable for node **N2** on T-881a

IY3 y-direction incrementation variable for node **N3** on T-881a

IY4 y-direction incrementation variable for node **N4** on T-881a

IY5 y-direction incrementation variable for node **N5** on T-881a

IY6 y-direction incrementation variable for node **N6** on T-881a

IY7 y-direction incrementation variable for node **N7** on T-881a

IY8 y-direction incrementation variable for node **N8** on T-881a

IUY y-direction incrementation variable for use with **USERELT**

Any of these incrementation variables can be negative, zero or positive.

if (**IANG** = 1) then *go to* T-881d
else *return to* T-100

T-881d E881 Material Orientation Record

If **IANG** > 0 (T-881), a single T-881d record must follow the T-881a record (or T-881b or T-881c record, if applicable) for the current **E881** solid element. T-881d specifies the material orientation for each of the **E881** elements that are to be generated by the current T-881 element-definition set.

XFX XFY XFZ YFX YFY YFZ

XFX, XFY, XFZ	vector components establishing the x orientation of the material
YFX, YFY, YFZ	vector components establishing the y orientation of the material

return to T-100

T-882 E882 18-Node Solid Element

The **E882** 18-node ANS solid element, in **STAGS**, is shown in Figure 9.11:

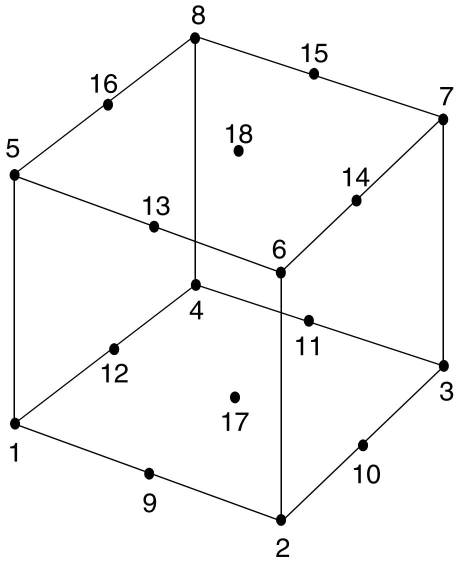


Figure 9.11 E882 18-Node ANS Solid Element

The nodal ordering for **E882** corresponds exactly to the ordering used in the **PATRAN** program.

The T-882 record is the first record of a multi-record set that defines one or more **E882** 18-node solid elements to be included in the current element unit. The *looping* capabilities provided here, *via* **NX** and **NY** on T-882 and the incrementation parameters on T-882b and T-882c, can be used effectively in many situations.

KELT IFAB IANG ILIN IPLAS NX NY

KELT must = 882

IFAB fabrication identifier for the element:

>0 – wall configuration number in the Wall Fabrication Table (K-1)
0 – wall properties are given in user-written subroutine WALL
<0 – fabrication identifier in the GCP Fabrication Table (I-22a)

IANG wall-reference option:

0 – use default strategy of projecting x_g, y_g to establish x_w
1 – input $\mathbf{r_w}$, which is projected to establish x_w

ILIN geometric-nonlinearity flag:

0 – use nonlinear strain-displacement relations
1 – use linear strain-displacement relations

IPLAS material-nonlinearity flag:

0 – elastic behavior only
1 – plasticity included, with the material law satisfied at each element integration point
2 – plasticity included, with the material law satisfied at the element centroid (centroidal plasticity)

NX number of elements to be generated in the x direction;
STAGS sets **NX** = 1 if it is nonpositive

NY number of elements to be generated in the y direction;
STAGS sets **NY** = 1 if it is nonpositive

go to T-882b

T-882a E882 Solid Element Nodes

A single T-882a record must follow the T-882 record, to identify the 18 user nodes (S-1) that define the first solid element of the set to be generated here.

(NODE(k), k =1,18) USERELT

NODE(k)	k^{th} of 18 node points for the initial **E882** solid element
USERELT	user-specified element number, used only if **IUWLE** = 1 on H-1

✦

NX	(T-882)	x-direction incrementation flag
NY	(T-882)	y-direction incrementation flag
IANG	(T-882)	wall-reference option

```
if      ( NX > 1 )     then  go to T-882b
elseif  ( NY > 1 )     then  go to T-882c
elseif  ( IANG > 0 )   then  go to T-882d
else    return to  T-100
```

T-882b E882 X-Direction Incrementations

Nineteen x-direction incrementation variables are specified here for use with the **NX** looping function invoked on the T-882 record and the initial node points established on T-882a.

(IX(k), k=1,18) IXU

IX(k) x-direction incrementation variable for node **NODE(k)** on T-882a

IXU x-direction incrementation variable for use with **USERELT**

Any of these incrementation variables can be negative, zero or positive.

```
✦   if       ( NY > 1)     then  go to  T-882c
    elseif   ( IANG = 1 )  then  go to  T-882d
    else     return to  T-100
```

T-882c E882 Y-Direction Incrementations

Nineteen y-direction incrementation variables are specified here for use with the **NY** looping function invoked on the T-882 record and the initial node points established on T-882a.

(IY(k), k=1,18) IYU

IY(k)	y-direction incrementation variable for node **NODE(k)** on T-882a
IYU	y-direction incrementation variable for use with **USERELT**

Any of these incrementation variables can be negative, zero or positive.

if (**IANG** = 1) then *go to* T-882d
else *return to* T-100

T-882d E882 Material Orientation Record

If **IANG** > 0 (T-882), a single T-882d record must follow the T-882a record (or T-882b or T-882c record, if applicable) for the current **E882** solid element. T-882d specifies the material orientation for each of the **E882** elements that are to be generated by the current T-882 element-definition set.

XFX XFY XFZ YFX YFY YFZ

XFX, XFY, XFZ vector components establishing the x orientation of the material

YFX, YFY, YFZ vector components establishing the y orientation of the material

return to T-100

T-883 E883 27-Node Solid Element

The **E883** 27-node ANS solid element, in **STAGS**, is shown in Figure 9.12:

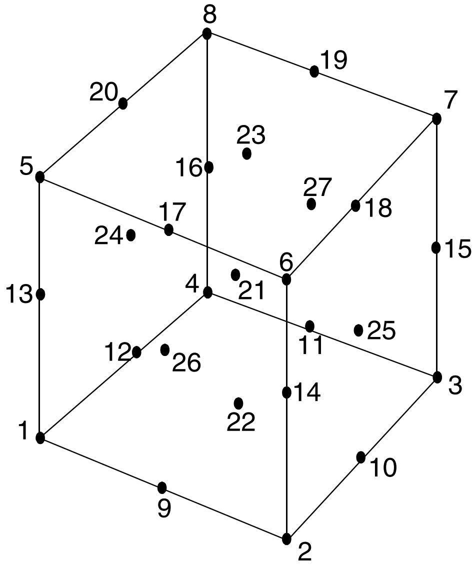


Figure 9.12 E883 27-Node ANS Solid Element

The nodal ordering for **E883** corresponds exactly to the ordering used in the **PATRAN** program.

The T-883 record is the first record of a multi-record set that defines one or more **E883** 27-node solid elements to be included in the current element unit. The *looping* capabilities provided here, *via* **NX** and **NY** on T-883 and the incrementation parameters on T-883b and T-883c, can be used effectively in many situations.

KELT IFAB IANG ILIN IPLAS NX NY

KELT must = 883

IFAB fabrication identifier for the element:

>0 – wall configuration number in the Wall Fabrication Table (K-1)
0 – wall properties are given in user-written subroutine WALL
<0 – fabrication identifier in the GCP Fabrication Table (I-22a)

IANG wall-reference option:

0 – use default strategy of projecting x_g, y_g to establish x_w
1 – input $\mathbf{r_w}$, which is projected to establish x_w

ILIN geometric-nonlinearity flag:

0 – use nonlinear strain-displacement relations
1 – use linear strain-displacement relations

IPLAS material-nonlinearity flag:

0 – elastic behavior only
1 – plasticity included, with the material law satisfied at each element integration point
2 – plasticity included, with the material law satisfied at the element centroid (centroidal plasticity)

NX number of elements to be generated in the x direction; **STAGS** sets **NX** = 1 if it is nonpositive

NY number of elements to be generated in the y direction; **STAGS** sets **NY** = 1 if it is nonpositive

✦ *go to* T-883b

T-883a E883 Solid Element Nodes

A single T-883a record must follow the T-883 record, to identify the 27 user nodes (S-1) that define the first solid element of the set to be generated here.

(NODE(k), k=1,27)   USERELT

NODE(k) k^{th} of 27 node points for the initial **E883** solid element

USERELT user-specified element number, used only if **IUWLE** = 1 on H-1

NX	(T-883)	x-direction incrementation flag
NY	(T-883)	y-direction incrementation flag
IANG	(T-883)	wall-reference option

```
if      ( NX > 1)      then  go to T-883b
elseif  ( NY > 1)      then  go to T-883c
elseif  ( IANG > 0 )   then  go to T-883d
else    return to  T-100
```

T-883b E883 X-Direction Incrementations

Twenty eight x-direction incrementation variables are specified here for use with the **NX** looping function invoked on the T-883 record and the initial node points established on T-883a.

(IX(k), k=1,27) IXU

IX(k) x-direction incrementation variable for node **NODE(k)** on T-883a

IXU x-direction incrementation variable for use with **USERELT**

Any of these incrementation variables can be negative, zero or positive.

```
if       ( NY > 1)      then   go to  T-883c
elseif   ( IANG = 1 )   then   go to  T-883d
else     return to  T-100
```

T-883c E883 Y-Direction Incrementations

Twenty eight y-direction incrementation variables are specified here for use with the **NY** looping function invoked on the T-883 record and the initial node points established on T-883a.

(IY(k), k=1,27) IYU

IY(k)	y-direction incrementation variable for node **NODE(k)** on T-883a
IYU	y-direction incrementation variable for use with **USERELT**

Any of these incrementation variables can be negative, zero or positive.

if (**IANG** = 1) then *go to* T-883d
else *return to* T-100

T-883d E883 Material Orientation Record

If **IANG** > 0 (T-883), a single T-883d record must follow the T-883a record (or T-883b or T-883c record, if applicable) for the current **E883** solid element. T-883d specifies the material orientation for each of the **E883** elements that are to be generated by the current T-883 element-definition set.

XFX XFY XFZ YFX YFY YFZ

XFX, XFY, XFZ	vector components establishing the x orientation of the material
YFX, YFY, YFZ	vector components establishing the y orientation of the material

return to T-100

T-885 E885 20-Node Solid Element

The **E885** 20-node displacement-based solid element, in **STAGS**, is shown in Figure 9.13:

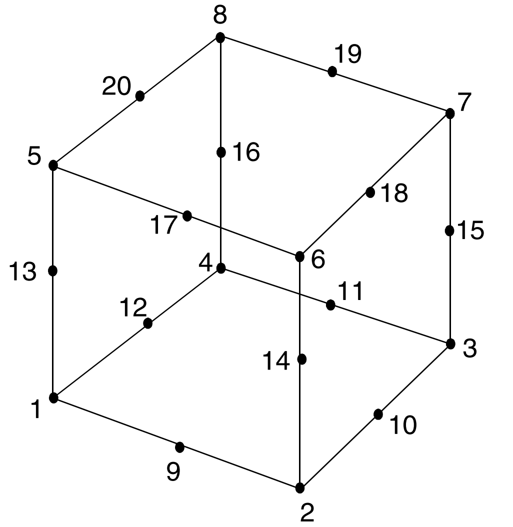


Figure 9.13 E885 20-Node Solid Element

The nodal ordering for **E885** corresponds exactly to the ordering used in the **PATRAN** program.

The T-885 record is the first record of a multi-record set that defines one or more **E885** 20-node solid elements to be included in the current element unit. The *looping* capabilities provided here, *via* **NX** and **NY** on T-885 and the incrementation parameters on T-885b and T-885c, can be used effectively in many situations.

KELT IFAB IANG ILIN IPLAS NX NY

KELT must = 885

IFAB fabrication identifier for the element; this is equivalent to the **WALL** parameter for **E410** quadrilateral elements:

>0 – wall configuration number in the Wall Fabrication Table (K-1)
0 – wall properties are given in user-written subroutine WALL
<0 – fabrication identifier in the GCP Fabrication Table (I-22a)

IANG wall-reference option:

0 – use default strategy of projecting x_g, y_g to establish x_w
1 – input $\mathbf{r_w}$, which is projected to establish x_w

ILIN geometric-nonlinearity flag:

0 – use nonlinear strain-displacement relations
1 – use linear strain-displacement relations

IPLAS material-nonlinearity flag:

0 – elastic behavior only
1 – plasticity included, with the material law satisfied at each element integration point
2 – plasticity included, with the material law satisfied at the element centroid (centroidal plasticity)

NX number of elements to be generated in the x direction; **STAGS** sets **NX** = 1 if it is nonpositive

NY number of elements to be generated in the y direction; **STAGS** sets **NY** = 1 if it is nonpositive

go to T-885b

T-885a E885 Solid Element Nodes

A single T-885a record must follow the T-885 record, to identify the 20 user nodes (S-1) that define the first solid element of the set to be generated here.

(NODE(k), k=1,20) USERELT

NODE(k) k^{th} of 20 node points for the initial **E885** solid element

USERELT user-specified element number, used only if **IUWLE** = 1 on H-1

NX	(T-885)	x-direction incrementation flag
NY	(T-885)	y-direction incrementation flag
IANG	(T-885)	wall-reference option

```
if       ( NX > 1)      then  go to T-885b
elseif   ( NY > 1)      then  go to T-885c
elseif   ( IANG > 0 )   then  go to T-885d
else     return to  T-100
```

T-885b E885 X-Direction Incrementations

Twenty one x-direction incrementation variables are specified here for use with the **NX** looping function invoked on the T-885 record and the initial node points established on T-885a.

(IX(k), k=1,20) IXU

IX(k) x-direction incrementation variable for node **NODE(k)** on T-885a

IXU x-direction incrementation variable for use with **USERELT**

Any of these incrementation variables can be negative, zero or positive.

```
if       ( NY > 1 )      then   go to  T-885c
elseif   ( IANG = 1 )    then   go to  T-885d
else     return to  T-100
```

T-885c E885 Y-Direction Incrementations

Twenty one y-direction incrementation variables are specified here for use with the **NY** looping function invoked on the T-885 record and the initial node points established on T-885a.

(IY(k), k=1,20) IYU

IY(k) y-direction incrementation variable for node **NODE(k)** on T-885a
IYU y-direction incrementation variable for use with **USERELT**

Any of these incrementation variables can be negative, zero or positive.

if (**IANG** = 1) then *go to* T-885d
else *return to* T-100

T-885d E885 Material Orientation Record

If **IANG** > 0 (T-885), a single T-885d record must follow the T-885a record (or T-885b or T-885c record, if applicable) for the current **E885** solid element. T-885d specifies the material orientation for each of the **E885** elements that are to be generated by the current T-885 element-definition set.

XFX XFY XFZ   YFX YFY YFZ

XFX, XFY, XFZ vector components establishing the x orientation of the material

YFX, YFY, YFZ vector components establishing the y orientation of the material

return to T-100

9.8 Definition and Utilization of User Elements

Recently-developed User element capabilities in **STAGS** 5.0 give advanced analysts and program developers powerful new tools for solving problems that lie beyond the scope of those that **STAGS** has traditionally treated. The process by which User elements are defined in **STAGS** is described briefly in the following Subsection, in somewhat greater detail in Chapter 13 of this document, and much more fully in the ***STAGS** Elements Manual*. The basic input records with which User elements may be utilized in constructing a **STAGS** model are described after that.

9.8.1 The User–element definition process

There are two distinct (but strongly coupled) operations that must be performed to define a User element for use in the construction of **STAGS** models and for use in conducting analyses with those models.

The first operation (which must be performed in generating the *INP* file that **STAGS**' ***s1*** processor reads and processes to construct the **STAGS** model for a given problem) is the analyst's definition of certain critical information about the User element—the element–type identifier by which it is to be referenced, the number of node points that are required to specify any given element of this type, the names and characteristics of data associated with all elements of this type, *etc*. This is easily accomplished by including a set of *User-element-definition directives* at any appropriate point in the analyst's *INP* file prior to any input records that command the inclusion of one or more User elements of that type in the model being constructed.

The second operation (which must generally be performed prior to executing any **STAGS** processor) is the analyst's (or developer's) generation of FORTRAN and/or C–language routines that **STAGS** processors must employ in the specification, analysis and postprocessing operations that are to be performed for any **STAGS** model in which these User elements are employed—and the successful linking of each of these User-element-enhanced processors.

Before getting into either of these operations, it is appropriate to pause briefly and note that the principal goal of the **STAGS** User element framework is to provide a set of features that enable element researchers to add new element types to **STAGS** without having to be concerned with details of the **STAGS** element integration process—focusing only on the development of their new elements. To provide an almost transparent element integration environment, the **STAGS** User element framework provides the following features:

- Arbitrary User element types are represented in the standard **STAGS** element description scheme as element types $900 \le \texttt{type} \le 999$.
- Any number (less than or equal to one hundred) of User element types and their associated data descriptions may be specified.
- Any number of User elements of any User element type may be defined in **STAGS** models.
- Each User element type definition specifies a set of named data that are available for every element of that type.
- User element program code can retrieve and store the values of individual User element data items by their names, or can access an element's integer and floating-point data blocks in the **ABAQUS** style.
- An arbitrary number of user-described Property Sets can be defined that specify a collection of named data that may be arbitrarily associated with one or more elements of any user-defined type.
- User element wrapper routines are invoked automatically by **STAGS** as required by a solution process. Users implementing new elements need not be concerned with the details of the **STAGS** solution process.

An arbitrary number of user-defined element types can be specified using a free field description of the nodal and data specifications for each element. These descriptions are entered directly into the **STAGS** model input file and provide the user the ability to describe the element type and its data requirements in any manner that facilitates the most natural ordering. Comments and flexible line spacing are allowed for enhanced readability.

Each User element type description may specify a collection of named integer and/or floating-point variables associated with each User element defined in a **STAGS** model. Naming User element variables greatly increases a user's understanding of both simple and complex datasets and reduces the likelihood of confusing data values required by different element types. This is a general capability; the developer or researcher is not restricted by the kind or amount of data that can be associated with each User element type.

The User element framework also introduces a new **STAGS** feature called Property Sets. A developer or researcher may define any number of property sets, each of which is identified by a meaningful name and a unique numeric identifier. The property items in a property set, entered by the user in free field format (much like User element type descriptions), collect integer and/or floating-point data that are best described when grouped together. This feature provides a general and flexible technique for describing data required by any new capabilities added by developers or researchers. The creation of new, user-defined element types is just one example.

Directives for User element definitions

Returning to the subject of *directives* for definition of User elements, we note that each User element type is described in the *INP* file for a **STAGS** model by a set of four required directives and two optional directives (within square brackets)—that are ordered as follows:

```
*userElement...            — initiate userElement specifications
   *dofOrdering...         — specify number and types of DOF at each node
   *nodeSequence...        — specify nodal sequence for transformations
  [*floatVariables...]     — specify float-type variables (if any)
  [*integerVariables...]   — specify integer-type variables (if any)
*end userElement           — terminate userElement specifications
```

Directive formatting is free-field. String values that contain one or more spaces must be enclosed in matching single or double quotes. Directive names and directive attribute names are case-insensitive. Empty (blank) lines and lines containing only $-initiated comments are ignored during parsing of directives.

The `*floatVariables` and `*integerVariables` data groups are both optional. They may appear in any order and may be repeated as many times as required. All float variable items are collected sequentially as they are defined and are placed in a single logical group of data type float. All integer variable items are collected sequentially as they are defined and are placed in a single logical group of type integer.

Example of User element definition

Rather than going through a long-winded presentation of directive syntax and conventions, let us simplify this by looking at a straightforward example that shows how a user might define a User element—to be referenced as a type 901 element—for a simple 3-node beam. The end nodes of this beam are identified as node number 1 and node number 2, and the internal node is identified as node number 3. A fourth node is associated with the element in order to compute the element's orientation matrix. Associated with this element type is a set of named floating-point variables and a set of named integer variables. These named data will be defined for each user-defined element created by **STAGS** and can be manipulated by developers and by the element researcher using utility routines that are described in Chapter 13 of this document and in greater detail in Chapter 9 of the ***STAGS*** *Elements Manual*.

```
*userElement name = "Beam Element"  type = 901  nodes = 4
      *dofOrdering
                  $  Node  DOF...
                  $  ----------------
                     1    1 2 3 4 5 6
                     2    1 2 3 4 5 6
                     3    1 2 3 4 5 6
                     4    0
      *nodeSequence
                  $  Nodes...
      $  --------
                     1 2 4
      *floatVariables
                  $  Name        Size
                  $  ----------------
                     MaxStress      1
                     MaxStressLoc   3
                     SectionData    5
                     ShearFactor    1
                     OtherStuff    15
      *integerVariables
                  $  Name  Size
                  $  ----------
                     NIPS     1
                     List    10
*end userElement
```

The following points about this example are generally true for all User element type definitions.

- User element type names must have string values and are used for descriptive purposes only.
- User element type names are limited to 40 characters in length.
- User element type numbers must be in the range $900 \le \mathtt{type} \le 999$, inclusive; and they must be unique (*i.e.*, a User element type must be defined only once).
- Some of the type numbers in the $900 \le \mathtt{type} \le 999$ cannot be used for new User elements because they are reserved for (already being used by) “built-in” **STAGS UEL**s (by the **E928** and **E940** elements, for example).
- A User element type may have any number of nodes.
- The DOF ordering for each node must be specified in a single group.
- All nodes are expected to have either zero (0), three (3) or six (6) degrees of freedom. DOF must currently be defined in agreement with **STAGS’** DOF-ordering convention:

1	:	x–displacement	4	:	x–rotation
2	:	y–displacement	5	:	y–rotation
3	:	z–displacement	6	:	z–rotation

- Element reference nodes are specified as having zero degrees of freedom (as for node 4 in this example).
- Nodes used to define an element’s orientation matrix are identified by a single, required `*nodeSequence` directive. Either three (3) or four (4) nodes in the `*dofOrdering` group are referenced by index in this directive. If three nodes are referenced, the element’s x–axis is directed from the first to the second node. The element’s z–axis is directed as the vector cross product of the x–axis and the vector from the first to the third node. The element’s y–axis follows from the right-hand rule with respect to the x–axis and the z–axis. If four nodes are referenced, the element’s x–axis is directed from the first to the second node. The element’s z–axis is directed as the vector cross product of the vector from the first to the third node and the vector from the second tor the fourth node. The element’s y–axis follows from the right-hand rule with respect to the x–axis and the z–axis.
- User element variable names are limited to 40 characters in length.
- Variable names containing one or more spaces must be enclosed in matching single or double quotes.
- Variable names are case-insensitive for comparison and must be unique within their User element type definition.
- A variable's size (logical length) must be specified and must be an integer number greater than zero.

Directives for User property set definitions

User property sets are described (during **STAGS** ***s1*** processing) through a set of directives as shown in the following example. Directives defining a User property set are ordered as follows:

```
*userProperty...         –  initiate userProperty specifications
   [*floatProps...]      –  define one or more float-type data parameters
   [*integerProps...]    –  define one or more integer-type data parameters
*end userProperty        –  initiate userProperty specifications
```

As with the User-element-definition directives described above, empty (blank) lines and lines containing only $-initiated comments are ignored during parsing of directives; and directive names and directive attribute names are case-insensitive. Directive formatting is free-field. String values that contain one or more spaces must be enclosed in matching single or double quotes.

The `*floatProps` data group is optional, and `*floatProps` data groups may appear in any order and may be repeated as many times as required. All float property items are collected sequentially as they are defined and are placed in a single logical group of data type float.

The *integerProps data group is optional when the analyst/developer chooses *not* to use **STAGS**' GCP processor to specify material properties and fabrications; it is mandatory when he/ she uses the GCP to do that. When needed, *integerProps data groups may appear in any order and may be repeated as many times as required. All integer property items are collected sequentially as they are defined and are placed in a single logical group of data type integer. Parameters that must be specified in the *integerProps data group when the GCP is used are described briefly in Chapter 13 of this document and more completely in Chapter 9 of the ***STAGS** Elements Manual*.

Examples of User property set definitions

These examples build on the previous example that showed how an element researcher might define a new element type for a 3-node beam with a single internal node. In addition to the element type's set of named integer and floating-point element variables, there may be several User property sets defined to complete the specification of an element. These property sets contain collections of related property items and can be logically associated with any number of elements or referenced from any number of appropriate contexts. User property sets can be manipulated by developers and element researchers using utility routines that are described briefly in Chapter 13 of this document and more completely in Chapter 9 of the ***STAGS** Elements Manual*.

```
*userProperty  name = "Beam Element"  id = 901

      *integerProps
                  $  Required Standard Data
                  $  ----------------------
                     ActiveNodes     2
                     SamplingCount  10
                     StrainCount     6
                     StressCount     6

*end userProperty

*userProperty  name = "Aluminum 6061-T6"  id = 6061

      *floatProps
                  E                         10.00e+6
                  G                          3.75e+6
                  MassDensity                2.54e-4
                  PoissonRatio               0.3
                  TensileUltimateStrength   38.00e+3
                  TensileYieldStrength      35.00e+3
                  CompresiveYieldStrength   35.00e+3
                  ShearYieldStrength        20.00e+3
                  ThermalExpansion           1.30e-5

*end userProperty
```

Notes for User property set definition examples

The following points made about these examples are generally true for all User property set definitions:

- For each User element type definition there must be one property set with an identifier (`id`) that matches the identifier of the type definition. In addition to any other properties this property set may contain, the following integer property items must be specified: `ActiveNodes` (the number of active nodes for the element type), `SamplingCount` (the number of locations where stresses and strains will be evaluated), `StrainCount` (the number of strain components associated with the element type), `StressCount` (the number of stress components associated with the element type). Failure to provide these property items in a property set associated with an element type definition will lead to a run-time error.
- User property set names must have string values and must be unique across all User property sets.
- Property set names are limited to 40 characters in length.
- User property set identifiers (IDs) must have numeric values and must be unique across all User property sets.
- Property item names containing one or more spaces must be enclosed in matching single or double quotes
- Property item names are limited to 40 characters in length.
- Property item names are case-insensitive for comparison and must be unique within their property set definition.

Subroutines facilitating User element implementations

When one or more types of User elements are to be employed in a **STAGS** model, it is *sometimes* necessary for the analyst (or developer) to generate a User-element-enhanced version of **STAGS**' ***s1*** (model-definition) processor. It is *always* necessary for him (or her) to generate User-element-enhanced versions of **STAGS**' ***s2*** (analysis) processor and of any of the **STAGS**–system post–analysis processor(s) that are to be used with that model. The broad outlines of how this may be done are sketched in the following paragraphs. The interested reader should consult Chapter 13 of this document for more information and should see Chapter 9 of the ***STAGS*** *Elements Manual* for all of the gory details.

It is sufficient to note here that when **STAGS'** ***s1*** processor encounters a User element, ***s1*** calls a number of generic User-element definition routines to perform operations that are required universally; and it also calls three other User-element "dispatch" routines to perform additional, nonstandard model–definition operations for that User element—as and if they are required. The primary function of each of these dispatch routines is evident by its name: `UelEltDef`, `UelLoadDef` and `UelPressDef`. Each of these dispatch routines calls one or more next–level program– or developer–supplied routines that perform nonstandard definition operations that are appropriate for each type of User element. The "program–supplied" qualifier is appropriate when no special operations are required; the "developer–supplied" qualifier applies when special operations are required. In any event, the program "architecture" within which this is done is shown in the following Table:

Subroutine	**calls subroutine**	
`UelEltDef`	`UelEltDef900`	for a type 900 element
`UelEltDef`	`UelEltDef901`	for a type 901 element
`UelEltDef`	`UelEltDef902`	for a type 902 element
:	:	
`UelLoadDef`	`UelLoadDef900`	for a type 900 element
`UelLoadDef`	`UelLoadDef901`	for a type 901 element
`UelLoadDef`	`UelLoadDef902`	for a type 902 element
:	:	
`UelPressDef`	`UelPressDef900`	for a type 900 element
`UelPressDef`	`UelPressDef901`	for a type 901 element
`UelPressDef`	`UelPressDef902`	for a type 902 element
:	:	

The names of these nine User-element-type-specific subroutines (for hypothetical user types 900, 901 and 902) are arbitrary (within the constraint that each unique User element type number must lie in the range from 900 to 999, inclusive) and may be changed to reflect the user's particular choice. A do-nothing "starter" template is provided for each of these particular routines. The three ***s1***-processor dispatch routines and their type-specific children are described more fully in Chapter 13 of this document and are fully documented in Chapter 9 of the ***STAGS*** *Elements Manual*. A comprehensive set of FORTRAN and C–language *utility routines* that is provided with **STAGS** to facilitate their implementation and use in ***s1*** and other **STAGS** processors is also documented there.

Similarly, when the **STAGS'** ***s2*** processes encounters a User element, it also calls a number of User-element "dispatch" routines to perform initialization and computation operations for that User element—as required. Depending on the type of analysis to be performed, ***s2*** may call some or all of the twelve User-element dispatch routines that are listed in the following Table:

<u>**subroutine**</u>	<u>***raison d’ étre***</u>
`UelPvDef`	Perform pre-variation operations for User elements
`UelMassDef`	Perform mass-computation operations for User elements
`UelFiDef`	Compute internal forces for User elements
`UelFlDef`	Compute live-loading forces for User elements
`UelKmDef`	Compute the material stiffness of the User elements
`UelKgDef`	Compute the geometric stiffness of the User elements
`UelStrainDef`	Determine the User-element strains
`UelStressDef`	Determine the User-element stresses
`UelResultantDef`	Determine the User-element resultants
`UelPrintStrainDef`	Print the User-element strains
`UelPrintStressDef`	Print the User-element stresses
`UelPrintResultantDef`	Print the User-element resultants

Each of these top-level dispatch routines in turn calls a corresponding lower-level, user-defined routine that is specific to a particular user-defined element type. For example, `UelPvDef` calls the provided templates `UelPvDef900`, `UelPvDef901` and `UelPvDef902`. Similar template routines are provided for the other dispatch routines. The names of these user element type-specific routines (for hypothetical user types 900, 901 and 902) are arbitrary and may be changed to reflect the user’s particular choice. These ***s2***–processor dispatch routines and their User-element-type-specific children are described in Chapter 13 of this document and are fully documented in Chapter 9 of the ***STAGS** Elements Manual*.

9.8.2 Utilization of User element(s) in STAGS

The basic input requirements for User elements are similar to those for other elements in the **STAGS** program. The reader can verify this by studying the following pages carefully.

T-900 E9XX User-Defined Element

In the current version of **STAGS**, the T-900 record is used to identify the type of **UEL** that the user wants to add to his current element unit (*via* the **KELT** variable) and to specify the values of of eight other variables that **STAGS** uses to specify one or more **UEL**s of that type. In the "general" case, the user can specify any type of **UEL** here that the program "recognizes" and "understands." This description of T-900 is intended to be used by developers and analysts who want to use **STAGS**' **UEL**-definition framework to develop, test, and use new types of User Written elements in and with the program. A **STAGS** developer/user who is doing that will typically be dealing with a new element that looks something like this

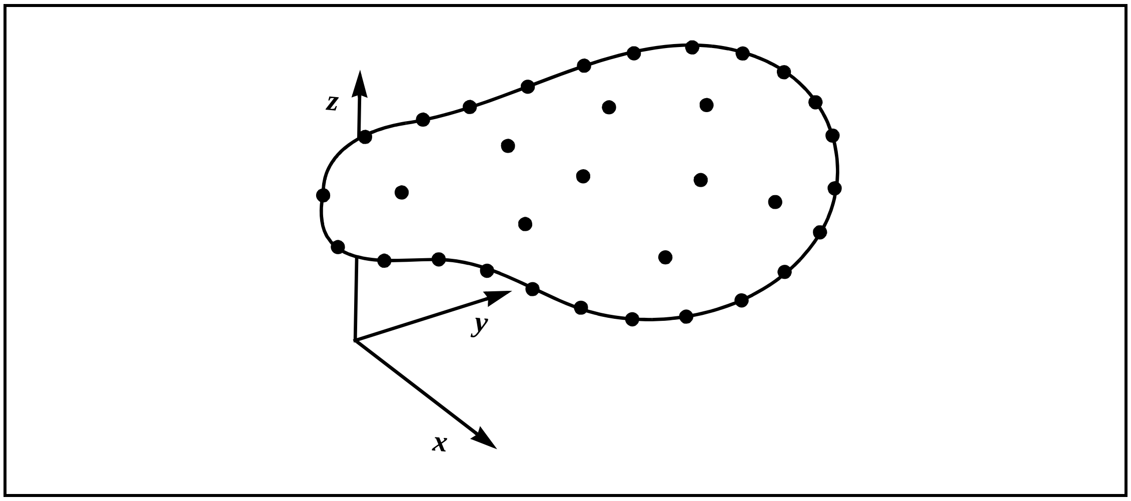


Figure 9.14 **E9XX** User-Written Element

where the black dots are nodes, where the element is defined in an element coordinate system that looks something like the one shown here, and where the developer/user's element typically looks like something other than a potato shown here. The developer or user who wants to develop or use this element in **STAGS** (as a User-Written element) will typically assign it a **UEL** type code (**KELT** identity) that lies somewhere in the range $900 \le \text{type} \le 999$. He should not use **910** or **928** or **940** as the type code for his **UEL** because those three type codes are not available to him. **STAGS** uses those three type codes for User Written elements that have been implemented in the program as "built-in" **UEL**s that anyone can use—the program's type-910 "actuator" element, its type-928 "3-node curved beam" element, and its type-940 "4-node MIN4 quadrilateral" element.

The user who wants to add one or more of **STAGS**' "built-in" **UEL**s to his current element unit should stop reading this description of the T-900 record and turn his attention to its ~~**E910**,~~ **E928**, and/or **E940** counterparts later in this section.

The user who is developing or using other types of **STAGS UEL**s should know that, whatever unique input requirements there may be for specifying one or more **UEL**s of any given type, he must first specify the most basic things that **STAGS** needs to know about that type of **UEL**—by including the appropriate type-definition directives for it in his *case.inp* file at an appropriate point before he adds any element of that type to any element unit. The user must also specify the (floating point and/or integer) values that he wants **STAGS** to use for properties and/or control variables in any property sets that his **UEL** uses—by including the appropriate property-set directive(s) in his *case.inp* file somewhere before **STAGS** needs that information.

Then... finally... the user must navigate to and use the T-900 record described here (a) to specify the type of **UEL** that he wants to add to his current element unit, (b) to specify the "element number" of the first **UEL** of this type to be added at this time, (c) to specify four input and control flags, and to specify three incrementation variables—*via* the **KELT**, **ID**, **IFAB**, **IANG**, **ILIN**, **IPLAS**, **NX**, **NY** and **NZ** variables on the following record:

KELT ID IFAB IANG ILIN IPLAS NX NY NZ

KELT User-element type; $900 \leq$ **KELT** ≤ 999: see **Note 1**, below

ID starting **UEL** element number

IFAB fabrication identifier: see **Note 2**, below

> 0 – wall configuration number in the Wall Fabrication Table (K-1)
< 0 – fabrication identifier in the GCP Fabrication Table (I-22a)
= 0 – fabrication properties are specified *via* **UEL** directives

IANG wall-reference option: see **Note 2**, below

0 – use default strategy of projecting x_g, y_g to establish x_w
1 – specify an x-direction vector for use in establishing the material orientation matrix
2 – specify x- and y-direction vectors for use in establishing the material orientation matrix

ILIN geometric-nonlinearity flag: see **Note 2**, below

0 – use nonlinear strain-displacement relations
1 – use linear strain-displacement relations

IPLAS material-nonlinearity flag: see **Note 2**, below

0 – elastic behavior only
> 0 – plasticity included

NX # of elements to be generated in the *x* direction (default=1) see **Note 3**, below
NY # of elements to be generated in the *y* direction (default=1) see **Note 3**, below
NZ # of elements to be generated in the *z* direction (default=1) see **Note 3**, below

Note 1: ~~If **KELT** = 910 on this T-900 record, the contents of this record are more accurately described on the T-910 record that is discussed later in this section.~~

If **KELT** = 928 on this T-900 record, the contents of this record are more accurately described on the T-928 record that is discussed later in this section.

If **KELT** = 940 on this T-900 record, the contents of this record are more accurately described on the T-940 record that is discussed later in this section.

Note 2: The current version of **STAGS**' **E928** 3-node curved beam element—its "built-in" type-928 **UEL**—"ignores" the **IFAB**, **IANG**, **ILIN** and **IPLAS** variables on this record because that element gets all of its fabrication and material property data from **UEL** directives; when **KELT**=928 on this record, the user must currently set each of these "place-holder" variables equal to 0 — at least until **STAGS**' **E928** **UEL** is upgraded to use the program's more flexible **GCP** facilities.

The current version of **STAGS**' **E940** MIN4 quadrilateral element—its "built-in" type-940 **UEL**—uses **STAGS**' **GCP** facilities exclusively (and does not use its older fabrication and material specification and computation methodologies); when **KELT**=940 on this record, the user must set **IFAB** equal to a negative number (in accord with the **GCP** fabrication that the current **E940** elements use), and he must also set **IANG**=**ILIN**=**IPLAS**=0 (for the time being, at least).

Note 3: The **NX** variable on this record can be used (with most types of **UEL**s) to generate a "string" of elements in the string's "row" space; the **NX** and **NY** variables can be used together (with many types of **UEL**s) to generate a "patch" of elements in its "row/column" space; and the **NX**, **NY** and **NZ** variables can be used (with a few types of **UEL**s) to generate a "block" of elements in its "row/column/layer" space.

The current version of **STAGS**' **E928** element "ignores" the **NY** and **NZ** variables on this record; when **KELT**=928 on this record, the user should set **NY**=**NZ**=0 (or 1).

The current version of **STAGS**' **E940** element "ignores" the **NZ** variable on this record; when **KELT**=940 on this record, the user should set **NZ**=0 (or 1).

```
if      ( KELT = 928 )    then
        go to T-928a
elseif  ( KELT = 940 )    then
        go to T-940a
else
        go to T-900a
endif
```

T-900a E9XX User-Element Nodes

For most types of **UEL**s, a single T-900a record must follow the T-900 record—to identify the user nodes (S-1 or S-3) that define the first element of the set to be generated here. Type-specific equivalents to this record are described later in this section for “built-in” **UEL**s: those records should be used instead of T-900a for “built-in” **UEL**s.

(NODE(k), k = 1, NNODES)

NODE(k) the k^{th} of **NNODES** node points for the initial type-**KELT** **UEL**, where **NNODES** is specified by the `*UserElement` directive with which a type **KELT** User element is defined

NX	(T-900)	x-direction incrementation flag
NY	(T-900)	y-direction incrementation flag
NZ	(T-900)	z-direction incrementation flag
IANG	(T-900)	wall-reference option

```
if      ( NX > 1 )     then
        go to T-900b
elseif  ( NY > 1 )     then
        go to T-900c
elseif  ( NZ > 1 )     then
        go to T-900d
elseif  ( IANG = 1 )   then
        go to T-900e
elseif  ( IANG = 2 )   then
        go to T-900f
else
        follow the instructions at the end of T-900f
endif
```

T-900b User-Element X-Direction Incrementations

NNODES incrementation variables are specified here for use with the **NX** (x-direction) looping function invoked on the T-900 record and the initial node points established on T-900a.

(IX(k), k = 1, NNODES) IXU

IX(k) x-direction incrementation variable for node **NODE(k)** on T-900a

IXU x-direction incrementation variable for use with the **ID** parameter on T-900a

Any of the **IX(k)** incrementation variables can be negative, zero or positive. **IXU** must be nonzero.

NY	(T-900)	y-direction incrementation flag
NZ	(T-900)	z-direction incrementation flag
IANG	(T-900)	wall-reference option

```
if      ( NY > 1 )      then
        go to T-900c
elseif  ( NZ > 1 )      then
        go to T-900d
elseif  ( IANG = 1 )    then
        go to T-900e
elseif  ( IANG = 2 )    then
        go to T-900f
else
        follow the instructions at the end of T-900f
endif
```

T-900c User-Element Y-Direction Incrementations

NNODES incrementation variables are specified here for use with the **NY** (y-direction) looping function invoked on the T-900 record and the initial node points established on T-900a.

(IY(k), k = 1, NNODES) IYU

IY(k) y-direction incrementation variable for node **NODE(k)** on T-900a

IYU y-direction incrementation variable for use with the **ID** parameter on T-900a

Any of the **IY(k)** incrementation variables can be negative, zero or positive. **IYU** must be nonzero.

NZ	(T-900)	z-direction incrementation flag
IANG	(T-900)	wall-reference option

```
if      ( NZ > 1 )      then
        go to T-900d
elseif  ( IANG = 1 )    then
        go to T-900e
elseif  ( IANG = 2 )    then
        go to T-900f
else
        follow the instructions at the end of T-900f
endif
```

T-900d User-Element Z-Direction Incrementations

NNODES incrementation variables are specified here for use with the **NZ** (z-direction) looping function invoked on the T-900 record and the initial node points established on T-900a.

(IZ(k), k = 1, NNODES)   IZU

IZ(k) z-direction incrementation variable for node **NODE(k)** on T-900a

IZU z-direction incrementation variable for use with the **ID** parameter on T-900a

Any of the **IZ(k)** incrementation variables can be negative, zero or positive. **IZU** must be nonzero.

```
IANG    (T-900)     wall-reference option

if      ( IANG = 1 )   then
        go to T-900e
elseif  ( IANG = 2 )   then
        go to T-900f
else
        follow the instructions at the end of T-900f
endif
```

T-900e User-Element Material Orientation Vector

If **IANG** = 1 (T-900), a single T-900e record must follow T-900a (or T-900b or T-900c or T-900d) for the current set of User elements. T-900e specifies a single x-direction vector that is used to establish the material orientation triad for each of the User elements that are to be generated by the current T-900 element-definition set.

XFX XFY XFZ

XFX, XFY, XFZ vector components establishing the x orientation of the material

follow the instructions at the end of T-900f

T-900f User-Element Material Orientation Vectors

If **IANG** = 2 (T-900), a single T-900f record must follow T-900a (or T-900b or T-900c or T-900d) for the current set of User elements. T-900f specifies an x-direction and a y-direction vector that are *both* used to establish the material orientation triad for each of the User elements that are to be generated by the current T-900 element-definition set.

XFX XFY XFZ   YFX YFY YFZ

XFX, XFY, XFZ vector components establishing the x orientation of the material

YFX, YFY, YFZ vector components establishing the y orientation of the material

```
if     ( the user wants to add another set of E900 elements )  then
         go to T-900
elseif ( the user wants to add a set of E928 elements )  then
         go to T-928
elseif ( the user wants to add a set of E940 elements )  then
         go to T-940
else
         return to T-100
endif
```

T-928 E928 3-Node Curved Beam UEL

STAGS' **E928** 3-node curved beam element—shown in the following Figure—is fully compatible with its classic **E480** 9-node ANS quadrilateral shell element and its **E849** 18-node sandwich element (which uses **E480** elements for its top and bottom face sheets). STAGS' **E928** element was originally implemented in the program as a User-Defined Element, in accord with the UEL specifications and conventions that are described here and in Chapter 13 of this document. After testing this User-Defined element successfully, it was incorporated into STAGS as a "built-in" UEL that anyone can use without having to re-make **s1**, **s2** and other STAGS processors to do so.

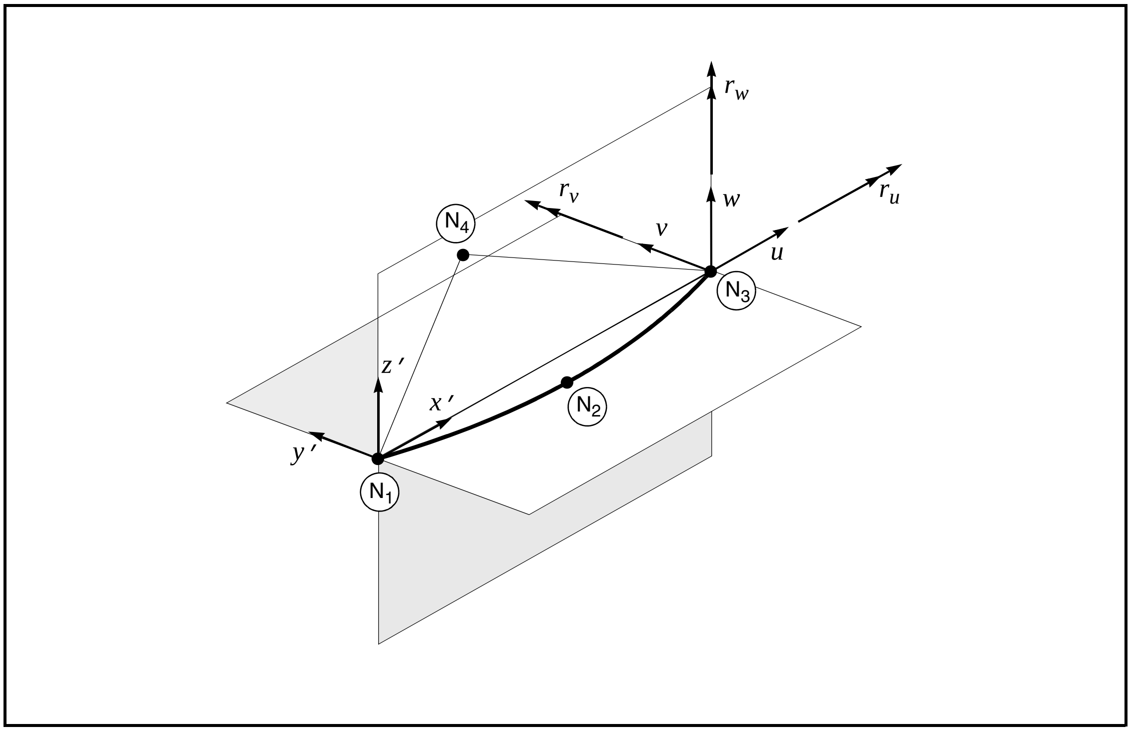


Figure 9.15 **E928** 3-Node Curved Beam Element

This T-928 element-specification record (set) should be used instead of the T-900 record (set) described earlier in this section when the user wants to add one or more "built-in" type-928 UELs to his current element unit. STAGS uses the same subroutines—and the same data spaces—to read and process all of the "generic" and type-specific input records that are needed for any type of UEL, so what we are calling the T-928 record here is actually a T-900 record that should be used as described here.

Before we turn our attentions to this record (and the other records in the T-928 record set), we need to remind the user whose model has one or more **E928** **UEL**s in it that he must include the following `*userElement` and `*userProperty` **UEL**-definition directives somewhere in his *case.inp* file for that model prior to his first use of any **E928** element:

```
*userElement  name = ”Uniform Beam Element”  type = 928  nodes = 4
*dofOrdering
   $ Node DOF
   $ ---- ---
     1    1 2 3 4 5 6
     2    1 2 3 4 5 6
     3    1 2 3 4 5 6
     4    0
*nodeSequence
   $ Nodes...
   $ --------
     1 3 4 2
*floatVariables
   $ Name       Size
   $ ----       ----
     Area          1
     Iy            1
     Iz            1
     J             1
     Material      1
     ShearFactorY  1
     ShearFactorZ  1
     Ecc           2
     Scc           2
*end userElement
*userProperty  name = ”Standard Data -- Uniform Beam Element”  id = 928
*integerProps
   $ Required Standard Data
   $ ----------------------
     ActiveNodes       3
     SamplingCount    10
     StrainCount       6
     StressCount       6
     Beam              1
*floatProps
   $ Nodal Stress/Strain Sampling Points
   $ -----------------------------------
     y1     -0.075
     z1     -0.500

     y2      0.075
     z2     -0.500

     y3      0.075
     z3      0.500

     y4     -0.075
     z4      0.500

     y5      0.0
     z5      0.0
*end userProperty
```

These directives replicate the “standard” element-type properties that the developer of this **UEL** specified when he implemented his 3-node curved beam element in **STAGS** as a type-928 element. These element-definition directives are printed in `Blue` to remind the user that they must be included in his *case.inp* file “precisely” as they are shown here—with no substantive changes.

When the user’s model has one or more **E928** elements in it, he must also include at least one `*userProperty` directive like the one that follows this paragraph—to specify the physical properties of each of the different materials that those elements use. Each of these `*userProperty` directives must have a unique `name` and a unique `id`, and each of them must be included in the user’s *case.inp* file prior to its first use by any **UEL** of any type.

```
*userProperty  name = ”Aluminum 6061-T6”  id = 6061
*floatProps
     E                         11.00000e+6
     G                          4.13534e+6
     MassDensity                2.540e-4
     PoissonRatio               0.33
     TensileUltimateStrength   38.0e+3
     TensileYieldStrength      35.0e+3
     CompressiveYieldStrength  35.0e+3
     ShearYieldStrength        20.0e+3
     ThermalExpansion           1.3e-5
*end userProperty
```

The `Blue` items in this directive define “standard” parts of any **E928** material specification data set and should be included “as is” in the analyst’s *case.inp* file. Each of the `Red` entries in this directive defines the *value* that the user specifies for the variable that precedes it — a short character string for the `name` variable, a (unique) integer value for the property identification variable (`id`), or a floating point value for one of the material-property variables (`E` = `11.0e+6`, for example). The user can and should change the values of the `Red` entries whenever he needs to do so to construct the model that he needs for the case at hand. In many “simple” cases, all of the **E928** elements in the user’s model use the same material properties: and he only needs to put one directive like this in his *case.inp* file. In more complex cases, where the model has **E928** elements that use different materials from group to group or from element to element, he will need to define each different material *via* its own material-property-definition directive—before using that material in any **UEL**.

In any event... with a *case.inp* that has all of the directives in it that are needed to define what a type-928 element is and to specify the material properties that it needs, the user can (finally) use the T-928 record that is described below (a) to specify his intention to add one or more **E928** elements to the current element unit, (b) to specify the “element number” of the first element in this set of elements, to specify “place-holder” values for the four input and control flags, and to specify one incrementation variable—*via* the **KELT**, **ID**, **IFAB**, **IANG**, **ILIN**, **IPLAS** and **NX** variables on this T-928 record:

KELT ID IFAB IANG ILIN IPLAS NX

KELT	must = 928 for this **E928 UEL**	see **Note 1**, below
ID	starting element number for first element in this element set	
IFAB	must = 0 (fabrication identifier)	see **Note 2**, below
IANG	must = 0 (wall-reference option)	see **Note 2**, below
ILIN	must = 0 (geometric-nonlinearity flag)	see **Note 2**, below
IPLAS	must = 0 (material-nonlinearity flag)	see **Note 2**, below
NX	# of elements to be generated in the *x* direction (default=1) .	see **Note 3**, below

Note 1: Any **KELT** value other than **928** on this record tells **STAGS** that the user wants to stop adding **E928** elements and start adding one or more type-**KELT UEL**s to the current element unit. In this case, the user should follow the prescriptions given elsewhere in this section for that type of **UEL** (instead of following the prescription given here for type-**928** elements).

Note 2: **E928** elements get all of the fabrication and material property information that they can use from **UEL** directives (currently), and they do not use **IFAB**, **IANG**, **ILIN** or **IPLAS**; the prudent user should set each of these variables equal to 0—especially if he uses the **NX** variable to generate a “string” of **E928 UEL**s.

Note 3: The user can generate a string of **E928 UEL**s using the **NX** incrementation variable on this record, but he cannot (currently) generate 2- or 3-dimensional sets of strings by using the **NY** and **NZ** parameters that T-900 accommodates; the prudent user should refrain from using T-900’s **NY** and **NZ** variables—or set both of them equal to 1 if he cannot bear to do that.

go to T-928a

T-928a E928 UEL Nodes

This is where the user specifies the four node points that define the first **E928** element that he wants to add to the current element unit *via* the current T-928 record set. **STAGS** “knows” that he must specify four nodes here because the `*userElement` directive that defines what a type-928 element “is” specified that each type-928 element in any given element unit must have four nodes—each of which is a node that is included in the nodal point list that he constructed *via* his S-1 or S-3 specifications for that unit.

Each T-928 record must be followed by a single T-928a **E928 UEL** NODES record:

N1 N2 N3 N4

N1	node # 1, at end “A” of the beam
N2	node # 2, at the “center” of the beam
N3	node # 3, at end “B” of the beam
N4	reference node

```
NX      (T-928)      x-direction incrementation flag

if      ( NX > 1 )      then
        go to T-928b
else
        go to T-928c
endif
```

T-928b E928 UEL X-Direction Incrementations

Incrementation variables are specified here for use with the **NX** (x-direction) looping function invoked on the T-928 record and the initial node points established on T-928a.

IX1 IX2 IX3 IX4 IXU

IX1	x-direction incrementation variable for node **N1** on T-928a
IX2	x-direction incrementation variable for node **N2** on T-928a
IX3	x-direction incrementation variable for node **N3** on T-928a
IX4	x-direction incrementation variable for node **N4** on T-928a
IXU	x-direction incrementation variable for use with the **ID** parameter on T-928a

Any of the first four of these incrementation variables can be negative, zero or positive. **IXU** must be nonzero.

✦ *go to* T-928c

T-928c E928 UEL floatVariables

This is where the user must specify the numeric value(s) of each of the nine floating point input variables that the developer of this type-928 **UEL** "created" for it (by defining the name and size of each of those variables in the `*floatVariables` part of his `*userElement` directive for that **UEL** (see the T-928 record description, above).

A single T-928c record must follow T-928a (or T-928b) for the current set of type-928 **UEL**s.

Area Iy Iz J Material
ShearFactorY ShearFactorZ
ECC(1) ECC(2) SCC(1) SCC(2)

Area	cross section area (uniform along the beam)
Iy	area moment of inertia about the element's y axis
Iz	area moment of inertia about the element's z axis
J	polar moment of inertia, about the element's x axis
Material	material property-set identifier
ShearFactorY	shear-correction factor for the beam's y-direction
ShearFactorZ	shear-correction factor for the beam's z-direction
ECC(1)	eccentricity in the y-direction for each of the active nodes
ECC(2)	eccentricity in the z-direction for each of the active nodes
SCC(1)	shear center offset in the y-direction along the uniform cross section
SCC(2)	shear center offset in the z-direction along the uniform cross section

```
if     ( the user wants to add another set of E928 elements )  then
         go to T-928
elseif ( the user wants to add a set of E940 elements )  then
         go to T-940
elseif ( the user wants to add a set of E900 elements )  then
         go to T-900
else
         return to T-100
endif
```

T-940 E940 MIN4 Quadrilateral UEL

STAGS' **E940** 4-node quadrilateral element—shown in the following Figure—was originally implemented in the program as a User-Defined Element, in accord with the **UEL** specifications and conventions that are described here and in Chapter 13 of this document. After testing this User-Defined element successfully, it was incorporated into **STAGS** as a "built-in" **UEL** that anyone can use without having to re-make **s1**, **s2** and other **STAGS** processors to do so.

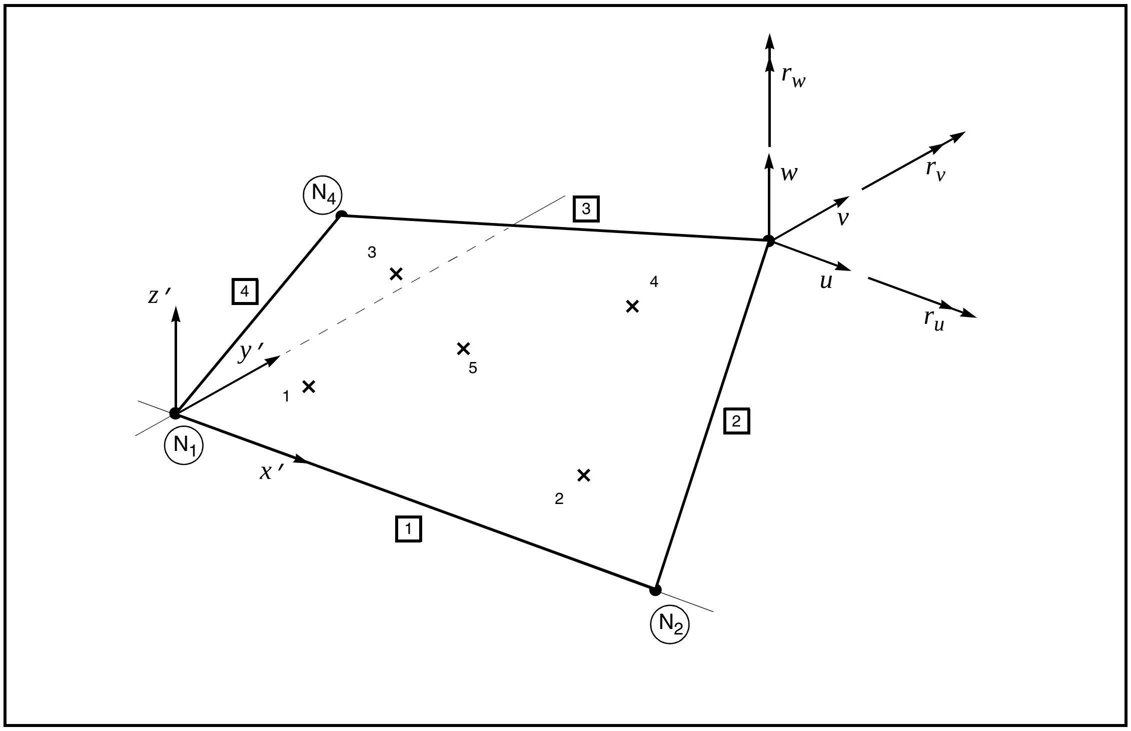


Figure 9.16 **E940** 4-Node MIN4 Quadrilateral Element

This T-940 element-specification record (set) should be used instead of the T-900 record (set) described earlier in this section when the user wants to add one or more "built-in" type-940 **UEL**s to his current element unit. **STAGS** uses the same subroutines—and the same data spaces—to read and process all of the "generic" and type-specific input records that are needed for any type of **UEL**, so what we are calling the T-940 record here is actually a T-900 record that should be used as described here.

Before we turn our attentions to this record (and the other records in the T-940 record set), we need to remind the user whose model has one or more **E940** **UEL**s in it that he must include the following *userElement and *userProperty **UEL**-definition directives somewhere in his *case.inp* file for that model prior to his first use of any **E940** element:

```
*userElement  name =”Uniform Plate Element”  type=940  nodes=4
*dofOrdering
   $ Node DOF ...
   $ ---- -----------
     1    1 2 3 4 5 6
     2    1 2 3 4 5 6
     3    1 2 3 4 5 6
     4    1 2 3 4 5 6
*nodeSequence
   $ Nodes...
   $ --------
     1 2 3 4
*floatVariables
   $ Name          Size
   $ ----          ----
     UniformPressure  2
*integerVariables
   $ Name          Size
   $ ----          ----
     IntegOrder       1
     LoadType         1
*end userElement

*userProperty  name =”Standard Data -- Uniform Plate Element”  id=940
*integerProps
   $ Required Standard Data
   $ ----------------------
     ActiveNodes      4
     SamplingCount    1
     StrainCount      8
     StressCount      8
   $ Data for GCP Interface
   $ ----------------------
     Class            2
     Kintype          1
*end userProperty
```

These directives replicate the “standard” properties that the developer of this **UEL** specified when he implemented his 4-node MIN4 quad element in **STAGS** as a type-940 element. These element-definition directives are printed in `Blue` here to remind the user that they must be included in his *case.inp* file “precisely” as they are shown here (with no substantive changes) somewhere in that file before the first **E840** element in the model is specified. The user does not have to include `*userProperty` directives in his *case.inp* file to specify geometric and/or material properties for those **E840** elements because **STAGS** gets all of the material and fabrication information that it needs for those elements from the program’s comprehensive **GCP** facilities.

That done, the analyst can then use a single T-940 record (which is in fact a **UEL**-type-specific T-900 record) to specify that he wants to add one or more **E940** elements to the current element unit—and to specify the “element number” for the first element in this set, the four input and control flags, and the two incrementation variables that he can use with **E940** **UEL**s:

KELT ID IFAB IANG ILIN IPLAS NX NY

KELT must = 940 for this **E940 UEL** . . . . see **Note 1**, below

ID starting element number for first element in this element set

IFAB fabrication identifier: must be < 0 for this **E940 UEL**, to identify a fabrication in the GCP Fabrication Table (I-22a)

IANG wall-reference option:

0 – use default strategy of projecting x_g, y_g to establish x_w

1 – specify an x-direction vector for use in establishing the material orientation matrix

2 – specify x- and y-direction vectors for use in establishing the material orientation matrix

ILIN geometric-nonlinearity flag:

0 – use nonlinear strain-displacement relations

1 – use linear strain-displacement relations

IPLAS material-nonlinearity flag:

0 – elastic behavior only

> 0 – plasticity included

NX # of **E940**s to be generated in the x direction (default=1) . . . see **Note 2**, below

NY # of **E940**s to be generated in the y direction (default=1) . . . see **Note 2**, below

Note 1: Any **KELT** value other than **940** on this record tells **STAGS** that the user wants to stop adding **E940** elements and start adding one or more type-**KELT UEL**s to the current element unit. In this case, the user should follow the prescriptions given elsewhere in this section for that type of **UEL** (instead of following the prescriptions given here for type-**940** elements).

Note 2: The user can generate a 2-dimensional “patch” of **E940 UEL**s using the **NX** and **NY** incrementation variables on this record, but he cannot (currently) generate a “layered” set of 2-dimensional patches by using all three of the incrementation variables that the T-900 record offers; the prudent user should refrain from using T-900’s **NZ** variable—or set it equal to 1 if he cannot bear to do that.

go to T-940a

T-940a E940 UEL Nodes

This is where the user specifies the four node points that define the first **E940** element that he wants to add to the current element unit *via* the current T-940 record set. **STAGS** “knows” that he must specify four nodes here because the `*userElement` directive that defines the attributes of a type-940 element specifies that each type-940 element in any given element unit must have four nodes—each of which is included in the nodal point list that he constructed *via* his S-1 or S-3 specifications for that unit.

Each T-940 record must be followed by a single T-940a **E940 UEL** NODES record:

N1 N2 N3 N4

N1	node # 1
N2	node # 2
N3	node # 3
N4	node # 4

NX	(T-940)	x-direction incrementation flag
NY	(T-940)	y-direction incrementation flag
IANG	(T-940)	wall-reference option

```
if      ( NX > 1 )      then
        go to T-940b
elseif  ( NY > 1 )      then
        go to T-940c
elseif  ( IANG = 1 )    then
        go to T-940d
elseif  ( IANG = 2 )    then
        go to T-940e
else
        follow the instructions at the end of T-940g
endif
```

T-940b E940 UEL X-Direction Incrementations

Incrementation variables are specified here for use with the **NX** (x-direction) looping function invoked on the T-900 record and the initial node points established on T-940a.

IX1 IX2 IX3 IX4 IXU

IX1 x-direction incrementation variable for node **N1** on T-940a

IX2 x-direction incrementation variable for node **N2** on T-940a

IX3 x-direction incrementation variable for node **N3** on T-940a

IX4 x-direction incrementation variable for node **N4** on T-940a

IXU x-direction incrementation variable for use with the **ID** parameter on T-940a

Any of the first four of these incrementation variables can be negative, zero or positive. **IXU** must be nonzero.

NY (T-940) y-direction incrementation flag

IANG (T-940) wall-reference option

```
if      ( NY > 1 )     then
        go to T-940c
elseif  ( IANG = 1 )   then
        go to T-940d
elseif  ( IANG = 2 )   then
        go to T-940e
else
        go to T-940f
endif
```

T-940c E940 UEL Y-Direction Incrementations

Incrementation variables are specified here for use with the **NY** (y-direction) looping function invoked on the T-900 record and the initial node points established on T-940a.

IY1 IY2 IY3 IY4 IYU

IY1 y-direction incrementation variable for node **N1** on T-940a

IY2 y-direction incrementation variable for node **N2** on T-940a

IY3 y-direction incrementation variable for node **N3** on T-940a

IY4 y-direction incrementation variable for node **N4** on T-940a

IYU y-direction incrementation variable for use with the **ID** parameter on T-940a

Any of the first four of these incrementation variables can be negative, zero or positive. **IYU** must be nonzero.

```
IANG    (T-940)     wall-reference option

if      ( IANG = 1 )  then
        go to T-940d
elseif  ( IANG = 2 )  then
        go to T-940e
else
        go to T-940f
endif
```

T-940d E940 UEL Material Orientation Vector

If **IANG** = 1 (T-940), a single T-940d record must follow T-940a (or T-940b or T-940c) for the current set of **E940** User elements. T-940d specifies a single x-direction vector that is used to establish the material orientation triad for each of the User elements that are to be generated by the current T-940 element-definition set.

XFX XFY XFZ

XFX, XFY, XFZ vector components establishing the x orientation of the material

go to T-940f

T-940e E940 UEL Material Orientation Vectors

If **IANG** = 2 (T-940), a single T-940e record must follow T-940a (or T-940b or T-940c) for the current set of **E940** User elements. T-940e specifies an x-direction and a y-direction vector that are *both* used to establish the material orientation triad for each of the User elements that are to be generated by the current T-940 element-definition set.

XFX XFY XFZ   YFX YFY YFZ

XFX, XFY, XFZ vector components establishing the x orientation of the material

YFX, YFY, YFZ vector components establishing the y orientation of the material

go to T-940f

T-940f E940 UEL floatVariable

This is where the user must specify the numeric values of the two floating point input variables that the developer of this type-940 **UEL** “created” for it (by defining their names and sizes in the `*floatVariables` part of his `*userElement` directive for that **UEL** (see the T-940 record description, above).

A single T-940f record must follow T-940a (or T-940b or T-940c or T-940d or T-940e) for the current set of type-940 **UEL**s.

UniformPressure(1) UniformPressure(2)

UniformPressure(1) **P1** component of uniform pressure loading (positive in the +z direction in the element’s local coordinate system); see T-940g, on the following page

UniformPressure(2) **P2** component of uniform pressure loading (positive in the +z direction in the element’s local coordinate system); see T-940g, on the following page

go to T-940g

T-940g E940 UEL integerVariables

This is where the user must specify the numeric values of the two integer input variables that the developer of this type-940 **UEL** "created" for it (by defining their names and sizes in the `*integerVariables` part of his `*userElement` directive for that **UEL** (see the T-940 record description, above).

A single T-940g record must follow the T-940f record for the current set of type-940 **UEL**s.

IntegOrder LoadType

IntegOrder integration order flag:

= 0 – stabilized reduced integration strategy that works very well in practice (strongly recommended)
= 1 – single (centroidal) integration point (never recommended)
= 4 – full integration

LoadType load type flag:

= -1 – ignore the **P1** and **P2** pressure loadings specified on the T-940f record; apply pressure loading(s) *via* the UPRESS user-written subroutine
= 0 – apply the **P1** pressure loading *via* the P_a loading system
= 1 – apply the **P1** pressure loading *via* the P_a loading system
= 2 – apply the **P1** pressure loading *via* the P_a loading system and apply the **P2** pressure loading *via* the P_b loading system

Note 1: The **P1** and **P2** uniform pressure loading components are specified *via* the **UniformPressure(1)** and **UniformPressure(2)** variables on the T-940f record (which is described on the preceding page)

```
if     ( the user wants to add another set of E940 elements )  then
        go to T-940
elseif ( the user wants to add a set of E928 elements )  then
        go to T-928
elseif ( the user wants to add a set of E900 elements )  then
        go to T-900
else
        return to T-100
endif
```

10
Model Input—Element Units (4)

This chapter contains descriptions of **STAGS** input requirements for specification of loadings that can be applied to an element unit, of specifications that can be made to control output produced by the program in generating and in processing an element unit, and of specifications that may be made to include externally-generated linear stiffness matrices in the model (after all of the element units in the model have been defined).

10.1 Element unit loadings

Element-unit loadings are in many ways similar to shell-unit loadings, which are described in Section 6.5 "Loads". The following discussion of element-unit loadings contains frequent references to Section 6.5 in lieu of repeating documentation presented there. Differences between element-unit and shell-unit loadings are pointed out, where they occur—as are features which are unique to element units. For the most part, however, the user may simply refer to the indicated shell-unit loading documentation. Other information which will be found particularly useful in a study of element-unit loading techniques is summarized below:

- Coordinate systems—Section 4.1 "Coordinate Systems" on page 4-1, and Section 14.2 "Algorithm for Determining the Element Frame" on page 14-2.
- Element node-numbering and edge-numbering conventions—Chapter 14 "The Element Library".
- Distributed loading—Section 4.6 "Loads" on page 4-11.
- Shell-units loads—Section 6.5 "Loads" on page 6-64.

The only type of surface traction that is permissible on shell elements is normal pressure, which may be input either as *dead* pressure (**LT**=4, U-3), which remains normal to the undeformed surface, or as *live* pressure (**LT**=5), which remains normal to the deformed surface throughout large deformations. The user must be aware that the (z') element normal determines the direction of pressure. That normal, in turn, is determined by the element node numbering (T-3, T-4). A complete discussion of node numbering can be found with those records. For line loads (**LT**=2), the situation is more complicated. The user is asked to provide the load direction (**LD**, U-3), the element number, and the element edge number. The user may select from three coordinate systems for expressing load directions—(x'', y'', z'') computational coordinates, $(\bar{x}_g, \bar{y}_g, \bar{z}_g)$ nodal-global coordinates, and (x_e, y_e, z_e) element-edge coordinates. Choice of coordinate system is independently specified for each load record (**LAX**, U-3). As explained in Section 4.1 “Coordinate Systems”, the user may optionally (**IAUX**, S-1) define a (x_a, y_a, z_a) nodal-auxiliary coordinate system at each node. Where a nodal-auxiliary system is defined, it determines the computational system at that node. Otherwise, the nodal-global system is used. It is the user’s responsibility to define sensible auxiliary systems in order for the loading to be physically meaningful.

Prestress for a linear eigenvalue analysis (bifurcation buckling or small vibrations) may be defined for element units by two methods. As for shell units, a uniform stress state is defined on a U-5 record (*cf*. Q-5, shell unit). The prestress state is defined in $(\bar{x}, \bar{y})$ fabrication coordinates and is applied to all shell elements in the unit. A non-uniform prestress field can be defined using U-3 records, **LT**=3, again in fabrication coordinates. Both options are allowed within each element unit. It is important to note that if both U-5 and U-3 prestress are specified, the U-3 records override the constant field for those elements where they have been defined.

For the element unit, it is possible to specify incremental boundary conditions for bifurcation buckling that are different from those applied to the prebuckling state. See Section 6.4 “Boundary Conditions” on page 6-57. The discussion there pertaining to *basic*/*incremental* BCs in shell units is also applicable to element units, with *dof* constraints imposed *via* specified displacements on U-3 $(\mathbf{LT} = -1)$. As for shell units, the value of the displacement (**P**, U-3) is ignored, and a *dof* constraint (*i.e.*, specified zero) is applied to the incremental BCs.

U-1 Loads Summary

This record summarizes the load data to be defined for the element unit. It is always included in each of the element units. Element-unit loading is similar to shell-unit loading. For information about that, see Section 10.1 “Element unit loadings” on page 10-1, and “Q-1 Loads Summary” on page 6-67.

NSYS NICS NAMS NUSS NHINGE NMOMNT NLEAST IPRESS

NSYS number of load systems

NICS number of sets of initial conditions

NAMS number of attached masses

NUSS **NUSS** > 0 indicates that a uniform basic stress state will be defined on U-5 for vibration or bifurcation buckling

NHINGE number of cable hinge restraint vectors

NMOMNT number of cable hinge moment loading vectors (must be 0, currently)

NLEAST number of least-squares loading sets

IPRESS
0 – no UPRESS
1 – UPRESS is included

User-written subroutine UPRESS defines pressure–surface loading which acts normal to the element surface. The inclusion of UPRESS precludes the definition of pressure loading in the *INP* file. When **IPRESS** = 1, any pressure loads defined on Q-3/U-3 records (**LT** = 4 or 5) are ignored.

```
if      ((NSYS > 0) or (NICS > 0)) then   go to U-2
elseif  (NAMS > 0)                 then   go to U-4
elseif  (NUSS > 0)                 then   go to U-5
elseif  (NHINGE > 0)               then   go to U-6
elseif  (NMOMNT > 0)               then   go to U-7
elseif  (NLEAST > 0)               then   go to U-8a
else                                      go to V-1
```

U-2 Load Set Summary

Element-unit loading is similar to shell-unit loading. For information about that, see Section 10.1 “Element unit loadings” on page 10-1, and “Q-2 Load Set Summary” on page 6-69.

The number of loadsets, S_l, is defined as $S_l = \mathbf{NSYS} + \mathbf{NICS}$ (U-1), where $\mathbf{NSYS} \le 2, \mathbf{NICS} \le 2$; therefore $S_l \le 4$. Each of the S_l load sets is defined in a U-2/ U-3 series. The order in which they are defined is established as:

- load system A
- load system B
- initial displacement
- initial velocity

All four load sets are optional. Each load set which is present must be completely defined *via* a U-2/3 series before moving on to the next set in the order specified above.

ISYS NN IFLG

ISYS for load systems:

1 – load system A

2 – load system B

for initial conditions:

0 – initial displacements

-1 – initial velocities

NN number of U-3 records needed to describe the loads or initial conditions

IFLG

0 – no USRLD

1 – loads defined in user-written subroutine USRLD are included

if (**NN** > 0) then *go to* U-3
else *follow instructions at end of* U-3

U-3 Load Definition

This record is included only if **NN** > 0 (U-2); it is repeated **NN** times. Element-unit loading is similar to shell-unit loading. For information about that, see Section 10.1 “Element unit loadings” on page 10-1, and “Q-3 Load Definition” on page 6-70.

Distributed loads are uniform over an element or over an element boundary. The location of a line load is given by the element edge number and the unit element number. Location of a surface traction is given by unit element number. Elements are automatically numbered by unit in the order that they are defined on the T records. The user can verify unit element numbering by referring to the *OUT1* (model output) file.

P LT LD LI LJ LAX NDEFS INC1 INC2 INC3

P magnitude of load, displacement, or velocity; the load type and direction are determined by **LT** and **LD**, respectively.

LT

-1 – prescribed displacement (translation or rotation), or initial condition (initial displacement or initial velocity)
1 – point force/moment
2 – line load/moment
3 – initial prestress
4 – dead pressure—normal to the undeformed element surface
5 – live pressure—normal to the deformed element surface throughout geometrically-nonlinear deformations
6 – ~~velocity dependent forces~~ (see E-1) — *INACTIVE*
7 – ~~surface traction~~ — *INACTIVE*

☞ Note that when **LT** $= 3$, any uniform prestress defined on U-5 is overridden for the corresponding element.

LD load direction; interpretation of (X, Y, Z) is dependent upon **LAX**, below. **LD** must be set to 3 when **LT** ≥ 4.

1 – *u*; force/translation in the *X* direction. N_{xx} prestress if **LT** = 3
2 – *v*; force/translation in the *Y* direction. N_{yy} prestress if **LT** = 3
3 – *w*; force/translation in the *Z* direction. N_{xy} prestress if **LT** = 3
4 – *ru*; moment/rotation, right-handed about the *X* axis
5 – *rv*; moment/rotation, right-handed about the *Y* axis
6 – *rw*; moment/rotation, right-handed about the *Z* axis

LI load location identifier

LT ≤ 1: node number

LT $= 2$: element edge number

LT ≥ 3: not used

LJ element number; irrelevant when **LT** ≤ 1. **LJ** = 0 applies pressure to all elements for **LT** ≥ 4.

LAX load axes, determining the interpretation of **LD**, above

0 – (X, Y, Z) correspond to (x'', y'', z'') computational coordinates

1 – (X, Y, Z) correspond to $(\bar{x}_g, \bar{y}_g, \bar{z}_g)$ nodal-global coordinates

2 – (X, Y, Z) correspond to (x_e, y_e, z_e) element-edge coordinates

LAX = 0 is required for **LT** = -1
LAX = 2 is permitted for line loads only
For **LT** $= 3$, the prestress state is defined in $(\bar{x}, \bar{y})$ fabrication coordinates.
The (z') element normal defines the direction of pressure

NDEFS number of loading definitions specified *via* the current U-3 record; set equal to unity by **STAGS** if less than 2 or if omitted

INC1 incrementation parameter for use with the **LD** variable

INC2 incrementation parameter for use with the **LI** variable

INC3 incrementation parameter for use with the **LJ** variable

NAMS	(U-1)	number of attached masses
NUSS	(U-1)	uniform basic stress state option for eigenanalysis
NHINGE	(U-1)	number of cable hinge restraint vectors
NMOMNT	(U-1)	number of cable hinge moment loading vectors
NLEAST	(U-1)	number of least-squares loading sets

```
if      (NAMS > 0)    then   go to U-4
elseif  (NUSS > 0)    then   go to U-5
elseif  (NHINGE > 0)  then   go to U-6
elseif  (NMOMNT > 0)  then   go to U-7
elseif  (NLEAST > 0)  then   go to U-8a
else                         go to V-1
```

U-4 Attached Mass

The U-4 records allow the user to define attached masses at any node point in the element unit. The record is repeated **NAMS** (U-1) times.

GM NM NDEFS INC

GM weight of attached mass, in units of *force*

NM node number of attached mass

NDEFS number of masses to be attached

INC incrementation parameter for the **NM** variable

NUSS	(U-1)	uniform basic stress state option for eigenanalysis
NHINGE	(U-1)	number of cable hinge restraint vectors
NMOMNT	(U-1)	number of cable hinge moment loading vectors
NLEAST	(U-1)	number of least-squares loading sets

```
if  (NAMS attached-mass records have been defined)  then
    if      (NUSS > 0)    then   go to  U-5
    elseif  (NHINGE > 0)  then   go to  U-6
    elseif  (NMOMNT > 0)  then   go to  U-7
    elseif  (NLEAST > 0)  then   go to  U-8a
    else                         go to  V-1
else    continue defining  U-4
```

U-5 Uniform Stress State for Eigenanalysis

This record may be used to define the stress resultants in a uniform basic stress state for bifurcation buckling or small vibration analysis. When a U-5 record is included, the only type of loading allowed is specified displacements (**LT** = -1, U-3). Any other loading (mechanical or thermal) which may be defined is ignored, not only in the current unit, but in all units. The stress resultants defined on this record are multiplied by the load factors **STLD(1)**,**STLD(2)** (C-1) for load systems A and B, respectively.

The prestress state is defined in $(\bar{x}, \bar{y})$ fabrication coordinates.

PNXA PNYA PNXYA PNXB PNYB PNXYB

PNXA value of the stress resultant in the $\bar{x}$ direction, load system A

PNYA value of the stress resultant in the $\bar{y}$ direction, load system A

PNXYA value of the shear resultant, load system A

PNXB value of the stress resultant in the $\bar{x}$ direction, load system B

PNYB value of the stress resultant in the $\bar{y}$ direction, load system B

PNXYB value of the shear resultant, load system B

NHINGE (U-1) number of cable hinge restraint vectors
NMOMNT (U-1) number of cable hinge moment loading vectors
NLEAST (U-1) number of least-squares loading sets

```
if      (NHINGE > 0)  then   go to U-6
elseif  (NMOMNT > 0)  then   go to U-7
elseif  (NLEAST > 0)  then   go to U-8a
else                         go to V-1
```

U-6 Cable Hinge Restraint

This record is included only if **NHINGE** > 0 (U-1); it is repeated **NHINGE** times.

See discussion of cable hinge restraints under U-1. The vector described below gives the direction of the constraint in (x'', y'', z'') computational coordinates. Although the magnitude of this vector does not theoretically influence the result, this is a multipoint constraint imposed by Lagrange multipliers. The new equation (automatically) produced by this constraint is assembled into the stiffness matrix along with the other freedoms. To avoid numerical problems, the magnitude of this vector is converted to a scaling constant to help the conditioning of the stiffness matrix. See the general discussion of Lagrange constraints under G-3 for more details.

IHND HRU HRV HRW NDEFS INC

IHND node number where constraint is applied

HRU, HRV, HRW the direction vector, in (x'', y'', z'') computational coordinates, along which rotation is prevented; the magnitude of this vector should be of the same order as the element torsional stiffness

NDEFS number of constraints to be applied

IHND incrementation parameter for the **IHND** variable

NHINGE	(U-1)	number of cable hinge restraint vectors
NMOMNT	(U-1)	number of cable hinge moment loading vectors
NLEAST	(U-1)	number of least-squares loading sets

```
if   (NHINGE cable hinge restraint vectors have been defined)  then
     if       (NMOMNT > 0)  then     go to  U-7
     elseif   (NLEAST > 0)   then    go to  U-8a
     else                            go to  V-1
else     continue defining  U-6
```

U-7 Cable Hinge Moment

NOTE**: This feature is currently disabled, and the user must set* **NMOMNT** $= 0$ (U-1). ***STAGS *automatically introduces cable moments for all applied moment loadings.*

This record is included only if **NMOMNT** > 0 (U-1); it is repeated **NMOMNT** times.

See discussion of cable hinge moment loads under U-1. The vector described below gives the direction and magnitude of the applied moment in (x'', y'', z'') computational coordinates.

IMND MSYS RUM RVM RWM NDEFS INC

IMND node number where moment is applied

MSYS
1 – load applies to the A system
2 – load applies to the B system

RUM, RVM, RWM moment vector components in (x'', y'', z'') computational coordinates

NDEFS number of moments to be applied

IMND incrementation parameter for the **IMND** variable

NMOMNT	(U-1)	number of cable hinge moment loading vectors
NLEAST	(U-1)	number of least-squares loading sets

```
if   (NMOMNT cable hinge moment loading vectors have been defined) then
     if   (NLEAST > 0)   then      go to  U-8a
     else                          go to  V-1
else     continue defining  U-7
```

U-8a Least Squares Loading Summary

There are **NLEAST** sets of U-8 records. Record U-8a is used to define the number **NSQR** of U-8b special loading records to follow, to define the reference node for the application of the least-squares summary loads or reactions, and to provide an overall scale factor **SCALE** for the six Lagrange constraints introduced automatically for each least-squares load set. The reference node must have been defined in the current or a previous unit. If any nodes not yet defined are referenced in any U-8 records, an error will result; to avoid this, postpone the definition of this least-squares set until after all pertinent nodes have been defined. As with all other Lagrange constraints that contribute to the stiffness matrix (see, for example, record G–3 and the ones that follow it), numerical roundoff considerations require that the values of the Lagrange unknowns not differ from other unknowns by too many orders of magnitude. This in turn means that the stiffness contributions should be near the same order as other members, or a **SCALE** value set to about equal to some average thickness times a modulus. The user should remember that this is only an order-of-magnitude estimate for numerical conditioning.

NSQR IUNIT IROW ICOL SCALE

NSQR number of U-8b data records required to define the edges involved in this least-squares load set.

IUNIT unit number for the reference node.

IROW row number for the reference node; if the reference node is in an element unit, **IROW** is the user point number (**IUPT**, S–1).

ICOL column number for the reference node; zero if node is in an element unit.

SCALE scale factor for numerical conditioning; we suggest something of the order of magnitude of the material modulus times a representative shell thickness.

✦ *go to* U-8b

U-8b Least Squares Load Definition

A least-squares constraint loading condition is specified by defining the following three components:

- A reference node with section weighting (see U-8a)
- A curve consisting of one or more arc segments and/or single nodes (U-8b).
- Loads on the reference node (see U-1, U-2, U-3 records)

U-8b input records define a curve consisting of one or more arc segments, or alternatively, individual nodes. There are a total of **NSQRS** U-8b records. A sequence of U-8b records, all with (**LU**, **LR**, **LC)** defining actual nodes, specifies one arc segment. Additional arc segments may then be defined by adding a U-8b record with (**LU**, **LR**, **LC)** = 0 followed by more U-8b records defining the next arc segment. If a segment consists of a single node, the node weight **P** is used unchanged. An individual U-8b record can specify several nodes at once in two ways:

- For shell units, **LR**=0 and **LC**>0 means the entire column **LC**, while **LR**>0 and **LC**=0 means the entire row **LR.**
- For either shell or element units, items **LNDA**, **LNDB**, and **LNDINC** may be used to describe a range of nodes.

P LU LR LC LNDA LNDB LNDINC

P Nodal weight. For sections of uniform composition, input 1.0. When the defining curve belongs to several distinct wall types, we suggest using 1.0 for the nodes in the stiffest structural areas and choosing other weights so that the set of **P** values are proportional to the modulus times the effective thickness (Eh).

LU Unit number of node (shell unit; or element unit if **LU** > **NUNITS**, B–2). If **LU** = 0, terminate the arc segment. Any U–8b records that follow describe a new arc segment to be added to this load set.

LR Row number of first node (not used in element unit)

LC Column number of first node (not used in element unit)

LNDA First node of (row if **LR** = 0) or (column if **LC** = 0) in shell unit. First node in element unit (**LR** = 0). If 0 for a shell unit, the first node on the row or column is chosen. Must be nonzero for an element unit.

LNDB Last node of (row if **LR**=0) or (column if **LC**=0) in shell unit. Last node in element unit (**LR**=0). If 0 for a shell unit, the last node on the row or column is chosen. Must be nonzero for an element unit. If **LNDB**=**LNDA**>0, then only one node is specified by this record.

LNDINC Increment for nodes from **LNDA** to **LNDB**. Increasing or decreasing ranges are allowed. If **LNDINC**=0, an increment of +1 is used for increasing ranges, and -1 for decreasing ranges.

```
NSQR      (U-8a)  number of U-8b records
NLEAST    (U-1)   number of least-squares loading sets

if   (NSQR U-8b records have been defined)  then
     if      (NLEAST loading sets have been defined)  then   go to  V-1
     else    return to  U-8a
else     continue defining  U-8b
```

10.2 Output Control

The last information required for an element unit is the small set of type V records on which output-control parameters are specified for the unit. As with shell units, the values of these output-control parameters (and the number of V-type records) can vary from element unit to element unit.

V-1 Output Control—Record 1

This record is always included for each unit. The constants governing the output can differ from one unit to another.

Element-unit output control is similar to that for shell units. For more information about this, please refer to "R-1 Output Control—Record 1" on page 6-89.

IPRD IPRR IPRE IPRS IPRP IPRF NSELD NSELS IPRDSP IPRSTR ISL ISS ISD

IPRD
0 – do not print displacements
>0 – displacements are printed at every **IPRD**th load or time step

IPRR
0 – do not print stress resultants
>0 – stress resultants are printed at every **IPRR**th load or time step (elastic analysis only)

IPRE
0 – do not print strains
>0 – strains are printed at every **IPRE**th load or time step

IPRS
0 – do not print stresses
>0 – stresses are printed at every **IPRS**th load or time step

☞ Stress output is obtained only where indicated for the corresponding shell wall or beam cross-section. Please check **LSOL** (K-2), **NSOYZ** (J-1), **ISP** (J-3a), and **ISOC** (J-3b). Also, see **ISL**, **ISS**, and **ISD**, below.

IPRP
0 – no additional stress output for points with yield
>0 – stresses and strains are printed at all points with yield at every **IPRP**th load or time step

IPRF
0 – do not print nodal point forces (internal force vector)
>0 – nodal point forces are printed at every **IPRF**th load or time step

NSELD number of records defining selected displacements (one record may correspond to a node, a row, or a column)

NSELS number of records defining selected stresses

IPRDSP
0 – print selected displacements at every load or time step
>0 – print selected displacements at every **IPRDSP**th load or time step

~~**IPRSTR**~~
0 – print selected stresses at every load or time step
>0 – ~~print selected stresses at every **IPRSTR**th load or time step~~ (disabled)

ISL
0 – element results are computed at centroids
1 – element results are computed at integration points

ISS
0 – no transverse shear stresses
1 – ~~compute transverse shear stresses~~ — *INACTIVE*

ISD
0 – print stress and strain components in $(\bar{x}, \bar{y})$ fabrication coordinates
1 – print stress components in both $(\bar{x}, \bar{y})$ fabrication coordinates and (ϕ_1, ϕ_2) material coordinates
2 – print stress components in both $(\bar{x}, \bar{y})$ fabrication coordinates and the principal directions (includes angle of orientation)

NUNITE (B-2) number of element units
NSTIFS (B-2) number of linear-stiffness-matrix contributions

```
if       (NSELD > 0)   then   go to V-2
elseif   (NSELS > 0)   then   go to V-3
else
    if       (less than NUNITE element units have been defined)  then
             return to S-1
    elseif   (NSTIFS > 0)   then   go to W-1
    else     data deck is complete
endif
```

V-2 Output Control—Record 2

This record defines a number of nodes at which displacement are to be printed at each load or time step. It is repeated **NSELD** times (V-1).

INOD1 INOD2 INODI

INOD1 node number of first node in group

INOD2 node number of last node in group

INODI node number increment

NSELD	(V-1)	number of selected displacements
NSELS	(V-1)	number of selected stresses
NUNITE	(B-2)	number of element units
NSTIFS	(B-2)	number of linear-stiffness-matrix contributions

```
if      (less than NSELD V-2 records have been defined)  then
        continue defining V-2
elseif  (NSELS > 0)     then     go to V-3
elseif  (less than NUNITE shell units have been defined)  then
                                 return to  S-1
elseif  (NSTIFS > 0)    then     go to W-1
else    data deck is complete
endif
```

V-3 Output Control—Record 3

This record defines a number of locations at which stresses will be printed at each load or time step. It is repeated **NSELS** times (V-1).

IELS1 IELS2 IELSI

IELS1	element number of first element in group
IELS2	element number of last element in group
IELSI	element number increment

NSELS	(V-1)	number of selected stresses
NUNITE	(B-2)	number of element units
NSTIFS	(B-2)	number of linear-stiffness-matrix contributions

```
if       ( less than NSELS V-3 records have been defined )  then
         continue defining V-3
elseif   ( less than NUNITE element units have been defined )  then
         return to S-1
elseif   ( NSTIFS > 0 )  then   go to W-1
else     data deck is complete
```

10.3 Linear-Stiffness Contributions

This information is required if and only if the **NSTIFS** parameter is positive on the user's B-2 record. A positive value for **NSTIFS** tells **STAGS** that **NSTIFS** externally-generated "linear-stiffness contribution" definitions are required to complete the model—where each such contribution is a supermatrix of linear stiffness matrices coupling all of the freedoms at each of the nodes with which they are associated.

A single W-1 record is required for each linear-stiffness contribution definition.

This W-1 record must be followed by any required W-2a/W-2b or W-3 records, as described below.

All of the linear-stiffness-contribution definition records are read after the last (output control) record for the final element unit in the user's model.

W-1 Linear-Stiffness Contribution—Record 1

This record is required for each of the **NSTIFS** (B-2) “linear-stiffness contributions” used for the entire model. A linear-stiffness contribution in this context is an externally-generated, **NRNOD** × **NRNOD** **[K]** supermatrix, each **NRDOF** × **NRDOF** submatrix K_{IJ} of which contains linear stiffness values for the Ith and Jth of the **NRNOD** nodes to which **[K]** contributes. Each of these nodes must have **NRDOF** degrees of freedom, where **NRDOF** is typically 3 or 6.

NRDOF NRNOD NRKIJ KLSTF NRDIS NRFOR

NRDOF number of freedoms at *each* of the nodes to which **[K]** contributes; typically, **NRDOF** = 3 or 6; **NRDOF** ≤ 6

NRNOD number of nodes to which **[K]** contributes

NRKIJ connectivity control flag *(see the note for the* **KLSTF** *parameter, below)*:
NRKIJ ≥ 0 read connectivity and stiffness data for this contribution
NRKIJ < 0 read connectivity data only

KLSTF connectivity and (optionally) contribution control flag:

KLSTF = 0 read nodal connectivities and stiffness-contribution values;

0 < **KLSTF** < *N* (where this is the *Nth* of **NSTIFS** W-1 records) ⇒ use the values given for **[K]** matrix number **KLSTF** for the current case (where contribution values must have been specified explicitly for case **KLSTF**); **KLSTF** = *N* read nodal connectivities and stiffness-contribution values

Note: STAGS sets* NRKIJ = −1 *if* KLSTF *is not equal to N

NRDIS ~~identifier of reduced-displacement vector~~ *(not implemented yet)*

NRFOR ~~identifier of reduced-force vector~~ *(not implemented yet)*

NSTIFS (B-2) number of linear-stiffness-matrix contributions

```
if  ( NSTIFS W-1 records have been defined )  then
    data deck is complete
else
    if  ( NRKIJ > 0 )  then    go to W-2a
    else                       go to W-3
endif
```

W-2a Linear-Stiffness Contribution—Record 2a

A W-2a record and its companion W-2b record are required to specify the nodal connectivity and stiffness values for each of the active submatrices K_{IJ} that comprise the **[K]** supermatrix for the current linear stiffness contribution.

The two nodes I = (**IUNIT,IROW,ICOL**) and J = (**JUNIT,JROW,JCOL**) for each active submatrix in the upper or lower triangular part of **[K]** are specified *via* the W-2a record, and the stiffness values are specified *via* W-2b. A submatrix is active if it has one or more nonzero stiffness values. Since the number of active submatrices is not known *a priori*, **STAGS** expects to read a user-controlled sequence of W-2a records—each followed by a companion W-2b record—with the user terminating the sequence *via* the **IUNIT** parameter, as described below.

IUNIT IROW ICOL JUNIT JROW JCOL

IUNIT unit number for node I; **IUNIT** ≤ 0 terminates the reading of W-2a input records

IROW row number for node I, if **IUNIT** is a shell unit; or I node number, if **IUNIT** is an element unit

ICOL column number for node I, if **IUNIT** is a shell unit; or ignored, if **IUNIT** is an element unit

JUNIT unit number for node J, if **JUNIT** is a shell unit; or J node number, if **JUNIT** is an element unit

JROW row number for node J, if **JUNIT** is a shell unit; or J node number, if **JUNIT** is an element unit

JCOL column number for node J, if **JUNIT** is a shell unit; or ignored, if **JUNIT** is an element unit

NSTIFS (B-2) number of linear-stiffness-matrix contributions

```
if      ( IUNIT>0 )      then      go to W-2b
elseif  ( NSTIFS linear-stiffness-contributions have been defined )then
        data deck is complete
else    go to W-1
endif
```

W-2b Linear-Stiffness Contribution—Record 2b

A W-2b record is required to specify the stiffness values for the active submatrix K_{IJ} that is identified by its above-described W-2a record.

((KIJ(m,n), n=1,NRDOF), m=1,NRDOF)

KIJ ... **NRDOF** × **NRDOF** submatrix of linear-stiffness-contribution values

✦ *go to* W-1

W-3 Linear-Stiffness Contribution—Record 3

A set of **NRNOD** (W-1) W-3 records is required to specify the nodal connectivities of a linear-stiffness contribution that uses the same stiffness values as a previously-specified contribution.

IUNIT(n) IROW(n) ICOL(n) **n = 1,2,3, ..., NRNOD**

IUNIT(n) unit number for node n

IROW(n) row number for node n, if **IUNIT(n)** is a shell unit; or node number, if **IUNIT(n)** is an element unit

ICOL(n) column number for node n, if **IUNIT(n)** is a shell unit; or ignored, if **IUNIT(n)** is an element unit

✦ *go to* W-1

11
Solution Input

11.1 Solution Options

Linear solutions require only the computation and assembly of the stiffness matrix and the solution of a linear system of algebraic equations with the displacements **d** as unknowns:

$$\mathbf{Kd} = \mathbf{f_e} \tag{11.1}$$

where $\mathbf{f_e}$ is the external force or load vector.

STAGS has two independent load sets that are combined using load-factors input on the Load Multiplier record, C-1 described on page 11-11. For a linear solution, the total load on the system is $(\text{“load set A”} \times \mathbf{STLD}(\mathbf{1})) + (\text{“load set B”} \times \mathbf{STLD}(\mathbf{2}))$. Except for thermal loads, no other information on the C-1 record is relevant. Setting $\mathbf{INDIC} = 0$ on record B-1 causes a linear stress analysis to be carried out.

There are two types of eigenvalue analyses: bifurcation buckling and vibration. To give the user more flexibility, eigenvalue strategy records are provided, which include data that controls the error or iterative change in the eigenvalue tolerance, the range and number of eigenvalue-eigenvector pairs, how much diagnostic data to print, and how much computer time can be spent during the run. Bifurcation analyses require a stress state, which can be linear or nonlinear. A linear bifurcation analysis will be performed if $\mathbf{INDIC} = 1$ on record B-1. In this case, **STAGS** will first perform a linear stress analysis using the loading case A. The linear stress state from that analysis is then used in generating the stability matrix required for the eigenanalysis. Alternatively, a uniform stress state can be specified for the shell elements and the stability matrix formed using that uniform state. Critical loading combinations are also output for each eigenvalue computed. For nonlinear bifurcation, the stress state from a previously-computed nonlinear static solution is used for the stiffness and stability matrices. The second type of eigenproblem treated by **STAGS** is the small vibration problem, which can be conducted either from a stress-free state $(\mathbf{INDIC} = 2)$, or from a pre-stressed state $(\mathbf{INDIC} = 5)$.

Nonlinear static solutions derive their nonlinearity from four sources. First, displacements may be so large that the force generated from deflections is no longer proportional to these deflections. This type of *geometric* nonlinearity arises from the kinematics of the problem, *i.e.*, from the strain-displacement relations. The second source of nonlinearity stems from non-proportional material behaviors and can include hyperelasticity, plastic flow, creep, and progressive damage. The third source of nonlinearity comes from follower loading, including "live" pressures, where the direction of the loading depends on the displacement unknowns. The fourth source of nonlinearity stems from changing boundary conditions—otherwise known as contact and slip. Whatever the cause of nonlinearity, instead of a simple set of linear equations to solve, the program must solve the nonlinear equilibrium equations

$$\mathbf{f_i}(\mathbf{d}) - \mathbf{f_e}(\mathbf{d}) = \mathbf{0} \tag{11.2}$$

where the vector $\mathbf{f_i}(\mathbf{d})$ is the internal force, with a component for each freedom in the system, and where dependence on the system displacements **d** is indicated. Since there is no direct way to solve such a system, the final solution must be obtained in steps. These equations are typically solved with an incremental-iterative procedure such as the Newton-Raphson method using the two basic techniques

- load incrementation
- iteration from a linearized equation system

Load parameter incrementation involves the choice of the independent state variable that controls the loading environment of the structure. In load control, both the A and B load systems are independently varied, using load steps whose magnitude depends on the success or failure to obtain a converged solution. For cases where the load reaches some maximum (limit) point along the solution path, load control breaks down and must be replaced by a state variable that more closely reflects the system response.

The preferred method for nonlinear static analysis is the so called path-parameter strategy, where an increment of arc-length along the solution path replaces load as the independent variable. The A system load factor P_A is used as the new unknown. The B system is tied to the A system, and "floats" along with the A system until it reaches one of the set limits, after which it is frozen. If the A system is fixed, the B system load factor P_B is used as the independent path parameter. The constant of proportionality between the A and B systems is determined by the increments input on the C-1 record. Users need to understand that the phrase "load factor" is used in a generic sense. **STAGS** provides a capability to apply external loads as well as specified displacements. The solution control strategy (see **NSTRAT** on the D-1 record for both cases is referred to as "load control" even though in the latter case it is actually "displacement control."

In all cases, nonlinear solutions are initiated from a linear solution, and load or arc-length increments are automatically adjusted as functions of the solution behavior.

Once a loading is chosen, a trial solution is selected by extrapolating the previous solutions based on the increments selected. Usually, this trial vector will not satisfy equilibrium equations, and a better approximation must then be computed. **STAGS** does this by linearizing the problem about the trial state and beginning with a modified- or true-Newton iteration sequence. If the trial solution is close enough, the sequence of approximate solutions will converge, as evidenced by a small value of the norm of both the displacement increment and the residual error.

For modified Newton, the stiffness matrix is computed only occasionally, often at the beginning of the solution step or when the solution fails to converge; the user has control of how often this is done (*via* record D-1).

For true Newton, a new stiffness is computed at each iteration. Even for modest systems, this is generally very expensive. There are instances, however, where because of sudden changes in system response, the only way out of difficulty is to take advantage of the enhanced quadratic convergence that the true-Newton iteration method yields. The most common strategy in these situations is to use the true-Newton method for a few steps, and then switch back to less intensive methods when the system settles down.

In any case, iteration stops either when the relative equilibrium and displacement norm ratios are within a specified error tolerance, **DELX** on record D-1, or after either divergence occurs or too many iterations are required. If no convergence is obtained, **STAGS** will compute a new tangent stiffness matrix based on the best available estimate of the solution. If that procedure fails, the code will try to solve the system using a smaller load or arc-length increment. After a specified number of repetitions (or cuts), also under user control, the code will give up and save results for subsequent restart.

Transient analyses involve the time integration of the initial value problem in time using a numerical time integrator. There are two types of time integrators:

- ~~explicit~~ INACTIVE
- implicit

Although explicit integrators have the advantage of not requiring a solution of an equation system (no stiffness matrix necessary), they suffer the usually severe numerical stability limit on the time increment, often making explicit integration much more expensive than the more complex implicit integration. Because explicit integrators track the response well throughout the frequency spectrum, they are very effective for early-time response. Currently, explicit time integration is not supported in **STAGS**.

Implicit integrators involve the solution of a nonlinear system that closely resembles its static analysis counterpart, requiring the complexity of a nonlinear solution iteration sequence. The advantage is that most implicit integrators are unconditionally stable, allowing much larger time increments suitable for the typical late-time response of a damped system dominated by lower vibration modes. With the E-1 and E-2 records, the user has considerable control over the integration strategy.

Solution-branch-switching algorithms offer the user the opportunity to jump from one solution path to another in the vicinity of a bifurcation point. Unlike simple limit points, bifurcation points are places where more than one solution exists for a given load state. If the desired response is on one of these alternate solution branches, one must be able to switch to it without convergence difficulties. One method is to introduce initial geometric imperfections. Most of the time, the imperfections will smooth out the solution, permitting a straightforward analysis along the minimum energy solution path. If branch switching is required, the Equivalence Transformation bifurcation processor (**ET**) can be used. **ET** avoids convergence problems by removing the variable that has the greatest magnitude in the local bifurcation mode and replacing it by an unknown scale factor times the eigenvector. In the majority of cases, the switch to the alternate path proceeds smoothly and efficiently.

Finally, **STAGS** provides the Load Relaxation option. If for some reason the system is left in a state far from equilibrium (as happens with the opening of a crack or with the switch from a transient to a static analysis), it is usually impossible to obtain a converged solution using the standard nonlinear solution techniques. Load relaxation allows the gradual transition from the non-equilibrium state to the desired equilibrium solution using the same solution methods that are available for ordinary static analysis.

11.2 Summary and Control Parameters

Two records in this group (A-1 and B-1) are always included, and a third record (B-2) is optional. The A-1 and B-1 records that appear in the BIN (solution input) file are similar to—but can and frequently do contain different information from—the A-1 and B-1 records for the INP (model input) file. The B-2 record, here, is very different from that in the INP file.

A-1, the Case Title record, contains a “case-title” character string that is included strictly for the user’s convenience. The B-1 (Analysis Type Definition) record contains parameters that define the type of analysis to be performed and (optionally) solution information to be saved and/or printed and (also optionally) whether or not the user exercises choice or control over the equation solver to be used.

☞ The B-1 and B-2 records in the BIN file are *not* interchangeable with the B-1 and B-2 records in the INP file: they contain different input data altogether.

A-1 Case Title

The case title is read on the first line, which may contain any alphanumeric characters. This text is printed at the beginning of the output for the case and for identification on any disk file saved for possible restart. Subsequently any number of comment records can be added provided they begin with a “$” character in column 1. Comments can also be included at the end of a data line—a “$” character terminating data, and the comment following. A list of the complete input file, including any comment records, is printed at the beginning of the *case.out2* text output file. The user is urged to use this record as a way to document the analysis.

COMMENT

COMMENT case title

✦ *go to* B-1

B-1 Analysis Type Definition and High-Level-Control Data

The B-1 record for the BIN (solution input) file contains basic analysis-type- and high-level-control-definition information and is *not* interchangeable with the B-1 record for the INP (model input) file: they contain different input data altogether.

INDIC IPOST ILIST ICOR IMPTHE ICHIST IFLU ISOLVR NFABC

INDIC analysis-type definition parameter:

0 – linear analysis
1 – bifurcation buckling analysis (linear stress state)
2 – small vibrations (stress free state)
3 – nonlinear static analysis
4 – provide nonlinear solutions at specified load levels
5 – small vibrations (linear or nonlinear stress state)
6 – transient response analysis (geometrically nonlinear)
7 – transient response analysis (geometrically linear)
8 – special purpose (experimental)
9 – special purpose (experimental)

IPOST displacement data archival switch:

0 – do not save displacement data
>0 – save displacement data every **IPOST**th step.

ILIST data printout option:

0 – normal printout
1 – full printout

ICOR corotation option:

0 – corotational procedure is used
1 – non–corotational procedure is used
-1 – approximate corotation (no rigid-body correction, the corotational projection operator is not used)

IMPTHE 0 – higher-order *initial strain* imperfections are used
1 – only perturbed *initial geometry* is used

ICHIST crack archive read option:

0 – update crack status using archived data
1 – use crack status and definitions from S1 only

IFLU fluid-interaction option:

0 – no fluid interaction
1 – ~~underwater shock (USA–**STAGS**) analysis~~ — INACTIVE

ISOLVR equation-solver-choice option:

0 – assemble the matrix in **STAGS**’ SKYLINE format; use **STAGS**’ SKYLINE solver
-1 – assemble the matrix system in **STAGS**’ compact format; use the VSS sparse matrix solver
1 – specify the system-matrix format and the equation solver to use, plus additional control parameters, *via* the B-2 record, described next

NFABC number of gradient fabrication specification records to process

```
if      ( ISOLVR = 1 )   then   go to  B-2
elseif  ( NFABC > 0 )    then   go to  B-3
else                            go to  C-1
endif
```

B-2 Solver Options

With this record, the user can specify the format in which system stiffness and stability matrices are to be assembled and can choose the equation solver to be used for the analysis to be performed.

With **ISOLVR** = 0 on the B-1 record, a future version of **STAGS** will choose the format and solver using basic system-size and/or solution-cost data; the current version of **STAGS** will use the program’s SKYLINE format and solver.

The following Solver-Options record is required if **ISOLVR** = 1 on record B-1:

ICPACT IITER IPRIM IPRIS ISAVE

ICPACT compact-format-selection parameter:
 0 – use the SKYLINE system-matrix format and solver
>0 – use **STAGS**’ row-based COMPACT system-matrix format

IITER iterative-solution-method switch (ignored if **ICPACT** = 0):
 0 – use the (NASA/GSP) VSS compact-format equation solver
>0 – use **STAGS**’ (experimental) iterative solver

IPRIM assembled-matrix printout switch (ignored if **ICPACT** = 0):
 0 – do not print the assembled matrix
>0 – print the assembled matrix

IPRIS intermediate-solution-data printout switch (ignored if **ICPACT** = 0):
 0 – do not print intermediate solution data
>0 – print intermediate solution data

ISAVE save-system-and-stop switch (ignored if **ICPACT** = 0):
 0 – proceed normally to obtain solutions within **STAGS** (default)
>0 – assemble the system matrix and RHS vector but do not solve the system within **STAGS**; save the matrix and RHS vector on ASCII-formatted output files, for examination and/or for solution operations outside **STAGS**), then stop

NFABC (B-1)

```
if  ( NFABC > 0 )  then    go to  B-3
else                       go to  C-1
endif
```

B-3 Gradient Fabrication Specification Records

If and only if the **NFABC** parameter is positive on record B-1, **NFABC** records of this type are required to specify the beam, shell and/or solid fabrication(s) for which gradient computations are to be performed by the program. For more information about this process, please see Appendix E of this document.

KFABTP KFB

KFABTP fabrication-class specification parameter:

- 1 – beam-class GCP fabrication (not active in the current version of **STAGS**)

- 2 – shell-class GCP fabrication

- 3 – solid-class GCP fabrication

1 – beam-class wall fabrication

2 – shell-class wall fabrication

3 – solid-class wall fabrication

KFAB fabrication-identification parameter:

0 – use all fabrications of the specified class

>0 – identifies a specific **KFABTP**-class fabrication for which gradient computations are to be performed

NFABC (B-1)

```
if  ( fewer than NFABC records have been processed )then
        go to  B-3
else
        go to  C-1
endif
```

Computational Strategy Parameters

The following is a summary of the input record sequence for each of the basic types of analysis that **STAGS** currently performs.

Linear Analysis

- C-1, C-5

Eigenanalysis

- C-1, C-5
- D-2, D-3

Nonlinear Static Analysis

- C-1, C-3, C-4, C-5
- D-1
- ET-1

Transient Analysis

- C-1, C-5
- D-1
- E-1–E-5

Solution Branching

- C-1, C-5
- D-1
- ET-1

Load Relaxation

- C-1, C-3, C-4, C-5
- D-1
- ET-1

C-1 Load Multipliers

This record is always included. The load factors specified here are meaningless with **INDIC** $= 2$ (B-1).

STAGS has two load systems, *load system A* and *load system B*. In each of these load systems, the actual load on the structure is equal to a *load factor* (or load multiplier) times a load distribution. For load system A, the load factor is called P_A, and for load system B, the factor is called P_B. The total load on the structure, L_{TOT}, is equal to

$$L_{TOT} = P_A \cdot L_A \; + \; P_B \cdot L_B$$

where L_A and L_B are the two independent *load distributions*, which can be quite general; these distributions are determined by the Q records or by the user-written subroutines ***USRLD*** and ***UPRESS***.

The first increments for each load system are determined by the load steps **STEP(1)** for system A and **STEP(2)** for system B. For arc-length solution control (see the discussion above), the first two load steps are performed using simple load control, after which the initial arc-length increments are adjusted based on convergence characteristics. The load increments can be positive, negative or zero, depending on the strategy chosen.

For a *restart* analysis under arc-length control, **STEP(1)** can be interpreted to mean *arc length*. If one selects **NSTRAT** < 0 (D-1), **STEP(1)** is applied as a *scale factor* to the arc length derived from the previous solutions. This is the variable labeled **DETA** in the *OUT2* file, and can be found with the iteration summary that is *always* printed. For a continuation of the solution without interruption, set **STEP(1)** to *unity,* which means that the program will use the same **DETA** that it had on the last load step. The user is free to change **STEP(1)** to greater or less than unity to obtain better convergence.

A maximum load step is included for both load systems. Using this maximum, it is possible to “freeze” the load factor for either of the A and B systems at some level.

The initial load in a nonlinear analysis is **STLD** times the base load.

- For linear analysis the total equals the initial load.
- For bifurcation buckling analysis the critical load combination is the initial load for system B plus the eigenvalue times the initial load for system A.
- For nonlinear static analysis the first load level at which solution is attempted is given by the initial load.
- For arc-length (Riks) load control, load system B "floats" with load system A, according to the relation

  $$P_B = \mathbf{STLD}(\mathbf{2}) + \left\{ \frac{\mathbf{STEP}(\mathbf{2})}{\mathbf{STEP}(\mathbf{1})} \times [P_A - \mathbf{STLD}(\mathbf{1})] \right\}$$

  which makes the *initial* B load equal to **STLD(2)** and the next B load value $\mathbf{STLD}(\mathbf{1}) + \mathbf{STLD}(\mathbf{2})$ (see below), as would be the case with pure load control for the first two steps.

Boundary and loading conditions may be changed at restart. To avoid difficulties in converging to the new nonlinear solution state, the user should be careful to introduce such changes gradually.

In transient analysis $(\mathbf{INDIC} = 6 \text{ or } 7)$, load parameters that are read on the E-2 record override the C-1 load factors. In order to permit the user to restart a transient analysis at the completion of a static analysis, the user can omit the time-dependent loading (E-2) and allow the C-1 factors to operate. For the most common application of a transient analysis restart at a fixed load level, **STLD** and **FACM** should be equal, and **STEP** should be zero for both load systems.

STLD(1) STEP(1) FACM(1) STLD(2) STEP(2) FACM(2) ITEMP NFIX

STLD(1) starting load factor for system A.* Not relevant for **INDIC** = 2 or 6 (see comments above).

STEP(1) load factor increment for system A. The load increment is **STEP(1)** times the base load. Meaningful only for nonlinear analysis **INDIC** = 3, 4, 5, 6, or linear transient analysis, **INDIC** = 7 (B-1). If it is positive, the increment will be added to **STLD(1)**; if negative, the absolute value of **STEP** will be subtracted from **STLD**. In an initial run under arc-length control, the solution will be executed under load control for the first *two* load steps, and the path parameter **DETA** will be adjusted according to the solution convergence characteristics. For load control restarts, **STEP** serves the same purpose as in the initial run. For arc-length control restarts, **STEP** will be a scale factor applied to the last path length step. For example, if **STEP** is 1.0, the previous path parameter value **DETA** will be taken from the restart file; if it is 0.5, half the previous **DETA** will be used. If a negative value of **STEP** is used, the solution will go in the *reverse direction* (or back up). It should be remembered that the previous path step may have corresponded to a decrease in the load factors.

FACM(1) maximum load factor for system A. The maximum load is **FACM** times the base load (this is meaningful only for a nonlinear analysis $3 \le \mathbf{INDIC} \le 5$). If $\mathbf{STLD}(1) < \mathbf{FACM}(1)$, the run is terminated when the load exceeds **FACM(1)**. If $\mathbf{STLD}(1) > \mathbf{FACM}(1)$, the run is terminated when the load is less than **FACM(1)**. If $\mathbf{FACM}(1) = \mathbf{STLD}(1)$, the B load set takes over, even under arc-length control. In that case, solution stops only when $P_B \ge \mathbf{FACM}(2)$.

STLD(2) starting load factor for system B. For a creep analysis, ($\mathbf{ICREEP} = 1$ on any I-1 record in the INP file), **STLD(2)** is the initial creep time.

STEP(2) load factor increment for system B (meaningful only for nonlinear analysis $3 \le \mathbf{INDIC} \le 5$). For a creep analysis, **STEP(2)** is the creep time increment.

* On restart, the value of this parameter must correspond to a solution saved from a previous run. (Compare **ISTART**, D-1).

FACM(2) maximum load factor for system B in a nonlinear analysis. For a creep analysis, this is the final creep time. When the B system load factor reaches **FACM(2)**, it becomes fixed. Analysis continues until the A system has reached **FACM(1)**. (But, see special use described under **FACM(1)**.)

ITEMP thermal-loading option; user-written subroutine TEMP is required when **ITEMP** > 0 .

0 – No thermal loads
1 – Thermal loading is generated and associated with load system A
2 – Thermal loading is generated and associated with load system B

NFIX if nonzero, the number of freedoms to be fixed, specified as *logical freedom numbers* with the C-5 record

INDIC (B-1)

0 – linear static
1 – bifurcation buckling
2 – small vibrations (stress free state)
3 – nonlinear static
4 – nonlinear solutions at specified load levels
5 – small vibrations (linear or nonlinear stress state)
6 – transient response analysis (geometrically nonlinear)
7 – transient response analysis (geometrically linear)

```
if      ( NFIX > 0 )  then
        if  ( INDIC=4  or  INDIC=5 )   then      go to C-3
        else                                     go to C-5
        endif
elseif  ( INDIC=0 )  then
        data deck is complete
elseif  ( INDIC=1  or  INDIC=2 )                 then  go to  D-2
elseif  ( INDIC=3  or  INDIC=6  or  INDIC=7 )    then  go to  D-1
elseif  ( INDIC=4  or  INDIC=5 )                 then  go to  C-3
endif
```

C-3 Nonlinear Stress State

This record is included only for bifurcation buckling analysis based on a nonlinear stress state or vibration analysis with initial stress, **INDIC** = 4 or 5 (B-1).

Eigenvalues (bifurcation buckling load factor or vibration frequencies) and corresponding modes may be computed at a number of load steps. This choice allows use of boundary conditions and other constraints in the eigenvalue analysis that differs from those used in the analysis of the basic stress state. The load levels at which data are saved or used in eigenvalue analysis are specified in terms of the load factor corresponding to System A. Note that the deinstallation parameters are automatically selected for **INDIC** = 4 or 5; therefore, the data on records D-2 and D-3 are not read in.

This record can also be used to extract solutions at specified load steps when using the arc-length control strategy. Since the load factors are part of the solution, there is no guarantee that a solution will be computed at particular desired load level. Setting **INDIC** = 4 solves the problem by switching to load control when near any load in the list (C-4).

NLDS IXEV

NLDS number of load factors for system A at which nonlinear stress states may be used as basis for an eigenvalue analysis (directly or in a subsequent run), **NLDS** ≤ 20; if **NLDS** = –1, then the load factor list will be generated automatically by **STAGS** using data on the C-4 record.

IXEV
0 – do not execute eigenvalue solution
>0 – number of modes desired

✦ *go to* C-4

C-4 Load Factors

This record is included only if **INDIC** $= 4$ or 5 (B-1). It gives the value of the load factor at which eigenvalue solutions are desired (buckling loads or vibration frequencies). The automatic choice of step size in the nonlinear analysis is overridden as necessary so that solutions are obtained for the specific set of **NLDS** values (C-3). The critical load factor in the case of bifurcation buckling from a nonlinear stress state is computed for load factor **i** as $\mathbf{PLDS}(\mathbf{i}) \times (1 + \lambda)$ where λ is the eigenvalue defined in the output. The result is rigorously valid only when the computed eigenvalue equals zero. This option works with arc-length solution control as well.

PLDS(i), i = 1, NLDS

PLDS(i) load factor values for system A at which nonlinear prestress solutions are desired; may be used as basis for an eigenvalue analysis (directly or in a subsequent run)

If **NLDS** $= -1$ on the C-3 record, then read three variables (**PLDA**, **PLDB** and **PLDSTEP**) on the C-4 record, where **PLDA** is the starting load factor, **PLDB** is the ending load factor and **PLDSTEP** is the desired load step size between these values. The number of solution steps is **NLDS**, which is defined as

$$\mathbf{NLDS} = \mathrm{NINT}\left[\frac{\mathbf{PLDB} - \mathbf{PLDA}}{\mathbf{PLDSTEP}}\right]$$

This option is useful to obtain a series of solutions at evenly-spaced load steps over all or only a portion of the solution space. The load factor may be adjusted due to convergence difficulties.

Note: Because of the possible complexity of load paths when using arc-length control, it is important to choose the list of load factors in the order expected for the problem at hand. Such a choice may become complicated for strongly-nonlinear cases.

```
NFIX (C-1)      freedom-suppression flag

if   (NFIX=0)   then    go to C-5
else                    go to D-1
endif
```

C-5 Suppress Selected Freedoms

The C-5 record provides the user with a mechanism to suppress nonstandard freedoms such as Lagrange constraints and other specialized freedoms that are generated automatically by the **STAGS** code. These freedoms are in contrast to ordinary nodal freedoms that are defined by the user and known in advance. Any type of freedom can be suppressed in the model input data with Q and/or U records. Sometimes, however, specialized freedoms turn out to be singular or ill-conditioned during system-matrix decomposition. This happens most often when Lagrange constraints are found to be redundant—when partial compatibilities and/or other constraints are also applied for the same freedoms.

If **STAGS** detects that any freedom is singular, it prints an informative message containing the logical freedom number and the model freedom designation for that freedom. If that freedom is a translational freedom, execution is stopped (because the user has not restrained rigid-body motion). If it is a rotational or a specialized freedom, that freedom is suppressed for the remainder of the current run and any subsequent continuation runs. Under some circumstances (when planar boundary conditions are applied to a not-quite-planar boundary, for example) this automatic deletion process fails, leading to erroneous results. Fortunately, **STAGS** also prints informative messages when any freedom is found to be ill-conditioned during the decomposition process. This provides the user with the information that is required to revise the model-definition input or to use this C-5-record mechanism in the solution phase to suppress those freedoms in subsequent runs.

IFIX(i), i = 1, NFIX

IFIX(i) logical freedoms to be suppressed

✦ **INDIC** (B-1)

0 – linear static
1 – bifurcation buckling
2 – small vibrations (stress free state)
3 – nonlinear static
4 – nonlinear solutions at specified load levels
5 – small vibrations (linear or nonlinear stress state)
6 – transient response analysis (geometrically nonlinear)
7 – transient response analysis (geometrically linear)

```
if      ( INDIC=0 )  then
        data deck is complete
elseif  ( INDIC=1  or  INDIC=2 )then     go to  D-2
else                                     go to  D-1
endif
```

D-1 Strategy Parameters

This record is included only for nonlinear analysis (including nonlinear stress states for bifurcation buckling or vibration analysis) and transient response analysis, $3 \le \textbf{INDIC} \le 6$ (B-1).

For nonlinear analysis and transient response analysis, intermediate data can be saved on the file *casename.rst*, and retrieved in a subsequent run so that the analysis can be restarted and continued. If $\textbf{IPOST} = 0$ (B-1), the last 3 displacement solutions obtained in a run are saved on file *casename.rst* to provide the solution algorithm with enough data to extrapolate to the next solution state, just as if the solution were continuing without interruption. If $\textbf{IPOST} > 0$, displacements are saved every **IPOST**, $\textbf{IPOST} - 1$, and $\textbf{IPOST} - 2$ steps, which means that if $\textbf{IPOST} \le 3$, all displacements are saved. For an example where $\textbf{IPOST} > 3$, let $\textbf{IPOST} = 10$; then steps 8, 9, and 10; 18, 19, and 20; and so on are saved. For this case a smooth restart can be attempted at steps 10, 20, and so on.

When the analysis is restarted, it is important that the starting load factors (C-1) correspond to the displacement on the record from which restart is attempted.

If convergence difficulties are encountered during the nonlinear iteration, **STAGS** will form and factor the stiffness matrix before continuing the iterations. The variable **NEWT** sets an upper limit on the number of refactorings allowed. If **NEWT** is set less than zero, refactoring is performed on every i^{th} load step, where $i = |\textbf{NEWT}|$, no matter how quickly the iterations lead to convergence, with no limit on the number of refactorings. If $\textbf{NEWT} = -20$, the true Newton method is used (refactoring on all iterations). This method can lead to accelerated convergence rates, but it can be very costly (see the introduction to this section for more detail).

If convergence difficulties persist, the increment that controls the arc length or load step will be cut. The size of this cut is a function of the iteration history leading up to the convergence failure. The variable **NCUT** puts an upper limit on how often the program can cut the step. Without this limit, the program can labor endlessly with unreasonably small increments; when **NCUT** is exceeded, the program exits gracefully, saving data for restart. When this happens, the user should examine the model and its loading environment carefully for important changes in the nature of the response. It is often necessary to initiate a bifurcation analysis at this point and switch to an alternate solution path.

Alternately, it may be necessary to initiate a new analysis, with a more refined imperfection pattern, or to switch to a transient analysis strategy (E-1–E-5).

The solution control strategy for static analysis is set by the variable **NSTRAT**. If $\textbf{NSTRAT} = 0$ (default), then arc-length control takes effect after the load step $\textbf{STLD} + \textbf{STEP}$ has been computed under load control. Thus, for the initial run, *two* solutions are computed under load control: **STLD** and **STLD** + **STEP**. These variables are found on record C-1, with the B load computed according to the formula on page 8-12. For a restart run, only the solution **STLD** + **STEP** is computed, because the solution for **STLD** already exists. All subsequent solutions are computed using arc-length control. For an initial run with **NSTRAT** = –1, the result is the same as for **NSTRAT** = 0. For a restart, however, the user input values of **STLD(1)** and **STLD(2)** (C-1) are checked with those stored with the restart step **ISTART** (see below). If they are different, execution terminates with an error message. If they are the same to within a very small tolerance, the **STEP(1)** parameter (C-1) is interpreted as a scale factor applied to the arc-length parameter **DETA** (C-1). For an ordinary restart with continuity expected from step **ISTART** to **ISTART** + 1, this is the most efficient mode of operation. If **NSTRAT** = 1, all subsequent steps are executed under load control.

The error tolerance for convergence (**DELX**) gives the error tolerance of the residual norm or displacement norm, whichever is larger. The residual error norm is normalized to the applied load and reaction forces from the initial solution step. If **DELX** is set to zero or left blank, a default value of *0.001* is used. If **WUND** is zero or blank, an initial relaxation of *1.0* is used. The relaxation factor is increased (automatically), if convergence is monotonic but slow, and it is decreased if convergence is oscillatory. If a nonzero value of **WUND** is specified, this value will be used regardless of the convergence behavior. It is uncommon to reset **WUND**.

Sometimes, especially during adaptive refinement or during a crack growth simulation, other software will generate a new mesh (essentially a different model) of the same physical system. In that case, it is advantageous to estimate the displacements at the nodal positions using interpolation from the previous converged solution. It is well known that these displacements, although not satisfying equilibrium for the new mesh, may in fact be an excellent initial guess for a nonlinear iteration to a subsequent solution and continuation with the new model. A special provision has been provided for that case. A **STAR** routine has been provided to place the initial guess displacement field into the database with a loadstep number, *n*. *n* is selected for the user’s convenience. To tell **STAGS** to use these displacements instead of an ordinary restart, choose **ISTART** = $-n$ below. An error will be reported if the special vector has not been installed in the **STAGS** database *via* **STAR**.

ISTART NSEC NCUT NEWT NSTRAT DELX WUND

ISTART starting code:

0 – begin new case

n – a positive integer specifies restart from the n^{th} load step. Make sure that corresponding data have been saved (see **IPOST**, B-1). *n* must correspond to the same load step as **STLD** (C-1).

-*n* – a negative integer specifies restart from the special vector identified by the *positive* integer *n*, where vector *n* was installed in the **STAGS** database *via* **STAR**; used most commonly during nonlinear adaptive refinement or crack growth simulation.

NSEC number of CPU seconds at which run will be terminated and data saved on restart file; **NSEC** = 0 permits unlimited time

NCUT total number of times the step size may be cut

NEWT total number of refactorings allowed; use of **NEWT** < 0 is discussed above

NSTRAT 0 – execute the first step(s) under load control, and then switch to arc-length control (see discussion above)

-1 – for initial run, proceed as for **NSTRAT** = 0; otherwise, interpret **STEP(1)** (C-1) as a scale factor for the arc-length parameter **DETA**. See the C-1 description for more complete information.

1 – execute under load control

NSTRAT is ignored for a transient analysis

DELX error tolerance; the default value for **DELX** is 0.001

WUND relaxation factor; the default value is 0.001

INDIC (B-1)

6 – transient response analysis (geometrically nonlinear)
7 – transient response analysis (geometrically linear)

if (**INDIC**=6 or **INDIC**=7) then *go to* E-1
else *go to* ET-1

D-2 Eigenvalue Control

The record is included only for *linear* buckling or vibration analysis.

If **DELEV** is zero or blank, a default value of 0.00001 is used. When the CPU time limit **NSEC** is reached, current estimates for eigenvalues and modes are printed and saved on the restart file as specified by **IPRINT** even if the convergence criterion is not satisfied. Use **IPRINT** = 0 or 1 unless there is a good reason to suppress the extra output. Eigenmodes are also saved on a special *casename.imp* file for possible use as initial bucking imperfections on a subsequent run.

NSEC DELEV IPRINT

NSEC number of CPU seconds at which eigenvalue analysis will be terminated; **NSEC** = 0 permits unlimited time

DELEV eigenvalue error tolerance; the default value for **DELEV** is 0.001

IPRINT
0 – print eigenvalues, modes and intermediate iteration data
1 – print eigenvalues and intermediate iteration data; suppress printout of the modes
2 – print the eigenvalues and modes, but suppress printout of intermediate iteration data (which are not bulky and may provide useful approximate information about eigenvalues beyond those requested on the D-3 record)
3 – print eigenvalues only

✦ *go to* D-3

D-3 Cluster Definition

If $\mathbf{EIGA} = \mathbf{EIGB}$, a number (**NEIG**) of eigenvalues closest to (above or below) a specified value (**SHIFT**) will be determined. If $\mathbf{EIGA} < \mathbf{EIGB}$, **SHIFT** is ignored and the **NEIG** eigenvalues closest to the center of the interval (**EIGA**, **EIGB**) are determined. Computations terminate when all eigenvalues in the interval have been found, even if their number is less than **NEIG**.

For buckling problems, $\mathbf{INDIC} = 1 \text{ or } 4$ (B-1), **SHIFT**, **EIGA**, **EIGB** relate to critical load factors (the load factors at which the Jacobian determinant vanishes). For vibration problems ($\mathbf{INDIC} = 2 \text{ or } 5$, they relate to frequencies (in cps). In this case (vibration analysis) the "center" c of the interval (**EIGA**, **EIGB**) is chosen to satisfy: $c^2 = (\mathbf{EIGA}^2 + \mathbf{EIGB}^2)/2$

If rigid body modes are to be included in a vibration analysis ($\mathbf{INDIC} = 2 \text{ or } 5$), an eigenvalue shift *must* be used (**SHIFT**, D-3) to prevent matrix singularities.

NEIG SHIFT EIGA EIGB

NEIG maximum number of eigenvalues to be computed, $\mathbf{NEIG} \le 20$

SHIFT initial eigenvalue shift; for vibration analysis of a free body, it is necessary to specify a non-zero shift

EIGA lower bound of eigenvalue range

EIGB upper bound of eigenvalue range

✦ *data deck is complete*

E-1 Time Integration—Record 1

The E-1 and E-2 records are included only for transient analysis, when **INDIC** = 6 or 7 (B-1). The user has the option of using a fixed or an automatically-controlled variable time step (**IERRF**, E-2). A maximum expected value of the displacement **SUP** is used in connection with the automatic step size control. Load systems A and B are used to define two independent loading histories, analogous to the static analysis option.

In the equation $M\ddot{u} + D(\dot{u}) + S(u) = f(t)$, D represents a damping vector. Its elements are determined by $D = \alpha M\dot{u} + \beta\dot{S} + \gamma P\dot{u}$. The diagonal matrix γP represents external, velocity dependent forces. The velocity-dependent base loads are defined in the sequence Q-1 through Q-3 in the same way as the regular forces on the structure. The damping matrix is obtained through multiplication by the "damping factor" γ.

TMIN TMAX DT SUP ALPHA BETA GAMMA THOLD

TMIN time, t, at which transient analysis begins

TMAX time, t, at which transient analysis terminates; **TMIN** $\leq$ **TMAX**

NOTE: The temporal variation of load factors (P_A, P_B) is defined on E-2 as $P_A = f(t)$, $P_B = g(t)$, where f and g can have one of several standard forms (see Figure 11.1 on page 11-28). Also note that a transient analysis can be restarted and that the load-factor history can be defined independently for a restart. Basic loading on the structure can also be changed for restart.

DT time step; initial time step if variable step selected (**IERRF**, E-2)

SUP maximum expected displacement; relevant only with variable time step

ALPHA mass damping factor α

BETA stiffness damping factor β

GAMMA ~~damping factor γ, which multiplies the velocity-dependent forces to give the "external damping"~~ — INACTIVE

THOLD the value of the problem time at which changes of the time step first are allowed. **THOLD** can be used to suppress automatic time step increases during the initial phase so that the loading history may be accurately defined.

go to E-2

E-2 Time Integration—Record 2

Include only for transient analysis **INDIC** = 6 or 7 (B-1).

With simple input data, a load-factor history is independently-defined for each of the load systems A and B. The temporal variation of load factors (P_A, P_B) is defined $P_A = f(t)$, $P_B = g(t)$, where t is time, and f and g are of the forms illustrated in Figure 11.1 on page 11-28. Note also that a transient analysis can be restarted and that the load-factor history can be defined independently for a restart. Basic loading on the structure can also be changed for restart. As the examples below demonstrate, clever definition of the A/B load histories, combined with effective restarting strategies, provides tremendous power and flexibility for applying arbitrary transient loading.

A “box wave,” for example, can be obtained from the linearly-varying load-factor history case (a) by setting

$$\textbf{CA2} = \textbf{CA3} = 0 \qquad \textbf{CA4} = \textbf{CA5}$$

Trigonometric variation is specified by load-factor history case (b) according to

$$P = A\cos\alpha + C \qquad\qquad \alpha = \frac{2\pi}{T}(t - \varphi) \tag{11.3}$$

where A is the amplitude, T is the period, φ is a phase shift, and C is a constant. The half-period, p, is defined as $p = T/2$, and **STAGS** input describing (11.3) is

$$\textbf{CA1} = A \qquad \textbf{CA2} = C \qquad \textbf{CA3} = p \qquad \textbf{CA4} = \varphi$$

Therefore, (11.3) can be rewritten in terms of input data as

$$P = \textbf{CA1} \cdot \cos\left\{\frac{2\pi}{2 \cdot \textbf{CA3}}(t - \textbf{CA4})\right\} + \textbf{CA2}$$

A cosine function is defined by

$$\textbf{CA1} = A \qquad \textbf{CA2} = 0 \qquad \textbf{CA3} = p \qquad \textbf{CA4} = 0$$

To define a sine function, the cosine function is shifted by 1/4 period, $T/4 = p/2$. Therefore, a sine function is defined as

$$\textbf{CA1} = A \qquad \textbf{CA2} = 0 \qquad \textbf{CA3} = p \qquad \textbf{CA4} = p/2$$

Though not readily apparent, (11.3) can be used to specify a $\cos^2$ (cosine squared) function defined by

$$P = A\cos^2\alpha + C \qquad \alpha = \frac{\pi}{T}(t - \varphi)$$

where A is the $\cos^2$ amplitude, and T is the $\cos^2$ period. By noting that $\cos^2$ is periodic in π , rather than 2π ; and that the range of $\cos^2$ is $[0, A]$, rather than $[-A, A]$; and by taking advantage of the trigonometric power relation $\cos^2\alpha = 1/2(\cos 2\alpha + 1)$; it follows that (11.3) defines a $\cos^2$ function when

$$\textbf{CA1} = A/2 \qquad \textbf{CA2} = A/2 \qquad \textbf{CA3} = p \qquad \textbf{CA4} = 0$$

For each of the load-factor history types, the duration of the corresponding loading event is determined by specification of both an initial time, t_i, and a final time, t_f; thus, the domain of t is $t_i \le t \le t_f$. Referring to (11.3) and Figure 11.1, the duration of the loading event represented by load-factor history case (b) is defined by

$$\textbf{CA5} = t_i \qquad \textbf{CA6} = t_f$$

For example, a single-wave cosine history starting at time $t = 0$ and ending at time $t = T$ is defined by

$$\textbf{CA1} = A \qquad \textbf{CA2} = 0 \qquad \textbf{CA3} = p \qquad \textbf{CA4} = 0 \qquad \textbf{CA5} = 0 \qquad \textbf{CA6} = T$$

Note that the initial/final times for load-factor histories are defined independently of the starting/stopping times for the transient analysis (**TMIN**/**TMAX**, E-1). For example, in load-factor history case (b), if $\textbf{TMIN} < \textbf{CA5}$, the structure is unloaded for $t < \textbf{CA5}$. If $\textbf{CA6} < \textbf{TMAX}$, the structure is unloaded for $t > \textbf{CA6}$.

Additional examples follow to illustrate the flexibility provided by creative definition of load-factor histories together with judicious combination of histories for the A/B systems. Keeping in mind that a transient analysis can be restarted and that the load-factor history, as well as the basic loading on the structure, can be defined independently for a restart, it can be seen that transient-loading capabilities are quite general in **STAGS**.

An impulse consisting of a single-wave $\sin^2$ (sine squared) form with an amplitude of A and a duration of one period, T, starting at time $t = 0$ at a load factor of $P = 0$, increasing to $P = A$ at $t = T/2 = p$, then falling back to $P = 0$ at $t = T$, is obtained from case (b) with:

$$\textbf{CA1} = A/2 \qquad \textbf{CA2} = A/2 \qquad \textbf{CA3} = p \qquad \textbf{CA4} = p \qquad \textbf{CA5} = 0 \qquad \textbf{CA6} = T$$

Note that $\cos^2$ is shifted by one half-period, p, to obtain $\sin^2$.

The load factor may be increased from $P = 0$ at $t = 0$ to a value of $P = A$ at $t = t_1$ with a $\sin^2$ form, and then held constant if P_A is determined from case (b) with:

CA1 $= A/2$ **CA2** $= A/2$ **CA3** $= t_1$ **CA4** $= t_1$ **CA5** $= 0$ **CA6** $= t_1$

and P_B is determined from case (a) with:

CA1 $= A$ **CA2** $=$ **CA3** $= t_1$ **CA4** $=$ **CA5** $\geq$ **TMAX**

The load factor may be linearly increased from $P = 0$ at $t = 0$ to a value of $P = A$ at $t = t_1$, and then exponentially decayed to $P = A/2$ at $t = t_2$ if P_A is determined from case (a) with:

CA1 $= A$ **CA2** $= 0$ **CA3** $=$ **CA4** $=$ **CA5** $= t_1$

and P_B is determined from case (c) with:

CA1 $= A$ **CA2** $= t_1$ **CA3** $= t_2 - t_1$ **CA4** $= A/2$

IMPL METHOD IERRF IVELO IFORCE IPA IPB

IMPL
0 – implicit integration
1 – ~~explicit integration~~ INACTIVE

METHOD indicates type of implicit integration
1 – trapezoidal formula
2 – ~~Gear’s second-order formula~~ INACTIVE
3 – ~~Gear’s third-order formula~~ INACTIVE
4 – K. C. Park’s formula[*]

IERRF
0 – constant time step
1 – variable (automatically-controlled) time step

IVELO number of weighted modal velocities, defined on E-5 records

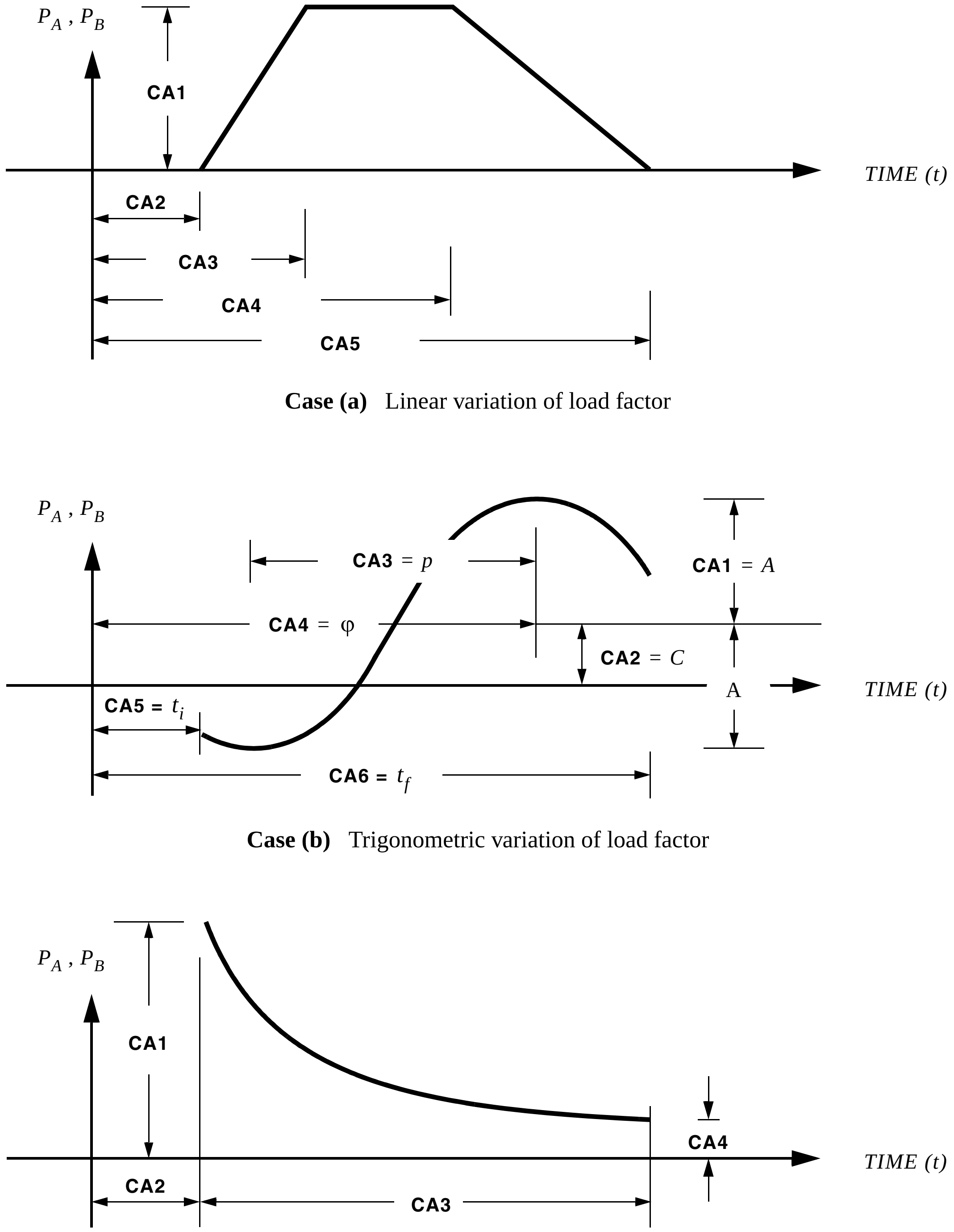
IFORCE
0 – no user written FORCET
1 – user written FORCET

IPA load-factor history option for system A; see Figure 11.1
0 – load system A not included
1 – linear variation, case (a)
2 – trigonometric variation, case (b)
3 – exponential decay, case (c)

IPB load-factor history option for system B; see Figure 11.1
0 – load system B not included
1 – linear variation, case (a)
2 – trigonometric variation, case (b)
3 – exponential decay, case (c)

```
if      (IPA > 0)    then   go to  E-3
elseif  (IPB > 0)    then   go to  E-4
elseif  (IVELO > 0)then     go to  E-5
else    data deck is complete
```

[*] Park, K.C., *“An Improved Stiffly Stable Method for Direct Integration of Nonlinear Structural Dynamics,”* ASME Journal of Applied Mechanics, Vol. 42, 1975, pp. 464–470



Case (a) Linear variation of load factor

Case (b) Trigonometric variation of load factor

Case (c) Exponential decay of load factor

Figure 11.1 Load-factor histories.

E-3 Load History—Record 1

This record defines constants to be used in the definition of the load-factor history corresponding to system A. It is only included if **IPA** > 0 (E-2).

CA1 CA2 CA3 CA4 CA5 CA6

CA1, CA2, CA3, CA4, CA5, CA6 variables defined in Figure 11.1.

IPB (E-2) load factor variation for system B
IVELO (E-2) number of weighted modal velocities

if (**IPB** > 0) then *go to* E-4
elseif (**IVELO** > 0) then *go to* E-5
else *data deck is complete*

E-4 Load History—Record 2

This record defines constants to be used in the definition of the load-factor history corresponding to system B. It is only included if **IPB** > 0 (E-2).

CB1 CB2 CB3 CB4 CB5 CB6

CB1, CB2, CB3, CB4, CB5, CB6 variables defined in Figure 8.1

✦ **IVELO** (E-2) number of weighted modal velocities

if (**IVELO** > 0) then *go to* E-5
else *data deck is complete*

E-5 Weighted Modal Initial Velocity

These records are included only when specified by setting **IVELO** > 0 (E-2). **STAGS** is set up to allow the user to include initial velocities from a number of executions of the same case. For example, one may have initially performed a linear bifurcation analysis, followed by a nonlinear collapse analysis, followed by an eigenanalysis base upon a nonlinear stress state. Another execution could be run from the beginning, including all the modes accumulated so far. **STAGS** always produces two files, the *IMP* file *(casename.imp)* and the *EGV* file *(casename.egv),* that contain all the modes computed during the entire history of the case. Each mode is identified by a unique combination of values for the data **IMSTEP**, **IMMODE**, and **IMRUN**. These data are written to the **STAGS** database when modes are saved. The user can generate an initial velocity field from a linear combination of these modes, specifying amplitudes with **EIGA**.

Remember, for each of the eigenmodes that is computed by **STAGS**, the largest *translational* component is normalized to unity.

EIGA IMSTEP IMMODE IMRUN

EIGA buckling mode amplitude; may be < 0 .

IMSTEP load step number

IMMODE mode number

IMRUN eigenvalue-execution ID number

IVELO (E-2) number of weighted modal velocities

```
if   (IVELO modes have been defined)  then
     data deck is complete
else
     continue defining  E-5
endif
```

ET-1 Solution Control

The most common choice for the variable **NPATH** (below) is 0.

If **NSTRAT** $= 1$ (D-1), load control is used throughout the analysis. If **NSTRAT** < 1, the path parameter method is used except for special starting or restarting procedures (which may also be affected by **NSOL**, ET-1).

For all values of **NSTRAT** and **NSOL**, the starting procedure (**ISTART** $= 0$, D-1) is identical. The linear solution with load factors P_A and P_B is computed as step 0 and saved on file—if **IPOST1** > 0 (B-1). A non-linear solution is then obtained with the same load factors and saved as step 1. The second non-linear solution, step 2, is computed with values of P_A and P_B incremented by the load increments on the C-1 record. For **NSTRAT** $= 1$, the remaining analysis continues under load control. However if **NSTRAT** < 1, the solution procedure shifts to the path parameter method using the initial two nonlinear solutions to establish a path.

Restarting procedures are fundamentally more complex. The input variable **NSOL** (ET-1) is introduced to provide greater flexibility. **NSOL** $= 0$ implies that restart is continuous with respect to loading and boundary conditions and therefore solutions stored on the restart file may be used in determining initial values for the next solution. If **NSOL** $= 1$, the solution is assumed discontinuous and only the restart step is used in the new solution. In either case, the restart step may not be in equilibrium because of changes in input loading or boundary conditions. Significant difficulties in convergence behavior could result from this situation. To help the user, the program evaluates equilibrium for the restart step and prints a warning message when a serious state of non-equilibrium is noted. An experimental option **NSOL** $= 2$ is being introduced to take special measures when the equilibrium test fails; more will be said about this option after further testing. If one is far from equilibrium and convergence fails, the relaxation procedure (**NPATH** $= 5$, ET-1) should be used first to return to equilibrium. A description of this option is found below.

If **NSTRAT** $= 0$, restart begins with one step under load control; values of P_A and P_B are incremented by **STEP** (C-1). The solution procedure then reverts to the path parameter method for the remainder of the analysis. The operation of the load incrementation algorithm is also described in record C-1.

If **NSTRAT** < 0, restart begins as a continuation of the path procedure. This requires the existence of at least two solutions on the restart file. The **STEP** increment on record C-1 is then interpreted as a path increment factor. This factor scales the new path step based on the last path length on the restart file. Thus if **STEP** $= 1.0$, the path continues with the same arc length used in the restart. The increment in path length may be doubled or halved, *etc*. as seems desirable. The value of **STEP** may also be negative which would reverse the path direction for restart. This is a convenient method for difficult unloading situations such as elastic unloading from a state of plastic deformation. After the first new solution is obtained. the analysis continues with the standard path parameter method. See "C-1 Load Multipliers" on page 11-11.

A special option **NPATH** = 1 is provided that switches the solution to an experimental "tangent" Equivalence Transformation method. Although this option helps in some cases, it is not recommended for ordinary analyses. The options **NPATH** = 2 and **NPATH** = 3 are the Equivalence Transformation options for branching on bifurcation. These options are described in Section 11.3.

The option **NPATH** = 5 allows for "Load Relaxation" in which the solution is to be relaxed from a nonequilibrium state. This is the only option provided for doing this. If **NPATH** = 5 (and **INDIC** = 3, B-1). Although **ISTART** (on D-1), and **STLD(1)** and **STLD(2)** (on C-1) govern the load state where the new equilibrium will be computed, the remainder of the information on the C-1 record controls the behavior *after* load relaxation has been completed, just as in a regular nonlinear run. This means that **STAGS** first executes the load relaxation process, and upon successful convergence to a new equilibrium state, continues with the execution after load relaxation is complete, automatically producing new solutions as directed by the user. The program internally determines what load relaxation parameters to use based on an estimate of how far from equilibrium the current state is. The interested reader is encouraged to obtain the references cited in the footnote.*

A special option **NPATH** = -1 has been provided to use the solution at restart to define the nonlinear stress state, stiffness and stability matrices for a buckling analysis. No new solutions are computed, and the analysis terminates after **NEV** eigenmodes have been found. Restart boundary conditions and load values can be altered as in any other restart. The ability to change boundary conditions offers the user a capability similar to the alternate buckling boundary conditions permitted for a linear bifurcation.

* See
Riks, E, C.C. Rankin and F.A. Brogan, *"On the Solution of Mode Jumping Phenomena in Thin-Walled Shell Structures,"* Computer Methods in Applied Mechanics and Engineering, Vol. 136, Nos. 1–2, September 1996, pp. 59–92
and
Riks, E. and C.C. Rankin, *"Computer Simulation of the Buckling Behavior of Thin Shells Under Quasi-Static Loads,"* Archives of Computational Methods in Engineering, Vol. 4, No. 4, 1997, pp. 325–351

NPATH NEV NSOL IE IGNORE LDMAX IUPLDA IUPLDB

NPATH

0 – use option chosen by **NSTRAT** (D-1)

1 – use the “tangent” **ET** method (experimental method)

-1 – compute **NEV** buckling modes on restart at load step **ISTART** (D-1), and PA and PB loads at **STLD**(1) and **STLD**(2) (C-1), respectively

2 – single mode branch switching (see 11.3 on page 11-36)

3 – ~~special **ET** option, see next section~~ — INACTIVE

5 – load relaxation (see explanation above)

NEV

0 – do not compute eigenmodes at run termination

>0 – compute **NEV** eigenmodes at run termination

NSOL

0 – assume the solution is continuous on restart, and perform quadratic extrapolation to estimate a new solution wherever possible

1 – assume that the solution is *discontinuous*, and do not extrapolate to estimate the next solution. In this case, the previous solution is used as the initial estimate, and the solution will be checked for equilibrium. If equilibrium is satisfied, proceed to full extrapolation after enough solutions have been accumulated. If equilibrium is not satisfied, print a warning message and attempt to find a new solution. If convergence is obtained, proceed to full extrapolation after enough solutions have been accumulated.

2 – special experimental option under development

3 – use the previous solution vector to start the first two iterations of each solution step; this option is particularly useful during progressive failure analysis.

Please see the next section for the role **NSOL** plays for the **ET** Bifurcation Processor special options

IE mode number for branch switching. Used only for special **ET** Bifurcation Processor options described in the next section.

IGNORE ignored; included for compatibility with old *casename.bin* files

LDMAX

0 – continue solution beyond any limit points found (points of maximum load, load system A only)

1 – stop solution upon reaching a maximum load (load system A only)

IUPLDA if nonzero, interpret the A load system as *follower loads*, or loads that *rotate* with each node

IUPLDB if nonzero, interpret the B load system as *follower loads*, or loads that *rotate* with each node

✦ *data deck is complete*

11.3 The Equivalence Transformation Bifurcation Processor (ET)

The Equivalence Transformation bifurcation processor **(ET)** provides a means to branch to alternate solution paths during the analysis of structures well into the postbuckling regime*. In many cases routine analysis fails because the equation system becomes ill conditioned near the critical limit and bifurcation points. Whereas path continuation methods offer help for limit point analyses, bifurcation points have proved more difficult. **ET** allows the user to select a solution branch in the direction of growth of a bifurcation mode that has been computed for the nonlinear stress state near the critical point. Combined with the usual arc-length control algorithms, the user can in principle turn from one solution branch to the next as part of an investigation of the solution space of lowest energy most likely to be seen in physical systems.

In order to use the **ET** options, the user must first decide very carefully what he wants to do in the vicinity of the bifurcation point. Typically, a bifurcation point is detected either by a change in sign of the determinant of the stiffness matrix, or by serious convergence difficulties near the critical point. In either case, the user can detect the presence of one or more closely-spaced modes in the area of interest. **NEV** modes are automatically computed at run termination when **NEV** > 0 (ET-1) (see above). To proceed further always involves a restart.

The variable **NPATH** (ET-1) controls what **ET** does, as follows:

NPATH

-1 – ~~modal analysis and computation of higher order expansion coefficients~~ — INACTIVE

0 – ordinary arc-length (Riks) path continuation algorithm.
go to "ET-1 Solution Control" on page 11-32.

1 – primary path (Equivalence Transformation **ET**) using the "path tangent" vector as the equivalence vector.
go to "ET-1 Solution Control" on page 11-32.

2 – branch to alternate path using *single mode* **ET**.
go to "ET-1 Solution Control" on page 11-38.

* See, for example:
Thurston, G.A., F.A. Brogan and P. Stehlin, *"Postbuckling Analysis Using a General-Purpose Code,"* AIAA Journal, Vol. 24, No. 6, June 1986, pp. 1013–1020
and
Rankin, C.C. and F.A. Brogan, *"Application of the Thurston Bifurcation Solution Strategy to Problems with Modal Interaction,"* AIAA Paper No. 88-2286, April 1988

Simple branch switching

The simplest branch-switching option is a restart using **NPATH** $= 2$. In this case, the user wishes to branch to an alternate path in the direction of a particular mode (specified by **IE**, below). This mode is held constant, and the load factor is adjusted to make the residual vanish. The restart file must contain the mode specified by **IE**. The A-1, B-1, C-1, and D-1 records are input in the same way as an ordinary restart. Remember that load step **ISTART** (D-1) must have been saved, along with the mode number **IE**. One can save the desired modes by setting **NEV** > 0 (ET-1) for any run with **NPATH** $= 0 \text{ or } 1$, and **INDIC** $= 3, 4, \text{ or } 5$ (B-1), nonlinear analysis.

For simple mode switching, record ET-1 must be input as follows:

ET-1 Solution Control

NPATH NEV NSOL IE IGNORE LDMAX IUPLDA IUPLDB

NPATH = 2 described above

NEV ignored

NSOL
0 – assume the solution is continuous on restart, and perform quadratic extrapolation to estimate a new solution wherever possible
1 – assume the solution is *discontinuous*, and do not extrapolate to estimate the next solution. In this case, the previous solution is used as the initial estimate, and the solution will be checked for equilibrium. If equilibrium is not satisfied, stop the execution with a message; otherwise, proceed to full extrapolation after enough solutions have been accumulated.
2 – proceed as if **NSOL** = 1, except attempt to obtain a new solution even if the equilibrium test fails. Users should be cautious with this option.
3 – use the previous solution vector to start the first two iterations of each solution step; this option is particularly useful during progressive failure analysis.

IE mode number used in single-mode **ET**. Note that the *amplitude* of the mode **IE** is taken to be **STEP(1)** (D-1) times the eigenmode **IE**. The modes are always normalized such that their largest component is unity.

IGNORE ignored by the program; included for compatibility with old input files

LDMAX
0 – continue solution beyond any limit points found
(points of maximum load, load system A only)
1 – stop solution upon reaching a maximum load
(load system A only)

IUPLDA if nonzero, interpret the A load system as *follower loads*, or loads that *rotate* with each node

IUPLDB if nonzero, interpret the B load system as *follower loads*, or loads that *rotate* with each node

If the solution converges, s2 continues the execution using the **NPATH** = 1 option (see above) until either the maximum load or some other limit is exceeded.

data deck is complete

12
User-Written Subroutines

User-written subroutines can be used in very basic ways as elegant alternatives to lengthy input decks; or, they can be used in more sophisticated ways to extend the generality of **STAGS**. For example, user-written subroutines can define arbitrary functional relationships, such as spatial variation of constitutive properties in a wall fabrication, or temporal variation of loading for transient analysis. In fact, nearly all aspects of model definition, from the most basic operations to extremely complex ones, can be performed *via* user-written subroutines.

Important details concerning applicability of user-written subroutines, along with functional and alphabetical summaries, comprise the remainder of this introduction. Conventions for passing input data to user-written subroutines and for returning output data to **STAGS** are described next, in Section 12.1. A practical example problem utilizing several routines is presented in Section 12.3. In between, Section 12.2 describes each of the routines, in alphabetical order.

CAUTION: Users should check documentation carefully before attempting to use any existing user-written subroutines with his or her version of **STAGS**.

Table 12.1 Functional summary of user-written subroutines.

category	name	description
Shell Unit Geometry	LAME	Reference surface geometry
Shell Unit Initial Geometric Imperfections	DIMP	Imperfections by discrete values
Element Unit Discretization	USRPT	Nodes, coordinates and DOF definitions
	USRELT	Elements connectivities and properties
Beam Cross Sections	CROSS	Beam cross section properties
Fabrications	USRFAB	Fabrication properties, *via* GCP
	WALL	Shell wall fabrication properties
Loads	FORCET	Load factor history for transient analysis
	TEMP	Thermal loadings
	UPRESS	Pressure loadings
	USRLD	General loadings
Displacement Constraints	UCONST	Lagrange constraints
Material Degradation and Failure	USRDGD	Material degradation (template)
	USRFPF	Material failure (template)
Discontinued	SKEWS UGRID WIMP	Skew stiffeners Grid generation Imperfections by functional definition

Table 12.1 presents a functional summary of the user-written subroutines. Table 12.2 lists them alphabetically, summarizing the conditions under which each is applicable. Also indicated in Table 12.2 are the analysis phases for which each subroutine is needed. Note that some user-written subroutines are required in the *model definition phase*, some are required in the *primary solution phase*, and some are required in the *secondary solution phase*. Some routines are needed for more than one phase of analysis.

Table 12.2 Alphabetical summary, showing analysis options that indicate user-written subroutines.

name	analysis option	location where defined	model	primary solution	secondary solution
CROSS	**ICROSS** = 0 **ICROSM** = 0	O-1a, O-2a, T-2, USRELT, K-6, WALL		✘	✘
DIMP	**IWIMP** = –1 **IUDIMP** = 1	M-5 H-1	✘		
FORCET	**IFORCE** = 1	E-2		✘	
LAME	**ISHELL** = 1	M-5	✘	✘	
TEMP	**ITEMP** > 0	C-1		✘	✘
UCONST	**NCONST** > 0	B-2	✘		
UPRESS	**IPRESS** = 1	Q-1, U-1		✘	
USRDGD	**IDGRD** = 99	I-5a, I-10a	✘	✘	✘
USRELT	**IUWE** = 1	H-1	✘		
USRFAB	**FABID** < 0	I-5a, T-3xx, T-4xx, USRELT		✘	✘
USRFPF	**IFAIL** = 99	I-5a, I-10a	✘	✘	✘
USRLD	**IFLG** = 1	Q-2, U-2	✘		
USRPT	**IUWP** = 1	H-1	✘		
WALL	**IWALL** = 0	M-5, T-3, T-4, USRELT		✘	✘

User-written subroutines must be linked with relevant **STAGS** processors to create application-specific executable code; refer to “Creating custom STAGS executables with makeuser (UNIX)” on page 2-14.

✔ Subroutines which are applicable in the model definition phase, such as USRPT, must be linked with the model executable, **s1**.

✔ Subroutines which are applicable in the primary solution phase, such as FORCET, must be linked with the solution executable, **s2**.

Table 12.2 Alphabetical summary, showing analysis options that indicate user-written subroutines.

name	analysis option	location where defined	model	primary solution	secondary solution

✔ User-written subroutines (such as WALL) which are applicable in the secondary solution phase must be linked with any processor that generates secondary solution data. For example, if the translator/post-processor **xytrans** is to be used to compute stresses in shell elements defined using WALL, then **xytrans** *must* be linked with the user-written WALL subroutine. If **xytrans** is to be used to provide primary solution data (such as nodal displacements) only, then it need *not* be linked with any user-written subroutines.

☞ The example user-written subroutines shown in this chapter are available in the **$STAGSHOME**/examples/usersub directory. Input files and user-written subroutines from Section 12.3 “Example Problem” are available in **$STAGSHOME**/examples/cylinder.

12.1 Input/Output Data Conventions

User-written subroutines are FORTRAN subroutines which receive *input* and produce *output*. This section discusses the various methods by which input data are passed to a *called* user-written subroutine from a *calling* **STAGS** program module and by which output data are returned to **STAGS**.

May user-written subroutines be coded in C?

Yes. While **STAGS** is a FORTRAN program, user-written subroutines may be coded in C provided that the user adheres to the conventions described in this section, and provided that the user’s programming environment supports calling C program modules from FORTRAN program modules. In fact, **STAGS** executables contain C code linked with FORTRAN code.

Data types

User-written subroutine input/output utilizes only two FORTRAN data types—INTEGER and REAL. The type for each data item is indicated in the corresponding description. Of course, other data types may be used for local data within each subroutine.

Input/output methods

Input/output functions in user-written subroutines utilize *parameter lists*, *argument lists*, and *common blocks*.

parameter lists

A parameter list is the list in a FORTRAN “subroutine” statement. For example, in the FORCET statement

```
subroutine FORCET ( t, k, Pf )
```

“`( t, k, Pf )`” is the parameter list. The *call by reference* technique is used exclusively for data in this category. For example, `Pf` refers to the *data address* where the contents of `Pf` are stored.

Parameter lists may be employed for both input and output functions. Not all user-written subroutines contain parameter lists.

argument lists

An argument list is the list in a FORTRAN “call” statement. For example, in the UCONST statement

```
call UCONST ( n, iu, ix, iy, id, cc )
```

“`( n, iu, ix, iy, id, cc )`” is the argument list. The *call by reference* technique generally applies here. However, *call by value* may be used where appropriate. For example, **`n`** may be a constant in the above list (see “UCONST Lagrange Constraints” on page 12-29). If in doubt, use a variable rather than a constant, as variables are always appropriate.

Obviously, call statements perform output only. The output data in the argument list are passed down to the *called* subroutine, rather than back up to the *calling* routine, as through parameter lists. Not all user-written subroutines output data *via* call statements.

common blocks

A FORTRAN common block contains global data, and may be employed for both input and output. For example, in subroutine USRPT

```
      COMMON / NEWSY /  xax, xay, xaz, yax, yay, yaz
```

is used to output the nodal-auxiliary coordinate system.

A special use of common blocks is for input of User Parameters;
see “L-1 User Parameters Summary” on page 5-143. The statements

```
      COMMON / UPI   /  UserInt(200)
      COMMON / UPF   /  UserFlo(200)
```

provide access to User Parameters in any **STAGS** subroutine.

Not all user-written subroutines utilize common blocks.

☞ User-written subroutines may call other user-provided subroutines. Subroutine TEMP, for example, could call a heat transfer processor to determine temperatures; or subroutine WALL could call a constitutive processor to compute constitutive properties. There are no hard limits on the allowable complexity of user-written subroutines or on the number of user-provided lower-level routines that they may call. Be careful, however, to avoid subroutine and common block name conflicts with **STAGS** code.

12.2 Subroutine Specifications

User-written subroutines are described in alphabetical order in this section. Some conventions that are used in the subroutine specifications are explained in the following.

User-written subroutines may be loosely grouped into three categories. Some have exact counterparts in input data records. Subroutine USRPT, for example, combines the functionalities of "S-1 User Points (upts protocol)", "S-2 Auxiliary Coordinate System (upts protocol)", and "U-4 Attached Mass". Each output data item in USRPT corresponds to one from those three data records. Therefore, USRPT is used either as an alternative to, or in combination with, those input records.

Other user-written subroutines extend the generality of **STAGS** by providing capabilities that do not exist in the input records. For example, subroutine TEMP represents the only method for applying thermal loading in a **STAGS** model. Finally, there are those subroutines that combine additional capabilities with the option of specifying data just as is done on input records. For example, subroutine WALL may describe a shell wall fabrication by specifying input as in the Wall Fabrication Table (K records). In addition, WALL may define fabrication properties which vary over the surface of a shell unit, something that cannot be done with input records. Another example involves the use of subroutines USRFPF and USRDGD for users to define their own failure criteria and material degradation models.

Subroutine structure

A template is provided for each subroutine—including the necessary coding to perform I/O functions. The user need only provide the coding to perform required computations and data assignments. The source for the subroutine templates is found in the directory **$STAGSHOME**/examples/usersub.

Common blocks

Some subroutines utilize FORTRAN common blocks for I/O; see "common blocks" on page 12-6. In general, not all of the common blocks shown for a specific subroutine will be required for a particular application. Only those common blocks that are pertinent to the application at hand need be included in the corresponding user-written subroutine. Of course, it does no harm to include unused common data. Just be sure not to make data assignments to those items which are not applicable.

Data description

Tabular descriptions are given for all I/O data for each subroutine. Where user-written subroutine output data are identical to data on a corresponding input record, that record is referenced in the subroutine specification in lieu of including redundant documentation. For example, in subroutine USRPT (see page 12-58), the table entry

C	COMMON/NEWSY/ xax xay xaz yax yay yaz	S-2 (p. 7-8)

indicates that “category **C**” USRPT output data are exact counterparts of data on an S-2 input record. Referring to the S-2 record description on page 7-8, it is obvious that the implied description of category **C** output data are

xax = **XAX** xay = **XAY** xaz = **XAZ**
yax = **YAX** yay = **YAY** yaz = **YAZ**

and that defining COMMON/NEWSY/ is equivalent to defining an S-2 record with the same data. This compact notation provides insight into the relationships that exist between user-written subroutines and input records.

CROSS Beam Cross Section Properties

Subroutine CROSS is called at each integration point on the reference axis of each beam having **ICROSS** = 0 (O-1a, O-2a, T-2, USRELT), and at each integration point on the reference surface of each shell element having a fabrication which contains smeared stiffeners having **ICROSM**=0 (K-6 or WALL). CROSS enables the user to define both geometric and material cross section properties as a function of position on the reference axis or surface. This is effected by reference to the Cross Section Table and/or by definition of data directly. As an example, the basic cross section properties can be defined with a Cross Section Table ID, and eccentricity can then be defined directly as a function of position on the beam axis.

Shell-unit rings

Rings are numbered locally within each shell unit, from 1 to **NRGS** (F-2), in the order defined on O-1a/1b. Subroutine CROSS is called for each discrete ring having **ICROSS** = 0.

Shell-unit stringers

Stringers are numbered locally within each shell unit, from 1 to **NSTR** (F-2), in the order defined on O-2a/2b. CROSS is called for each discrete stringer having **ICROSS** = 0.

Element-unit beams

Elements are numbered sequentially as they are defined in each element unit, from 1 to $n_T + n_U$, where n_T is the number of elements defined on T records, and n_U is the number of elements defined in USRELT. This establishes *local* element numbering within each element unit. Subroutine CROSS is called for each element-unit beam element having **ICROSS**=0 (defined either on a T-2 record or in USRELT).

Smeared stiffeners

Smeared stiffeners are identified by a set ID, numbered locally within each applicable shell wall fabrication from 1 to **NSMRS** (K-1/WALL), in the order defined on K-6 records or in WALL. Subroutine CROSS is called for each smeared stiffener having **ICROSM**=0. Smeared stiffeners are applicable in both shell units and element units.

CROSS Structure

```
      subroutine CROSS (iunit, ielt, kelt, itype, XYZg, XYs,
     :                  xsi,   ecy,  ecz,  ilin,  iplas)

      INTEGER        maxSUB
      PARAMETER    ( maxSUB = 10 )

      INTEGER        iunit,    ielt,     kelt,     itype,
     :               ilin,     iplas
      REAL           XYZg(3),  XYs(2),   xsi,      ecy,      ecz

      COMMON/CROSSX/ itab,     kcross,   matb,     nsub,
     :               torj,     scy,      scz,      nsoyz,
     :               kapy,     kapz
      INTEGER        itab,     kcross,   matb,     nsub,     nsoyz
      REAL           torj,     scy,      scz,      kapy,     kapz

      COMMON/CROSS1/ ba,       biy,      biz,      biyz,
     :               soy(4),   soz(4)
      REAL           ba,       biy,      biz,      biyz,
     :               soy,      soz

      COMMON/CROSS2/ sa (maxSUB),   sy (maxSUB),   sz  (maxSUB),
     :               siy(maxSUB),   siz(maxSUB),   siyz(maxSUB),
     :               isp(maxSUB)
      INTEGER        isp
      REAL           sa,       sy,       sz,
     :               siy,      siz,      siyz

      COMMON/CROSS3/ y1 (maxSUB),   y2 (maxSUB),
     :               z1 (maxSUB),   z2 (maxSUB),   isoc(maxSUB)
      INTEGER        isoc
      REAL           y1,       y2,       z1,       z2

      COMMON/CROSS4/ ccc(4,4), bma
      REAL           ccc,      bma

      COMMON/CROSSM/ eb,       gb,       rhob,     alb
      REAL           eb,       gb,       rhob,     alb

*****       Define cross section properties.       *****

      return
      end
```

$STAGSHOME/examples/usersub/cross.F contains the code shown in "CROSS Structure".

CROSS Data

Input

`iunit`	unit number
`ielt`	(Refer to p. 12-9) Shell-unit ring: unit *local* ring ID Shell-unit stringer: unit *local* stringer ID Element-unit beam: unit *local* element number Smeared stiffener: smeared stiffener set ID
`kelt`	beam element code; *e.g.*, 210. Irrelevant for smeared stiffeners.
`itype`	beam type: 0 – element-unit beam 1 – shell-unit ring 2 – shell-unit stringer 3 – ~~skew stiffener~~ 4 – smeared stiffener
`XYZg(3)`	$(\mathbf{x}_g, \mathbf{y}_g, \mathbf{z}_g)$ global coordinates
`XYs(2)`	$(\mathbf{X}, \mathbf{Y})$ surface coordinates; relevant for *shell units* only.

Output

A	`xsi ecy ecz`
	`ilin iplas`
		ring: O-1a (p. 6-50)
		stringer: O-2a (p. 6-54)
		beam: T-2 (p. 8-9)

B	`COMMON/CROSSX/`
	`itab kcross matb`
	`nsub torj scy`
	`scz nsoyz kapy`
	`kapz`
		J-1 (p. 5-118)

C	`COMMON/CROSS1/`
	`ba biy biz`
	`biyz soy(4)`
	`soz(4)`
		J-2a (p. 5-121)J-2b (p. 5-123)

D	`COMMON/CROSS2/`
	`sa sy sz`
	`siy siz siyz`
	`isp`
		J-3a (p. 5-124)

E	`COMMON/CROSS3/`
	`y1 y2 z1`
	`z2 isoc`
		J-3b (p. 5-125)

F	`COMMON/CROSS4/`
	`ccc(4,4) bma`
		J-4a (p. 5-126)J-4b (p. 5-127)

G	`COMMON/CROSSM/`
	`eb gb rhob`
	`alb`
		E Young’s modulus
		G shear modulus
		ρ weight density
		α coefficient of thermal expansion

✔ **A** data are always defined, except for smeared stiffeners, for which it is irrelevant.

Restrictions on variation of cross-section properties

`ilin, iplas` (**A** data) and `kcross` (**B** data) must be constant within each element.

When plasticity is included (**`iplas`** ≥ 1), all data must be constant within each element.

If either of the two above restrictions is violated by CROSS (called at each integration point), **STAGS** will resolve the discrepancies by resetting conflicting data to the values given for integration point 1.

Cross section table selection

Set `itab` > 0. The remaining **B** data are irrelevant.

General cross section

Set `itab` = 0 and `kcross` = 1. Define **B**, **C** data.

General subelement cross section

Set `itab` = 0 and `kcross` = 2. Define **B**, **D** data.

Rectangular subelement cross section

Set `itab` = 0 and `kcross` = 3. Define **B**, **E** data.

Arbitrary cross section

Set `itab` = 0 and `kcross` = 4. Define **B**, **F** data.

Define elastic material properties

When `itab` = 0 only: set `matb` = 0 and define **G** data.

Note that nonlinear material properties may be defined indirectly only, by reference to a Cross Section Table entry (see “Cross section table selection” on page 12-12).

DIMP Imperfections by Discrete Values

Subroutine DIMP is called for *each node point* in each shell unit with **IWIMP** = -1 on the associated M-5 record and in each element unit with **IUDIMP** = 1 on the associated H-1 record.

DIMP defines initial geometric imperfections by specifying discrete nodal displacements representing perturbations of the idealized geometry. Ordinarily, only $(\mathbf{u}, \mathbf{v}, \mathbf{w})$ need be defined. However, to include higher-order strain imperfections, $(\mathbf{ru}, \mathbf{rv}, \mathbf{rw})$ should also be defined. For shell units, $(\mathbf{u}, \mathbf{v}, \mathbf{w})$ are translations in the $(\mathbf{X}', \mathbf{Y}', \mathbf{Z}')$ shell coordinate directions, and $(\mathbf{ru}, \mathbf{rv}, \mathbf{rw})$ are the corresponding rotations. This holds for all shell types, including the user-generated shell unit ($\mathbf{ISHELL} = 1$, M-1). Figure 6.6 on page 6-58 shows the positive directions for the $(\mathbf{u}, \mathbf{v}, \mathbf{w}, \mathbf{ru}, \mathbf{rv}, \mathbf{rw})$ components. For element units, displacements are in the $(\mathbf{x}'', \mathbf{y}'', \mathbf{z}'')$ computational coordinate directions; refer to Figure 7.1 on page 7-6.

For the **E410** and **E411** shell elements, imperfections can be generated in two ways: either by perturbing the geometry alone, or by combining perturbed geometry with initial strain imperfections. The latter allows a more refined definition because the high-order cubic displacement element interpolation is made available. For most other elements, only the initial geometry is perturbed by adding the displacements from DIMP to the idealized initial geometry. It is sufficient for the great majority of applications to define only a suitable initial geometry. If **IMPTHE** = 1 (B-1, *BIN* file), only initial geometry is used in any case; otherwise, **STAGS** will attempt to raise the order of the imperfections using slope information from DIMP.

For element units, the only way to generate the higher-order information is to have access to the type of shell solid model idealization that created the model. This means access to some type of parametric surface coordinates for the surface from which the slope information can be derived. It is a safe bet that for most any model generated by an element unit, a simple perturbed initial geometry will suffice, with zero input for the rotations.

Shell units are defined analytically, according to equation (4.1) on page 4-8. Because this relationship exists, slopes can be computed, allowing rotations to be defined as

$$\mathbf{ru} = \beta_{\mathbf{y}} \qquad \mathbf{rv} = -\beta_{\mathbf{x}} \qquad \mathbf{rw} = \gamma$$

Specific formulas for the so-called *bending numbers* $\beta_{\mathbf{x}}$, $\beta_{\mathbf{y}}$, and γ for each **STAGS** shell type (**ISHELL**, M-1) are given in Appendix K. It should be noted that **STAGS** uses this information automatically when trigonometric expansions are input on the M-6 records.

$STAGSHOME/examples/usersub/dimp.F contains the code shown in “DIMP Structure”.

DIMP Structure

```
      subroutine DIMP (iunit, inode, prop, XYZg, XYs, U)

      INTEGER
     :   iunit,         inode
      REAL
     :   prop(8),       XYZg(3),       XYs(2),        U(6)


*****       Define U(1:6) = (u,v,w,ru,rv,rw).       *****


      return
      end
```

DIMP Data

Input

`iunit`	unit number
`inode`	unit *local* node number
`prop(8)`	M-2 (p. 6-16); relevant for *shell units* only.
`XYZg(3)`	$(\mathbf{x_g}, \mathbf{y_g}, \mathbf{z_g})$ global coordinates
`XYs(2)`	$(\mathbf{X}, \mathbf{Y})$ surface coordinates; relevant for *shell units* only.

Output

`U(6)`	$(\mathbf{u}, \mathbf{v}, \mathbf{w}, \mathbf{ru}, \mathbf{rv}, \mathbf{rw})$

Example problem: cylinder with harmonic imperfections

A cylinder with an imperfection defined as the product of an *n* = 2 (ovalizing) mode and a axial half-wave mode is described in the following example. The maximum amplitude of the imperfections is 0.01. Although this example makes rigorous use of the information in Appendix K, the user will see from the comments that many of the terms are quite small and should be omitted in a real analysis. Consult Appendix K for more details.

The example subroutine shown below is the default subroutine DIMP.

```
      SUBROUTINE DIMP ( IUNIT, INODE, PROP, XYZg, XYs,   VV )
C
C     DIMP requires the user to provide output in the array VV.
C     Imperfections in VV form the imperfection displacement vector
C     at a given node as follows:
C
C     VV(1) -- U
C     VV(2) -- V
C     VV(3) -- W
C     VV(4) -- 0 or Ru (beta_y)
C     VV(5) -- 0 or Rv (-beta_x)
C     VV(6) -- 0 or Rw (gamma or drilling freedom)
C
C     INPUTS
C
C     IUNIT -- Shell Unit Number
C     INODE -- Local (user's) Unit Node #
C      PROP -- PROP array from STAGS Manual
C      XYZg -- Global coordinate of node
C       XYs -- Surface coordinates
C
C     OUTPUT
C
C        VV -- Array of six displacements. Translations are in
C              units of length and rotations are in radians.
C
#include “keydefs.h”
c
      INTEGER  IUNIT,    INODE
      REAL PROP(8),   XYZg(3),    XYs(2),    VV(6)
```

```
C
C     Example User Input for trigonometric representation of
C     imperfection vector for a cylinder of length 15, radius 25.
C     For general DIMP, user programming replaces example below.
C
      X      = XYs(1)
      y      = XYs(2)
      SPAN   = PROP(2) - PROP(1)
      PI     = 3.1415927
      RADIUS = PROP(5)
      Y1     = PI*Y/180.
      WMAX   = .01
      CX     = COS(PI*X/SPAN)
      CY     = COS(2.*Y1)
      SX     = SIN(PI*X/SPAN)
      SY     = SIN(2.*Y1)
      WX     = -WMAX*(PI/SPAN)*SX*CY
      WY     = -2.*WMAX*CX*SY
      WXY    =  2.*WMAX*(PI/SPAN)*SX*SY
C
C     TRANSLATIONS (NOTE HOW SMALL VV(1) AND VV(2) ARE)
C
      VV(1) = WX**2*SPAN/2.
      VV(2) = WY**2/(2.*RADIUS)
      VV(3) = WMAX*CX*CY
C
C     IN-PLANE DERIVATIVES (NOTE HOW VERY SMALL!)
C
      U_Y = WX*SPAN*WXY
      V_X = WY*WXY/RADIUS
C
C     ROTATIONS, FROM FORMULAS (2.24 and 2.57)
C
      BETAX = WX
      BETAY = (WY-VV(2))/RADIUS
      GAMMA = 0.5*(V_X - U_Y/RADIUS)
      VV(4) =  BETAY
      VV(5) = -BETAX
      VV(6) =  GAMMA
C
C     End Example
C
      RETURN
      END
```

FORCET Load Factor History for Transient Analysis

Subroutine FORCET is called when **IFORCE** = 1 on the E-2 record.

$STAGSHOME/examples/usersub/forcet.F contains the code shown in “FORCET Structure”.

FORCET Structure

```
      subroutine FORCET (t, k, Pf)

      INTEGER
     :   k
      REAL
     :   t,           Pf


*****      Define load factor.      *****


      return
      end
```

FORCET Data

Input

t	time
k	load set ID 1 – load system A 2 – load system B

Output

Pf	load factor

LAME Reference Surface Geometry

Subroutine LAME is called for *each node point* in each shell unit with **ISHELL** = 1 on the associated M-1 record. It specifies:

- the position of the node in $(\mathbf{x}, \mathbf{y}, \mathbf{z})$ branch coordinates given the $(\mathbf{X}, \mathbf{Y})$ surface coordinates
- the tangents (also in $(\mathbf{x}, \mathbf{y}, \mathbf{z})$ branch coordinates) to the coordinate lines generated by the $(\mathbf{X}, \mathbf{Y})$ surface coordinates
- a degree-of freedom (*dof*) option, relevant only when $(\mathbf{X}, \mathbf{Y})$ are non-orthogonal

If the radius vector $\mathbf{r}$ from the origin of the branch (shell unit) to a given nodal point is defined by a relation of the type

$$\mathbf{r} = \begin{Bmatrix} \mathbf{x} \\ \mathbf{y} \\ \mathbf{z} \end{Bmatrix} = \begin{Bmatrix} \mathbf{f}(\mathbf{X}, \mathbf{Y}) \\ \mathbf{g}(\mathbf{X}, \mathbf{Y}) \\ \mathbf{h}(\mathbf{X}, \mathbf{Y}) \end{Bmatrix}$$

then the tangent vectors $\mathbf{r},_{\mathbf{X}}$ and $\mathbf{r},_{\mathbf{Y}}$ are

$$\mathbf{r},_{\mathbf{X}} = \left\{ \begin{vmatrix} \mathbf{f},_{\mathbf{X}} \\ \mathbf{g},_{\mathbf{X}} \\ \mathbf{h},_{\mathbf{X}} \end{vmatrix} \right\} = \frac{\partial \mathbf{r}}{\partial \mathbf{X}} \qquad \mathbf{r},_{\mathbf{Y}} = \left\{ \begin{vmatrix} \mathbf{f},_{\mathbf{Y}} \\ \mathbf{g},_{\mathbf{Y}} \\ \mathbf{h},_{\mathbf{Y}} \end{vmatrix} \right\} = \frac{\partial \mathbf{r}}{\partial \mathbf{Y}}$$

The user must provide the radius vector and its partial derivatives at each node

$$\mathbf{r}(\mathbf{X}, \mathbf{Y}) \qquad \frac{\partial \mathbf{r}}{\partial \mathbf{X}} \qquad \frac{\partial \mathbf{r}}{\partial \mathbf{Y}}$$

By default, **PROP** (M-2, p. 6-16) is used to set the range of $(\mathbf{X}, \mathbf{Y})$ as

$$\mathbf{PROP}(\mathbf{1}) \le \mathbf{X} \le \mathbf{PROP}(\mathbf{2}) \qquad \mathbf{PROP}(\mathbf{3}) \le \mathbf{Y} \le \mathbf{PROP}(\mathbf{4})$$

However, when **IUGRID** = 1 (N-1, p. 6-34), the range of $(\mathbf{X}, \mathbf{Y})$ is set to

$$0 \le \mathbf{X} \le 1 \qquad 0 \le \mathbf{Y} \le 1$$

PROP remains intact, but is not used to set the range of $(\mathbf{X}, \mathbf{Y})$ when **IUGRID** = 1;
see M-2, p. 6-16, and N-1, p. 6-34.

STAGS uses the tangent vectors $\mathbf{r}_{,\mathbf{X}}$ and $\mathbf{r}_{,\mathbf{Y}}$ to generate the $(\mathbf{X}', \mathbf{Y}')$ shell coordinates. The $\mathbf{Z}'$ shell normal direction is defined by the cross product $\mathbf{X}' \times \mathbf{Y}'$.

Non-orthogonal surface coordinates

When the $(\mathbf{X}, \mathbf{Y})$ surface coordinates are non-orthogonal, the user selects either $\mathbf{r}_{,\mathbf{X}}$ or $\mathbf{r}_{,\mathbf{Y}}$ to determine one of $(\mathbf{X}', \mathbf{Y}')$. The remaining axis is chosen to complete a right-handed orthogonal system. If `islam` is set to 1, $\mathbf{X}'$ is in the direction defined by $\mathbf{r}_{,\mathbf{X}}$. If `islam` is set to 2, $\mathbf{Y}'$ is in the direction defined by $\mathbf{r}_{,\mathbf{Y}}$. For most shell definitions, the direction vectors are naturally orthogonal, and the choice of `islam` is immaterial. If the direction vectors are not orthogonal, the choice of `islam` may be important, since the model boundary conditions and specified displacements depend on this choice. It will always be possible to define the commonly-used boundary conditions such as symmetry and simple support with a suitable choice of `islam`.

$STAGSHOME/examples/usersub/lame.F contains the code shown in “LAME Structure”.

LAME Structure

```
      subroutine LAME ( iunit, prop, XYs, islam )

      COMMON / LAMEX /  f,             g,             h,
     &                 fX,            gX,            hX,
     &                 fY,            gY,            hY
      INTEGER           iunit,         islam
      REAL              prop(8),       XYs(2),
     &                 f              g,             h,
     &                 fX,            gX,            hX,
     &                 fY,            gY,            hY

***  Define   f   g   h      fX  gX  hX      fY  gY  hY         ***
***                                                             ***
***  Set islam when (X,Y) surface coordinates are nonorthogonal ***

      return
      end
```

LAME Data

Input

`iunit`	shell unit number
`prop(8)`	M-2 (p. 6-16)
`XYs(2)`	$(\mathbf{X}, \mathbf{Y})$ surface coordinates

Output

`islam`	*dof* option: 1 – $\mathbf{X}'$ is parallel to X 2 – $\mathbf{Y}'$ is parallel to Y relevant when $(\mathbf{X}, \mathbf{Y})$ are non-orthogonal

`COMMON/LAMEX/`
`f g h`
`fX gX hX`
`fY gY hY`
	$\mathbf{r}$
	$\mathbf{r}_{,\mathbf{X}}$
	$\mathbf{r}_{,\mathbf{Y}}$

Example problem: quadrilateral plate with shell coordinates derived from (ξ, η) directions

In the Quadrilateral Plate (**ISHELL** = 3, M-1), the $(\mathbf{X}', \mathbf{Y}', \mathbf{Z}')$ shell coordinates are parallel to the $(\mathbf{x}, \mathbf{y}, \mathbf{z})$ branch coordinates (see "Standard Shell Surfaces" on page 6-2). This can be inconvenient when loading and boundary conditions require that $(\mathbf{u}, \mathbf{v}, \mathbf{w})$ on the boundary be aligned with the edge (see Figure 6.6 on page 6-58). This example solves this problem by assigning $\mathbf{X}'$ to the tangent line generated by the $\mathbf{X}$ surface coordinate (`islam=1`) for all interior points plus boundary lines 2 and 4. For those points lying along boundary lines 1 and 3, `islam=2` is set, meaning that the $\mathbf{Y}$ surface tangent will be aligned with the $\mathbf{Y}'$ shell coordinate.

In this example, **IUGRID** = 1 (N-1, p. 6-34) must be set. This option defines the range of the $(\mathbf{X}, \mathbf{Y})$ surface coordinates as

$$0 \le \mathbf{X} \le 1 \qquad 0 \le \mathbf{Y} \le 1$$

PROP(1:8) (M-2, p. 6-16) are used to define the $(\mathbf{x}, \mathbf{y})$ branch coordinates of the four corner points according to the conventions used for the Quadrilateral Plate (**ISHELL** = 3, M-1).

The example subroutine shown below is the default subroutine LAME.

```
      subroutine LAME ( IUNIT,  PROP,  XYs,  ISLAM )

      Integer
     :      IUNIT,   ISLAM, init

      save init

      Real
     :      XS,   YS, PROP(*),
     :      F,     G,     H,
     :      FX,   GX,   HX,
     :      FY,   GY,   HY,   XYs(2)

#include “stndcm.h”

      Common /LAMEX /
     :      F,     G,     H,
     :      FX,   GX,   HX,
     :      FY,   GY,   HY

      data init/1/
C
C     Given Shell Unit No. IUNIT, and surface coordinates XYs
C     compute branch coordinates F,  G,  H of the point.
C
C     Compute the First Fundamental Form, or the derivative of the
C     position vector F, G, H as a function of XYs(1) (FX, GX, HX) or of
C     XYs(2) (FY, GY, HY).  If ISLAM = 1, STAGS aligns the local x axis
C     along the vector (FX, GX, HX); if ISLAM = 2, STAGS aligns the
C     local y axis along the vector (FY, GY, HY).  The z axis is
C     always perpendicular to both base vectors (FX, GX, HX) and
C     (FY, GY, HY)
C
C     In this example, create a grid for the quadrilateral plate (ISHELL=3,
C     see STAGS Manual), except this time align the X' shell coordinate
C     direction along the (FX, GX, HX) direction, and assign the Y' axis
C     to complete a right-hand orthogonal system. Only Boundary Lines 1 and
C     3, (XS = 0. or XS = 1.), align the Y' axis with (FY, GY, HY) so that
C     the local coordinates line up with the boundary lines (for loads and
C     boundary conditions).
C
C *** NOTE: TO RUN THIS ROUTINE, ASSIGN IUGRD = 1, Record N-1. This causes
C *** 0<=XS<=1.;0<=YS<=1. Also, assign PROP array in the same manner as
C *** in ISHELL = 3 (Quadrilateral Plate).
```

```
C
C     Begin Execution
C
      XS = XYs(1)
      YS = XYs(2)
      if (init .eq. 1) then
        init = 0
        write(not, 1)
      endif
    1 format(/,1x,'*************   WARNING!!   ************',/
     &       1x,'Default Lame for quadrilateral plate used.',/)
C
C     Compute reduced coordinate functions
C
      f1 = (1.-XS)*(1.-YS)
      f2 = (1.-XS)*YS
      f3 = XS*YS
      f4 = XS*(1.-YS)
C
C     Compute position coordinates of point at XS,YS
C
      F = f1*PROP(1) + f2*PROP(3) + f3*PROP(5) + f4*PROP(7)
      G = f1*PROP(2) + f2*PROP(4) + f3*PROP(6) + f4*PROP(8)
      H = 0.
C
C     Compute X' direction vector
C
      f1x = -(1.-YS)
      f2x = -YS
      f3x =  YS
      f4x = -f1x
      FX  = f1x*PROP(1) + f2x*PROP(3) + f3x*PROP(5) + f4x*PROP(7)
      GX  = f1x*PROP(2) + f2x*PROP(4) + f3x*PROP(6) + f4x*PROP(8)
      HX  = 0.
C
C     Compute the Y' direction vector
C
      f1y = -(1.-XS)
      f2y = -f1y
      f3y =  XS
      f4y = -XS
      FY  = f1y*PROP(1) + f2y*PROP(3) + f3y*PROP(5) + f4y*PROP(7)
      GY  = f1y*PROP(2) + f2y*PROP(4) + f3y*PROP(6) + f4y*PROP(8)
      HY  = 0.
```

```
C
C     Check if on boundary line (to within real * 4 accuracy)
C
      if (XS .lt. 1.e-5   .or. ABS(XS -1.) .lt. 1.e-5) then
C
C        You are on boundary line 1 or 3: set Y' = (FY, GY, HY)
C        by setting ISLAM = 2 (STAGS does the rest)
C
         ISLAM = 2

      ELSE
C
C        You are in the interior, or on lines 2 and 4: default is OK
C
         ISLAM = 1

      ENDIF
C
C     End computation
C
      return
      end
```

TEMP Thermal Loading

Subroutine TEMP is applicable if and only if **ITEMP** > 0 on the C-1 record (indicating that thermal loadings are to be taken into account during analysis and post-processing operations). When thermal loadings are taken into account, subroutine TEMP is called at each integration point on the reference surface for shell elements and for each point on the reference axis for beams. Nodal points are used instead of integration points for **E48X** and **E8XX** elements. At each reference point, TEMP is called once for each through-thickness integration point in shell wall fabrications. TEMP is also called once at the centroid of each subelement in beam cross sections (where thermal loading is permitted only for **KCROSS** ≤ 3, J-1). TEMP is also called during the post-processing phase at each point selected for stress output. See the notes subsection, below, for information about thermal analysis capabilities in the current version of **STAGS**.

By convention, the stress-free temperature is taken as zero in **STAGS**. It is incumbent upon the user to define *relative* temperatures in TEMP: if the actual environmental condition at integration point *i* is $\mathbf{T_i}$ and the corresponding stress-free temperature is $\bar{\mathbf{T}}$, the temperature defined by TEMP should be $\mathbf{T} = \mathbf{T_i} - \bar{\mathbf{T}}$.

Thermal loading is added to mechanical loading as part of the *base loads*, which are scaled by the *load factors* $\mathbf{P_A}$ and $\mathbf{P_B}$ (see Section 6.5 “Loads” on page 6-64). Thermal loading is added exclusively to either Load System A or Load System B, as specified by **ITEMP**, C-1.

$STAGSHOME/examples/usersub/temp.F contains the code shown in “TEMP Structure”.

TEMP Structure

```
      subroutine TEMP ( iunit, ielt, kelt, itype,
     :                  XYZg,  XYs,   Zfab, YZsec, h, T )

      INTEGER  iunit,   ielt,   kelt, itype
      REAL     XYZg(3), XYs(2), Zfab, YZsec(2), h, T

***** Define temperature, T. *****

      return
      end
```

TEMP Data

Input

`iunit`	unit number
`ielt`	element number (unit *local* element ID)
`kelt`	element code; *e.g.*, 410
`itype`	element type: 1 – shell element 2 – element-unit beam 3 – shell-unit ring 4 – shell-unit stringer
`XYZg(3)`	$(\mathbf{x_g}, \mathbf{y_g}, \mathbf{z_g})$ global coordinates
`XYs(2)`	$(\mathbf{X}, \mathbf{Y})$ surface coordinates
`Zfab`	$\bar{\mathbf{z}}$, fabrication normal coordinate
`YZsec(2)`	$(\bar{\mathbf{y}}, \bar{\mathbf{z}})$ cross-section coordinates
`h`	shell wall thickness

- `XYs` is relevant for *shell units* only.
- `Zfab` and `h` are relevant for *shell elements* only.
- `YZsec` is relevant for *beam elements* only.
- The remaining data are always relevant.

Output

`T`	temperature

Example problem: linear through-thickness shell-wall temperature gradient

A linear thermal gradient through the thickness of a shell wall may be expressed as

$$\mathbf{T}_0 = (\mathbf{T}_{\mathbf{top}} + \mathbf{T}_{\mathbf{bot}})/2 \qquad \Delta\mathbf{T} = \mathbf{T}_{\mathbf{top}} - \mathbf{T}_{\mathbf{bot}} \qquad \mathbf{T} = \mathbf{T}_0 + \frac{\Delta\mathbf{T}}{\mathbf{h}}\bar{\mathbf{z}}$$

where $\bar{\mathbf{z}}$ is the fabrication normal coordinate, *h* is the wall thickness, $\mathbf{T}_0$ is the temperature at $\bar{\mathbf{z}} = 0$ (*i.e.*, the middle-surface temperature), $\mathbf{T}_{\mathbf{top}}$ is the top-surface temperature, and $\mathbf{T}_{\mathbf{bot}}$ is the bottom-surface temperature (see Figure 5.6 on page 5-130).

Utilizing User Parameters (see “L-1 User Parameters Summary” on page 5-143) to input the top-surface and bottom-surface temperatures,

$$\mathtt{Ttop} = \mathbf{T}_{\mathbf{top}} \quad \text{and} \quad \mathtt{Tbot} = \mathbf{T}_{\mathbf{bot}} ,$$

TEMP can define a linear temperature variation as in the code shown below.

```
      subroutine TEMP (iunit, ielt, kelt, itype,
     :                 XYZg,  XYs,  Zfab, YZsec, h, T)

      COMMON
     : / UPF   /   Ttop,     Tbot,     UserFlo(198)
      INTEGER
     :   iunit,          ielt,          kelt,          itype
      REAL
     :   XYZg(3),        XYs(2),        Zfab,          YZsec(2),
     :   h,              T,
     :   Ttop,           Tbot,          UserFlo,
     :   Tmid,           delT,          Tgrad


      Tmid  =  (Ttop + Tbot)/2
      delT  =   Ttop - Tbot
      Tgrad = delT/h
      T = Tmid + Tgrad*Zfab


      return
      end
```

The example subroutine shown above is the default subroutine TEMP.

Notes:

In a recent effort to evaluate thermal analysis capabilities in the current version of **STAGS** for shell and solid elements and in doing so to correct "simple" errors that were found, the following observations about **STAGS'** thermal analysis capabilities and shortcomings were reported:

> Test cases for free thermal expansion provide excellent indications that the machinery in **STAGS** for thermal loading is working. Standard free thermal expansion analysis cases were run—using "historical" material and fabrication specification options and using GCP (Generalized Constitutive Processor) material and fabrication specification options—for all of the basic shell and solid elements in the current version of **STAGS**. For shell elements, the default plane-stress material response should yield zero energy for free expansion. All of the shell and solid elements in the current version of **STAGS** passed this test.
>
> The **E330**, **E430** and **E480** shell elements *must* be defined with GCP material and fabrication specifications when thermal loadings are applied: these elements do not take thermal loadings into account when the historical material- and fabrication-specification methods are used. To obtain correct energy printouts with these elements, three or more integration points must be used through the thickness of each layer. This is needed for accuracy anyway, when thermal gradients are present. A single integration point may be used in each layer of a fabrication with many layers—if the analyst's user-written TEMP subroutine takes that into account.
>
> With the **E320**, **E410** and **E420** shell elements in the current version of **STAGS**, the *plane-strain* material option is only available for ISOTROPIC materials that are specified *via* the "historical" procedures. This option is not implemented *via* the GCP, yet. Results obtained for these elements (with historical plane-strain specifications) were identical with results obtained with **STAGS**' solid elements (with responses in the thickness direction suppressed).
>
> To implement a *plane-strain* option in the GCP, a new kinematic class must be added. The new kinematic class (which can be implemented with a few weeks of *funded* effort) is *essential* for the **E330**, **E430** and **E480** shell elements. It is not critically required for **STAGS**' **E8XX** sandwich elements, though: plane strain behavior can be modeled *via* boundary conditions, with them.
>
> There is not enough information in the "historical" material and fabrication specification procedures in the current version of **STAGS** to specify generalized plane-strain materials: material properties in the thickness direction are not defined. That information could be added to the historical procedures, but the cost/benefit figures for doing so are unattractive (at best). Much better results are anticipated from enhancements to the GCP.

UCONST Lagrange Constraints

Subroutine UCONST is called when **NCONST** > 0 on the B-2 record.

UCONST Structure

```
      subroutine UCONST

      INTEGER     maxN
      PARAMETER ( maxN = 100 )

      INTEGER  iu(maxN), ix(maxN), iy(maxN), iz(maxN), id(maxN)
      REAL     cc(maxN)

      INTEGER  nterms


***** Repeat for each constraint.       *****

      call CONSTR ( nterms, iu, ix, iy, iz, id, cc )

      return
      end
```

UCONST Data

Output

nterms	G-3 (p. 5-40)
iu ix iy iz id cc	G-4 (p. 5-43)

$STAGSHOME/examples/usersub/uconst.F contains the code shown in “UCONST Structure”. See Section 12.3 “Example Problem” on page 12-66 for a practical example of UCONST.

UPRESS Pressure Loading

Subroutine UPRESS is called at each integration point on the reference surface of each shell element where **IPRESS** = 1 on the associated Q-1 (shell unit) or U-1 (element unit) record. (Nodal points are used instead of integration points for elements **E480** and **E6XX**.)

Applied loads are normally computed as the product of *base loads* and *load factors*, summed for *load systems A and B* (see Section 6.5 “Loads” on page 6-64). UPRESS provides a more generalized pressure-loading feature. Input arguments include time (`t`) and load factors (`pA`,`pB`), and output is a pressure value (`p`) which is added directly to the applied loads (*i.e.*, UPRESS output is not placed in either load system and is not scaled). Normally, UPRESS should define the pressure, *p*, as

$$p = P_A \cdot p_A + P_B \cdot p_B$$

where P_A, P_B are the load factors for load systems A and B; and p_A, p_B are the base load pressure values for the two load systems. UPRESS permits more general pressure loading, however.

Subroutine UPRESS is called at each load/time step, and may allow pressure distribution (base loading) to vary during the analysis history in any arbitrary way. UPRESS is the only means by which base loads may be varied during an analysis. For all other loading features, only load factors vary, with base loads held constant.

When subroutine UPRESS is utilized, any pressure loads defined in the *INP* file (**LT** = 4 or 5, Q-3/U-3) are ignored.

$STAGSHOME/examples/usersub/upress.F contains the code shown below:

UPRESS Structure

```
      subroutine UPRESS ( t, pA, pB,  iunit, ielt, kelt,
     :                    XYZg,  XYs, live,  press )

      INTEGER iunit, ielt, kelt, live
      REAL    t,     pA,   pB,   XYZg(3), XYs(2), press

***** Define pressure. *****

      return
      end
```

UPRESS Data

Input

`t`	time
`pA`	load factor for load system A
`pB`	load factor for load system B
`iunit`	unit number
`ielt`	element number (unit *local* element ID)
`kelt`	element code; *e.g.*, 410
`XYZg(3)`	$(\mathbf{x_g}, \mathbf{y_g}, \mathbf{z_g})$ global coordinates
`XYs(2)`	$(\mathbf{X}, \mathbf{Y})$ surface coordinates

✔ `XYs` is relevant for shell units only.

✔ The remaining data are relevant for shell units *and* element units.

Output

`live`	pressure type 0 – dead pressure 1 – live pressure
`press`	pressure value

USRDGD Material Degradation Model

Subroutine USRDGD allows the **STAGS** user to implement his or her own material degradation model or to modify one of the existing degradation models (which are implemented in the current version of **STAGS** in DEGRADi.F subroutines). The existing first–ply failure models (which are implemented in **STAGS** in FPFi.F routines) can be utilized with the user’s USRDGD subroutine if they fit the user’s model. It will be necessary for the user to write his or her own USRFPF subroutine to implement a new failure model if they do not fit. Subroutine USRDGD is called [by **STAGS**’ Generic Constitutive Processor (GCP) facility] for each element that is fabricated with an orthotropic elastic brittle GCP material for which **IDGRD** = 99 on the I-10a (ORT_EL_BR_MATERIAL) record that defines that material.

As a template for adventuresome **STAGS** users, a material degradation model using the maximum strain criteria has been implemented in the USRDGD subroutine that is distributed with the program (and which is listed below for the reader’s convenience). The calling arguments to USRDGD are documented in this listing and will not be further described here.

USRDGD Template

```
c=deck    usrdgd
c=purpose Material degradation model using a user-written routine
c=author  Norm Knight/Veridian
c=version January 2000

#include “keydefs.h”

*  *********************************************************************
*  *  This routine is provided as a template for a user that wants to  *
*  *  install a personal material degradation model. It is called iff  *
*  *  the IDGRD parameter in the ORT_EL_BR_MATERIAL GCP material       *
*  *  model data is set equal to 99                                     *
*  *********************************************************************

#if   _usage_
*     ------------------------------------------------------------------
*     CALLING SEQUENCE:
*
*     call USRDGD ( iCMtyp, mpd,   oldhmd, newhmd,
*    &              nwold,  nwnew, flag,   status )
*
*     INPUT ARGUMENT TYPE DESCRIPTION
*
*     iCMtyp         [I]  Kinematic option for material processing
*     mpd(*)         [R]  Material property data
*     nwold          [I]  Number of words of old historical data
*     oldhmd(*)      [R]  Historical data (from previous converged soln)
*     flag(*)        [I]  Failure flag vector
*
*     OUTPUT ARGUMENTS:
*
*     nwnew          [I]  Number of words of new historical data
*     newhmd(*)      [R]  New historical data
*     status          [I]  Return status: (OK==>status=qOK)
*     ----------------------------------------------------------------
#endif

      subroutine USRDGD ( iCMtyp, mpd,   oldhmd, newhmd,
     &                    nwold,  nwnew, flag,   status )

      _implicit_none_

#include "cs4xxx.h"
#include "qgcp.h"
#include "stndcm.h"
#include "upfi.h"

      integer iCMtyp
      real    mpd(*)
      _float_ oldhmd(*)
      _float_ newhmd(*)
      integer nwold
      integer nwnew
      integer flag(*)
      integer status

*     The original input material data are stored in the mpd array
*     in the order given in the  ORT_EL_BR_MATERIAL  material data
*     input line for the GCP data

*     ----------------------------------------------------------------
*     I N T E R N A L   D E C L A R A T I O N S
*     ----------------------------------------------------------------

      integer numcol

      _float_ E1,   E2,   E3
      _float_ G23,  G13,  G12
      _float_ nu23, nu13, nu12

*     dfactr is equivalent to beta in the write-ups and
*     it is used to degrade the material properties

      _float_ dfactr

* ... BETA=dfactr ...
*
*     If beta (which is mpd(39)) is less than zero, then degrade by
*     beta only once on initial failure;  if beta is positive, then
*     degrade recursively on each solution step

      dfactr = ABS(mpd(39))

*     ----------------------------------------------------------------
*     L O G I C
*     ----------------------------------------------------------------
*
*     Set up nwnew and the newhmd array with new
*     data based on element type

      if ( iCMtyp.eq.1 ) then

*       1D CONTINUUM (ROD OR BAR ELEMENT)
*         =================================
          numcol = 1

      elseif ( iCMtyp.eq.2 ) then

*       C0/C1 BEAM
*         ==========
          numcol = 3
      elseif ( iCMtyp.eq.3 ) then

*       C0 SHELL
*        ========
         numcol = 5

      elseif ( iCMtyp.eq.4 ) then

*       C1 SHELL (PLANE STRESS)
*        =======================
         numcol = 3

*        First load in constitutive data into local variables
*        using original data if nwold=0 and historical data
*        if nwold .ne. 0

         if ( nwold.eq.0 ) then

*           Set original material data values in
*           elastic constant variables

            E1   = mpd(1)
            E2   = mpd(2)
            E3   = mpd(3)
            G23  = mpd(4)
            G13  = mpd(5)
            G12  = mpd(6)
            nu23 = mpd(7)
            nu13 = mpd(8)
            nu12 = mpd(9)

         else

*           Set saved historical data values in elastic constant
*           variables (values from the last previously converged
*           and archived set)

            E1   = oldhmd(1)
            E2   = oldhmd(2)
            E3   = oldhmd(3)
            G23  = oldhmd(4)
            G13  = oldhmd(5)
            G12  = oldhmd(6)
            nu23 = oldhmd(7)
            nu13 = oldhmd(8)
            nu12 = oldhmd(9)

         endif

*        Degrade properties if failure criterion indicates failure

         if ( flag(1) .ne. 0 ) then

*           Fiber failure

            if ( mpd(39).lt.0.0 .and. NINT(oldhmd(10)).ne.0 ) then
               E1   = oldhmd(1)
               nu12 = oldhmd(9)
            else
              E1   = dfactr*E1
               nu12 = dfactr*nu12
            endif

         endif

         if ( flag(2).ne.0 ) then

*           Matrix failure
```

```
            if ( mpd(39).lt.0.0 .and. NINT(oldhmd(11)).ne.0 ) then
               E2   = oldhmd(2)
               nu12 = oldhmd(9)
            else
              E2   = dfactr*E2
              nu12 = dfactr*nu12
            endif

         endif

         if ( flag(3).ne.0 ) then

*           In-plane shear failure

            if (mpd(39).lt.0.0 .and. NINT(oldhmd(12)).ne.0 ) then
               G12 = oldhmd(6)
            else
               G12 = dfactr*G12
            endif

         endif

*        Set nwnew = number of words of constitutive historical data

         nwnew = 12

*        Store new properties for this point

         newhmd( 1) = E1
         newhmd( 2) = E2
         newhmd( 3) = E3
         newhmd( 4) = G23
         newhmd( 5) = G13
         newhmd( 6) = G12
         newhmd( 7) = nu23
         newhmd( 8) = nu13
         newhmd( 9) = nu12
         newhmd(10) = flag(1)
         newhmd(11) = flag(2)
         newhmd(12) = flag(3)

      elseif ( iCMtyp.eq.5 ) then

*       2D PLANE STRAIN CONTINUUM
*        ========================
         numcol = 3

      elseif ( iCMtyp.eq.6 ) then

*        2D axisymmetric continuum
*        =========================

         numcol = 4

      elseif ( iCMtyp.eq.7 ) then

*       3D CONTINUUM
*        ============
         numcol = 6

      endif

*     SET STATUS VARIABLE
*     ===================
      status = qOK

      end
```

The user may include data in addition to that which is transmitted to and from subroutine USRDGD through its calling sequence *via* **STAGS'** user parameter input facility—using L-2a and/or L-2b records as required (for integers and real variables, respectively). This may be accomplished by including the *upfi.h* header file or by including the following explicit declarations and common statements:

```
       integer userint
       common / upi / userint(200)
```

and

```
       real userflo
       common / upf / userflo(200)
```

The *csrxxx.h* header file that is included in this version of USRDGD contains four integer variables that are used to identify which material point is being examined:

idelt Element number within a unit

eltip Element surface integration point number

layer Layer number within the laminate

layip Through-the-thickness integration point within a layer

On entry into the routine, a check is made to identify the kinematics option for the element by testing the value of the parameter **iCMtyp**. For C^1 shell elements, **iCMtyp** equals 3, and there are three stress values (σ_{xx}, σ_{yy}, τ_{xy}). Similarly there are three strain values.

Next, the value of **nwold** is checked. If **nwold** is zero, then no failure at this material point has occurred previously (*i.e.,* at a previous solution step, not at a previous iteration); and the original values for the elastic constants from the **mpd** array are loaded into local variables for these material constants. For convenience, local variables for a three-dimensional elastic system are stored. If **nwold** is nonzero, however, then failure at this material point has occurred previously; and the degraded elastic constants from the previous solution step are loaded from the **oldhmd** array into the local variables.

The next step is to test to determine if failure in the fiber (or 1) direction has occurred during this step (if **flag**(1) is not zero) or if no failure has yet occurred (**flag**(1) equals zero). If **flag**(1) is not zero, then the material properties are degraded in a manner that depends on whether the failure is tensile (**flag**(1) = +1) or compressive (**flag**(1) = -1). Before the properties are degraded, the type of degradation to use is determined based on the sign of **mpd**(37) that corresponds to the variable β in the ORT_EL_BR_MATERIAL input for GCP. If this value is negative, then the degradation factor is applied only once. If it is positive, then the degradation factor is applied recursively for each solution step. As such, the properties may be degraded instantaneously to nearly zero, or they may be gradually reduced over several solution steps. If **flag**(1) equals zero, then no material degradation is done. A check is also made to determine if failure occurred during the previous solution step so that an initial degradation of the material properties is performed. This test examines the entries in the **oldhmd** array corresponding to the failure flags (*e.g.,* **oldhmd**(10) corresponds to **flag**(1) and so on). The process continues with **flag**(2) and **flag**(3) in a similar manner.

After testing each value of the **flag** array, the new values of the elastic constants are stored in the **newhmd** array. Again for convenience, the elastic constants for a three-dimensional solid are stored. In addition, the three failure flags are also stored. Hence a total of **nwnew** real numbers are stored in the **newhmd** array for each material point that has failed. In this template, **nwnew** equals 12 because there are nine elastic constants and three failure flags.

Subroutine USRDGD is called for each layer integration point through the thickness of each layer in the laminate for each surface integration point of the element and for each element. It is a very low-level routine that is called many, many times; and if the user should choose to print output within this routine, he or she should expect a *lot!*

Because USRDGD is a low-level routine, it is called during the evaluation of both the first and second variations during a nonlinear iteration. Hence multiple passes through this routine may occur as a consistent state for the first and second variation is always sought.

USRELT Elements

Subroutine USRELT is called once for each element unit where **IUWE** = 1 on the associated H-1 record. USRELT may define all of the elements in a given element unit, or it may be used to complement elements defined on T records. Elements are numbered sequentially as they are defined in USRELT, from $n_T + 1$ to $n_T + n_U$, where n_T is the number of elements defined on T records, and n_U is the number of elements defined in USRELT. Thus, element numbering is continuous, from 1 to $n_T + n_U$ within each element unit.

USRELT Structure

```
      subroutine USRELT ( iunit )

      INTEGER           maxN
      PARAMETER       ( maxN = 9 )
      INTEGER
     :   iunit,
     :   node(maxN),    kelt,          icross,        iwall,
     :   ilin,          iplas,         integ,         ipenl,
     :   iang
      REAL
     :   xsi,           zeta,          ecy,           ecz,
     :   rx,            ry,            rz

*****       Repeat for each beam element.        *****

            call BEAM  (node,  kelt,  icross,
     :                  xsi,   ecy,   ecz,
     :                  ilin,  iplas)

*****       Repeat for each shell element.       *****

            call SHELL (node,  kelt,  iwall,
     :                  zeta,  ecz,
     :                  ilin,  iplas,
     :                  integ, ipenl, iang,
     :                  rx,    ry,    rz   )

      return
      end
```

USRELT Data

Input

`iunit`	unit number

Output

A	`node kelt icross`
	`xsi ecy ecz`
	`ilin iplas`
		T-2 (p. 8-9)
		See below re: `node` array.

B	`node kelt iwall`
	`zeta ecz`
	`ilin iplas`
	`integ ipenl iang`
		Triangle: T-3 (p. 8-14)
		Quadrilateral: T-4 (p. 8-17)
		T-4a (p. 8-23)
		See below re: `node` array.

C	`rx ry rz`	Triangle: T-3a (p. 8-16) Quadrilateral: T-4b (p. 8-24)

✔ **A** data applies to beams.

✔ When `icross` = 0, then the remaining **A** data are irrelevant.

✔ **B**, **C** data apply to shells.

✔ When `iwall` = 0, then the remaining **B** data, except `iang`, is irrelevant.

✔ **C** data are relevant only when `iang` = 1.

✔ `integ` and `ipenl` are not used for triangles, but must appear in the `call SHELL` argument list.

Beams	`node(1)` = **N1**	`node(2)` = **N2**	`node(3)` = **NR**
Triangles	`node(1)` = **N1**	`node(2)` = **N2**	`node(3)` = **N3**
Quadrilaterals	`node(1)` = **N1**	. . .	`node(9)` = **N9**

$STAGSHOME/examples/usersub/usrelt.F contains the code shown in “USRELT Structure”. See Section 12.3 “Example Problem” on page 12-66 for a practical example of USRELT.

USRFAB User-Specified Material & Fabrication Properties

User-written subroutine USRFAB, like subroutine WALL, enables the user to specify material and/or fabrication properties at each surface integration point of selected elements. Subroutine WALL lets the user do this for shell elements for which material and fabrication properties are defined *via* historical methods (*via* I*, J* and K* records, but not with the GCP), when it is necessary or desirable to circumvent or supplement **STAGS**' regular property specification procedures. The user does this with subroutine WALL by setting the **IWALL** parameter equal to zero for any shell– and/or element–unit element(s) for which some or all of the material and/or geometric properties must be specified individually (see M-5, T-3, T-3xx, T-4xx and USRELT, for example). Subroutine USRFAB enables the user to specify material and/or fabrication properties at each surface integration point, for each of the layer points through the thickness, of selected elements that utilize the GCP for specification of and operations with these properties.

When a user-written GCP fabrication—which requires the specification of a GCP material and the specification of the GCP fabrication (geometric and control) parameters to be used—is desired for selected elements, the user (in his or her model-specification input file for **STAGS**' ***s1*** processor) must specify nominal (default) GCP material properties for these elements in the usual way (*via* I-6a, I-7a, I-8a, I-9a, I-10a and/or I-11a material-property-specification records, as appropriate); and he (or she) must specify nominal (default) GCP fabrication properties *via* I-21a and/or I-22a fabrication-specification records that are commanded by I-5a records on which the fabrication-identification parameter **INFO(1)** (which translates to **FABID** on I-21a and I-22a) is *negative*. When an element that has been assigned this "tagged" fabrication is encountered in **STAGS**' ***s2*** processor (or in other post-model-generation **STAGS** processors), the original material and fabrication properties are loaded into their appropriate header files (common blocks). User-written subroutine USRFAB is then called for each integration point—to redefine zero or more of these properties, as and if it is necessary to do so.

The user's USRFAB subroutine must not change the number of layers in the fabrication; but it can modify most of the other fabrication properties (thicknesses, orientation angles, *etc.*), as and if it is necessary to do so.

The user's USRFAB subroutine must not change the material type (ISOELASTIC, ORTHOELAST, PLASTIC_WB, *etc.*); but it can select and use a different material of the same type, if desired. On entry into subroutine USRFAB, all of the data for the original (nominal) material are defined in the appropriate header file(s) for that material (see the header-file listings following the USRFAB Structure table). If any or all of these data are modified for any given layer(s), USRFAB must call **STAGS**' subroutine MATSET (to identify the layer(s) that have changed) before returning to the calling program. For a layered shell fabrication with a material that varies from layer to layer, USRFAB must specify changes (from the nominal material properties) for one or more layers, then call MATSET to identify the modified layer(s). This process must be repeated until all modified layers have been changed and identified. Each call to MATSET generates a material data entry that will be used in various routines to load material data needed for computations.

The FORTRAN code shown in the “USRFAB Template” listing is available in the **$STAGSHOME**/ examples/usersub directory. The user must replace the boldfaced “**`write...`**,” “**`format...`**” and “**`STOP`**” lines, on page 12-44, with coding that is appropriate for his or her problem. The header files referenced in the boldfaced include statements, on page 12-44, are shown after this “USRFAB Template” listing. The calling sequence for subroutine MATSET is documented immediately after these header file listings.

USRFAB Template

```
c=deck    usrfab
c=purpose Template for user-written subroutine USRFAB
c=version May, 2002

#include “keydefs.h”

#if   _usage_
*
*     Calling sequence:
*
*         call USRFAB ( t,      Pa,     Pb,     iunit,
*                       ielt,   kelt,   kfab,   eltip,
*                       XYZg,   XYs,    ntvals, tvals,
*                       nlayrs, lays,   laymat, laythk,
*                       layint, layang, zeta,   ecz,
*                       ilin,   iplas )
*
*     Input Arguments
*     ===============
*     t      = Time (seconds)
*     Pa     = Load factor for system A
*     Pb     = Load factor for system B
*     iunit  = Unit number; unit = 0 specifies the entire model
*     ielt   = Local element number within the specified unit; when
*                   unit = 0, elt specifies the global elt number
*     kelt   = 1 -- Unit is a shell unit
*            = 2 -- Unit is an element unit
*     kfab   = Fabrication number assigned for this element
*     eltip  = Surface (volume) integration point number in element
*     XYZg   = Global coordinates at integration point
*     XYs    = Shell X,Y coordinates at integration point
*     ntvals = Number of temperature sampling points
*     tvals  = Temperature gradient at sampling points
*     nlayrs = Number of layers in fabrication KFAB
*     lays   = Integer array for (optional) use in call to MATSET
*
*     Output Arguments
*     ================
*     laymat(j) = Material identifier for layer j
*     layint(j) = # of through-layer integration pts for layer j
*     laythk(j) = Thickness of layer j
*     layang(j) = Fabrication orientation angle of layer j
*     zeta      = Angle from wall-ref coord to fabrication coord
*     ecz       = Eccentricity in Z' dirn (Z' coord of mid surface)
```

USRFAB Template (continued)

```
*     ilin      = 0 -- Nonlinear strain-displacement relations
*               = 1 -- Linear strain-displacement relations
*     iplas     = 0 -- Elastic material properties used
*               = 1 -- Plasticity theory enforced at all integ pts
*               = 2 -- Plasticity theory enforced at elt centroid
*
#endif

*******************************************************************
         subroutine USRFAB ( t,      Pa,     Pb,     iunit,
     &                       ielt,   kelt,   kfab,   eltip,
     &                       XYZg,   XYs,    ntvals, tvals,
     &                       nlayrs, lays,   laymat, laythk,
     &                       layint, layang, zeta,   ecz,
     &                       ilin,   iplas )
*******************************************************************

      _implicit_none_

      Real     t
      Real     Pa
      Real     Pb
      Integer  iunit
      Integer  ielt
      Integer  kelt
      Integer  kfab
      Integer  eltip
      Real     XYZg(3)
      Real     XYs(2)
      Integer  nlayrs
      Integer  ntvals
      Real     tvals(ntvals)
      Integer  lays(nlayrs)
      Integer  laymat(nlayrs)
      Real     laythk(nlayrs)
      Integer  layint(nlayrs)
      Real     layang(nlayrs)
      Real     zeta
      Real     ecz
      Integer  ilin
      Integer  iplas
```

USRFAB Template (continued)

```
#include “mater1.h”
#include “mater2.h”
#include “mater3.h”
#include “mater4.h”
#include “mater7.h”
#include “mater8.h”
#include “mater9.h”
#include “mater10.h”

#include “stndcm.h”

      Logical  debug
      Logical  NTITLE

*     ====================
*     MATERIAL TYPE CODES:
*     ====================
*
*     Code   Items   Description
*     ----   -----   -----------
*       1       7    Linear elastic isotropic material
*       2      18    Linear elastic orthotropic material
*       3      54    Mechanical sub-layer plasticity material
*       4      44    Linear elastic orthotropic brittle material
*       5      12    Shape-memory-alloy material
*       6      54    Plane-strain material
*       7      36    PDCOMP/PDLAM property material
*       8      32    Abaqus umat material
*       9      19    SHM membrane material
*      10      10    Hahn nonlinear elastic orthotropic material

      debug = .false.
      if (NTITLE('X_UsrFab')) debug = .true.

      write (not,1000)
1000  format (//'ERROR: Subroutine USRFAB has not been provided.' )

      STOP

      end
```

mater1.h Header File

```
*     **************************************************************
*     mater1.h header file,
*     for Linear elastic isotropic material
*     **************************************************************

      Real            e_1, gnu_1, rho_1, alpha_1, beta_1, t_1, m_1
      common /mater1/ e_1, gnu_1, rho_1, alpha_1, beta_1, t_1, m_1
```

mater2.h Header File

```
*     **************************************************************
*     mater2.h header file,
*     for Linear elastic orthotropic material
*     **************************************************************
      Real            e1_2,  e2_2,  e3_2,  g12_2, g13_2, g23_2
      Real            p12_2, p13_2, p23_2, rho_2, a1_2,  a2_2, a3_2
      Real            b1_2,  b2_2,  b3_2,  T_2,   M_2
      common /mater2/ e1_2,  e2_2,  e3_2,  g12_2, g13_2, g23_2,
     &                p12_2, p13_2, p23_2, rho_2, a1_2,  a2_2, a3_2,
     &                b1_2,  b2_2,  b3_2,  T_2,   M_2
```

mater3.h Header File

```
*     **************************************************************
*     mater3.h header file,
*     for mechanical sublayer plasticity material
*     **************************************************************
      Real            e_3, gnu_3, rho_3, alpha_3
      Integer         nsubs
      Real            ee_ss_3
      common /mater3/ e_3, gnu_3, rho_3, alpha_3,
     &                nsubs,
     &                ee_ss_3(2,20)
```

mater4.h Header File

```
*     *************************************************************
*     mater4.h header file,
*     for linear orthotropic elastic brittle matl
*     *************************************************************

      Real            E1_4,    E2_4,    E3_4
      Real            G12_4,   G13_4,   G23_4
      Real            P12_4,   P13_4,   P23_4,    Rho_4
      Real            a1_4,    a2_4,    a3_4
      Real            b1_4,    b2_4,    b3_4,     T_4,     M_4
      Real            e1c_4,   e1t_4,   e2c_4,    e2t_4,   gam12f_4
      Real            e3c_4,   e3t_4,   gam23f_4, gam13f_4
      Real            Xc_4,    Xt_4,    Yc_4,     Yt_4,    Sxy_4
      Real            Zc_4,    Zt_4,    Syz_4,    Sxz_4
      Real            alpha_4, F12_4,   beta_4,   IFAIL_4, IDGRD_4
      Real            visf0_4, visf1_4, visff_4

      common /mater4/ E1_4,    E2_4,    E3_4,
     &                G12_4,   G13_4,   G23_4,
     &                P12_4,   P13_4,   P23_4,    Rho_4,
     &                a1_4,    a2_4,    a3_4,
     &                b1_4,    b2_4,    b3_4,     T_4,     M_4,
     &                e1c_4,   e1t_4,   e2c_4,    e2t_4,   gam12f_4,
     &                e3c_4,   e3t_4,   gam23f_4, gam13f_4,
     &                Xc_4,    Xt_4,    Yc_4,     Yt_4,    Sxy_4,
     &                Zc_4,    Zt_4,    Syz_4,    Sxz_4,
     &                alpha_4, F12_4,   beta_4,   IFAIL_4, IDGRD_4,
     &                visf0_4, visf1_4, visff_4
```

mater8.h Header File

```
*     *************************************************************
*     mater8.h header file, for Abaqus UMAT material
*     *************************************************************
      Real            E1_8,     E2_8,     P12_8,    G12_8
      Real            XT_8,     YC_8,     XC_8,     ALPHA_8
      Real            NLAY_8,   LSF_8,    NOTOEL_8, MONINODE_8
      Real            FIVISC_8, DTIME_8,  DFMIN_8,  DPHIO_8
      Real            DELTA_8,  BETA_8_8, ETA_8_8,  BETAC_8
      Real            IORX_8,   SDPARA_8, VRUINC_8, VISFAC_8
      Real            NIFVE_8,  DAFF_8,   IDAMP_8,  ZR1_8
      Real            ZR2_8,    G23_8_8,  G13_8_8,  RHO_8
      common /mater8/ E1_8,     E2_8,     P12_8,    G12_8,
     &                XT_8,     YC_8,     XC_8,     ALPHA_8,
     &                NLAY_8,   LSF_8,    NOTOEL_8, MONINODE_8,
     &                FIVISC_8, DTIME_8,  DFMIN_8,  DPHIO_8,
     &                DELTA_8,  BETA_8_8, ETA_8_8,  BETAC_8,
     &                IORX_8,   SDPARA_8, VRUINC_8, VISFAC_8,
     &                NIFVE_8,  DAFF_8,   IDAMP_8,  ZR1_8,
     &                ZR2_8,    G23_8_8,  G13_8_8,  RHO_8
```

USRFAB must call **STAGS**' subroutine MATSET if any material properties are changed. The three arguments in the calling sequence for MATSET are documented in the following listing. Note: MATSET is a **STAGS** routine that the user should not modify under any conditions.

```
c=deck    matset
c=purpose STAGS subroutine that is called from user-written USRFAB
c=purpose to set modified material data for a group of layers at a
c=purpose single surface integration point of a given element
c=version May 2002

#if   _usage_
*
*     calling sequence: call MATSET ( imatl, nlayrs, lays )
*
*     Input Arguments:
*     ================
*     imatl  =  Material type (see USRFAB and mater1.h --> mater8.h)
*     nlayrs =  Number of layers to use modified material data
*     lays   =  List of nlayrs layer numbers to be reset
*
#endif _usage_
```

The following example shows the "business" part of a typical user-written USRFAB subroutine (*i.e.*, the coding that replaces the three boldfaced lines at the bottom of the USRFAB template that is shown on page 12-44):

```
      Integer i
      Integer mattyp
      Real    e1_s1 (2,3)

      data (e1_s1(1,i),i=1,3) / 0.014,
     &                          0.029,
     &                          0.060 /
      data (e1_s1(2,i),i=1,3) / 3628.39988,
     &                          6200.0,
     &                          8600.0 /

      if ( iunit.eq.7 )  then
         if ( (ielt.ge.37 .and. ielt.le.40)    .or.
     &        (ielt.ge.46 .and. ielt.le.49) )  then

            zeta  = 0.0
            ecz   = 0.0
            ilin  = 0
            iplas = 1

c           Set material data for this element integration point
c           for material type "PLASTIC_WB" (see "mater3.h"); all
c           other data remain unchanged from the original input.

            mattyp = 3

            do 10 i = 1, 3
               ee_ss_3(1,i) = e1_s1(1,i)
               ee_ss_3(2,i) = e1_s1(2,i)
10          continue

            call MATSET ( mattyp,1,1 )

            write (not,100) iunit,  ielt,  eltip,  kfab,
     &                      mattyp, ee_ss_3(1,3)

         endif
      endif

100   format ( ' USRFAB: iunit, ielt, eltip, kfab, mattyp, e36=',
     &           5i8, f14.8 )
```

Note that this coding specifies new properties for 8 elements in unit 7 of the user's model—calling MATSET because material properties for those 8 elements are changed.

USRFPF Failure Model

Subroutine USRFPF allows the **STAGS** user to implement his or her own first–ply failure model or to modify one of the existing failure models (which are implemented in the current version of **STAGS** in FPFi.F subroutines). The existing material degradation models (which are implemented in **STAGS** in DGRADi.F routines) can be utilized with the user's USRFPF subroutine if they fit the user's model. It will be necessary for the user to write his or her own USRDGD subroutine to implement a new material degradation model if the existing degradation models do not fit the new model.

Subroutine USRFPF is called [by **STAGS**' Generic Constitutive Processor (GCP) facility] for each element that is fabricated with an orthotropic elastic brittle GCP material for which **IFAIL** = 99 on the I-10a (ORT_EL_BR_MATERIAL) record that defines that material.

As a template for adventuresome **STAGS** users, a failure model using the maximum strain criteria has been implemented in the USRFPF subroutine that is distributed with the program (and which is listed below for the reader's convenience). The calling arguments to USRFPF are documented in this listing and will not be further described here.

USRFPF Template

```
c=deck    usrfpf
c=purpose Evaluate User-Written Failure Criterion
c=author  Norm Knight/Veridian
c=version January 2000

#include "keydefs.h"

*  *******************************************************************
*  *  This routine is a template to guide the user in implementing a   *
*  *  failure model in STAGS using the ORT_EL_BR_MATERIAL GCP material *
*  *  model -- where the failure selection flag IFAIL is set to 99     *
*  *******************************************************************

#if   _usage_
*     ----------------------------------------------------------------
*     CALLING SEQUENCE:
*
*     call USRFPF ( iCMtyp, mpd, strain, stress, flag )
*
*     INPUT ARGUMENT TYPE DESCRIPTION
*     ============== ==== ===========
*     iCMtyp         [I]  Kinematic option for material processing
*     mpd(*)         [R]  Material property data
*     strain(*)      [R]  Mechanical strain vector
*     stress(*)      [R]  Stress vector
*
*     OUTPUT ARGUMENTS
*     ================
*     flag(*)        [I]  Failure flags
*     --------------------------------------------------------------
#endif

      subroutine USRFPF ( iCMtyp, mpd, strain, stress, flag )

      _implicit_none_

      integer iCMtyp
      real    mpd(*)
      _float_ strain(*)
      _float_ stress(*)
      integer flag(*)

*     These are the user-parameters available to these routines
*     (read in through the L-records)

      integer      userint
      common /upi/ userint(200)

      real         userflo
      common /upf/ userflo(200)

#include "con5.h"
#include "cs4xxx.h"
#include "pain3.h"
#include "stndcm.h"

*     --------------------------------------------------------------
*     I N T E R N A L   D E C L A R A T I O N S
*     --------------------------------------------------------------

      real      eps1C
      real      eps1T
      real      eps2C
      real      eps2T
      real      eps6
      real      eps6F
      real      index(6)
      character mode*28
      logical   NTITLE
      integer   numcol

*     --------------------------------------------------------------
*     L O G I C
*     --------------------------------------------------------------
*
*     Perform Failure Analysis using the Maximum Strain Criteria

      if ( iCMtyp.eq.1 ) then

*        1D CONTINUUM (ROD OR BAR ELEMENT)
*        =================================
         numcol = 1

      elseif ( iCMtyp.eq.2 ) then

*        C0/C1 BEAM
*        ==========
         numcol = 3

      elseif ( iCMtyp.eq.3 ) then

*        C0 SHELL
*        ========
         numcol = 5

      elseif ( iCMtyp.eq.4 ) then

*        C1 SHELL (PLANE STRESS)
*        ======================
         numcol = 3

*        Read strength data for ply
*        -------------------------
         eps1C = mpd(19)
         eps1T = mpd(20)
         eps2C = mpd(21)
         eps2T = mpd(22)
         eps6F = mpd(23)

         if ( NTITLE('X_Usrfpf') )  then
            write (not,910)  idelt, eltip, layer, layip, (flag(i),i=1,3)
            write (not,920)  strain(1), strain(2), strain(3)
         endif

*        Compute failure indices:

         if ( flag(1).eq.0 ) then

*           Fiber tension failure:
*           ----------------------

            if ( NTITLE('X_Usrfpf') )  then
               write (not,930)  strain(1), flag(1), index(1), eps1T
            endif

            if (strain(1) .ge. 0.) then

               index(1) = strain(1)/eps1T

               if (index(1).ge.+1.0) then
                  flag(1) = + istep
                  mode    = ‘FIBER TENSILE FAILURE:      ‘
                  if (nsp3.gt.0) write(not,900)
     &            mode, idelt,eltip,layer,layip
               else
                  flag(1) = 0
               endif

            endif

*           Fiber compression failure
*           ------------------------
            if (strain(1) .lt. 0.) then

               index(1) = strain(1)/eps1C
               if (index(1).le.-1.0) then
                  flag(1) = - istep
                  mode    = ‘FIBER COMPRESSIVE FAILURE:  ‘
                  if (nsp3.gt.0) write(not,900)
     &            mode, idelt,eltip,layer,layip
               else
                  flag(1) = 0
               endif

            endif

         endif

         if (flag(2).eq.0) then

            if ( NTITLE('X_Usrfpf') )  then
               write (not,940)  strain(2), flag(2), index(2), eps2T
            endif

            if (strain(2) .ge. 0.) then

*              Matrix tension failure:
```

```
*              -----------------------
               index(2) = strain(2)/eps2T
               if (index(2).ge.+1.0) then
                  flag(2) = + istep
                  mode    = ‘MATRIX TENSILE FAILURE:     `
                  if (nsp3.gt.0) write(not,900)
     &            mode, idelt,eltip,layer,layip
               else
                  flag(2) = 0
               endif

            endif

            if (strain(2) .lt. 0.) then

*              Matrix compression failure:
*              ---------------------------
               index(2) = strain(2)/eps2C
               if (index(2).le.-1.0) then
                  flag(2) = - istep
                  mode    = ‘MATRIX COMPRESSIVE FAILURE: `
                  if (nsp3.gt.0) write(not,900)
     &            mode, idelt,eltip,layer,layip
               else
                  flag(2) = 0
               endif

            endif

         endif

         if (flag(3).eq.0) then

*           Fiber/matrix shear failure:
*           ---------------------------

            if ( NTITLE('X_Usrfpf') )  then
               write (not,950)  strain(3), flag(3), index(3), eps6F
            endif

            eps6     = ABS(strain(3))
            index(3) = eps6/eps6F

            if (index(3).ge.+1.0) then
               flag(3) = + istep
               mode    = ‘INPLANE SHEAR FAILURE:     `
               if (nsp3.gt.0) write(not,900)
     &         mode, idelt,eltip,layer,layip
            else
               flag(3) = 0
            endif

         endif

         if ( NTITLE('X_Usrfpf') )  then
            write (not,960)  idelt, eltip, layer, layip, (flag(i),i=1,3)
         endif

      elseif ( iCMtyp.eq.5 ) then

*        2D PLANE STRAIN CONTINUUM
*        =========================
         numcol = 3

      elseif ( iCMtyp.eq.6 ) then

*        2D AXISYMMETRIC CONTINUUM
*        =========================
         numcol = 4
      elseif ( iCMtyp.eq.7 ) then

*        3D CONTINUUM
*        ============
         numcol = 6

      endif

900   format( a28,
     &        '  ELDid=',i5,
     &        '; ELTip=',i1,
     &        '; Layer=',i3,
     &        '; LayIP=',i1 )
910   format ('  ELDid=',i5,
     &        '; ELTip=',i1,
     &        '; Layer=',i3,
     &        '; LayIP=',i1,
     &        '; BEGIN FAIL FLAGS=',3i2 )
920   format ('  Input strain vector:',2x,e13.6,3x,e13.6,3x,e13.6 )
930   format ('  DEBUG1 ***',5x,e13.6,i2,3x,e13.6,3x,e13.6 )
940   format ('  DEBUG2 ***',5x,e13.6,i2,3x,e13.6,3x,e13.6 )
950   format ('  DEBUG3 ***',5x,e13.6,i2,3x,e13.6,3x,e13.6 )
960   format ('  ELDid=',i5,
     &        '; ELTip=',i1,
     &        '; Layer=',i3,
     &        '; LayIP=',i1,
     &        '; FINAL FAIL FLAGS=',3i4 )

      end
```

The user may include data in addition to that which is transmitted to and from subroutine USRFPF through its calling sequence *via* **STAGS**' user parameter input facility—using L-2a and/or L-2b records as required (for integers and real variables, respectively). This may be accomplished by including the *upfi.h* header file or (as is done here) by including the following explicit declarations and common statements:

```
       integer userint
       common / upi / userint(200)
```

and

```
       real userflo
       common / upf / userflo(200)
```

The *cs4xxx.h* header file that is included in this version of USRFPF contains four integer variables that are used to identify which material point is being examined:

idelt Element number within a unit

eltip Element surface integration point number

layer Layer number within the laminate

layip Through-the-thickness integration point within a layer

On entry into the USRFPF routine, a check is made to identify the kinematics option for the element by testing the value of the parameter **iCMtyp**. For C^1 shell elements, **iCMtyp** equals 3, and there are three stress values (σ_{xx}, σ_{yy}, τ_{xy}). Similarly there are three strain values. Next the strain allowable values are loaded into local variables from the **mpd**(*) array (these are always the original input values).

The next step is to test to determine if failure in the fiber (or 1 direction) has occurred previously (if **flag**(1) is not zero) or that no failure has yet occurred (**flag**(1) equals zero). If **flag**(1) is not zero, then no further check is made for that mode and the process moves to **flag**(2) and **flag**(3) in a similar manner. If **flag**(1) equals zero, then the strain state is examined for failure (using the maximum strain criterion in this template). Tests are made for tension and compression independently. If failure is detected, then the alphanumeric variable **mode** is set to a 28–character string (users may change this value) that describes the failure mode for output purposes. If failure is detected, then **flag**(1) is set to a positive value for tensile failure or to a negative value for compressive failure. Shear failures are always set equal to a positive value. Typically, the magnitude of this value is the solution step number **istep** at which the failure was first detected.

Subroutine USRFPF is called for each layer integration point through the thickness of each layer in the laminate for each surface integration point of the element and for each element. It is a very low-level routine that is called *many, many* times; and if the user should choose to print output within this routine, he or she should expect a *lot!* Limited output control is provided through the integer parameter **nsp3** (which is the same as the **ILIST** parameter on the B-1 record of the ***s2*** input data. Setting that variable to a positive nonzero number will cause USRFPF (as well as other FPF* models) to print the failure mode and location.

Because USRFPF is a low-level routine, it is called during the evaluation of both the first and second variations during a nonlinear iteration. Hence multiple passes through this routine for each iteration may occur as a consistent state for the first and second variation is always sought.

USRLD General Loading

Subroutine USRLD is called once for each unit where **IFLG** = 1 on the associated Q-2 (shell unit) or U-2 (element unit) record. USRLD may define all of the loads in a given unit, or it may be used to complement loads defined on Q-3 (shell unit) or U-3 (element unit) records.

USRLD Structure

```
      subroutine USRLD (iunit, X, Y, nrows, ncols, isys)

      INTEGER
     :   iunit,         nrows,         ncols,         isys,
     :   lt,            ld,            li,            lj,
     :   lax
      REAL
     :   X(nrows),      Y(ncols),      P

***** Repeat for each load.      *****

      call FORCE ( P, lt, ld, li, lj, lax )

      return
      end
```

USRLD Data

Input

A	`iunit` `isys`	unit number Shell unit: **ISYS**, Q-2 (p. 6-70) Element unit: **ISYS**, U-2 (p. 10-4)

B	`nrows`
	`ncols`
	`X(nrows)`
	`Y(ncols)`
		NROWS(i), i=`iunit` F-1
		NCOLS(i), i=`iunit` F-1
		X surface coordinate along each row
		Y surface coordinate along each column

- ✔ **A** data are always relevant.
- ✔ **B** data are relevant for shell units only.

Output

`P`	`lt`	`ld`	Shell unit: Q-3 (p. 6-70)
`li`	`lj`	`lax`	Element unit: U-3 (p. 10-5)

$STAGSHOME/examples/usersub/usrld.F contains the code shown in “USRLD Structure”. See Section 12.3 “Example Problem” on page 12-66 for a practical example of USRLD.

USRPT Nodes

Subroutine USRPT is called once for each element unit where **IUWP** = 1 on the associated H-1 record. USRPT may define all of the nodes in a given element unit, or it may be used to complement nodes defined on S-1 records. Whether nodes are defined in USRPT or on S-1 records or in combination, they may be defined in any order, but when completely defined must be numbered continuously starting with 1. Thus, node numbering within each element unit is from 1 to $\mathbf{n_S} + \mathbf{n_U}$, where $\mathbf{n_S}$ is the number of nodes defined on corresponding S-1 records, and $\mathbf{n_U}$ is the number of nodes defined in USRPT for the corresponding element unit.

USRPT Structure

```
      subroutine USRPT (iunit)

      COMMON
     : / NEWSY /   xax,      xay,      xaz,
     :             yax,      yay,      yaz,
     :             zax,      zay,      zaz
      INTEGER
     :   iunit,         iupt,
     :   ius,           irs,            ics,
     :   iuvw,          iruvw,          iaux
      REAL
     :   xax,           xay,            xaz,
     :   yax,           yay,            yaz,
     :   zax,           zay,            zaz,
     :   xg,            yg,             zg,
     :   gm

*****       Repeat for each node.       *****

            call NODE (iupt,  ius,   irs,   ics,
     :                 xg,    yg,    zg,
     :                 iuvw,  iruvw, iaux,  gm )


      return
      end
```

USRPT Data

Input

iunit	unit number

Output

A	iupt ius irs ics xg yg zg iuvw iruvw iaux	S-1 (p. 7-3)
B	gm	U-4 (p. 10-7)
C	COMMON/NEWSY/ xax xay xaz yax yay yaz	S-2 (p. 7-8)

- ✔ **A, B** data are always defined.
- ✔ **C** data are relevant only when iaux = 1.
  Note that zax, zay, zaz are not set in USRPT; they are computed by **STAGS** (see S-2).

$STAGSHOME/examples/usersub/usrpt.F contains the code shown in “USRPT Structure”. See Section 12.3 “Example Problem” on page 12-66 for a practical example of USRPT.

WALL Shell Wall Fabrication Properties

User-written subroutine WALL is called at each integration point on the reference surface of each shell element where **IWALL** = 0 (M-5, T-3a, T-4a, USRELT). (For type **E480** elements, subroutine WALL is called only once, at the element centroid.)

Subroutine WALL enables the user to define both geometric and material cross section properties as a function of position on the shell reference surface. This is effected by reference to the Wall Fabrication Table and/or by definition of data directly. As an example, the basic wall fabrication properties can be defined with a Wall Fabrication Table ID, and eccentricity can then be defined directly as a function of the position of each integration point on the shell reference surface.

Shell Units

Shell elements are numbered *locally* within each shell unit, from 1 to **NROWS** × **NCOLS** (F-1), in row-major order.

Subroutine WALL is called for each shell element in each shell unit having **IWALL** = 0 (M-5).

Element Units

Elements are numbered sequentially as they are defined in each element unit, from 1 to $\mathbf{n_T} + \mathbf{n_U}$, where $\mathbf{n_T}$ is the number of elements defined on T records and $\mathbf{n_U}$ is the number of elements defined in USRELT. This establishes *local* element numbering within each element unit. Subroutine WALL is called for each element-unit shell element for which **IWALL** = 0 (defined on a T-3, T-320, T-330, T-4, T-410, T-411 or T-480 record, or in USRELT).

The FORTRAN code shown in the following “WALL Template” listing is available in the **$STAGSHOME**/examples/usersub directory. The user must replace the lines that are printed in boldface type, on page 12-62, with coding that is appropriate for his or her problem.

WALL Template

```
c=deck    wall
c=purpose User-written WALL subroutine
c=version April 2002

#include “keydefs.h”

#if   _usage_
*
*     calling sequence: call WALL ( iunit, ielt, kelt, XYZg, XYs,
*                                   zeta,  ecz,  ilin, iplas )
*
*     Input Arguments:
*     ================
*     iunit = unit number
*     ielt  = local element number (in unit iunit)
*     kelt  = element type code
*     XYZg  = {x,y,z} global coordinates
*     XYs   = {s,t} surface coordinates (shell unit, only)
*
*     Output Arguments:
*     =================
*     zeta  = zeta (see M-5 or T-3 for details)
*     ecz   = eccentricity (see M-5 or T-3 for details)
*     ilin  = nonlinearity flag
*     iplas = plasticity flag
*
#endif

*******************************************************************
            subroutine WALL ( iunit, ielt, kelt, XYZg, XYs,
     &                        zeta,  ecz,  ilin, iplas )
*******************************************************************

      _implicit_none_

      Integer    iunit
      Integer    ielt
      Integer    kelt
      Integer    ilin
      Integer    iplas
      Real       XYZg(3)
      Real       XYs(2)
      Real       zeta
      Real       ecz

      Integer         maxLAY
      PARAMETER     ( maxLAY = 100 )
```

WALL Template (continued)

```
       Integer          maxSM
       PARAMETER      ( maxSM  = 3 )

       Integer          nit,  not
       common /nitnot/ nit,  not

       Integer          itaw, kwall, nlay, nlip, nsmrs
       common /WALLX / itaw, kwall, nlay, nlip, nsmrs

       Integer          matL (maxLAY)
       Real             tL   (maxLAY)
       Real             zetL (maxLAY)
       Integer          lsoL (maxLAY)
       Real             e1L  (maxLAY)
       Real             u12L (maxLAY)
       Real             gL   (maxLAY)
       Real             rhoL (maxLAY)
       Real             a1L  (maxLAY)
       Real             e2L  (maxLAY)
       Real             a2L  (maxLAY)
       common /WALL1 / matL, tL,   zetL, lsoL, e1L, u12L,
      &                 gL,   rhoL, a1L,  e2L,  a2L

       Integer          matF, matM
       Real             ttL   (maxLAY)
       Real             xxL   (maxLAY)
       Real             zetwL (maxLAY)
       Real             oL    (maxLAY)
       Real             eF,   uF,   rhoF,  alF
       Real             eM,   uM,   rhoM,  alM
       common /WALL2 / matF, matM,
      &                 ttL,  xxL,  zetwL, oL,
      &                 eF,   uF,   rhoF,  alF,
      &                 eM,   uM,   rhoM,  alM

       Integer          matC, matS
       Real             ct,   cc,   ch,   cd,   cb
       Real             ts,   phi,  anc
       Real             eC,   uC,   rhoC, alC
       Real             eS,   uS,   rhoS, alS
       common /WALL3 / matC, matS,
      &                 ct,   cc,   ch,   cd,   cb,
      &                 ts,   phi,  anc,
      &                 eC,   uC,   rhoC, alC,
      &                 eS,   uS,   rhoS, alS
```

WALL Template (continued)

```
      Integer         ta,   mat,  itvs, idumt
      Real            ccc,        cts
      common /WALL4 / ta,   mat,  itvs, idumt,
     &                ccc(6,6),   cts(2,2)


      Integer         icroSM (maxSM)
      Real            spaSM  (maxSM)
      Real            zetSM  (maxSM)
      Real            xsiSM  (maxSM)
      Real            eczSM  (maxSM)
      common /SMEAR / icroSM, spaSM, zetSM, xsiSM, eczSM

      write (not,900)
  900 format (//' SUBROUTINE WALL HAS NOT BEEN PROVIDED.')

      STOP

      end
```

WALL Data

Input

`iunit`	unit number
`ielt`	unit *local* element number
`kelt`	shell element code; *e.g.*, 410
`XYZg(3)`	$(\mathbf{x_g}, \mathbf{y_g}, \mathbf{z_g})$ global coordinates
`XYs(2)`	$(\mathbf{X}, \mathbf{Y})$ surface coordinates; relevant for *shell units* only.

Output

A	`zeta` `ecz`
	`ilin` `iplas`
		Shell units:
		M-5 (p. 6-24)
		Element units:
		T-3 (p. 8-14) T-4 (p. 8-17)

B	`COMMON/WALLX/`
	`itaw` `kwall`
	`nlay` `nlip`
	`nsmrs`
		K-1 (p. 5-129)

C	`COMMON/WALL1/`
	`matL` `tL` `zetL`
	`lsoL`
	`e1L` `u12L` `gL`
	`rhoL` `a1L` `e2L`
	`a2L`
		K-2 (p. 5-133)
		
		Elastic material properties:
		for each layer `i`:
		define `matL(i)`
		if and only if `matL(i)` = 0
		define $E_1, \nu_{12}, G, \rho, \alpha_1, E_2, \alpha_2$
		for layer `i`

D	COMMON/WALL2/ matF matM ttL xxL zetwL oL eF uF rhoF alF eM uM rhoM alM	K-3a (p. 5-134) K-3b (p. 5-135) Fiber elastic material properties: when matF = 0, define E, ν, ρ, α Matrix elastic material properties: when matM = 0, define E, ν, ρ, α
E	COMMON/WALL3/ matC matS ct cc ch cd cb ts phi anc eC uC rhoC alC eS uS rhoS alS	K-4a (p. 5-136) K-4b (p. 5-137) Corrugation elastic material properties: when matC = 0, define E, ν, ρ, α Skin elastic material properties: when matS = 0, define E, ν, ρ, α

F	COMMON/WALL4/
	ta mat itvs
	ccc(6,6)
	cts(2,2)
		K-5a (p. 5-138)
		K-5b (p. 5-139)
		K-5c (p. 5-140)

G	COMMON/SMEAR/ icroSM spaSM zetSM xsiSM eczSM	K-6 (p. 5-141)

✔ **A** data are always defined.

Restrictions on variation of wall properties

ilin, iplas (**A** data) and kwall, nlip (**B** data) must be constant within each element.

When plasticity is included ($\texttt{iplas} \geq 1$), all data must be constant within each element.

If either of the two above restrictions is violated by WALL (called at each integration point), **STAGS** will resolve the discrepancies by resetting conflicting data to the values given for integration point 1.

Material properties

Linear elastic material properties may be defined in **C**, **D**, and **E** data. However nonlinear material properties may be defined indirectly only, by reference to a Wall Fabrication Table entry (see "Wall fabrication table selection" on page 12-65).

Wall fabrication table selection

Set $\texttt{itaw} > 0$. The remaining **B** data are irrelevant.

Layered wall

Set $\texttt{itaw} = 0$ and $\texttt{kwall} = 1$. Define **B**, **C** data.

Fiber reinforced wall

Set $\texttt{itaw} = 0$ and $\texttt{kwall} = 2$. Define **B**, **D** data.

Corrugation stiffened wall

Set $\texttt{itaw} = 0$ and $\texttt{kwall} = 3$. Define **B**, **E** data.

General wall

Set $\texttt{itaw} = 0$ and $\texttt{kwall} = 4$. Define **B**, **F** data.

Smeared stiffeners

When $\texttt{itaw} = 0$ only: set $\texttt{nsmrs} > 0$ and define **G** data.

Material behavior is restricted to linear elasticity in walls containing smeared stiffeners.

12.3 Example Problem

Figure 12.1 contains a sketch of the example problem used to illustrate the user-written subroutine concept. The structure is a quarter cylinder, bounded circumferentially by $\theta = 0°$ and $\theta = 90°$, and axially by $\mathbf{x_g} = 0$ and $\mathbf{x_g} = \mathbf{L}$. The reference surface is defined by the expressions $\mathbf{y_g} = \mathbf{R}\sin\theta$, $\mathbf{z_g} = \mathbf{R}\cos\theta$. The transformation between $(\mathbf{x_g}, \mathbf{y_g}, \mathbf{z_g})$ global coordinates and $(\mathbf{x_a}, \mathbf{y_a}, \mathbf{z_a})$ nodal-auxiliary coordinates is indicated. Boundary conditions and loads are defined in the nodal-auxiliary coordinate system. The nodal load *P* is shown acting in the positive *u* direction, and the normal pressure *q* is shown acting in the positive *w* direction. Negative values for *P*, *q* will result in loading acting in the negative *u*, *w* directions, respectively. Note that on the $\mathbf{x_g} = 0$ boundary, in addition to the symmetry boundary condition, the constraint $\mathbf{u} = \mathbf{c}$, where *c* is a constant, is prescribed. The effect of requiring uniform axial displacement along the $\mathbf{x_g} = 0$ boundary is that the discrete nodal load *P* acts like a line load $\mathbf{p} = \mathbf{P}/(\pi\mathbf{R}/2)$ on that edge.

Just as the loading is parameterized by *P* and *q*, the geometry is parameterized by the radius, *R*, and the length, *L*. Two additional parameters, *nrows* and *ncols*, the number of rows and columns, control discretization. A 9×9 mesh is shown in Figure 12.1.

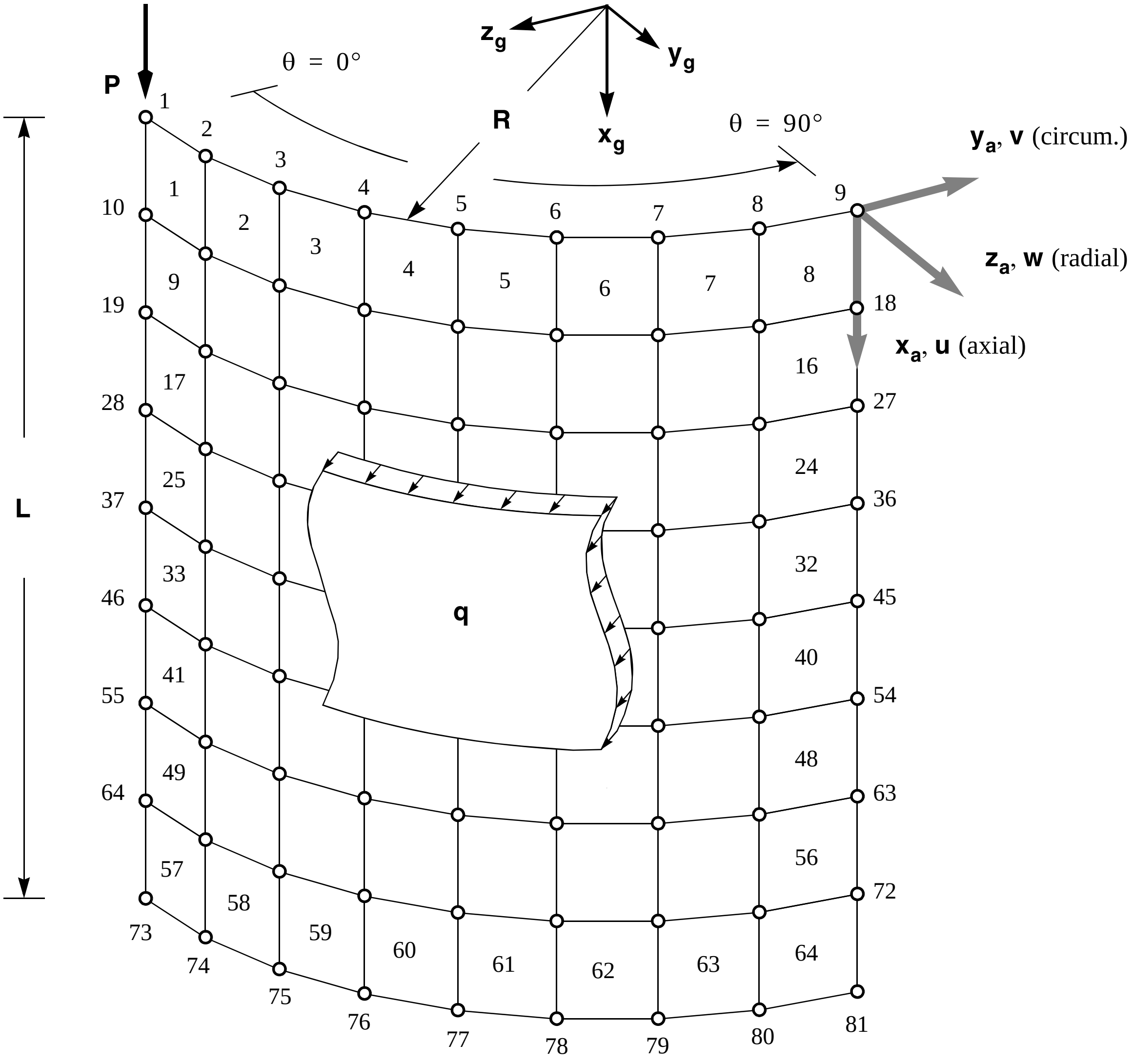
The four user-written subroutines employed to model this quarter cylinder are:

USRPT	defines nodal locations, boundary conditions, and nodal-auxiliary coordinate systems
USRELT	defines quadrilateral shell elements
USRLD	defines the loading, *P* and *q*
UCONST	defines the $\mathbf{u} = \mathbf{c}$ constraint on the $\mathbf{x_g} = 0$ boundary

This model could be further parameterized by replacing *L* with $\mathbf{x_g^1}$ and $\mathbf{x_g^2}$, thereby permitting a cylinder of axial length $\mathbf{x_g^1} \le \mathbf{x_g} \le \mathbf{x_g^2}$. Adding two additional parameters, θ^1 and θ^2, would allow a cylinder of arclength $\theta^1 \le \theta \le \theta^2$. Minor modifications to USRPT are all that would be necessary. Similarly, the element type could be added as a parameter, requiring only minor modifications to USRELT. The wall fabrication could be parameterized in a user-written subroutine WALL, and so forth.

The *INP* and *BIN* input files are shown next, followed by listings of the FORTRAN code for the user-written subroutines.

☞ The input files, along with files containing source code for the user-written subroutines, are found in **$STAGSHOME**/examples/cylinder.



$$0 \le \mathbf{x_g} \le \mathbf{L} \qquad 0 \le \theta \le 90° \qquad \mathbf{y_g} = \mathbf{R}\sin\theta \qquad \mathbf{z_g} = \mathbf{R}\cos\theta$$

boundary conditions: $\mathbf{x_g} = 0$: **simple support** & $\mathbf{u}$ = *constant*

$\mathbf{x_g} = \mathbf{L}$: **clamped**

$\theta = 0°, 90°$: **symmetry**

$$\left\{\begin{matrix} \mathbf{x_a} \\ \mathbf{y_a} \\ \mathbf{z_a} \end{matrix}\right\} = \begin{bmatrix} 1 & 0 & 0 \\ 0 & \cos\theta & -\sin\theta \\ 0 & \sin\theta & \cos\theta \end{bmatrix} \left\{\begin{matrix} \mathbf{x_g} \\ \mathbf{y_g} \\ \mathbf{z_g} \end{matrix}\right\}$$

Figure 12.1 User-written subroutines—cylindrical shell example problem.

cylinder.inp

```
Quarter Cylinder, User-Written Subroutines   $ A-1
    0                                        $ B-1
    0    1    0    0    0    8               $ B-2     UCONST
    1    0    1    1                         $ B-3
    0    0    0    0    0    0    1    1     $ H-1     USRPT     USRELT
    1                                        $ I-1
  10.0E6     0.3                             $ I-2
    1    1    1                              $ K-1
    1   0.1  0.0    1                        $ K-2
    2   4                                    $ L-1
$ ------------------------------------------ $
$      rows      cols                        $
$      ----      ----                        $
         9         9                         $ L-2A    discretization
$ ------------------------------------------ $
$        R         L         P         q     $
$       ---       ---       ---       ---    $
        6.4      10.0      1.5E5    -100.0   $ L-2B    geometry, loads
$ ------------------------------------------ $
    1                                        $ U-1
    1    0    1                              $ U-2     USRLD
    1                                        $ V-1
```

cylinder.bin

```
Quarter Cylinder, User-Written Subroutines   $ A-1
    0    1                                   $ B-1
   1.0                                       $ C-1
```

USRPT

```
      subroutine USRPT (iunit)

      COMMON
     : / UPI   /   nrows,  ncols,  UserInt(198)
     : / UPF   /   R,      L,      P,      q,      UserFlo(196)
     : / NEWSY /   xax,    xay,    xaz,
     :             yax,    yay,    yaz
      INTEGER
     :   iunit,         nrows,         ncols,         UserInt,
     :   iupt,          ius,           irs,           ics,
     :   iuvw,          iruvw,         iaux,
     :   i,             j
      REAL
     :   R,             L,             P,             q,
     :   xax,           xay,           xaz,           UserFlo,
     :   yax,           yay,           yaz,
     :   xg,            yg,            zg,            gm,
     :   delX,          delY,          pi,
     :   theta,         Ct,            St

      iupt = 0
      ius  = 0
      irs  = 0
      ics  = 0
      iaux = 1
      gm   = 0

      xax  = 1
      xay  = 0
      xaz  = 0
      yax  = 0

      pi   = 4 * ATAN(1.)
      delX = L/(nrows-1)
      delY = (pi/2)/(ncols-1)

      do 20 j = 1,nrows
         xg = (j-1)*delX
         do 10 i = 1,ncols
            theta = (i-1)*delY
            Ct    = COS(theta)
            St    = SIN(theta)
            yg    = R*St
            zg    = R*Ct
            yay   =   Ct
            yaz   =  -St




            if (j .eq. 1) then
               if ((i .eq. 1) .or. (i .eq. ncols)) then
                  iuvw  = 100
                  iruvw = 010
               else
                  iuvw  = 100
                  iruvw = 011
               endif
            elseif (j .eq. nrows) then
               iuvw  = 000
               iruvw = 000
            elseif ((i .eq. 1) .or. (i .eq. ncols)) then
               iuvw  = 101
               iruvw = 010
            else
               iuvw  = 111
               iruvw = 111
            endif
            iupt  = iupt + 1
            call NODE (iupt, ius,  irs,  ics,
     :                 xg,   yg,   zg,
     :                 iuvw, iruvw,iaux, gm )
   10    continue
   20 continue

      return
      end
```

USRELT

```
       subroutine USRELT (iunit)

      COMMON
     : / UPI   /   nrows,  ncols,  UserInt(198)
      INTEGER
     :   maxN
      PARAMETER
     : ( maxN = 9 )
      INTEGER
     :   iunit,         nrows,         ncols,         UserInt,
     :   node(maxN),    kelt,          iwall,
     :   ilin,          iplas,         integ,         ipenl,
     :   iang,          n0,            i,             j
      REAL
     :   zeta,          ecz,
     :   rx,            ry,            rz

      kelt  = 410
      iwall = 1
      zeta  = 0
      ecz   = 0
      ilin  = 0
      iplas = 0
      integ = 0
      ipenl = 0
      iang  = 0

      do 20 j = 1,nrows-1
         n0 = (j-1)*ncols
         do 10 i = 1,ncols-1
            node(1) = n0      + i
            node(2) = node(1) + ncols
            node(3) = node(2) + 1
            node(4) = node(1) + 1
            call SHELL (node, kelt,  iwall, zeta, ecz,
     :                  ilin, iplas, integ, ipenl,
     :                  iang, rx,    ry,    rz)
   10    continue
   20 continue

      return
      end
```

USRLD

```
      subroutine USRLD (iunit, X, Y, nrows, ncols, isys)

      COMMON
     : / UPF   /   R,       L,       P,       q,       UserFlo(196)
      INTEGER
     :   iunit,         nrows,         ncols,         isys,
     :   lt,            ld,            li,            lj,
     :   lax
      REAL
     :   X(nrows),      Y(ncols),      UserFlo,
     :   R,             L,             P,             q

      lt  = 1
      ld  = 1
      li  = 1
      lj  = 0
      lax = 0

      call FORCE (P, lt, ld, li, lj, lax)

      lt  = 4
      ld  = 3
      li  = 0

      call FORCE (q, lt, ld, li, lj, lax)

      return
      end
```

UCONST

```
      subroutine UCONST

      INTEGER      maxN
      PARAMETER ( maxN = 2 )

      INTEGER iu(maxN)
      INTEGER ix(maxN), iy(maxN), iz(maxN)
      INTEGER id(maxN)
      REAL    cc(maxN)

      INTEGER        nrows, ncols, UserInt
      COMMON / UPI / nrows, ncols, UserInt(198)

      INTEGER i
      INTEGER nterms

      nterms = 2

      iu(1) = 1
      iu(2) = 1

      ix(1) = 1

      iy(1) = 0
      iy(2) = 0

      iz(1) = 1
      iz(2) = 1

      id(1) = 1
      id(2) = 1

      cc(1) =  1.0E7
      cc(2) = -1.0E7

      do 10 i = 2,ncols
         ix(2) = i
         call CONSTR ( nterms, iu, ix, iy, iz, id, cc )
   10 continue

      return
      end
```

13
User–Defined Elements

13.1 Introduction

The User element (UEL) feature in **STAGS** 5.0 gives advanced analysts and developers powerful new tools for solving problems that lie beyond the scope of those that **STAGS** has traditionally treated. The process by which User elements are defined in **STAGS** is described concisely here and fully in Chapter 9 of the ***STAGS*** *Elements Manual*. The input records with which User elements may be employed in constructing a **STAGS** model are described in Section 9.8 on page 9-163.

As noted in Section 9.8, there are two distinct (but strongly coupled) operations that must be performed to define a User element for use in the construction of **STAGS** models and for use in conducting analyses with those models.

The first operation (which must be performed in generating the *INP* file that **STAGS**' **s1** processor reads and processes to construct the **STAGS** model for a given problem) is the analyst's definition of top-level information about the User element—including (but not limited to) the element-type identifier by which it is to be referenced, the number of node points required to specify any given element of this type, the names and characteristics of data associated with all elements of this type, *etc*. This is done by including a set of *user-element-definition directives* (see Sections 13.2 and 13.3) at any appropriate point in the analyst's *INP* file prior to any input records that command the inclusion of one or more User elements of that type in the model being constructed.

The second operation (which must be performed prior to executing any **STAGS** processor) is the analyst's (developer's) generation of all user-element-specific FORTRAN- and C-language routines as described in Section 13.4. These routines may contain explicit definitions of the element features (internal force vector, stiffness matrix, stress and strain recovery, etc.) or they may contain CALL statements to other subroutines or functions that compute the various features.

STAGS processors need these routines to construct a **STAGS** model in which these user-defined elements are employed and to perform analysis and postprocessing operations with that model—and the successful linking of each of these user-element-enhanced processors.

Before getting into either of these operations, it is appropriate to pause briefly and note that the principal goal of the **STAGS** User element framework is to provide a set of features that enable element researchers and advanced or adventuresome analysts to add new element types to **STAGS** without having to be overly concerned with the gory and sometimes excruciating details of the **STAGS** element integration process—focusing only on the development of their new elements.

To provide an almost transparent element integration environment, the **STAGS** User element framework provides the following features:

- Arbitrary User element types are represented in the standard **STAGS** element description scheme as element types `900≤ type ≤999`.
- Any number (less than or equal to one hundred) of User element types and their associated data descriptions may be specified.
- Any number of User elements of any UEL type may be defined in **STAGS** models.
- Each User element type definition specifies a set of named data that are available for every element of that type.
- User element program code can retrieve and store the values of individual User element data items by their names, or can access an element's integer and floating-point data blocks in the **ABAQUS** style.
- An arbitrary number of user-described property sets can be defined that specify a collection of named data that may be arbitrarily associated with one or more elements of any user-defined type.
- User element wrapper routines are invoked automatically by **STAGS** as required by a solution process. Users implementing new elements need not be concerned with the details of the **STAGS** solution process.

An arbitrary number of user-defined element types can be specified using a free field description of the nodal and data specifications for each element. These descriptions are entered directly into the **STAGS** model input file and provide the user the ability to describe the element type and its data requirements in any manner that facilitates the most natural ordering. Comments and flexible line spacing are allowed for enhanced readability.

Each User element type description may specify a collection of named integer and/or floating-point variables associated with each User element defined in a **STAGS** model. Naming User element variables greatly increases a user's understanding of both simple and complex datasets and reduces the likelihood of confusing data values required by different element types. This is a general capability; the developer or researcher is not restricted by the kind or amount of data that can be associated with each User element type.

The User element framework also introduces a new **STAGS** feature called *User property sets*. A developer or researcher may define any number of property sets, each of which is identified by a meaningful name and a unique numeric identifier. The property items in a property set, entered by the user in free field format (much like User element type descriptions), collect integer and/or floating-point data that are best described when grouped together. This feature provides a general and flexible technique for describing data required by any new capabilities added by developers or researchers. The creation of new, user-defined element types is just one example.

13.2 User Element Definition Directives

Returning to the subject of *directives* for definition of User elements, we note that each UEL type is described in the *INP* file for a **STAGS** model by a set of four required directives and two optional directives (printed in square brackets) that are ordered as follows:

```
*userElement...            — initiate userElement specifications
    *dofOrdering...        — specify number and types of DOF at each node
    *nodeSequence...       — specify nodal sequence for transformations
   [*floatVariables...]    — specify float-type variables (if any)
   [*integerVariables...]— specify integer-type variables (if any)
*end userElement           — terminate userElement specifications
```

Directive formatting is free-field. String values that contain one or more spaces must be enclosed in matching single or double quotes. Directive names and directive attribute names are case-insensitive. Empty (blank) lines and lines containing only $-initiated comments are ignored during parsing of directives.

The **`*floatVariables`** data groups are optional. They may appear in any order and may be repeated as many times as required. All float variable items are collected sequentially as they are defined and are placed in a single logical group of data type float.

The **`*integerVariables`** data groups are also optional . They may appear in any order and may be repeated as many times as required. All float variable items are collected sequentially as they are defined and are placed in a single logical group of data type float. All integer variable items are collected sequentially as they are defined and are placed in a single logical group of type integer.

Example of User element definition

Rather than going through a long-winded presentation of directive syntax and conventions, let us simplify this by looking at a straightforward example that shows how a user might define a User element—to be referenced as a type 901 element—for a simple three-noded beam. The end nodes of this beam are identified as node number 1 and node number 2, and the internal node is identified as node number 3. A fourth node is associated with the element in order to compute the element's orientation matrix. Associated with this element type is a set of named floating-point variables and a set of named integer variables. These named data will be defined for each user-defined element created by **STAGS** and can be manipulated by developers and by the element researcher using utility routines that are described briefly below and in greater detail in Chapter 9 of the ***STAGS*** *Elements Manual*.

```
*userElement name = "Beam Element"  type = 901  nodes = 4

      *dofOrdering
                  $  Node  DOF...
                  $  ----------------
                     1    1 2 3 4 5 6
                     2    1 2 3 4 5 6
                     3    1 2 3 4 5 6
                     4    0

      *nodeSequence
                  $  Nodes...
                  $  --------
                     1 2 4

      *floatVariables
                  $  Name        Size
                  $  ----------------
                     MaxStress      1
                     MaxStressLoc   3
                     SectionData    5
                     ShearFactor    1
                     OtherStuff    15

      *integerVariables
                  $  Name  Size
                  $  ----------
                     NIPS     1
                     List    10

*end userElement
```

Notes about this User element definition example

The following points about this example are generally true for all User element type definitions:

- User element type names must have string values and are used for descriptive purposes only.
- User element type names are limited to 40 characters in length.
- User element type numbers must be in the range $900 \le \texttt{type} \le 999$, inclusive and must be unique (*i.e.*, a UEL type must be defined only once).
- A User element type may have any number of nodes.
- The DOF ordering for each node must be specified in a single group.
- All nodes are expected to have zero (0), three (3) or six (6) degrees of freedom, with DOFs defined in agreement with **STAGS'** DOF-ordering convention:

1	:	x–displacement	4	:	x–rotation
2	:	y–displacement	5	:	y–rotation
3	:	z–displacement	6	:	z–rotation

- Element reference nodes are specified as having zero degrees of freedom (as for node 4 in this example).
- Nodes used to define an element's orientation matrix are identified by a single, required `*nodeSequence` directive. Either three (3) or four (4) nodes in the `*dofOrdering` group are referenced by index in this directive. If three nodes are referenced, the element's x–axis is directed from the first to the second node. The element's z–axis is directed as the vector cross product of the x–axis and the vector from the first to the third node. The element's y–axis follows from the right-hand rule with respect to the x–axis and the z–axis. If four nodes are referenced, the element's x–axis is directed from the first to the second node. The element's z–axis is directed as the vector cross product of the vector from the first to the third node and the vector from the second tor the fourth node. The element's y–axis follows from the right-hand rule with respect to the x–axis and the z–axis.
- User element variable names are limited to 40 characters in length.
- Variable names containing one or more spaces must be enclosed in matching single or double quotes.
- Variable names are case-insensitive for comparison and must be unique within their User element type definition.
- A variable's size (logical length) must be specified and must be an integer number greater than zero.

13.3 User Property Set Definition Directives

User property sets are described (during **STAGS s1** processing) through a set of directives as shown in the following example. Directives defining a User property set are ordered as follows:

```
*userProperty...      –    initiate userProperty specifications
   [*floatProps...]   –    define one or more float-type data parameters
   [*integerProps...]–     define one or more integer-type data parameters
*end userProperty     –    initiate userProperty specifications
```

As with the previously-described user-element–definition directives, empty (blank) lines and lines containing only $-initiated comments are ignored during parsing of directives; and directive names and directive attribute names are case-insensitive. Directive formatting is free-field. String values that contain one or more spaces must be enclosed in matching single or double quotes.

The **`*floatProps`** data group is optional; `*floatProps` data groups may appear in any order and may be repeated as many times as required. All float property items are collected sequentially as they are defined and are placed in a single logical group of data type float. The **`*integerProps`** data group is optional when the analyst/developer chooses not to use **STAGS**' GCP processor to specify material properties and fabrications; it is mandatory when he/she uses the GCP. When needed, `*integerProps` data groups may appear in any order and may be repeated as many times as required. All integer property items are collected sequentially as they are defined and are placed in a single logical group of data type integer.

Example # 1 of User property set definition

```
*userProperty  name = "Beam Element"  id = 901

      *integerProps
                       $  Required Standard Data
                       $  ----------------------
                          ActiveNodes     2
                          SamplingCount  10
                          StrainCount     6
                          StressCount     6

*end userProperty

*userProperty  name = "Aluminum 6061-T6"  id = 6061

      *floatProps
                  E                         10.00e+6
                  G                          3.75e+6
                  MassDensity                2.54e-4
                  PoissonRatio               0.3
                  TensileUltimateStrength   38.00e+3
                  TensileYieldStrength      35.00e+3
                  CompresiveYieldStrength   35.00e+3
                  ShearYieldStrength        20.00e+3
                  ThermalExpansion           1.30e-5

*end userProperty
```

This example builds on the previous example that showed how an element researcher might define a new element type for a three-noded beam with a single internal node. In addition to the element type's set of named integer and floating-point element variables, there may be several User property sets defined to complete the specification of an element. These property sets contain collections of related property items and can be logically associated with any number of elements or referenced from any number of appropriate contexts. User property sets can be manipulated by developers and element researchers using utility routines that are described briefly below and more completely in Chapter 9 of the ***STAGS*** *Elements Manual*.

As noted above, the **`*integerProps`** data group is mandatory when the analyst/developer employs **STAGS**' GCP processor to specify material properties and fabrications. Under these circumstances, two integer GCP-interface parameters (`Class` and `Kintype`) must be specified in addition to the four other parameters that are typically required (`ActiveNodes`, `SamplingCount`, `StrainCount` and `StressCount`). In the current versions of **STAGS**, the `Class` and `Kintype` parameters may have the following values:

`Class` specifies class type for the element(s) in question:

= 0 — not specified (do not use the GCP interface)
= 1 — beam (1-D) elements
= 2 — shell (2-D) elements
= 3 — solid (3-D) elements

and

`Kintype` specifies the kinematic type for the element(s) in question:

= 0 — not specified (do not use the GCP interface)

= 1 — type C^0 (`qC0`) elements — isoparametric (Mindlin) shell elements with shear (and usually no natural drill freedom); examples include the **MIN4** and **E480** (ANS) quads; beams of this type have 8 resultant components; shells have 6

= 2 — Kirchoff elements with C^1 (`qC1`) compatibility; beams of this type have 4 resultant components; shells have 6

= 3 — 3-D (solid) elements (`q3D`), with 6 stresses

The following example shows a User property set that might be used to define some of the integer-type properties of a type-900 user element—a quadrilateral C^0 shell element, in this case—when the the GCP processor is used to specify its material properties and fabrications:

Example # 2 of User property set definition

```
*userProperty  name = "MIN4 Element"  id = 900

      *integerProps
                        $  Required Standard Data
                        $  ---------------------
                           ActiveNodes     4
                           SamplingCount   4
                           StrainCount     8
                           StressCount     8

                        $  GCP-interface Data
                        $  -----------------
                           Class           2
                           Kintype         1

*end userProperty
```

The following points made about these two User property set definition examples are generally true for all such definitions:

- For each User element type definition there must be one property set with an identifier (`id`) that matches the identifier of the type definition. In addition to any other properties this property set may contain, the following integer property items must be specified: `ActiveNodes` (the number of active nodes for the element type), `SamplingCount` (the number of locations where stresses and strains will be evaluated), `StrainCount` (the number of strain components associated with the element type), `StressCount` (the number of stress components associated with the element type). Failure to provide these property items in a property set associated with an element type definition will lead to a run-time error.
- User property set names must have string values and must be unique across all User property sets.
- User property set names are limited to 40 characters in length.
- User property set identifiers (IDs) must have numeric values and must be unique across all User property sets.
- Property item names containing one or more spaces must be enclosed in matching single or double quotes
- Property item names are limited to 40 characters in length.
- Property item names are case-insensitive for comparison and must be unique within their property set definition.

13.4 User Element Model–Definition Routines

When one or more types of User elements are to be employed in a **STAGS** model, it is *sometimes* necessary for the analyst (or developer) to generate a user-element-enhanced version of **STAGS**' **s1** (model–definition) processor. It is *always* necessary for him (or her) to generate User–element–enhanced versions of **STAGS' s2** (analysis) processor and of any of the **STAGS**-system post-analysis processor(s) that are to be used with that model. The broad outlines of how this may be done are described in the following paragraphs. The interested reader should consult Chapter 9 of the ***STAGS** Elements Manual.* for more information about this.

Top–level model–definition routines

When **STAGS' s1** processor encounters a User element, **s1** calls a number of generic User–element definition routines to perform operations that are required universally. **s1** also calls upon three other user-element "dispatch" routines to perform additional, nonstandard model-definition operations for that User element—as and if they are required. The primary function of each of these dispatch routines is evident by its name: **UelEltDef**, **UelLoadDef** and **UelPressDef**. Each of these dispatch routines calls one or more next–level program- or developer-supplied routines that perform nonstandard definition operations that are appropriate for each type of User element. The "program-supplied" qualifier is appropriate when special operations are *no*t required; the "developer-supplied" qualifier applies when special operations *are* required.

For reference purposes, the current *default* version of the **UelEltDef** dispatch routine is shown in the FORTRAN listing beginning on the next page. The current *default* versions of subroutines **UelLoadDef** and **UelPressDef** are listed in Chapter 9 of the ***STAGS** Elements Manual*. The names of the three user-element-type-specific routines that this version of **UelEltDef** calls—**UelEltDef900**, **UeltEltDef901** and **UelEltDef902**, for user-element types 900, 901 and 902, respectively—are completely arbitrary and may be changed to reflect the user's particular choice (subject to the architectural constraint that each User element type must have a unique identifier number that lies in the range from 900 to 999, inclusive). A do-nothing "starter" template is provided for each of the three particular subroutines that this *template* version of **UelEltDef** calls. The default version of the **UelEltDef900** routine that this version of **UelEltDef** calls is shown in the listing following that of **UelEltDef**. All three top-level **s1**-processor dispatch routines and their respective type-specific children are documented in Chapter 9 of the ***STAGS** Elements Manual*.

subroutine UelEltDef

```
c=deck     UelEltDef
c=purpose  Perform definition operations for a user-defined element
c=author   --------------------------------------------------------
c=author   Lyle W. Swenson, Jr.  Knowledge Management Systems, Inc.
c=author   --------------------  Ph: (858)259-2773 or (858)481-9907
c=version  January 2005

#if _usage_
*
*     call UelEltDef (idef,   type,   unit,   uid,
*                     ifab,   iang,   ilin,   iplas,
*                     nnodes, nodseq, triad,  unodes,
*                     nodes,  maxdof, nfvars, nivars,
*                     t0,     xg,     xe)
*
*     Input Arguments
*     ---------------
*     idef    =  current User element definition index
*     type    =  element type: >=900
*     unit    =  current unit number
*     uid     =  user specified element number
*     ifab    =  fabrication code
*     iang    =  material angle flag
*     ilin    =  linearity flag
*     iplas   =  plasticity flag
*     nnodes  =  number of nodes
*     nodseq  =  nodal sequence for element frame
*     triad   =  material orientation matrix
*     unodes  =  element nodes (user-definition)
*     nodes   =  element nodes (STAGS-definition)
*     maxdof  =  nodal maxdof vector
*     nfvars  =  number of user float variables
*     nivars  =  number of user integer variables
*     t0      =  element orientation matrix
*     xg      =  global nodal coordinates
*     xe      =  local  nodal coordinates
*
#endif

************************************************************************
          Subroutine UelEltDef (idef,   type,   unit,   uid,
     &                          ifab,   iang,   ilin,   iplas,
     &                          nnodes, nodseq, triad,  unodes,
     &                          nodes,  maxdof, nfvars, nivars,
     &                          t0,     xg,     xe)
************************************************************************

#     include   “keydefs.h”

      _implicit_none_
```

subroutine UelEltDef (continued)

```

#     include   “stndcm.h”

      Integer    idef
      Integer    type
      Integer    unit
      Integer    uid
      Integer    ifab
      Integer    iang
      Integer    ilin
      Integer    iplas
      Integer    nnodes
      Integer    nodseq(4)
      _float_    triad(3,3)
      Integer    unodes(nnodes)
      Integer    nodes(nnodes)
      Integer    maxdof(nnodes)
      Integer    nfvars
      Integer    nivars
      _float_    t0(3,3)
      Real       xg(3,nnodes)
      _float_    xe(3,nnodes)

      Integer    a
      Integer    b
      Integer    m
      Character  msg*44
      Logical    NTITLE

      if (NTITLE('X_EltDef')) then

         m = min(nnodes,20)

         print 100, idef,   type,   unit,   uid,
     &              ifab,   iang,   ilin,   iplas,
     &              nnodes, nodseq, nfvars, nivars,
     &              triad

         print 200, (unodes(a),a=1,m)
         print 300, (nodes (a),a=1,m)
         print 400, (maxdof(a),a=1,m)
         print 500, ((t0(a,b),a=1,3),b=1,3)
         print 600, ((xg(a,b),a=1,3),b=1,m)
         print 700, ((xe(a,b),a=1,3),b=1,m)

      endif

*     PERFORM DEFINITION OPERATIONS FOR A USER-DEFINED ELEMENT
*     ======================================================
```

subroutine UelEltDef (continued)

```
      if (type.eq.900) then

         call UelEltDef900 (idef,   type,   unit,   uid,
     &                      ifab,   iang,   ilin,   iplas,
     &                      nnodes, nodseq, triad,  unodes,
     &                      nodes,  maxdof, nfvars, nivars,
     &                      t0,     xg,     xe)

      elseif (type.eq.901) then

         call UelEltDef901 (idef,   type,   unit,   uid,
     &                      ifab,   iang,   ilin,   iplas,
     &                      nnodes, nodseq, triad,  unodes,
     &                      nodes,  maxdof, nfvars, nivars,
     &                      t0,     xg,     xe)

      elseif (type.eq.902) then

         call UelEltDef902 (idef,   type,   unit,   uid,
     &                      ifab,   iang,   ilin,   iplas,
     &                      nnodes, nodseq, triad,  unodes,
     &                      nodes,  maxdof, nfvars, nivars,
     &                      t0,     xg,     xe)

      elseif (type.eq.910) then

         call UelEltDef910 (idef,   type,   unit,   uid,
     &                      ifab,   iang,   ilin,   iplas,
     &                      nnodes, nodseq, triad,  unodes,
     &                      nodes,  maxdof, nfvars, nivars,
     &                      t0,     xg,     xe)

      else

*        USER-DEFINED ELEMENT TYPE NOT FOUND
*        ===================================
         write (msg,800) type
         call solstp (msg)

      endif

100   format(/' <<<< UelEltDef >>>>'
     &      //' idef ......', i5
     &       /' type ......', i5
     &       /' unit ......', i5
     &       /' uid .......', i5
     &       /' ifab ......', i5
     &       /' iang ......', i5
     &       /' ilin ......', i5
     &       /' iplas .....', i5
```

subroutine **UelEltDef** (continued)

```
150:      &        /' nnodes ....', i5
151:      &        /' nodseq ....', 4i5
152:      &        /' nfvars ....', i5
153:      &        /' nivars ....', i5
154:      &        /' triad .....', 1p9e12.4)
155: 200   format( ' unodes ....', 20i5)
156: 300   format( ' nodes .....', 20i5)
157: 400   format( ' maxdof ....', 20i5)
158: 500   format( ' t0 ........', 1p3e14.6 / (12x,1p3e14.6))
159: 600   format( ' xg ........', 1p3e14.6 / (12x,1p3e14.6))
160: 700   format( ' xe ........', 1p3e14.6 / (12x,1p3e14.6))
161: 800   format( 'UelEltDef: Undefined User Element Type:', i5)
162:
163:       end
```

The portions that are printed with **boldface** type in this listing of subroutine **UelEltDef** (lines 100–122, inclusive) may be changed, as noted above, to reflect the user’s particular choices in assigning identifier (type) numbers and subroutine names to each of his or her unique User element types. The calling sequences shown here, however, should *not* be changed.

The observant reader will have noticed that in lines 124–130 of this version of **UelEltDef** there is a test to determine if the current element is a type 910 element, followed by a call to **UelEltDef910** if it is. This logic accommodates **STAGS**’ “actuator” element, which started out as a developer’s user element and then migrated into current versions of the program as a “regular” or “standard” **STAGS** element that any analyst can utilize. See the ***STAGS** Elements Manual* for more information about this interesting and useful element.

The default version of subroutine **UelEltDef900** (one of the three “children” called by the above-listed version of **UelEltDef**) is shown in the following listing:

subroutine UelEltDef900

```
c=deck     UelEltDef900
c=purpose  Perform definition operations for user-written E900
c=author   --------------------------------------------------------
c=author   Lyle W. Swenson, Jr.  Knowledge Management Systems, Inc.
c=author   --------------------  Ph: (858)259-2773 or (858)481-9907
c=version  January 2002

#if _usage_
*
*     call UelEltDef900 (idef,   type,   unit,   uid,
*                        ifab,   iang,   ilin,   iplas,
*                        nnodes, nodseq, triad,  unodes,
*                        nodes,  maxdof, nfvars, nivars,
*                        t0,     xgg,    xe)
*
*     Input Arguments
*     ---------------
*     idef    =  current User element definition index
*     type    =  element type (=900)
*     unit    =  current unit number
*     uid     =  user specified element number
*     ifab    =  fabrication code
*     iang    =  material angle flag
*     ilin    =  linearity flag
*     iplas   =  plasticity flag
*     nnodes  =  number of nodes
*     nodseq  =  nodal sequence for element frame
*     triad   =  material orientation matrix
*     unodes  =  element nodes (user-definition)
*     nodes   =  element nodes (STAGS-definition)
*     nfvars  =  number of user float variables
*     nivars  =  number of user integer variables
*     t0      =  element orientation matrix
*     xgg     =  global nodal coordinates
*     xe      =  local  nodal coordinates
*
#endif

************************************************************************
        Subroutine UelEltDef900 (idef,   type,   unit,   uid,
     &                           ifab,   iang,   ilin,   iplas,
     &                           nnodes, nodseq, triad,  unodes,
     &                           nodes,  maxdof, nfvars, nivars,
     &                           t0,     xgg,    xe)
************************************************************************

#     include “keydefs.h”
```

subroutine UelEltDef900 (continued)

```
48:
49:       _implicit_none_
50:
51: #     include "stndcm.h"
52:
53:       Integer    idef
54:       Integer    type
55:       Integer    unit
56:       Integer    uid
57:       Integer    ifab
58:       Integer    iang
59:       Integer    ilin
60:       Integer    iplas
61:       Integer    nnodes
62:       Integer    nodseq(4)
63:       _float_    triad(3,3)
64:       Integer    unodes(nnodes)
65:       Integer    nodes(nnodes)
66:       Integer    maxdof(nnodes)
67:       Integer    nfvars
68:       Integer    nivars
69:       _float_    t0(3,3)
70:       Real       xgg(3,nnodes)
71:       _float_    xe(3,nnodes)
72:
73: *     TO BE IMPLEMENTED BY THE USER
74: *     =============================
75:
76:       end
```

The two **boldface** lines (73 and 74), here, are to be implemented by the User element developer.

A comprehensive set of FORTRAN– and C–language utility routines is provided with **STAGS** to facilitate the implementation and utilization of user-defined elements in **STAGS' s1** model–definition processor and in other **STAGS** processors. These utilities are described briefly later in this chapter and are documented more comprehensively in the ***STAGS** Elements Manual*.

13.5 User Element Model–Analysis Routines

When the **STAGS' s2** processor encounters a User element, it also calls upon a number of user-element "dispatch" routines to perform initialization and computation operations for that UEL—

as and if required. Depending on the type of analysis to be performed, **s2** may call some or all of the user-element dispatch routines that are listed in the following Table:

subroutine	***raison d' étre***
UelPvDef	Perform pre-variation operations for User elements
UelMassDef	Perform mass-computation operations for User elements
UelFiDef	Compute internal forces for User elements
UelFlDef	Compute live-loading forces for User elements
UelKmDef	Compute the material stiffness of the User elements
UelKgDef	Compute the geometric stiffness of the User elements
UelStrainDef	Determine the user-element strains
UelStressDef	Determine the user-element stresses
UelResultantDef	Determine the user-element resultants
UelPrintStrainDef	Print the user-element strains
UelPrintStressDef	Print the user-element stresses
UelPrintResultantDef	Print the user-element resultants

Each of these dispatch routines in turn calls a corresponding user-defined routine that is specific to a particular user-defined element type. Subroutine **UelPvDef**, for example, calls the provided templates **UelPvDef900**, **UelPvDef901** and **UelPvDef902**. Similar template routines are provided for the other dispatch routines. As with the previously-described top-level model-definition routines, the names of these user-element-type-specific model-analysis routines (for hypothetical user types 900, 901 and 902) are arbitrary and may be changed to reflect the user's particular choice. In any event, it should be obvious that User element name and type choices implemented in **STAGS**' **s1** (model-definition) operations should also be used in **s2** (model-analysis) operations and in other (post-processing) activities.

For reference purposes, the current *default* version of the **UelPvDef** dispatch routine is shown in the following FORTRAN listing:

subroutine UelPvDef

```
c=deck     UelPvDef
c=purpose  Perform pre-variation operations for a User element
c=author   --------------------------------------------------------
c=author   Lyle W. Swenson, Jr.  Knowledge Management Systems, Inc.
c=author   --------------------  Ph: (858)259-2773 or (858)481-9907
c=version  January 2005

#if _usage_
*
*     call UelPvDef (type,  elt,   nnodes, active, nvars,
*                    nodes, mxdof, nff,    ivg,    xe)
*
*     Input Arguments
*     ---------------
*     type    =  element type: >= 900
*     elt     =  element number of type TYPE in the model
*     nnodes  =  number of nodes
*     active  =  number of active nodes
*     nvars   =  number of element variables
*     nodes   =  element nodes
*     mxdof   =  nodal maxdof vector
*     nff     =  nodal DOF-count vector
*     ivg     =  nodal DOF vector
*     xe      =  nodal coordinates
*
#endif

************************************************************************
         Subroutine UelPvDef (type,  elt,   nnodes, active, nvars,
     &                        nodes, mxdof, nff,    ivg,    xe)
************************************************************************

#     include   “keydefs.h”

      _implicit_none_

#     include   “stndcm.h”

      Integer    type
      Integer    elt
      Integer    nnodes
      Integer    active
      Integer    nvars
      Integer    nodes(nnodes)
      Integer    mxdof(nnodes)
      Integer    nff(nnodes)
      Integer    ivg(nvars)
```

subroutine UelPvDef (continued)

```
      _float_    xe(3,nnodes)
      Integer    i
      Integer    j
      Integer    m
      Character  msg*48
      Logical    NTITLE

      if ( NTITLE( 'X_UelPvDef') )  then

         m = min(nnodes,20)

         write (not,100) type, elt, nnodes, active, nvars
         write (not,200) (nodes(i),i=1,m)
         write (not,300) (mxdof(i),i=1,m)
         write (not,400) (nff  (i),i=1,m)
         write (not,500) (ivg  (i),i=1,min(nvars,20))
         write (not,600) ((xe(i,j),i=1,3),j=1,m)

      endif

*     PERFORM PRE-VARIATION OPERATIONS FOR A USER-WRITTEN ELEMENT
*     ===========================================================
      if (type.eq.900) then

         call UelPvDef900 (type,  elt,   nnodes, active, nvars,
     &                     nodes, mxdof, nff,    ivg,    xe)

      elseif (type.eq.901) then

         call UelPvDef901 (type,  elt,   nnodes, active, nvars,
     &                     nodes, mxdof, nff,    ivg,    xe)

      elseif (type.eq.902) then

         call UelPvDef902 (type,  elt,   nnodes, active, nvars,
     &                     nodes, mxdof, nff,    ivg,    xe)

      elseif (type.eq.910) then

         call UelPvDef910 (type,  elt,   nnodes, active, nvars,
     &                     nodes, mxdof, nff,    ivg,    xe)

      else

*        USER-WRITTEN ELEMENT TYPE NOT FOUND
*        ===================================
         write (msg,700) type
         call solstp (msg)
```

subroutine UelPvDef (continued)

```
 96:
 96:       endif
 96:
 96:       return
 96:
 96: 100   format(/' <<<<<<<<<<<<<<  UelPvDef  >>>>>>>>>>>>>>'
 97:      &      //' element type .....................', i5
 98:      &       /' element number of type in model ...', i5
 99:      &       /' number of nodes ...................', i5
100:      &       /' number of active nodes ...........', i5
101:      &       /' number of variables ...............', i5
102:      &       /' dataset record number .............', i5)
103:
104: 200   format(' nodes ....', 20i5)
105: 300   format(' maxdof ...', 20i5)
106: 400   format(' nff ......', 20i5)
107: 500   format(' ivg ......', 20i5)
108: 600   format(' xe .......', 1p3e14.6 / (11x,1p3e14.6))
109:
110: 700   format('UelPvDef: Undefined User element type:', i5)
111:
112:       end
```

The specific UEL type designations and the names of the next–level subroutines that **UelPvDef** calls are typically arbitrary and may be changed to reflect the user's choices—subject to the architectural constraint that each User element type must have a unique identifier number in the range from 900 to 999, inclusive. The top–level **UelPvDef** dispatch routine documented in this listing treats type 900, 901 and 902 User elements in lines 70–83, inclusive (printed in **boldface** type)—calling next–level subroutines **UelPvDef900**, **UeltPvDef901** and **UelPvDef902** to perform pre–variation operations for the current element when it is necessary to do so. The *names* of the next–level routines that **UelPvDef** calls are arbitrary, but their calling sequences are fixed and should *not* be changed.

This version of **UelPvDef** treats a type 910 User element in lines 85–88—calling **UelPvDef910** to do pre–variation work for a type 910 element. If the analyst/developer intends to use the "actuator" element that has been implemented as a type 910 UEL in current versions of **STAGS**, he/she should not touch this portion of the code. If the analyst/developer has implemented something else as a type 910 UEL, anything goes.

In any event, all of the top-level **s2**-processor dispatch routines and their respective children are documented in Chapter 9 of the ***STAGS** Elements Manual*.

13.6 User Element Post-Processing Routines

Post-processing capabilities for user-developed elements in **STAGS** are built primarily around the **stapl** post-processor, which provides the quickest means for the analyst to visualize his (or her) UEL elements and results obtained with them. User-developed elements can have almost any geometry—simple or complex. Complex user-developed "super" elements can be constructed, for example, from static condensations of one or more groups of standard and/or other types of User elements: these typically "reduce" a complex sub-model to a computationally manageable size by eliminating "interior" nodes and retaining only those nodes that are required to define its internal state—primarily (but not necessarily exclusively)—nodes along the outer boundary of the sub-model. **STAGS** users can save significant amounts of computer resources with this kind of User element—with some losses in the immediate visibilities of their models and of results obtained with them.

As for the model definition and analsis tasks (in the **s1** and **s2** processors, respectively), **STAGS** provides hooks that facilitate the implementation of user-written software for visualizing user-written elements and results obtained with them—in **stapl** and in other **STAGS** post-processors, and in **s1** (which uses **stapl** software to generate configuration plots of the analyst's model).

When any **STAGS** processor that generates model-configuration and/or -data plots encounters a User element to be visualized, it calls upon one or more of the top-level "dispatch" routines that are listed in the following Table to facilitate the accomplishment of that objective:

subroutine	***raison d' étre***
UelQuadDef	Determine the number of quads to be used to visualize a UEL of type `type`
UelGeomDef	Provide nodal connectivity and geometry data for a specific UEL of type `type`
UelValuesDef	Provide result value(s) for a specific UEL of type `type`

Each of these top-level dispatch routines in turn calls a corresponding user-defined routine that is specific to a particular user-defined element type. Subroutine **UelQuadDef**, for example, calls the provided templates **UelQuadDef900**, **UelQuadDef901** and **UelQuadDef902**. Similar template routines are provided for the other dispatch routines. As with all of the top-level dispatch routines described here and earlier in this chapter, the names of these user-element-type-specific model-analysis routines (for hypothetical user types 900, 901 and 902) are totally arbitrary and may be changed to reflect the user's particular choice. For completeness and consistency, User element name and type choices implemented in **s1** and **s2** should also be implemented in **stapl** and other (post-processing) processors.

For reference purposes, the current *default* versions of the **UelQuadDef** and **UelValuesDef** dispatch routines are shown in the following two FORTRAN listings:

subroutine UelQuadDef

```
c=deck    UelQuadDef
c=purpose Return # of subelements for visualizing a user-written element
c=author  --------------------------------------------------------------
c=author  Lyle W. Swenson, Jr.  Knowledge Management Systems, Inc.
c=author  --------------------  Ph: (858)259-2773 or (858)481-9907
c=version October 2004

#if _usage_
*
*     CALL UelQuadDef (type,gelt, nsubs)
*
*     Input Arguments
*     ---------------
*     type    =  element type: >=900
*     gelt    =  global element number
*
*     Output Arguments
*     ----------------
*     nsubs   =  number of subelements for visualizing a
*                user-written element
*
#endif

************************************************************************
             Subroutine UelQuadDef (type,gelt, nsubs)
************************************************************************

#     include   “keydefs.h”

      _implicit_none_

#     include   “stndcm.h”

      Integer    type
      Integer    gelt
      Integer    nsubs

      Integer    elt
      Character  msg*48
      Logical    NTITLE

      if (NTITLE(‘X_UelQuadDef’)) then
         write(not,100) type, gelt, elt
      endif

```

subroutine UelQuadDef (continued)

```
*     INITIALIZE OUTPUT ARGUMENTS
*     ===========================
      nsubs = 0

*     OBTAIN # OF ELEMENT type
*     ========================
      call UelEltp (gelt,type, elt)

*     RETURN NUMBER OF QUADS TO VISUALIZE A USER-WRITTEN ELEMENT
*     ==========================================================
      if (type.eq.900) then

         call UelQuadDef900 (type,gelt,elt, nsubs)

     elseif (type.eq.901) then

         call UelQuadDef901 (type,gelt,elt, nsubs)

     elseif (type.eq.902) then

         call UelQuadDef902 (type,gelt,elt, nsubs)

     elseif (type.eq.910) then

         call UelQuadDef910 (type,gelt,elt, nsubs)

     else

*        USER-WRITTEN ELEMENT TYPE NOT FOUND
*        ===================================
         write (msg,200) type
         call solstp (msg)

      endif

100   format(/’ <<<<<<<<<<<<  UelQuadDef  >>>>>>>>>>>>>>’
     &      //’ element type ......................’, i5
     &       /’ global element number .............’, i5
     &       /’ element number of type in model ...’, i5)

200   format(‘UelQuadDef: Undefined user element type: ‘,i5)

      end
```

and

subroutine UelValuesDef

```
c=deck     UelValuesDef
c=purpose  Return solution values for a user-written element
c=author   -------------------------------------------------------
c=author   Lyle W. Swenson, Jr.  Knowledge Management Systems, Inc.
c=author   --------------------  Ph: (858)259-2773 or (858)481-9907
c=version  November 2004

#if _usage_
*
*     CALL UelValuesDef (type, gelt,   sub,   name, loc, dsx,
*                         step, iplast, layer, zloc, eref,
*                         nval, values, status)
*
*     Input Arguments
*     ---------------
*     type    =  element type: >=900
*     gelt    =  global element number
*     sub     =  subelement identifier ( 1 <= sub <= Nsubs )
*                (cf. subroutine UelQuadDef)
*     name    =  name of data to be returned
*     loc     =  output location: ‘N’ (nodes) or ‘C’ (centroid)
*     dsx     =  dataset containing displacement solution
*     step    =  solution step number
*     iplast  =  plasticity flag
*     layer   =  fabrication layer, or 0 (see below)
*     zloc    =  'B' - Bottom of layer "layer" -- or bottom of
*                      layer 1, if "layer" = 0;   or
*             =  ‘T’ - Top of layer "layer" -- or top of
*                      layer NLAYS, where NLAYS = total # of
*                      layers in the fabrication
*     eref    =  ‘F’ - Fabrication reference frame; or
*                ‘M’ - Material reference frame
*
*     Output Arguments
*     ----------------
*     nval    =  if loc = ‘N’, number of values returned per node
*                if loc = ‘C’, number of values returned
*     values  =  data to be returned:
*                loc = ‘N’ : 4 value sets
*                loc = ‘C’ : 1 value set
*     status  =  success/failure indicator:
*                =  0 : data retrieved successfully
*                = -1 : data not defined for element
*                = -2 : data not defined at requested location
*
#endif

```

subroutine UelValuesDef (continued)

```
************************************************************************
      Subroutine UelValuesDef (type, gelt,   sub,   name, loc, dsx,
     &                         step, iplast, layer, zloc, eref,
     &                         nval, values, status)
************************************************************************

#     include   “keydefs.h”

      _implicit_none_

#     include   “stndcm.h”
#     include   “dsuni.h”
#     include   “spec.h”
#     include   “unc0.h”
#     include   “unc2.h”
#     include   “xstep.h”

      Integer      type
      Integer      gelt
      Integer      sub
      Character    name*(*)
      Character    loc*(*)
      Integer      dsx
      Integer      step
      Integer      iplast
      Integer      layer
      Character*1  zloc
      Character*1  eref
      Integer      nval
      _float_      values(*)
      Integer      status

      Integer      elt
      Character    msg*48
      Logical      NTITLE
      Integer      nwr
      Integer      UnitDat

      if (NTITLE(‘X_UelValuesDef’)) then
         write(not,100) type, gelt, elt, sub, name, loc, dsx, step
      endif

*     INITIALIZE STATUS ARGUMENT
*     ==========================
      status = 0

*     OBTAIN # OF ELEMENT type
*     ========================
      call UelEltp (gelt,type, elt)
```

subroutine UelValuesDef (continued)

```

*     INITIALIZE UNIT OFFSET DATA
*     ===========================
      call QROFF (dselt,gelt,1,13,1, nwr,UnitDat)
      call QREAD (dsunit,UnitDat,3,0, lnod)

*     RETURN SOLUTION VALUES FOR A USER-WRITTEN ELEMENT
*     =================================================
      if (type.eq.900) then

         call UelValuesDef900 (type,   gelt,   elt,  sub,  name,
     &                         loc,    dsx,    step, xpa,  xpb,
     &                         iplast, layer,  zloc, eref,
     &                         nval,   values, status)

      elseif (type.eq.901) then

         call UelValuesDef901 (type,   gelt,   elt,  sub,  name,
     &                         loc,    dsx,    step, xpa,  xpb,
     &                         iplast, layer,  zloc, eref,
     &                         nval,   values, status)

      elseif (type.eq.902) then

         call UelValuesDef902 (type,   gelt,   elt,  sub,  name,
     &                         loc,    dsx,    step, xpa,  xpb,
     &                         iplast, layer,  zloc, eref,
     &                         nval,   values, status)

      elseif (type.eq.910) then

         call UelValuesDef910 (type,   gelt,   elt,  sub,  name,
     &                         loc,    dsx,    step, xpa,  xpb,
     &                         iplast, layer,  zloc, eref,
     &                         nval,   values, status)

      else

*        USER-WRITTEN ELEMENT TYPE NOT FOUND
*        ===================================
         write (msg,200) type
         call solstp (msg)

      endif

100   format(/' <<<<<<<<<<<  UelValuesDef   >>>>>>>>>>>>>'
     &      //' element type .......................', i5
     &       /' global element number ..............', i5
```

subroutine UelValuesDef (continued)

```
145:      &       /’ element number of type in model ...’, i5
146:      &       /’ subelement identifier .............’, i5
147:      &       /’ name of requested data ............ ‘, a
148:      &       /’ location of requested data ........ ‘, a
149:      &       /’ solution dataset identifier .......’, i5
150:      &       /’ solution step number ..............’, i5)
151:
152: 200   format(‘UelValuesDef: Undefined user element type: ‘,i5)
153:
154:      end
```

As noted earlier, the specific User element type designations and the names of the routines that the **UelQuadDef** and **UelValuesDef** dispatch routines call—**UelQuadDef900**, **UeltQuadDef901** & **UelQuadDef902**, and **UelValuesDef900**, **UeltValuesDef901** & **UelValuesDef902** for UEL types 900, 901 and 902, here—are completely arbitrary and may be changed to reflect the user’s particular choices (subject to the architectural constraint that each UEL type must have a unique identifier number in the range from 900 to 999, inclusive). The portions that are printed in **boldface** type in these listings (lines 56–66 in **UelQuadDef** and lines 105–124 in **UelValuesDef**) may be changed to reflect the user’s particular choices in assigning identifier (type) numbers and subroutine names to each unique User element type. The calling sequences shown here should *not* be changed, however.

The three top-level visualization dispatch routines and their respective children are more fully documented in Chapter 9 of the ***STAGS** Elements Manual*.

13.7 FORTRAN– and C–Language Utility Routines

A comprehensive set of utility routines is provided with **STAGS** to facilitate the implementation and utilization of user-defined elements in **STAGS' s1** (model–definition) and other processors. Some of these utilities (principally those that are written in the C programming language) are very low-level architectural routines that **STAGS** users and element developers do not generally need to know about or use. Others (in the FORTRAN language) may be employed effectively in one or more phases of **STAGS** model–definition, analysis and/or post-processing operations. The principal utilities are described briefly here, and the full set of utilities is documented fully in the ***STAGS*** *Elements Manual*.

Before getting into these descriptions, let us pause briefly to tell the user and element developer that the top-level **phase1** routine in **STAGS**' **s1** processor calls subroutine **cards** to read all of the input in the user's *INP* model–definition input file. Subroutine **cards**, in turn, calls upon subroutines **cread** and **parse**—in cooperation with subroutines **XUelParse** and **parse2**—to assist in reading and in parsing user-specified directives—most notably the `*userElement` and the `*userProperty` directives. After a **STAGS s1** input file has been fully assimilated and processed, subroutine **phase1** calls user-element subroutine **UelToQdb** (which uses a number of lower-level C– and FORTRAN–language routines) to create **STAGS** databases for all of the specified User element types and variables that are specified in the input file. The average user and element developer should be aware of but not intensely concerned about any of these operations. The user/developer's attention should be focused exclusively on higher-level operations in defining and utilizing his/her user-developed elements.

Similarly, in the analysis phase of **STAGS** operations, the top-level **work** routine in **STAGS**' **s2** processor also calls upon subroutine **cards** to read all of the input in the user's *BIN* model–analysis input file. In the **s2** processor, as in **s1**, subroutine **cards** utilizes lower-level subroutines **cread** and **parse** to assist in reading and in parsing the user's input. It is not appropriate for the user to have any `*userElement` or `*userProperty` user-element- or user-property-set definition directives here: these directives *must* be included in the user's model–definition *INP* input file. Here, too, the user/developer's attention should be focused exclusively on higher-level operations in utilizing his/her user-developed elements.

With this in mind, the following Table contains brief descriptions of 19 FORTRAN–language subroutines that the user/developer can employ to load information into and to retrieve information from the **STAGS** User Element Type databases. The interested user/developer should see Chapter 9 of the ***STAGS*** *Elements Manual* for more information (calling sequences, *etc*.) about these and other User element type database utility routines.

Table 13.1 User Element Type Database Utility Routines

Routine	Purpose	Input & Output
UelCount	Retrieve the number of User element types	eltCount = *Number of User element types*
UelGetModelCount	Retrieve the number of User elements by type	type = *User element type* (900 ≤ type ≤ 999) count = *Number of User elements of type type in the model* dse9xx = User *element dataset handle for type* type

UelGetUnitCount	Retrieve the number of User elements by type and unit	type = *User element type* (900 ≤ type ≤ 999)
		unit = *STAGS model unit identifier*
		count = *Number of User elements of type* type *in unit* unit
		dse9xx = *User element dataset handle for type* type

UelIndex	Retrieve the index for a User element type	type = *User element type* (900 ≤ type ≤ 999) elt = *Index for User element of type* type *(if the User element type does not exist, then zero is returned for the element type index)*
UelInfo	Retrieve metadata for a User element type	elt = *Index of User element type* type = *User element type* (900 ≤ type ≤ 999) nodeCount = *Number of nodes for User element type* type nevars = *Number of element variables* nodeSeq = *Node sequence (3 or 4) to compute element frame* nfvars = *Number of element type float variables* nivars = *Number of element type integer variables* name = *Name of User element type* nameLen = *Number of characters in* name
UelVarInfo	Retrieve the number of User element type variables	elt = *Index of User element type* floCount = *Number of float variables for this User element type* intCount = *Number of integer variables for this User element type*

UelFloVar	Retrieve metadata for a User element type float variable	elt = *Index of User element type*
		var = *Index of User element type float variable*
		size = *Variable size (in logical words)*
		histIdx = *Variable index in history buffer (if positive)*
		name = *Variable name*
		nameLen = *Length of variable name*

UelIntVar	Retrieve metadata for a User element type integer variable	elt = *Index of User element type* var = *Index of User element type integer variable* size = *Variable size in logical words* histIdx = *Variable index in history buffer (if positive)* name = *Variable name* nameLen = *Length of variable name*

Table 13.1 User Element Type Database Utility Routines (continued)

Routine	Purpose	Input & Output

UelSetFloVar	Set User element type float variable(s)	type = *User element type* ($900 \leq \texttt{type} \leq 999$)
		elt = *Index of User element type*
		name = *Name of float variable*
		data = *Float variable data*
		size = *Size of* data *stored (in logical words)*

UelGetFloVar	Retrieve a User element type float variable(s); it is the caller's responsibility to ensure that the data buffer is large enough to hold the returned items	type = *User element type* ($900 \leq \texttt{type} \leq 999$) elt = *Index of User element type* name = *Name of float variable ('*' => all float variables)* data = *Float variable data vector* size = *Size of* data *(in logical words); set to zero if* name *does not exist*

UelSetIntVar	Set User element type integer variable(s)	type = *User element type* ($900 \leq \texttt{type} \leq 999$)
		elt = *Index of User element type*
		name = *Name of integer variable ('*' => all integer variables)*
		data = *Integer variable data*
		size = *Size of* data *stored (in logical words)*

UelGetIntVar	Retrieve User element type integer variable(s); it is the caller's responsibility to ensure that the data buffer is large enough to hold the returned items	type = *User element type* ($900 \leq \texttt{type} \leq 999$) elt = *Index of User element type* name = *Name of integer variable ('*' => all integer variables)* data = *Integer variable data vector* size = *Size of* data *(in logical words);* size *is set to zero if* name *does not exist*

UelSetHistVar	Set all of the User element historical variables	type = *User element type* ($900 \leq \texttt{type} \leq 999$)
		elt = *Index of User element type*
		data = *history variable*
		size = *Size of* data *stored (in floating point words)*

UelSetHistFloVar	Set a User element historical floating point variable	type = *User element type* ($900 \leq \texttt{type} \leq 999$)
		elt = *Index of User element type*
		name = *Name of float variable ('*' => all float variables)*
		data = *floating point history variable(s)*
		size = *Size of* data *stored (in logical words)*

UelSetHistIntVar	Set a User element historical integer variable	type = *User element type* ($900 \leq \texttt{type} \leq 999$)
		elt = *Index of User element type*
		name = *Name of integer variable ('*' => all integer variables)*
		data = *Integer history variable(s)*
		size = *Size of* data *stored (in logicalwords)*

Table 13.1 User Element Type Database Utility Routines (continued)

Routine	Purpose	Input & Output

UelGetHistFloVar	Retrieve a User element historical floating point variable	type = *User element type* ($900 \le$ type ≤ 999)
		elt = *Index of User element type*
		name = *Name of float variable ('*' => all float variables)*
		data = *floating point history variable(s)*
		size = *Size of* data *retrieved (in logical words)*

UelSetHistIntVar	Retrieve a User element historical integer variable	type = *User element type* ($900 \le$ type ≤ 999)
		elt = *Index of User element type*
		name = *Name of integer variable ('*' => all integer variables)*
		data = *Integer history variable(s)*
		size = *Size of* data *retrieved (in logicalwords)*

UelSetStr	Map a character string into an array of encoded integers	string = *Character string to be copied into* ibuff *(trailing spaces are ignored).* nlen = ibuff *length holding* string. ibuff = *Integer array with the structure: {stringLen, char1, char2, ..., charN}*
UelGetStr	Retrieve a character string from an array of integer-encoded characters	ibuff = *Integer array with the structure: {stringLen, char1, char2, ..., charN}* stringLen = *Length of character string* string string = *Character string retrieved from* ibuff

The following Table contains brief descriptions of 9 FORTRAN–language subroutines that the user/developer can employ to load information into and to retrieve information from the **STAGS** User property set databases. The interested user/developer should see Chapter 9 of the ***STAGS** Elements Manual* for more information (calling sequences, *etc*.) about these and other User property set database utility routines.

Table 13.2 User Property Set Database Utility Routines

Routine	Purpose	Input & Output
UPropCount	Retrieve the number of User property sets	`propCount` = *Number of User property sets*
UPropIndex	Retrieve the index for a user property set	`id` = *User property set identifier (specified by the user)* `prop` = *Index of User property set*
UPropInfo	Retrieve metadata for a user property item	`prop` = *User property set index* `id` = *User property set identifier (specified by the user)* `floCount` = *Number of user property set float items* `intCount` = *Number of user property set integer items* `name` = *Name of user property set* `nameLen` = *Number of characters in* `name`
UPropFloVal	Retrieve metadata for a user property set float value	`prop` = *User property set index* `item` = *User property set float item index* `data` = *Float property data* `name` = *Property item* `name` `nameLen` = *Property item name length*
UelSetFloProp	Set user property float item(s)	`id` = *User property set identifier (specified by the user)* `name` = *Name of float property ('*' => all float properties)* `data` = *float property data items* `size` = *Size of* `data` *(in logical words); set to zero if* `name` *does not exist*
UelGetFloProp	Retrieve float user property item(s)	`id` = *User property set identifier (specified by the user)* `name` = *Name of float property ('*' => all float properties)* `data` = *Float property data items (it is the caller's responsibility to ensure that the* `data` *buffer is large enough to hold the returned items)* `size` = *Size of* `data` *(in logical words); set to zero if* `name` *does not exist*
UPropIntVal	Retrieve metadata for a user property set integer value	`prop` = *User property set index* `item` = *User property set integer item index* `data` = *Integer property data* `name` = *Property item name* `nameLen` = *Property item name length*
UelSetIntProp	Set user property integer item(s)	`id` = *User property set identifier (specified by the user)* `name` = *Name of integer property ('*' => all integer properties)* `data` = *integer property data items* `size` = *Size of* `data` *(in logical words); set to zero if* `name` *does not exist*
UelGetIntProp	Retrieve integer user property item(s); it is the caller's responsibility to ensure that the `data` buffer is large enough to hold the returned items	`id` = *User property set identifier (specified by the user)* `name` = *Name of integer property ('*' => all integer properties)* `data` = *Integer property data items* `size` = *Size of* `data` *(in logical words); set to zero if* `name` *does not exist*

Last, but not least, the following Table contains brief descriptions of 4 FORTRAN–language routines that the analyst/developer can employ to retrieve element–property information and results from **STAGS** databases when **STAGS**' GCP processor is employed in specifying material properties and element fabrications. See Chapter 9 of the ***STAGS*** *Elements Manual* for more information about these and other GCP–interface routines.

Table 13.3 User Element GCP–Interface Routines

Routine	Purpose	Input & Output

e9xxcp	Retrieve the CC matrix for a UEL-GCP installation	nlin = *Nonlinear-strain/displacement-relations flag*
		iplast = *Plasticity-theory use flag*
		i1 = *Local-angles-defining-planar-rotation flag*
		ag = *Local angles defining planar rotations*
		ccp = *Full (non-triangular) ABD matrix*
		status = *Success/change-step-size/failure flag*

e9xxgss	Obtain the stress resultants for a UEL-GCP installation	nlin = *Nonlinear-strain/displacement-relations flag*
		iplast = *Plasticity-theory use flag*
		pa = *Load factor for system A*
		pb = *Load factor for system B*
		kinflg = *kinematic type flag for the element*
		i1 = *Local-angles-defining-planar-rotation flag*
		ag = *Local angles defining planar rotations*
		strainr = *Element strains/curvatures*
		stressr = *Stress resultants corresponding to given strains*
		edens = *Energy density (nips values)*
		status = *Success/change-step-size/failure flag*

e9xxms	Obtain the inertia terms for a UEL-GCP installation	inertia = *Mass per unit volume, surface or length*

e9xxpse	Obtain the stress resultants for a multi-layer UEL-GCP installation	step = *Load step number*
		pa = *Load factor for system A*
		pb = *Load factor for system B*
		i1 = *Local-angles-defining-planar-rotation flag*
		ag = *Local angles defining planar rotations (nips values)*
		iplast = *Plasticity-theory use flag*
		ilayr = *Layer # for which output is desired*
		zloc = *Z location (through thickness) where output is desired*
		eref = *Reference frame for stress/strain computations*
		zetr = *Angle between reference frame and direction of results*
		strainr = *Element strains/curvatures (nsr*nips points)*
		epsilon = *Strain vector (nsc components at nsp points)*
		plep = *Plastic strains (nsc components at nsp points)*
		nsc = *Number of strain components*
		epseff = *Effective strain at nsp points*
		sigma = *Stress vector (nsc components at nsp points)*
		sigeff = *Effective stress at nsp points*
		status = *Success/change-step-size/failure flag*

13.8 Uniform Beam Example

This section shows the use of some of **STAGS**' User element features in solving the textbook problem that is shown in Figure 13.1:

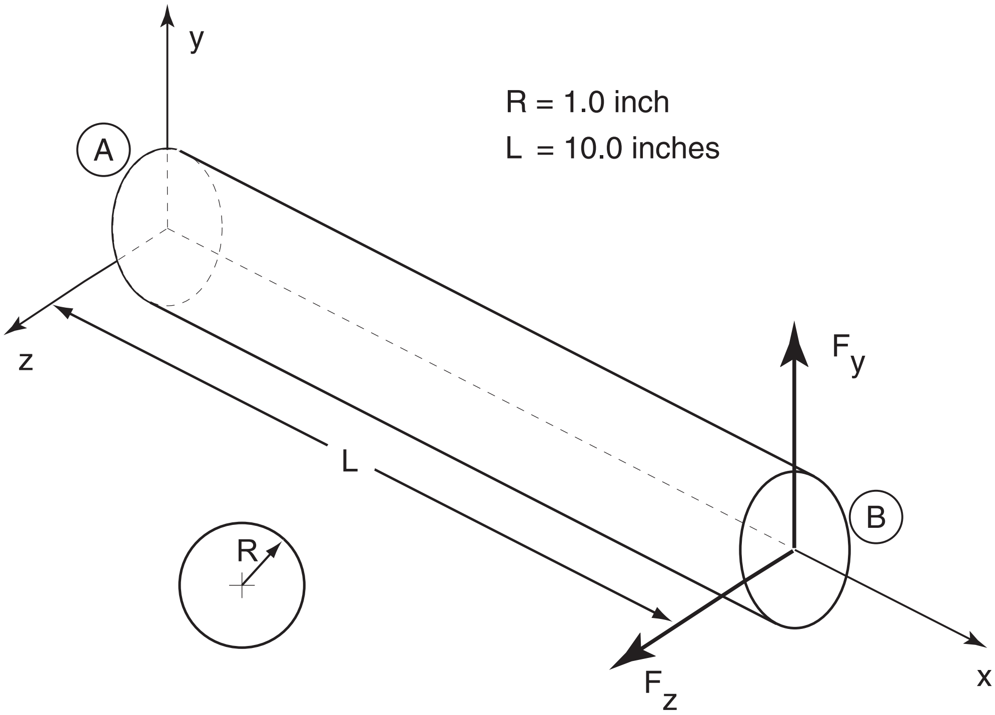


Figure 13.1 Uniform Beam Example Problem

This straight, uniform beam with a circular cross section—10.0 inches long with a 1.0 inch radius—is fully clamped at x=0 (End A) and is loaded at the free end at x=L (End B) with 1.0 pound forces in the y– and z–directions.

The user-defined beam element that is to be used in solving this problem is described by Przemieniecki.* It has uniform cross-section and material properties and has two active nodes, each with six degrees of freedom. A third (inactive) node is used for reference purposes: with the two active nodes, the third node defines the beam's principle x–y plane. The nodal force directions for this user-defined beam element are shown in Figure 13.2.

* Przemieniecki, J.S., "Theory of Matrix Structural Analysis," McGraw-Hill Book Company 1968, pp. 70–82.

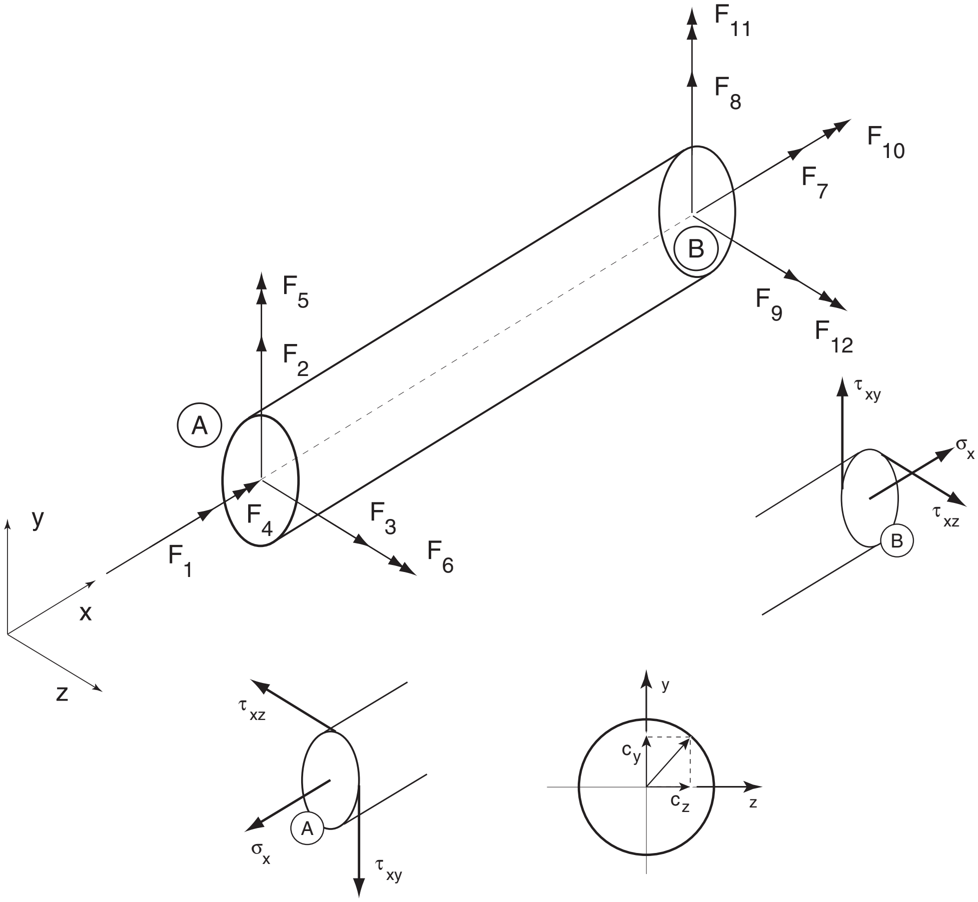


Figure 13.2 User-Defined Beam Element: Forces, Moments and Stresses

The nonzero stresses at node **A** for this element are

$$\sigma_{\mathbf{x}} = -\frac{\mathbf{F}_1}{\mathbf{A}} - \frac{\mathbf{F}_5\mathbf{c_z}}{\mathbf{I_y}} + \frac{\mathbf{F}_6\mathbf{c_y}}{\mathbf{I_z}} \tag{13.1}$$

$$\tau_{\mathbf{xy}} = \mathbf{SF_T}\ \frac{\mathbf{F}_4\mathbf{c_z}}{\mathbf{J}} \tag{13.2}$$

$$\tau_{\mathbf{xz}} = -\mathbf{SF_T}\ \frac{\mathbf{F}_4\mathbf{c_y}}{\mathbf{J}} \tag{13.3}$$

where **A** is the area of the cross–section of the beam ($= \pi\mathbf{R}^2$), where ($\mathbf{SF_T} = 1$), and where $\mathbf{c_y}$ and $\mathbf{c_z}$ are defined in Figure 13.2. The $\mathbf{c_y}$ and $\mathbf{c_z}$ parameters define sampling point coordinates on the beam cross section, for stress recovery. The nonzero stresses at node **B** for this element are

$$\sigma_{\mathbf{x}} = \frac{\mathbf{F}_7}{\mathbf{A}} + \frac{\mathbf{F}_{11}\mathbf{c_z}}{\mathbf{I_y}} - \frac{\mathbf{F}_{12}\mathbf{c_y}}{\mathbf{I_z}} \tag{13.4}$$

$$\tau_{xy} = -SF_T \frac{F_{10} c_z}{J} \tag{13.5}$$

$$\tau_{xz} = SF_T \frac{F_{10} c_y}{J} \tag{13.6}$$

Model- and User-element definition operations

The **STAGS** problem description file (`ubeam1.inp`) is given below (with line numbers on the left shown for reference purposes):

`ubeam1.inp` **input file for uniform beam example**

```
  1:  Straight Uniform Beam via User Defined Elements
  2:  0  0  0  0  0  0  0                              $ b1
  3:  0  1  0  0  0  0  0  0  0  0                     $ b2
  4:  0  0  0  0  0  0                                 $ b3
  5:  0  0  0  0  0  0                                 $ h1
  6:  $
  7:  $=====================================================
  8:  $   User Element Definitions
  9:  $=====================================================
 10:  $
 11:  *userElement name=”Uniform Beam Element”  type=900  nodes=3
 12:
 13:  *dofOrdering
 14:
 15:  $  Node  DOF...
 16:  $  -----------------
 17:       1     1  2  3  4  5  6
 18:       2     1  2  3  4  5  6
 19:       3     0
 20:
 21:  *nodeSequence
 22:
 23:  $  Nodes...
 24:  $  --------
 25:       1  2  3
 26:
 27:  *floatVariables
 28:
 29:  $  Name          Size
 30:  $  ------------------
 31:     Area            1
```

`ubeam1.inp` input file for uniform beam example (continued)

```
     AreaInShearY    1
     AreaInShearZ    1
     Iy              1
     Iz              1
     J               1
     Length          1
     Material        1
     MaxCompression  1
     MaxShear        1
     MaxTension      1
     ShearDefY       1
     ShearDefZ       1
     ShearFactorT    1
     ShearFactorY    1
     ShearFactorZ    1

*end userElement

*userProperty  name=”Standard Data -- Uniform Beam Element”  id=900

*integerProps
            $  Required Standard Data
            $  ----------------------
               ActiveNodes     2
               SamplingCount  10
               StrainCount     6
               StressCount     6
*floatProps
            $  Nodal Stress/Strain Sampling Points
            $  -----------------------------------
               y1   0.0
               z1   1.0

               y2   1.0
               z2   0.0

               y3   0.0
               z3  -1.0

               y4  -1.0
               z4   0.0

               y5   0.0
               z5   0.0

*end userProperty

```

`ubeam1.inp` **input file for uniform beam example (concluded)**

```
 79:  *userProperty  name=”Aluminum 6061-T6”  id=6061
 80:
 81:  *floatProps
 82:            E                        10.000e+6
 83:            G                         3.846e+6
 84:            MassDensity               2.540e-4
 85:            PoissonRatio              0.3
 86:            TensileUltimateStrength  38.0e+3
 87:            TensileYieldStrength     35.0e+3
 88:            CompresiveYieldStrength  35.0e+3
 89:            ShearYieldStrength       20.0e+3
 90:            ThermalExpansion          1.3e-5
 91:
 92:  *end userProperty
 93:  $
 94:  $================================================
 95:  $   Element Unit
 96:  $================================================
 97:    0  3*0  0.0  0.0  0.0  111 111  0 11 0       $ s3
 98:    1  3*0  1.0  0.0  0.0                        $ s3a
 99:    0  3*0  5.0  1.0  0.0  000 000  0  1 0       $ s3
100:    999999                                       $ s3
101:  $------------------------------------------------
102:  E9XX_elements 1                                $ t100
103:  900  1  0  0  0  0 10  1  1                    $ ----
104:    1  2 12                                      $ nodes
105:    1  1  0  1                                   $ {nodes} & elt x-incs
106:    3.142  1.0+12  1.0+12,                       $ A,    Asy,  Asz,
107:    0.7854 0.7854  1.571,                        $ Iy,   Iz,   J,
108:    0.0    6061.0  0.0                           $ L,    Mat,  Sigc,
109:    0.0    0.0,                                  $ Sigs, Sigt,
110:    0.0    0.0     1.0                           $ SDy,  SDz, SFt,
111:    1.333  1.333                                 $ SFy,  SFz
112:  END                                            $ t100
113:  $------------------------------------------------
114:  $   Specified Displacements & Forces
115:  $------------------------------------------------
116:    1                                            $ u1
117:    1 3                                          $ u2
118:    0.0 -1  1  1  0  0  6  1 0 0  0              $ u3
119:    1.0 +1  2 11  0  0  1  0 0 0  0              $ u3
120:    1.0 +1  3 11  0  0  1  0 0 0  0              $ u3
121:  $------------------------------------------------
122:    1 0 0 0 0 1 0 0 0 0 0                        $ v1
```

The observant reader will note that line 11 in this model-definition input file is the starting point for a `*userElement` directive defining a User element type which will (arbitrarily) be identified as a type 900 element. Each type 900 element is defined by three nodes whose nodal

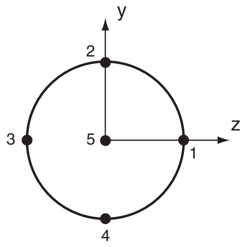
DOF are specified with the `*dofOrdering` directive, as shown in lines 17–19. The beam element's active nodes each have six DOF while the reference node has zero DOF.

> Note: Each node in a user-defined element must currently have 0, 3 or 6 DOF.

The `*nodeSequence` directive (on lines 21–26) must contain either three or four indices identifying nodes in the previous node-DOF specification that are to be used to define the local reference frame for the User element (see Section 13.2 for a discussion of how an element's local frame is constructed). In this case, the sequence 1,2,3 specifies that the first, second and third node in the previous node-DOF list are to be used to define the local reference frame for the element.

Each type 900 beam element has a set of sixteen floating-point data items as specified by the `*floatVariables` directive on lines 27–47. These data items specify an element's characteristic geometry data (`Area`, `AreaInShear`, *etc.*) and solution results (`MaxCompression`, `MaxShear`, *etc.*). Note that the variable called `Material` is used as a pointer to the element's material data that are specified later as User property information. There are no integer data for this User element type, so the `*userElement` directive terminates at line 48.

In this example, the User property items that are required for the User element type definition (`ActiveNodes`, `SamplingCount`, `StrainCount` and `StressCount`) are combined with additional data using the `*userProperty` directive beginning on line 52. Note that this user property set has an identifier value that is identical to the identifier of the User element type definition (*i.e.*, 900); this causes this particular property set to be associated with User element type definition identified by 900. In addition to the required integer element data given on lines 56–58, this property set also contains floating-point data (in lines 59–76)—these data define y–z sampling point coordinates where stresses and strains are to be evaluated at each end of a beam element, as shown in the following Figure:



This first property set definition is terminated at line 77. A second user property set directive, contained on lines 79–92, defines material data for aluminum 6061-T6. Full use of long property names is used here to make the items self describing. Note that while any unique identifier could be used to tag this property set (other than 900, as discussed above), an `id` value of 6061 seems appropriate. This property set terminates on line 92.

Following the one User element type definition and two property set definitions, standard **STAGS** input continues at line 97 with the definition of an element unit containing 11 nodes spaced one inch along the x–axis beginning at the global origin. These nodes are unconstrained in both translation and rotation. A twelfth node is located at (5,1,0); this node is fully fixed and is used as the principle x–y plane reference node for each of the beam elements.

Line 102 tells **STAGS** that one user-defined element type is used in this model. Lines 103–112 define ten type 900 elements and their variable data. The first beam element is connected between nodes 1 and 2 and uses node 12 as its principle x–y plane reference node. Subsequent elements are connected between nodes (2,3), (3,4), *etc.* All elements use node 12 as their principle x–y plane reference node.

Values for the element's variable data (which were declared on lines 31–46) are contained on lines 106–111. In general, all User element floating-point data are specified first, followed by all integer data. These data are entered in the order that they were declared in `*floatVariables` and `*integerVariables` directives within the `*userElement` directive. Regardless of how many `*floatVariables` and `*integerVariables` directives are used, or in what order they are actually given, float and integer variable declarations are separately combined in the order that each type is declared. Note that the material type identifier (`Material)` is defined as a floating-point variable in the `*floatVariables` part of the `*userElement` definition (on line 38) for this User element, so the value of `Material` is specified as a floating-point number (`6061.0)` on line 108 of the user's input file. If `Material` had been defined as an integer variable (in the `*integerVariables` part of the `*userElement` definition, its value would have to have been specified later, as an integer number.

As noted earlier, some of these User element variables characterize the element (and require specified input values) while the other variables will be specified later with values that are to be filled-in by user-written code. For example, the data on line 106 and 107 give the beam cross sectional area, effective area in shear, area moments of inertia and torsion factor. Data values on lines 108 and 109 are all place holders, with the exception of the value for `Material,` and will be specified later by user-written code. The value of `Material` being set to 6061 is used by the analyst to link these elements to the aluminum material data in the property set identified as 6061. Data on lines 110 and 111 are mixed; the shear deformation parameters (`ShearDefY` and `ShearDefZ`) are computed by code and the shear factors (`ShearFactorT`, `ShearFactorY` and `ShearFactorZ`) are specified.

Standard **STAGS** input continues on lines 116–122, which specify the boundary conditions and applied loads. On line 118, all displacement and rotation DOF for the root node are specified to have zero values. Lines 119–120 specify that one pound force loadings are applied at node 11 in the y– and z–directions, respectively.

Finally, line 122 requests that **STAGS** output displacement and internal force solution results.

User Element Definition Routines

This example problem does not require any special processing in **STAGS s1** processor for the type 900 user-defined beam element. The user-written routines called by the dispatchers **UelEltDef**, **UelLoadDef** and **UelPressDef** (*cf.* Section 13.4) only need to be implemented as empty routines. The template routines **UelEltDef900**, **UelLoadDef900** and **UelPressDef900** `that are` supplied as part of the **STAGS** distribution will work perfectly fine, for this problem. Because these template routines are automatically linked as part of standard **STAGS**, no additional actions are necessary.

Since this user-defined element will be used in a static nonlinear analysis, only a few model-analysis routines will need to be written to support **STAGS**' **s2** processing (*cf.* Section13.5). Recall that **STAGS**' **s2** processor typically calls twelve top-level dispatch routines during the solution process:

UelPvDef,
UelMassDef,
UelFiDef,
UelFlDef,
UelKmDef,
UelKgDef,
UelStrainDef,
UelStressDef,
UelResultantDef,
UelPrintStrainDef
UelPrintStressDef

and

UelPrintResultantDef.

Each of these dispatch routines in turn calls a corresponding user-written subroutine that is specific to each user-defined element type. For this example, the following user-written routines should typically be supplied for this type 900 element:

UelPvDef900,
UelFiDef900,
UelKmDef900,

UelStrainDef900,
UelStressDef900,
UelPrintStrainDef900
and
UelPrintStressDef900.

The **UelMassDef900**, **UelFlDef900** and **UelKgDef900** subroutines only need to be implemented as empty routines. The template versions of **UelMassDef900**, **UelFlDef900** and **UelKgDef900** that are supplied as part of the **STAGS** distribution will work fine, for this problem, so no additional work on them is required.

User beam pre-variation definition routine—**UelPvDef900**

The purpose of a User element pre-variation definition routine (such as **UelPvDef900**) is to compute and store element parameters using operations that only need to be performed once. Each User element pre-variation routine that is called by the **UelPvDef** dispatcher is provided for this purpose. The pre-variation definition routine for this User element is presented below (with line numbers shown on the left for reference purposes):

subroutine UelPvDef900

```
c=deck     UelPvDef900
c=purpose  Perform pre-variation operations for User element E900
c=author   --------------------------------------------------------
c=author   Lyle W. Swenson, Jr.  Knowledge Management Systems, Inc.
c=author   --------------------  Ph: (858)259-2773 or (858)481-9907
c=version  December 2001

#if _usage_
*
*     call UelPvDef900 (type,  elt,   nnodes, active, nvars,
*                       nodes, mxdof, nff,    ivg,    xe)
*
*     Input Arguments
*     ---------------
*     type    =  element type (=900)
*     elt     =  element number of type TYPE in the model
*     nnodes  =  number of nodes
*     active  =  number of active nodes
*     nvars   =  number of element variables
*     nodes   =  element nodes
*     mxdof   =  nodal maxdof vector
*     nff     =  nodal DOF-count vector
*     ivg     =  nodal DOF vector
*     xe      =  nodal coordinates
*
#endif

************************************************************************
       Subroutine UelPvDef900 (type,  elt,   nnodes, active, nvars,
     &                         nodes, mxdof, nff,    ivg,    xe)
************************************************************************

#     include   “keydefs.h”

      _implicit_none_

#     include   “stndcm.h”

      Integer    type
      Integer    elt
      Integer    nnodes
      Integer    active
      Integer    nvars
      Integer    nodes(nnodes)
      Integer    mxdof(nnodes)
      Integer    nff(nnodes)
      Integer    ivg(nvars)
     _float_     xe(3,nnodes)

*     TO BE IMPLEMENTED BY THE USER
*     =============================

      Integer    size

      _float_    Asy
      _float_    Asz
      _float_    E
      _float_    G
      _float_    Iy
      _float_    Iz
      _float_    L
      _float_    Mat
      _float_    SDy
      _float_    SDz

      call UelGetFloVar (type,elt,'AreaInShearY', Asy, size)
      call UelGetFloVar (type,elt,'AreaInShearZ', Asz, size)
      call UelGetFloVar (type,elt,'Iy',           Iy,  size)
      call UelGetFloVar (type,elt,'Iz',           Iz,  size)
      call UelGetFloVar (type,elt,'Material',     Mat, size)

      call UelGetFloProp (nint(Mat),'E', E, size)
      call UelGetFloProp (nint(Mat),'G', G, size)

*     Compute Beam Length and Shear Deformation Parameters
*     ----------------------------------------------------
      L = sqrt( (xe(1,1)-xe(1,2))**2 +
     &          (xe(2,1)-xe(2,2))**2 +
     &          (xe(3,1)-xe(3,2))**2 )

      SDy = 12*E*Iz/(G*Asy*L*L)
      SDz = 12*E*Iy/(G*Asz*L*L)

      call UelSetFloVar (type,elt,'Length',    L,   size)
      call UelSetFloVar (type,elt,'ShearDefY', SDy, size)
      call UelSetFloVar (type,elt,'ShearDefZ', SDz, size)

      end
```

Lines 1–52 are provided as part of the standard **UelPvDef900** template routine. The idea of any template is to provide developers all the data they might need to calculate the requested output or internal intermediate data.

Lines 53–64 define all the variables that are needed for the local operations. For demonstration purposes, this routine computes some of the beam parameters that will be used later by other type 900 routines.

Lines 66–70 retrieve some floating-point User element variables for a specific type 900 element. Notice that the names in the **UelGetFloVar** calls were created by the user in the `*userElement` directive in the model description file. The material identification parameter (`Material`) is used as a User property set identifier in lines 72–73 to retrieve the material properties for this particular element.

Computations on lines 77–82 are performed to compute the beam element's length and shear deformation parameters. These computed parameters are stored as part of the User element variables on lines 84–86. While these computations are very simple, they do demonstate the purpose of a User element prevariation routine—to compute invariant element parameters once and store them for later use.

User beam internal force vector definition routine—**UelFiDef900**

The purpose of a User element internal force definition routine (such as **UelFiDef900**) is to compute and return the internal force vector, a plastic strain code and the internal energy for a specific UEL. Each User element internal force definition routine that is called by the **UelFiDef** dispatcher is provided for this purpose. The internal force definition routine for this User element is presented below (with line numbers shown on the left for reference purposes):

subroutine UelFiDef900

```
 1:  c=deck     UelFiDef900
 2:  c=purpose  Compute internal force vector for user-written E900
 3:  c=author   --------------------------------------------------------
 4:  c=author   Lyle W. Swenson, Jr.  Knowledge Management Systems, Inc.
 5:  c=author   --------------------  Ph: (858)259-2773 or (858)481-9907
 6:  c=version  December 2001
 7:
 8:  #if _usage_
 9:  *
10:  *     call UelFiDef900 (type, elt, nlin,   iplast, istep,
11:  *                       pa,   pb,  active, nvars,  ix,
12:  *                       de,   fi,  iplmax, energy)
13:  *
14:  *     Input Arguments
15:  *     ---------------
16:  *     type    =  element type (=900)
17:  *     elt     =  element number of type TYPE in the model
18:  *     nlin    =  =0 - do not use nonlinear strain/displ. relations
19:  *                =1 - use nonlinear relations for applicable elements
20:  *     iplast  =  =0 - do not use plasticity theory
21:  *                =1 - use plasticity theory
22:  *     istep   =  step number of displacement vector
23:  *     pa      =  system A load factor
24:  *     pb      =  system B load factor
25:  *     active  =  number of active element nodes
26:  *     nvars   =  number of element variables
27:  *     ix      =  node permutation array
28:  *     de      =  element local deformation vector
29:  *
30:  *     Output Arguments
31:  *     ----------------
32:  *     fi      =  internal forces
33:  *     iplmax  =  =0 - plastic strains not excessive (plasticity only)
34:  *                >0 - plastic strains excessive, stop first variation
35:  *     energy  =  element internal energy
36:  *
37:  #endif
38:
39:  ************************************************************************
```

```
       Subroutine UelFiDef900 (type, elt, nlin,   iplast, istep,
    &                         pa,   pb,  active, nvars,  ix,
    &                         de,   fi,  iplmax, energy)
************************************************************************

#     include   “keydefs.h”

      _implicit_none_

#     include   “stndcm.h”

      Integer    type
      Integer    elt
      Integer    nlin
      Integer    iplast
      Integer    istep
      _float_    pa
      _float_    pb
      Integer    active
      Integer    nvars
      Integer    ix(active)
      _float_    de(nvars)
      _float_    fi(nvars)
      Integer    iplmax
      _float_    energy

*     TO BE IMPLEMENTED BY THE USER
*     =============================

      Integer    i
      Integer    size

      _float_    A
      _float_    E
      _float_    G
      _float_    Iy
      _float_    Iz
      _float_    J
      _float_    L
      _float_    Mat
      _float_    SDy
      _float_    SDz

      _float_    K0101
      _float_    K0202
      _float_    K0206
      _float_    K0303
      _float_    K0305
      _float_    K0404
      _float_    K0505
      _float_    K0511
      _float_    K0606
      _float_    K0612

*     Retrieve Element And Material Properties
*     ----------------------------------------
      call UelGetFloVar (type,elt,'Area',      A,   size)
      call UelGetFloVar (type,elt,'Iy',        Iy,  size)
      call UelGetFloVar (type,elt,'Iz',        Iz,  size)
      call UelGetFloVar (type,elt,'J',         J,   size)
      call UelGetFloVar (type,elt,'Length',    L,   size)
      call UelGetFloVar (type,elt,'Material',  Mat, size)
      call UelGetFloVar (type,elt,'ShearDefY', SDy, size)
      call UelGetFloVar (type,elt,'ShearDefZ', SDz, size)

      call UelGetFloProp (nint(Mat),'E', E, size)
      call UelGetFloProp (nint(Mat),'G', G, size)

*     Stiffness Coefficients
*     ----------------------
      K0101 = E*A/L

      K0202 = 12*E*Iz/((1+SDy)*L**3)
      K0206 =  6*E*Iz/((1+SDy)*L**2)

      K0303 = 12*E*Iy/((1+SDz)*L**3)
      K0305 =  6*E*Iy/((1+SDz)*L**2)

      K0404 = G*J/L

      K0505 = (4+SDz)*E*Iy/((1+SDz)*L)
      K0511 = (2-SDz)*E*Iy/((1+SDz)*L)

      K0606 = (4+SDy)*E*Iz/((1+SDy)*L)
      K0612 = (2-SDy)*E*Iz/((1+SDy)*L)

*     X-Forces: S1 and S7
*     -------------------
      fi(1) = K0101 * (de(1)-de(7))
      fi(7) = -fi(1)

*     Y-Forces: S2 and S8
*     -------------------
      fi(2) = K0202 * (de(2)-de(8)) + K0206 * (de(6)+de(12))
      fi(8) = -fi(2)

*     Z-Forces: S3 and S9
*     -------------------
      fi(3) = K0303 * (de(3)-de(9)) - K0305 * (de(5)+de(11))
      fi(9) = -fi(3)

*     X-Moments: S4 and S10
*     ---------------------
      fi( 4) = K0404 * (de(4) - de(10))
```

```
144:        fi(10) = -fi(4)
145:
146:  *     Y-Moments: S5 and S11
147:  *     ---------------------
148:        fi( 5) = K0505 * de(5) + K0511 * de(11) + K0305 * (de(9)-de(3))
149:        fi(11) = K0511 * de(5) + K0505 * de(11) + K0305 * (de(9)-de(3))
150:
151:  *     Z-Moments: S6 and S12
152:  *     ---------------------
153:        fi( 6) = K0606 * de(6) + K0612 * de(12) + K0206 * (de(2)-de(8))
154:        fi(12) = K0612 * de(6) + K0606 * de(12) + K0206 * (de(2)-de(8))
155:
156:  *     Plasticity Code
157:  *     ---------------
158:        iplmax = 0
159:
160:  *     Element Energy
161:  *     --------------
162:        energy = 0.d0
163:
164:        do 10 i=1,nvars
165:           energy = energy + de(i)*fi(i)
166:  10    continue
167:
168:        energy = 0.5d0 * energy
169:
170:        end
```

Lines 1–68 are provided as part of the standard **UelFiDef900** template routine. The idea of any template is to provide developers all the data they might need to calculate the requested output or internal intermediate data.

Lines 69–92 define all the variables that are needed for the local operations. This routine is going to compute an element’s internal force vector. Lines 96–103 retrieve some floating-point User element variables for a specific type 900 element. Notice that the names in the **UelGetFloVar** calls were created by the user in the `*userElement` directive in the model description file. The material identification parameter (`Material`) is utilized as a User property set identifier in lines 105–106 to retrieve the material properties for this particular element.

Computations on lines 110–124 are performed to calculate the beam element’s stiffness coefficients. These stiffness values are then used on lines 128–154, along with the element’s deformations, to determine the element’s internal force components. Finally, the plastic strain code is set to zero and the element’s internal energy are computed on lines 158 and 162–168, respectively. While these computations are very simple, they do demonstrate the general approach for any User element internal force definition routine.

User beam material stiffness matrix definition routine—**UelKmDef900**

The purpose of a User element material stiffness matrix definition routine (such as **UelKmDef900**) is to compute and return the material stiffness matrix for a specific UEL. Each User element material stiffness matrix definition routine called by the **UelKmDef** dispatcher is provided for this purpose. The material stiffness matrix definition routine for this User element is presented below (with line numbers shown on the left for reference purposes):

subroutine UelKmDef900

```
c=deck     UelKmDef900
c=purpose  Compute material stiffness matrix for user-written E900
c=author   --------------------------------------------------------
c=author   Lyle W. Swenson, Jr.  Knowledge Management Systems, Inc.
c=author   --------------------  Ph: (858)259-2773 or (858)481-9907
c=version  December 2001

#if _usage_
*
*     call UelKmDef900 (type,   elt,   nlin, iplast, nnodes,
*                       active, nvars, xe,   de,     km)
*
*     Input Arguments
*     ---------------
*     type    =  element type (=900)
*     elt     =  element number of type TYPE in the model
*     nlin    =  0 - do not use nonlinear strain/displ. relations
*                1 - use nonlinear relations for applicable elements
*     iplast  =  0 - do not use plasticity theory
*                1 - use plasticity theory
*     nnodes  =  number of element nodes
*     active  =  number of active element nodes
*     nvars   =  number of element variables
*     xe      =  element local coordinates
*     de      =  element local deformation vector
*
*     Output Arguments
*     ----------------
*     km      =  material stiffness matrix
*
#endif

************************************************************************
      Subroutine UelKmDef900 (type,   elt,   nlin, iplast, nnodes,
     &                        active, nvars, xe,   de,     km)
************************************************************************

#     include   “keydefs.h”

```

```
      _implicit_none_

#     include   “stndcm.h”

      Integer    type
      Integer    elt
      Integer    nlin
      Integer    iplast
      Integer    nnodes
      Integer    active
      Integer    nvars
      _float_    xe(3,nnodes)
      _float_    de(nvars)
      _float_    km(*)

*     TO BE IMPLEMENTED BY THE USER
*     =============================

      Integer    size

      _float_    A
      _float_    E
      _float_    G
      _float_    Iy
      _float_    Iz
      _float_    J
      _float_    L
      _float_    Mat
      _float_    SDy
      _float_    SDz

      _float_    K0101
      _float_    K0202
      _float_    K0206
      _float_    K0303
      _float_    K0305
      _float_    K0404
      _float_    K0505
      _float_    K0511
      _float_    K0606
      _float_    K0612

*     Retrieve Element And Material Properties
*     ----------------------------------------
      call UelGetFloVar (type,elt,'Area',      A,   size)
      call UelGetFloVar (type,elt,'Iy',        Iy,  size)
      call UelGetFloVar (type,elt,'Iz',        Iz,  size)
      call UelGetFloVar (type,elt,'J',         J,   size)
      call UelGetFloVar (type,elt,'Length',    L,   size)
      call UelGetFloVar (type,elt,'Material',  Mat, size)
      call UelGetFloVar (type,elt,'ShearDefY', SDy, size)
      call UelGetFloVar (type,elt,'ShearDefZ', SDz, size)

      call UelGetFloProp (nint(Mat),'E', E, size)
      call UelGetFloProp (nint(Mat),'G', G, size)

*     Stiffness Coefficients
*     ----------------------
      K0101 = E*A/L

      K0202 = 12*E*Iz/((1+SDy)*L**3)
      K0206 =  6*E*Iz/((1+SDy)*L**2)

      K0303 = 12*E*Iy/((1+SDz)*L**3)
      K0305 =  6*E*Iy/((1+SDz)*L**2)

      K0404 = G*J/L

*     K0505 = (4+SDz)*E*Iy/((1+SDz)*L)
*     K0511 = (2-SDz)*E*Iy/((1+SDz)*L)

      K0606 = (4+SDy)*E*Iz/((1+SDy)*L)
      K0612 = (2-SDy)*E*Iz/((1+SDy)*L)

*     Material Stiffness Matrix
*     -------------------------
      km( 1) =  K0101
      km(22) = -K0101

      km( 3) =  K0202
      km(17) =  K0206
      km(30) = -K0202
      km(68) =  K0206

      km( 6) =  K0303
      km(13) = -K0305
      km(39) = -K0303
      km(58) = -K0305

      km(10) =  K0404
      km(49) = -K0404

      km(15) =  K0505
      km(41) =  K0305
      km(60) =  K0511

      km(21) =  K0606
      km(34) = -K0206
      km(72) =  K0612

      km(28) =  K0101

      km(36) =  K0202
      km(74) = -K0206
```

```
144:
145:        km(45) =  K0303
146:        km(64) =  K0305
147:
148:        km(55) =  K0404
149:
150:        km(66) =  K0505
151:
152:        km(78) =  K0606
153:
154:        end
```

Lines 1–57 are provided as part of the standard **UelKmDef900** template routine. The idea of any template is to provide developers all the data that they might need to calculate the requested output or internal intermediate data.

Lines 58–80 define all the variables that are needed for the local operations. This routine is going to compute an element’s material stiffness matrix.

Lines 84–91 retrieve some floating-point User element variables for this specific type 900 element. Notice that the names in the **UelGetFloVar** calls were created by the user in the `*userElement` directive in the model description file. The material identification parameter (`Material`) is used as a User property set identifier on lines 93–94 to retrieve the material properties for this particular element.

Computations on lines 98–112 are performed to calculate the beam element’s stiffness coefficients. These stiffness values are then used on lines 116–152 to set the element’s material stiffness matrix components. Notice that only the nonzero components need to be set since the matrix work space has been initialized to zero by **STAGS**. While these computations are very simple, they do demonstrate the general approach for any User element material stiffness matrix definition routine.

User beam strain vector definition routine—**UelStrainDef900**

The purpose of a User element strain vector definition routine (such as **UelStrainDef900**) is to compute and return the strain vector for a specific User element at a number of sampling points. Each User element strain vector definition routine called by the **UelStrainDef** dispatcher is provided for this purpose. The strain vector definition routine for this User element is presented below (with line numbers shown on the left for reference purposes):

subroutine UelStrainDef900

```
 1:  c=deck     UelStrainDef900
 2:  c=purpose  Compute strain vector for user-written element E900
 3:  c=author   --------------------------------------------------------
 4:  c=author   Lyle W. Swenson, Jr.  Knowledge Management Systems, Inc.
 5:  c=author   --------------------  Ph: (858)259-2773 or (858)481-9907
 6:  c=version  December 2001
 7:
 8:  #if _usage_
 9:  *
10:  *     call UelStrainDef900 (type,   elt,    nlin,  iplast,
11:  *                           nnodes, active, nvars, nips,
12:  *                           neps,   ix,     xe,    de,
13:  *                           strain)
14:  *
15:  *     Input Arguments
16:  *     ---------------
17:  *     type    =  element type (=900)
18:  *     elt     =  element number of type TYPE in the model
19:  *     nlin    =  =0 - do not use nonlinear strain/displ. relations
20:  *                =1 - use nonlinear relations for applicable elements
21:  *     iplast  =  =0 - do not use plasticity theory
22:  *                =1 - use plasticity theory
23:  *     nnodes  =  number of element nodes
24:  *     active  =  number of active element nodes
25:  *     nvars   =  number of element variables
26:  *     nips    =  number of strain sampling points
27:  *     neps    =  number of strain components
28:  *     ix      =  node permutation array
29:  *     xe      =  nodal coordinates in element system
30:  *     de      =  element local deformation vector
31:  *
32:  *     Output Arguments
33:  *     ----------------
34:  *     strain  =  element strain vector at each sampling point
35:  *
36:  #endif
37:
38:  ************************************************************************
39:         Subroutine UelStrainDef900 (type,   elt,    nlin,  iplast,
     &                             nnodes, active, nvars, nips,
     &                             neps,   ix,     xe,    de,
     &                             strain)
************************************************************************

#     include   “keydefs.h”

      _implicit_none_

#     include   “stndcm.h”

      Integer    type
      Integer    elt
      Integer    nlin
      Integer    iplast
      Integer    nnodes
      Integer    active
      Integer    nvars
      Integer    nips
      Integer    neps
      Integer    ix(active)
      _float_    xe(3,nnodes)
      _float_    de(nvars)
      _float_    strain(neps,nips)

*     TO BE IMPLEMENTED BY THE USER
*     =============================

      _float_    E
      _float_    G
      _float_    Mat
      _float_    Pr

      Integer    i
      Integer    n
      _float_    s(6)
      Integer    size

*     Retrieve Element And Material Properties
*     ----------------------------------------
      call UelGetFloVar (type,elt,'Material', Mat, size)

      call UelGetFloProp (nint(Mat),'E',            E,  size)
      call UelGetFloProp (nint(Mat),'G',            G,  size)
      call UelGetFloProp (nint(Mat),'PoissonRatio', Pr, size)

*     Compute Beam Element Stresses At Each Sampling Point
*     ----------------------------------------------------

      call UelStressDef900 (type,   elt,    nlin,  iplast,
     &                      nnodes, active, nvars, nips,
     &                      neps,   ix,     xe,    de,
 92:       &                      strain)
 93:
 94:  *     Compute Beam Element Strains At Each Sampling Point
 95:  *     ---------------------------------------------------
 96:  *     +------------+
 97:  *     | Strains:   |
 98:  *     |   1. exx   |
 99:  *     |   2. eyy   |
100:  *     |   3. ezz   |
101:  *     |   4. exy   |
102:  *     |   5. exz   |
103:  *     |   6. eyz   |
104:  *     +------------+
105:
106:        n = nips/2
107:
108:        do 10 i=1,n
109:
110:  *        First Node...
111:  *        -------------
112:           call scopud (6,strain(1,i), s)
113:
114:           strain(1,i) = ( s(1) - Pr * (s(2) + s(3)) ) / E
115:           strain(2,i) = ( s(2) - Pr * (s(3) + s(1)) ) / E
116:           strain(3,i) = ( s(3) - Pr * (s(1) + s(2)) ) / E
117:           strain(4,i) = s(4) / G
118:           strain(5,i) = s(5) / G
119:           strain(6,i) = s(6) / G
120:
121:  *        Second Node...
122:  *        --------------
123:           call scopud (6,strain(1,i+n), s)
124:
125:           strain(1,i+n) = ( s(1) - Pr * (s(2) + s(3)) ) / E
126:           strain(2,i+n) = ( s(2) - Pr * (s(3) + s(1)) ) / E
127:           strain(3,i+n) = ( s(3) - Pr * (s(1) + s(2)) ) / E
128:           strain(4,i+n) = s(4) / G
129:           strain(5,i+n) = s(5) / G
130:           strain(6,i+n) = s(6) / G
131:
132:  10    continue
133:
134:        end
```

Lines 1–67 are provided as part of the standard **UelStrainDef900** template routine. The idea of any template is to provide developers all the data they might need to calculate the requested output or internal intermediate data.

Lines 68–76 define all the variables that are needed for the local operations. This routine is going to compute an element’s strain vector at a number of sampling points.

Line 80 retrieves the material identifier for this specific type 900 element. Notice that the names in the **UelGetFloVar** calls were created by the user in the `*userElement` directive in the model description file. The material identification parameter (`Material`) is used as a User property set identifier in lines 82–84 to retrieve the material properties for this particular element.

Because of its formulation, this particular User element computes element stresses from element internal forces (using **UelStressDef900**) and element strains from the element stresses. The element's stresses are computed *via* the call to **UelStressDef900** on lines 89–92. Notice that this stress routine invocation is possible because all of its required arguments are also arguments passed to the strain calculation routine. The stress values are then used on lines 106–132 to set the element's strain components. While these computations are very simple, they do demonstrate the general approach for any User element strain vector definition routine.

User beam stress vector definition routine—UelStressDef900

The purpose of a User element stress vector definition routine (such as **UelStressDef900**) is to compute and return the stress vector for a specific UEL at a number of sampling points. Each User element stress vector definition routine called by the **UelStressDef** dispatcher is provided for this purpose. The stress vector definition routine for this User element is presented below (with line numbers shown on the left for reference purposes):

subroutine UelStressDef900

```
 1:  c=deck     UelStressDef900
 2:  c=purpose  Compute stress vector for user-written element E900
 3:  c=author   --------------------------------------------------------
 4:  c=author   Lyle W. Swenson, Jr.  Knowledge Management Systems, Inc.
 5:  c=author   --------------------  Ph: (858)259-2773 or (858)481-9907
 6:  c=version  December 2001
 7:
 8:  #if _usage_
 9:  *
10:  *     call UelStressDef900 (type,   elt,    nlin,  iplast,
11:  *                           nnodes, active, nvars, nips,
12:  *                           nsig,   ix,     xe,    de,
13:  *                           stress)
14:  *
15:  *     Input Arguments
16:  *     ---------------
17:  *     type    =  element type (=900)
18:  *     elt     =  element number of type TYPE in the model
19:  *     nlin    =  =0 - do not use nonlinear strain/displ. relations
20:  *                =1 - use nonlinear relations for applicable elements
21:  *     iplast  =  =0 - do not use plasticity theory
22:  *                =1 - use plasticity theory
23:  *     nnodes  =  number of element nodes
24:  *     active  =  number of active element nodes
25:  *     nvars   =  number of element variables
26:  *     nips    =  number of stress sampling points
27:  *     nsig    =  number of stress components
28:  *     ix      =  node permutation array
29:  *     xe      =  nodal coordinates in element system
30:  *     de      =  element local deformation vector
31:  *
32:  *     Output Arguments
33:  *     ----------------
34:  *     stress  =  element stress vector at each sampling point
35:  *
36:  #endif
37:
38:  ************************************************************************
39:         Subroutine UelStressDef900 (type,   elt,    nlin,  iplast,
     &                             nnodes, active, nvars, nips,
     &                             nsig,   ix,     xe,    de,
     &                             stress)
************************************************************************

#     include   “keydefs.h”

      _implicit_none_

#     include   “stndcm.h”

      Integer    type
      Integer    elt
      Integer    nlin
      Integer    iplast
      Integer    nnodes
      Integer    active
      Integer    nvars
      Integer    nips
      Integer    nsig
      Integer    ix(active)
      _float_    xe(3,nnodes)
      _float_    de(nvars)
      _float_    stress(nsig,nips)

*     TO BE IMPLEMENTED BY THE USER
*     =============================

      _float_    A
      _float_    Iy
      _float_    Iz
      _float_    J
      _float_    SFt
      _float_    SFy
      _float_    SFz

      _float_    energy
      _float_    fi(12)
      Integer    i
      Integer    iplmax
      Integer    istep
      Integer    n
      _float_    pa
      _float_    pb
      Integer    size
      _float_    y(5)
      _float_    z(5)

*     Retrieve Element And Material Properties
*     ----------------------------------------
      call UelGetFloVar (type,elt,'Area',         A,   size)
      call UelGetFloVar (type,elt,'Iy',           Iy,  size)
      call UelGetFloVar (type,elt,'Iz',           Iz,  size)
      call UelGetFloVar (type,elt,'J',            J,   size)
      call UelGetFloVar (type,elt,'ShearFactorT', SFt, size)
      call UelGetFloVar (type,elt,'ShearFactorY', SFy, size)
      call UelGetFloVar (type,elt,'ShearFactorZ', SFz, size)

*     Retrieve Stress Sampling Points
*     -------------------------------
      call UelGetFloProp (type,'y1', y(1), size)
      call UelGetFloProp (type,'y2', y(2), size)
      call UelGetFloProp (type,'y3', y(3), size)
      call UelGetFloProp (type,'y4', y(4), size)
      call UelGetFloProp (type,'y5', y(5), size)

      call UelGetFloProp (type,'z1', z(1), size)
      call UelGetFloProp (type,'z2', z(2), size)
      call UelGetFloProp (type,'z3', z(3), size)
      call UelGetFloProp (type,'z4', z(4), size)
      call UelGetFloProp (type,'z5', z(5), size)

*     Compute Beam Element Internal Forces -- FI
*     ------------------------------------------
      istep = 0
      pa    = 0.0
      pb    = 0.0

      call UelFiDef900 (type, elt, nlin,   iplast, istep,
    &                  pa,   pb,  active, nvars,  ix,
    &                  de,   fi,  iplmax, energy)

*     Compute Beam Element Stresses At Each Sampling Point
*     ----------------------------------------------------
*     +------------+
*     | Stresses:  |
*     |   1. sxx   |
*     |   2. syy   |
*     |   3. szz   |
*     |   4. sxy   |
*     |   5. sxz   |
*     |   6. syz   |
*     +------------+

      n = nips/2

      do 10 i=1,n

*        First Node...
*        -------------
         stress(1,i) = -fi(1)/A - fi(5)*z(i)/Iy + fi(6)*y(i)/Iz
         stress(2,i) =  0.0
         stress(3,i) =  0.0

```

```
144:           if (i.ne.n) then
145:              stress(4,i) =  fi(4)*z(i)*SFt/J
146:              stress(5,i) = -fi(4)*y(i)*SFt/J
147:              stress(6,i) =  0.0
148:           else
149:              stress(4,i) = -fi(2)*SFy/A
150:              stress(5,i) = -fi(3)*SFz/A
151:              stress(6,i) =  0.0
152:           endif
153:
154:  *        Second Node...
155:  *        --------------
156:           stress(1,i+n) = fi(7)/A + fi(11)*z(i)/Iy - fi(12)*y(i)/Iz
157:           stress(2,i+n) = 0.0
158:           stress(3,i+n) = 0.0
159:
160:           if (i.ne.n) then
161:              stress(4,i+n) = -fi(10)*z(i)*SFt/J
162:              stress(5,i+n) =  fi(10)*y(i)*SFt/J
163:              stress(6,i+n) =  0.0
164:           else
165:              stress(4,i+n) = fi(8)*SFy/A
166:              stress(5,i+n) = fi(9)*SFz/A
167:              stress(6,i+n) = 0.0
168:           endif
169:
170:  10    continue
171:
172:        end
```

Lines 1–67 are provided as part of the standard **UelStressDef900** template routine. The idea of any template is to provide developers all the data they might need to calculate the requested output or internal intermediate data.

Lines 68–86 define all the variables that are needed for the local operations. This routine computes an element’s stress vector at a number of sampling points.

Lines 90–96 retrieve some floating-point User element variables for a specific type 900 element. Notice that the names in the **UelGetFloVar** calls were created by the user in the `*userElement` directive in the model description file.

Lines 100–110 retrieve the sampling points provided in the User property set tagged with the same identifier as the User element identifier. Recall that the sampling points could have been placed in any property set the user might have created—not necessarily the property set (*i.e.*, the one with `id=900`) with the parameters required for the User element type.

This particular User element computes element stresses from element internal force components given the element’s deformations (using **UelFiDef900**). The element’s internal forces are computed *via* the call to **UelFiDef900** on lines 118–120. Notice that this internal force invocation is possible because most of its required arguments are also arguments passed to the stress calculation routine. The internal force values are then used on lines 140–170 to compute the element’s stress components. While these computations are very simple, they do demonstrate the general approach for any User element stress vector definition routine.

User beam strain printing definition routine—**UelPrintStrainDef900**

The purpose of a User element strain printing definition routine (such as **UelPrintStrainDef900**) is to print the strain vector for a specific User element at a number of sampling points. Each User element strain printing routine called by the **UelPrintStrainDef** dispatcher is provided for this purpose. The strain printing definition routine for this User element is presented below (with line numbers shown on the left for reference purposes):

subroutine UelPrintStrainDef900

```
 1:  c=deck     UelPrintStrainDef900
 2:  c=purpose  Print strain vector for a user-written element E900
 3:  c=author   ---------------------------------------------------------
 4:  c=author   Lyle W. Swenson, Jr.  Knowledge Management Systems, Inc.
 5:  c=author   --------------------  Ph: (858)259-2773 or (858)481-9907
 6:  c=version  December 2001
 7:
 8:  #if _usage_
 9:  *
10:  *     call UelPrintStrainDef900 (type,   elt,      nnodes, active,
11:  *                                nips,   neps,     ix,     xe,
12:  *                                strain, maxLines, lines)
13:  *
14:  *     Input Arguments
15:  *     ---------------
16:  *     type      =  element type (=900)
17:  *     elt       =  element number of type TYPE in the model
18:  *     nnodes    =  number of element nodes
19:  *     active    =  number of active element nodes
20:  *     nips      =  number of strain sampling points
21:  *     neps      =  number of strain components
22:  *     ix        =  node permutation array
23:  *     xe        =  nodal coordinates in element system
24:  *     strain    =  element strain vector at each sampling point
25:  *     maxLines  =  number of lines per “page”
26:  *     lines     =  number of lines printed prior to the call
27:  *
28:  *     Output Arguments
29:  *     ----------------
30:  *     lines     =  number of lines printed after the call
31:  *
32:  #endif
33:
34:  ************************************************************************
35:        Subroutine UelPrintStrainDef900 (type,   elt,      nnodes, active,
36:       &                                 nips,   neps,     ix,     xe,
37:       &                                 strain, maxLines, lines)
38:  ************************************************************************
39:
```

```
#     include   “keydefs.h”

      _implicit_none_

#     include   “stndcm.h”

      Integer    type
      Integer    elt
      Integer    nnodes
      Integer    active
      Integer    nips
      Integer    neps
      Integer    ix(active)
      _float_    xe(3,nnodes)
      _float_    strain(neps,nips)
      Integer    maxLines
      Integer    lines

*     TO BE IMPLEMENTED BY THE USER
*     =============================

      Integer    i
      Integer    j

*     CHECK FOR NEW HEADER
*     --------------------
      if (lines+nips .gt. maxLines) then
         write(not,100) type
         lines = 6
     endif

*     PRINT STRAINS AT EACH SAMPLING POINT
*     ------------------------------------
      do 10 j=1,nips
         write(not,200) elt, j, (strain(i,j),i=1,neps)
10    continue

      write(not,300)
      lines = lines + nips + 1

100   format(/' -------------------------------'
     &       /' Strain for User Element Type',i4
     &       /' -------------------------------'
     &      //' Element  Point',7x,'Exx',11x'Eyy',11x,'Ezz',11x,
     &        'Exy',11x,'Exz',11x,'Eyz'
     &       /' -------  -----',6('  ------------'))

200   format(i8,i7,1p6e14.5)

300   format(' ')

      end
```

Lines 1–60 are provided as the core part of the standard **UelPrintStrainDef900** template routine. The idea of any template is to provide developers all the data they might need to calculate the requested output or internal intermediate data.

The templates that are supplied with **STAGS** for printing strain (*i.e.*, strain printing definition routines **UelPrintStrainDef9xx**) also include a simple implementation to provide users a head-start on specialization. The sample implementation is described in the remainder of this section.

Lines 61–62 define all the variables needed for the local operations.

Lines 66–69 check to determine if a new header needs to be printed before the strain components are printed and prints the header if it is required.

Lines 73–75 print the element's strain components at each of the sampling points.

Finally, lines 77–78 print a spacer line and increments the output line count argument by the number of lines just printed.

The sample strain printing implementations assume that there are six (6) strain components with a certain ordering (*i.e.*, `Exx, Eyy, Ezz, Exy, Exz` and `Eyz`). If your User element strain calculations meet these conditions, then the **UelPrintStrainDef9xx** templates can be used as they are. Otherwise, only minor modifications will probably be required. For this example, no modifications to the **UelPrintStrainDef900** template were required.

Beam stress printing definition routine—UelPrintStressDef900

The purpose of a User element stress printing definition routine (like **UelPrintStressDef900**) is to print the stress vector for a specific UEL at a number of sampling points. Each User element stress printing routine called by the **UelPrintStressDef** dispatcher is provided for this purpose. The stress printing definition routine for this User element is presented below (with line numbers shown on the left for reference purposes):

subroutine UelPrintStressDef900

```
 1:  c=deck     UelPrintStressDef900
 2:  c=purpose  Print stress vector for a user-written element E900
 3:  c=author   -------------------------------------------------------
 4:  c=author   Lyle W. Swenson, Jr.  Knowledge Management Systems, Inc.
 5:  c=author   --------------------  Ph: (858)259-2773 or (858)481-9907
 6:  c=version  December 2001
 7:
 8:  #if _usage_
 9:  *
10:  *     call UelPrintStressDef900 (type,   elt,      nnodes, active,
11:  *                                nips,   nsig,     ix,     xe,
12:  *                                stress, maxLines, lines)
13:  *
14:  *     Input Arguments
15:  *     ---------------
16:  *     type      =  element type (=900)
17:  *     elt       =  element number of type TYPE in the model
18:  *     nnodes    =  number of element nodes
19:  *     active    =  number of active element nodes
20:  *     nips      =  number of stress sampling points
21:  *     nsig      =  number of stress components
22:  *     ix        =  node permutation array
23:  *     xe        =  nodal coordinates in element system
24:  *     stress    =  element stress vector at each sampling point
25:  *     maxLines  =  number of lines per “page”
26:  *     lines     =  number of lines printed prior to the call
27:  *
28:  *     Output Arguments
29:  *     ----------------
30:  *     lines     =  number of lines printed after the call
31:  *
32:  #endif
33:
34:  ************************************************************************
35:        Subroutine UelPrintStressDef900 (type,   elt,      nnodes, active,
36:       &                                 nips,   nsig,     ix,     xe,
37:       &                                 stress, maxLines, lines)
38:  ************************************************************************
39:
```

```
#     include   “keydefs.h”

      _implicit_none_

#     include   “stndcm.h”

      Integer    type
      Integer    elt
      Integer    nnodes
      Integer    active
      Integer    nips
      Integer    nsig
      Integer    ix(active)
      _float_    xe(3,nnodes)
      _float_    stress(nsig,nips)
      Integer    maxLines
      Integer    lines

*     TO BE IMPLEMENTED BY THE USER
*     =============================

      Integer    i
      Integer    j

*     CHECK FOR NEW HEADER
*     --------------------
      if (lines+nips .gt. maxLines) then
         write(not,100) type
         lines = 6
     endif

*     PRINT STRESS AT EACH SAMPLING POINT
*     -----------------------------------
      do 10 j=1,nips
         write(not,200) elt, j, (stress(i,j),i=1,nsig)
10    continue

      write(not,300)
      lines = lines + nips + 1

100   format(/' -------------------------------'
     &       /' Stress for User Element Type',i4
     &       /' -------------------------------'
     &      //' Element  Point',7x,'Sxx',11x'Syy',11x,'Szz',11x,
     &        'Sxy',11x,'Sxz',11x,'Syz'
     &       /' -------  -----',6('  ------------'))

200   format(i8,i7,1p6e14.5)

300   format(' ')

      end
```

Lines 1–60 are provided as the core part of the standard **UelPrintStressDef900** template routine. The idea of any template is to provide developers all the data they might need to calculate the requested output or internal intermediate data.

The templates that are provided with **STAGS** for printing stress (*i.e.*, stress printing definition routines **UelPrintStressDef9xx**) also include a simple implementation to provide users a head-start on specialization. The sample implementation is described in the remainder of this section.

Lines 61–62 define all the variables needed for the local operations.

Lines 66–69 check to determine if a new header needs to be printed before the stress components are printed and prints the header if required.

Lines 73–75 print the element's stress components at each of the sampling points.

Finally, lines 77–78 print a spacer line and increments the output line count argument by the number of lines just printed.

The sample stress printing implementations assume that there are six (6) stress components with a certain ordering (*i.e.*, `Sxx`, `Syy`, `Szz`, `Sxy`, `Sxz` and `Syz`). If your User element stress calculations meet these conditions, then the **UelPrintStressDef9xx** templates can be used as they are. Otherwise, only minor modification will probably be required. For this example, no modifications to the **UelPrintStressDef900** template were required.

Analysis and Results

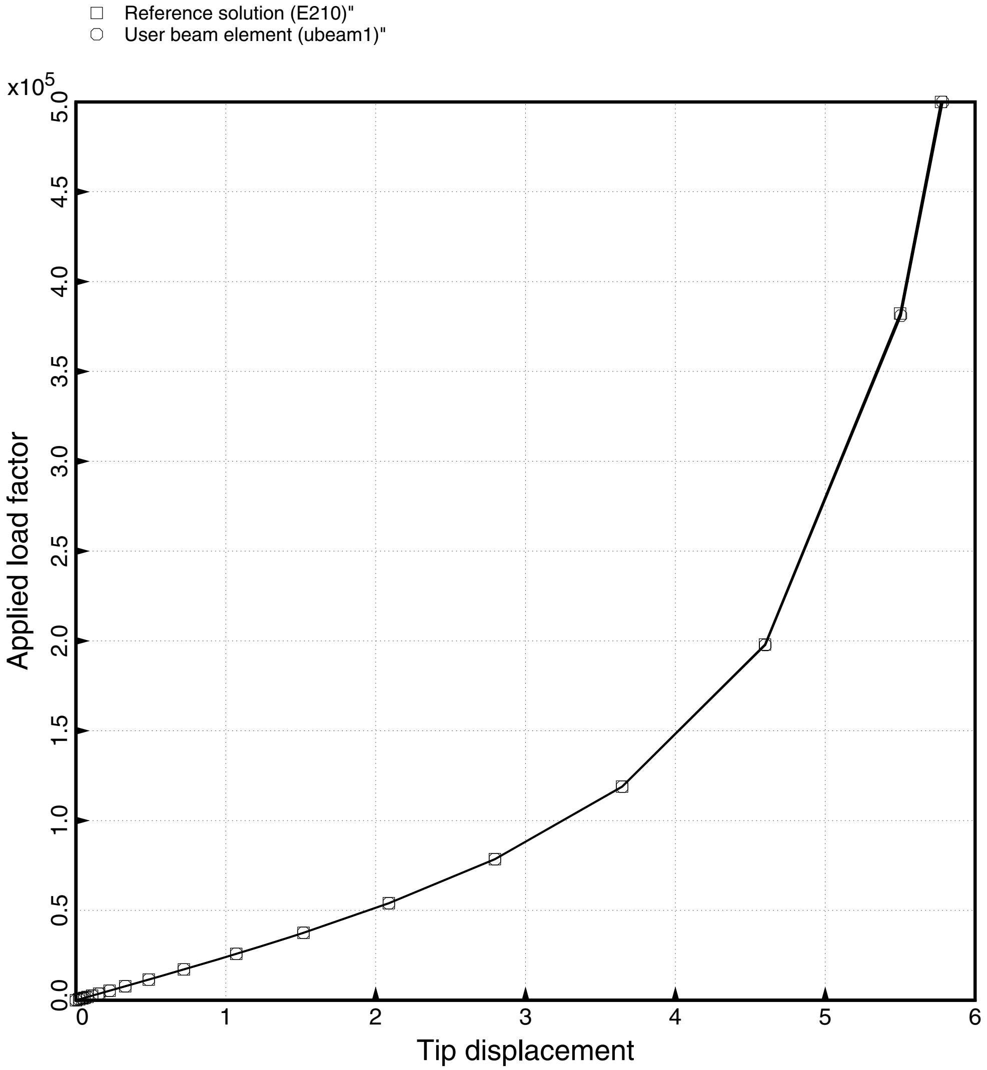
A nonlinear static analysis was performed for the beam model and User element described above. The **STAGS** solution description file (`ubeam1.bin`) is given below (with line numbers on the left shown for reference purposes):

ubeam1.bin

```
 1:  User Beam Nonlinear Analysis
 2:  3 1 1 0  0 0 0  1        $ b1  -- indic,ipost,ilist,icor,..,isolvr
 3:  1 0 0                    $ b2  -- icpact,iter,iprim,...
 4:  500.0  500.0  500000.0   $ c1  -- stld,step,facm,...
 5:  0 0 5  -20 0  1.0e-6     $ d1  -- istart,nsec,ncut,newt,nstrat,delx,...
 6:  0                         $ et1 -- npath,...
```

The applied load magnitudes (500,000 lb) are highly unrealistic here (*i.e.*, they are extremely large). These values were chosen to create large nonlinear displacements and rotations and to demonstrate the efficacy of **STAGS'** corotation architecture. No special work is required on the part of users or developers to benefit from these powerful corotational features. Although linear element formulations will not suffice for all geometrically nonlinear problems, there are many situations were materially linear elements with automatic corotational corrections yield excellent results.

A load versus displacement plot is shown in the following Figure for the beam tip in the z–direction. For comparison purposes the plot also includes the result for the same problem using **STAGS' E210** beam elements. Although the **E210** element uses a nonlinear strain-displacement formulation, for this problem the results are virtually indistinguishable.



14
The Element Library

14.1 Organization

This Chapter contains a very brief (summary) description of each of the “standard” and “special-purpose” elements that are implemented in the current version of the **STAGS** program. Element definition *via* User-written subroutines is discussed in Chapter 12 of this document, and the construction and utilization of User-defined elements is discussed (briefly) in Chapter 13. The ***STAGS** Elements Manual* contains fuller descriptions and discussions of many (but not all) of the standard and special-purpose elements that are summarized here. It also contains essential information about the construction and utilization of User-defined elements. As in the ***STAGS** Elements Manual*, the standard and special-purpose **STAGS** elements are organized here in six main groups:

- “spring” elements
- “beam” elements
- shell and mesh-transition shell elements
- sandwich and mesh-transition sandwich elements
- solid elements
- contact elements

User-defined elements are described in the preceding Chapter and in the ***STAGS** Elements Manual*, and will not be discussed here. The discussion of each element is accompanied by a figure that contains a graphical representation of that element. Some common symbols used in the figures are:

- ⓝ – node *n*
- $\boxed{\text{n}}$ – side *n*
- × n – integration point *n*

14.2 Algorithm for Determining the Element Frame

The origin of the element frame (x', y', z') is located at node 1, with the nodes numbered in *counterclockwise* order, *corner nodes first*. Although this numbering is strictly adhered to, for element units the origin (node 1) is selected by **STAGS** to provide the best possible local frame for the element computations. For this reason, the user should avoid stress and strain output in element coordinates, since the local element coordinate system can vary from element to element. As was stated before, the default **STAGS** option for output is in the *shell-wall*, or $(\bar{x}, \bar{y})$ system, thereby avoiding any reference to the element system. By a suitable definition $(\bar{x}, \bar{y})$ for the wall and (ϕ_1, ϕ_2) for the material layers, the user can select whatever coordinate system he wants for the output of these quantities.

The actual algorithm for triangles and quadrilaterals is now described, with (x_g, y_g, z_g) representing the *updated* or *current* global coordinates of the nodal points when corotation is invoked (default). For triangles, x' points from node 1 to node 2. The following formulas determine the orientation of the axes:

$$\begin{aligned} x' &= \frac{x_{g_2} - x_{g_1}}{\left|x_{g_2} - x_{g_1}\right|} \\ r &= x_{g_3} - x_{g_1} \\ z' &= \frac{x' \times r}{|x' \times r|} \\ y' &= z' \times x' \end{aligned} \tag{14.1}$$

where the numerical subscripts refer to the three corner nodes of the triangle. For quadrilaterals, we first determine the normal as the cross product of the diagonals:

$$z' = \frac{(x_{g_3} - x_{g_1}) \times (x_{g_4} - x_{g_2})}{\left|(x_{g_3} - x_{g_1}) \times (x_{g_4} - x_{g_2})\right|} \tag{14.2}$$

The other two axes are determined by

$$\begin{aligned} r &= x_{g_4} - x_{g_1} \\ x' &= \frac{r \times z'}{|r \times z'|} \\ y' &= z' \times x' \end{aligned} \tag{14.3}$$

For beams, we first determine the initial element system using an *auxiliary node*. This auxiliary node is along the shell normal with its origin at node 1 (in the case of shell units), or it is given by the user (element units). In all cases, x' is determined by the vector joining the endpoints of the beam:

$$x' = \frac{x_{g_2} - x_{g_1}}{\left|x_{g_2} - x_{g_1}\right|} \tag{14.4}$$

For shell units, the initial system follows

$$\begin{aligned} r &= x_{g_3} - x_{g_1} \\ y' &= \frac{r \times x'}{|r \times x'|} \\ z' &= x' \times y' \end{aligned} \tag{14.5}$$

whereas for the element units

$$\begin{aligned} r &= x_{g_3} - x_{g_1} \\ z' &= \frac{x' \times r}{|x' \times r|} \\ y' &= z' \times x' \end{aligned} \tag{14.6}$$

or the same as for triangles (14.1). In order obtain the element system for a current configuration using the corotational option, it is necessary to account for both the translation and rotation of the two endpoint nodes. Initially, the *nodal orientation* for both nodes is taken to be the same as in the initial element system. In subsequent steps in the analysis, both the coordinates and the nodal orientations change. **STAGS** keeps track of the nodal orientations by storing the rotation $\mathbf{T}$ necessary to take the node from its initial position to the current position. The current orientation of node *a* is

$$\mathbf{R}_a = \mathbf{T}_a \mathbf{E}_0 \tag{14.7}$$

where $\mathbf{E}_0$ is the initial element system determined from (14.5) or (14.6). After the initial step, the beam system is determined as follows:

$$
\begin{aligned}
x' &= \frac{x_{g_2} - x_{g_1}}{\left|x_{g_2} - x_{g_1}\right|} \\
\mathbf{R}_{1/2} &= \mathrm{int}(\mathbf{R}_1, \mathbf{R}_2) \\
y' &= \hat{\mathbf{r}}_2 - (x' \cdot \hat{\mathbf{r}}_2)\left(\frac{\hat{\mathbf{r}}_1 + x'}{1 + x' \cdot \hat{\mathbf{r}}_1}\right) \\
z' &= \hat{\mathbf{r}}_3 - (x' \cdot \hat{\mathbf{r}}_3)\left(\frac{\hat{\mathbf{r}}_1 + x'}{1 + x' \cdot \hat{\mathbf{r}}_1}\right)
\end{aligned}
\tag{14.8}
$$

where the expression "$\mathrm{int}(\mathbf{R}_1, \mathbf{R}_2)$" is shorthand for determining the triad that is the midpoint interpolation of triads $\mathbf{R}_1$ and $\mathbf{R}_2$, and where $\hat{\mathbf{r}}_i$ is the ith *column* of the matrix $\mathbf{R}_{1/2}$. The last equation of (14.8) is the result of rotating the *interpolated* $\hat{\mathbf{r}}_1$ axis in $\mathbf{R}_{1/2}$ until it coincides with the line joining the endpoints of the beam element; there is a unique formula for rotating $\mathbf{R}_{1/2}$ the *minimum possible amount* until the two x axes coincide.

14.3 “Spring” Elements

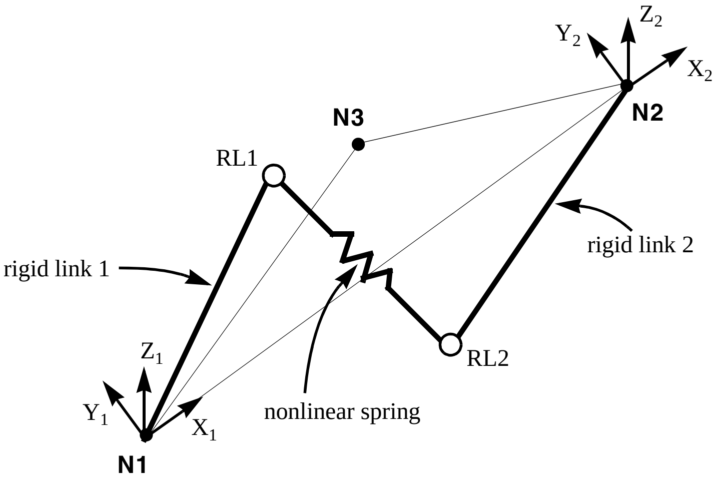
The current version of the **STAGS** program has the following four ***E100**-series* “spring” elements:

- the **E110** Mount element
- the **E120** Rigid Link element
- the **E121** Soft Link element
- the **E130** Generalized Fastener element

For geometric reasons, all of these elements are called “spring” elements. The **E120** (rigid link) element is considered to be a *standard* element; but the **E110** (mount), **E121** (soft link) and **E130** (generalized fastener) elements are considered to be *special-purpose*—for reasons that should be clear from the descriptions in the next four subsections.

E110 Mount element

The **E110** mount element, shown in Figure 14.1, uses a special nonlinear spring that is capable of modeling a User-defined displacement-velocity-force profile. The action of the force resulting from the extension and/or motion of the nonlinear spring's end-points can be applied with an offset from the element's nodes. This is achieved using rigid links connecting the element's nodes (denoted **N1** and **N2**) and the nonlinear spring's end-points (see Figure 14.1). Rigid links provide a method for defining rotational stiffness in addition to axial spring stiffness. Geometry for the node **N1** and node **N2** rigid links is expressed in the node's local element coordinate system (X_1,Y_1,Z_1) and (X_2,Y_2,Z_2), respectively, as shown in Figure 14.1. The coordinate X1 is in the direction of the line connecting **N1** and **N2**. The Y_1 axis is normal to X_1 and in the plane defined by **N1**, **N2**, and **N3**, completing a right-handed system. (Clearly, node **N3** must not lie on the same line as **N1** and **N2**.) **N3** can be either a structural node or a dummy node, defined only for reference to the mount. Any freedoms defined on dummy nodes are ignored. For rigid link 1, the origin of the (X_1,Y_1,Z_1) system is situated at **N1**, and the distance $RL1_x$, $RL1_y$, and $RL1_z$ are expressed in this system. For rigid link 2, the (X_2,Y_2,Z_2) system, with origin at **N2**, is used to express the distances $RL2_x$, $RL2_y$, and $RL2_z$. The component values can be positive, negative, or zero. When all components for a rigid link are zero, the rigid link does not exist. See Figure 14.1.



- nodes **N1**, **N2** and **N3** define the (X_1,Y_1) plane
- (X_1,Y_1,Z_1) is analogous to (x', y', z') in the **E210** Beam
- (X_2,Y_2,Z_2) has origin at node 2, and has the same directions as (X_1,Y_1,Z_1)
- point RL1 is defined in (X_1,Y_1,Z_1) coordinates
- point RL2 is defined in (X_2,Y_2,Z_2) coordinates

Figure 14.1 **E110** Mount element

E120 Rigid link element

The **E120** rigid link element, shown in Figure 14.2, constrains the distance between two nodes (**N1** and **N2**) to be an invariant during an analysis. The displacements of node **N2** are dependent on the displacements and rotations of node **N1** through a rigid-link constraint equation, which is enforced *via* Lagrange multipliers (see Figure 14.2), and the more complete discussion of this element in the ***STAGS*** *Elements Manual*. Note that the rotations for **N2** are not constrained by the motion of **N1**; if **N2** rotations are to be constrained, then the constraints must be explicitly specified, or the reference node **N3** must have a nonzero value. In the latter case, **STAGS** will generate partial compatibility constraints (see records G-2) constraining the rotations of **N2** to be the same as those of **N1**.

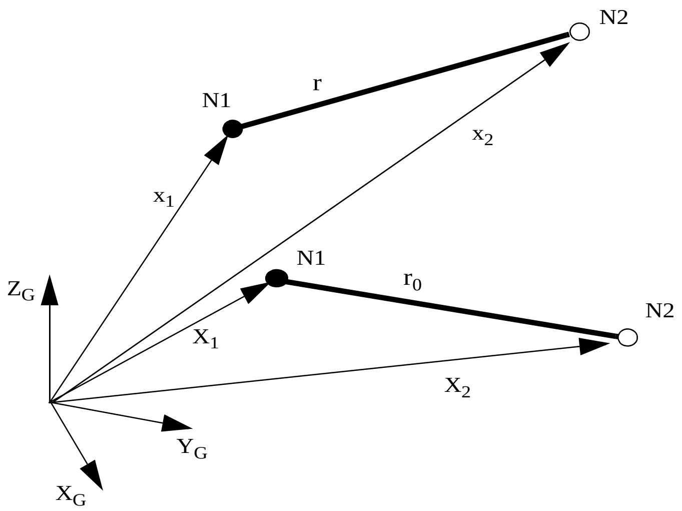


Figure 14.2 **E120** Rigid link element

E121 Soft link element

The three-node **E121** soft link element, shown in Figure 14.3, has been designed for use at junctions between surfaces idealized by shell elements and assemblages of solid elements. The **E121** element forces two solid-element nodes (**N_1** and **N_k**) at a junction to remain “straight,” or aligned along the shell normal $\hat{z}$ of the shell node **N_0** to which they are joined. The shell normal, in turn, rotates rigidly with the shell node in response to equilibrium. The position of the shell node can be described as a linear weighted average of the solid nodes through the thickness. The solid element nodes are free to move along the shell normal—allowing for stress relief in the thickness direction, consistent with a plane-stress

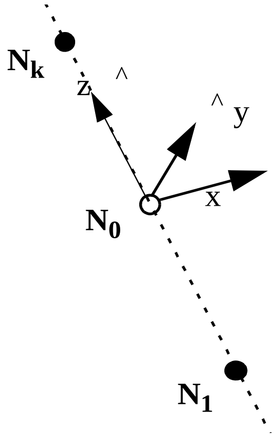
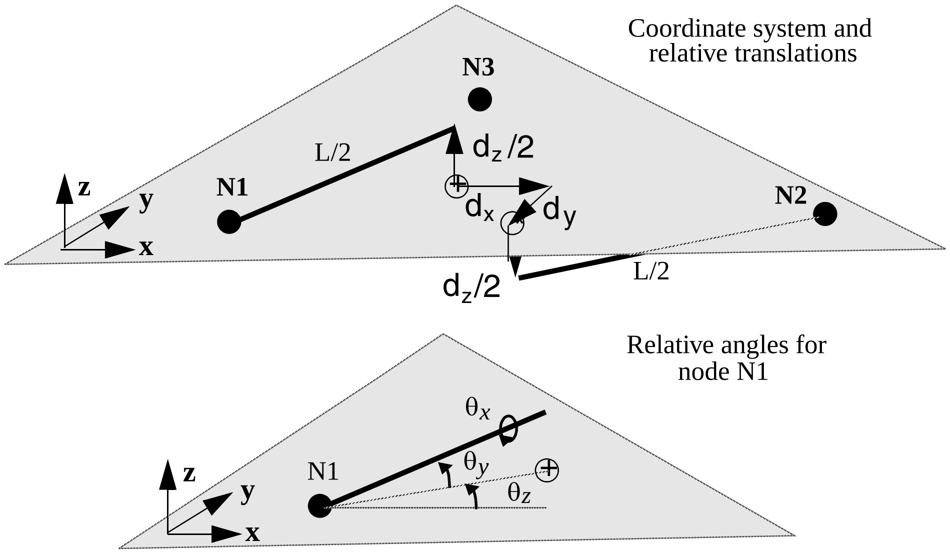


Figure 14.3 **E121** Soft link element

approximation. For a full discussion of this element, please see the ***STAGS*** *Elements Manual*.

E130 Generalized fastener element

The **E130** fastener element is shown in Figure 14.4:



Coordinate system and relative translations
N3
L/2
d_z /2
z
y
x
N1
d_x
d_y
N2
d_z/2
L/2
Relative angles for node N1
θ_x
θ_y
θ_z
z
y
x
N1

Figure 14.4 Fastener element local coordinates, displacements, and rotations

The **E130** element is a generalization of the **E110** Mount with the provision of *six* hyperelastic and/or elastic-plastic spring functions (see Figure 7.1 “Degree-of-Freedom Directions at an Auxiliary Node” on page 7-6), with a potentially different function for each of the three local translations and rotations. The local directions are illustrated in Figure 14.4 on page 14-8, where we find that the local x axis lies along the line between the first two nodes, labeled **N1** and **N2** in the figure. The local z axis is normal to the plane determined by **N1**, **N2**, and the *reference node* **N3**. The y axis completes a right-hand orthogonal system. Before deformation, the direction vector along the line between **N1** and **N2** is split evenly into two *rigid links* of length *L/2*. Local deformational rotation and translation of each node brings these links into new positions illustrated in the top half of the picture. The translational deformations are labeled near the center of the triangle, where the open circles denote the projection of the ends of the links onto the plane. If $\mathbf{u}_i$ and θ_i are the local displacement and rotation vectors belonging to **N1** or **N2** for i = 1 or 2 respectively, then the displacement of the tip of the link is

$$\mathbf{d}_i = \frac{\theta_i \times \mathbf{x}_{12}^i}{2} + \mathbf{u}_i \tag{14.9}$$

Here, $\mathbf{x}_{12}^i$ is the vector that points *from* the node i to the other node, which also means that $\mathbf{x}_{12}^2$ is $-\mathbf{x}_{12}^1$. The bottom half of the figure shows the deformational angles for node N1. θ_x is the twist around the link in the x direction, θ_y is the counter-clockwise out-of-plane angle, and θ_z is the in-plane angle. The relative translations and rotations are

$$\begin{aligned} \hat{\mathbf{d}} &= \mathbf{d}_2 - \mathbf{d}_1 \\ \hat{\theta} &= \theta_2 - \theta_1 \end{aligned} \tag{14.10}$$

The nodal displacements by this time have been passed through the same corotational software as is used for the **E210** beam. This insures that any rigid motion of the fastener has been eliminated, and consequently, that the deformational displacements are small for all practical cases.

The potential energy is a function only of the local displacements $\hat{\mathbf{d}}$ and $\hat{\theta}$:

$$U(\hat{\mathbf{d}}, \hat{\theta}) = \sum_{i=1}^{3} [g_i(\hat{d}^i) + h_i(\hat{\theta}^i)] \tag{14.11}$$

where the index i refers to *components*. If the local freedoms are ordered as

$$\hat{\mathbf{d}}^T = \left\{ \hat{\mathbf{d}}^T \ \hat{\theta}^T \right\}, \tag{14.12}$$

and the nodal freedoms are ordered as

$$\bar{\mathbf{d}}^T = \left\{ \mathbf{d}_1^T\ \theta_1^T\ \mathbf{d}_2^T\ \theta_2^T \right\}, \tag{14.13}$$

and if we define the moment arm as

$$L_{12} = \frac{\mathbf{x}_{12}}{2}, \tag{14.14}$$

then equations (14.9) and (14.10) can be expressed as the matrix equation

$$\begin{aligned} \hat{\mathbf{d}} &= \hat{\mathbf{P}}\bar{\mathbf{d}} \\ \hat{\mathbf{P}} &= \begin{bmatrix} -\mathbf{I} & \tilde{L}_{12} & \mathbf{I} & -\tilde{L}_{12} \\ \mathbf{0} & -\mathbf{I} & \mathbf{0} & \mathbf{I} \end{bmatrix}, \end{aligned} \tag{14.15}$$

where we have used the tilde notation on the moment arms L_{12} to denote the equivalent skew-symmetric matrix. If we take the first derivative of equation (14.11) and use the chain rule and equation (14.15), the nodal forces become

$$\begin{aligned} \mathbf{f} &= \mathbf{P}\ \mathbf{f} \\ \hat{\mathbf{f}} &= \begin{Bmatrix} \mathbf{g}' \\ \mathbf{h}' \end{Bmatrix}, \end{aligned} \tag{14.16}$$

where we have defined the *six primitive spring forces* from the first variation of equation (14.9) as a function of the local displacements:

$$\begin{aligned} \mathbf{g}' &= \frac{\partial \mathbf{g}}{\partial \hat{\mathbf{d}}} \\ \mathbf{h}' &= \frac{\partial \mathbf{h}}{\partial \hat{\theta}} \end{aligned} \tag{14.17}$$

Since the potential energy itself is not needed to generate forces for the equilibrium equations, $\mathbf{g}'$ and $\mathbf{h}'$ can be defined directly by user input in the form of tables (or possibly from a User-written subroutine). Local forces for a particular point are linearly interpolated from the values in the table, and the local tangent stiffness is numerically computed from the derivatives of these forces and expressed as a 6x6 diagonal matrix $\hat{\mathbf{K}}$. From the chain rule and equations (14.15) and (14.16), we obtain the final nodal tangent stiffness:

$$\bar{\mathbf{K}} = \hat{\mathbf{P}}^T\hat{\mathbf{K}}\hat{\mathbf{P}} \tag{14.18}$$

Each relative displacement freedom can be matched up with a different nonlinear spring expressed as a Mount Table defined in the I-4 “material” records. At present, **E130** fastener elements do not allow for velocity-dependent nonlinear spring response (if velocities are included in the table, the zero value is used). Otherwise, any force-deflection curve is acceptable. Type **E130** elements must be referenced in an element unit.

14.4 "Beam" Elements

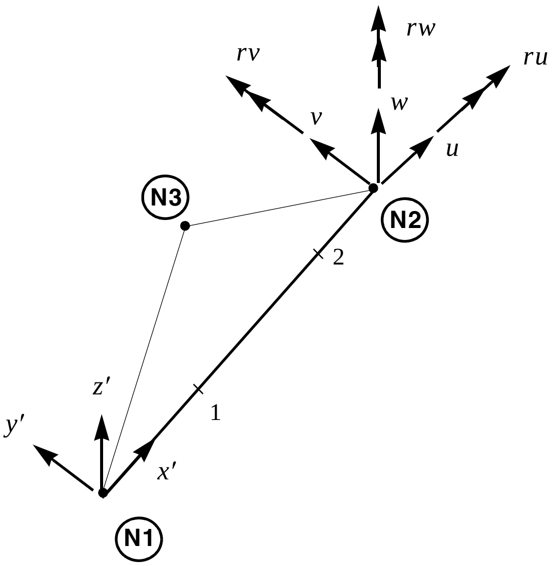
The current version of the **STAGS** program has the following two ***E200**-series* "beam" elements:

- the **E210** Beam element
- the **E250** Planar Boundary Condition element

For historical (and geometric) reasons, both of these elements are called "beam" elements. The **E210** (beam) element is a *standard* single- or multiple-component beam element; but the **E250** (Planar Boundary Condition) "element" is considered to be *special*—for reasons that should be clear from the descriptions in the next two subsections.

E210 Beam element

The **E210** beam element, shown in Figure 14.5, is “classic” in all senses of the word. Its cross-section geometry, specified *via* J-series Cross-Section records described in Chapter 5 of this document, is uniform along the length of the beam.



$$r_{12} = r_2 - r_1$$

$$r_{13} = r_3 - r_1$$

$$x' = \frac{r_{12}}{|r_{12}|}$$

$$z' = \frac{x' \times r_{13}}{|x' \times r_{13}|}$$

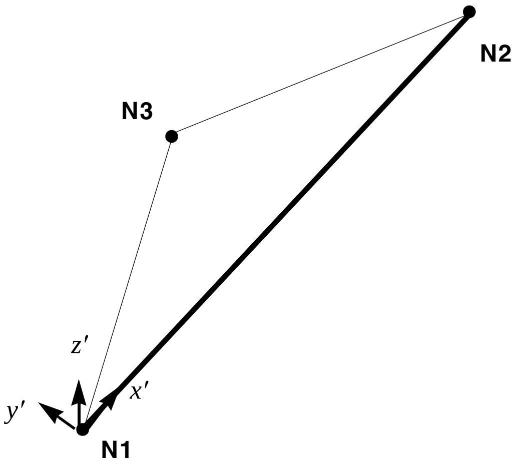
$$y' = z' \times x'$$

- nodes **N1**, **N2** and **N3** define the (x', y') plane
- z' is normal to the (x', y') plane
- (x', y', z') – element coordinate system

Figure 14.5 **E210** Beam element

E250 Planar boundary condition element

The **E250** Planar Boundary Condition “element”* in **STAGS,** shown in Figure 14.6, is **STAGS**’ response to the fact that there are situations that arise where the analyst wishes to constrain a section through or along a structure to remain in a specified plane but be free to move otherwise. This constraint can be visualized as an imaginary cut through the structure with the part that is on one side of the boundary modeled by FEM methods and the part that is on the other side of the boundary simulated by the planar (moving plane) boundary. Such a



(x', y', z')	– element coordinate system (see **E210** Beam)
$(\hat{x}, \hat{y}, \hat{z})$	– updated nodal orientation coordinate system
r_1	– coordinates of node **N1**
r_2	– coordinates of node **N2**
d_1	– displacement at node **N1**
d_2	– displacement at node **N2**

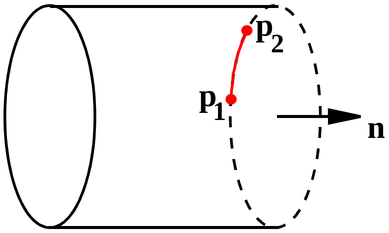
A planar boundary condition is enforced by the following:

- $(\hat{x}, \hat{y}, \hat{z}) = (x', y', z')$ initially
- $\hat{z}_1 \bullet ((r_2 + d_2) - (r_1 + d_1)) = 0$
- $\hat{z}_2 \bullet \hat{x}_1 = \hat{z}_2 \bullet \hat{y}_1 = 0$

Figure 14.6 **E250** Planar boundary condition

* See Nour-Omid, S., F.A. Brogan and G.M. Stanley, “*The Computational Structural Mechanics Testbed Structural Element Processor ES6: STAGS Beam Element,*” NASA CR–4359, 1991

moving plane is free to rotate and translate. A special case of this boundary is symmetry, where such a plane is constrained. An example of the moving plane is shown in the following figure:

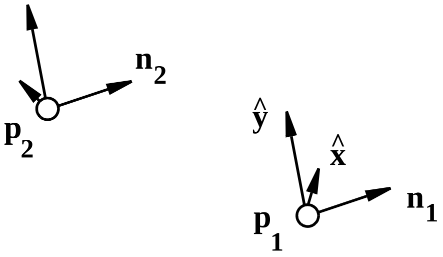


Description of the constraint

The equation for the position of a point in a plane is

$$\begin{gathered} \boldsymbol{n} \bullet \Delta\boldsymbol{p} = \boldsymbol{n}_1 \bullet \Delta\boldsymbol{p} = \boldsymbol{0} \\ \Delta\boldsymbol{p} = \boldsymbol{p}_2 - \boldsymbol{p}_1 \end{gathered} \tag{14.19}$$

where **n** is the normal to the plane, and $\mathbf{p}_1$ is already assumed to lie in the plane. It follows that $\mathbf{p}_2$ must also lie in the plane defined by **n** if equation (14.19) is satisfied. One can see how a full boundary line can be constructed. First allow the first point $\mathbf{p}_1$ to define the position of the plane. If we apply equation (14.19) to this segment, $\mathbf{p}_2$ must also lie in the plane. By induction, we can continue the line as long as desired by enforcing additional points in succession. The only requirement is that these points must originally satisfy equation (14.19) in the *undeformed* configuration. This is achieved by using a third node (labeled **N3** in Figure 14.6), to determine the initial orientation of the plane containing **N1**, **N2** and **N3**. Because of our ability to construct the entire boundary with individual coplanar segments that are linked together, we only need to consider one segment—shown in the figure above. For shell structures, we also have rotational freedoms that must leave any normal to the plane unchanged. This constraint is best achieved by the following construction:



Let us assume that $\boldsymbol{n}_1 = \boldsymbol{n}$ is normal to the plane. Then the following will allow free rotation about $\mathbf{n}_2$ but will leave the normal at the new point $\mathbf{p}_2$ unchanged:

$$\begin{aligned} \hat{x} \bullet \boldsymbol{n}_2 &= \mathbf{0} \\ \hat{y} \bullet \boldsymbol{n}_2 &= \mathbf{0} \end{aligned} \tag{14.20}$$

If we assume that the auxiliary vectors $\hat{x}$ and $\hat{y}$ rotate rigidly along with the normal $\mathbf{n}_1$, the second normal $\mathbf{n}_2$ will remain parallel to $\mathbf{n}_1$ no matter how much that triad rotates. $\hat{x}$ and $\hat{y}$ are otherwise arbitrary and are easily constructed, for example, by using the vector joining the two nodes and completing a right hand system. Thus, equations (14.19) and (14.20) taken together are three nonlinear constraints that are valid no matter how large the subsequent motion of the system may be.

Constraint kinematics

The unit vectors $\hat{x}$, $\hat{y}$ and $\mathbf{n}_1$ rotate rigidly in response to rotations at node $\mathbf{p}_1$ from their initial positions $\hat{x}_{\mathbf{0}}$, $\hat{y}_{\mathbf{0}}$ and $(\boldsymbol{n}_{\mathbf{1}})_{\mathbf{0}}$, where the rotation of $\mathbf{n}_1$ is possible because the plane in question may rotate. This rotation is expressed by a triad $\Delta\mathbf{R}$ formed from the product of rotations that are required to satisfy equilibrium. The kinematic equations are

$$\begin{aligned} \hat{\mathbf{x}} &= \Delta\mathbf{R}\hat{\mathbf{x}}_0 \\ \hat{\mathbf{y}} &= \Delta\mathbf{R}\hat{\mathbf{y}}_0 \\ \mathbf{n_1} &= \Delta\mathbf{R}(\mathbf{n}_1)_0 \\ \Delta\mathrm{R} &\leftarrow \exp(\delta\tilde{\omega})\Delta\mathbf{R} \end{aligned} \tag{14.21}$$

where $\delta\omega$ is the skew-symmetric (tilde symbol) matrix that is constructed from the rotation increments derived from the solution of the displacement equations, and where the last equation in this set expresses the update or correction of the triad from the previous iteration.

Enforcement of the constraint

Equations (14.19) and (14.20) can be enforced by adding the constraints to the potential energy *via* Lagrange multipliers. To prevent numerical difficulties with the stiffness factorization operation, it is essential to augment this constraint with a "penalty" function consisting of functions that are identically zero when equations (14.19) and (14.20) are satisfied. These additional terms do not affect the resulting displacement field. The modified potential function takes the simple form:

$$\begin{aligned}\Pi &= U(\mathbf{p}_1\ ,\mathbf{p}_2\ \ldots) + \beta \bullet \mathbf{n}_2 + \lambda_p \Delta\mathbf{p} \bullet \mathbf{n}_1 \\ &+ \frac{s}{2}\left[\ 1 - (\mathbf{n}_1 \bullet \mathbf{n}_2)^2 + (\Delta\mathbf{p} \bullet \mathbf{n}_1)^2\ \right] \\ \beta &= \lambda_x \hat{\mathbf{x}} + \lambda_y \hat{\mathbf{y}}\end{aligned} \tag{14.22}$$

where U is the ordinary finite element potential function, s is the penalty scaling constant, and the λ are Lagrange multipliers. Contributions to the internal force are computed by taking the variation of equation (14.22), with the following contributions from the constraints in equation (14.22):

$$\begin{aligned} f_1 &= -(\lambda_p + s\Delta\mathbf{p} \bullet \mathbf{n}_1)\mathbf{n}_1 \\ m_1 &= -\mathbf{m}_2 + \Delta\mathbf{p} \times \mathbf{f}_1 \\ f_2 &= -\mathbf{f_1} \\ m_2 &= -\beta \times \mathbf{n}_2 + s\mathbf{n}_1 \times \mathbf{n}_2 \\ f_{\lambda_p} &= \Delta\mathbf{p} \bullet \mathbf{n}_1 \\ f_{\lambda_x} &= \hat{\mathbf{x}} \bullet \mathbf{n}_2 \\ f_{\lambda_y} &= \hat{\mathbf{y}} \bullet \mathbf{n}_2 \end{aligned} \tag{14.23}$$

The reader will notice that $\mathbf{f}_1$ is the force on the first node that is required to constrain the second node to lie on the plane and that there is obviously an equal and opposite reaction $\mathbf{f}_2$ at the second node. The moment $\mathbf{m}_1$ required to align $\mathbf{n}_2$ with $\mathbf{n}_1$ is opposed by $\mathbf{m}_2$. $\mathbf{m}_1$ also has the additional moment $\Delta\mathbf{p} \times \mathbf{f}_1$ that is generated by the pair of forces $\mathbf{f}_1$ and $\mathbf{f}_2$. If equations (14.19) and (14.20) are satisfied, equation (14.23) simplifies to (since $\mathbf{n}_1 \times \mathbf{n}_2$ must also vanish):

$$\begin{aligned} f_1 &= -\lambda_p \mathbf{n}_1 \\ m_1 &= -\mathbf{m}_2 + \Delta\mathbf{p} \times \mathbf{f}_1 \\ f_2 &= -\mathbf{f_1} \\ m_2 &= -\beta \times \mathbf{n}_2 \\ f_{\lambda_p} &= \Delta\mathbf{p} \bullet \mathbf{n}_1 \\ f_{\lambda_x} &= \hat{\mathbf{x}} \bullet \mathbf{n}_2 \\ f_{\lambda_y} &= \hat{\mathbf{y}} \bullet \mathbf{n}_2 \end{aligned} \tag{14.24}$$

The stiffness (at equilibrium) is symmetric, with the structure

$$\begin{bmatrix} s\mathbf{n}_1\mathbf{n}_1^T & \mathbf{K}_{12} & -s\mathbf{n}_1\mathbf{n}_1^T & \mathbf{0} & -\mathbf{n}_1 & \mathbf{0} & \mathbf{0} \\ \mathbf{K}_{12}^T & \mathbf{K}_{22} & \mathbf{K}_{23} & \mathbf{K}_{24} & \mathbf{n}_1 \times \Delta\mathbf{p} & \hat{\mathbf{x}} \times \mathbf{n}_2 & \hat{\mathbf{y}} \times \mathbf{n}_2 \\ -s\mathbf{n}_1\mathbf{n}_1^T & \mathbf{K}_{23}^T & s\mathbf{n}_1\mathbf{n}_1^T & \mathbf{0} & \mathbf{n}_1 & \mathbf{0} & \mathbf{0} \\ \mathbf{0} & \mathbf{K}_{24}^T & \mathbf{0} & \mathbf{K}_{44} & \mathbf{0} & -\hat{\mathbf{x}} \times \mathbf{n}_2 & -\hat{\mathbf{y}} \times \mathbf{n}_2 \\ -\mathbf{n}_1^T & (\mathbf{n}_1 \times \Delta\mathbf{p})^T & \mathbf{n}_1^T & \mathbf{0} & \mathbf{0} & \mathbf{0} & \mathbf{0} \\ \mathbf{0} & (\hat{\mathbf{x}} \times \mathbf{n}_2)^T & \mathbf{0} & -(\hat{\mathbf{x}} \times \mathbf{n}_2)^T & \mathbf{0} & \mathbf{0} & \mathbf{0} \\ \mathbf{0} & (\hat{\mathbf{y}} \times \mathbf{n}_2)^T & \mathbf{0} & -(\hat{\mathbf{y}} \times \mathbf{n}_2)^T & \mathbf{0} & \mathbf{0} & \mathbf{0} \end{bmatrix} \begin{bmatrix} \mathbf{p}_1 \\ \omega_1 \\ \mathbf{p}_2 \\ \omega_2 \\ \lambda_p \\ \lambda_x \\ \lambda_y \end{bmatrix} \tag{14.25}$$

where the vector shows the order of the freedoms. ω represents the rotational counterpart of the displacements **p** for the node indicated (subscript). The only other nonzero terms are displayed in equations (14.26):

$$\begin{aligned} \mathbf{K}_{12} &= -\tilde{\mathbf{f}}_1 - s\mathbf{n}_1(\Delta\mathbf{p} \times \mathbf{n}_1)^T \\ \mathbf{K}_{22} &= \mathbf{K}_{44} + \frac{1}{2}\lambda_p(\Delta\mathbf{p}\mathbf{n}_1^T + \mathbf{n}_1\Delta\mathbf{p}^T) + s(\Delta\mathbf{p} \times \mathbf{n}_1)(\Delta\mathbf{p} \times \mathbf{n}_1)^T \\ \mathbf{K}_{23} &= -\tilde{\mathbf{f}}_1 - s(\Delta\mathbf{p} \times \mathbf{n}_1)\mathbf{n}_1^T \\ \mathbf{K}_{24} &= -\mathbf{n}_2\beta^T + s(\mathbf{n}_1\mathbf{n}_1^T - \mathbf{I}_3) \\ \mathbf{K}_{44} &= \frac{1}{2}(\beta\mathbf{n}_2^T + \mathbf{n}_2\beta^T) + s(\mathbf{I}_3 - \mathbf{n}_1\mathbf{n}_1^T) \end{aligned} \tag{14.26}$$

where for any vector **v**,

$$\tilde{\mathbf{v}} = \begin{bmatrix} 0 & -v_z & v_y \\ v_z & 0 & -v_x \\ -v_y & v_x & 0 \end{bmatrix} \tag{14.27}$$

and where $\mathbf{I}_3$ is the 3x3 identity matrix. Note that in deriving equations (14.26), we used the fact that at equilibrium, $\mathbf{n}_1 = \mathbf{n}_2$.

It is very simple to derive the noncorotational and linear forms for the force and stiffness by dropping higher order terms, so those details are omitted here.

14.5 Shell and Mesh-Transition Shell Elements

The current version of the **STAGS** program has the following two ***E300**-series* triangular shell elements and the following five ***E400**-series* quadrilateral shell and mesh-transition shell elements:

- the **E320** triangular shell element
- the **E330** triangular shell element

- the **E410** 4-node quadrilateral shell element
- the **E411** 4-node quadrilateral shell element
- the **E480** 9-node quadrilateral shell element

- the **E510** 5-node quadrilateral mesh-transition shell element
- the **E710** 7-node quadrilateral mesh-transition shell element

These seven elements are described in the following six Subsections. The final Subsection in this Section describes how mesh transitions can also be performed using triangular elements.

E320 Triangular shell element

The **E320** triangular shell element, shown in Figure 14.7, is *a* “classic” triangular element.

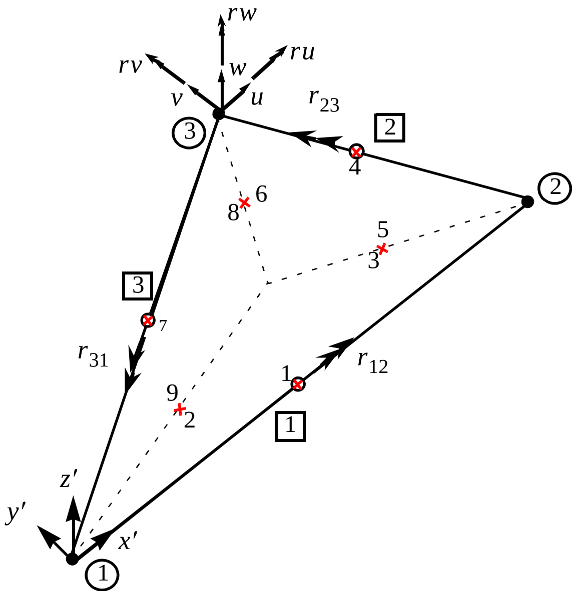


Figure 14.7 **E320** Triangular shell element

The nine integration-point locations are shown here. Element stress/strain results are computed at the element centroid only.

E330 Triangular shell element

The **E330** triangular shell element, shown in Figure 14.8, is **STAGS**’ adaptation of the **COMET** program’s **MIN3** element.[*] [†]

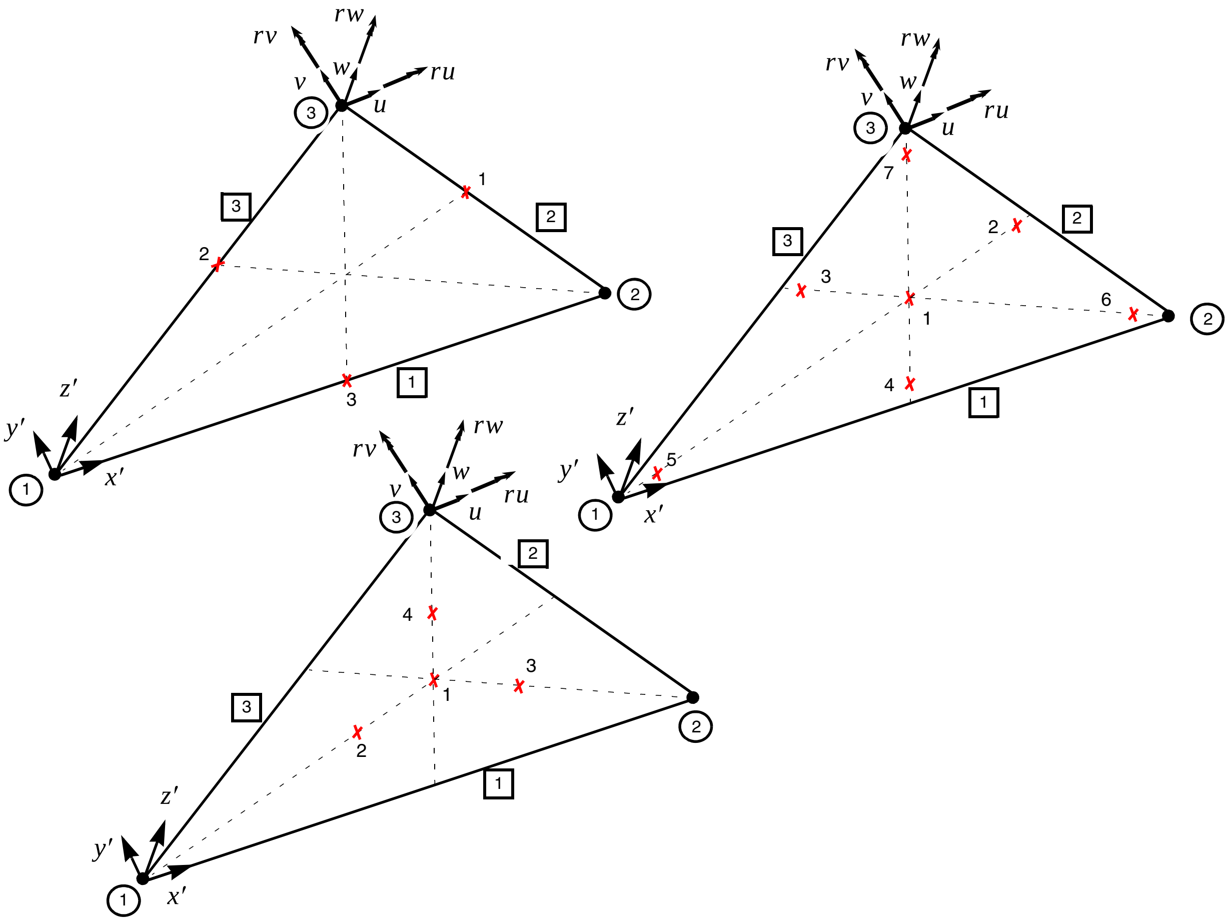


Figure 14.8 **E330** Triangular shell element

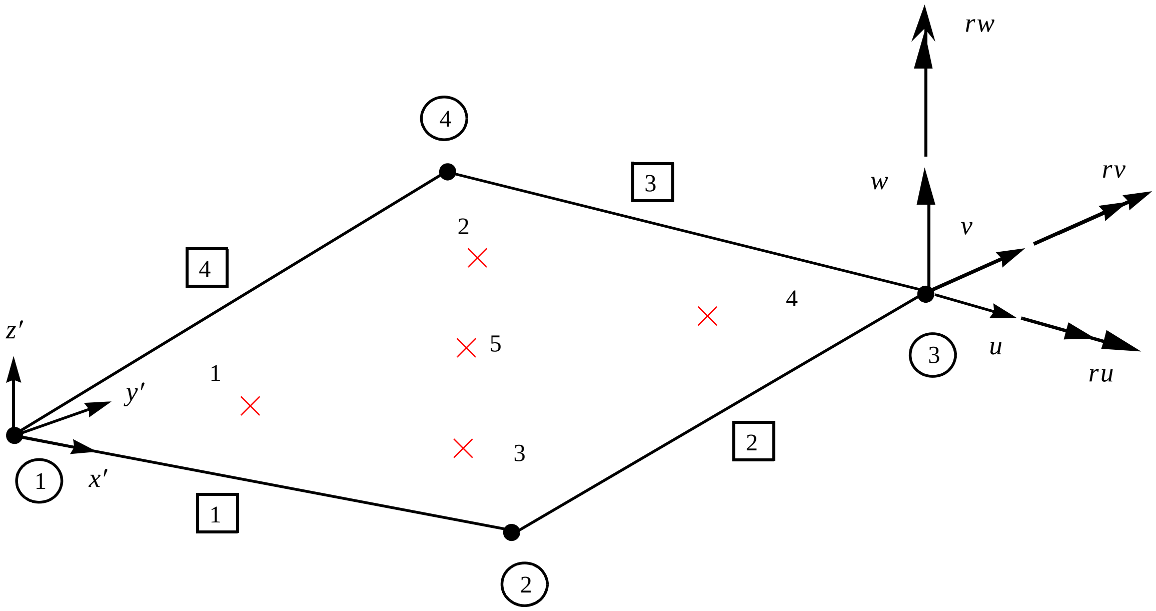
In a shell unit, this element may have one, three (the default number), four or seven integration-points—depending on the **INTEG** parameter on the **N-1** record. In an element unit, this element currently has three integration points. Element stress/strain results may be computed at each integration point or just at the element centroid.

[*] Tessler, A., “*A C^0-Anisoparametric Three-Node Shallow Shell Element,*” Computer Methods in Applied Mechanics and Engineering, Vol. 78, 1990, pp. 89–103

[†] Barut, A., E. Madenci and A. Tessler, “*Nonlinear Analysis of Laminates Through a Mindlin-Type Shear Deformable Shallow Shell Element,*” Computer Methods in Applied Mechanics and Engineering, Vol. 143, Nos 1–2, April 1997, pp. 157–173

E410 4–Node quadrilateral shell element

The **E410** 4–node quadrilateral shell element in the current version of **STAGS**, shown in Figure 14.9, is a “classic” 4–node quadrilateral shell element.[*]



INTEG = 0 – 4-point integration
INTEG = 1 – 5-point integration

Figure 14.9 **E410** 4–Node quadrilateral shell element

[*] Rankin, C.C. and F.A. Brogan, *“The Computational Structural Mechanics Testbed Structural Element Processor ES5: STAGS Shell Element,”* NASA CR–4358, 1991

E411 4–Node quadrilateral shell element

The **E411** quadrilateral shell element, shown in Figure 14.10, has four user-specified nodes and an additional set of four mid-side nodes that are constructed by the program.

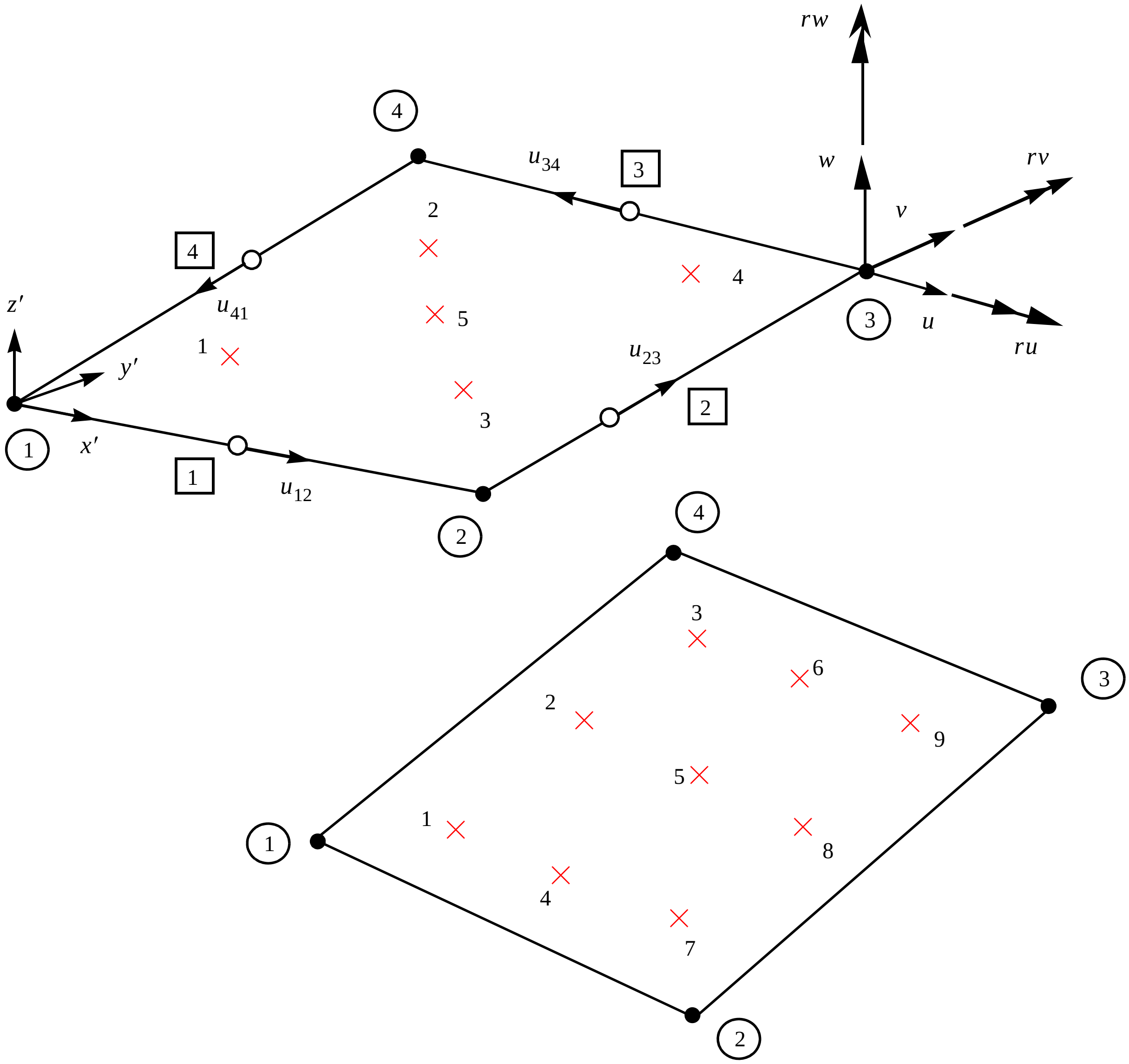


Figure 14.10 **E411** 4–Node quadrilateral shell element

E480 9–Node quadrilateral shell element

The **E480** 9–node quadrilateral shell element in the current version of **STAGS**, shown in Figure 14.11, is a classic 9–node ANS shell element.[*] [†]

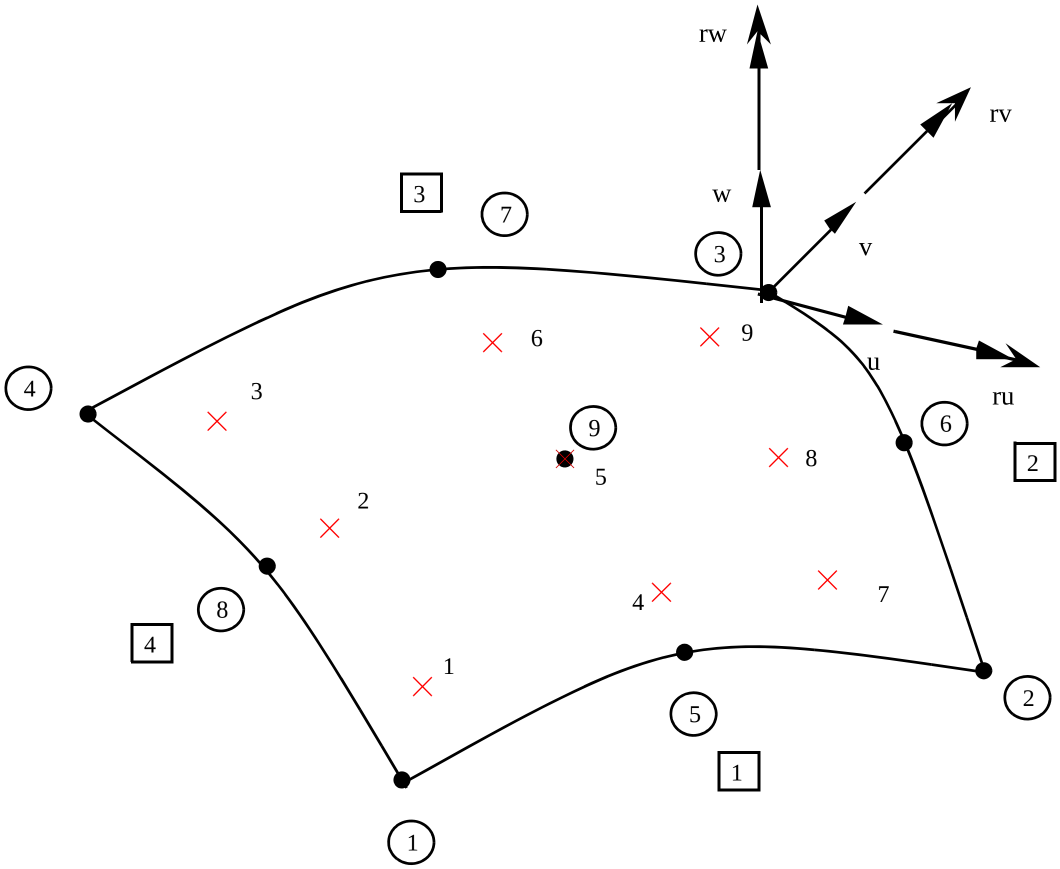


Figure 14.11 **E480** 9–Node quadrilateral shell element

[*] Stanley, G.M., *“The Computational Structural Mechanics Testbed Structural Element Processor ES1: Basic SRI and ANS Shell Elements,”* NASA CR–4357, 1990

[†] Park, K.C. and G.M. Stanley, *“A Curved C^0 Shell Element Based on Assumed Natural-Coordinate Strains,”* ASME Journal of Applied Mechanics, Vol. 108, 1986, pp. 278–290

E510 and E710 Quadrilateral mesh-transition shell elements

Transition meshes can be generated very easily in **STAGS** shell units with simple input. Two types of juncture lines are recognized, as has been the case for some time. The simplest juncture is defined along an entire shell unit boundary, *via* G-1 records. The limitation is that only whole boundaries are recognized, and thus it is not possible to insert a unit with double the mesh density along only part of a shell unit boundary, as illustrated in Figure 14.12. To cope with this situation with the minimum number of shell units, the user must join shell units along only part of a juncture line (for example, the line along the bottom of unit 1 in the figure) and place the units properly by using **IGLOBE** = 0, 3 or 4 (on the M-2 record). This process should be familiar to **STAGS** users for models containing stiffeners that are modeled as shell units. After the units are properly located, master-slave relationships are generated by G-2 records in which **IDIR** = 0 for both groups of nodes.

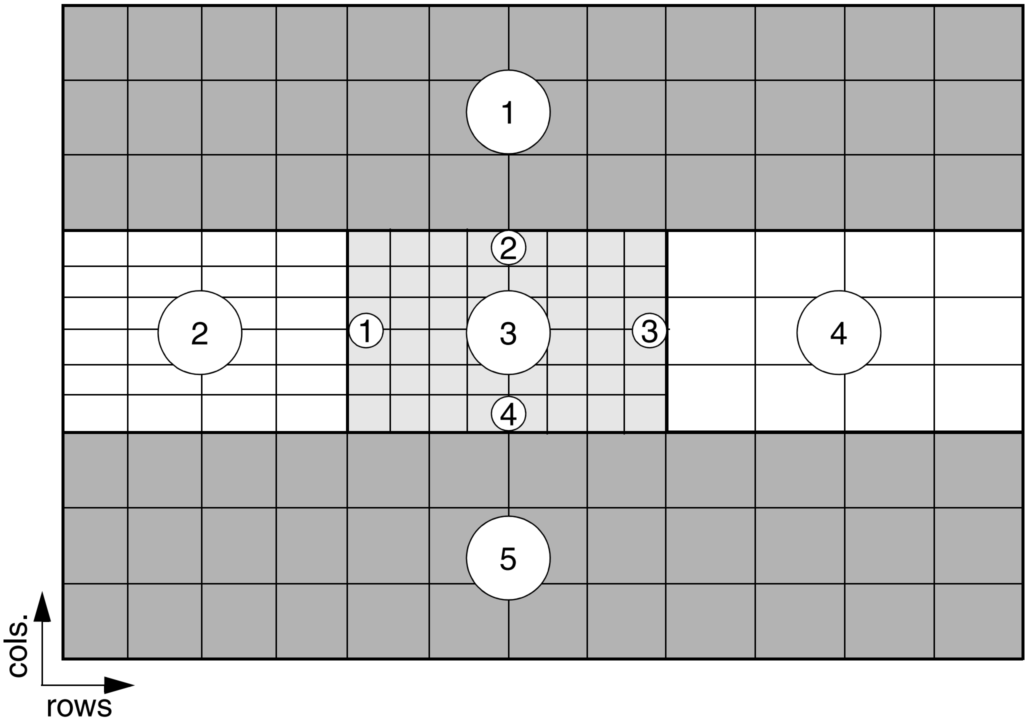


Figure 14.12 Mesh refinement example

In Figure 14.12, you will also notice the *dangling* nodes in unit 3. These nodes are omitted from any G-2 reference. To understand how **STAGS** copes with this situation, it is useful to consider unit 3 in isolation. Each edge or *boundary line* is numbered *clockwise* starting with boundary line 1, which runs along row 1; these conventions are also discussed under Record

P-1 (Boundary Conditions). In Figure 14.12, for example, let us assume that row number 1 is the vertical line on the left edge of unit 3 and that column number 1 runs along the bottom side. Then the boundary lines are as labeled in the figure (small circles). Notice that the mesh halves in density along lines 2, 3 and 4, but not along line 1 as one crosses from unit 3 to the adjacent units. Special variables **MESH1** through **MESH4** (N-1) take the value 0 for a boundary line where the mesh is to be *continuous* with adjacent shell units, and 1 (or 3) where the mesh *halves* across the boundary line.

This input signals the code to interpret *every other* node as a dependent node that is constrained automatically by introducing an **E510** quadrilateral mesh-transition element along the boundary for which **MESHi** is set equal to 1, and/or by introducing an **E710** mesh-transition quadrilateral element at any corner for which the **MESHi** and **MESHj** parameters for the lines meeting at that corner are both set equal to 1. One can readily see that this has the effect of imposing a halving of the mesh along the affected boundaries. The choice of **E510** or **E710** depends on the number of dependent nodes that have to be constrained. Note that since the number of intervals is doubling as you move in from an adjacent unit, the number of mesh lines must be 2N-1, where N is the number of mesh lines in the adjoining *coarser* mesh (the number of mesh lines are specified in the F-1 records). For unit 3 in Figure 14.12, the N-1 record would look like

```
   410   0   0   0   0   0   0     0 1 1 1  $ N-1
```

where we have assumed in this example that the user wants to use type **E410** elements with unit 3, to have no mesh irregularities, to keep equal mesh spacing, and to use default values for the penalty and integration order. The last four integers correspond to the situation in unit 3, Figure 14.12.

If the user wishes to join the shell units with G-1 records (remembering that the relevant boundary lines must be compatible, as always), the same input applies, except that the input may be simpler since **STAGS** will often be able to locate the units automatically. In Figure 14.12, unit 3 boundary lines 1 and 3 satisfy G-1 requirements.

In an element unit, quadrilateral mesh-transition shell elements are identified by *element type* **E510** or **E710**. These elements must be included in the count **NQUAD** of quads, on record H-1. For either element, if the desired normal is pointing *toward* the viewer, the 4 corner nodes are numbered first on record T-4a in *counter-clockwise* order (the same as for the **E410**); and the remainder of the nodes are input on record T-4b including the midside nodes and the center node (for the **E710** only). The midside nodes are numbered in the same order as the corner nodes, starting with the first one to the right (or left for *clockwise* input) of corner node 1. If there is no midside node along a given side, *a 0 is input*. This tells **STAGS** where to put the dependent nodes. It must be remembered that only two topologies are possible, as shown in Figure 14.13. For the **E510** case, the single midside node can be located on any of the four sides. The dependent node is opposite the extra node, and is invisible to the user.

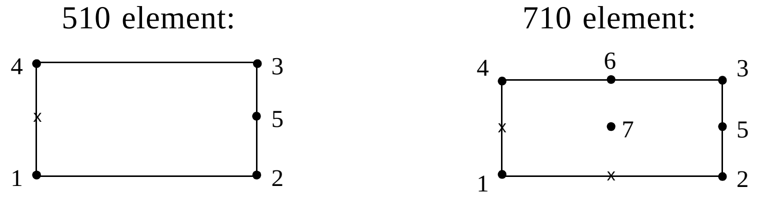


Figure 14.13 Node numbering for mesh-transition elements

For the **E510** element shown in the left half of this figure, the user should input

```
1   2   3   4   510  1  $ T-4a
0   5   0   0   0       $ T-4b
```

where in this example wall 1 and defaults for the other entries on T-4a are selected. Note that for this case the only nonzero entry on T-4b is in the second slot, since the extra node is located on the second side with reference to node 1, in the counter-clockwise order. The following input describes the **E710** element in the right half of this figure:

```
1   2   3   4  710   1  $ T-4a
0   5   6   0  7        $ T-4b
```

Note how similar this input is to the previous example, except that here we have the extra midside node 6 adjacent to 5, and that there is an extra node 7 in the fifth slot. The midside nodes can start on any side and are *always adjacent*. The center node must appear *last* as the fifth entry on the record. In a real case, the node numbers will of course correspond to user point numbers generated previously.

For both shell and element unit input, the user will find that just about any type of mesh-doubling scenario can be covered with just these two quadrilateral mesh-transition elements. As viewed from inside the doubled region, the **E510**'s lie along a mesh-transition boundary, and **E710**'s occupy any corners where the mesh is coarser along two adjacent lines. More severe refinement can be done in stages, with one refinement level per boundary line. It will be seen that with the mesh doubling for each line, a very fine mesh can be had in short order.

Example: Aircraft Panel Quarter Model with Crack in Refined Region

In this example, we have a quarter of a fuselage panel section containing rings and stringers that are modeled as shell units—a typical ASIP model. Figure 14.14 gives a view of the model and the mesh structure. There are 12 shell units in this example, 7 of which lie on the planform in the figure. Stiffeners, composed of shell units, are marked by the heavy lines. Each shell unit is labeled by a number in the order that it appears in the **STAGS** input. Arrows point to the stiffener shell units, which are viewed edge-on. All boundaries are symmetry, except for the crack (free edge), marked by the heavy dashed line. The left-hand boundary is symmetry with a specified, constant nonzero *u*. *u* is aligned along the cylinder axis, which is

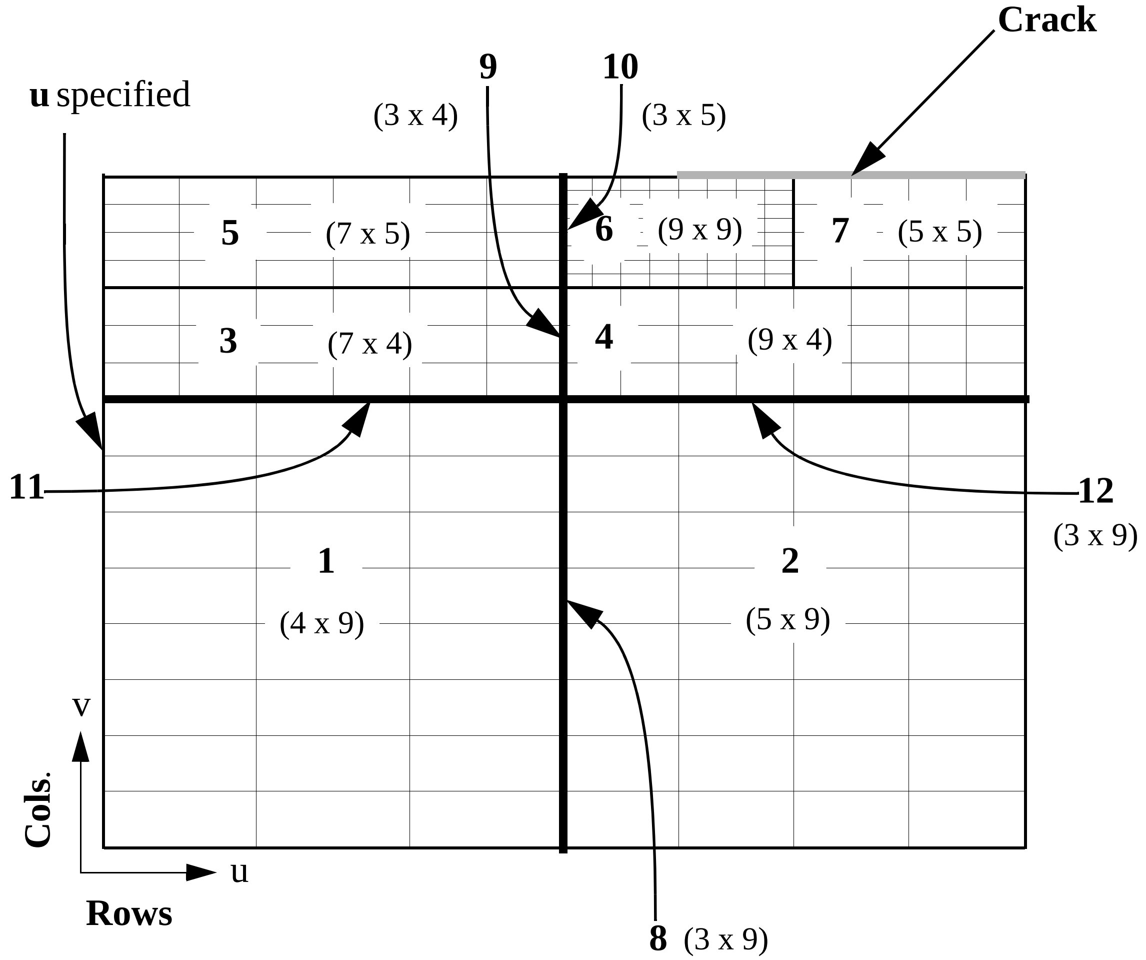
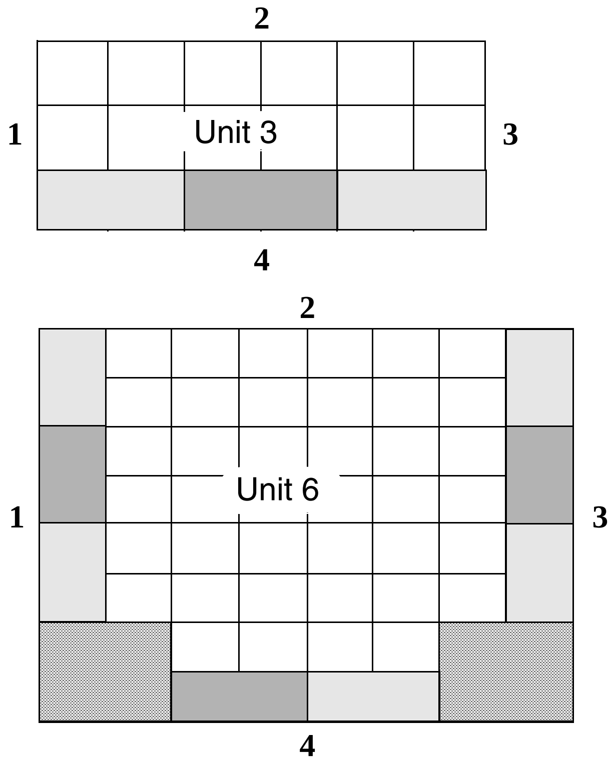


Figure 14.14 Quarter panel model with crack in refined region

horizontal and labeled on the lower left-hand corner of the model. In addition to the specified displacement, a uniform pressure load is applied to units 1 through 7. With each shell unit, we have included the number of rows and columns, rows first, just as they appear on the F-1 record. The direction of increasing rows and column number is also illustrated in the lower left-hand corner of the model.

Now let us walk through the input in this case. You will readily recognize that the F-1 record input matches the numbers in parentheses in Figure 14.14, unit for unit. Check the figure and understand that the mesh numbering corresponds exactly to the number of mesh lines in the row and column direction for each unit. Next come 15 G-1 records that connect whole boundaries between units. Check the figure to ensure that the full boundary line condition is fulfilled. Note that only the first 7 records apply to the skin, while the remainder describe connections to the stiffeners. The next 9 G-2 records are most interesting, because here is a case where both unit 6 (containing the crack tip) and unit 7 connect to line 2 of unit 4. The first 5 partial compatibility records illustrate the requirement that only *every other* node in the denser-meshed unit 6 is connected to unit 4. As we explained before, the intervening nodes on 6 are *dependent nodes* and are invisible to the user. The next set of 4 compatibility records defines a continuous mesh between unit 4 and 7. The last G-2 record joins the stringer to the ring stiffener.

The first refinement line lies along boundary 4 on unit 3, illustrated on the top half of Figure 14.15, where the unit *boundary lines* are marked by the numerals:



Three E415 elements shaded, Unit 3

Eight E415 elements are shaded along boundaries, and two E417 in corners (hatched).

Figure 14.15 Generation of transition elements

From Figure 14.14, transition elements must be placed along this line to reduce the number of independent nodes to every other line in the unit. As described earlier, the special input on record N-1 tells **STAGS** where to put dependent nodes. For this reason, we label in the input that boundary line 4 as *reduced* for unit 3. What **STAGS** actually does is to introduce three **E415** quadrilateral elements along line 4, as shown by the shaded squares along line 4. Since unit 4 shows the same pattern as unit 3, it is not surprising that the input to **STAGS** is identical. Unit 6 is more complicated. Here, doubling occurs along *three* boundary lines (1, 3, and 4 as shown in the lower half of Figure 14.15), with the expected input on the N-1 record. The element pattern shows an **E417** element in each of the two corners along line 4, and the remainder **E415**’s along boundary lines 1, 3, and 4.

The model for this example is constructed *via* the following *INP* file:

Aircraft Panel Quarter Model—*INP* File

```
Transition mesh for 15” crack  (1/4 model)     $ A-1
0 0 1 0 0 0 1                                  $ B-1
12 0 0 15 10 0 0 0 0 0                         $ B-2
2 0 8                                          $ B-3
1.0 0.1 1.0                                    $ C-1
4 9  5 9   7 4  9 4   7 5   9 9   5 5   3 9  3 4  3 5   2 4  2 5 $ F-1
1 3  2 1                                       $ G-1
1 2  3 4                                       $ G-1
2 2  4 4                                       $ G-1
3 3  4 1                                       $ G-1
3 2  5 4                                       $ G-1
5 3  6 1                                       $ G-1
6 3  7 1                                       $ G-1
1 3  8 3                                       $ G-1
3 3  9 3                                       $ G-1
5 3  10 3                                      $ G-1
8 2  9 4                                       $ G-1
9 2  10 4                                      $ G-1
1 2  11 3                                      $ G-1
2 2  12 3                                      $ G-1
11 2  12 4                                     $ G-1
4 1 4 0  6 1 1 0                               $ G-2
4 2 4 0  6 3 1 0                               $ G-2
4 3 4 0  6 5 1 0                               $ G-2
4 4 4 0  6 7 1 0                               $ G-2
4 5 4 0  6 9 1 0                               $ G-2
4 6 4 0  7 2 1 0                               $ G-2
4 7 4 0  7 3 1 0                               $ G-2
4 8 4 0  7 4 1 0                               $ G-2
4 9 4 0  7 5 1 0                               $ G-2
8 2 9 0  11 1 4 0                              $ G-2
1  / 10.5E6 0.33                               $ I-1/2
2  / 10.7E6 0.33                               $ I-1/2
1 1 1  /  1 .036                               $ K-1/2
2 1 1  /  1 .036                               $ K-1/2
3 1 1  /  1 .036                               $ K-1/2
4 1 1  /  1 .036                               $ K-1/2
5 1 1  /  2 .17075                             $ K-1/2
6 1 1  /  2 .17075                             $ K-1/2
7 1 1  /  2 .34229                             $ K-1/2
8 1 1  /  2 .34229                             $ K-1/2
$
$    ****   SHELL UNIT 1   ****
5 0                                            $ M-1 #1
0. 10. 165.6 172.8  74.0                       $ M-2A #1
```

```
1                                              $ M-5
410 0 0                                        $ N-1
0 6 6 4                                        $ P-1
111 100                                        $ P-2 (symmetry with set u)
1/ 1 2                                         $ Q-1/Q-2
 8. 5 3 0 0                                    $ Q-3 (pressure)
 -.0022 -1 1 1 0                               $ Q-3 edge displ.
0                                              $ R-1 #1
$
$    ****   SHELL UNIT 2   ****
$
5 0                                            $ M-1 #2
10. 20. 165.6 172.8  74.0                      $ M-2A #2
2                                              $ M-5
410 0 0                                        $ N-1
6 6 4 4                                        $ P-1
1/ 1 1                                         $ Q-1/2
 8. 5 3 0 0                                    $ Q-3 (pressure)
4 0 0 0 0 0                                    $ R-1 #2
$
$    ****   SHELL UNIT 3   ****
$
0 0                                            $ M-1 #3
0. 10.  172.8 174.6  74.                       $ M-2A
3                                              $ M-5 Wall 3
410 0 0  0 0 0 0  0 0 0 1                      $ N-1 #3 line 4 is  reduced
0 6 6 6                                        $ P-1
111 100                                        $ P-2 ”symmetry” with nonzero u
1/ 1 2                                         $ Q-1/2
  8. 5 3 0 0                                   $ Q-3 (pressure)
 -.0022 -1 1 1 0                               $ Q-3 edge displ.
4 0 0 0 0 8                                    $ R-1 #3
$
$    ****   SHELL UNIT 4   ****
$
5 0                                            $ M-1 #4
10. 20.  172.8 174.6  74.                      $ M-2A
4                                              $ M-5 Wall 4
410 0 0  0 0 0 0  0 0 0 1                      $ N-1 #4 line 4 is  reduced
6 6 4 6                                        $ P-1
1/ 1 1
  8. 5 3 0 0
4 0 0 0 0 0                                    $ R-1 #4
$
$    ****   SHELL UNIT 5   ****
$
5 0                                            $ M-1 #5
0. 10.  174.6 176.4   74.                      $ M-2A
3                                              $ M-5
410                                            $ N-1 #5
0 4 6 6                                        $ P-1
111 100                                        $ P-2 (symmetry with set u)
1/ 1 2                                         $ Q-1/2
  8. 5 3 0 0                                   $ Q-3 (pressure)
 -.0022 -1 1 1 0                               $ Q-3 edge displ.
0                                              $ R-1 #5
$
```

```
$    ****   SHELL UNIT 6   (Contains CRACK tip!)  ****
$
5 0                                            $ M-1 #6
10. 15.  174.6 176.4   74.                     $ M-2A
4                                              $ M-5 Wall 4
410 0 0  0 0 0 0  1 0 1 1                      $ N-1 # 6 lines 1,3,4 reduced
6 3 6 6                                        $ P-1
1/ 1 13                                        $ Q-1/2 (note number of records)
 8. 5 3 0 0                                    $ Q-3 (pressure)
0. -1 2 2 9                                    $ Q-3 (Forced disp.to close crack)
0. -1 4 2 9                                    $ Q-3 (Forced disp.to close crack)
0. -1 6 2 9                                    $ Q-3 (Forced disp.to close crack)
0. -1 2 3 9                                    $ Q-3 (Forced disp.to close crack)
0. -1 4 3 9                                    $ Q-3 (Forced disp.to close crack)
0. -1 6 3 9                                    $ Q-3 (Forced disp.to close crack)
0. -1 2 4 9                                    $ Q-3 (Forced disp.to close crack)
0. -1 4 4 9                                    $ Q-3 (Forced disp.to close crack)
0. -1 6 4 9                                    $ Q-3 (Forced disp.to close crack)
0. -1 2 5 9                                    $ Q-3 (Forced disp.to close crack)
0. -1 4 5 9                                    $ Q-3 (Forced disp.to close crack)
0. -1 6 5 9                                    $ Q-3 (Forced disp.to close crack)
0 0 0 0 0 0                                    $ R-1 #6
$
$    ****   SHELL UNIT 7   ****
$
5 0                                            $ M-1 #7
15. 20.  174.6 176.4   74.                     $ M-2A
4                                              $ M-5 Wall 4
410 0 0  0 0 0 0   0 0 0 0                     $ N-1 #7
6 3 4 6                                        $ P-1
1/ 1 1                                         $ Q-1/2
8. 5 3 0 0                                     $ Q-3 (pressure
0 0 0 0 0 0                                    $ R-1 #7
$
$    ****   SHELL UNIT 8   ****
$
4 4                                            $ M-1 #8
72.0 74.0 165.6 172.8                          $ M-2A #8
10.0 0.0 0.0                                   $ M-4D #8 (note translation of unit)
0.0 0.0 0.0                                    $ M-4E #8
5 0 0. 0. 0 0 0                                $ M-5 #8
410 0 0  0 0 0 0                               $ N-1 #8
3 6 6 4 0                                      $ P-1 #8
0                                              $ Q-1
0 0                                            $ R-1 #8
$
$    ****   SHELL UNIT 9   ****
$
4 4                                            $ M-1 #9
72.0 74.0 172.8 174.6                          $ M-2A #9
10.0 0.0 0.0                                   $ M-4D #9
0.0 0.0 0.0                                    $ M-4E #9
6 0 0. 0. 0 0 0                                $ M-5 #9
410 0 0  0 0 0 0                               $ N-1 #9
3 6 6 6 0                                      $ P-1 #9
0                                              $ Q-1
0 0                                            $ R-1 #9
```

```
$
$    ****   SHELL UNIT 10  ****
$
4 4                                            $ M-1 #10
72.0 74.0 174.6 176.4                          $ M-2A #10
10.0 0.0 0.0                                   $ M-4D #10
0.0 0.0 0.0                                    $ M-4E #10
6 0 0. 0. 0 0 0                                $ M-5 #10
410 0 0  0 0 0 0                               $ N-1 #10
3 4 6 6 0                                      $ P-1 #10
0                                              $ Q-1
0                                              $ R-1 #10
$
$    ****   SHELL UNIT 11  ****
$
2 3                                            $ M-1 #11
0.0 1.0 0.0 10.0                               $ M-2A #11
0. 9.1493261 -72.424373                        $ M-4A #11
10. 9.1493261 -72.424373                       $ M-4B #11
10. 9.2746593 -73.416488                       $ M-4C #11
7 0 0. 0. 0 0 0                                $ M-5 #11
410 0 0 0 0 0 0                                $ N-1 #11
3 6 6 3 0                                      $ P-1 #11
0 0 0 0                                        $ Q-1 #11
                                              $ R-1 #11
$
$    ****   SHELL UNIT 12  ****
$
2 3                                            $ M-1 #12
0.0 1.0 10.0 20.0                              $ M-2A #12
10. 9.1493261 -72.424373                       $ M-4A #12
20. 9.1493261 -72.424373                       $ M-4B #12
20. 9.2746593 -73.416488                       $ M-4C #12
8 0 0. 0. 0 0 0                                $ M-5 #12
410 0 0 0 0 0 0                                $ N-1 #12
3 4 6 6 0                                      $ P-1 #12
0 0 0 0                                        $ Q-1 #12
0                                              $ R-1 #12
```

E330 Triangular mesh-transition shell elements

Transition meshes between and among shell units, using type **E330** triangular shell elements instead of type **E510** and/or **E710** quadrilateral elements, can also be generated very easily *via* the **MESH1**, **MESH2**, **MESH3** and/or **MESH4** parameters (on the N-1 record). This **STAGS** feature closely parallels the **E510** and **E710** quadrilateral mesh-transition shell element capabilities described above. Setting **MESH1**, **MESH2**, **MESH3** and/or **MESH4** equal to 3 on an N-1 record signals **STAGS** to interpret *every other* node on the associated boundary as a dependent node that is constrained automatically by introducing as many **E330** triangular transition elements as may be required along that boundary or at the corner of defined by adjacent boundaries that are tagged in this manner. This has the effect of halving the mesh along the affected boundaries. Since the number of intervals is doubling as you move in from an adjacent unit, the number of mesh lines must be 2N-1, where N is the number of mesh lines in the adjoining *coarser* mesh (the number of mesh lines are specified in the F-1 records). To employ type **E330** (instead of **E510** and **E710**) shell transition elements for unit 3 of the example problem shown in Figure 14.12, the N-1 record would look like

```
410   0   0   0   0   0   0     0 3 3 3  $ N-1
```

(assuming that the analyst wants to use type **E410** elements with unit 3, to have no mesh irregularities, to keep equal mesh spacing, and to use default values for the penalty and integration order). The last four integers correspond to the situation in unit 3, Figure 14.12. The difference here is that **STAGS** generates three type **E330** triangular shell elements in each transition “side cell” for which the **MESHi** value of 1 generates an **E510** element, and/or four type **E330** triangular elements for each “corner cell” for which adjacent boundaries have **MESHi** and **MESHj** both equal to 3. The patterns for this are shown in Figure 14.16:

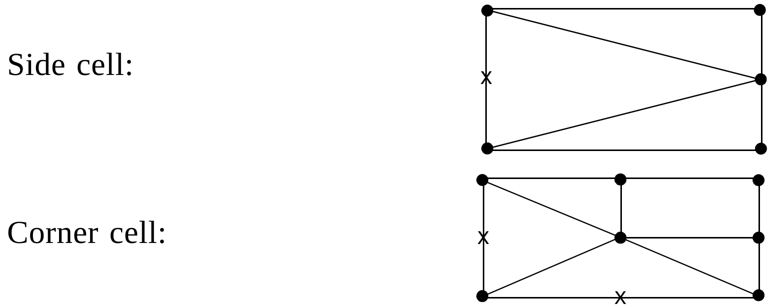


Figure 14.16 Triangular mesh-transition shell elements

When the **MESH*** parameters that were set to 1 in the example just discussed are set to 3, instead of 1, the transition mesh shown in Figure 14.17 is generated:

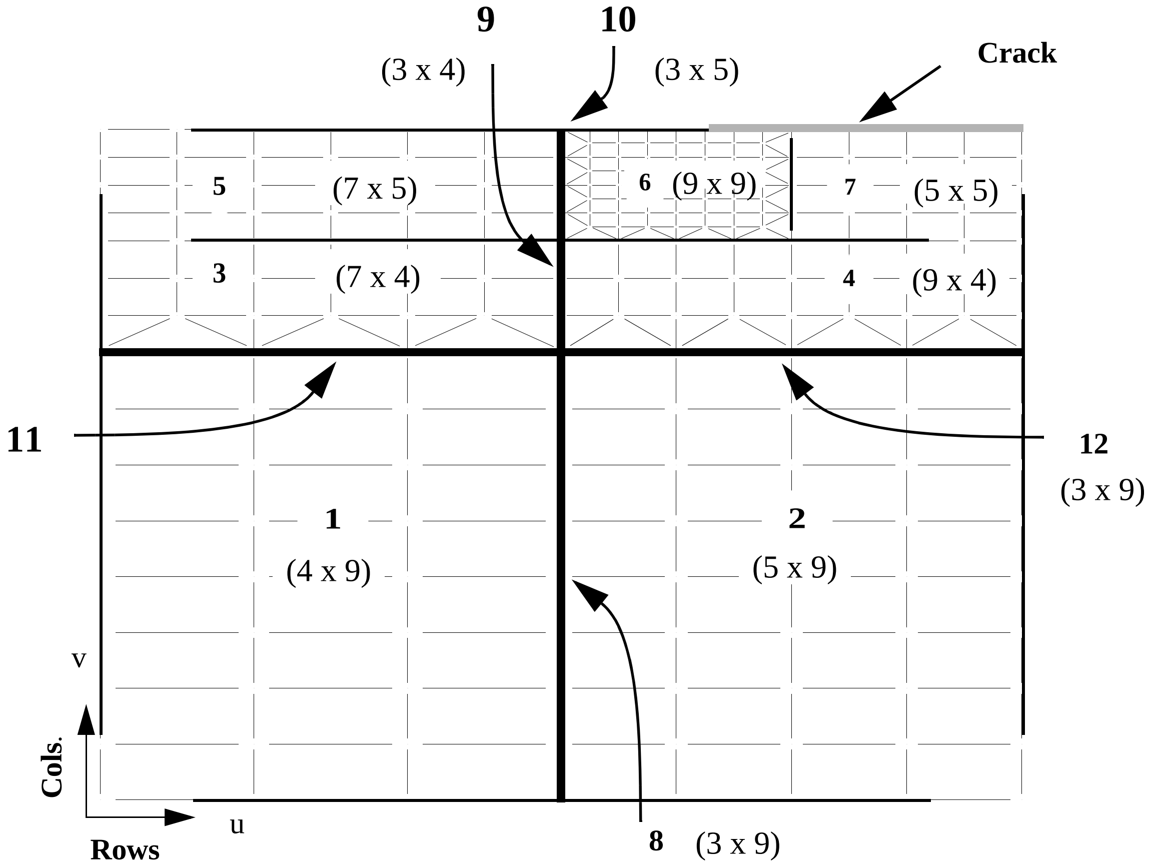


Figure 14.17 Quarter panel model with crack in refined region

14.6 Sandwich and Mesh-Transition Sandwich Elements

The current version of the **STAGS** program has the following three “standard” sandwich elements and the following two mesh-transition sandwich elements:

- the **E830** 6-node sandwich element
- the **E840** 8-node sandwich element
- the **E849** 18-node sandwich element

and

- the **E845** 10-node mesh transition sandwich element
- the **E847** 14-node mesh transition sandwich element

These are described in the following four Subsections.

E830 6–Node sandwich element

Sandwich components play increasingly important roles in the design of many aerospace structures, and it is necessary to determine their behavior adequately. The 6–node sandwich element (see Figure 14.18) discussed here and the 8–node sandwich element (see Figure 14.19) discussed in the next subsection are important additions to **STAGS**’ modeling capabilities and will be used more and more as time goes on.

The classical approach to the modeling of sandwiches corresponds to an extension of the theory of thin shells. In this approach, the behavior of the sandwich as a three dimensional object is reduced to the behavior of a two dimensional surface with in-plane and out of the plane stiffness properties. Because sandwiches (in contrast to thin walled shells) also undergo transverse shear deformations, two extra parameters are required to describe this mode of deformation. The classical theory of sandwich shells is a two dimensional theory in the sense that the behavior of the three dimensional sandwich shell is described by the deformation of a reference surface and two additional geometric parameters (shear angles) that are locally attached to this surface. Successful finite element discretizations of these classical models have been made in the past, but applications of these discretizations are mostly confined to linear or moderately nonlinear analysis situations.

For implementation into a general purpose finite element code, sandwich elements based on classical theory have at least two undesirable aspects. The first is that a complete new coding of the element drivers must be introduced. The second is that the code must deal with boundary conditions along the edges of the shell that involve shear angles. This departure from standard conventions is cumbersome and requires alterations in the organization of the existing software. A less difficult modeling technique is a welcome alternative.

The classical model of a sandwich reduces the behavior of the aggregate to that of two membranes that are held apart by a core. The core is considered to be virtually inextensional in the transverse direction, usually with a relatively large resistance against transverse shear. However, in the plane of the middle surface of the aggregate, the core possesses virtually no stiffness. It is noted here that it is possible to call a composite of this type a sandwich of the first kind.

A more general type of sandwich emerges if one considers the two faces to consist of shells—with shell surfaces having bending stiffness as well as the usual membrane stiffness—that are held apart by a lightweight core. The latter may have three dimensional elastic properties. Examples of such structural elements are sandwich walls made of glass fibre faces with polyurethane foam as the core material. This type of wall construction can be called a sandwich of the second kind.

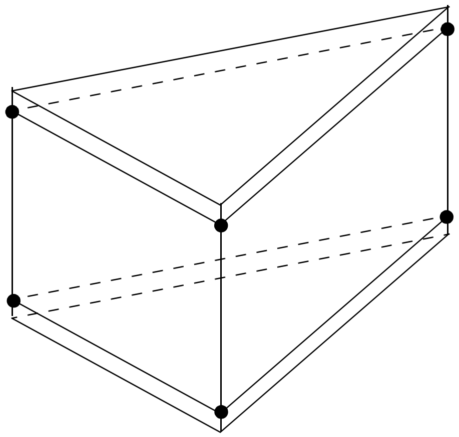


Figure 14.18 E830 6–node sandwich element

The implementation of a sandwich of the second kind in a general purpose finite element code is easier and more straightforward than the implementation of the classical concept of a sandwich in such a code, provided the code possesses a mature shell finite element modeling capability.

Sandwich element internal force and material and geometric stiffness matrices

Formulation of the internal force and material and geometric stiffness matrices for a 6–node sandwich element follows standard finite element procedures. An overview of the algorithmic steps used to develop these quantities is outlined in this section. As will be seen, internal force and stiffness matrix terms depend on the element’s constitutive properties and on the components of its displacement gradient field. Detailed discussion of the assumptions made for the sandwich element's displacement field, and computation of the displacement field derivatives, is presented in the next section.

Formulation of the internal force and stiffness matrices begins with the definition of the engineering Green's strain, which is given as

$$\varepsilon = \begin{Bmatrix} u_{,x} + \frac{1}{2}(u_{,x}^2 + v_{,x}^2 + w_{,x}^2) \\ v_{,y} + \frac{1}{2}(u_{,y}^2 + v_{,y}^2 + w_{,y}^2) \\ w_{,z} + \frac{1}{2}(u_{,z}^2 + v_{,z}^2 + w_{,z}^2) \\ v_{,x} + u_{,y} + u_{,x}u_{,y} + v_{,x}v_{,y} + w_{,x}w_{,y} \\ w_{,y} + v_{,z} + u_{,y}u_{,z} + v_{,y}v_{,z} + w_{,y}w_{,z} \\ u_{,z} + w_{,x} + u_{,z}u_{,x} + v_{,z}v_{,x} + w_{,z}w_{,x} \end{Bmatrix} \tag{14.28}$$

Note that the engineering shearing strains are twice the corresponding tensor values, in agreement with common practice. Let us assume for simplicity that the internal energy can be written as the quadratic form

$$U = \frac{1}{2}\varepsilon^T\mathbf{D}\varepsilon = \frac{1}{2}\sigma^T\varepsilon \tag{14.29}$$

where

$$\sigma = \mathbf{D}\varepsilon \tag{14.30}$$

and where **D** is a constitutive matrix and σ is the stress conjugate to the strain. The generalization to a nonlinear constitutive function does not affect these arguments.

The first variation of the energy is

$$\delta U = \sigma^T\delta\varepsilon \tag{14.31}$$

where **D** is assumed to be symmetric and where δε is the variation of the strain, which in turn is a function of the element displacement field through its derivatives in equation (14.28).

In practice, these displacement field derivatives are approximated using so-called interpolating shape function "formulas." Without loss of generality, we can define

$$\lfloor u_{,x}\ u_{,y}\ u_{,z}\ v_{,x}\ v_{,y}\ v_{,z}\ w_{,x}\ w_{,y}\ w_{,z} \rfloor^T = \mathbf{Gd} \tag{14.32}$$

where the transpose of the row matrix gives the order of the displacement gradient quantities chosen, where **G** is a matrix of constants (dependent on the initial geometry) with nine rows corresponding to each of the derivatives listed and with as many columns as there are freedoms in the element (in general). **d** is the vector of nodal displacements (freedoms). It is assumed here that **G** is known by standard finite element methods. If the derivatives in equation (14.32) are inserted into equation (14.28), with some rearrangement we obtain the variation in the strain:

$$\delta\varepsilon = \mathbf{WG}\delta\mathbf{d} \tag{14.33}$$

where the “core strain derivative” matrix **W** is defined as

$$\mathbf{W}(\mathbf{d}) = \begin{bmatrix} 1+u_{,x} & 0 & 0 & v_{,x} & 0 & 0 & w_{,x} & 0 & 0 \\ 0 & u_{,y} & 0 & 0 & 1+v_{,y} & 0 & 0 & w_{,y} & 0 \\ 0 & 0 & u_{,z} & 0 & 0 & v_{,z} & 0 & 0 & 1+w_{,z} \\ 0 & u_{,z} & u_{,y} & 0 & v_{,z} & 1+v_{,y} & 0 & 1+w_{,z} & w_{,y} \\ u_{,z} & 0 & 1+u_{,x} & v_{z} & 0 & v_{,x} & 1+w_{,z} & 0 & w_{,x} \\ u_{,y} & 1+u_{,x} & 0 & 1+v_{,y} & v_{,x} & 0 & w_{,y} & w_{,x} & 0 \end{bmatrix} \tag{14.34}$$

and where the dependence of **W** on **d** is emphasized. Once a set of displacements is known and the derivatives in equation (14.32) are computed, the variation in the strain is known from equation (14.33).

The internal force vector is computed using equation (14.33):

$$\mathbf{f}^T\delta\mathbf{d} = \sigma^T\delta\varepsilon = \sigma^T\mathbf{WG}\delta\mathbf{d} \tag{14.35}$$

from which the force (per integration point) is defined

$$\mathbf{f} = \mathbf{B}^T\sigma \tag{14.36}$$

and the nonlinear strain-displacement matrix is given by

$$\mathbf{B} = \mathbf{WG} \tag{14.37}$$

The total second variation of the energy as given in equation (14.31) comes in two parts:

$$\Delta\delta U = \Delta\varepsilon^T\mathbf{D}\delta\varepsilon + \sigma^T\Delta\delta\varepsilon \tag{14.38}$$

The first term (referred to as the “material stiffness”) is computed directly from equation (14.38):

$$\mathbf{K}_M = \mathbf{B}^T\mathbf{D}\mathbf{B} \tag{14.39}$$

The “geometric” second variation always appears as the inner product of the stress with the second variation of the strain:

$$\mathbf{K}_G = \mathbf{G}^T\begin{bmatrix} \mathbf{S} & 0 & 0 \\ 0 & \mathbf{S} & 0 \\ 0 & 0 & \mathbf{S} \end{bmatrix}\mathbf{G} \tag{14.40}$$

where **S** is the 3x3 matrix of stresses in the usual order.

Sandwich element displacement and displacement gradient calculations

The displacement of any point in the core of a sandwich element is assumed to vary linearly through the thickness between values at the upper and lower bond lines of the face sheets with the core. If the core’s coordinate system is taken to be the same as that for the lower face sheet reference surface, then the core displacement can be written as

$$\mathbf{u} = a\mathbf{H}_N\mathbf{d}_N + b\hat{\bar{\mathbf{H}}}_M\bar{\mathbf{d}}_M \tag{14.41}$$

where $a = \frac{1}{2}(1-\zeta)$ and $b = \frac{1}{2}(1+\zeta)$ are linear interpolation coefficients parameterized by $\zeta = \frac{2}{h}z$ and where h is the core local thickness and *z* is the thickness coordinate over the range [-h/2, h/2]. The sandwich core shape functions are given by

$$\mathbf{H}_N = \begin{pmatrix} \mathbf{H}_N^u & \mathbf{H}_N^\theta \end{pmatrix} \tag{14.42}$$

$$\hat{\bar{\mathbf{H}}}_M = \begin{pmatrix} \hat{\bar{\mathbf{H}}}_M^u & \hat{\bar{\mathbf{H}}}_M^\theta \end{pmatrix} \tag{14.43}$$

where $\mathbf{H}_N$ is the matrix of shape functions associated with lower face sheet freedoms at a node *N*, and $\hat{\bar{\mathbf{H}}}_M$ is the matrix of shape functions associated with upper face sheet freedoms at a node *M*. Both of these matrices are partitioned into two parts that give the contribution to the total displacement due to nodal displacement and nodal rotation freedoms, respectively.

The nodal freedoms for the lower and upper face sheet reference surfaces are also partitioned into displacement and rotation freedoms, respectively:

$$\mathbf{d}_N = \begin{Bmatrix} \mathbf{d}_N^u \\ \mathbf{d}_N^\theta \end{Bmatrix} \tag{14.44}$$

$$\bar{\mathbf{d}}_M = \begin{Bmatrix} \bar{\mathbf{d}}_M^u \\ \bar{\mathbf{d}}_M^\theta \end{Bmatrix} \tag{14.45}$$

The sandwich core displacement given in equation (14.28) allows for the upper face sheet reference surface to be arbitrarily oriented with respect to the lower face sheet reference surface (and the sandwich core coordinate system). If x and $\bar{x}$ represent coordinates of a point expressed in lower and upper reference surface coordinate systems, respectively, and are related by an orthogonal rotation matrix $\mathbf{T}$ such that

$$\mathbf{x} = \mathbf{T}\bar{\mathbf{x}} \tag{14.46}$$

then the displacement shape function matrices associated with upper face sheet reference surface displacement and rotation freedoms at a node M, but with components expressed in the lower face sheet coordinate system, are given by

$$\hat{\bar{\mathbf{H}}}_M^u = \mathbf{T}\bar{\mathbf{H}}_M^u\mathbf{T}^T \tag{14.47}$$

$$\hat{\bar{\mathbf{H}}}_M^\theta = \mathbf{T}\bar{\mathbf{H}}_M^\theta\mathbf{T}^T \tag{14.48}$$

Here $\bar{\mathbf{H}}_M^u$ and $\bar{\mathbf{H}}_M^\theta$ are the displacement shape function matrices associated with upper face sheet displacement and rotation freedoms at a node M, and whose components are expressed in the upper face sheet coordinate system.

The displacement gradient for the sandwich core can now be determined from equation (14.41) to be

$$\frac{\partial \mathbf{u}}{\partial x_i} = \frac{da}{dx_i}\mathbf{H}_N\mathbf{d}_N + a\frac{\partial \mathbf{H}_N}{\partial x_i}\mathbf{d}_N + \frac{db}{dx_i}\hat{\bar{\mathbf{H}}}_M\bar{\mathbf{d}}_M + b\frac{\partial \hat{\bar{\mathbf{H}}}_M}{\partial x_i}\bar{\mathbf{d}}_M \tag{14.49}$$

where the gradient of the upper face sheet shape functions with respect to the sandwich core coordinate system is given by

$$\frac{\partial \hat{\bar{\mathbf{H}}}_M}{\partial x_i} = \begin{bmatrix} \dfrac{\partial \hat{\bar{\mathbf{H}}}_M^u}{\partial x_i} & \dfrac{\partial \hat{\bar{\mathbf{H}}}_M^\theta}{\partial x_i} \end{bmatrix} \tag{14.50}$$

The gradient of the upper face sheet reference surface shape function submatrices identified in equation (14.50) can be expressed in the upper face sheet reference surface coordinate system (the barred system) by using the chain rule along with equation (14.46) and the relations in equations (14.47) and (14.48):

$$\frac{\partial\hat{\bar{\mathbf{H}}}{}^{u}_{M}}{\partial x_i} = \mathbf{T}\frac{\partial\bar{\mathbf{H}}{}^{u}_{M}}{\partial\bar{x}_k}\frac{\partial\bar{x}_k}{\partial x_i}\mathbf{T}^T = \mathbf{T}\frac{\partial\bar{\mathbf{H}}{}^{u}_{M}}{\partial\bar{x}_k}T_{ik}\mathbf{T}^T \tag{14.51}$$

$$\frac{\partial\hat{\bar{\mathbf{H}}}{}^{\theta}_{M}}{\partial x_i} = \mathbf{T}\frac{\partial\bar{\mathbf{H}}{}^{\theta}_{M}}{\partial\bar{x}_k}\frac{\partial\bar{x}_k}{\partial x_i}\mathbf{T}^T = \mathbf{T}\frac{\partial\bar{\mathbf{H}}{}^{\theta}_{M}}{\partial\bar{x}_k}T_{ik}\mathbf{T}^T \tag{14.52}$$

For the sandwich elements that are implemented in the current version of **STAGS**, the upper and lower face sheets are modeled with shell elements of the same type (*i.e.,* **E330** shells for an **E830** sandwich and **E410** shells for an **E840** sandwich). Consequently, using the following definitions for the shape function derivatives,

$$\mathbf{G}^{u}_{N,x} = \frac{\partial\mathbf{H}^{u}_{N}}{\partial x} = \frac{\partial\bar{\mathbf{H}}{}^{u}_{N}}{\partial\bar{x}} \qquad \mathbf{G}^{u}_{N,y} = \frac{\partial\mathbf{H}^{u}_{N}}{\partial y} = \frac{\partial\bar{\mathbf{H}}{}^{u}_{N}}{\partial\bar{y}} \qquad \mathbf{G}^{u}_{N,z} = \mathbf{0} \tag{14.53}$$

$$\mathbf{G}^{\theta}_{N,x} = \frac{\partial\mathbf{H}^{\theta}_{N}}{\partial x} = \frac{\partial\bar{\mathbf{H}}{}^{\theta}_{N}}{\partial\bar{x}} \qquad \mathbf{G}^{\theta}_{N,y} = \frac{\partial\mathbf{H}^{\theta}_{N}}{\partial y} = \frac{\partial\bar{\mathbf{H}}{}^{\theta}_{N}}{\partial\bar{y}} \qquad \mathbf{G}^{\theta}_{N,z} = \mathbf{0} \tag{14.54}$$

the components for the sandwich core displacement gradient, as expressed in equation (14.49), can be written as

$$\frac{\partial\mathbf{u}}{\partial x} = a(\mathbf{G}^{u}_{N,x}\ \ \mathbf{G}^{\theta}_{N,x})\mathbf{d}_N + b(\mathbf{T}(\mathbf{G}^{u}_{M,x}T_{11} + \mathbf{G}^{u}_{M,y}T_{12})\mathbf{T}^T\ \ \mathbf{T}(\mathbf{G}^{\theta}_{M,x}T_{11} + \mathbf{G}^{\theta}_{M,y}T_{12})\mathbf{T}^T)\bar{\mathbf{d}}_M \tag{14.55}$$

$$\frac{\partial\mathbf{u}}{\partial y} = a(\mathbf{G}^{u}_{N,y}\ \ \mathbf{G}^{\theta}_{N,y})\mathbf{d}_N + b(\mathbf{T}(\mathbf{G}^{u}_{M,x}T_{21} + \mathbf{G}^{u}_{M,y}T_{22})\mathbf{T}^T\ \ \mathbf{T}(\mathbf{G}^{\theta}_{M,x}T_{21} + \mathbf{G}^{\theta}_{M,y}T_{22})\mathbf{T}^T)\bar{\mathbf{d}}_M \tag{14.56}$$

$$\begin{aligned}\frac{\partial\mathbf{u}}{\partial z} = -\frac{1}{h}(\mathbf{H}^{u}_{N}\ \ \mathbf{H}^{\theta}_{N})\mathbf{d}_N + \frac{1}{h}(\mathbf{T}\bar{\mathbf{H}}{}^{u}_{M}\mathbf{T}^T\ \ \mathbf{T}\bar{\mathbf{H}}{}^{\theta}_{M}\mathbf{T}^T)\bar{\mathbf{d}}_M +\\ b(\mathbf{T}(\mathbf{G}^{u}_{M,x}T_{31} + \mathbf{G}^{u}_{M,y}T_{32})\mathbf{T}^T\ \ \mathbf{T}(\mathbf{G}^{\theta}_{M,x}T_{31} + \mathbf{G}^{\theta}_{M,y}T_{32})\mathbf{T}^T)\bar{\mathbf{d}}_M\end{aligned} \tag{14.57}$$

Displacement at the bond line between sandwich core and face sheet

Displacement at a bond line between a sandwich face sheet and core is given in terms of the face sheet reference surface displacement and the eccentricity of the bond line with respect to the face sheet reference surface as follows:

$$\mathbf{u} = \mathbf{u}_R + \Theta \times \mathbf{e} \tag{14.58}$$

Here $\mathbf{u}_R$ is the face sheet reference surface displacement, Θ is the local reference surface rotation, and **e** is the eccentricity of the sandwich bond line from the face sheet reference surface.

For an **E330** triangle face sheet shell element, the reference surface rotation components are independent degrees of freedom and are not related to the transverse reference surface *w*-displacement component. In addition, the only nonzero component of the eccentricity is e_3. Consequently, the displacement components at a bond line, as given in equation (14.58), can be written as

$$u = u_R + \theta_2 e_3 \tag{14.59}$$

$$v = v_R - \theta_1 e_3 \tag{14.60}$$

$$w = w_R \tag{14.61}$$

From these results, the nodal shape function matrices for the **E830** sandwich element can be written as

$$\mathbf{H}_N^u = \begin{bmatrix} h_N^{uu} + e_3 h_N^{\theta_2 u} & h_N^{uv} + e_3 h_N^{\theta_2 v} & h_N^{uw} + e_3 h_N^{\theta_2 w} \\ h_N^{vu} - e_3 h_N^{\theta_1 u} & h_N^{vv} - e_3 h_N^{\theta_1 v} & h_N^{vw} - e_3 h_N^{\theta_1 w} \\ h_N^{wu} & h_N^{wv} & h_N^{ww} \end{bmatrix} \tag{14.62}$$

$$\mathbf{H}_N^\theta = \begin{bmatrix} h_N^{u\theta_1} & h_N^{u\theta_2} & h_N^{u\theta_3} \\ h_N^{v\theta_1} & h_N^{v\theta_2} & h_N^{uv\theta_3} \\ h_N^{w\theta_1} & h_N^{w\theta_2} & h_N^{w\theta_3} \end{bmatrix} \tag{14.63}$$

and h_N^{ij} is the shape function for freedom i, due to freedom j, at node N.

E840 8–Node sandwich element

Formulation of the internal force and material and geometric stiffness matrices for the **E840** sandwich element follows exactly the same approach as presented above for the **E830** sandwich element. Results for these quantities are given in equations (14.36), (14.39), and (14.40), respectively.

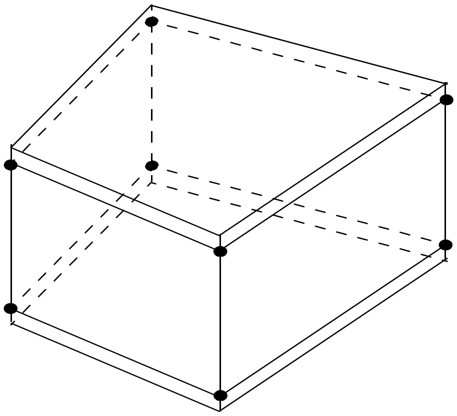


Figure 14.19 **E840** 8–Node sandwich element

Similarly, the **E840** sandwich core displacement follows the same assumptions as presented above for the **E830** sandwich element, as represented in equation (14.41). The displacement gradient components are given in equations (14.55), (14.56), and (14.57).

Displacement at a bond line between a sandwich face sheet and core is given in terms of the face sheet reference surface displacement and the eccentricity of the bond line with respect to the face sheet reference surface as follows:

$$\mathbf{u} = \mathbf{u}_R + \Theta \times \mathbf{e} \tag{14.64}$$

Here $\mathbf{u}_R$ is the face sheet reference surface displacement, Θ is the local reference surface rotation, and **e** is the eccentricity of the sandwich bond line from the face sheet reference surface.

For an **E410** quadrilateral shell element, Kirchhoff assumptions for the transverse *w*-displacement component at a sandwich bond line can be written as

$$w = w_R + w_{R,x} e_1 + w_{R,y} e_2 \tag{14.65}$$

Comparing equation (14.65) with the third component of equation (14.64), the face sheet reference surface rotation vector components are seen to be related to the transverse *w*-derivatives as follows:

$$\theta_1 = w_{R,y} \tag{14.66}$$

$$\theta_2 = -w_{R,x} \tag{14.67}$$

$$\theta_3 = 0 \tag{14.68}$$

In addition, the only nonzero component of the eccentricity is e$_3$. Consequently, the displacement components at a bond line, as given inequation (14.64), can be written as

$$u = u_R - w_{R,x} e_3 \tag{14.69}$$

$$v = v_R - w_{R,y} e_3 \tag{14.70}$$

$$w = w_R \tag{14.71}$$

From these results, the nodal shape function matrices for the **E840** sandwich element can be written as

$$\mathbf{H}_N^u = \begin{bmatrix} h_N^{uu} - e_3 h_{N,x}^{wu} & h_N^{uv} - e_3 h_{N,x}^{wv} & h_N^{uw} - e_3 h_{N,x}^{ww} \\ h_N^{vu} - e_3 h_{N,y}^{wu} & h_N^{vv} - e_3 h_{N,y}^{wv} & h_N^{vw} - e_3 h_{N,y}^{ww} \\ h_N^{wu} & h_N^{wv} & h_N^{ww} \end{bmatrix} \tag{14.72}$$

$$\mathbf{H}_N^\theta = \begin{bmatrix} h_N^{u\theta_1} & h_N^{u\theta_2} & h_N^{u\theta_3} \\ h_N^{v\theta_1} & h_N^{v\theta_2} & h_N^{uv\theta_3} \\ h_N^{w\theta_1} & h_N^{w\theta_2} & h_N^{w\theta_3} \end{bmatrix} \tag{14.73}$$

and h_N^{ij} is the shape function for u_i, due to freedom *j*, at node *N*.

E849 18–Node sandwich element

The description of the **E849** sandwich element in element units is *in preparation*.

E845 and E847 mesh-transition sandwich elements

With shell units that are constructed with **E840** sandwich elements, transition meshes can be generated in exactly the same way as described above for the standard quadrilateral-shell-elements case. This is done *via* G-1 and G-2c records (specifying full and partial compatibilities, respectively) and *via* the **MESH1** through **MESH4** variables on the N-1 record for any shell unit that has one or more mesh-transition elements. These variables take the value 0 for a boundary line where the mesh is to be *continuous* with adjacent shell units, or 1 where the mesh *halves* across the boundary line. This input tells **STAGS** to interpret *every other* node on each of the nodal layers of the shell as a dependent node that is constrained automatically by introducing an **E845** or an **E847** mesh-transition sandwich element along the boundary. The choice of **E845** or **E847** depends on the number of dependent nodes that have to be constrained. Note that since the number of intervals is doubling as you move in from an adjacent unit, the number of mesh lines in each layer of the shell must be 2N-1, where N is the number of mesh lines in the adjoining *coarser* mesh (the number of mesh lines are specified in the F-1 records).

The description of **845** and **847** sandwich mesh-transition sandwich elements in element units is *in preparation*.

14.7 Solid Elements

The current version of the **STAGS** program has the following four “standard” solid elements:

- **E881** 8-node ANS solid element
- **E882** 18-node ANS solid element
- **E883** 27-node ANS solid element
- **E885** 20-node displacement-based solid element

These are described in the following four subsections.

E881 8-Node ANS solid element

The **E881** 8-node ANS solid element, in **STAGS**, is shown in Figure 14.20:

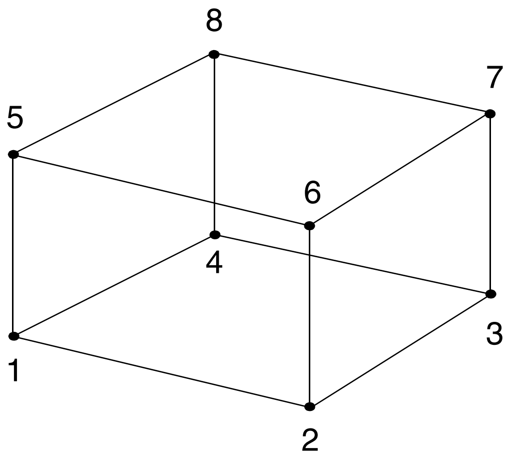


Figure 14.20 The **E881** 8-node ANS solid element

E882 18-Node solid element

The **E882** 18-node ANS solid element, in **STAGS**, shown in Figure 14.21:

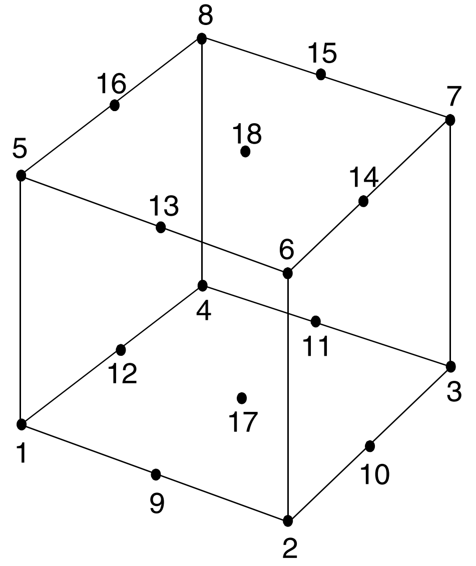


Figure 14.21 The **E882** 18-node ANS solid element

E883 27-Node solid element

The **E883** 27-node ANS solid element, in **STAGS**, shown in Figure 14.22:

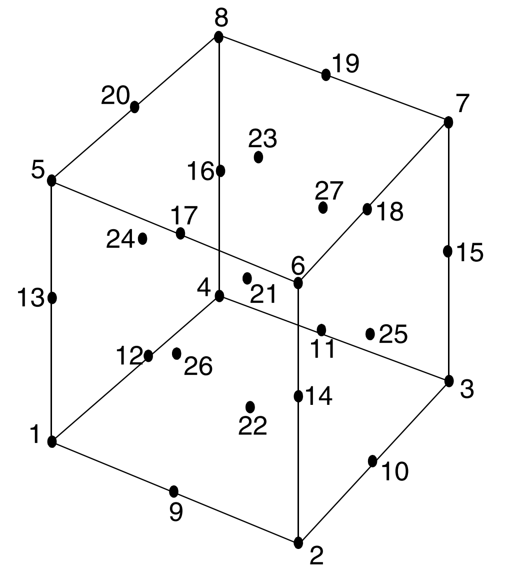


Figure 14.22 The **E883** 27-node ANS solid element

E885 20-Node displacement-based solid element

The **E885** 20-node displacement-based solid element, in **STAGS**, shown in Figure 14.23:

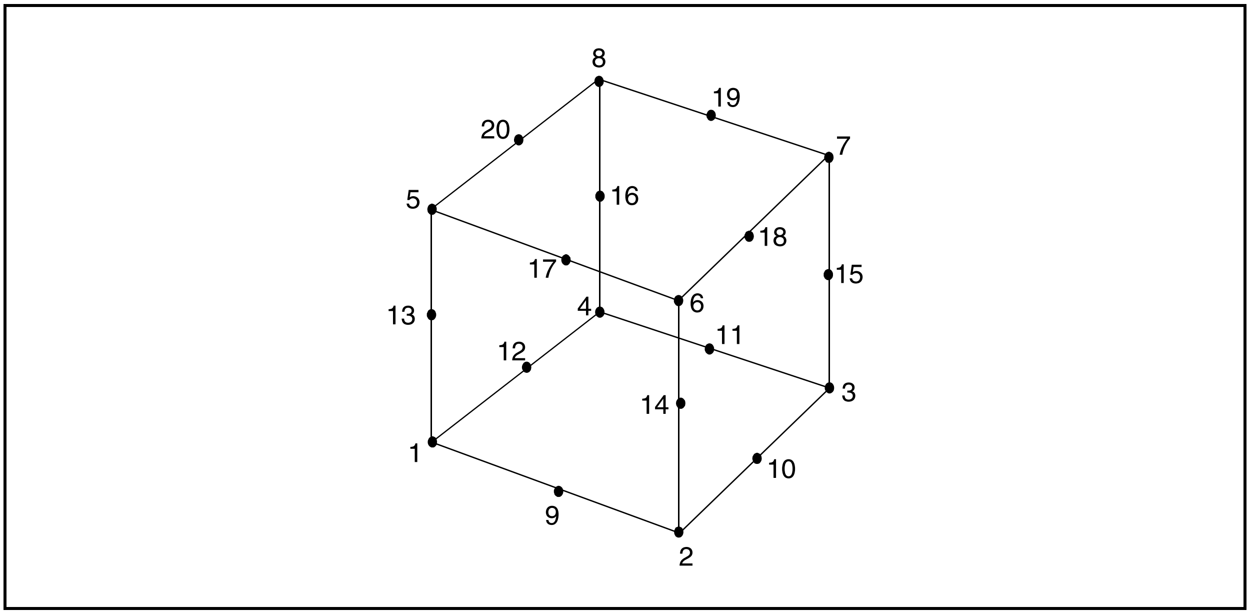


Figure 14.23 The **E885** 20-node displacement-based solid element

14.8 Contact Elements

The three types of contact elements that are implemented in the current version of **STAGS** are summarized below:

- **E810** Pad Contact Element
- **E820** General Contact Element
- **E822** Line Contact Element

A discussion of each of these element types follows.

E810 Pad contact element

The 8-node surface-to-surface “pad” contact element developed by Carlos Davila[*] has been implemented in the current version of **STAGS** as the type **E810** pad element. This element, shown in Figure 14.24, enables the user to treat some problems in which different shells come into contact with each other or in which shells come into contact with parts of themselves. The pad element is essentially a set of four independent nonlinear springs connecting the corner nodes of two **E410** shell elements—the “lower” **E410** coinciding with the lower face and the “upper” **E410** coinciding with the upper face of the pad. This arrangement facilitates use of a local coordinate system which corotates with the lower **E410** element, and it provides a simple definition of the average normal to that surface for simple monitoring of the “gaps” that are used to determine the spring forces when contact occurs.

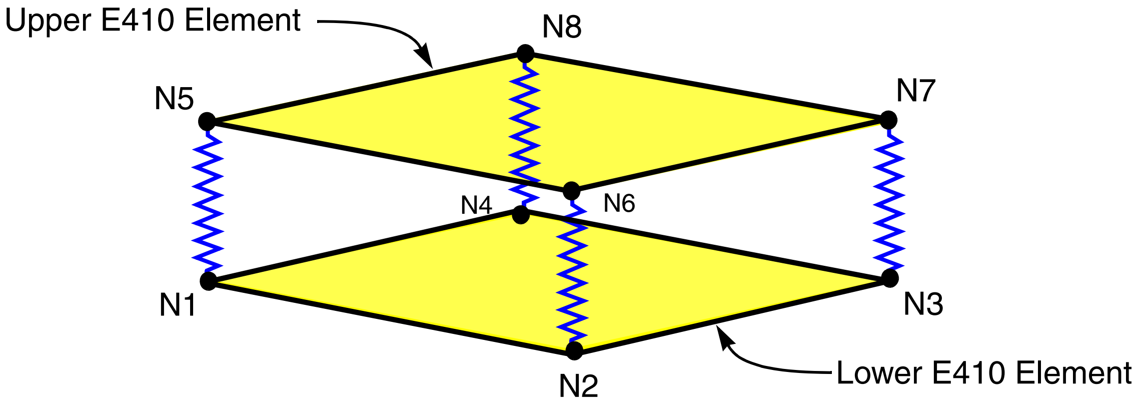


Figure 14.24 The **E810** pad contact element

[*] Davila, Carlos: “Pad Elements for Gaps, Contact Problems and Crack Closure in Fracture Mechanics,” NASA/Langley Computational Mechanics Branch Report, 18 August 1992.

Forces from the nonlinear corner springs, which enforce the no-penetration inequality constraints on contacting structures, are computed with one or more I-4a tables, which contain *stiffness vs. penetration* penalty function specifications. The simplest *stiffness vs. penetration* curve is bilinear—giving zero (or negligibly small) forces and stiffnesses when the gap for a given pair of nodes is zero or positive, and producing large forces and stiffnesses (which act to minimize penetration) when the gap is negative. For best results, the *stiffness vs. penetration* curves specified in these tables should be “S” shaped—with a pronounced “toe” near the origin. See the “**Force and Stiffness Computations”** topic, below, for more information about this important subject.

The **E810** pad element is designed for use in situations where the contact region is known *a priori* and where individual elements coming into contact can be readily identified and paired with each other. It enables the user to treat (some) lap-joint and other types of contact problems, for example; but it is *not* designed for use in more general situations where the contact regions are not known *a priori* or when sliding occurs or friction is present. Pad elements can also be used to treat contact (minimize penetration) between pairs of 8-node *solid* elements. They can also be used (in sets of four **E810** elements) for contact situations for shells that are constructed with 9-node **E480** shell elements. (Note: these capabilities have not been tested and cannot be guaranteed to work correctly with the current version of **STAGS**.) With the lower pad-element nodes specified as immobilized *auxiliary user points*, pad elements can be used to treat contact between a flexible shell (the *upper* surface of the pad element) and a rigid wall (the *lower* surface of the pad element). This capability has been tested and can be exploited by **STAGS** users in appropriate situations.

E810 pad elements must be defined in an element unit, referencing User Points (nodes) that coincide with—and are slaved to—the nodes of the underlying **E410** shell elements (or E880 solid elements). As noted above, each pad-element definition references a penalty function table that specifies the nonlinear *spring* *stiffness* for each of the springs comprising the pad element as a function of *penetration*.

Force and stiffness computations

As noted above, the 8-node **E810** pad element consists of four independent springs connecting the nodes on the *lower face* of the element to those on its *upper face*—the lower-face nodes generally being associated with an **E410** element on one structural component and the upper-face nodes being associated with an **E410** element on a different component. Forces and stiffnesses for the coupled ensemble of springs are expressed in a local element coordinate system which rotates with the lower face element. Neglecting frictional forces, the Davila formulation gives

$$\begin{bmatrix} F_e \end{bmatrix} = \begin{bmatrix} f^n \\ f^n \end{bmatrix} \tag{14.74}$$

and

$$\begin{bmatrix} \bar{K}_e \end{bmatrix} = \begin{bmatrix} k^n & -k^n \\ -k^n & k^n \end{bmatrix} \tag{14.75}$$

for the contact-element force vector and stiffness matrix, respectively, with the *n* superscript taking on values from 1 to 4 (for the four springs), where

$$f^n = \begin{bmatrix} 0 \\ 0 \\ \hat{f}^n \end{bmatrix} \tag{14.76}$$

and

$$k^n = \begin{bmatrix} 0 & 0 & 0 \\ 0 & 0 & 0 \\ 0 & 0 & \alpha^n \end{bmatrix} \tag{14.77}$$

In the Davila formulation, the α^n quantities are penalty functions representing the spring stiffnesses and the $\hat{f}^n = (\alpha^n - \alpha^o)g^n + (U^n - L^n)\alpha^n$ quantities represent spring forces. Here α^o is the spring stiffness in its “open” configuration, where U^n and L^n are the normal displacement components (with respect to the co-rotated lower-face element) of the upper-face and lower-face spring nodes, respectively, and g^n is the so-called *clearance* for the nodal pair in the undeformed configuration.

In Davila’s original formulation, $\alpha^n = \alpha^o$ when $U^n - L^n - g^n \leq 0$ and $\alpha^n = \alpha$ when $U^n - L^n - g^n > 0$ (where α is an analyst-supplied penalty-function parameter for the element). The initial implementation in **STAGS** of the Davila pad element used these expressions—but with the α^n defined by the analyst, on an element-by-element basis, as a spring-stiffness-*vs*-displacement (penalty) function. Numerical difficulties stemming from that implementation were surmounted in the current version of **STAGS** by replacing the above-cited expression for f^n by

$$f^n = \begin{bmatrix} 0 \\ 0 \\ r^n \end{bmatrix} \qquad (14.78)$$

where $r^n = r^n(\delta^n)$ is the integrated value of $\alpha(\delta)$ over $0 \le \delta \le \delta^n$, and δ^n represents the normal penetration of the lower-face reference plane by the n^{th} upper-face node point.

This approach is especially effective when the user specifies a stiffness-*vs*-displacement function that, with integration, gives a smoothly increasing force with increasing penetration of the target-element. This approach to force computation for the pad element was motivated by successes realized in overcoming contact-induced numerical problems by using it first with mount elements, and then with the general-contact elements that are described later.

For some examples illustrating some of the ways in which **E810** PAD elements can be used, please see the ***STAGS** Elements Manual* and the ***STAGS** Test Cases Manual* documents.

E820 General contact element

The **E820** point/surface contact "element" was implemented in **STAGS** to treat structural contact problems that are more general than those that can be handled with the **E810** element. In discussing this point/surface approach, it is only necessary to consider the case where two structural components experience contact with each other, as shown schematically in Figure 14.25:

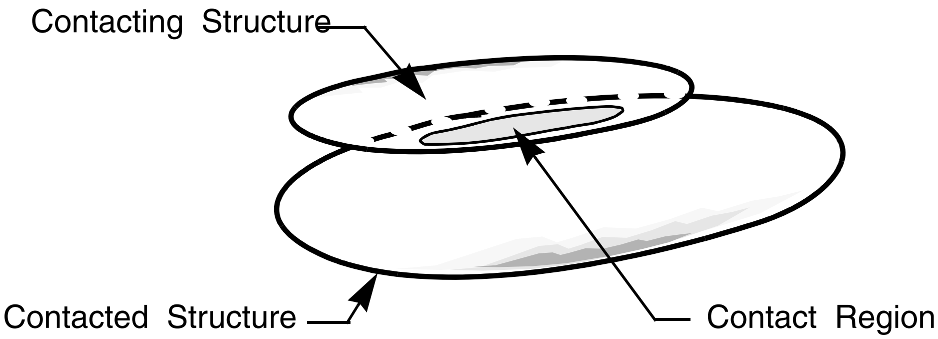


Figure 14.25 Two-body contact situation

One of these bodies is arbitrarily designated as the *contacting* structure, and the other is referred to as the *contacted* structure. These two structures are different bodies in the following discussion, but everything generalizes to the *same*- and to the *multi-body* contact situations.

To use the **E810** (pad) element in an analysis involving structural contact, the analyst must know *a priori* which element(s) of the *contacting* structure come into contact with which elements of the *contacted* structure, so that an 8-node pad element (which is basically a set of four nonlinear springs connecting the corresponding vertices of contacting quadrilaterals) can be constructed for each such pair of elements.

The pad-element approach is inconvenient and inefficient (at best) for problems in which the contacting and/or the contacted elements are not known *a priori,* and it is totally inappropriate for problems in which the contacting and/or contacted elements change as the analysis progresses. More general *surface/surface* or *point/surface* contact capabilities are required for problems of that nature.

With a completely general surface/surface contact capability, the analyst would only need to specify that two (or more) structures might experience contact with each other, and the program would do whatever it needs to detect and deal with contacts as they occur. It is something of an understatement to note that this would be a very expensive luxury for most problems of significant size and/or complexity. In many problems, good advantage can be taken of user specifications that some part(s) of the contacting structure may experience contact with some part(s) of the contacted structure, so that only elements and/or points in the designated regions need to be considered during the contact operations that the program must perform.

With this level of generality, a *surface/surface* contact implementation permits the analyst to specify that one or more members of a specific set of elements on the surface of the contacting structure may initially be in contact (or may subsequently come into contact) with one or more members of a different set of elements on the surface the contacted structure. The program would then need to detect and deal with all kinds of situations in which various parts of each contacting element interact with various parts of one or more contacted elements. That is generally computationally demanding and *very* expensive.

With the same level of generality, a point/surface implementation permits the analyst to specify that one or more contact points on the surface of the contacting structure may initially be in contact (or may come into contact) with one or more members of a set of target elements on the surface the contacted structure. Here, the program need only detect and deal with interactions between individual contact points and the specific target elements that comprise the contact surface.

This point/surface approach has been implemented in **STAGS**, to treat the situation that is shown schematically in Figure 14.26:

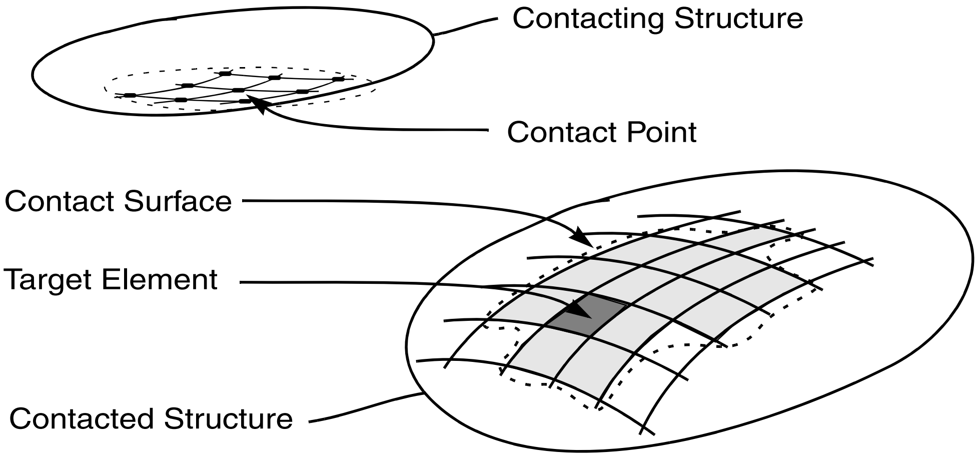


Figure 14.26 Point/surface contact definition

For problems requiring this more general treatment of structural contact, the user of **STAGS** must include one or more so-called contact-definition specifications in an element unit for the model to be analyzed. With each contact-definition, the analyst specifies that one or more contact points in the contacting structure may experience contact with one or more of the target elements that comprise the contact surface region of the contacted structure. (The contact points and the contacted surfaces are usually, but not necessarily, in different shell units in the model.) **STAGS** then considers the possibility that during the analysis any of these contact points may be in contact with any of these target elements—where each point in contact with the contact surface can move (without friction) from one target element of the contact surface to a neighbor, as loadings and deformations dictate.

It is important to note that each point/surface contact definition produces one **E820** “contact-point element” in the **STAGS** model for each designated contact point, and one **E821** “target element” in the model for each designated target element. No actual structural elements are defined by these definitions.

The analyst informs **STAGS** (*via* contact definitions) at the outset of an analysis that the indicated contacts are possible. **STAGS** then takes contact-induced forces and stiffnesses into account during the course of the analysis by using appropriate combinations of these **E820** and **E821** elements to construct structural elements on-the-fly when they are required for each actual contact between a contact point and the contacted target element.

Two major aspects of the current point/surface contact implementation in **STAGS** are discussed in the following two sub-sections: how **STAGS** determines the *status* of each contact point—*i.e.*, how the program determines whether or not each contact point is in contact with its target surface (and, if so, which element(s) it is contacting), and how **STAGS** computes the contact-induced forces and stiffnesses. Results obtained using the new point/surface contact capabilities are presented and discussed after that.

Determination of contact status

Information about contact is organized on two distinct levels in **STAGS**. On the first level, analyst-supplied contact-definition information is used to generate a number of multi-value dictionaries (tables) that are used to keep track of which contact-points and target elements are included in each contact-definition. These tables facilitate access to information such as (a) the node points that are associated with the set of target elements for the contact region, (b) the target elements that are attached to each of these nodes, (c) the other target elements (if any) that are connected to each edge of each target element on the target surface, and other things like that. On the second level, contact status information is maintained for each contact point, and configuration information is maintained for each contact point and each target element. Some of this information is maintained in datasets that disappear on completion of the analysis, and some of it is maintained in the *case.rst* file along with other information required to re-start a **STAGS** analysis.

When **STAGS** performs a first or second variation for a problem, the program checks first to determine the contact status of each contact point. Figure 14.27 shows an overview of the logic used in **STAGS** to determine the contact-status.

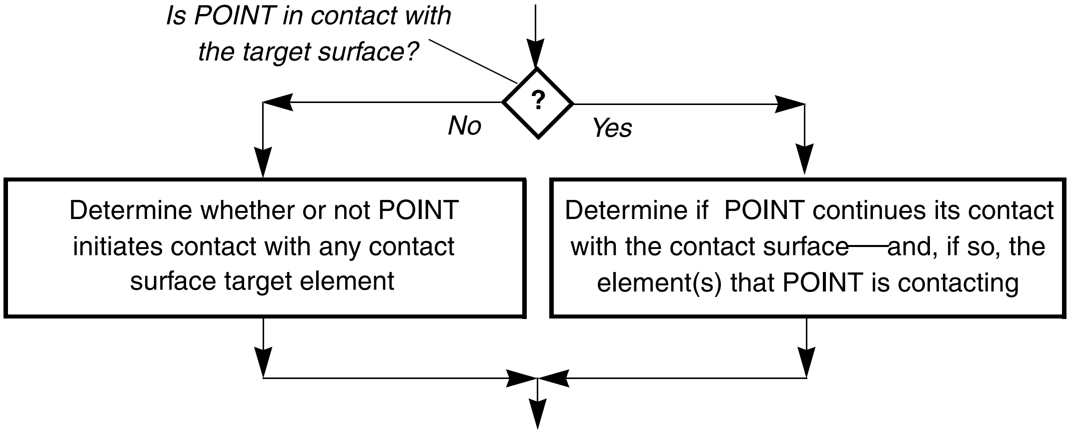

Is POINT in contact with
the target surface?
?
No
Yes
Determine whether or not POINT initiates contact with any contact surface target element
Determine if POINT continues its contact with the contact surface—and, if so, the element(s) that POINT is contacting

Figure 14.27 Contact-status determination

If the contact point is *not* in contact with its contact surface, **STAGS** uses the logic shown in Figure 14.28 to determine whether or not that point initiates contact with its contact surface during the current step.

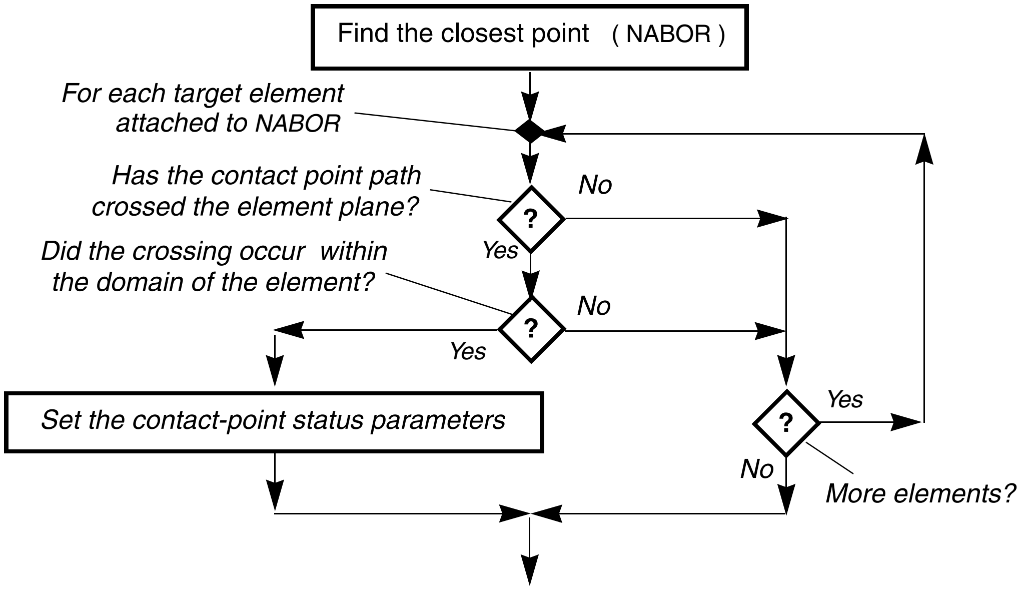

Find the closest point (NABOR)
For each target element attached to NABOR
Has the contact point path crossed the element plane?
No
?
Yes
Did the crossing occur within the domain of the element?
No
?
Yes
Set the contact-point status parameters
Yes
?
No
More elements?

Figure 14.28 Determination of contact initiation

STAGS begins by comparing the current position of the point to that of each node on the contact surface to identify ***NABOR***—the contact surface node closest to the point. **STAGS** then examines the positional relationships between point and each target element attached to ***NABOR*** at the start of the current step and for the current solution, to determine if point is on the same side of the element as it was at the start of the current step (in which case contact is not initiated), or if the path of point (during the current step) has crossed the element (in which case contact is initiated). **STAGS** takes the target element thicknesses into account, and utilizes a user-specified contact-point ***RADIUS*** parameter to account for the thickness of the contacting structure, in determining whether or not contact occurs. If the path of this contact point crosses the interior of a given target element, the point initiates contact only with that particular target element. If the crossing occurs on an edge or at a vertex of the target element, the point initiates contact with the crossed target element and with its neighbor (on the crossed edge) or with its neighbors (at the crossed vertex).

The algorithm that **STAGS** uses to determine initial contact also has an exhaustive-search option, to examine all contact-point/target-element contact possibilities (instead of just those stemming from ***NABOR***). This option is in the code but cannot be user-activated at the present time. If the contact point ***is*** in contact with its contact surface, **STAGS** uses the logic shown in Figure 14.29 to determine whether or not that contact continues.

Subroutines **E820Q2** and **E820T2** (in the *No* branch from the *“Is the contact point inside the element at start of step?”* question, in Figure 14.29) are called when the target element that the contact point is contacting at the start of the step is a quadrilateral or a triangle,

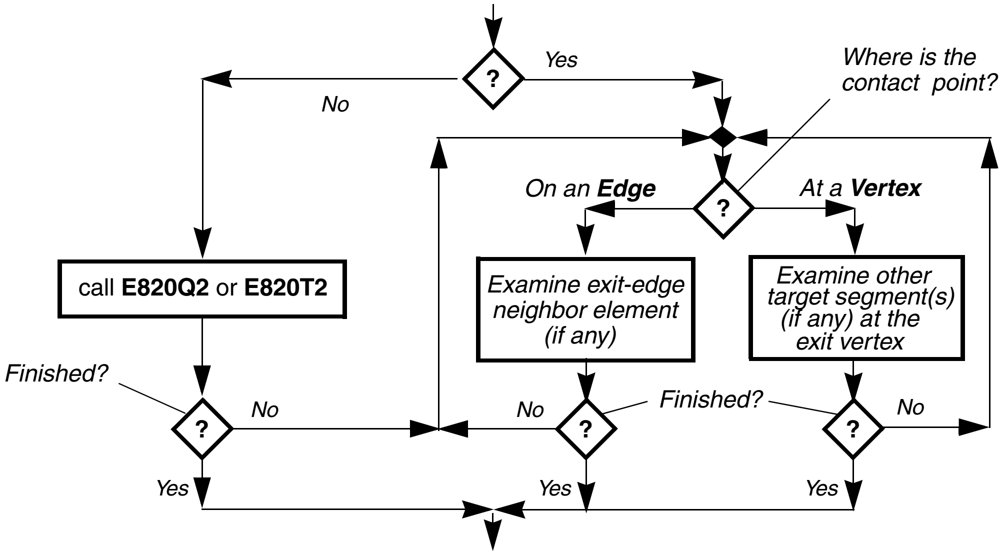

?
Yes
No
Where is the contact point?
On an Edge
At a Vertex
call E820Q2 or E820T2
Examine exit-edge neighbor element (if any)
Examine other target segment(s) (if any) at the exit vertex
Finished?
No
Finished?
No
No
Yes
Yes
Yes

Figure 14.29 Determination of contact continuation

respectively. Each of these routines tests to determine (a) if during the current step the contact point crosses the surface of the target element within its domain (in which case contact with the entire contact surface is terminated), (b) if the contact point is still within the interior of the start-of-step target element (in which case contact with that target element continues), and/or (c) if the contact point is currently on an edge or at a vertex of the target element (in which case contact continues with all of the target elements that are attached to that vertex. If it is determined that the contact point continues its contact with the given target element (or that it stops contacting the entire contact surface), an *"I am finished!"* signal is returned to the calling routine (along with the necessary contact-point status parameters).

The *"Examine exit-edge neighbor element"* and *"Examine other target segment(s) ... at the exit vertex"* portions of the *Yes* branch from the *"Is the contact point inside the element at start of step?"* question, in Figure 14.29) are basically calls to control routines (**NABOR1** and **AMIGO1**) that perform similar tests for the contact point with respect to the one target element that is connected to the flagged edge of the original target element or to each of the target elements that are connected to the flagged vertex of the original target element, respectively. An *"I am finished!"* signal from either of these routines terminates efforts to determine if contact continues, with the contact-point status fully determined. If either routine returns to the control level (shown in Figure 14.29) without the *"I am finished!"* signal, testing continues until all viable contact-continuation candidates have been checked.

Here, it is important to note that continued testing may be required for three reasons: because the path of the contact point, originally in the interior of a given target element, has taken it across an edge of or through a vertex of that element (then into or through a neighboring element, if any); because the point, originally on an edge of the given target element, has moved off that edge (and possibly into or through the neighboring element, if any); or because the point, originally at a vertex of the given target element, has moved off that vertex (and possibly into or through a neighboring element, if any). The word *through* is used in two senses in the preceding sentence: some tests are performed to determine whether or not the path of the contact point crosses the appropriate surface plane of the candidate element (in which case contact ceases), and other tests are performed to determine if the path of the contact point is such that the candidate element is traversed without crossing the surface of that element (in which case contact *may* continue).

Under some conditions, the contact status of a given contact point and its target surface cannot be determined without adding a few "twists" to these tests, principally in order to take more global (than at the element level) contact-surface curvatures into account. In essence, these twists supplement the simple *"Am I in the domain of the (given) element?"* test that **STAGS** uses throughout most of its contact-status determination process.

Force and stiffness computations

The general-contact quadrilateral element used in **STAGS** is based on the variational approach used by Parisch.* The general-contact triangular element in **STAGS** is based on the formulation that is described farther below.

The Parisch formulation for the contact stiffness matrix and force vector begins with the assumption that a contact point is penetrating a target element at a known location, $c(\xi,\eta)$, where ξ and η are the *surface coordinates* of the contact point. Applying the usual variational techniques to the energy functionals, Parisch obtained the following consistent tangent stiffness matrix and force vector for a quadrilateral target element:

$$K_e = \varepsilon\{\Theta_1 + \Theta_2 + \Theta_3 + \Theta_4 + \Theta_5\} \tag{14.79}$$

and

$$F_e = \varepsilon\delta \cdot N \tag{14.80}$$

where

$$\Theta_1 = N \cdot N^* \tag{14.81}$$

* Parisch, H., *"A Consistent Tangent Stiffness Matrix for Three-Dimensional Non-Linear Contact Analysis,"* International Journal for Numerical Methods in Engineering, v. 28, p. 1803*ff* (1989).

$$\Theta_2 = \delta\left(\frac{x^3\delta}{h}\bar{m}_{12} - 1\right)[U_1V_1{*} + U_2V_2{*} + V_1U_1{*} + V_2U_2{*}] \tag{14.82}$$

$$\Theta_3 = \frac{-g^2}{h}[m_{22}U_1U_1{*} + m_{11}U_2U_2{*} - \bar{m}_{12}(U_1U_2{*} + U_2U_1{*})] \tag{14.83}$$

$$\Theta_4 = \frac{-x^3\delta}{h}[(m_{11}m_{22} - \bar{m}_{12}m_{12})(V_1V_2{*} + V_2V_1{*}) - x^3\delta(m_{11}V_1V_1{*} + m_{22}V_2V_2{*})] \tag{14.84}$$

$$\Theta_5 = \frac{-x^3\delta^2}{h}[m_{22}(U_1V_2{*} + V_2U_1{*}) + m_{11}(U_2V_1{*} + V_1U_2{*})] \tag{14.85}$$

and

$$N{*} = \{-n\psi_1, -n\psi_2, -n\psi_3, -n\psi_4, n\} \tag{14.86}$$

$$U_1{*} = \{n\psi_{1,\,\xi}, n\psi_{2,\,\xi}, n\psi_{3,\,\xi}, n\psi_{4,\,\xi}, 0, 0, 0\} \tag{14.87}$$

$$U_2{*} = \{n\psi_{1,\,\eta}, n\psi_{2,\,\eta}, n\psi_{3,\,\eta}, n\psi_{4,\,\eta}, 0, 0, 0\} \tag{14.88}$$

$$V_1{*} = \{-e^1\psi_1, -e^1\psi_2, -e^1\psi_3, -e^1\psi_4, e^1\} \tag{14.89}$$

$$V_2{*} = \{-e^2\psi_1, -e^2\psi_2, -e^2\psi_3, -e^2\psi_4, e^2\} \tag{14.90}$$

In these expressions, the ψ_n are the basis functions evaluated at the nodes of the target element; e^1, e^2, and n are the contravariant tangent vectors and the normal vector at the contact point on the target element; h and the m_{ij} are contact-point-related geometric quantities; x^3 measures warping of the deformed target element surface; δ represents the penetration by the contact point of the target element at $c(\xi,\eta)$; and ε is the user-supplied penalty function parameter.

For the triangular element, the normal-direction components of the material stiffness matrix are

$$[K_m] = \alpha\begin{bmatrix} L_1L_1 & L_1L_2 & L_1L_3 & -L_1 \\ & L_2L_2 & L_2L_3 & -L_2 \\ & & L_3L_3 & -L_3 \\ sym & & & 1 \end{bmatrix} \tag{14.91}$$

and the full geometric stiffness matrix is

$$[K_g] = K_{g_1} + K_{g_2} + K_{g_3} + K_{g_4} \tag{14.92}$$

where

$$K_{g_1} = f \cdot [SP^* + PS^*] / bh \tag{14.93}$$

$$K_{g_2} = f \cdot [T] / bh \tag{14.94}$$

$$K_{g_3} = -f\delta \cdot [PP^*] / b^2 h^2 \tag{14.95}$$

$$K_{g_4} = -f \cdot [RQ^* + QR^*] / b^2 h^2 \tag{14.96}$$

where

$$P^* = \begin{bmatrix} 0 & 0 & h & 0 & 0 & -h & 0 & 0 & 0 & 0 & 0 & 0 \\ 0 & 0 & (b-s) & 0 & 0 & s & 0 & 0 & -b & 0 & 0 & 0 \end{bmatrix} \tag{14.97}$$

$$Q^* = \begin{bmatrix} h & (b-s) & 0 & -h & s & 0 & 0 & -b & 0 & 0 & 0 & 0 \end{bmatrix} \tag{14.98}$$

$$R^* = \begin{bmatrix} 0 & 0 & r_1 & 0 & 0 & r_2 & 0 & 0 & r_3 & 0 & 0 & 0 \end{bmatrix} \tag{14.99}$$

$$S^* = \begin{bmatrix} -1 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 1 & 0 & 0 \\ 0 & -1 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 1 & 0 \end{bmatrix} \tag{14.100}$$

$$T = 0 \begin{bmatrix} 0 & 0 & 0 & 0 & 0 & -x_2 & 0 & 0 & x_2 & 0 & 0 & 0 \\ & 0 & 0 & 0 & 0 & x_1 & 0 & 0 & -x_1 & 0 & 0 & 0 \\ & & 0 & x_2 & -x_1 & 0 & -x_2 & x_1 & 0 & 0 & 0 & 0 \\ & & & 0 & 0 & 0 & 0 & 0 & -x_2 & 0 & 0 & 0 \\ & & & & 0 & 0 & 0 & 0 & x_1 & 0 & 0 & 0 \\ & & & & & 0 & x_2 & -x_1 & 0 & 0 & 0 & 0 \\ & & & & & & 0 & 0 & 0 & 0 & 0 & 0 \\ & & & & & & & 0 & 0 & 0 & 0 & 0 \\ & & S & y & m & & & & 0 & 0 & 0 & 0 \\ & & & & & & & & & 0 & 0 & 0 \\ & & & & & & & & & & 0 & 0 \\ & & & & & & & & & & & 0 \end{bmatrix} \tag{14.101}$$

where b and h are the base and height dimensions of the triangle (in its local coordinate system); the L_i are the basis functions (area coordinates) in the triangle at the point of contact; δ is the penetration; s is the (local-system) x-coordinate of the triangle's third (non-base) node point; and where the r_i and x_i parameters are functions of the contact-point location in the triangle. The α and f parameters, here, represent the user-specified stiffness (as a function of the penetration) and its integration over the stiffness/penetration curve, as described above.

The normal-direction force contributions for the triangular element are given by

$$\{F\} = \alpha \cdot \begin{Bmatrix} -L_1 \\ -L_2 \\ -L_3 \\ 1 \end{Bmatrix} \qquad (14.102)$$

For examples illustrating the use of **E820** general contact elements, see the ***STAGS*** *Elements Manual* and the ***STAGS*** *Test Cases Manual* documents.

E822 Line contact element

The line contact element that **STAGS** constructs on-the-fly when contact occurs between two line-pair segments is based on the formulation that is described in the paper by Rankin, Chien, Loden and Swenson.*

Let us suppose that two lines in space are defined by ordered sets of nodes $\{N_i\}$ and $\{M_i\}$ for contacting line L1 and contacted line L2, respectively, as shown in Figure 14.30. Also let us assume that any point **p** between any two nodes N_i and N_{i+1} on a given line is described by linear interpolation.

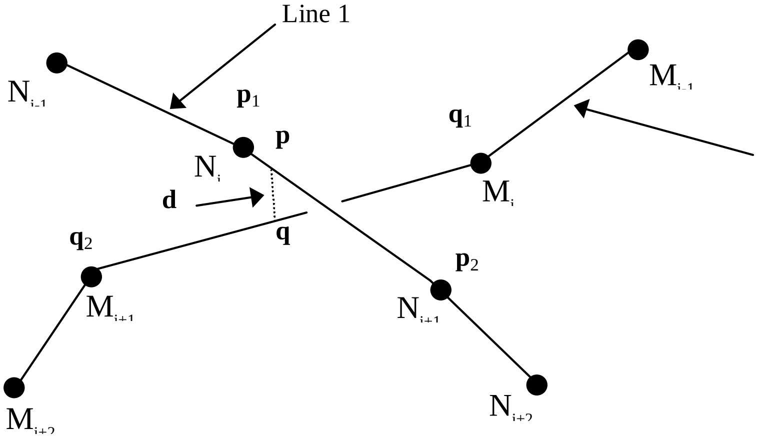


Figure 14.30 Line-contact lines

* Rankin, C.C., L.S. Chien, W.A. Loden and L.W. Swenson, Jr., *"Line-to-Line Contact Behavior of Shell Structures,"* AIAA Paper No. 99–1237, April 1999

We have labeled the minimum distance **d** between the two lines, as shown in the figure. Any point between, for example, two nodes N_i and N_{i+1} is interpolated by a parameter ξ as follows:

$$\mathbf{p}(\xi) = \frac{1}{2}\ [\mathbf{p}_1(1-\xi) + \mathbf{p}_2(1+\xi)] \tag{14.103}$$

and for the second line, we have

$$\mathbf{q}(\eta) = \frac{1}{2}\ [\mathbf{q}_1(1-\eta) + \mathbf{q}_2(1+\eta)] \tag{14.104}$$

where this time, the points **q** refer to nodes M_i and M_{i+1} on the other line. The distance between **p** and **q** is clearly

$$\mathbf{d}(\xi, \eta) = \mathbf{p} - \mathbf{q} \tag{14.105}$$

To determine if contact has taken place, we wish to find the minimum value of **d** as a function of ξ and η, or

$$\begin{aligned} \mathbf{d} \bullet \mathbf{p}_{,\xi} &= 0 \\ \mathbf{d} \bullet \mathbf{q}_{,\eta} &= 0 \end{aligned} \tag{14.106}$$

Since

$$\begin{aligned} \mathbf{p}_{,\xi} &= \frac{1}{2}\ (\mathbf{p}_2 - \mathbf{p}_1) \\ \mathbf{q}_{,\eta} &= \frac{1}{2}\ (\mathbf{q}_2 - \mathbf{q}_1) \end{aligned} \tag{14.107}$$

Equations (14.107) yield a linear equation in ξ and η:

$$\begin{bmatrix} |\mathbf{p}_2 - \mathbf{p}_1|^2 & -(\mathbf{p}_2 - \mathbf{p}_1) \bullet (\mathbf{q}_2 - \mathbf{q}_1) \\ -(\mathbf{p}_2 - \mathbf{p}_1) \bullet (\mathbf{q}_2 - \mathbf{q}_1) & |\mathbf{q}_2 - \mathbf{q}_1|^2 \end{bmatrix} \begin{bmatrix} \xi \\ \eta \end{bmatrix} = \begin{bmatrix} -2\Delta\mathbf{d}_c \bullet (\mathbf{p}_2 - \mathbf{p}_1) \\ 2\Delta\mathbf{d}_c \bullet (\mathbf{q}_2 - \mathbf{q}_1) \end{bmatrix} \tag{14.108}$$

or

$$\mathbf{Ce} = \mathbf{r} \tag{14.109}$$

where $\Delta\mathbf{d_c}$ is the distance between the centroids of the line segments belonging to the nodes in question:

$$\Delta\mathbf{d}_c = \frac{1}{2}[(\mathbf{p}_2+\mathbf{p}_1)-(\mathbf{q}_2+\mathbf{q}_1)] \tag{14.110}$$

and **C**, **e**, and **r** in equation (14.109) correspond to the matrix and vectors in equation (14.108). A solution to equation (14.108) always exists except in the pathological case that the two lines are parallel to one another, in which case an infinite number of solutions exist; such a case can be treated by other methods. A suggested technique is to find which pair of centroids yields a minimum distance, and then solve equation (14.108). If equation (14.108) has a solution in the range [-1,+1] for both ξ and η, the segment with minimum distance has been found; otherwise, neighboring segments need to be tried.

The penalty method of contact enforcement is expressed through the enforcement function $g(|\mathbf{d}|)$ which acts to repel the segments whenever **d** is negative, negative being defined when any segment crosses any shell or solid element face. To determine whether a crossing has occurred, combine equation (14.103) with the equation interpolating the element surface, and solve. Taking the corner nodes and using a bilinear interpolation:

$$\frac{1}{2}[\mathbf{p}_1(1-\xi)+\mathbf{p}_2(1+\xi)] = \frac{1}{4}\sum_k(1-\mathrm{rr}_k)(1-\mathrm{ss}_k)\mathbf{x}_k \tag{14.111}$$

for the unknowns ξ, *r*, and *s*. If there is a crossing, all three of these variables will lie in the interval $[-1,1]$. If **d** is negative, then the segments will be repelled by a force proportional to its first variation:

$$\delta g(|\mathbf{d}|) = \frac{g'}{|\mathbf{d}|}\mathbf{d}\bullet\delta\mathbf{d} = f\hat{\mathbf{d}}\bullet\delta\mathbf{d} \tag{14.112}$$

where g' is the derivative of g (or the quantity f most often interpolated from a one-dimensional table) and $\hat{d} = d/|d|$ is the normalized minimum distance vector. Expressed in terms of the problem unknowns, we obtain

$$\begin{aligned}\delta g(|\mathbf{d}|) &= \frac{1}{2}g'\hat{\mathbf{d}}\bullet[(\delta\mathbf{p}_2+\delta\mathbf{p}_1)-(\delta\mathbf{q}_2+\delta\mathbf{q}_1)+(\mathbf{p}_2-\mathbf{p}_1)\delta\xi-(\mathbf{q}_2-\mathbf{q}_1)\delta\eta+\xi(\delta\mathbf{p}_2-\delta\mathbf{p}_1)-\eta(\delta\mathbf{q}_2-\delta\mathbf{q}_1)] \\ &= \frac{1}{2}g'\hat{\mathbf{d}}\bullet[(\delta\mathbf{p}_2+\delta\mathbf{p}_1)-(\delta\mathbf{q}_2+\delta\mathbf{q}_1)+\xi(\delta\mathbf{p}_2-\delta\mathbf{p}_1)-\eta(\delta\mathbf{q}_2-\delta\mathbf{q}_1)]\end{aligned} \tag{14.113}$$

where dependence on (δξ,δη) vanishes because of equations (14.106) and (14.107).

The first and second variation is simplified by a straightforward change of variables:

$$\begin{bmatrix} \mathbf{v}_1 \\ \mathbf{v}_2 \\ \mathbf{v}_3 \\ \mathbf{v}_4 \end{bmatrix} = \frac{1}{2}\begin{bmatrix} \mathbf{I} & \mathbf{I} & & \\ & & \mathbf{I} & \mathbf{I} \\ \mathbf{I} & -\mathbf{I} & & \\ & & \mathbf{I} & -\mathbf{I} \end{bmatrix}\begin{bmatrix} \mathbf{p}_1 \\ \mathbf{p}_2 \\ \mathbf{q}_1 \\ \mathbf{q}_2 \end{bmatrix} = \mathbf{R}\begin{bmatrix} \mathbf{p}_1 \\ \mathbf{p}_2 \\ \mathbf{q}_1 \\ \mathbf{q}_2 \end{bmatrix} \tag{14.114}$$

from which equations (14.103)-(14.105) become

$$\begin{aligned} \mathbf{p} &= \mathbf{v}_1 + \xi\mathbf{v}_3 \\ \mathbf{q} &= \mathbf{v}_2 + \eta\mathbf{v}_4 \\ \mathbf{d} &= \mathbf{v}_1 - \mathbf{v}_2 + \xi\mathbf{v}_3 - \eta\mathbf{v}_4 \end{aligned} \tag{14.115}$$

The “internal force” due to contact becomes

$$f_{int} = g'\begin{bmatrix} \mathbf{I} \\ -\mathbf{I} \\ \xi\mathbf{I} \\ -\eta\mathbf{I} \end{bmatrix}\hat{\mathbf{d}} = g'\mathbf{Z}\hat{\mathbf{d}} \tag{14.116}$$

where the matrix **Z** will appear many times. The force transforms to the original system by multiplying by the transpose of **R**.

The second variation comes in three parts. The so-called “material” portion in the modified coordinate system can be written down immediately:

$$\mathbf{K}_m = \mathbf{Z}\hat{\mathbf{d}}g''(\mathbf{Z}\hat{\mathbf{d}})^T \tag{14.117}$$

where *g″* is the second derivative of *g*, or the first derivative *f′* of the table quantity *f*.

Although more difficult to compute, the “geometric” part is made much simpler by our change of variables. The first task is to determine the derivatives of ξ and η with respect to **v**, where we leave off the subscript on **v** for now. To do this, we first note that equation (14.109) is transformed into the new system as follows:

$$\begin{bmatrix} |\mathbf{v}_3|^2 & -\mathbf{v}_3 \bullet \mathbf{v}_4 \\ -\mathbf{v}_3 \bullet \mathbf{v}_4 & |\mathbf{v}_4|^2 \end{bmatrix} \begin{bmatrix} \xi \\ \eta \end{bmatrix} = \begin{bmatrix} -(\mathbf{v}_1 - \mathbf{v}_2) \bullet \mathbf{v}_3 \\ (\mathbf{v}_1 - \mathbf{v}_2) \bullet \mathbf{v}_4 \end{bmatrix}$$

$$\bar{\mathbf{C}}\mathbf{e} = \bar{\mathbf{r}} \qquad (14.118)$$

Now we take the derivative of equation (14.118):

$$\bar{\mathbf{C}}_{,\mathrm{v}}\mathbf{e} + \bar{\mathbf{C}}\mathbf{e}_{,\mathrm{v}} = \bar{\mathbf{r}}_{,\mathrm{v}} \qquad (14.119)$$

from which the unknown quantities $e_{,v}$ can be computed. The following derivations are lengthy but straightforward:

$$\bar{\mathbf{C}}\mathbf{e}_{,\mathrm{v}} = \bar{\mathbf{r}}_{,\mathrm{v}} - \bar{\mathbf{C}}_{,\mathrm{v}}\mathbf{e}$$

$$= \begin{bmatrix} -\mathbf{v}_3{}^{\mathrm{T}} & \mathbf{v}_3{}^{\mathrm{T}} & -(\mathbf{v}_1 - \mathbf{v}_2 + 2\xi\mathbf{v}_3 - \eta\mathbf{v}_4)^{\mathrm{T}} & \eta\mathbf{v}_3{}^{\mathrm{T}} \\ \mathbf{v}_4{}^{\mathrm{T}} & -\mathbf{v}_4{}^{\mathrm{T}} & \xi\mathbf{v}_4{}^{\mathrm{T}} & (\mathbf{v}_1 - \mathbf{v}_2 - 2\eta\mathbf{v}_4 + \xi\mathbf{v}_3)^{\mathrm{T}} \end{bmatrix} \qquad (14.120)$$

Note that there are 12 columns on the right hand side of equation (14.120), which correspond to the derivatives with respect to each component in turn of the transformed independent variable **v**. The result is a 2 x 12 matrix of derivatives $\boldsymbol{e}_{,v}$.

Next, we must compute the derivative of the unit vector $\hat{d}$ by the well-known formula

$$\hat{\mathbf{d}}_{\mathrm{V}} = \left(\mathbf{I} - \hat{\mathbf{d}}\hat{\mathbf{d}}^{\mathbf{T}}\right)\frac{\mathbf{d}_{,\mathrm{v}}}{|\mathbf{d}|}$$

$$= \mathbf{Q}\mathbf{d}_{,\mathrm{v}} \qquad (14.121)$$

$$\mathbf{Q} = \frac{\left(\mathbf{I} - \hat{\mathbf{d}}\hat{\mathbf{d}}^{\mathbf{T}}\right)}{|\mathbf{d}|}$$

$\boldsymbol{d}_{,v}$ is computed long-hand to yield:

$$\mathbf{d}_{,\mathrm{v}} = \left[\mathbf{I} + \mathbf{v}_3\xi_{,\mathrm{v}_1} - \mathbf{v}_4\eta_{,\mathrm{v}_1} \;\; -\mathbf{I} + \mathbf{v}_3\xi_{,\mathrm{v}_2} - \mathbf{v}_4\eta_{,\mathrm{v}_2} \;\; \xi\mathbf{I} + \mathbf{v}_3\xi_{,\mathrm{v}_3} - \mathbf{v}_4\eta_{,\mathrm{v}_3} \;\; -\eta\mathbf{I} + \mathbf{v}_3\xi_{,\mathrm{v}_4} - \mathbf{v}_4\eta_{,\mathrm{v}_4}\right] \qquad (14.122)$$

$$= \mathbf{Z}^{\mathrm{T}} + [\mathbf{v}_3 - \mathbf{v}_4]\mathbf{e}_{,\mathrm{v}}$$

If we now combine equations (14.121), (14.122), and use the chain rule on equation (14.116), we obtain the following:

$$
\begin{aligned}
\mathbf{K}_g &= \mathbf{K}_1 + \mathbf{K}_2 \\
\mathbf{K}_1 &= g'\mathbf{ZQd}_{,v} \\
\mathbf{K}_2 &= g'\begin{bmatrix} \mathbf{0}_{12} \\ \mathbf{0}_{12} \\ \left\{ \begin{matrix} \hat{\mathbf{d}} & \mathbf{0}_3 \\ \mathbf{0}_3 & -\hat{\mathbf{d}} \end{matrix} \right\} \mathbf{e}_{,v} \end{bmatrix}
\end{aligned}
\tag{14.123}
$$

Note that for equations (14.123), $\mathbf{0}_{12}$ represents a 3x12 matrix of zeros and $\mathbf{0}_3$ a 3x1 matrix of zeros. Also, recall that dimensions of $\boldsymbol{e}_{,v}$ and $\boldsymbol{d}_{,v}$ are 2x12 and 3x12 respectively, as they must be.

Finally, the total stiffness (second variation) is

$$
\mathbf{K}_{tot} = \mathbf{K}_m + \mathbf{K}_g \tag{14.124}
$$

and that the stiffness in the original system is

$$
\mathbf{K}_{tan} = \mathbf{R}^T\mathbf{K}_{tot}\mathbf{R} \tag{14.125}
$$

where K_{tan} is the required output “tangent” stiffness for the contact penalty function with freedoms arranged as in equations (14.103) and (14.104). That transformation can be carried out symbolically, resulting in the following:

$$
\begin{aligned}
\mathbf{K}_{tan} &= \mathbf{R}^T \begin{bmatrix} K_{11} & K_{12} & K_{13} & K_{14} \\ K^T_{12} & K_{22} & K_{23} & K_{24} \\ K^T_{13} & K^T_{23} & K_{33} & K_{34} \\ K^T_{14} & K^T_{24} & K^T_{34} & K_{44} \end{bmatrix} \mathbf{R} \\
&= \begin{bmatrix} K_{11}+K_{13}+K_{31}+K_{33} & K_{11}-K_{13}+K_{31}-K_{33} & K_{12}+K_{14}+K_{32}+K_{34} & K_{12}-K_{14}+K_{32}-K_{34} \\ & K_{11}-K_{13}-K_{31}+K_{33} & K_{12}+K_{14}-K_{32}-K_{34} & K_{12}-K_{14}-K_{32}+K_{34} \\ \text{Symmetric} & & K_{22}+K_{24}+K_{42}+K_{44} & K_{22}-K_{24}+K_{42}-K_{44} \\ & & & K_{22}-K_{24}-K_{42}+K_{44} \end{bmatrix}
\end{aligned}
\tag{14.126}
$$

See the ***STAGS*** *Elements Manual* and the ***STAGS*** *Test Cases Manual* documents for examples illustrating the use of **E822** line contact capabilities.

15
Analysis Techniques

15.1 Modeling Strategy

The modern computer has made it possible for the structural analyst to consider models that approximate rather closely the actual structure. However, there are still several limitations set by computer runtime and storage capacity. The quality of the analysis that can be achieved within a fixed budget depends largely on the ability of the analyst to transform the given structure into a tractable model. In cases requiring a significant computer expense, the user with moderate experience would be well advised to consult with an expert on such questions as modeling, choice of analysis method, and strategy used in the nonlinear analysis. The simplifications that can be made and the possible pitfalls in modeling are so diverse that it is impossible to give advice that covers all significant questions. The interested reader should study the Bushnell papers given in the footnote.[*]

A general principle that almost always should be followed is to consider carefully before the analysis what kind of results are to be expected. Unexpected developments tend to result in a need to rerun the analysis after modification of the model. When the analysis is planned it is prudent to assume that more than one run will be needed even without allowance for redesign. Questions about modeling of the structure can probably best be answered after some preliminary analyses of models with relatively few degrees of freedom.

[*] Bushnell, D., *"Static Collapse: A Survey of Methods and Modes of Behavior,"* Finite Elements in Analysis and Design, Vol. 1, No. 2, August 1985, pp. 165–205
and
Bushnell, D., *"Buckling of Shells—Pitfall for Designers,"* AIAA Paper No. 80-0665, 1980
and
Bushnell, D., *"Computerized Buckling Analysis of Shells,"* Kluwer Academic Publishers, Dorbrecht, 1985

If the budget situation does not allow a nonlinear analysis of a relatively true model of the structure, a bifurcation (linear pre-buckling) analysis may be used instead. It may be possible to verify the adequacy of such an approach by comparison of results from nonlinear and bifurcation analyses for a smaller model that can be expected to exhibit similar behavior. Another possibility is to make a nonlinear analysis of only a part of the structure. For example, for a shell with several cutouts the influence of each cutout may be evaluated separately. If the cutouts are sufficiently far apart, the interaction of their effects may be disregarded. It may be possible to conclude that the effects of geometric nonlinearity in some part of the structure are negligible. Such a conclusion may for example be based on a preliminary bifurcation buckling analysis. In that case, it is possible to omit the nonlinear terms in one or more branches [see the description of the M-1 record, in Chapter 6].

It is sometimes necessary to model the structure as composed of several shell units; in other cases, it may be convenient but not necessary to do so. It may be possible to avoid use of a user written geometry subroutine by definition of more than one shell unit. This affects the numbering system for the grid points, however, and may therefore result in increased computer time.

When a structure is made up of several shell units, the unknowns are in general assigned freedom numbers in the order in which the shell units are given. The way in which the units are numbered can significantly affect the computational effort and disc storage required for assembly and decomposition of the overall stiffness matrix. The greatest efficiency is obtained by minimizing the differences between freedom numbers on boundary lines which are connected. Thus the user should attempt to define his structure so that successive shell units are connected where possible with the last row or column of one unit connected to the first row or column of the next unit.

Any one of the shell units must be defined so that it can be mapped onto a surface with four edges. For this purpose, it is sufficient to define a numbering system by rows and columns for the grid points. An example is shown in Figure 15.1, where a shell surface (a quarter of a plate with a rectangular hole) with five “edges” is mapped onto a rectangular surface. Triangular domains approximated with finite elements can be introduced to make the modeling of the shell easier.

A $360°$ segment of a shell of revolution (or any “two–sided” shell unit) can be mapped onto a four–sided domain if some generator is chosen to represent both sides 2 and 4. A data record is included to indicate displacement compatibility on these two sides. If the shell of revolution defined by user-written subroutines is closed at the apex, the user defines a shell with a hole at the apex. In addition, regular data records can be used to define triangular elements at the apex. For standard shell geometries, the **STAGS** program automatically includes a number of triangular elements.

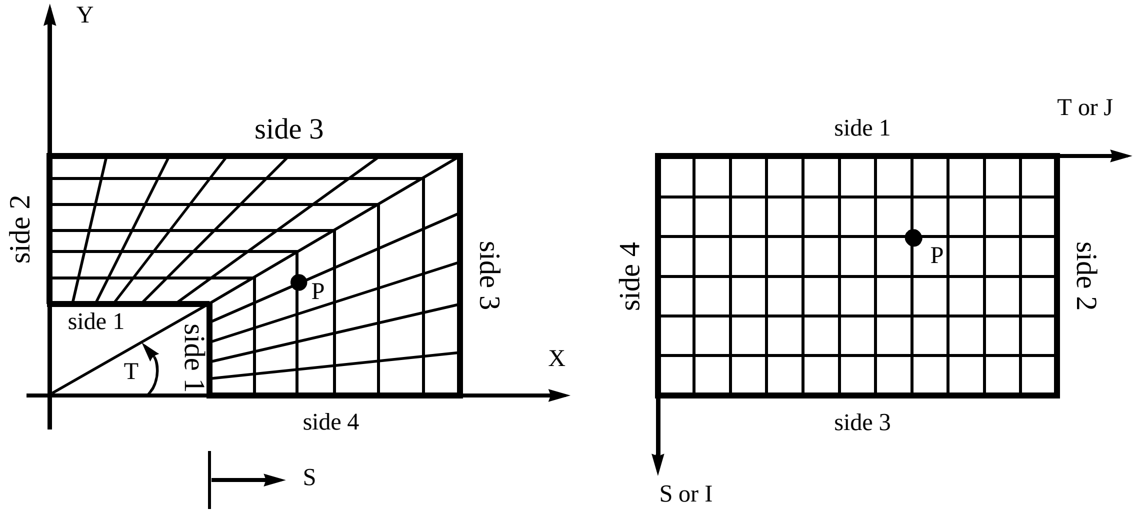
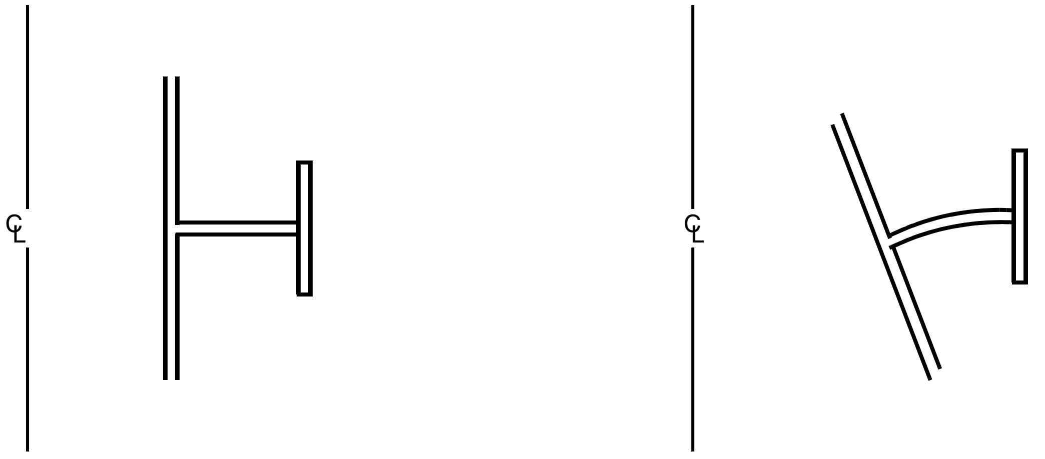


Figure 15.1

Sometimes it is difficult to decide whether a part of the structure, such as a relatively deep ring, should be represented as a separate shell unit or as a stiffener. If it is modeled as a stiffener, it follows that the effect of warping and cross-section distortions are omitted. Clearly, this may lead to unconservative results. For example, the T-stiffener shown in Figure 15.2 has the additional freedom represented by bending of the web. The flange will rotate through an angle which is smaller than the rotations occurring during buckling. A rather extensive study of this general problem is presented in a classic paper by D. Bushnell.* Cross-section deformation is also the reason that a reduction factor on the torsional stiffness must be introduced for the corrugation stiffened shell [see the description of the K-4b record, in Chapter 5]. The results presented in the above–cited Bushnell paper may be of some help in the choice of the constant **PHI** (K-4b). Structural elements are defined as stiffeners if the strain energy can be sufficiently accurately determined in terms of the value of the displacement components at the reference surface. The presence of a stiffener does not add much to the number of degrees of freedom and considerable computer time may be saved by modeling a part of the structure as a stiffener. Sometimes, if use of the stiffener approach is too unconservative, stiffeners with reduced stiffness properties may be defined rather than one or more extra shell branches. Separate studies on small models may be performed to determine such reduction factors.

* Bushnell, D., *"Evaluation of Various Analytical Models for Buckling and Vibration of Stiffened Shells,"* AIAA Journal, Vol. 11, 1973, pp. 1284–1291



UNDEFORMED SHELL DEFORMED SHELL

Figure 15.2

The analysis of a stiffener is based on beam theory. Contributions to the final equations from beams and stiffeners are computed in the same parts of the computer program. They are handled separately in the input because a stiffener always has displacements that are compatible with those of a shell unit. It is assumed in the beam theory that the cross-section of a beam remains plane after deformation. Therefore, unless thermal expansion or inelastic strains complicate the situation strain energy can be defined in terms of reference surface quantities and a few geometric parameters—such as area and moments of inertia. For that case the beam can be defined as having a “cross-section of general type.” However, the user might find it more convenient to define the cross-section as consisting of a number of rectangular sub-elements.

If the beam is subject to bending, *plastic* strains will not vary linearly with the distance to the reference surface. In that case it is not sufficient to define the geometric parameters of the cross-section. It is necessary to describe the cross-section in detail. In **STAGS** that is done by breaking the cross-section up into a number of elements in such a way that the moment of inertia of each sub-element can be ignored. The same method is used if the temperature varies over the stiffener cross-section. A cross-section of sub-element type can be defined as consisting of only rectangular sub-elements. In that case the user gives the dimensions of the element and its area and moments of inertia are computed. This method often represents the easiest way to define a cross-section composed of rectangular parts.

It is possible to consider the stiffeners as discrete. In that case the location of each stiffener must be defined. The other option is to define the stiffeners as “smeared,” that is, their contribution to the shell wall stiffness is considered to be uniformly distributed over the shell surface. The shell stiffener combination is then represented by an equivalent orthotropic shell wall.

Use of discrete stiffeners entails more work in preparation of data records. Also, it requires some additional computational effort and computer storage space. Discrete stiffeners must be used if the possibility of lateral buckling of the stiffeners is considered and if the shell wall deformation between stiffeners is important. Notice that then it is also necessary to include a few points between the stiffeners. Therefore, a model in which there are no grid lines between discrete stiffeners would often have been better defined with smeared stiffeners. An exception may be the case in which the cross-section of the stiffeners varies from one stiffener to another but not along the length of the stiffeners. In that case the definition of smeared stiffeners in a user–written WALL will entail as much work as the discrete stiffener option. Smeared stiffeners may be used to suppress the shell wall deformation between stiffeners.

The position of a stiffener that does not follow a grid line is defined by use of a functional relationship in a user-written subroutine.

Standard boundary conditions (applied to an entire boundary line) may be specified by Boundary Condition data records. Point–wise constraints may be specified by load records (Q-1, Q-2) or in user written subroutine USRLD. Any other linear displacement constraints can be specified by user–written subroutine UCONST.

If a free body is subjected to a self–equilibrated load system, it is advisable, and sometimes necessary, to add artificial constraints to prevent rigid body motions. These of course, must be chosen so that they do not prevent deformation of the shell. In that case, zero forces are exerted on the shell at the points of artificial constraint.

In order to make sure that no rigid body motions are permitted, consider the structure in any Cartesian coordinate system that is convenient in the case. Make sure that translation *along* and the rotation *about* each of the three coordinate axes are constrained. Notice, for example, that a cylindrical shell “simply supported” at both ends is free to move in the axial direction. Such motion is prevented by restraining (Q-1, Q-2) axial motion at one point on the shell surface.

15.2 Solution Strategy

The first task, confronting the analyst of a shell structure, is to consider possible failure modes and based on this to decide what type of analysis he needs to perform. A nonlinear transient analysis with an accurately determined loading history answers all question regarding structural adequacy, barring the special conceptual difficulties in connection with inelastic deformation and imperfection sensitivity. However, such an analysis is almost as a rule too expensive and the analyst must consider the possibilities of obtaining approximate solutions that still are satisfactory.

Is the problem static or dynamic?

A static analysis serves as a satisfactory approximation if the load is applied sufficiently slowly. It may also be accepted if can be shown to be conservative.

If the expected mode of failure is due to local excessive stresses (brittle failure, spallation) rather than a general collapse of the structure (buckling), inclusion of dynamic effects (stress wave propagation) may be required if the time for application of the load is small in comparison to a typical distance (length, radius) divided by the velocity of sound in the material.

If the expected mode of failure is collapse of the structure or critical stresses (brittle failure or excessive plastic strain) primarily due to long wave bending stresses, the time for load application should rather be compared to the period for the vibration modes that are dominant in the deformation pattern causing collapse. If the time it takes to apply the load is about the same or larger than the time for a period of the slowest vibration mode, the static analysis gives satisfactory results. Not much experience is available in this area, but this contention seems to be corroborated by results presented in 1974 by Almroth and Meller.[*] It should be noticed that the period of vibration varies with the applied load so that a point of unstable equilibrium at least one mode has a zero frequency.

For cases in which the mode of failure is collapse, it appears that a static analysis may be accepted as conservative in some situations. If the load is applied during a very short time interval, the inertial inhibits development of displacements, corresponding to those obtained from a static analysis under the same load. A static analysis is then generally conservative.

[*] Almroth, B. O. and E. Meller, *“Nonlinear Transient Response Analysis of General Shells,”* proc. IUTAM Symposium on Buckling of Structures, Harvard University, June 1974

On the other hand if the load is rapidly applied and then sustained for a time that is at least of the same order of size as the period of the lowest vibration frequency, the static analysis is unconservative (it does not include the “overshoot”). In such a case it appears that static analysis based on twice the maximum load would be clearly conservative.

To answer the question of the need for a transient analysis, it appears that it often is useful and sometimes necessary to determine a few of the lowest vibration frequencies. If collapse and plastic deformation are excluded, these frequencies and corresponding “virtual masses” may be used directly in a modal transient analysis (not included in **STAGS**). Evaluation of the results of such an analysis may reveal whether or not a nonlinear transient analysis of the discrete system is needed (see discussion below).

Is a linear analysis sufficient?

In general, the results from a linear analysis are accurate if, under the design load, the squares of the rotations are small in comparison to the strains. However, large rotations, if confined to a narrow boundary layer, would have little effect on the shell behavior in general and do not preclude the use of linear analysis. On the other hand, the possibility of loss of structural stability must be considered even if the linear analysis results in small rotations. A bifurcation buckling analysis as discussed below would indicate a load level at which a rapid growth of the displacements may be expected.

Unless experience with similar cases is available to the user, it is suggested that the nonlinear static analysis be used as a matter of course. If the nonlinear effects are negligible, the design load an be applied and convergence will occur within a few iterations. In that case, the computer run time will exceed the time for a linear analysis only by some 10 to 30 percent because **STAGS** is based on the modified Newton–Raphson method. If convergence is not obtained, the linear solution is printed but a warning is served that it may be inaccurate. Usually, this indicates that the nonlinear terms at the applied load level are too large. An inspection of the results of the linear analysis may indicate that a nonlinear analysis is desirable.

Convergence failure may be caused by an ill–conditioned matrix. With a system that is almost singular, a solution will be obtained from the linear analysis that deviates from the true solution even if nonlinear terms are negligible. Such a situation may be revealed by inspection of the size of printed “equilibrium forces.” If there is doubt about the reason for nonconvergence, it may be advisable to rerun with the parameter **ILIN** = 1 (M-1). Convergence failure in that case clearly indicates ill–conditioning and suggests that the model be reconsidered as discussed below. Whenever convergence fails and the equilibrium forces indicate that the equation system is satisfied the nonlinearities may be of significance.

In some cases, consecutive iterations tend to oscillate and nonconvergence at the design load may occur even if the linear analysis predicts stresses and displacements within a few percent. It appears that if the squares of the rotations are small in comparison to the strains and in addition a bifurcation buckling analysis indicates a large safety margin, then the linear solution is probably of sufficient accuracy even if nonlinearities cause nonconvergence. If the squares of the rotations are significant or if the bifurcation buckling analysis shows only a moderate margin of strength, a nonlinear analysis must be recommended.

In the case of transient response analysis by use of the explicit scheme the inclusion of nonlinear terms add little to the computer time.

Can the stability problem be solved by use of a bifurcation buckling analysis?

Loss of structural stability at a bifurcation in the load displacement path is discussed elsewhere. The bifurcation buckling theory gives information about the load level at which bifurcation occurs. In some cases loads can be applied far above the bifurcation buckling load without significant damage to the structure. In other cases the structure collapses well below this load due to imperfection sensitivity. Often experience (from experiments or from nonlinear analysis) indicates that the bifurcation buckling load is a significant design parameter.

Stability loss at a bifurcation point occurs only if the corresponding deformation mode is *not* contained in the deformation mode for arbitrarily small loads. For example, a flat plate with in–plane loading experiences no lateral displacements in the pre–buckling range. Thus it does not contain the lateral displacement modes of the buckled plate. Likewise, if the structure as well as loading is symmetric about some plane, all deformation modes antisymmetric with respect to that plane are possible bifurcation buckling modes. In such cases, we may choose to perform a buckling analysis with a nonlinear basic stress state. This question is further discussed under STRATEGY below.

Sometimes when a bifurcation point does not exist at all, the bifurcation buckling approach may still lead to an acceptable estimate of the critical load. A detailed discussion of this problem was presented in a 1972 paper by Almroth and Brogan.* Briefly, it may be stated that the bifurcation approach is questionable (too conservative) if the structure is statically indeterminate and thus allows favorable redistribution of the stresses (e.g. shells with cutouts). The bifurcation approach gives unconservative results if the stiffness of the shell deteriorates with increasing load (*e.g.* long cylinders under bending).

* Almroth, B. O. and F. A. Brogan, “*Bifurcation Buckling as an Approximation of the Collapse Load for General Shells,*” AIAA Journal, Vol. 10, 1972, pp. 463–467

The bifurcation buckling analysis with a linear stress state is probably a good approximation for any case in which the squares of the rotations in the linear solution are small in comparison to the membrane strains at the load level corresponding to bifurcation.

Linear static analysis

A linear stress analysis is straightforward and does not require any decisions about the computational strategy. If an adequate model of the structure has been defined and the grid is fine enough, a satisfactory solution is obtained unless the coefficient matrix is seriously ill–conditioned. This problem is discussed below.

Eigenvalue analysis

The strategy in the eigenvalue analysis is determined by the choice of suitable values for the parameters read on the D-2 and D-3 records. If vibration frequencies or bifurcation bucking loads are based on a nonlinear stress state, there are other decisions to make in connection with computation of the stress state. The strategy in such computations does not differ from the strategy in the regular nonlinear stress analysis discussed in a later paragraph.

In the case of nonlinear stress state, an option is provided to perform the stress analysis first, save the data for a certain number of load steps on tape and later decide for which of those load steps vibration frequencies or buckling loads should be obtained. This option may save some computer time. First, it may be easier to decide on the load levels at which eigenvalues are desired after the results of the stress analysis have been studied. The arrangement also makes it possible to find additional eigenvalues in a subsequent run. When eigenvalues are computed in a later run, the input data file for the nonlinear prestress analysis can be used with the exception that **IXEV** is set equal to 3 on the D-2 record. In addition, the user has the option of changing **NLDS** (D-2) and **PLDS** on the D-3 record to select certain of the data sets saved on tape for eigenvalue solution. Changes in boundary conditions are also permitted at this time.

For free vibrations in the presence of a nonzero stress state determined from a linear analysis, the same procedure can be used with **INDIC** = 5 on the B-1 record and **ILIN** = 1 on the M-1 record.

In a free vibration analysis, the eigenvalues correspond to vibration frequencies in [cps]. All eigenvalues are positive, except that those corresponding to rigid body motions, if such are allowed correspond to zero frequencies. The user can ask for a number of clusters of eigenvalues, each within a specified frequency range. In most practical applications the interest is confined to one range of eigenvalues, especially to a sequence of the lowest eigenvalues.

The user specifies the range of eigenvalues as well as maximum number of eigenvalues to be computed. If the I lowest eigenvalues are needed, the user can set **EIGA**=**EIGB**, **SHIFT**=0, and **NEIG**=I. If **EIGA**=**EIBG** and **SHIFT** is nonzero, then the **NEIG** eigenvalues closest to **SHIFT** will be determined. If $\mathbf{EIGA} < \mathbf{EIGB}$ the analysis will be terminated when all eigenvalues in that range have been determined even if the number is less than **NEIG**.

If there exists a symmetry plane, in loading as well as in geometry, the size of the problem can be reduced and significant savings in the total computational effort can be achieved. If the structure on one side of the symmetry plane is considered, only the frequencies of symmetric modes are obtained. In a separate run with **IBOND**=1 on the P-1 record the antisymmetric modes can be determined. If the eigenvalue analysis is based on a nonzero prestress analysis with symmetry conditions and an eigenvalue analysis with boundary conditions corresponding to antisymmetry.

The eigenvalue approach for bifurcation buckling analysis with linear stress state is discussed elsewhere. This problem is slightly more complicated than the vibration problem because eigenvalues can be negative as well as positive. The **NEIG** eigenvalues closest to the point of shift (**SHIFT** or (**EIGA** + **EIGB**)/2) are found, independently of the sign.

Often the user is only interested in one eigenvalue—the lowest positive one. If the analysis is performed without a shift, it may happen that only negative eigenvalues are found because these are smaller in magnitude. In that case, the analysis has to be repeated with a positive shift. In choosing the shift for a repeated run the user can take advantage of the knowledge that the smallest positive eigenvalue is larger in magnitude than the largest of the negative eigenvalues that were found. Sometimes the buckling loads are symmetric with respect to zero. This is the case, for example, if a plate or a cylinder is subjected to uniform a shear load.

It may often be advisable to request more than one eigenvalue also in bucking analysis. If the structure shows insufficient strength and only the lowest eigenvalue and corresponding mode are known, reinforcements may be introduced that have little effect on secondary buckling mode with the eigenvalue below the design load.

It is usually possible to save time as well as computer cost by preliminary determination of approximate values for the buckling load under negative as well as positive load, before a large scale analysis is carried out. A linear analysis with a rather coarse grid will give some idea about the stress distribution. Once such a distribution is available it is usually possible to find “ball park” values by use of well known solutions for buckling of plates, spheres, or cylinders. Such knowledge is useful when the grid is defined, as well as in decisions regarding the shift.

The bifurcation buckling with a nonlinear prestress is of limited usefulness. Bifurcation buckling occurs only if the deformation mode corresponding to collapse is orthogonal to the deformation pattern in the basic stress state. If bifurcation takes place (into a mode that is permitted by boundary conditions), this will be apparent to the output from the nonlinear analysis since the coefficient matrix will have a negative root for each bifurcation point below that applied load. Introduction of geometric imperfections in the nonlinear analysis will remove the bifurcation an collapse will be indicated by a rapid growth of the collapse mode just before the critical load is reached. This problem is discussed under nonlinear analysis below. If at some level the nonlinear analysis is terminated due to the presence of a negative root, a bifurcation bucking analysis based on the stress distribution corresponding to a load factor somewhat below the critical load may be executed. This can be done, if in the nonlinear analysis some results have been saved—*i.e*, if **INDIC**=4 or 6 (B-1) and **IXEV**=0 (D-2). The results of such an analysis would reveal the approximate buckling mode. It is feasible that the negative root found in the nonlinear analysis is due to inaccuracy (ill–conditioning) in the computations rather than to impending buckling. This is probably the case if the computed eigenvalue far exceeds the value at which the determinant changes sign.

If the nonlinear analysis is terminated at the maximum load level, it is possible to gain some idea about the size of the margin of safety against collapse through the execution of an analysis of bifurcation from the nonlinear stress state. In that case the final solution is saved for subsequent bifurcation buckling analysis.

Another situation in which a bifurcation buckling analysis with nonlinear prestress may be useful arises when a symmetry plane exists. The situation in that case is the same as in the case of the free vibration analysis. The symmetry plane makes it possible to reduce the size of the problem only if buckling into antisymmetric modes is considered separately in a bifurcation buckling analysis with nonlinear symmetric prestress. It should be noticed that the computed eigenvalue gives a good estimate of the critical load only if the computed bifurcation load is close to the load level corresponding to the basic stress state. It may often prove practical to save data from a nonlinear run and attempt an antisymmetric bifurcation analysis somewhat below the collapse load for symmetric deformations. Such an analysis is likely to reveal whether the question of antisymmetric buckling need be further pursued.

Nonlinear static analysis

In the nonlinear stress analysis, a significant part of the computer time is devoted to the solution of a system of nonlinear algebraic equations. The computer time involved in those computations depends to some degree on the decisions the program user make regarding certain parameters on the D-1 record that governs the computational strategy in **STAGS**.

Some understanding of the solution of those constants. Such understanding will also help the user in proper interpretation of the results and in avoiding certain pitfalls.

The solution of the nonlinear algebraic equations is *usually* based on the modified Newton–Raphson method. In general, solutions to the equations are obtained at a number of step–wise increasing load levels. The coefficient matrix is not necessarily reformed and factored when the load is increased, but attempts are made to obtain convergence by use of the factored matrix that is already available from computations at some earlier load step. The accuracy of the solution does not depend on the accuracy of the factored matrix. Two convergence criteria have to be satisfied before the solution is accepted. One of these requires that if the largest correction of a displacement unknown during the iteration divided by the largest displacement is less than a prescribed valued **DELX** (D-1). The other criterion is applied to normalized values of the unbalanced forces, *i.e,.* the vector representing the error in the individual equations.

The procedure converges only if reasonably good initial estimates of the unknowns are available. For the first load step, a linear solution is obtained and used as initial estimate. In the second load step, estimates are obtained by use of a linear extrapolation (based on the zero load solution and the first nonzero solution). From then on, estimates are obtained by use of a quadratic extrapolation. The user can suppress the extrapolation by use of the parameter **NSTRAT** (D-1). Such action may, for example, be warranted if the analysis of the accuracy requirement is loosened by modification of **DELX** (D-1). In order that convergence be obtained, neither the initial load factor nor the load step must be too large. Generally, the computer economy is best if the step is chosen so that convergence is obtained after two or three iterations. The first two load steps have less accurate estimates, and convergence is often somewhat slower. The number of iterations allowed in the effort to obtain convergence is internal tot he code; it is not a user’s option. In general, seven iterations are allowed. However, for the first load step, 15 iterations are allowed, unless the rate of decrease in consecutive corrections is so slow that continuation is meaningless. If convergence is not obtained on the first load step, the computations are discontinued so the user can reconsider his choice of initial load and maybe re-examine the discretization of the structure.

If nonconvergence occurs at a later stage in the analysis, the load step will be cut by a factor of 2, or the matrix will be refactored, depending on the values of the input parameters **NCUT**, **NEWT** (D-1). The choice of these parameters is discussed below.

STAGS assumes that nonconvergence has occurred if convergence is not achieved after seven iterations, if the solution is diverging for two successive iterations, or if the rate of convergence is indicated by two successive iterations is so slow that it is unlikely that the criterion will be satisfied within 7 iterations. If convergence has been obtained in the seventh iteration, then the following load step will be cut in half or a refactoring made (depending on the user-selected strategy parameters **NCUT** and **NEWT**) before the iterations are started on that load step. Finally, if convergence is extremely easy, *i.e.* if convergence occurs in one iteration on the present as well as the preceding load level, the step will be automatically increased through multiplication by a factor of 2.0.

The choice of the initial load level and the load step is the first decision the user has to make regarding the computational strategy. If it is expected that nonlinearities are of little influence at the design load, it may be possible to obtain convergence directly at that load level. In that case, the maximum load is set equal to the initial load and the step size is irrelevant. However, if a value of the collapse load is to be established or if there are considerable effects of nonlinearity at the design load, then the equations must be solved under a step-wise increasing load. In some cases, the nonlinearities are relatively insignificant until a point is reached that is close to the collapse load. In that case, a relatively large initial load and a smaller load step may be used. In other cases, such as cylinders with nonuniform external pressure or long cylinders under bending, convergence has been found to be difficult for relatively small loads. The initial load step may have to be as small as 5% of the collapse load, and sometimes even less. If there is no special reason to proceed differently, it is suggested that the initial load as well as the load step is set equal to about one tenth of the estimated collapse load. such an estimate can, for example, be obtained by consideration of a simple equivalent structure, for which an analytical solution is available, or from a bifurcation bucking analysis. A load step that is too small for an efficient analysis gradually will be corrected by successive automatic increases in the step size.

Very slow convergence with the modified Newton method is usually connected with oscillatory solutions. In that case it is recommended that a true Newton method be used, **NEWT** = -20 (D-1).

In most cases, the nonlinear analysis will not be completed in one run. Intermediate solutions are saved on tape or file so that the analysis can be restarted after the user has studied the results and reconsidered his strategy. The last three displacement solutions (if available) are saved on the tape so that a restart can begin with a quadratic extrapolation for initial estimates. Sometimes, as will be seen below, there may be reasons to restart from record one or two. At restart, the initial load factor must be the load factor corresponding to the record from which restart takes place. Before restart, it is advisable to ascertain that the data were properly recorded.

The input record with strategy parameters also includes a parameter **NSEC**. Occasionally, during computations, a check is made of whether the elapsed computer time exceeds **NSEC**; if so, intermediate results are saved on a data tape. **NSEC** should be chosen to be a few seconds less than the time estimate at which the operator aborts the run. Before each refactoring, the program also checks that sufficient time is available to make refactoring meaningful. To refactor at the end of a run would be wasteful because a restart run always begins with factoring.

After initial convergence has been obtained, the program continues with the input load step until a load level is reached at which the analysis fails to converge within prescribed limits (or convergence is easy enough to allow load step increase). The program then either cuts the load increment in half or updates the factored matrix by use of the displacement vector solution obtained for the previous load step. The choice between these two alternatives is based on the following strategy parameters, input by the user:

NCUT —Total number of times load increments may be cut in half.

NEWT —Number of times the factored matrix may be recomputed.

On nonconvergence the normal action is reformulation and refactoring of the matrix. If convergence still fails the load step will be cut by a factor of two unless the step already has been cut **NCUT** times, in which case the program stops with the message that “convergence difficulties cannot be resolved.” If nonconvergence should occur after **NEWT** refactorings already have been performed, the load step will be cut until the number of load step cuts equals **NCUT**.

In view of the highly unpredictable nature of nonlinear behavior, it is very difficult to prescribe the best value for the strategy parameters in advance. As an initial choice for an unfamiliar type of shell, the values

ICUT = 2

INEWT = 4

are suggested. By observing the convergence behavior in previous computer runs, a more effective set of these values and the load step may be selected for continuation. In general, it seems advisable to restrict each computer run to some 10 to 20 times the computer time for one factoring so that the convergence behavior can guide the selection of strategy. In such a case, there should be little reason to control the number of factorings by **INEWT**. However, for very large systems with expensive factoring, especially in transient analysis, it may be better to continue an analysis with smaller steps than to repeatedly refactor the matrix. In that case **INEWT** may be set to 0, 1, or 2. **ICUT** essentially serves to define a minimum step size below which the user finds it impractical to perform the analysis. Choose **ICUT** such that the analysis will remain economically feasible.

The user may force factoring independently of any convergence difficulties. If **NEWT**=-N, then the matrix will be refactored at every Nth load step. Such a strategy is probably useful for problems with a relatively inexpensive. If convergence is slow, an over– or under–relaxation factor is automatically applied, depending on whether the convergence is uniform or oscillating. The user generally leaves blank fields for convergence parameters and relaxation factor. This means that the convergence parameter is applied as indicated above. The user may loosen the convergence criterion if it is indicated from the results that round-off errors make convergence difficult or even impossible. The criterion also may be tightened as subsequently discussed. The relaxation factor should be determined by the user only if he has considerable experience with the program. If the relaxation factor is given any value on the input record (including 1.0), this factor will be used throughout the analysis.

A collapse load is represented by a maximum in the load–displacement path. If a displacement is controlled and the load computed, it will be possible to compute points through and beyond the maximum. If, on the other hand, the load is the independent variable, instability is indicated by a failure to converge even with a very small load step. This, of course, is less satisfactory because convergence failure could have been caused by numerical difficulties rather than by rapidly growing displacements. Therefore, if convergence difficulties indicate that the collapse load is approached, the applied load may be plotted versus some representative displacement, the component that shows the greatest increase between the last two load steps may be selected. A better indication of collapse can be obtained if the load factor is plotted as a function of the determinant. This is possible only if a reasonably large number of refactorings have been executed. The value of the determinant is zero at the point of collapse for “dead load” but not for displacement or thermal loading. The best way to determine whether a limit point has been reached may be to restart the analysis in the dynamic mode. At the load level corresponding to nonconvergence or slightly higher the analysis is restarted as a transient analysis. In the presence of a limit point the solution vector will undergo large changes after only a few time steps.

The problems associated with the use of the load factor as independent parameter are related to solution prediction beyond the limit point and ill conditioning in the neighborhood of a limit point. Both these problems can be circumvented if some “path length” parameter is used as independent parameter. Such procedures were first published by Riks and are here referred to as the Riks method. While other procedures have been tried with some success, the Riks method is the most straightforward and clearly the most promising choice for introduction in the **STAGS** computer program. The path parameter introduced is the length of a vector with two components: a load parameter and some norm of the displacements. Since the components have physically different dimensions, they must be balanced in an appropriate way.

Some trial runs indicate that good results are obtained if the base load is chosen such that collapse will occur at a load factor of the order of unity. A procedure for selection of load step size based on the “curvature of the path” seems to be working well. Only limited experience with the Riks method is presently available. However, in addition to the fact that computations can be carried beyond the limit point, it appears that this procedure is more efficient in terms of computer time.

For a dead weight (or a pressure applied by a compressible medium such as air) the true behavior of the structure at the limit point will be represented only by the results of a dynamic analysis. The limit point is first closely approached in a static analysis. Results from this analysis are used in a restart with increasing load and with dynamic effects included.

If a pressure is applied over a part of the structure through an incompressible medium such as water, the stability is not lost at the limit point and points on the falling part of the curve will represent meaningful results. However, these are difficult to determine. One method that sometimes can be used is to add fictitious springs so that the slope of the load displacement curve remains positive. The load carried by the springs is eventually subtracted out.

The existence of a bifurcation point along the primary path would be indicated by the vanishing of the determinant. Above the bifurcation point, the equilibrium on the primary path is unstable and the determinant is not positive definite: an attempt to refactor will result in a message that the matrix has one or more negative roots. This will occur only if the boundary condition in the model allows the corresponding bifurcation buckling mode.

Theoretically, as the critical load is reached, the round–off errors should trigger the deformation corresponding to the buckling mode. In practical application, it is generally found that in the early stage of buckling the amplitude of the buckling mode is so small in comparison to the displacement corresponding to the basic stress state that its growth, although in a relative sense large, will not violate the specified convergence criterion. This difficulty is avoided by the specification of initial imperfections in the shell geometry which are small enough not to appreciably affect the buckling load but large enough to trigger the new deformation pattern. The program, therefore, includes an option to add an initial lateral displacement pattern. This procedure has to be used, for example, if a study is made of post-buckling behavior of a shell of revolution subject to symmetric loading.

It has been found during use of the program that the imperfections may be useful as triggers also in other cases than those with perfect axial symmetry. For example, in the analysis of an elliptical cylinder with an aspect ration of 1.5, it was found that without a trigger it was necessary to use a very severe convergence criterion $\varepsilon = 10^{-5}$ but if a small imperfection is added, the same collapse load may be computed in about half the run time with a less severe convergence criterion $\varepsilon = 10^{-3}$. If the elliptical cylinder has a significantly smaller aspect ratio, it is likely that the amplitude of the buckling pattern which is present in the pre–critical displacement pattern is too small to act effectively as a trigger. In this case, the computation of a collapse load must include the use of a small imperfection. The choice of imperfection mode may often be aided by knowledge of the bifurcation bucking mode.

If difficulties like these do occur, they will be discovered when refactoring at a load level above the collapse load leads to a coefficient matrix which is not positive definite. In such a case, the user must either sharpen his convergence criterion or introduce an imperfection. If the imperfection is too small the unstable branch of the load-displacement curve for the perfect cylinder represents a configuration for which the equilibrium is almost satisfied. Since the convergence criterion cannot be made arbitrarily fine, this will at times lead to a false indication of convergence.

The run which ends with a message that negative roots are present, may sometimes be saved if a new run is restarted from an earlier solution. There also may be other reasons to suspect that an inaccurate solution has been accepted in which case restart from an earlier solution is advisable.

Through use of additional analyses with various degree of imperfections, the user of the program can get some notion of the imperfection sensitivity of the collapse load.

Finally, it may be advisable, often to set **INDIC** = 4 or 5 even if bifurcation or vibration analyses are not part of the original plans. Such a choice leaves the option open if the results of the nonlinear analysis indicate that a subsequent eigenvalue analysis may be helpful.

Transient analysis

A nonlinear transient analysis must be used if a structure that would be susceptible to buckling under static loading is subject to rapidly varying loads. However, such an analysis is generally quite expensive, and the user faced with the necessity may be willing to sacrifice accuracy in order to save on computer cost. It is necessary that the user is able to obtain some estimate on the computer run time before a decision is made on the procedure to be followed.

The strategy in the transient analysis is determined by a number of parameters defined on the E-1 and E-2 records. After defining a structural model and a preliminary grid the user must decide on the integration procedure.

Shell structures usually result in the so–called “stiff” system of differential equations– that is, the eigenvalues corresponding to free vibrations cover a very large range. The highest eigenvalues determine the numerical stability of explicit integration method. Therefore, a very small time step must be used. On the other hand, it is relatively easy to determine the maximum time step. In the linear case the critical time step is given by

$$\Delta t = 2/\omega_{max} \tag{15.1}$$

where ω_{max} is the highest vibration frequency of the system. Usually the highest frequency does not vary much with the applied load in the nonlinear case. It is suggested therefore that in a nonlinear transient analysis with the explicit method the time step is chosen to be about 80 percent of that given by this equation. However, for cases in which geometric nonlinearities are important, it is likely that the lower frequencies of the system are the more important. In that case the implicit methods are generally more efficient.

Based on a finite difference formulation (of second order accuracy) for a shell of isotropic properties the critical time step is found to be

$$\Delta t = MIN \begin{bmatrix} \left[(c/(\Delta\alpha))^2 + (c_s/(\Delta\beta))^2\right]^{-\frac{1}{2}} \\ \frac{\sqrt{3}}{hc}\left[(1/(\Delta\alpha))^2 + (1/(\Delta\beta))^2\right]^{-1} \end{bmatrix} \tag{15.2}$$

where $c^2 = [\rho(1-\nu^2)]$, $c_s^2 = G/\rho$, and $\rho =$ mass density of the material. The quantities $\Delta\alpha$ and $\Delta\beta$ represent grid spacings in arclength in the two directions such that $\Delta\beta \le \Delta\alpha$. For layered and composite materials an average value of E can be used. If a higher order finite element formulation is used, the critical time step may be considerably smaller. With elements for which $\Delta\alpha$, $\Delta\beta$ are considerably larger than h—say twice as much or more— Δt according to equation (15.2) is probably reasonably accurate unless a refined membrane element is used. For refined membrane elements the critical time step may have to be decreased by a factor of two or more.

Except for some special cases then, equation (15.2) gives only an indication about where to start in a trial and error estimate of the critical time step. If the critical time step is exceeded computed displacement will grow very rapidly and the problem is noticed after only a few time steps. Instead of reliance on a trial and error procedure the user may take advantage of the knowledge that the highest frequency of the system is equal to or less than the maximum frequency for an individual element. Thus it is possible to choose the critical time step from an eigenvalue analysis for the smallest of all elements in the structure.

Notice that c is the velocity of a sound in the material. If in the one-dimensional case Δt is chosen to be exactly $c\ \Delta\alpha$ then a stress wave progresses through the material with the speed of sound. Only for this value of Δt is the solution accurate (barring discretization errors). If Δt exceeds the critical value a small error will be magnified with each time step. If Δt is less than the critical value error does not accumulate and the solution obtained is reasonably accurate except in case the loading is so severe that the magnitude of the nonlinear terms changes significantly during one time step.

Therefore, the explicit method is somewhat easier to use than any of the implicit methods. The latter are used for the purpose of reducing computer runtime. In particular, implicit methods are more flexible as they allow the choice of a larger time step with the purpose of sacrificing accuracy for a reduction in computer cost. With the explicit method no large systems of equations need be solved and no large matrices need be stored. Therefore, it may be possible to obtain solutions with the explicit scheme for cases that are beyond the capability of the implicit scheme (core or disk storage).

Several implicit methods have been provided in **STAGS** for use in transient response analysis. These are the trapezoidal formula, the Gear 2nd and 3rd order formulas and a formula due to K. C. Park. For a purely linear transient analysis (**ILIN** = 1 on the M-1 record for all branches), the stability and accuracy of the trapezoidal formula make it the natural choice. When nonlinear effects are included in some part of the structure, the trapezoidal formula may become numerically unstable while the 2nd order Gear formula and the Park formula remain stable. The 3rd order Gear formula is also stable for sufficiently large time steps. Damping of higher frequency modes is substantially greater with the second-order Gear method. Consequently, the Park method is recommended for general nonlinear transient analysis. Figure 15.3 shows the damping in percent on each period as a function

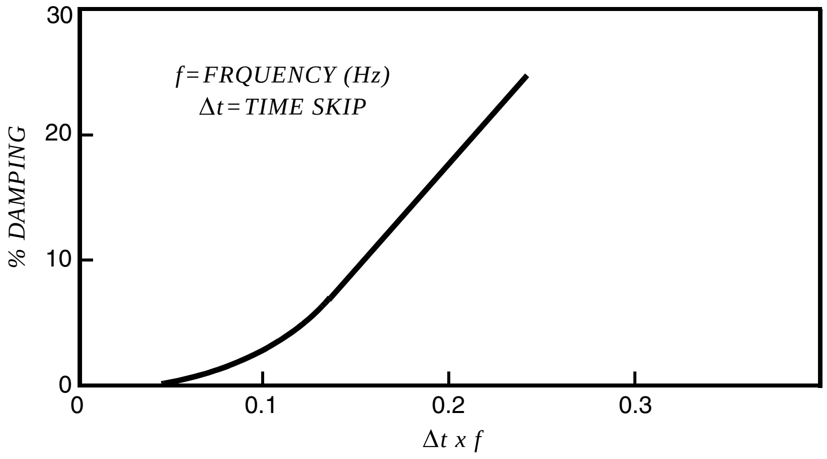


Figure 15.3

of time steps per period. However, the special properties of the Gear methods may be useful to users whose knowledge of their behavior is relatively sophisticated.

Typical for the implicit integration schemes is that a large time step results in inaccuracy in the form of artificial damping. Consequently the modes corresponding to the higher frequencies are damped out quickly. In order to obtain reasonably accurate results for the motion in the highest frequency modes, we must choose a time step that is of the same order of size as for the explicit integration. Therefore, implicit methods are not suitable for analysis of stress wave propagation.

If the problem is to determine whether the shell would collapse under some history of loading, the following procedure is recommended:

- Determine a number of deformation modes and frequencies for the stress-free structure. The number may depend on the case, say five to twenty modes. By use of a shift it may be possible to reduce the number of eigenvalues and vectors determined.
- The half period for the “highest mode” which must be reasonably accurately represented in the analysis is determined.
- Decide how much damping of this mode is acceptable and determine the time step from Figure 15.3.
- Check critical time step for explicit integration. If this is more than one-third of that determined above, use the explicit scheme. Otherwise use the K. C. Park method.
- Make an estimate of the number of time steps that would be required to complete the analysis.
- Approximate values for the average computer time per time step are given above.
- The total computer time for the analysis can now be determined. It seems prudent to estimate that at least twice as much time may be required due to false starts and wasted runs.
- If the estimate shows that the analysis is not economically feasible, several options may be considered such as: static analysis only, linear analysis, a coarser grid, other changes in the model, or a larger time step.

In the nonlinear transient analysis, the time step must be adjusted so that the accuracy is satisfactory without undue expense, and also it must be small enough to admit convergence at each stop. If nonconvergence occurs the matrix is always refactored. Should convergence fail after refactoring, the time step will be cut *once*.

Very little experience is available on the option with a variable time step. This part of the program must therefore be considered to be experimental. However, if the option is used, an unsuitable choice of the initial time step would be automatically adjusted. Thus, the choice of **DT** (E-1 record) is less critical. On the other hand, **SUP** (E-1) must be defined since the error that is permitted at each time step is proportional to this value (the largest displacement to be expected, or rather the largest value of the maximum displacement value for which we still expect to obtain reasonable accuracy).

15.3 Progressive Failure Solution Strategy*

The progressive failure solution strategy implemented in **STAGS** leverages on the overall nonlinear solution algorithms already existing in **STAGS**. Composite damage modeling for laminated composite structures is treated in a manner similar to plasticity for metallic structures. The key difference here is the material degradation model for the composite damage models considered involves discrete reductions in lamina properties at material points (ply discounting as opposed to a flow rule). As an alternative to ply discounting for material degradation, another progressive damage model based on the crack-density state-variable approach developed by Prof. F. K. Chang of Stanford University has been implemented. Discrete local changes in stiffness cause difficulties for the nonlinear solution procedure. Chang’s approach includes some damping terms to stabilize the solution. The following sections describe the overall modeling aspects, choice of solution strategy parameters, maintaining equilibrium, and recommended guidelines.

Modeling

Modeling for composite damage simulations follows the usual **STAGS** approach for element and node generation (shell units or element units). Only the **STAGS** **E410** and **E480** shell elements have been tested. The material modeling is done through the GCP (generic constitutive processor) feature within **STAGS**. Some elements do not currently support the GCP option for material modeling (*e.g.,* the **E210** beam) and are restricted to **STAGS’** historical approach using I- and K- records. With **STAGS**’ implementation of GCP, the composite damage modeling is available for orthotropic elastic brittle materials *via* the

* This section is based on material given in Knight, Norman F., Jr., *“Enhancement of* ***STAGS*** *Progressive Failure Capability,”* MRJ Technology Solutions Final Report for MRJ Task 1410, October 1999, pp. 32–37

ORT_EL_BR_MATERIAL option and for Chang's progressive damage model based on the crack density state variable *via* the ABAQUS_UMAT_MATERIAL option.

The **NGCP** parameter on the B-3 record for the S1 processor indicates whether GCP input will be used (**NGCP**=1) or will not be used (**NGCP**=0). GCP material data libraries may be used exclusively in the model or in combination with K- record material data.

Input for the GCP material types begins with the I-5a input record using an alphanumeric command verb instructing **STAGS** to read specific GCP material data.

The input data for the ORT_EL_BR_MATERIAL command verb are defined on the I-10a record. This record gives the linear elastic material properties, the strain and/or strength allowables, the degradation parameter, some other material values, and identifiers to select the failure model and degradation model to be used.

The input data for the ABAQUS_UMAT_MATERIAL command verb are defined on the I-11a record. This record gives the linear elastic material properties, selected strength allowables, and various damage and damping model parameters required by Chang's progressive damage model. The laminate data (layer material number, number of layer integration points per layer, layer orientation, and layer thickness) for both material types are specified using the I-21a GCP shell fabrication record.

For the ORT_EL_BR_MATERIAL material type, the user has the option of specifying nonzero positive values for either the strain allowables or the strength allowables or both. If the strain allowables are nonzero and the strength allowables are zero, then the strain allowables are used with the elastic constants to calculate strength allowables *(e.g.*, $X_T = E_{11}\ \varepsilon_{1t}$). Likewise if the strain allowables are zero, then they are computed internally based on the strength allowables. All values must be given as either zero or nonzero, and all values must be positive. Nonzero values must be given for all strain allowables or all strength allowables. Users cannot specify a mixed set of nonzero strain and strength allowables.

For the ABAQUS_UMAT_MATERIAL material type, the user must also provide several ASCII files in a specific subdirectory named OUTDIR. A unit–cell plane strain analysis and a curing residual thermal strain analysis generate these files. These files are generated by the execution of the PDCOMP and RSDE codes provided by Prof. F. K. Chang. Only the **STAGS E410** shell element has been validated for this damage model.

Choosing solution strategy parameters

STAGS provides a number of parameters that are associated with the solution strategy. Incorporating the progressive failure capability into **STAGS** resulted in the addition of several new features. This new capability has only been tested with the traditional solution control procedures (load control and displacement control). Parameters that affect the nonlinear solution process include **NCUT**, **NEWT**, and **DELX** on the D-1 solution parameter record and **NSOL** on the ET-1 solution control record used by the **STAGS**' ***s2*** processor.

The nonlinear solver in **STAGS** is a Newton–Raphson procedure for solving a system of nonlinear algebraic equations. The process involves a left-hand-side tangent stiffness matrix (second variation), a right-hand-side force imbalance or residual vector (first variation), an iterative increment in the displacement vector, an updating step for the iterative change in the displacement solution, and the formation of an initial guess or starting vector for the next solution step. These four parameters (**NCUT**, **NEWT**, **DELX**, and **NSOL**) affect these steps.

The **NCUT** parameter defines the total number of times the load/displacement factor (step size) can be cut before the solution process is stopped by **STAGS**. Generally this parameter is set to a value between 5 and 10. Frequent cuts of step size generally indicates difficulties in the solution process; and careful examination of the results generated up to that point may reveal a modeling problem, a collapse behavior or some other event unforeseen by the user at the start of the analysis. A value of 5 is recommended until some familiarity with the problem is obtained.

The **NEWT** parameter defines the number of refactorings of the tangent stiffness matrix allowed during the execution. This parameter is discussed under the D-1 record and only a brief description will be given here. For **NEWT**=-20, the tangent stiffness matrix is evaluated, formed, assembled, and factored on each and every iteration. For **NEWT** = -1, the tangent stiffness matrix is evaluated, formed, assembled, and factored at the beginning of each and every solution step and possibly during the iteration process for that solution step as required by the solution strategy. However, it is always recomputed at the beginning of each solution step. For negative values of **NEWT**, the number of times the tangent stiffness matrix can be refactored is unlimited. For positive values of **NEWT**, the tangent stiffness matrix is recomputed as required by the solution strategy until a total of **NEWT** refactorings have occurred. With continuing increases in computer processor speeds and the availability of faster equation solvers, the trend towards using a true Newton procedure (update the tangent stiffness matrix on each iteration) is becoming a reality.

The **DELX** parameter defines the error tolerance on the iterative solution used as a stopping criterion for each solution step. After each iterative solution update, the norm of the iterative change in the displacement vector and the norm of the force imbalance or residual vector are computed and compared with the value **DELX**. If either of those norms is smaller than **DELX**, then the solution for that step is said to have converged. The default value of **DELX** is 10^{-3}; however, typical values are usually between 10^{-4} and 10^{-6}. In some cases, the default value may be used to get a solution and then a restart step performed using a smaller value of **DELX** to verify that an equilibrium state has actually been achieved. Setting **DELX** to a value larger than the default value is not recommended in general, and if done, requires the analyst to carefully examine the solution.

The **NSOL** parameter on the ET-1 record has been used primarily for restarts in the past. For the progressive failure capability, a new option (**NSOL**=3) was added. This option specifies that the previously converged solution will be used as the initial guess for the starting vector during the first two iteration of the next solution step. This option was developed in an attempt to avoid excessive amounts of new damage being created when an extrapolated initial guess is used to start the next solution step.

One solution parameter that users do not have control over is the number of iterations permitted per solution step, **ITLIM**. This is an internal parameter and is set to 11. For a progressive failure analysis in **STAGS**, this limit is *automatically* doubled. If the iterative process is converging very slowly, then the tangent stiffness matrix will be refactored (provided the number of refactorings is not greater than **NEWT**) and/or the step size will be cut (provided the number of cuts is not greater than **NCUT**). Users may enter “X_40_” on the A-1 title record for the **STAGS** ***s2*** processor in order to allow a maximum of 40 iterations. This doubling of **ITLIM** appears to be necessary in some cases as the damage progresses during each iteration and may not have reached a stable damage state within 11 iterations. Some cases needed 15 to 20 iterations before no additional failures were detected for that solution step. Convergence of the nonlinear solution procedure is affected by the continual local stiffness changes as damage is detected, material properties degraded, and stress redistribution occurs.

During the iteration process, several variables are output and can be monitored. The residual error norm **RNORM** and the displacement solution norm **DNORM0** indicate the relative performance of the algorithm in achieving convergence. The solution strategy is controlled primarily by **RNORM**. In a full Newton–Raphson approach, the value of **RNORM** may increase up to a value of unity before the load factor is reduced. Once it reaches unity, the load factor is reduced regardless of the number of iterations.

In order to monitor this process, a new output parameter **TOTFAL** was added to the single line of output printed after each iteration cycle. This parameter gives the total number of points where failure has been detected up through that iteration. Once that value stabilizes (stops changing), no additional failures occur for this solution step. Then convergence to within the error tolerance **DELX** is relatively fast. If that value continues to increase, then additional failures are occurring and possible overall failure of the structure may be imminent. **TOTFAL** represents the total number of failed layer points in the model. It has a maximum value equal to the product of the number of layers, the number of surface integration points per element, and the number of elements with linear orthotropic elastic brittle and/or **ABAQUS**

UMAT materials. During iteration for the current solution step, **TOTFAL** should never be smaller than the value obtained from the last converged solution step. Each layer of the laminate has a specified number of layer integration points (see the I-21b record). If any or all layer integration points detect failure, this failure counts as only one layer failure point. For example, the maximum number of layer failure points for a 16-ply laminate is 64 for the **E410** element with 4 surface integration points and 144 for the **E480** element with 9 surface integration points—regardless of the number of layer integration points per layer.

Maintaining equilibrium

Establishing and re-establishing equilibrium for a nonlinear problem is a continuous problem during any nonlinear simulation even without brittle failures at the lamina level. The Newton–Raphson solution procedure is employed by **STAGS** to establish equilibrium at each solution step. The nonlinear solution strategy can be load control, displacement control or an arc-length-parameter control. Under load or displacement control, the load or displacement is incriminated and fixed during the iteration, and a new solution is found. Under arc-length control, the load and displacement are both changing during the iteration. So far, only the load and displacement control features of **STAGS** have been tested with the new progressive failure capability.

The Newton–Raphson procedure involves essentially four main stages. First, an initial guess for the next solution step is needed. Currently two options are provided: use the previously converged nonlinear displacement solution as the initial guess for the next solution step; and use previously converged solutions to perform a quadratic extrapolation for the next solution. If the step size is large, then the extrapolated initial guess may result is excessive amounts of damage and the solution may not converge. The load step would be cut and the iteration process continued until **NCUTS** cuts have been made.

Second, the second variation of the energy functional is needed which gives the “tangent” stiffness matrix (*i.e.,* “tangent” only if evaluated using a converged nonlinear solution). This matrix can be evaluated, assembled, and factored on each iteration (full Newton–Raphson is obtained by setting **NEWT** = -20) or perhaps only at the beginning of each solution step (obtained by setting **NEWT** = -1) or if the error measures begin to increase rather than decrease (modified Newton–Raphson). To evaluate the “tangent” stiffness matrix, the material properties, the stress state, and the displacements are needed. The material properties for *each* iteration are initially those values archived after obtaining convergence for the previous solution step (*i.e.,* this will be called the reference material state for this solution step). When the iterative change in displacements is computed and the displacement solution is updated, new strains are computed and new stresses are computed based on the archived material data. These stresses are then used in a failure analysis; and if failures are detected, the material properties are degraded. The stresses are then recomputed using these degraded properties. At this point in a given iteration, the displacement solution has been updated; and the stresses and material properties are consistent with this solution. These values are then used to evaluate the “tangent” stiffness matrix for the next iteration. Then when a new displacement solution is obtained for the next iteration, the new stresses are computed based on the archived material data (i.e., the reference material state for this solution step)—not the material state from the previous iteration. Once convergence has occurred, the degraded material properties from the final iteration of the current solution step are archived to the historical database and used as the reference set of material data for the next step. In the modified Newton–Raphson procedure, the “tangent” stiffness matrix is updated periodically (*e.g., at* the beginning of each solution step (**NEWT** = -1)).

Third, the first variation of the energy functional is needed which gives the internal force vector and residual or force-imbalance vector. This vector is computed during every iteration for both the full and modified Newton–Raphson procedures. The computational process to evaluate the first variation is similar to the process used to evaluate the “tangent” stiffness matrix.

Finally, the displacement solution is updated on each iteration. Each iteration starts from the reference material state (*i.e.,* the archived material data from the previous converged solution). The solution increment obtained by solving a system of equations based on the second variation and a right-hand-side vector based on the first variation is added to the solution vector from the previous iteration. As such, equilibrium is established and maintained throughout the solution process. Once a solution step has converged, the values of the degraded material properties for each material point with damage are saved (or archived) in the historical database as the converged material data for the next solution step. These data provide the reference material state for the next step.

Recommended guidelines

The following values for the solution parameters are recommended (based on limited testing):

- **NEWT** = -1 unless geometric nonlinearities are also very strong (*i.e.*, collapse of a shell)
- **NCUT** = 5 since a restart can be performed if necessary
- **DELX** = 0.000001 to ensure convergence and equilibrium for each step; **DELX** = 0.0001 is typically used for problems involving plasticity
- **NSOL** = 3 to reduce the overshoot in the solution and generate excessive damage in the model that is not really present
- **BETA** should be a small number if degradation is applied recursively (say 0.1; make it negative for degrade only once) or 0.000001 if it is only degraded once. Values equal to 0.1 appear to work well in either case but will generate some stress values that are not close to zero.
- The iteration output should be monitored and if the number of failures has not stabilized within 7 iterations, then a restart with "`X_40_`" on the A-1 title record for the **STAGS** ***s2*** processor should be performed.
- Monitor the iteration history for each step. Once the total number of failed ply points (**TOTFAL**) stops changing, convergence should be very fast. If this is not true, then examine the value of the determinant (**DETERM**) and the degree of freedom associated with the largest residual term (**DOF**). These values are printed for each iteration. If these values are changing, then the solution is most likely still having trouble finding an equilibrium solution. If the values are not changing, an inconsistency in the implementation may have been detected.
- Post-process the results by plotting the percent of failed plies per element should be done to watch the damage progression. These contour plots are generated by setting the **ITEM** parameter on the PL-3 record for **stapl** to a value of 8 and the parameter **ICOMP** to zero. A "patch quilt" plot or element assignment plot can be generated for this parameter by including the character string "`DISCONT`" anywhere on the PL-1 record for **stapl**. In this case, an element is assigned a color based on the value of this parameter; no contouring across element boundaries occurs.

16
Interpretation of Results

An understanding of the definitions and sign conventions used in **STAGS** is crucial to interpretation of secondary solution data. The analyst will find this section an indispensable reference for understanding the meaning of the strains, curvatures, stresses, forces, and moments arising from both membrane action and flexure. Before going further, a few words about coordinate systems. Some solution data, such as Von Mises stresses and eigenvalues, are invariant with respect to coordinate transformation; but in general, post-processing involves transformation of both vector and tensor quantities into coordinate systems which are most meaningful to the application at hand. For this reason, **STAGS** gives the user great flexibility in specifying the system(s) in which results are to be expressed. Therefore, it is essential that the various coordinate systems used in **STAGS** be understood by the analyst. It will be helpful to refer to Section 4.1 “Coordinate Systems” as necessary to avoid any ambiguity regarding coordinate systems appearing in this discussion.

16.1 Shell Results

Figure 16.1 shows a curved shell with stress resultants (membrane forces) and moment resultants (flexural forces) expressed in shell coordinates (X', Y', Z'). Figure 16.2 gives conventions for interpreting membrane forces, and Figure 16.3 gives conventions for interpreting flexural forces. Each of these last two figures shows a section of a curved shell whose dimensions are $dx \times dy$. The (x, y, z) coordinate system attached to this differential section is an arbitrary rectangular system in the plane of the shell. The z direction is normal to the shell at the point at which results are computed. Since the conventions for interpreting resultants are independent of the coordinate system in which they are expressed, it is not necessary to specify this (x, y, z) system further. In practice, resultants are usually expressed in either material coordinates (ϕ_1, ϕ_2) or fabrication coordinates $(\bar{x}, \bar{y})$, although the user may select any rectangular system in which the $(1, 2)$ axes are in the plane of the shell and the 3 axis is normal to the shell.

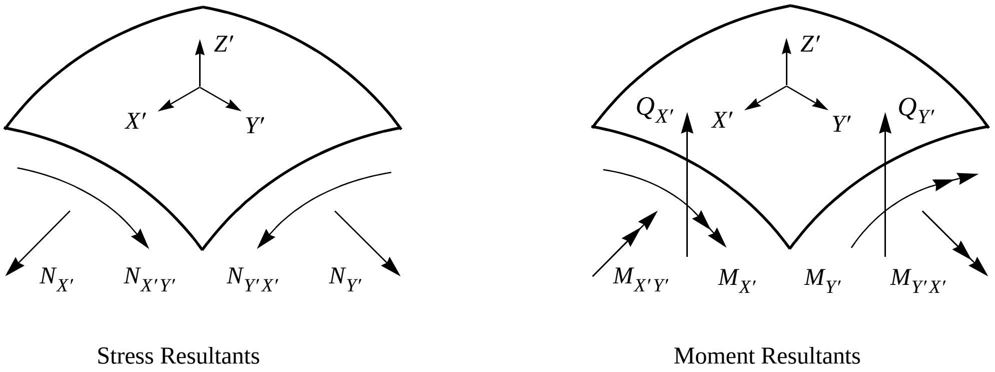
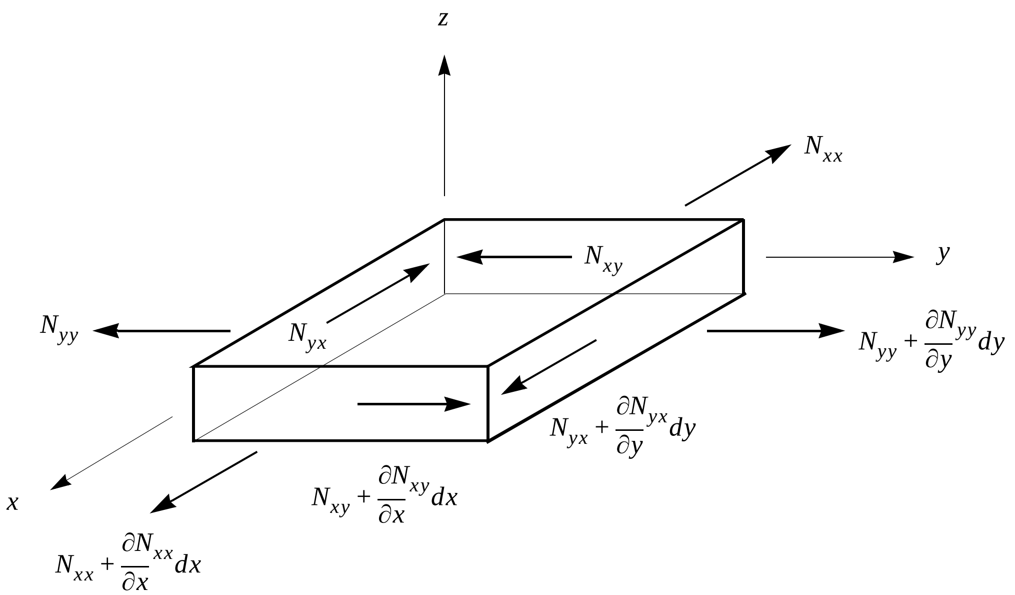


Figure 16.1 Sign conventions for stress and moment resultants.


z
N_{xx}
N_{xy}
y
N_{yy}
N_{yx}
$N_{yy} + \frac{\partial N_{yy}}{\partial y} dy$
$N_{yx} + \frac{\partial N_{yx}}{\partial y} dy$
x
$N_{xy} + \frac{\partial N_{xy}}{\partial x} dx$
$N_{xx} + \frac{\partial N_{xx}}{\partial x} dx$

Conventions for Interpreting Membrane Forces:

stress resultants, *N*, have units of [force/length]

positive normal forces N_{xx} and N_{yy} cause tension

positive shear $N_{xy} = N_{yx}$ acts in a positive coordinate direction on a positive face and in a negative direction on a negative face

Figure 16.2 Membrane forces. All forces are shown acting in their respective positive senses.

☞ Refer to Figure 6.6 on page 6-58 for nodal-displacement conventions

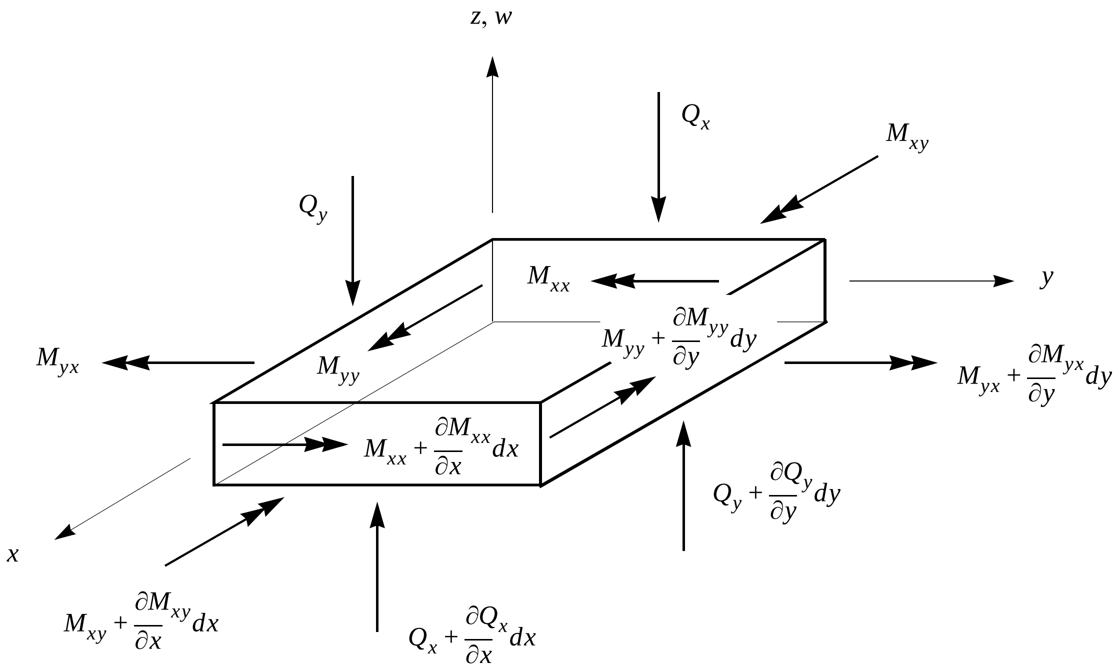

z, w
Q_x
M_{xy}
Q_y
M_{xx}
y
$M_{yy} + \frac{\partial M_{yy}}{\partial y} dy$
M_{yx}
M_{yy}
$M_{yx} + \frac{\partial M_{yx}}{\partial y} dy$
$M_{xx} + \frac{\partial M_{xx}}{\partial x} dx$
$Q_y + \frac{\partial Q_y}{\partial y} dy$
x
$M_{xy} + \frac{\partial M_{xy}}{\partial x} dx$
$Q_x + \frac{\partial Q_x}{\partial x} dx$

Figure 16.3 Flexural forces. All forces are shown acting in their respective positive senses.

Conventions for Interpreting Flexural Forces

- moment resultants, M, have units of $(force \times length)/length$
- shear resultants, Q, have units of $force/length$
- the right-hand rule applies consistently for interpreting moments
- positive bending moment (M_{xx}, M_{yy}) causes tension on the top surface
- positive twisting moment $(M_{xy} = M_{yx})$ is directed "inward" on the $x = c$ faces and "outward" on the $y = c$ faces
- positive shear (Q_x, Q_y) acts in the $+z$ direction on positive faces, and in the $-z$ direction on negative faces

In **STAGS**, curvature is defined as

$$\begin{Bmatrix} \kappa_{xx} \\ \kappa_{yy} \\ \kappa_{xy} \end{Bmatrix} = \begin{Bmatrix} -w,_{xx} \\ -w,_{yy} \\ -2w,_{xy} \end{Bmatrix} \tag{16.1}$$

D, shell flexural rigidity, and **C**, a constitutive matrix, are defined for convenience as

$$D = \frac{Eh^3}{12(1-v^2)}$$

$$\mathbf{C} = \begin{bmatrix} 1 & \nu & 0 \\ \nu & 1 & 0 \\ 0 & 0 & \frac{1-\nu}{2} \end{bmatrix} \qquad (16.2)$$

where *h* is thickness, and *E* and ν are elastic constants.

Moments are then defined as

$$\begin{Bmatrix} M_{xx} \\ M_{yy} \\ M_{xy} \end{Bmatrix} = D\,[\mathbf{C}] \begin{Bmatrix} \kappa_{xx} \\ \kappa_{yy} \\ \kappa_{xy} \end{Bmatrix}$$

$$= \frac{Eh^3}{12(1-v^2)} \begin{bmatrix} 1 & \nu & 0 \\ \nu & 1 & 0 \\ 0 & 0 & \frac{1-\nu}{2} \end{bmatrix} \begin{Bmatrix} -w,_{xx} \\ -w,_{yy} \\ -2w,_{xy} \end{Bmatrix} \qquad (16.3)$$

> In some references, the “twist” term (κ_{xy}) is defined as $\kappa_{xy} = -w,_{xy}$, omitting the factor of 2. When this is done, $C(3,3) = 1-\nu$.
> **STAGS** consistently uses the definition $\kappa_{xy} = -2w,_{xy}$.

Transverse shear is defined as

$$\begin{aligned} Q_x &= M_{xx,x} + M_{yx,y} \\ &= D(-w,_{xxx} - w,_{xyy}) \\ Q_y &= M_{xy,x} + M_{yy,y} \\ &= D(-w,_{xxy} - w,_{yyy}) \end{aligned} \qquad (16.4)$$

Strains are defined as

$$\begin{Bmatrix} \varepsilon_{xx} \\ \varepsilon_{yy} \\ \gamma_{xy} \end{Bmatrix} = \begin{Bmatrix} \varepsilon^0_{xx} \\ \varepsilon^0_{yy} \\ \gamma^0_{xy} \end{Bmatrix} + z \cdot \begin{Bmatrix} \kappa_{xx} \\ \kappa_{yy} \\ \kappa_{xy} \end{Bmatrix} \tag{16.5}$$

where the superscript 0 refers to reference-surface strains, and z is the through-thickness distance from the *reference surface* (see “Effects of Eccentricity” on page 16-6) to the strain sampling point, the location where strains are computed.

Stresses follow from strains according to the following, where **C** is from (16.2).

$$\begin{Bmatrix} \sigma_{xx} \\ \sigma_{yy} \\ \tau_{xy} \end{Bmatrix} = \frac{E}{1 - v^2} \; [\mathbf{C}] \begin{Bmatrix} \varepsilon_{xx} \\ \varepsilon_{yy} \\ \gamma_{xy} \end{Bmatrix} \tag{16.6}$$

Interpretation of stresses can be inferred from the definition of resultants. The following equations define the relationships between stresses and resultants.

Membrane Forces

- normal forces

$$\begin{aligned} N_{xx} &= \int_h \sigma_{xx} dz \\ N_{yy} &= \int_h \sigma_{yy} dz \end{aligned} \tag{16.7}$$

- planar shear forces

$$N_{xy} = N_{yx} = \int_h \tau_{xy} dz \tag{16.8}$$

Flexural Forces

- transverse shear forces

$$Q_x = \int_h \tau_{zx} dz$$

$$Q_y = \int_h \tau_{yz} dz \qquad (16.9)$$

- bending moments

$$M_{xx} = \int_h \sigma_{xx} \cdot z \;\; dz$$

$$M_{yy} = \int_h \sigma_{yy} \cdot z \;\; dz \qquad (16.10)$$

- twisting moments

$$M_{xy} = M_{yx} = \int_h \tau_{xy} \cdot z \;\; dz \qquad (16.11)$$

Effects of Eccentricity

STAGS permits flexibility in positioning the shell wall with respect to the *reference surface*, the surface on which the nodes lie. The amount by which the *middle surface*, the surface defined by the center of the shell wall, is offset from the reference surface is known as *eccentricity*, and the analyst must be aware of its effects upon computed values of moment resultants. As shown in Figure 6.2 on page 6-28, the eccentricity, *e*, is defined as the Z' (shell unit) or z' (element unit) value of the middle surface.

In equations (16.7) – (16.11), the limits of through-thickness integration are determined by the wall thickness, *h*, and the eccentricity, *e*. For example, if the reference surface coincides with the middle surface, then the integrals are of the form

$$\int_{-h/2}^{h/2} f(\sigma) dz \qquad \text{or} \qquad \int_{-h/2}^{h/2} f(\sigma) \cdot z \;\; dz \;.$$

Or, if the reference surface coincides with the bottom surface, then

$$\int_0^h f(\sigma)dz \qquad \text{or} \qquad \int_0^h f(\sigma)\cdot z\ \ dz\ .$$

Inspection of equations (16.7) – (16.9) show that computed values for force resultants are independent of eccentricity, but equations (16.10) – (16.11) show that computed values for moment resultants are not. For the case shown in Figure 6.2, a contour plot of moments can be misleading! This is not a matter of computing the *correct* moments, but rather a subtle point regarding the *interpretation* of moments. Fortunately, other results are not affected, and generally it is stresses and strains, rather than resultants, that are of primary interest.

The analyst may wish to "transfer" reference-surface moment resultants to the middle surface. This merely requires adding the effect of the eccentric membrane force resultants. This operation can be derived by considering the familiar expression

$$\mathbf{M}_o = \mathbf{r}\times\mathbf{F}$$

where $\mathbf{M}_o$ is a moment vector at point *o* due to the eccentric force vector, **F**, and **r** is a position vector defining the eccentricity of **F** relative to point *o*. Here, **r** is the position of the reference surface relative to the middle surface, $\mathbf{r} = (0\ \ 0\ \ -e)$, where *e* is the eccentricity (refer to Figure 6.2). It follows that

$$\begin{Bmatrix} M_{xx} \\ M_{yy} \\ M_{xy} \end{Bmatrix}_m = \begin{Bmatrix} M_{xx} \\ M_{yy} \\ M_{xy} \end{Bmatrix}_r - e\cdot\begin{Bmatrix} N_{xx} \\ N_{yy} \\ N_{xy} \end{Bmatrix} \qquad (16.12)$$

where the subscript *m* refers to the middle surface, and *r* to the reference surface.

☞ One final point regarding eccentricity—its effect on loading. During model development, the analyst should bear in mind that an eccentric membrane force is equivalent to a force plus a moment applied to the middle surface.

16.2 Beam Results

Figure 16.4 on page 16-10 shows a beam with resultant forces. V_y and M_z are due to bending about the z axis; V_z and M_y are due to bending about the y axis; T is due to torsion, or twisting about the x axis (not shown); and N is due to axial deformation. It is helpful to establish some terminology before continuing. Some of the terms and symbols used here are described elsewhere in this manual, and some are unique to beam results and are not found elsewhere.

Each beam element in **STAGS** is categorized using the following three classes:

- **ring** a shell stiffener occurring along a row $(X = \text{constant})$ of a shell unit. Refer to Figure 6.5 on page 6-52 and records O-1a—O-1b, starting on page 6-50.
- **stringer** a shell stiffener occurring along a column $(Y = \text{constant})$ of a shell unit. Refer to Figure 6.5 on page 6-52 and records O-2a—O-2b, starting on page 6-54.
- **beam** a beam element in an element unit. Refer to Figure 8.5 on page 8-33 and record T-2 on page 8-9. Beam elements may also be defined via user-written subroutine USRELT.

Compare Figure 16.4 with Figure 6.5 and Figure 8.5 to help understand the distinctions among the three beam categories. Also refer to Figure 5.5 on page 5-122 regarding cross-section definition, and Figure 14.5 on page 14-13 for establishing the beam (x', y', z') element coordinate system.

The element *reference axis* is established by the vector r_{12}, which points from node 1 to node 2 (Figure 14.5). The beam *cross-section axis*, parallel to the reference axis, intersects the cross-section plane at the origin of the $(\bar{y}, \bar{z})$ cross-section coordinate system. Referring to Figure 16.4, it can be seen that the reference axis is established by x' in a beam, X' in a stringer, and Y' in a ring. The cross-section axis is established by the cross-section coordinate $\bar{x}$. The $\bar{x}$ axis is not shown, but it is always parallel to the reference axis.

The cross-section axis is *positioned* using eccentricities, **ECY** and **ECZ**, which offset it from the reference axis. The cross-section is *oriented* by rotating it through an angle **XSI**, indicated by ξ in Figure 16.4. **ECY**, **ECZ**, and **XSI** thus establish the position and orientation of the $(\bar{y}, \bar{z})$ cross-section coordinate system. Figure 16.4 shows an additional coordinate system, (y, z), which is coincident with the unrotated $(\xi = 0)$ cross-section coordinate system. The x axis, coincident with $\bar{x}$ and parallel to the reference axis, is not shown. For all three beam categories, a positive **ECY** is directed from the reference axis in the positive y direction, and a positive **ECZ** is directed from the reference axis in the positive z direction. Negative **ECY**, **ECZ** are directed in the negative y, z directions, respectively. **XSI** is a right-handed rotation about the cross-section axis (x or $\bar{x}$). The rotation vector points in the positive $\bar{x}$ direction for a positive **XSI**.

☞ Beam results are expressed in the (y, z) *unrotated* cross-section coordinate system. Figure 16.4 gives conventions for interpreting beam resultant forces, which are related to axial and torsional-shear stresses by the relations

$$N_x = \int_A \sigma_{xx}(y, z)\, dydz \qquad M_z = \int_A y\sigma_{xx}(y, z)\, dydz \qquad M_y = \int_A z\sigma_{xx}(y, z)\, dydz$$

$$T = \int_A [y\tau_{xz}(y, z) - z\tau_{xy}(y, z)]\, dydz$$

Reference-axis strain, curvature, and unit twist are defined by the relations

$$\varepsilon_x = u,_x \qquad \kappa_z = -v,_{xx} \qquad \kappa_y = -w,_{xx} \qquad \alpha = (R_x^2 - R_x^1)/l$$

where (u, v, w) are displacements in the (x, y, z) directions, l is the length of the beam, R_x^1 and R_x^2 are the axial rotations at nodes 1 and 2, and the unit twist (α) has units of $radians/length$.

Transformation of beam resultants

Moments and curvatures may be transformed from the (y, z) *unrotated* cross-section coordinate system to the $(\bar{y}, \bar{z})$ cross-section coordinate system according to

$$\begin{Bmatrix} M_{\bar{z}} \\ M_{\bar{y}} \end{Bmatrix} = \begin{bmatrix} \cos\xi & \sin\xi \\ -\sin\xi & \cos\xi \end{bmatrix} \cdot \begin{Bmatrix} M_z \\ M_y \end{Bmatrix}$$

(16.13)

$$\begin{Bmatrix} \kappa_{\bar{z}} \\ \kappa_{\bar{y}} \end{Bmatrix} = \begin{bmatrix} \cos\xi & \sin\xi \\ -\sin\xi & \cos\xi \end{bmatrix} \cdot \begin{Bmatrix} \kappa_z \\ \kappa_y \end{Bmatrix}$$

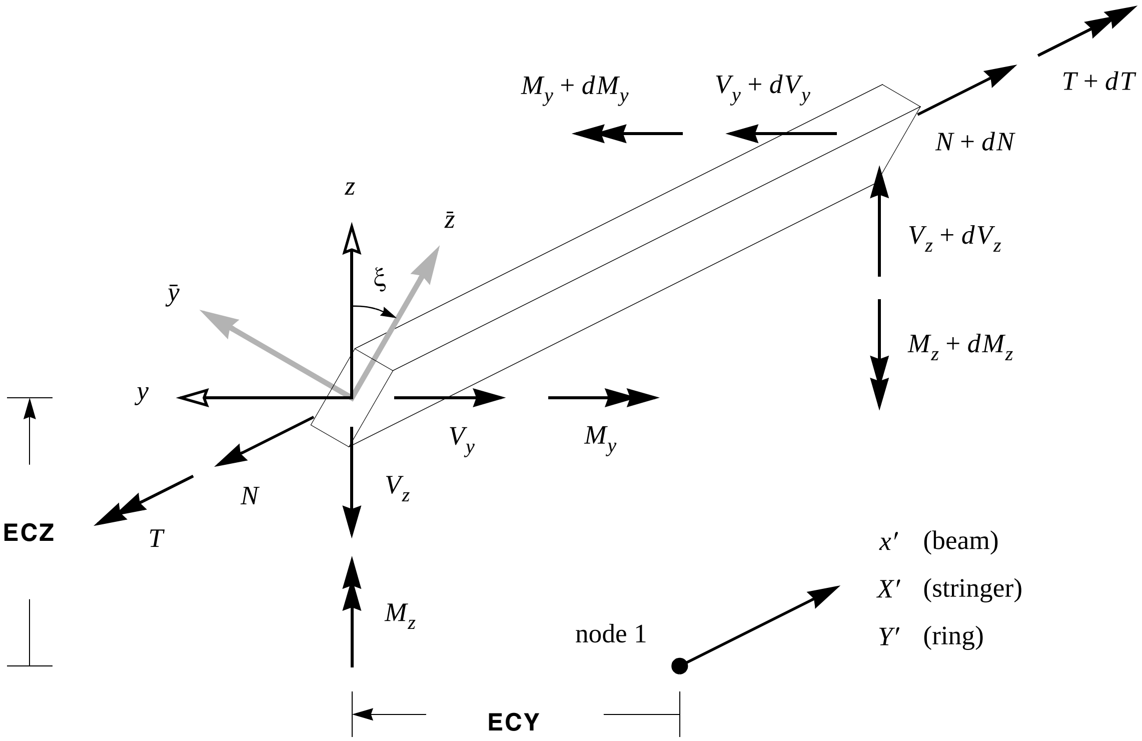


Figure 16.4 Beam resultant forces. All forces are shown acting in their respective positive senses.

Conventions for Interpreting Beam Resultant Forces

- stress resultants, *N*, have units of $force$
- moment resultants, *M*, have units of $force \times length$
- flexural shear resultants, *V*, have units of $force$
- torsional shear resultants, *T*, have units of $force \times length$
- the right-hand rule applies consistently for interpreting moments
- positive normal force *N* causes axial tension
- positive bending moment M_z causes axial tension on the $+y$ surface
- positive bending moment M_y causes axial tension on the $+z$ surface
- positive shear V_y acts in the $+y$ direction on $+x$ faces, and in the $-y$ direction on $-x$ faces
- positive shear V_z acts in the $+z$ direction on $+x$ faces, and in the $-z$ direction on $-x$ faces
- positive torsion, *T*, is directed in the $+x$ direction on $+x$ faces, and in the $-x$ direction on $-x$ faces

Axial stress and strain

Since the x axis is coincident with the $\bar{x}$ axis, there is no ambiguity regarding interpretation of axial stress and strain. Still, greater insight to the behavior of beams can be gained by considering the following relations among curvatures, moments, strains, and stresses.

Curvatures from (16.13) may be combined with axial strain at the cross-section axis (ε_x^0) to compute strain anywhere in the cross section according to

$$\varepsilon_x = \varepsilon_{\bar{x}} = \varepsilon_x^0 + \bar{y}\kappa_{\bar{z}} + \bar{z}\kappa_{\bar{y}} \tag{16.14}$$

Elastic stresses may then be computed as $\sigma_x = \sigma_{\bar{x}} = E \cdot \varepsilon_x$

Alternatively, when $(\bar{y}, \bar{z})$ are principal axes $(I_{\bar{y}\bar{z}} = 0)$, elastic stresses may be computed according to

$$\sigma_x = \frac{N}{A} + \frac{M_{\bar{z}} \cdot \bar{y}}{I_{\bar{z}}} + \frac{M_{\bar{y}} \cdot \bar{z}}{I_{\bar{y}}} \tag{16.15}$$

Torsional shear

STAGS assumes that torsional shear strain varies linearly with distance from the twist axis. In general, this assumption is valid only for circular cross sections. **STAGS** does not report torsional shear strain, but computes torsional shear stress using the familiar expression

$$\tau = \frac{Tr}{J}$$

where r is the radial distance from the twist axis, and τ is the resultant shear stress acting in the circumferential direction.

☞ Torsional shear results computed by **STAGS** should not be relied upon for non-circular cross sections. The torsional moment (T) and the unit twist (α) are valid, however, and may be used to compute torsional shear stress by the analyst who has knowledge of stress distribution over a given cross section.

Flexural shear

STAGS computes flexural shear resultants, V_y and V_z. No assumption is made regarding cross-sectional variation of shear strain, however average values $(\bar{\gamma}_y, \bar{\gamma}_z)$ are computed.

Flexural shear stresses are not reported. V_y and V_z may be used to compute flexural shear stress by the analyst who has knowledge of stress distribution over a given cross section.

Combined shear

Net shear strains $(\gamma_{xy}, \gamma_{xz})$ and stresses (τ_{xy}, τ_{xz}) may be computed by combining flexural and torsional results, where the analyst has computed these. **STAGS** does not compute cross-sectional variation of shear in beams, which is a complex matter for all but the simplest of situations, such as a circular cross-section under pure torsion or a rectangular cross-section under pure flexure.

☞ If rigorous treatment of beams is important, they should be modeled using shells. For example, a Tee-stiffener can be modeled using separate shell branches for web and flange.

16.3 Evaluating Solution Quality

16.4 Interpreting Diagnostic Messages

16.5 Overcoming Difficulties

It is important that the output be carefully studied. For example, even if only the bifurcation buckling load is of direct interest, it is worthwhile to study carefully the buckling mode. Such a study may reveal a flaw in the modeling which makes the computed critical load questionable. In general, a study of the output may indicate whether a suitable grid has been chosen. It is a good habit to look through the entire output even if everything appears to be all right.

Arrangements have been made so that the program can be used as a preprocessor of data records. If the program module S2 is excluded, all input records are read, error checks are made, but no time-consuming computations will be carried out. The printout from such a run contains all of the messages that are based on the input data directly including possible error messages. It also contains the matrix of shell wall stiffnesses. A plot of the grid can be obtained in an isometric view. Because such a run generally executes in a few seconds and only requires minimum computer core storage, it can be made on a high priority basis as a preliminary to a longer low priority run.

Error messages are obtained when various indices are outside of their allowed or specified range. In many cases, input record errors will cause the remaining data records to be read in an incorrect sequence which will normally cause the run to abort. In such a case, additional errors will not be found unless the run is repeated after correction of the error.

Error messages may appear embedded in the regular output. If the run is aborted for reasons that are not immediately clear, look through the output for such messages.

The following text discusses some special problems that may occur and their possible solutions. Computer system problems are not included in this discussion.

Linear static analysis

Problem Output from matrix decomposition indicates that the stiffness matrix is singular or near-singular.

Action The stiffness matrix becomes singular when rigid body motion is not prevented. Errors or omissions in data defining wall construction and material properties may lead to a singular system. It may also be noted that as the mesh spacing is reduced, the stiffness matrix will approach a singular condition in the limit.

Problem The displacement or stress solution appears not to vary smoothly with the shell coordinates.

Action One possibility is that the grid is too coarse. It is also possible that the solution is inaccurate because of roundoff errors. Check equilibrium forces! An accurate solution possibly can be obtained by use of nonlinear analysis as a form of linear refinement. If convergence is not obtained in a nonlinear analysis, look for reasons for ill-conditioning and try to improve the model.

Problem The displacements appear to be too large.

Action An error in the model or in the shell stiffness is conceivable. It is also possible that the boundary conditions allow rigid body motions. Check equilibrium forces!

Problem The displacements are all zero.

Action Probably the case has been specified so that there is no load. Check if the load is in conflict with boundary conditions, *e.g.* applied at a point at which the boundary conditions do not allow displacement.

Problem The average bandwidth of the stiffness matrix is zero and the determinant is exactly 1.0.

Action These symptoms occur when there are no nonzero terms in the stiffness matrix. The problem is probably caused by errors in the data defining the wall properties. The stiffness matrix will also vanish identically when all freedoms of the system have been constrained by boundary conditions or specified displacements in the load data.

Problem The stress at some point does not appear to converge with the grid size.

Action A singularity may exist. If it is necessary to find accurate values for the stress at the point in question, a special analysis based on three-dimensional inelastic analysis may have to be carried out for a part of the structure in the immediate vicinity of the singularity. If displacements appear to converge, the displacement solution and the stresses away from the singularity are probably satisfactory.

Eigenvalue analysis

Problem The output indicates the existence of negative roots when the matrix is refactored after the shift. (If negative roots occur without shift, see linear analysis above.)

Action Each negative root represents an eigenvalue between zero and the value of the shift. If the number of negative roots is larger than the number of computed eigenvalues between zero and the value of the shift, there must be additional eigenvalues between zero and the smallest computed eigenvalue. A rerun is then needed if the lowest eigenvalues are required.

Problem Only negative eigenvalues were obtained, though a positive value was desire.

Action It is necessary to use a positive shift.

Problem The buckling or vibration mode shows jumpiness in the displacement, changing sign at every grid point.

Action The grid is probably too coarse and should be modified. The occurrence of such buckling modes is discussed under STRATEGY.

Problem No convergence on all or some of the requested eigenvalues.

Action The program iterates 30 times. This is usually sufficient. Should nonconvergence occur, the intermediate values of the eigenvalues (if printed) will give some information. They indicate approximate values of buckling loads or vibration frequencies. A repeated analysis with a shift closer to the nonconverged eigenvalues will probably remedy the problem. It may be useful to ask for more than one cluster of eigenvalues in the repeat run, so that none of the eigenvalues to be determined are too far away from a point of shift.

Nonlinear static analysis

In the nonlinear analysis, a normal exit can occur in several different ways. Normal exit does not always mean that the analysis has been successfully completed. The program output advertises when one of the following normal exits occurs:

- Convergence not obtained at first step.
- The time limit **NSEC** is exceeded or there is not enough time left to perform the next option.
- The maximum load is reached.
- Convergence not obtained and the values set on the parameter **NEWT** and **NCUT** have been reached.
- Convergence difficulties cannot be resolved if the maximum number of cuts is reached and nonconvergence occurs after refactoring.

An abnormal exit can occur for several reasons, none of which can be indicated by the program output. Examples of abnormal exits are:

- Maximum time on control record has been exceeded.
- Maximum I/O time allowed has been exceeded.
- Maximum allowed computer core storage or disc storage exceeded.
- Systems error.
- Error in user-written subroutine.

If the analysis is to be continued, check in the system output that the appropriate data have been saved on tape or disc file.

Problem No convergence on first load step for an original run (not restart).

Action The cause may be that the system is ill-conditioned or that the effect of nonlinearities is too large. Use of a less severe convergence criterion is possible if the ill-conditioning is moderate. However, this may lead to an unnecessarily expensive analysis as convergence difficulties will be recurring. If too much nonlinearity prevents convergence, this may be caused by a mistake in modeling or in the data input. Nonconvergence will usually result if rigid body motion is permitted, even though applied loads are in balance.

Problem No convergence on first load step of a restart.

Action This may be because a load level has been reached that is close to a limit point. If the load displacement curve based on the previous runs does not indicate clearly that collapse is about to occur, continue the analysis, with much smaller steps. The nonconvergence also m ay be caused by an error in input data. It should be determined also whether the initial load factor corresponds to the solution on the selected restart record and whether the previous run was properly saved; check **ISTART** and **STLD**!

Problem The output indicates that convergence difficulties cannot be resolved.

Action This may not be a problem. Such output is obtained when convergence fails if the number of cuts of load step has reached **NCUT**, but the number of refactorings is still below **NEWT**. It would not serve any purpose to do additional factorings without a cut in the load step. If it appears that the run should be continued, it must be restarted with a smaller load step.

Problem At refactoring the determinant is found not to be positive definite (this could happen at restart or during the run).

Action This is an indication that either there is a bifurcation point on the primary path below the load level is reached, or that an inaccurate solution was accepted at a previous step. If there is a true bifurcation, the analysis can be rerun with a small imperfection (or perhaps a small lateral load) which will trigger displacements in the critical mode. If a true bifurcation does not exist, there may be present a displacement mode that has an extremely small amplitude at moderate loads. At some load level (close to a sharp maximum in the load displacement curve) this amplitude begins to grow rapidly. In that case either an imperfection may be used or the convergence criterion may be sharpened. This is discussed under strategy for nonlinear analysis.

Problem Convergence difficulties seem to persist even with moderate nonlinearity.

Action The system may be ill-conditioned; the accuracy of the computations are marginal in comparison to the convergence criterion. This problem may be cured by use of a less severe convergence criterion. However, with a coarser criterion, less accurate solutions will be accepted, and the predictions for initial estimate will be inaccurate. The output indicates for each iteration at which point the largest change is displacement occurs. If the convergence is nonuniform oscillating, it may be practical to switch to a true Newton method.

Problem At some load level, the displacement solution does not appear to be smooth.

Action A jumpy solution probably indicates that a spurious mode of collapse is developing. Use a finer grid!

Transient analysis

Problem Convergence difficulties or negative roots.

Action See Nonlinear Analysis.

Problem The explicit scheme is used and the displacement components grow extremely rapidly.

Action Mathematical instability occurs because the time step is too large. Rerun with smaller time step!

Problem One of the implicit integration methods is used. The motion of the structure seems to indicate unwarranted damping.

Action The time step is probably too large. Reduce the time step or use the option with a variable time step. If the problem occurs with a variable time step, reduce the value of **SUP** (E-1).

Problem The third order Gear method is used. The motion of the structure seems to indicate that energy is added to the system in a way that is not due to the work of external forces. A vibration with increasing amplitude in the lowest frequency mode is a reason for suspicion.

Action The chosen time step is such that at least one of the deformation modes is in the unstable range. Choose other integration method, modify (increase) time step, or add some structural damping.

17
Input/Output Files

STAGS uses various file systems; *e.g.,* text input/output files, binary database files, and scratch files. Understanding these file systems is important for effective use of **STAGS**. This is especially so for restarting an analysis, for pre/postprocessing, and for interfacing with the database via **STAR**, the **STAGS** Access Routines.

There are two sections in this chapter. Section 17.1 describes each file, and section 17.2 summarizes file requirements according to the various **STAGS** processors.

See Section 3.5 “File Systems” on page 3-8 for additional information on files.

17.1 Description of I/O Files

This section gives a brief description of each **STAGS** file. The files appear in alphabetical order.

ACCEL *casename*.accel.*i*

The *ACCEL* file, created by **stp** per user request, contains text data in **PATRAN** “results” format representing the nodal accelerations at load/ timestep *i*. See **$STAGSHOME**/doc/stpfiles for more information.

BIN *casename*.bin

The *BIN* file contains input to the **STAGS** solution processor, **s2**.
Solution input data are described in Chapter 11.

BSR *casename*.bsr

The *BSR* file is a binary scratch data file that is present only during execution of certain **STAGS** processors. If an orphan *BSR* file is found after all processors have finished, it should be deleted. *BSR* files can grow quite large!

DISP *casename*.disp.*i*

The *DISP* file, created by **stp** per user request, contains text data in **PATRAN** “results” format representing the nodal displacements at load/time step *i*. See **$STAGSHOME**/doc/stpfiles for more information.

EGV *casename*.egv

The *EGV* file contains a binary representation of eigenvector data for selected load/time steps during each run or execution of the **STAGS** processor **s2**. The *EGV* file is indexed by the *IMP* file.

EGV.bak *casename*.egv.bak

The *EGV.bak* file contains a backup copy of the *EGV* file. The *EGV.bak* file is copied from an *EGV* file when **s2** is run and an *EGV* file for that case exists. Only one *EGV.bak* file exists at any time. The user can suppress the creation of the *EGV.bak* file by specifying the appropriate option with the `stags` command.

EGV.BOMB *casename*.egv.BOMB

The *EGV.BOMB* file contains the most recently obtained eigenvector data when the **s2** process terminates abnormally. Often the *EGV.BOMB* file will be usable, but since the case terminated abnormally, there is no guarantee. Usually an *EGV.BOMB* file will contain load/time step data up to the step that triggered the abnormal termination. In the event the user encounters an *EGV.BOMB* file, he/she must decide whether to use it or the *EGV.bak* file that is normally available before performing further analysis.

EIG *casename*.eig.*i.j*

The *EIG* file, created by **stp** per user request, contains text data in **PATRAN** “results” format representing a normalized displacement due to eigenmode *j* for loadstep *i*. See **$STAGSHOME**/doc/stpfiles for more information.

elmI *casename*.elmI.*i*

The *elmI* file, created by **stp** per user request, contains text data in **PATRAN** “results” format representing stress and moment resultants for solution time/load step *i*. See **$STAGSHOME**/doc/stpfiles for more information.

elmP *casename*.elmP.*i.j*

The *elmP* file, created by **stp** per user request, contains text data in **PATRAN** “results” format representing plastic strains for solution time/load step *i* in material layer *j* for those cases where plastic strains exist. See **$STAGSHOME**/doc/stpfiles for more information.

elmR *casename*.elmR.*i*

The *elmR* file, created by **stp** per user request, contains text data in **PATRAN** “results” format representing reference-surface strains and curvatures for solution time/load step *i*. See **$STAGSHOME**/doc/stpfiles for more information.

elmT *casename*.elmT.*i.j*

The *elmT* file, created by **stp** per user request, contains text data in **PATRAN** “results” format representing strains and stresses for solution time/load step *i* in material layer *j*. See **$STAGSHOME**/doc/stpfiles for more information.

FINT *casename*.fint.*i*

The *FINT* file, created by **stp** per user request, contains text data in **PATRAN** “results” format representing the nodal forces at load/time step *i* for the given **STAGS** model. See **$STAGSHOME**/doc/stpfiles for more information.

FORT fort.*

TMP and *FORT* files are miscellaneous scratch files and should disappear upon termination of the process that created them. If you are sure no **STAGS** processes are running in the current directory and these files exist, you may delete them.

IMP *casename*.imp

The *IMP* file contains an index of the latest set of data contained in the *EGV* file.

IMP.bak *casename*.imp.bak

The *IMP.bak* file contains a backup copy of the *IMP* file. The *IMP.bak* file is copied from an *IMP* file when **s2** is run and an *IMP* file exists for that case. Only one *IMP.bak* file exists at any time. The user can suppress the creation of the *IMP.bak* file by specifying the appropriate option with the `stags` command.

IMP.BOMB *casename*.imp.BOMB

The *IMP.BOMB* file contains the most recently obtained eigenvector data when the **s2** process terminates abnormally. Often the *IMP.BOMB* file will be usable, but since the case terminated abnormally, there is no guarantee. Usually an *IMP.BOMB* file will contain load/time step data up to the step that triggered the abnormal termination. In the event the user encounters an *IMP.BOMB* file, he/she must decide whether to use it or the *IMP.bak* file that is normally available before performing further analysis.

INP *casename*.inp

The *INP* file contains input to the **STAGS** model processor, **s1**. Model input data are described in Chapters 5–10.

LOD *casename*.lod

The *LOD* file is a binary scratch file used by **stp** to store selected displacement data. It is deleted upon normal termination of **stp**.

LOG *casename*.log

The *LOG* file contains text diagnostics from the latest `stags` command.

MDL *casename*.mdl

The *MDL* file is a **PATRAN** Neutral File that is created by the **STAGS**-to-**PATRAN** model translation function of **stp**.

OUT1 *casename*.out1

The *OUT1* file contains text output from the **STAGS** processor **s1**.

OUT2 *casename*.out2

The *OUT2* file contains text output from the most recent invocation of the **STAGS** processor **s2**.

OUT2.i *casename*.out2.*i*

An *OUT2.i* file results when the **STAGS** processor **s2** is run through the `stags` command and an *OUT2* file exists. The existing *OUT2* file is renamed to an *OUT2.i* file where *i* is either 1 or the greatest *i* plus 1 of existing *OUT2.i* files.

Examples

If the file ring.out2 exists and we run **s2** through the `stags` command, ring.out2 will be renamed ring.out2.1 and the output from the latest execution of **s2** will be placed in the file ring.out2.

If the following files exist: ring.out2, ring.out2.1, ring.out2.2, and ring.out2.3 and if **s2** is executed through the `stags` command, the file ring.out2 will be renamed to ring.out2.4 and output from the latest execution of **s2** will be placed in the file ring.out2.

If the files ring.out2.1 and ring.out2.2 exist but ring.out2 does not exist and if **s2** is executed through the `stags` command, output will be placed in the file ring.out2, and no renaming will occur.

Once an *OUT2* file becomes an *OUT2.i* file, no further renaming occurs.

The *OUT2* file always contains the latest output of an **s2** execution. Previous executions of **s2** on the same case are placed in numerical order in *OUT2.i* files from oldest, $i = 1$, to second newest, $i = j$, where *j* is the maximum of all *i*’s.

Note: *OUT2* files are renamed to *OUT2.i* files in the fashion described above only if **s2** is executed through the `stags` command or if the user explicitly renames the files.

PDF *casename_m*.pdf and *casename*.pdf

These *PDF* files contain plots generated in Adobe’s *Portable Document Format* (pdf) by **STAGS**’ **stapl** plotting processor for the model and selected solutions, respectively.

PIN *casename*.pin

The *PIN* file contains input for **STAGS**’ **stapl** plotting processor.

PLOT *casename.i*.plot

The *PLOT* file is a text file created by the i^{th} invocation of the “xy” function from within a single **stp** session. The *PLOT* file may be used directly as input to xgraph or plotps.

The integer *i* is used to age the *PLOT* files. If no *PLOT* file exists then $i = 1$, otherwise $i = j + 1$ where *j* is the highest-numbered existing *PLOT* file. See **$STAGSHOME**/doc/stpfiles for more information.

POUT *casename*.pout

The *POUT* file contains printed output from the **stapl** plotting processor.

PS *casename_m*.ps and *casename.i*.ps

PS files contain data for plots generated in Adobe's *PostScript format* (ps) by the **stapl** program; they can be printed directly on a PostScript printer or viewed in a PostScript viewer.

The *casename_m*.ps file is a *PostScript-formatted* plot—generated by **STAGS**' **s1** (model definition) processor—of the undeformed model;.

Each *casename.i*.ps file contains one plot of the undeformed or deformed configuration, with or without solution information, generated by the **stapl** processor; the integer *i* is used to age the *PS* files; if no *PS* file exists then **stapl** sets $i = 1$, otherwise it sets it to $i = j + 1$, where *j* is the highest-numbered existing *PS* file.

PXY *casename*.pxy

The *PXY* text file contains y(x) data generated by **STAGS**' **xyrans** processor; these files facilitate visual inspection of **STAGS** results and can often be used effectively as (part of the) input into an xy plotting program.

RES *casename*.res

The *RES* file contains a binary representation of the solution state for the load/time steps evaluated in the current, and if applicable, previous executions of the **STAGS** processor **s2**. The *RES* file is indexed by the *RST* file. The *RES* file is created the first time **s2** is run for a given case. Each subsequent run of **s2** for that case appends and/or overwrites data to the *RES* file.

RES.bak *casename*.res.bak

The *RES.bak* file contains a backup copy of the *RES* file. The *RES.bak* file is copied from an *RES* file when **s2** is run and an *RES* file for that case exists. Only one *RES.bak* file exists at any time. In case the *RES* file is very large (i.e. more than 1/2 available free disk space), the user can suppress the creation of the *RES.bak* file by specifying the appropriate option with the `stags` command.

RES.i *casename*.res.*i*

When the user selects the "pcopy" function of **stp**, he or she is asked to select a subset of load/time steps from the current *RES* file and copy them into a new *RES* file that is usually much smaller. The original *RES* file is renamed to an *RES.i* file where *i* is either 1 or the highest plus one of existing *RES.i* files. The file *RST.i* indexes the database file *RES.i*.

RES.BOMB *casename*.res.BOMB

The *RES.BOMB* file contains the current database when the **s2** process terminates abnormally. Often the *RES.BOMB* file will contain usable data; but since the case terminated abnormally, there is no way to guarantee that the database is intact. Usually a *RES.BOMB* file will contain load/time step data up to but not including the step that triggered the abnormal termination. In the event the user encounters a *RES.BOMB* file, he/she must decide whether to use it or the *RES.bak* file that is normally available before performing further analysis.

CAUTION: If a truly bad *RES.BOMB* file is renamed to a *RES* file and the creation of a *RES.bak* file is suppressed during an **s2** execution, the database could be lost.

RST *casename*.rst

The *RST* file contains an index of the *RES* file for the load/time step solutions generated from running the **STAGS** processor **s2**.

RST.bak *casename*.rst.bak

The *RST.bak* file contains a backup copy of the *RST* file. The *RST.bak* file is copied from an *RST* file when **s2** is run and an *RST* file for that case exists. Only one *RST.bak* file exists at any time. The user can suppress the creation of the *RST.bak* file by specifying the appropriate option with the `stags` command.

RST.i *casename*.rst.i, where *i* is an integer

When the **STAGS** user selects the “pcopy” function of **stp**, he or she is asked to select a subset of load/time steps from the current *RST* file and copy them into a new *RST* file that is usually much smaller. The original *RST* file is renamed to an *RST.i* file where *i* is either 1 or the highest plus one of existing *RST.i* files. The file *RST.i* indexes the database file *RES.i*.

RST.BOMB *casename*.rst.BOMB

The *RST.BOMB* file contains an index for the current database when the **s2** process terminates abnormally. Often the *RST.BOMB* file will be usable, but since the case terminated abnormally, there is no guarantee. Usually an *RST.BOMB* file will contain load/time step data up to the step that triggered the abnormal termination. In the event the user encounters an *RST.BOMB* file, he/she must decide whether to use it or the *RST.bak* file that is normally available before performing further analysis.

SAV *casename*.sav

The *SAV* file, a binary representation of the **STAGS** model, is created by the **STAGS** processor **s1**. One can also create a *SAV* file by making the appropriate calls to the “data put” (DP) routines in the **STAR** library.

SOT *casename*.sot.*i*

The *SOT* file contains text diagnostics from running a program that calls the **STAR** library. The file is created upon a call to DUOPEN and upon a normal call to DUCLOSE, the file is deleted.

STEP *casename*.step

The *STEP* file contains a complete listing of the load/time step history contained in the *RES* file. The *STEP* file is created by various postprocessors.

The integer *i* is used to age the *SOT* files. If no *SOT* file exists then $i = 1$, otherwise $i = j + 1$ where *j* is the highest-numbered existing *SOT* file.

TMP tmp.*

TMP and *FORT* files are miscellaneous scratch files and should disappear upon termination of the process that created them. If you are sure no **STAGS** processes are running in the current directory and these files exist, you may delete them.

17.2 Summary of I/O File Requirements

The following sections discuss input files required for each **STAGS** processor and the output files generated or modified. Files marked with an asterisk (*) are read and/or written under certain conditions only. See the file descriptions above for details. Files marked with a hash (#) are temporary files that may be present while the processor is running but which should disappear upon termination.

s1—Model processor

Input:	INP	EGV*	IMP*		
Output:	LOG	OUT1	SAV	BSR#	TMP#
	PDF (casename_m.pdf)		or	PS (casename_m.ps)	

s2—Solution processor

Input:	BIN	SAV	EGV*	IMP*	RES*
	RST*				
Output:	LOG	OUT2	RES	RST	EGV*
	IMP*	OUT2.i*	BSR#	FORT#	TMP#

stapl—Plotting processor

Input:	PIN	SAV	RES*	RST*
Output:	PDF	PS	POUT	

stp—STAGS translator/postprocessor

Input:	PCN*	RES*	RST*	SAV*	
	PATRAN Neutral File *(input to **PAT2S**, Appendix X)				
Output:	ACCEL*	DISP*	EIG*		
	elmI*	elmP*	elmR*	elmT*	
	FINT*	MDL*	PCN*	PLOT*	PS*
	RES*	RES.i*	RST*	RST.i*	
	SAV*	SOT*	STP*	VELO*	
	BSR#	FORT#	LOD#	PD#	TMP#

A
STAGS Input Record Catalog

Model Input—*INP* File

Summary and Control Parameters

A-1 Case Title

COMMENT

B-1 Analysis Type Definition

IGRAV ICHECK ILIST INCBC NRUNIT NROTS KDEV

B-1a Model Unit List (for plotting)

(IUNIS(i), i = 1, NRUNIT)

B-1b Sequence of Model Rotations (for plotting; **NROTS** records required)

IROT ROT

B-2 General Model Summary

NUNITS NUNITE NSTFS NINTS NPATS NCONST NIMPFS INERT NINSR NPATX NSTIFS

B-3 Data Tables Summary

NTAM NTAB NTAW NTAP NTAMT NGCP

B-4 Gravitational Acceleration

GRAV

B-5 Buckling Mode Imperfections

WIMPFA IMSTEP IMMODE IMRUN

B-6 Inertial Loads Summary

ISYS IA IOM IAL IOPT

B-6a Inertial Loads — Acceleration

AX AY AZ

B-6b Inertial Loads — Angular Velocity

OMX OMY OMZ

B-6c Inertial Loads — Angular Acceleration

ALX ALY ALZ

B-6d Inertial Loads — Position Vector

X Y Z

Discretization and Connectivity Summary

F-1 Grid Summary

(NROWS(i) NCOLS(i)), i = 1, NUNITS

F-2 Stiffener Summary

IUNIT NRGS NSTR

G-1 Shell Unit Connections

MUNIT MBOUND NUNIT NBOUND NDEFS INC1 INC2 INC3 INC4

G-2 Partial Displacement Compatibility

IU1 IR1 IC1 ID1 IU2 IR2 IC2 ID2 ND1A ND1B INC1 ND2A ND2B INC2 NDEFS

G-2a Partial Compatibility Incrementations

JU1 JR1 JC1 JD1 JU2 JR2 JC2 JD2

G-2c Partial Displacement Compatibility

IU1 IR1 IC1 IL1 ID1 IU2 IR2 IC2 IL2 ID2 ND1A ND1B INC1 ND2A ND2B INC2

G-2d Partial Compatibility Looping and Incrementations

NDEFS JU1 JR1 JC1 JL1 JD1 JU2 JR2 JC2 JL2 JD2

G-3 Constraint—Record 1

NTERMS NX INC1 INC2 INC3 INC4 INC5

G-4 Constraint—Record 2

IU(i) IX(i) IY(i) ID(i) CC(i) IZ(i)

G-5 Crack Inserted Node Set—Record 1

NCRACK INNODS INELTS ITEAR ACRIT CTOD
ACRITT SAWL SAWT CSCALE IDREC

G-6 Crack Inserted Node Set—Record 2

ICOPEN ICUNIT ICROW1 ICCOL1 ICROW2 ICCOL2
JCUNIT JCROW1 JCCOL1 JCROW2 JCCOL2 THETA

G-7 Crack Inserted Node Set—Record 3

JETYPE JCUNIT JCROW1 JCCOL1 JCROW2 JCCOL2

H-1 Element Unit Summary (NUNITE records required)

NUPT NT1 NT2 NT3 NT4 NT5 IUWP IUWE IUDIMP IUWLE NS5

Data Tables

I-1 Material Properties

ITAM NESP IPLST ITANST ICREEP IPLANE

I-2 Material Elastic Properties

E1 U12 G RHO A1 E2 A2

I-3 Material Plastic Properties

(E(i), S(i)), i=1, NESP

I-3a Material Creep Properties

ACO BCO M N

I-4a Mount Element Table Size

IMNT NRD NRV

I-4b Relative Displacement Vector

DISP(j), j = 1, NRD

I-4c Relative Velocity Vector

RVEL(i), i = 1, NRV

I-4d Mount Force Matrix

FORCE(j), j = 1, NRD

I-5a GCP Command Record

COMMAND INFO(j), j = 1, 7

I-6a Linear Elastic Isotropic GCP Material

E GNU RHO ALPHA BETA T M

I-7a Linear Elastic Orthotropic GCP Material

E1 E2 E3 G12 G13 G23 P12 P13 P23 RHO A1 A2 A3 B1 B2 B3 T M

I-8a Plane-Strain-Plasticity GCP Material

E GNU RHO ALPHA BETA T M

I-9a Mechanical Sublayer Plasticity GCP Material

E GNU RHO ALPHA NSUBS T

I-9b Stress-Strain Curve for a Given State

(E(i), S(i)), i = 1, NSUBS

I-10a Linear Orthotropic Elastic Brittle GCP Material

E1 E2 E3 G12 G13 G23 P12 P13 P23 RHO A1 A2 A3 B1 B2 B3 T M
EPS1C EPS1T ESP2C EPS2T EPS6F EPS3C EPS3T EPS4F EPS5F
XC XT YC YT SXY ZC ZT SYZ SXZ ALPHA F12 BETA IFAIL IDGRD
VISF0 VISF1 VISFF

I-11a PDLAM GCP Material

E1	**E2**	**E3**	**G12**	**G13**	**G23**	**P12**	**P13**	**P23**
RHO	**A1**	**A2**	**A3**	**B1**	**B2**	**B3**	**T**	**M**
XC	**XT**	**YC**	**SXZ**	**SYZ**	**ALPHA**	**CURET**	**G1C**	**G2C**
VISF0	**VISF1**	**VISFF**	**DPHI0**	**DELTA**	**DFMIN**	**BETA**	**ETA**	**BETAC**

I-12a ABAQUS UMAT GCP Material

PROPS(1) PROPS(2) ... PROPS(40)

I-13a SHM-Membrane GCP Material

E GNU RHO ALPHA BETA T M PENLTY IWRINK ISTATE

I-14a Nonlinear Orthotropic Elastic GCP Material

E1	**E2**	**E3**	**G12**	**G13**	**G23**	**P12**	**P13**	**P23**	**RHO**
A1	**A2**	**A3**	**B1**	**B2**	**B3**	**T**	**M**	**S6666**	

I-21a GCP Shell Fabrication Record

MATID(j) j = NX, NLAYER

I-21b GCP Shell Integration Points Record

INTSHL(j) j = NX, NLAYER

I-21c GCP Shell Layer Thickness Record

THKSHL(j) j = NX, NLAYER

I-21d GCP Shell Layer Orientation Record

ANGSHL(j) j = NX, NLAYER

I-21e Shear Factor Specification Record

SCF1 SCF2

I-22a GCP Solid Fabrication Record

THICK

I-22b GCP Solid Fabrication Orientation Record

ANGLE

J-1 Cross-Section

ITAB KCROSS MATB NSUB TORJ SCY SCZ NSOYZ KAPY KAPZ

J-2a General Cross-Section—Record 1

BA BIY BIZ BIYZ

J-2b General Cross-Section—Record 2

(SOY(i), SOZ(i)), i = 1, NSOYZ

J-3a General Subelement Cross-Section

SA(i) SY(i) SZ(i) SIY(i) SIZ(i) SIYZ(i) ISP(i)

J-3b Rectangular Subelement Cross-Section

Y1(i) Y2(i) Z1(i) Z2(i) ISOC(i)

J-4a Arbitrary Cross-Section—Record 1

BMA

J-4b Arbitrary Cross-Section—Record 2

(CCC(i,j), j=1,4), i=1,4

K-1 Shell Wall Properties

ITAW KWALL NLAY NLIP NSMRS SHEAR1 SHEAR2

K-2 Layered Wall

MATL TL ZETL LSOL

K-3a Fiber Reinforced Wall—Record 1

MATF MATM

K-3b Fiber Reinforced Wall—Record 2

TT XX ZETW O

K-4a Corrugation Stiffened Wall—Record 1

MATC MATS CT CC CH CD CB

K-4b Corrugation Stiffened Wall—Record 2

TS PHI ANC

K-5a General Wall—Record 1

TA MAT ITVS

K-5b General Wall—Record 2

(CCC(i,j), j = 1, 6), i = 1, 6

K-5c General Wall—Record 3

(CTS(i,j), j = 1, 2), i = 1, 2

K-6 Smeared Stiffener

ICROSM SPASM ZETSM XSISM ECZSM

L-1 User Parameters Summary

NPI NPF

L-2a Integer Parameters

USERINT(i), i = 1, NPI

L-2b Floating-Point Parameters

USERFLO(i), i = 1, NPF

Shell Units

M-1 Shell Type

ISHELL IGLOBE NROWS NCOLS NLAYS NFABS

M-2 Shell Surface Constants

PROP(i), i=1,8

M-3 Shell Unit Orientation—Straight-Line Boundary

NREP NCEP XGEP YGEP ZGEP

M-4a Shell Unit Orientation—Corner Point 1

XGC1 YGC1 ZGC1

M-4b Shell Unit Orientation—Corner Point 2

XGC2 YGC2 ZGC2

M-4c Shell Unit Orientation—Corner Point 3

XGC3 YGC3 ZGC3

M-4d Shell Unit Orientation—Translation

XG YG ZG

M-4e Shell Unit Orientation—Rotation

XGROT YGROT ZGROT

M-5 Shell Wall (**NFABS** records required)

IWALL IWIMP ZETA ECZ ILIN IPLAS IRAMP

M-6 Shell Imperfections

X1 Y1 XL YL WAMP ID

M-7a Random Imperfection Shapes

N1 N2 NI M1 M2 MI KTEST

M-7b Random Imperfection Amplitudes

GRAMP RANK EXP

N-1 Discretization Control

KELT NNX NNY IRREG IUGRID INTEG IPENL MESH1 MESH2 MESH3 MESH4 KELTX

N-2 X-Segment Length

SEGLX(i), i=1,NNX

N-3 X-Segment Spacing

NSEGX(i), i=1,NNX

N-4 X-Coordinate

X(i), i = 1, NRWS

N-5 Y-Segment Length

SEGLY(j), j = 1, NNY

N-6 Y-Segment Spacing

NSEGY(j), j = 1, NNY

N-7 Y-Coordinate

Y(j), j = 1, NCLS

N-8 Mesh Irregularity

NRW1 NRW2 NCL1 NCL2

O-1a Discrete Ring—Record 1

ICROSS XSI ECY ECZ ILIN IPLAS

O-1b Discrete Ring—Record 2

IR JR1 JR2 XR YR1 YR2

O-2a Discrete Stringer—Record 1

ICROSS XSI ECY ECZ ILIN IPLAS

O-2b Discrete Stringer—Record 2

JS IS1 IS2 YS XS1 XS2

P-1 Boundary Conditions—Record 1

IBLN(i), i = 1, 4 IBOND

P-2 Boundary Conditions—Record 2

ITRA IROT

P-3 Boundary Conditions—Record 3

JBLN(i), i = 1, 4

P-4 Boundary Conditions—Record 4

JTRA JROT

Q-1 Loads Summary

NSYS NICS NAMS NUSS NHINGE NMOMNT NLEAST IPRESS

Q-2 Load Set Summary

ISYS NN IFLG

Q-3 Load Definition

P LT LD LI LJ LAX NX INC1 INC2 INC3 ILAY

Q-4 Attached Mass (**NN** records required)

GM IRM ICM LAYER NX INC1 INC2 INC3

Q-5 Uniform Stress State for Eigenanalysis

PNXA PNYA PNXYA PNXB PNYB PNXYB

Q-6 Cable Hinge Restraint

IROW ICOL HRU HRV HRW LAYER NX INC1 INC2 INC3

Q-7 Cable Hinge Moment

IROW ICOL MSYS RUM RVM RWM LAYER NX INC1 INC2 INC3

Q-8a Least Squares Loading Summary

NSQR IUNIT IROW ICOL SCALE

Q-8b Least Squares Load Definition

P LU LR LC LNDA LNDB LNDINC

R-1 Output Control—Record 1

IPRD IPRR IPRE IPRS IPRP IPRF NSELD NSELS IPRDSP IPRSTR ISL ISS ISD

R-2 Output Control—Record 2

IROWD ICOLD

R-3 Output Control—Record 3

IROWS ICOLS

Element Units—Points & Lines

S-1 User Points (upts protocol)

IUPT IUS IRS ICS XG YG ZG IUVW IRUVW IAUX NPTS ILAY

S-1a User Point Incrementations (upts protocol)

JUPT JUS JRS JCS Dxg Dyg Dzg

S-2 Auxiliary Coordinate System (upts protocol)

XAX XAY XAZ YAX YAY YAZ

S-3 User Points (user-points protocol)

IUPT IUS IRS ICS XG YG ZG IUVW IRUVW IAUX NPTS ILAY

S-3a User Point Incrementations (user-points protocol)

JUPT JUS JRS JCS Dxg Dyg Dzg

S-4 Auxiliary Coordinate System (user-points protocol)

XAX XAY XAZ YAX YAY YAZ

S-5 Contact-Line Definition

LINEID UNITID NRECS

S-5a Contact Line on a Shell Unit

II JJ NPTS INC

S-5b Contact Line on an Element Unit

II NPTS INC

Element Units—Edef Protocol

T-1 Spring Element

N1 N2 N3 KELT NX INC1 INC2 INC3 USERELT INC4

T-1a Mount

IMNT1 IMNT2 RLX1 RLY1 RLZ1 RLX2 RLY2 RLZ2

T-1b Rigid or Soft Link

SCALE

T-1c Generalized Fastener

IMNT1 IMNT2 IMNT3 IMNT4 IMNT5 IMNT6 PLAS1 PLAS2 PLAS3 PLAS4 PLAS5 PLAS6

T-2 Beam

N1 N2 N3 KELT ICROSS XSI ECY ECZ ILIN IPLAS NX USERELT

T-2a Beam Incrementations

INC1 INC2 INC3 INC4

T-3 Triangular Shell

N1 N2 N3 KELT IWALL ZETA ECZ ILIN IPLAS IANG USERELT

T-3a Wall Reference Vector

RX RY RZ

T-4 Quadrilateral Shell

N1 N2 N3 N4 KELT IWALL ZETA ECZ ILIN IPLAS INTEG IPENL IANG USERELT

T-4a Extra Nodes

NODE(i), i=5,n

T-4b Wall Reference Vector

RX RY RZ

T-5 Contact, Sandwich, and Solid Element Flags

N810 N820 N822 N830 N840 N845 N847 N849 N880

T-6 E810 PAD Contact Element

N1 N2 N3 N4 N5 N6 N7 N8 KELT ITAB OFFSET NX USERELT

T-6a PAD Element Incrementations

I1 I2 I3 I4 I5 I6 I7 I8 I9

T-7 General Contact Definition

KELT NSRF NPTS

T-7a E820 Row & Column Contact-Element Specifications

USRF TYPE LI LJ ID NI NJ

T-7b E820 Element-Number Contact-Element Specifications

USRF TYPE I1 I2 INC ID

T-7c Row & Column Contact-Point Specifications

UNITP LI LJ RADIUS TOUCHE NI NJ

T-7d Point-Number Contact-Point Specifications

UNITP I1 I2 INC RADIUS TOUCHE

T-8 Line-Contact Interaction Definition

LINE1 LINE2 IPEN NX INC1 INC2 INC3

T-9 E830 6-Node Sandwich Element Definition

KELT ILIN INTEG IPEN NX NY USERC USER1 USER2

T-9a E830 Lower Face-Sheet Properties

N1 N2 N3 IFABL ZETAL ECZL IPLASL IANGL

T-9b E830 Lower Face-Sheet Wall Reference Vector

RXL RYL RZL

T-9c E830 Upper Face-Sheet Properties

N4 N5 N6 IFABU ZETAU ECZU IPLASU IANGU

T-9d E830 Upper Face-Sheet Wall Reference Vector

RXU RYU RZU

T-9e E830 Core Properties

IFABC ZETAC IPLASC IANGC

T-9f E830 Core Reference Vector

RXC RYC RZC

T-9g E830 X-Direction Incrementations

I1 I2 I3 I4 I5 I6 I7 I8 I9

T-9h E830 Y-Direction Incrementations

J1 J2 J3 J4 J5 J6 J7 J8 J9

T-10 E840 8-Node Sandwich Element Definition

KELT ILIN INTEG IPEN NX NY USERC USER1 USER2

T-10a E840 Lower Face-Sheet Properties

N1 N2 N3 N4 IFABL ZETAL ECZL IPLASL IANGL

T-10b E840 Lower Face-Sheet Wall Reference Vector

RXL RYL RZL

T-10c E840 Upper Face-Sheet Properties

N5 N6 N7 N8 IFABU ZETAU ECZU IPLASU IANGU

T-10d E840 Upper Face-Sheet Wall Reference Vector

RXU RYU RZU

T-10e E840 Core Properties

IFABC ZETAC IPLASC IANGC

T-10f E840 Core Reference Vector

RXC RYC RZC

T-10g E840 X-Direction Incrementations

I1 I2 I3 I4 I5 I6 I7 I8 I9 I10 I11

T-10h E840 Y-Direction Incrementations

J1 J2 J3 J4 J5 J6 J7 J8 J9 J10 J11

T-11 E845 10-Node Sandwich Transition Element Definition

KELT ILIN INTEG IPEN IEDGE NX NY USER

T-11a E845 Lower Face-Sheet Properties

N1 N2 N3 N4 N5 IFABL ZETAL ECZL IPLASL IANGL

T-11b E845 Lower Face-Sheet Wall Reference Vector

RXL RYL RZL

T-11c E845 Upper Face-Sheet Properties

N6 N7 N8 N9 N10 IFABU ZETAU ECZU IPLASU IANGU

T-11d E845 Upper Face-Sheet Wall Reference Vector

RXU RYU RZU

T-11e E845 Core Properties

IFABC ZETAC IPLASC IANGC

T-11f E845 Core Reference Vector

RXC RYC RZC

T-11g E845 X-Direction Incrementations

I1 I2 I3 I4 I5 I6 I7 I8 I9 I10 I11

T-11h E845 Y-Direction Incrementations

J1 J2 J3 J4 J5 J6 J7 J8 J9 J10 J11

T-12 E847 14-Node Sandwich Transition Element Definition

KELT ILIN INTEG IPEN IEDGE NX NY USER

T-12a E847 Lower Face-Sheet Properties

N1 N2 N3 N4 N5 N6 N7 IFABL ZETAL ECZL IPLASL IANGL

T-12b E847 Lower Face-Sheet Wall Reference Vector

RXL RYL RZL

T-12c E847 Upper Face-Sheet Properties

N8 N9 N10 N11 N12 N13 N14 IFABU ZETAU ECZU IPLASU IANGU

T-12d E847 Upper Face-Sheet Wall Reference Vector

RXU RYU RZU

T-12e E847 Core Properties

IFABC ZETAC IPLASC IANGC

T-12f E847 Core Reference Vector

RXC RYC RZC

T-12g E847 X-Direction Incrementations

I1 I2 I3 I4 I5 I6 I7 I8 I9 I10 I11 I12 I13 I14 I15

T-12h E847 Y-Direction Incrementations

J1 J2 J3 J4 J5 J6 J7 J8 J9 J10 J11 J12 J13 J14 J15

T-13 E849 18-Node Sandwich Element Definition

KELT ILIN INTEG IPEN NX NY USERC USER1 USER2

T-13a E849 Lower Face-Sheet Properties

N1 N2 N3 N4 N5 N6 N7 N8 N9 IFABL ZETAL ECZL IPLASL IANGL

T-13b E849 Lower Face-Sheet Wall Reference Vector

RXL RYL RZL

T-13c E849 Upper Face-Sheet Properties

N10 N11 N12 N13 N14 N15 N16 N17 N18 IFABU ZETAU ECZU IPLASU IANGU

T-13d E849 Upper Face-Sheet Wall Reference Vector

RXU RYU RZU

T-13e E849 Core Properties

IFABC ZETAC IPLASC IANGC

T-13f E849 Core Reference Vector

RXC RYC RZC

T-13g E849 X-Direction Incrementations

(IX(k), k=1,18) IXC IX1 IX2

T-13h E849 Y-Direction Incrementations

(IY(k), k=1,18) IYC IY1 IY2

T-14 E880-Family Solid Element

KELT IFAB IANG ILIN IPLAS NX NY

T-14a E880 Solid Element Nodes

(NODE(k), k=1,NPTS) USERELT

T-14b E880 X-Direction Incrementations

IX1 IX2 IX3 IX4 IX5 IX6 IX7 IX8 IUX

T-14c E880 Y-Direction Incrementations

IY1 IY2 IY3 IY4 IY5 IY6 IY7 IY8 IUY

T-14d E880 Material Orientation Record

XFX XFY XFZ YFX YFY YFZ

Element Units—Ecom Protocol

T-100 Element Command Record

Ecom Control or Element-Specification Record

T-110 Additional E110 Elements

N1 N2 N3 KELT NX INC1 INC2 INC3 USERELT INC4

T-110a E110 Element Data

IMNT1 IMNT2 RLX1 RLY1 RLZ1 RLX2 RLY2 RLZ2

T-120 Additional E120 Elements

N1 N2 N3 KELT NX INC1 INC2 INC3 USERELT INC4

T-120a E120 Element Data

SCALE

T-121 Additional E121 Elements

N1 N2 N3 KELT NX INC1 INC2 INC3 USERELT INC4

T-121a E121 Element Data

SCALE

T-130 Additional E130 Elements

N1 N2 N3 KELT NX INC1 INC2 INC3 USERELT INC4

T-130a E130 Element Data

IMNT1 IMNT2 IMNT3 IMNT4 IMNT5 IMNT6 PLAS1 PLAS2 PLAS3 PLAS4 PLAS5 PLAS6

T-210 Additional E210 Elements

N1 N2 N3 KELT ICROSS XSI ECY ECZ ILIN IPLAS NX USERELT

T-210a E210 Incrementations

INC1 INC2 INC3 INC4

T-250 Additional E250 Elements

N1 N2 N3 KELT ICROSS XSI ECY ECZ ILIN IPLAS NX USERELT

T-250a E250 Incrementations

INC1 INC2 INC3 INC4

T-320 Additional E320 Elements

N1 N2 N3 KELT IWALL ZETA ECZ ILIN IPLAS IANG USERELT NX NY

T-320a E320 X-Direction Incrementations

IX1 IX2 IX3 IX4

T-320b E320 Y-Direction Incrementations

IY1 IY2 IY3 IY4

T-320c E320 Wall Reference Vector

RX RY RZ

T-330 Additional E330 Elements

N1 N2 N3 KELT IWALL ZETA ECZ ILIN IPLAS IANG USERELT NX NY

T-330a E330 X-Direction Incrementations

IX1 IX2 IX3 IX4

T-330b E330 Y-Direction Incrementations

IY1 IY2 IY3 IY4

T-330c E330 Wall Reference Vector

RX RY RZ

T-410 Additional E410 Elements

N1 N2 N3 N4 KELT IWALL ZETA ECZ ILIN IPLAS INTEG IPENL IANG USERELT NX NY

T-410a E410 X-Direction Incrementations

IX1 IX2 IX3 IX4 IX5

T-410b E410 Y-Direction Incrementations

IY1 IY2 IY3 IY4 IY5

T-410c E410 Wall Reference Vector

RX RY RZ

T-411 Additional E411 Elements

N1 N2 N3 N4 KELT IWALL ZETA ECZ ILIN IPLAS INTEG IPENL IANG USERELT NX NY

T-411a E411 X-Direction Incrementations

IX1 IX2 IX3 IX4 IX5

T-411b E411 Y-Direction Incrementations

IY1 IY2 IY3 IY4 IY5

T-411c E411 Wall Reference Vector

RX RY RZ

T-480 Additional E480 Elements

N1 N2 N3 N4 KELT IWALL ZETA ECZ ILIN IPLAS INTEG IPENL IANG USERELT NX NY

T-480a E480 Extra Nodes Specification

N5 N6 N7 N8 N9

T-480b E480 X-Direction Incrementations

IX1 IX2 IX3 IX4 IX5 IX6 IX7 IX8 IX9 IXU

T-480c E480 Y-Direction Incrementations

IY1 IY2 IY3 IY4 IY5 IY6 IY7 IY8 IX9 IYU

T-480d E480 Wall Reference Vector

RX RY RZ

T-510 Additional E510 Elements

N1 N2 N3 N4 KELT IWALL ZETA ECZ ILIN IPLAS INTEG IPENL IANG USERELT NX

T-510a E510 Extra Node Specification

N5

T-510b E510 Incrementations

IX1 IX2 IX3 IX4 IX5 IXU

T-510c E510 Wall Reference Vector

RX RY RZ

T-710 Additional E710 Elements

N1 N2 N3 N4 KELT IWALL ZETA ECZ ILIN IPLAS INTEG IPENL IANG USERELT NX

T-710a E710 Extra Nodes Specification

N5 N6 N7

T-710b E710 Incrementations

IX1 IX2 IX3 IX4 IX5 IX6 IX7 IXU

T-710c E710 Wall Reference Vector

RX RY RZ

T-810 E810 PAD Contact Element

N1 N2 N3 N4 N5 N6 N7 N8 KELT ITAB OFFSET NX USERELT

T-810a PAD Element Incrementations

I1 I2 I3 I4 I5 I6 I7 I8 I9

T-820 General Contact Definition

KELT NSRF NPTS

T-820a E820 Row & Column Contact-Element Specifications

USRF TYPE LI LJ ID NI NJ

T-820b E820 Element-Number Contact-Element Specifications

USRF TYPE I1 I2 INC ID

T-820c Row & Column Contact-Point Specifications

UNITP LI LJ RADIUS TOUCHE NI NJ

T-820d Point-Number Contact-Point Specifications

UNITP I1 I2 INC RADIUS TOUCHE

T-822 Line-Contact Interaction Definition

LINE1 LINE2 IPEN NX INC1 INC2 INC3

T-830 E830 6-Node Sandwich Element Definition

KELT ILIN INTEG IPEN NX NY USERC USER1 USER2

T-830a E830 Lower Face-Sheet Properties

N1 N2 N3 IFABL ZETAL ECZL IPLASL IANGL

T-830b E830 Lower Face-Sheet Wall Reference Vector

RXL RYL RZL

T-830c E830 Upper Face-Sheet Properties

N4 N5 N6 IFABU ZETAU ECZU IPLASU IANGU

T-830d E830 Upper Face-Sheet Wall Reference Vector

RXU RYU RZU

T-830e E830 Core Properties

IFABC ZETAC IPLASC IANGC

T-830f E830 Core Reference Vector

RXC RYC RZC

T-830g X-Direction Incrementations

I1 I2 I3 I4 I5 I6 I7 I8 I9

T-830h Y-Direction Incrementations

J1 J2 J3 J4 J5 J6 J7 J8 J9

T-840 E840 8-Node Sandwich Element Definition

KELT ILIN INTEG IPEN NX NY USERC USER1 USER2

T-840a E840 Lower Face-Sheet Properties

N1 N2 N3 N4 IFABL ZETAL ECZL IPLASL IANGL

T-840b E840 Lower Face-Sheet Wall Reference Vector

RXL RYL RZL

T-840c E840 Upper Face-Sheet Properties

N5 N6 N7 N8 IFABU ZETAU ECZU IPLASU IANGU

T-840d E840 Upper Face-Sheet Wall Reference Vector

RXU RYU RZU

T-840e E840 Core Properties

IFABC ZETAC IPLASC IANGC

T-840f E840 Core Reference Vector

RXC RYC RZC

T-840g X-Direction Incrementations

I1 I2 I3 I4 I5 I6 I7 I8 I9 I10 I11

T-840h Y-Direction Incrementations

J1 J2 J3 J4 J5 J6 J7 J8 J9 J10 J11

T-845 E845 10-Node Sandwich Transition Element Definition

KELT ILIN INTEG IPEN IEDGE NX NY USER

T-845a E845 Lower Face-Sheet Properties

N1 N2 N3 N4 N5 IFABL ZETAL ECZL IPLASL IANGL

T-845b E845 Lower Face-Sheet Wall Reference Vector

RXL RYL RZL

T-845c E845 Upper Face-Sheet Properties

N6 N7 N8 N9 N10 IFABU ZETAU ECZU IPLASU IANGU

T-845d E845 Upper Face-Sheet Wall Reference Vector

RXU RYU RZU

T-845e E845 Core Properties

IFABC ZETAC IPLASC IANGC

T-845f E845 Core Reference Vector

RXC RYC RZC

T-845g E845 X-Direction Incrementations

I1 I2 I3 I4 I5 I6 I7 I8 I9 I10 I11

T-845h Y-Direction Incrementations

J1 J2 J3 J4 J5 J6 J7 J8 J9 J10 J11

T-847 14-Node Sandwich Transition Element Definition

KELT ILIN INTEG IPEN IEDGE NX NY USER

T-847a E847 Lower Face-Sheet Properties

N1 N2 N3 N4 N5 N6 N7 IFABL ZETAL ECZL IPLASL IANGL

T-847b E847 Lower Face-Sheet Wall Reference Vector

RXL RYL RZL

T-847c E847 Upper Face-Sheet Properties

N8 N9 N10 N11 N12 N13 N14 IFABU ZETAU ECZU IPLASU IANGU

T-847d E847 Upper Face-Sheet Wall Reference Vector

RXU RYU RZU

T-847e E847 Core Properties

IFABC ZETAC IPLASC IANGC

T-847f E847 Core Reference Vector

RXC RYC RZC

T-847g X-Direction Incrementations

I1 I2 I3 I4 I5 I6 I7 I8 I9 I10 I11 I12 I13 I14 I15

T-847h E847 Y-Direction Incrementations

J1 J2 J3 J4 J5 J6 J7 J8 J9 J10 J11 J12 J13 J14 J15

T-849 E849 18-Node Sandwich Element Definition

KELT ILIN INTEG IPEN NX NY USERC USER1 USER2

T-849a E849 Lower Face-Sheet Properties

N1 N2 N3 N4 N5 N6 N7 N8 N9 IFABL ZETAL ECZL IPLASL IANGL

T-849b E849 Lower Face-Sheet Wall Reference Vector

RXL RYL RZL

T-849c E849 Upper Face-Sheet Properties

N10 N11 N12 N13 N14 N15 N16 N17 N18 IFABU ZETAU ECZU IPLASU IANGU

T-849d E849 Upper Face-Sheet Wall Reference Vector

RXU RYU RZU

T-849e E849 Core Properties

IFABC ZETAC IPLASC IANGC

T-849f E849 Core Reference Vector

RXC RYC RZC

T-849g X-Direction Incrementations

(IX(k), k=1,18) IXC IX1 IX2

T-849h Y-Direction Incrementations

(IY(k), k=1,18) IYC IY1 IY2

T-860 ~~E860 ORACLE Solid Element~~

KELT NNODES IFAB IANG ILIN IPLAS NX NY

T-860a ~~E860 Solid Element Nodes~~

(NODE(k), k=1,NNODES) USERELT

T-860b ~~E860 X-Direction Incrementations~~

(IX(k), k=1,NNODES)   IXU

T-860c E~~860 Y-Direction Incrementations~~

(IY(k), k=1,NNODES)   IYU

T-860d ~~E860 Material Orientation Record~~

XFX XFY XFZ   YFX YFY YFZ

T-881 E881 8-Node Solid Element

KELT   IFAB IANG ILIN IPLAS   NX NY

T-881a E881 Solid Element Nodes

(NODE(k), k=1,8)   USERELT

T-881b E881 X-Direction Incrementations

IX1 IX2 IX3 IX4 IX5 IX6 IX7 IX8   IUX

T-881c E881 Y-Direction Incrementations

IY1 IY2 IY3 IY4 IY5 IY6 IY7 IY8   IUY

T-881d E881 Material Orientation Record

XFX XFY XFZ   YFX YFY YFZ

T-882 E882 18-Node Solid Element

KELT   IFAB IANG ILIN IPLAS   NX NY

T-882a E882 Solid Element Nodes

(NODE(k), k =1,18)   USERELT

T-882b E882 X-Direction Incrementations

(IX(k), k=1,18)   IXU

T-882c E882 Y-Direction Incrementations

(IY(k), k=1,18)   IYU

T-882d E882 Material Orientation Record

XFX XFY XFZ   YFX YFY YFZ

T-883 E883 27-Node Solid Element

KELT   IFAB IANG ILIN IPLAS   NX NY

T-883a E883 Solid Element Nodes

(NODE(k), k=1,27)   USERELT

T-883b E883 X-Direction Incrementations

(IX(k), k=1,27)   IXU 151

T-883c E883 Y-Direction Incrementations

(IY(k), k=1,27)   IYU 152

T-883d E883 Material Orientation Record

XFX XFY XFZ   YFX YFY YFZ

T-885 E885 20-Node Solid Element

KELT   IFAB IANG ILIN IPLAS   NX NY

T-885a E885 Solid Element Nodes

(NODE(k), k=1,20)   USERELT

T-885b E885 X-Direction Incrementations

(IX(k), k=1,20)   IXU

T-885c E885 Y-Direction Incrementations

(IY(k), k=1,20)   IYU

T-885d E885 Material Orientation Record

XFX XFY XFZ   YFX YFY YFZ

T-900 E9XX User-Defined Element

KELT   ID   IFAB IANG ILIN IPLAS   NX NY NZ

T-900a E9XX User-Element Nodes

(NODE(k), k = 1, NNODES)

T-900b User-Element X-Direction Incrementations

(IX(k), k = 1, NNODES)   IXU

T-900c User-Element Y-Direction Incrementation

(IY(k), k = 1, NNODES)   IYU

T-900d User-Element Z-Direction Incrementations

(IZ(k), k = 1, NNODES)   IZU

T-900e User-Element Material Orientation Vector

XFX XFY XFZ

T-900f User-Element Material Orientation Vectors

XFX XFY XFZ   YFX YFY YFZ

T-928 E928 3-Node Curved Beam UEL

KELT   ID   IFAB IANG ILIN IPLAS   NX

T-928a E928 UEL Nodes

N1 N2 N3 N4

T-928b E928 UEL X-Direction Incrementations

IX1 IX2 IX3 IX4   IXU

T-928c E928 UEL floatVariables

Area Iy Iz J Material ShearFactorY ShearFactorZ
ECC(1) ECC(2) SCC(1) SCC(2)

T-940 E940 MIN4 Quadrilateral UEL

KELT   ID   IFAB IANG ILIN IPLAS   NX NY

T-928a E940 UEL Nodes

N1 N2 N3 N4

T-940b E940 UEL X-Direction Incrementations

IX1 IX2 IX3 IX4   IXU

T-940c E940 UEL Y-Direction Incrementations

IY1 IY2 IY3 IY4   IYU

T-940d E940 UEL Material Orientation Vector

XFX XFY XFZ

T-940e E940 UEL Material Orientation Vectors

XFX XFY XFZ   YFX YFY YFZ

T-940f E940 UEL floatVariables

UniformPressure(1) UniformPressure(2)

T-940g E940 UEL integerVariables

IntegOrder LoadType

Element Units—Loadings, *et al*.

U-1 Loads Summary

NSYS NICS NAMS NUSS NHINGE NMOMNT NLEAST IPRESS

U-2 Load Set Summary

ISYS NN IFLG

U-3 Load Definition (**NN** records required)

P LT LD LI LJ LAX NDEFS INC1 INC2 INC3

U-4 Attached Mass

GM NM NDEFS INC

U-5 Uniform Stress State for Eigenanalysis

PNXA PNYA PNXYA PNXB PNYB PNXYB

U-6 Cable Hinge Restraint

IHND HRU HRV HRW NDEFS INC

U-7 Cable Hinge Moment

IMND MSYS RUM RVM RWM NDEFS INC

U-8a Least Squares Loading Summary

NSQR IUNIT IROW ICOL SCALE

U-8b Least Squares Load Definition

P LU LR LC LNDA LNDB LNDINC

V-1 Output Control—Record 1

IPRD IPRR IPRE IPRS IPRP IPRF NSELD NSELS IPRDSP IPRSTR ISL ISS ISD

V-2 Output Control—Record 2

INOD1 INOD2 INODI

V-3 Output Control—Record 3

IELS1 IELS2 IELSI

W-1 Linear-Stiffness Contribution—Record 1

NRDOF NRNOD NRKIJ KLSTF NRDIS NRFOR

W-2a Linear-Stiffness Contribution—Record 2a

IUNIT IROW ICOL JUNIT JROW JCOL

W-2b Linear-Stiffness Contribution—Record 2b

{ (KIJ(m,n), n=1,NRDOF), m=1,NRDOF }

W-2c Linear-Stiffness Contribution—Record 2b

IUNIT(n) IROW(n) ICOL(n) **n = 1,2,3, ..., NRNOD**

Solution Input—*BIN* File

Summary and Control Parameters

A-1 Case Title

COMMENT

B-1 Analysis Type Definition

INDIC IPOST ILIST ICOR IMPTHE ICHIST IFLU ISOLVR NFABC

B-2 Solver Options

ICPACT ITER IPRIM IPRIS ISAVE

B-3 Gradient Fabrication Specification Records

KFABTP KFB

Computational Strategy Parameters

C-1 Load Multipliers

STLD(1) STEP(1) FACM(1) STLD(2) STEP(2) FACM(2) ITEMP NFIX

C-3 Nonlinear Stress State

NLDS IXEV

C-4 Load Factors

PLDS(i), i=1,NLDS

C-5 Suppress Selected Freedoms

IFIX(i), i=1,NFIX

D-1 Strategy Parameters

ISTART NSEC NCUT NEWT NSTRAT DELX WUND

D-2 Eigenvalue Control

NSEC DELEV IPRINT

D-3 Cluster Definition

NEIG SHIFT EIGA EIGB

E-1 Time Integration—Record 1

TMIN TMAX DT SUP ALPHA BETA GAMMA THOLD

E-2 Time Integration—Record 2

IMPL METHOD IERRF IVELO IFORCE IPA IPB

E-3 Load History—Record 1

CA1 CA2 CA3 CA4 CA5 CA6

E-4 Load History—Record 2

CB1 CB2 CB3 CB4 CB5 CB6

E-5 Weighted Modal Initial Velocity

EIGA IMSTEP IMMODE IMRUN

ET-1 Solution Control

NPATH NEV NSOL IE NFIX LDMAX IUPLDA IUPLDB

The Equivalence Transformation Bifurcation Processor (ET)

ET-1 Solution Control

NPATH NEV NSOL IE NFIX LDMAX IUPLDA IUPLDB

B
STAPL Input

Introduction

STAPL is a stand-alone **STAGS** *post-processor* that generates PostScript- or pdf-formatted plots of a complete **STAGS** model (or a partial **STAGS** model) in its undeformed or deformed states—with contour maps of user-selected displacement, strain, stress,... fields that are superimposed on them as and if appropriate. The original version of **STAPL** was developed some years ago as an in-house processor to generate platform-independent, PostScript-formatted plots for use in verifying **STAGS** models and for use in visualizing and understanding results obtained by **STAGS** for those models. That version of **STAPL** was updated to construct PostScript or pdf-formatted output files soon after Adobe’s PDF technology was developed—and has been updated several times since then. The most recent enhancements to **STAPL** have brought it as up-to-date as possible with respect to the current version of the **STAGS** program. **STAPL** is distributed with the **STAGS** program suite.

Input file

To use the **STAPL** post-processor, the analyst must first generate a **STAGS** model by creating a *case.inp* input file for it and running **STAGS’ s1** program to a successful conclusion with that input file. **STAPL** uses the *case.sav* file that **s1** produces as its primary source of information about the geometry and construction of the model for which one or more plots are to be generated. The analyst who wants to use **STAPL** to generate plots that show the deformed model—with or without contours showing the displacement, strain, stress, or any other relevant field information—must first obtain those results by running **STAGS’ s2** program successfully.

Execution and input requirements

To execute **STAPL** on a UNIX system—for a particular *case*—the user must navigate to a “working” directory that must contain information that is required to make any plots and may contain other information that may be required or used advantageously to make the plots that the user wants to generate for that case. Positioned in that working directory, the user must then execute **STAPL** *via* the following OS-level command:

```
% stapl case
```

where `case` is the name of the case.

If the analyst only wants **STAPL** to produce one or more plots that show one or more parts of the original (undeformed) model, the only file that *must* be included in the working directory is the *case.sav* file that **s1** has generated for the case in question. Other files and scripts *may* be present in the working directory, but the *case.sav* file *must* be included. If the analyst wants **STAPL** to produce one or more plots that show deformations, strains, stresses and/or other field-variable “results” (and/or imperfections and/or eigensolutions), **s2**’s *case.res (results)* and *case.rst (indexing)* files must also be in his working directory—along with **s2**’s *case.egv (eigensolutions)* file and/or **s1**’s *case.imp (imperfections)* file as and if those files are needed.

In either case, the OS-level `stapl case` command initiates execution of **STAPL** for the case in question. After its initialization operations, the first thing that **STAPL** does is check to determine whether or not the analyst’s working directory contains an optional input (text) file called *case.pin*.

If the working directory does not contain a *case.pin* file, then **STAPL** operates in its *interview* mode. In this mode, **STAPL** prints messages specifying the information that it needs and waits for the user to respond with appropriate answers before continuing. Operating in its interview mode, **STAPL** takes user responses into account and only requests input data that are appropriate for the case and plotting situation at hand. Operating in this mode, **STAPL** generates an annotated *case.pin* output file that the user can edit and employ with subsequent (batch-mode) **STAPL** runs to generate the same kinds of plots with other model components and/or results. The user who wants to generate a large number of plots should start by executing **STAPL** in its interview mode—then use his (or her) favorite text editor to modify the *case.pin* file generated in that run to construct new *case.pin* files for batch-mode executions of **STAPL** to generate the additional plots that are wanted. The ins and outs of

STAPL's interview mode are beyond the scope of this appendix. The interested user is strongly encouraged to read the "***STAPL** User Manual*" for more information about that.

If the working directory does contain a *case.pin* file, then **STAPL** operates in its *batch* mode—using that *case.pin* file (and *case.sav* and other *case.** files, as appropriate) to generate the plot(s) that *case.pin* specifies.

The *case.pin* input requirements for **STAPL** are described in the pages that follow the next three paragraphs.

Output files

As noted above, a successful interview-mode execution of **STAPL** gives the user an annotated *case.pin* output text file that can be edited and used for subsequent batch-mode executions of the program. With any execution of **STAPL,** the program also generates an informative (but disposable) *case.pout* text file that summarizes what **STAPL** does with the user's *case.pin*, *case.sav* and *case.** results data.

When **STAPL** is executed successfully, it generates a one-page PostScript-formatted file for each plot that the analyst requests, or a single pdf-formatted file that contains all of the plots that **STAPL** generates during that execution. The output format is specified by the analyst, as described in the PL-2 record, on page B-5.

The **STAPL** post-processor does not modify the *case.sav, case.res, case.rst, case.egv, case.imp* or any other *case.** files that it may need and use to produce the requested plots.

PL-1 Case Title

The first thing that **STAPL** expects (and reads) from the user's live or scripted input stream is a plotting-case-title character string called **TITLE**—which may contain up to but not more than 72 alphanumeric characters. **STAPL** prints the user's **TITLE** string on each plot that it produces.

After this Case Title record, the user can and is encouraged to append comment strings and to add comment lines to his (or her) input stream to document that input. Comment strings can be included at the end of any data line by interrupting or terminating the data with a "`$`" character and using the remainder of that line for comment material. Comment lines can be included within or between data records by starting those lines with "`C`" or "`$`" as the first non-blank character. **STAPL** prints a listing of the complete input file—including any comment records—at the beginning of the *case.pout* text output file that **STAPL** produces for the current execution of the program.

TITLE

TITLE case title (72 characters or less)

Note: If the User's **TITLE** specification has the 4-character '`3DMF`' string imbedded within it, **STAPL** will produce a *case.3dmf* output file for use with the ***VIEWER*** application that is being developed for examining and doing other exciting things with **STAGS** models and solutions.

✦ *go to* PL-2

PL-2 Post-Processing Summary Record

This record specifies the number of plots that the analyst wants **STAPL** to generate, the output format that the analyst wants, and other information that **STAPL** needs before it can generate the plot(s) that the analyst desires.

NPLOT IPREP IPRS KDEV KXSTEP

NPLOT number of plots to be generated (see the **Note**, below)

IPREP solution-data-required flag:

0 - model and solution archive data are both required (default)
1 - model data required; solution data not required

IPRS undeformed-model display flag:

0 - show the undeformed model (as a dashed blue wire frame) in addition to the deformed model (default)
1 - show the deformed model only

KDEV output-format flag:

0 - generate all plots (one plot per page) in a single, Acrobat (pdf-formatted) *case.pdf* output file (default)
1 - generate each plot *k* as a separate, PostScript-formatted *case.k.ps* output file

KXSTEP solution-scale-factor index:

0 - determine scale factors for each solution step independently of all other steps (default)
> 0 - use scale factors from step # **KXSTEP** for each solution step treated in the current **STAPL** execution

go to PL-3

Note: A **STAPL** input (PIN) file may contain more than one PL-2 record, for convenience. All of the input records in the PIN file are read and echoed to the POUT output file, but **STAPL** will only process and generate plots for the very first PL-2 record in the PIN file.

PL-3 Plot Description Record

This record and the records it requires generates one plot. **NPLOT** PL-3 records are required.

KPLOT VIEW ITEM STEP MODE IFRNG COLOR ICOMP LAYER FIBR LAY3D FACE

KPLOT **primary plot control flag:**

0 - plot all or a portion of the undeformed model (default)
- 1 - plot all or a portion of the undeformed model, coloring the outer surface red and the inner surface blue
1 - plot all or a portion of the deformed model, with a selected solution projected as its “deformed geometry”
2 - plot all or a portion of the deformed model, with a selected continuous solution field texture-mapped onto the deformed surface in color or in grayscale mode
3 - same as 2, when the solution is discontinuous
-3 - plot contours using a continuous solution field, for elements of the same type—even if their fabrications are different
4 - plot gradient contours on all or a portion of the deformed model, with a selected continuous gradient field texture-mapped onto the deformed surface in color or in grayscale mode
5 - same as 4, when the gradient field is discontinuous
6 - reserved for use with **STAGS**’ ***VIEWER*** application

VIEW **plot view control flag:**

0 - plot the entire model (default)
> 0 - plot only the **NUNIT** units listed in record PL-4, described below
< 0 - plot only the fabrications listed in record PL-4, described below

ITEM **secondary plot control flag:**

when KPLOT = 0 — number-plotting option:

ITEM = 0 - do not plot the element, fabrication or node numbers
ITEM = 1 - plot **STAGS**’ global element number inside each element
ITEM = 2 - plot the User’s element number inside each element
ITEM = 3 - plot the unit number and the user’s element number
ITEM = 4 - only plot the unit number inside each element
ITEM = 5 - plot the fabrication number in each element
ITEM = 6 - plot **STAGS**’ global node number beside each node
ITEM = 7 - plot the global node numbers with minimum font size

ITEM = 8 - plot the User's node number beside each node
ITEM = 9 - same as 8, for wire–frame plot(s) of the model
ITEM = 10 - highlight beam elements (with red color and wide lines)

when KPLOT = 1, 2 or 3 or -3 — solution–type flag:

ITEM = 1 - plot a displacement solution
ITEM = 2 - plot a velocity vector
ITEM = 3 - plot an imperfection vector
ITEM = 4 - plot an eigenvector
ITEM = -4 - plot a displacement-differences vector (*see* **MODE**, *below*)

when KPLOT = 2 or 3 or -3 — solution–type flag:

ITEM = 5 - plot stress resultants (*see* **ICOMP**, *below*):

for 2D elements and sandwich–element face sheets:
Nx, Ny, Nxy, Mx, My, Mxy

for 3D elements: *ignored*

ITEM = 6 - plot strains/curvatures (integrated) (*see* **ICOMP**, *below*):

for 2D elements and sandwich–element face sheets:
Ex, Ey, Exy, Kx, Ky, Kxy

for sandwich–element core components:
Exx, Eyy, Ezz, Eyz, Ezx, Exy

for 3D elements:
Exx, Eyy, Ezz, Eyz, Ezx, Exy (in the fabrication system)

ITEM = 7 - plot stresses (*sigf*, *sigm*, *sigp*), (strains, plane-strains)
(*see* **ICOMP**, *below*):
for 2D elements and sandwich–element face sheets:
Sx, Sy, Sxy
for sandwich–element core components:
Sxx, Syy, Szz, Syz, Szx, Sxy
for 3D elements:
Sxx, Syy, Szz, Syz, Szx, Sxy (in the fabrication system)

ITEM = 8 - plot ply damage percentage (when **ICOMP**=0, as noted below)
ITEM = 8 - plot plastic strains (when **ICOMP**=1–3)

ITEM = 9 - plot energy densities
ITEM = 10 - plot temperature gradients
ITEM = 11 - plot element thicknesses

ITEM = 12 - ~~plot nternal forces~~ *(not operational, yet)*
ITEM = 13 - ~~plot external forces~~ *(not operational, yet)*

ITEM = 14 - plot PFA or UMAT state variable (**ICOMP** = 1–20)
ITEM = 15 - plot selected ply failure types (*see the* PL-3c *record*, *below*)

STEP load step number (for static analysis, 0 selects the *linear* solution; for transient analysis, 0 selects the *initial-conditions*)

MODE vector selection parameter:

if **ITEM** = 4, **MODE** = eigenvector (mode) number;
if **ITEM** = – 4, displacement difference from step **MODE** to step **STEP**

IFRNG fringe-plot control flag:

0 - use 32 color or grayscale gradations (default)
1 - minimal (16-color) gradation
2 - full fringe plot

COLOR color/scale-control flag:

0 - generate color plot, with maximum to minimum scale
1 - generate color plot, with minimum to maximum scale
2 - generate grayscale plot, with maximum black & minimum white
3 - generate grayscale plot, with maximum white & minimum black

ICOMP **tertiary plot control flag** (meaningful only when **KPLOT** = 2 or 3):

0 - plot the solution magnitude (when 1 ≤ **ITEM** ≤ 4, above), or
plot the effective stress (when **ITEM** = 7) (see note, below), or
plot the ply damage percentage (when **ITEM** = 8)

1 - plot U or NX or EXI or S1F or EPX or EXX or SXX — depending on **ITEM**, above

2 - plot V or NY or EYI or S2F or EPY or EYY or SYY — depending on **ITEM**

3 - plot W or NXY or EXYI or T12F or EPXY or EZZ or SZZ — depending on **ITEM**

4 - plot RU or MX or KX or S1M or EYZ or SYZ — depending on **ITEM**

5 - plot RV or MY or KY or S2M or EZX or SZX — depending on **ITEM**

6 - plot RW or MXY or 2KXY or T12M or EXY or SXY — depending on **ITEM**

7 - plot the surface normal component (when 1 ≤ **ITEM** ≤ 4), or
plot QX or EXZ (when **ITEM** = 5 or 6), or
plot S1P (principal stress) (when **ITEM** = 7)

8 - plot QY or EYZ (when **ITEM** = 5 or 6), or
plot S2P (principal stress) (when **ITEM** = 7)

9 - plot N1P (principal resultant) (when **ITEM** = 5), or
plot S3P (principal stress) (when **ITEM** = 7)

10 - plot N2P (principal resultant) (when **ITEM** = 5), or
plot mxshr (**E840** maximum shear) (when **ITEM** = 7)

11 - plot N3P (principal resultant) (when **ITEM** = 5), or
plot EX (total strain at selected fiber location) (when **ITEM** = 7)

12 - plot EY (total strain at selected fiber location) (when **ITEM** = 7)

13 - plot EXY (total strain at selected fiber location) (when **ITEM** = 7)

14 - plot S3F (plane strain at selected fiber location) (when **ITEM** = 7)

Note: with **ITEM** = 7, **ICOMP** = 0, selects effective stresses in the *fabrication* (1–3), *material* (4–6) or *principal* (7–9) systems

LAYER selection flag for 2D shell-element layer (used when **ITEM** = 7 or 8):

0 - plot layer # 1 (inner layer), if **FIBR** < 2
plot layer # **NLAY (**outer layer), if **FIBR** = 2
> 0 - plot layer # **LAYER** (omitted if **LAYER** > **NLAY**)

FIBR selection flag for 2D shell-element layer fiber (used when **ITEM** = 7, 8 or 10):

0 , 1 - plot the inner fiber (minimum *z* value)
2 - plot the outer fiber (maximum *z* value)
-1 - plot the inner and outer fibers

LAY3D, FACE **layer and face selection flags for sandwich or solid elements**:

For E840-sandwich core elements (when face elements are **not** plotted):

LAY3D = 0 - plot all sandwich core elements (when **FACE** = -1 or -2)
LAY3D > 0 - plot sandwich core element # **LAY3D** (in stack)

FACE = -1 - plot **E840** core elements, omitting their **E410** face sheets
FACE = -2 - **E840** core elements, omitting all other elements

For E840-sandwich face elements:

LAY3D - this item is ignored when **E840** face elements are plotted

FACE = 0 - plot all of the **E410** (inner and outer) face sheets
FACE = 1 - only plot the inner face sheets
FACE = 2 - only plot the outer face sheets

For E88* solid elements (when **ITEM** = 6 or 7):

LAY3D = 0 - plot all layers of solid elements
LAY3D > 0 - only plot layer # **LAY3D**

FACE = 0 - plot all of the solid-element surfaces
FACE > 0 - only plot surface # **FACE** (where 1 ≤ **FACE** ≤ 6)

```
if     ( KPLOT = 4 or 5 )    then
    go to PL-3a
elseif    ( KPLOT = 1 and ITEM = 15 )    then
    go to PL-3c
elseif    ( VIEW ≠ 0 )    then
    go to PL-4
else
    go to PL-5
endif
```

Note: For convenience, a **STAPL** input (PIN) file may contain more than **NPLOTS** PL-3 records—where **NPLOTS** is the value that the user specifies for the **NPLOT** parameter in the very first PL-2 record in the PIN file. **STAPL** reads all of the records in the user's PIN file (and prints them in its POUT file), but **STAPL** will only process and generate the first **NPLOTS** plots.

PL-3a Strain Gradient Control Record

This record is read if and only if the **KPLOT** parameter is 4 or 5 on the PL-3 record.

MODE1 MODE2 MODINC

MODE1 field type or starting index:

0 - displacement gradient or load vector (in which case the values of **MODE2** and **MODINC** are ignored)

> 0 - first mode number

MODE2 last mode number (must not exceed 24 for shell)

MODINC mode-number increment

```
if ( MODE1 > 0 ) then
    go to PL-3b
else
    go to PL-4
endif
```

PL-3b Strain Gradient Coefficient Record

(STGD(i), i = MODE1, MODE2, MODINC)

STGD list of strain gradient coefficients (note: coefficients less than 25 not in this list are set equal to zero)

```
if   ( [ KPLOT = 2 or 3 or -3 ] and ITEM = 15 )  then
     go to PL-3c
else
     go to PL-4
endif
```

PL-3c Selected Ply Failure Record

This record is read if and only if the **KPLOT** parameter is 2 or 3 and the **KPLOT** parameter is 15 on the PL-3 record.

MATID FLAG

MATID material identifier

0 - plot all elements fabricated with ply-failure-analysis materials

> 0 - plot elements with material # **MATID**

FLAG failure-mode selection flag:

0 - all failure modes

1 - fiber tensile failure mode

2 - matrix tensile failure mode

3 - inplane shear failure mode (shell elements), or
interlaminal tensile failure mode (solid elements)

4 - transverse (13) failure mode

5 - transverse (23) failure mode

6 - inplane shear failure mode (solid elements)

-1 - fiber compressive failure mode

-2 - matrix compressive failure mode

-3 - interlaminal compressive failure mode (solid elements)

```
if ( VIEW $\neq$ 0 ) then
    go to PL-4
else
    go to PL-5
endif
```

PL-4 Model View Record

This record is read if and only if the plot view control flag (**VIEW**) on record PL-3 is not zero. With the PL-4 record, the analyst can select a subset of the shell and/or element units in the complete model to be plotted in the current **STAPL** plot (when **VIEW** > 0) or a subset of the element–fabrication types to be plotted (when **VIEW** < 0). The magnitude of **VIEW** must clearly be less than or equal to the total number of units in the complete model (when **VIEW** > 0) or the number of fabrications (when **VIEW** < 0).

(LIST(j), j=1, | VIEW |)

LIST(j) unit number for shell or element unit to be included in the current plot (when **VIEW** > 0), or fabrication number to be included (when **VIEW** < 0)

✦ *go to* PL-5

PL-5 Plot Control Record

This record is required for specification of scaling, orientation, and other parameters for the current **STAPL** plot.

DSCALE NROTS LWSCALE RNGMIN RNGMAX NUMBRS NFONT

DSCALE scaling factor to be used with solution data, for deformed-model plots:

0 - **STAPL** sets **DSCALE** = 0.5 (default value) and scales the displacement vector by multiplying it by **DSCALE** times the maximum dimension of the projected model

> 0 - **STAPL** scales the displacement vector by multiplying it by **DSCALE** times the maximum dimension of the projected mode

< 0 - **STAPL** scales the displacement vector by multiplying it by | **DSCALE |** times the maximum dimension of the projected mode; the actual deformations are shown if **DSCALE** = -1.0

NROTS number of PL-6 orientation records required:

0 - **STAPL** uses its default orientation parameters

> 0 - **STAPL** reads and uses orientation parameters specified on the **NROTS** type PL-6 records following this record

LWSCALE factor to be used in scaling line width (element edges):

0 - use the default line width

> 0 - set the line width to **LWSCALE** times the default width

- 1 - omit edge lines, except on unit boundaries

- 2 - add wire frame plot of the undeformed model (dashed blue lines)

RNGMIN plot–range scaling factor (see **RNGMAX**)

RNGMAX plot–range scaling factor:

If **RNGMIN** = **RNGMAX** = 0**,** the range scale for the plot uses the minimum and maximum values from the solution vector; if **RNGMIN** and/or **RNGMAX** are not zero, the range scale uses **RNGMIN** and **RNGMAX** for its extrema

NUMBRS annotation flag, for contour plots:

0 - do not plot element, node or fabrication numbers
1 - plot **STAGS**’ global element number inside each element
2 - plot the User’s element number inside each element
3 - plot the unit numbers and the User’s element numbers
4 - only plot the unit numbers on the model
5 - only plot the fabrication numbers on the model
6 - plot **STAGS**’ global node numbers on the model
7 - plot **STAGS**’ global node numbers (minimum font size)
8 - plot the User’s node numbers on the model
9 - plot the User’s node numbers on a wire-frame model

NFONT font-size specification flag (for element or node numbers):

0 - use **STAPL**’s default font size
> 0 - use a font size determined by the **NFONT** parameter, where: the font size increases with increasing **NFONT** and where **NFONT** is in the range 1 ≤ **NFONT** ≤ 16

```
if   ( NROTS > 0 )    then
    go to PL-6
else
    follow instructions at end of PL-6
endif
```

PL-6 Orientation Records

A record of this type is required for specification of each user-specified orientation (rotation) operation that **STAPL** is to perform. Rotations are performed in the order specified by these records. **NROTS** (PL-5) PL-6 records must be included here. For more information about this type of orientation specification, see the "B-1b Sequence of Model Rotations" description on 5-11, in Chapter 5 of this document.

IROT ROT

IROT axis selection flag:

1 - rotate the model by **ROT** degrees about its current X axis
2 - rotate the model by **ROT** degrees about its current Y axis
3 - rotate the model by **ROT** degrees about its current Z axis

ROT rotation angle, in degrees

✦ **NPLOT** (PL-2) number of plots to be generated

```
if      ( less than NPLOT plots have been generated )  then
              return to PL-3
else
              data deck is complete
endif
```

Examples

An *interview-mode* execution of **STAPL** for the ACORO test-suite case, with simple “show me the model” user responses to **STAPL** prompts, generated the plot shown in Figure B.1:

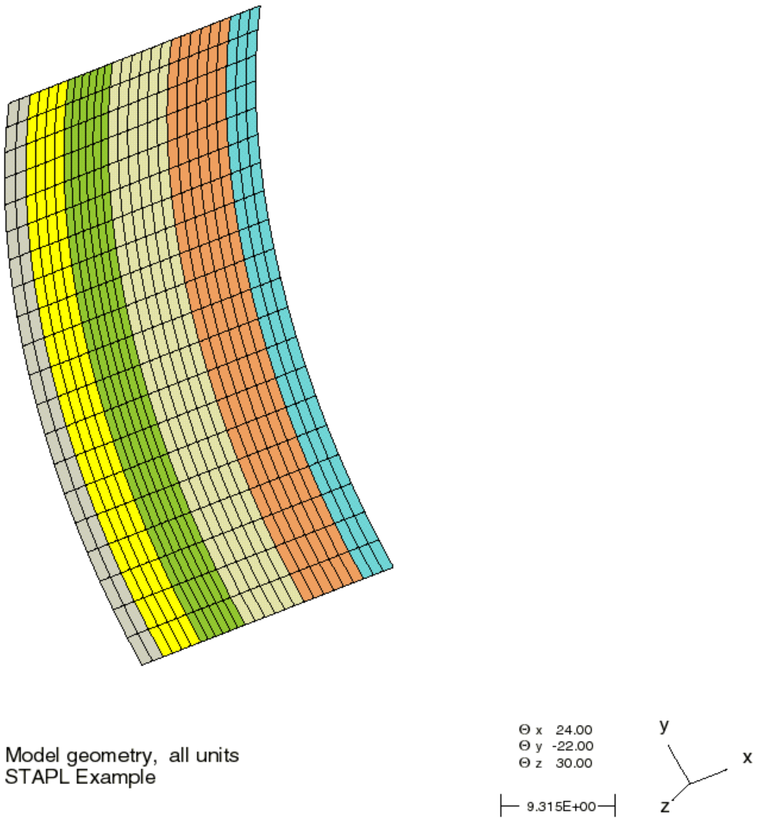


Figure B.1 **STAPL** plot of undeformed ACORO configuration

STAPL also generated the following *acoro.pin* output text file for this execution:

```
STAPL Example
  1  1  0  1  $PL-2  NPLOT,IPREP,IPRS,KDEV
     0     0  $PL-3  KPLOT,NUNIT
   0.00000000E+00  0  $PL-5  DSCALE,NROTS
```

This *case.pin* file shows (with NROTS=0) that the analyst did not specify the spatial orientation of the model in this *interview-mode* run. The plot that **STAPL** generated used the program’s default rotation angles to define the orientation of the model and its default color sequence to show each shell unit in the model in a different color.

Seeing that **STAPL**’s default orientation hides significant parts of the structure, the user might want to edit the *acoro.pin* file that **STAPL** generated in the *interview-mode* execution, to specify more suitable rotation angles, as follows:

```
STAPL Example -- Reoriented configuration
  1  1  0  1           $ PL-2  NPLOT,IPREP,IPRS,KDEV
    0     0            $ PL-3  KPLOT,NUNIT
   0.00000000E+00  3   $ PL-5  DSCALE,NROTS
  1   -80.0            $ PL-6
  2   -25.0            $ PL-6
  3   -15.0            $ PL-6
```

A *batch-mode* execution of **STAPL** after doing that produces the configuration plot that is shown in Figure B.2:

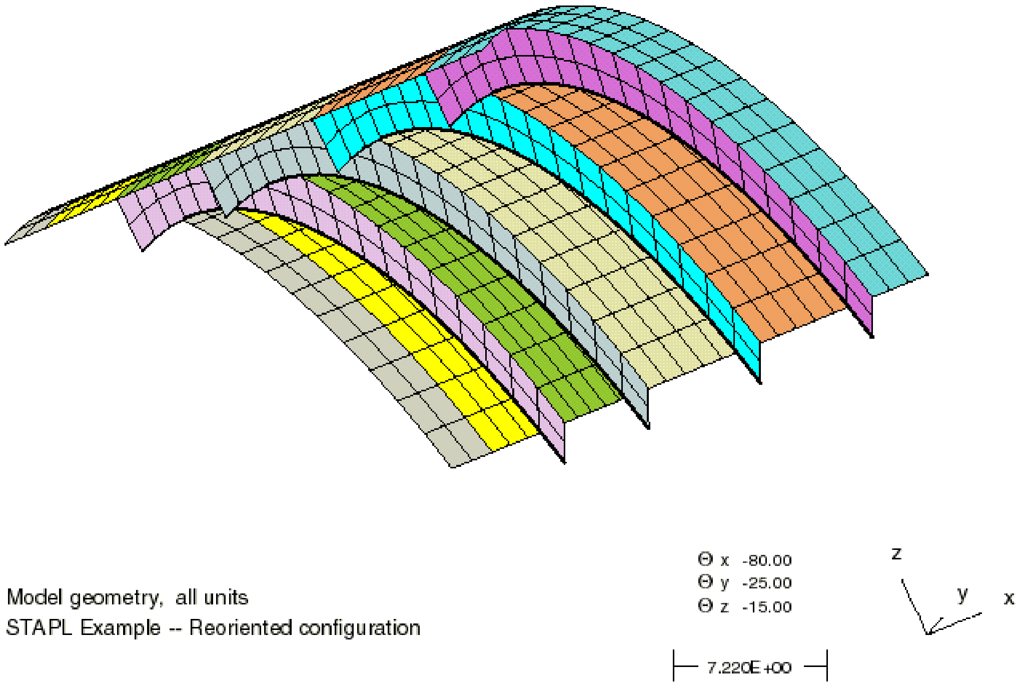
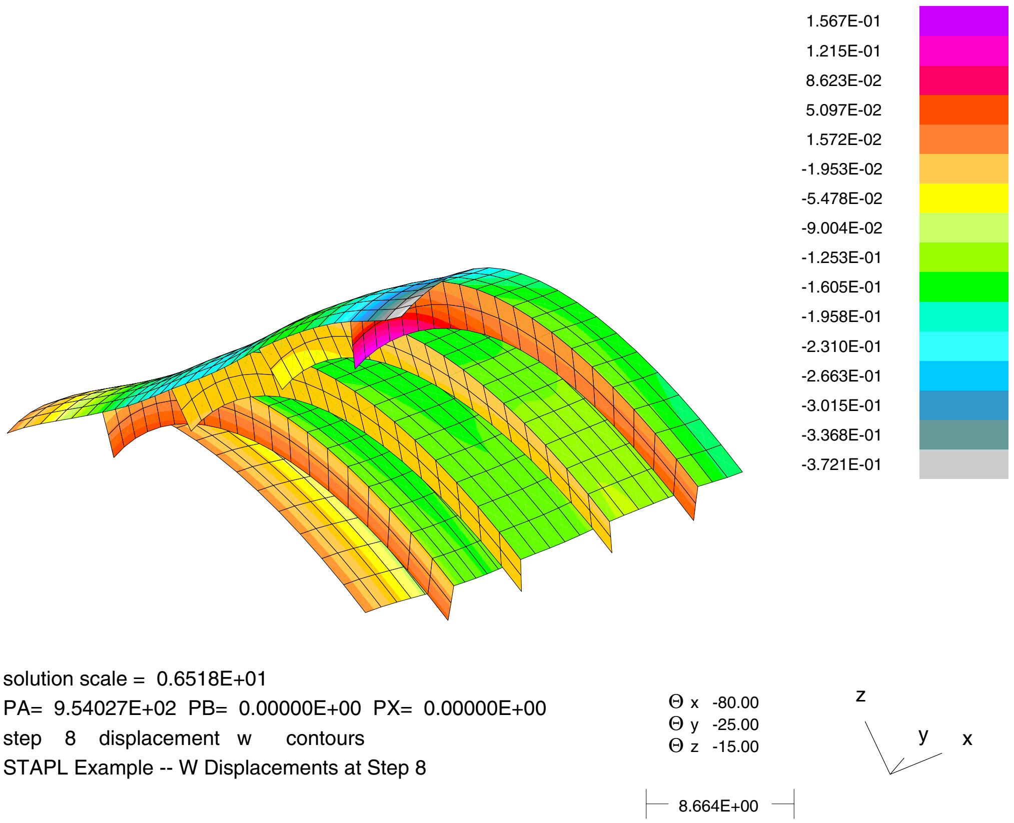

Model geometry, all units
STAPL Example -- Reoriented configuration
Θ x -80.00
Θ y -25.00
Θ z -15.00
7.220E+00
z
y
x

Figure B.2 **STAPL** plot of reoriented ACORO model

Encouraged by this success, the intrepid user might modify this second *acoro.pin* file to use this improved orientation and other specifications to generate a third plot that shows how this model is deformed at step 8 of the analysis that he/she has performed—generating the following *acoro.pin* file for the next *batch-mode* **STAPL** run:

```
STAPL Example -- W Displacements at Step 8
  1 0 1 1                $ PL-2  NPLOT,IPREP,IPRS,KDEV
  2 0 1 8 0 0 0 3 0 2 $ PL-3  KPLOT,NUNIT
  0.00000000E+00 3       $ PL-5  DSCALE,NROTS
  1   -80.0              $ PL-6
  2   -25.0              $ PL-6
  3   -15.0              $ PL-6
```

Note that this user has chosen to show the *w* displacement contours in full color on the deformed configuration. **STAPL** produces the plot shown in Figure B.3 with this *acoro.pin* file:



```
solution scale =  0.6518E+01
PA=  9.54027E+02  PB=  0.00000E+00  PX=  0.00000E+00
step   8   displacement   w     contours
STAPL Example -- W Displacements at Step 8
```

Figure B.3 **STAPL** plot of ACORO results for step 8

Note that the deformed shape shown here has the actual displacements scaled by a factor of 6.518—the (0.05 times the maximum dimension of the projected model) value that **STAPL** computed when the user set **DSCALE** equal to zero.

C
PITRANS Input

Introduction

PITRANS is a stand-alone post-processor that was developed years ago to translate **STAGS** model and solution data for a particular (user-specified) "case" into formatted input files for **PATRAN** and **IDEAS** programs. **PITRANS** is rarely (if ever) used for that purpose, these days; but it is used frequently to generate **PATRAN**-formatted "neutral" files and/or **IDEAS**-formatted "universal" files that contain model and solution information that can be extracted from those files and used for other purposes. The **PITRANS** post-processor is distributed with the **STAGS** program suite.

Prerequisites

To use **PITRANS** to translate any **STAGS** data for the case at hand into **PATRAN**- or **IDEAS**-formatted files**,** the analyst must first generate a **STAGS** model by creating a *case.inp* input file for that case and by running **STAGS' s1** program successfully with that input file. **PITRANS** uses **s1**'s *case.sav* output file as its sole source of information about the geometry and construction of the user's model. To use **PITRANS** to generate **PATRAN**- or **IDEAS**-formatted output files that contain or depend upon **STAGS**' solution data, the analyst must also create one or more *case.bin* input files for **STAGS' s2** program and run **s2** successfully with those input files to perform the analyses that they request. **PITRANS** uses **s2**'s *case.res* and *case.rst* output files as its primary sources of information about the solution(s) that **STAGS** has generated for the case at hand.

Execution of the program

To execute **PITRANS** on a LINUX or on a UNIX system, the user must navigate to a "working" directory that must contain all of the "**STAGS**" files that **PITRANS** needs to generate the

PATRAN- or **IDEAS**-compatible output file(s) that he wants. Most frequently, that working directory must contain **s1**'s *case.sav* file and **s2**'s *case.res* and *case.rst* files for the case at hand. It may also contain other files, but they are not required and are generally ignored. Positioned in that directory, the user may then execute **PITRANS** *via* one or the other of the following two OS-level commands:

```
% pitrans
```

or

```
% pitrans < case.pix
```

where `case` is the name of the case at hand and where *case.pix* is a text-formatted input file that the user must have created before executing **PITRANS**.

Input requirements and output files

The **PITRANS** program (like **STAPL**) operates in what we call its "interview" mode—where it prompts the user for an answer and performs one or more actions in response to that answer—then prompts the user again (and again, and again) until the user is finished specifying what he wants the program to do. Unlike the **STAPL** program, **PITRANS** does not construct a "journal" file that records the user's answers and does not test to determine if a program-generated or a user-constructed journal (or script) file exists and use it (instead of the user's keyboard responses) to read the user's input for the case at hand. The adventuresome user can "force" **PITRANS** to operate in a "batch" mode (of sorts) by constructing a bare-bones (or a very carefully annotated) text file that contains the answers that **PITRANS** expects (and little if anything else) and by executing **PITRANS** as suggested in the second OS-level command, above—redirecting the program to seek the answers that it expects for the questions that it asks from that file instead getting it from the keyboard. The file name for that "input" file is arbitrary. We are calling it *case.pix* here and in the remainder of this Appendix for convenience and consistency.

In any event, **PITRANS** is fundamentally an interview-mode program. **PITRANS** prompts the user to give it the input that it needs, checks the user's input to determine that it is valid (and prompts him for it again if it is not), asks for more information (if necessary), and generates the output that the user requests—following the logic that is shown in the "navigation" diagram on the following page. The **RED** items in that "flow" chart represent "addresses" (resembling statement numbers in FORTRAN and C programs). The **BLUE** items represent prompts that direct the user to give **PITRANS** the input information (data record) that it needs to do what the user wants it to do, followed by the program's attempt to read the user's answers to those prompts. The upper-case **BLACK** items in that diagram are the

```
PX1     specify the Output Format ( PX-1 record )                     FORM
PX2     specify the Stags Case Name  ( PX-2 record )                  CASE

PX3     specify the Output Data Option ( PX-3 record )                ODATA
        if         ( ODATA = 'M' or 'm' )      then
              go to PX7
        elseif     ( ODATA = 'V' or 'v' )      then
              go to PX4
        elseif     ( ODATA = 'I' or 'i' )      then
              go to PX5
        elseif     ( ODATA = 'S' or 's' )      then
              go to PX8
        elseif     ( ODATA = 'Q' or 'q' )      then
              finished !!!
        else
              go to PX3
        endif

PX4     specify the Vector Type ( PX-4 record )                       VTYPE
        if  ( VTYPE = 'D' or 'd' or 'V'  or 'v'  or 'F' or 'f' )  go to PX7
        go to PX4

PX5     specify the Integrated Stress Type ( PX-5 record )            STYPE
        if  ( STYPE = 'S' or 's'  or 'M' or 'm' )   go to PX6
        go to PX5

PX6     specify the Next Step ( PX-6 record )                         ISTEP
        if  ( ISTEP = 'Q' )   go to PX3
        go to PX6

PX7     specify the Model Type ( PX-7 record )                        MTYPE
        if  ( MTYPE  ≠  'F' or 'f' or 'C' or 'c' )   go to PX7
        if  ( ODATA = 'M' or 'm' )   go to PX3
        if  ( ODATA = 'V' or 'v' )   go to PX8

PX8     specify the Next Step ( PX-7 record )                         STEP
        if  ( STEP = 'Q' )   go to PX3
        if  ( ODATA = 'S' or 's' )   go to PX9
        go to PX8

PX9     specify the Layer Number ( PX-8 record )                      LAYER
        if  ( LAYER is not valid )   go to PX9
        if  ( nr840 > 0 or nr880 > 0 )   then
PX9a          specify the Output Point Location ( PX-8a record )      SLOC
              if  ( SLOC  ≠   'C' or 'c' or 'I' or 'i' or 'N' or 'n' )  go to PX9a
        endif
        if  ( plasx and .not. makeplas )   then
PX9b          specify Plastic Strains ( PX-8b record )                IPLAST
        endif
PX9c    specify Reference Frame ( PX-8c record )                      FRAME
        go to PX8
```

user’s answers (the user-specified input parameters)—with the `X` and `x` items indicating the answers that **PITRANS** recognizes for the prompt at hand. The lower-case **black** items in that diagram are parameters that **PITRANS** extracts from the **STAGS** database for the case at hand or constructs using those parameters and the user’s responses to prompts that **PITRANS** has made during the current execution.

PITRANS starts (at **PX1** in the navigation chart) by asking the user to specify the “output format” that he wants the program to use for all of the output files that it generates during the current run—by printing the following “prompt” to the screen:

```
        Enter output type: (P)ATRAN, (I)DEAS = >
```

and waiting (where the `'>'` symbol is) for the user to specify (in the **FORM** input parameter) that he wants **PITRANS** to give him output in **PATRAN**’s “neutral file” format (in which case he should answer the prompt with an upper case `'P'` or a lower case `'p'` response) or to specify that he wants **PITRANS** to give him output in **IDEAS’** “universal file” format (in which case he should answer the prompt with an upper case `'I'` or a lower case `'i'` response). If the user’s answer is anything other than one or the other of those four characters, **PITRANS** will repeat the **PX1** prompt and wait for the user’s next answer to the same question.

Immediately after getting a valid answer to its first prompt, **PITRANS** responds (at **PX2** in the navigation chart) by asking the user for the **STAGS** “case” name for the case at hand—by printing the following “prompt” to the screen:

```
        Enter Stags Case Name = >
```

and waiting (where the `'>'` symbol is) for the user’s answer to that question (the **CASE** input parameter) at the **PX2** location. **PITRANS** expects a character string here that identifies the case at hand and enables **PITRANS** to gain access to the *case.sav* (and other) **STAGS** database files in the user’s working directory to extract and process the information that the user is about to request.

Then (at location **PX3** in the flow chart) **PITRANS** continues by asking the user what he wants the program to do next—by printing the following “prompt” to the screen:

```
        Data:  (M)odel only data (nodes, elements, bc, etc)
               (V)ector results  (displ, veloc, accel, forces)
               (I)ntegrated Stresses -or-  Mid-Surface Strains
               (S)tress and Strains  (equivalent nodal values)
               (Q)uit making Stags plot files ................ = >
```

and waiting (where the `'>'` symbol is) for the user to specify (*via* the **ODATA** input parameter) that he wants **PITRANS** to give him information about the model (with an `'M'` or `'m'` response to the prompt), or to give him displacement, velocity, or reaction force results from the solution database (with a `'V'` or `'v'` response), or to give him integrated stress or mid-surface strain results from the solution database (with an `'I'` or `'i'` response), or to give him nodal stress or strain results (with an `'S'` or `'s'` response), or to "quit" the current execution of the program (with a `'Q'` or `'q'` response). If the user's answer is anything other than one or the other of those ten characters, **PITRANS** will repeat the **PX3** prompt and wait for the user's next answer to the same question. If the user's answer is one of those ten characters (one of those five options), **PITRANS** will react in accord with the user's request (as explained below).

If the user sets **ODATA** = `'M'` or `'m'` at its **PX3** control point—to ask for information about the model—**PITRANS** will go to its **PX7** control point and ask the user to specify that the **STAGS** database for the case at hand contains information for the full model (by setting **MTYPE** = `'F'` or `'f'`) or to specify that it contains information for a condensed model (by setting **MTYPE** = `'C'` or `'c'`). If the user's answer to the **PX7** prompt is anything other than one or the other of those four characters, **PITRANS** will repeat the prompt and wait for the user's next answer to the same question. If the answer is one of those four characters, **PITRANS** will give the user a formatted output file called *case.mdl* that contains the desired information and will then return to its **PX3** control point and prompt the user for his next instruction(s).

If the user sets **ODATA** = `'V'` or `'v'` at the program's **PX3** control point—to ask for displacement, velocity, or reaction force results from the solution database—**PITRANS** will go to its **PX4** control point and ask the user to specify (*via* the **VTYPE** parameter) that he wants the program to give him displacement results (by setting **VTYPE** = `'D'` or `'d'`), or velocity results (by setting **VTYPE** = `'V'` or `'v'`) or reaction forces (by setting **VTYPE** = `'F'` or `'f'`). If the user's answer is anything other than one or the other of those six characters, **PITRANS** will repeat the **PX4** prompt and wait for the user's next answer to the same question. If the user's answer is one of those six characters, **PITRANS** will transfer to its **PX7** control point and ask the user to specify that the **STAGS** database for the case at hand contains information for the full model (by setting **MTYPE** = `'F'` or `'f'`) or that it contains information for a condensed model (by setting **MTYPE** = `'C'` or `'c'`). If the user's answer to this **PX7** prompt is anything other than one or the other of those four characters, **PITRANS** will repeat the prompt and wait for the user's next answer to the same question. If the answer is one of those four characters, **PITRANS** will transfer to its **PX8** control point, will display its current "load table" (which contains some or all of the *load step*, *load factor*, *time*, and *"# of modes"* information that the user needs to know for the case at hand) on the screen and save it in a formatted (text) output file called *case.step* (if it hasn't already done so), and will prompt the user to specify (*via* the **STEP** input parameter) what he wants the program to do:

> If the user has set **STEP** = `'P'` or `'S'` at **PX8**, then **PITRANS** will print information from another part of the "load table," then return to **PX8** to ask the user what he wants the program to do next.
>
> If the user has set **STEP** = **N** at **PX8** (where **N** is a valid step number for the case at hand), then **PITRANS** will extract the (displacement, velocity or reaction force) results that he wants (for that step number) from the **STAGS** solutions database

> and will give it to him in a vector-formatted output file called *case.dis.**N*** or *case.vel.**N*** or *case.fint.**N*** (depending on **VTYPE**). After doing that, **PITRANS** will return to its **PX8** control point to prompt the user for his next instruction(s).
>
> If the user has set **STEP** = `'Q'` at **PX8**, then **PITRANS** will "quit" its **PX8** activities and will return to the program's **PX3** control point to prompt the user for his next instruction(s).

If the user sets **ODATA** = `'I'` or `'i'` at the program's **PX3** control point—to ask for integrated stress or mid-surface strain results from the solution database—**PITRANS** will go to its **PX5** control point and prompt the user to specify that he wants **PITRANS** to give him integrated stresses (resultants and moments) (by setting the **STYPE** input parameter equal to `'S'` or `'s'`) or that he wants **PITRANS** to give him mid-surface strains and curvatures (by setting **STYPE** = `'M'` or `'m'`). If the user's answer is anything other than one or the other of those four characters, **PITRANS** will repeat the **PX5** prompt and wait for the user's next answer to the same question. If the user's answer is one of those four characters, **PITRANS** will then go to its **PX6** control point, display its current "load table" on the screen and save it in a formatted (text) output file called *case.step* (if it hasn't already done so), and prompt the user to specify (*via* the **ISTEP** input parameter) what he wants the program to do next:

> If the user has set **ISTEP** = `'P'` or `'S'` at **PX6**, then **PITRANS** will print information from another part of the "load table," then return to **PX6** to ask the user what he wants the program to do next.
>
> If the user has set **ISTEP** = **N** at **PX6** (where **N** is a valid step number for the case at hand) and if he has set **STYPE** = `'S'` or `'s'` at **PX5**, then **PITRANS** will extract the integrated stresses that he wants for step **N** from the **STAGS** solutions database and give them to him in a formatted output file called *case.elmI.**N***—or if he has set **STYPE** = `'M'` or `'m'` at **PX5**, then **PITRANS** will extract the midsurface strains and curvatures from the database and give them to him in *case.elmR.**N***. After doing one or the other of those two things, then **PITRANS** will return to its **PX6** control point to prompt the user for his next instruction(s).
>
> If the user has set **ISTEP** = `'Q'` at **PX6**, then **PITRANS** will "quit" its **PX6** activities and return to the program's **PX3** control point to prompt the user for his next instruction(s).

If the user sets **ODATA** = `'S'` or `'s'` at the program's **PX3** control point—to ask for nodal stress or strain results from the solution database—**PITRANS** will go to its **PX8** control point, will display its current "load table" on the screen and save it in a formatted (text) output file called *case.step* (if it hasn't already done so), and prompt the user to specify (*via* the **STEP** input parameter) what he wants the program to do next:

If the user has set **STEP** = `'P'` or `'S'` at **PX8**, then **PITRANS** will print information from another part of the “load table,” then return to **PX8** to ask the user what he wants the program to do next.

If the user has set **STEP** = **N** at **PX8** (where **N** is a valid step number for the case at hand), then **PITRANS** will ask the user for more information, as discussed in the next three sub-paragraphs:

> With a valid step number in hand, **PITRANS** will go to its **PX9** control point and prompt the user to specify a valid layer number—by setting the **LAYER** parameter equal to an integer value (to select a particular layer) or to zero (to select all layers) for some or all the elements in the model. **PITRANS** will check to ensure that **LAYER** is valid and will return to **PX9** if it is not.
>
> Then, with a valid **LAYER** specification in hand, **PITRANS** will check the **nr840** and **nr880** parameters that it retrieves from *case.sav* to determine whether or not the user’s model has any sandwich or solid elements in it. If it does, **PITRANS** will go to its **PX9a** control point and prompt the user to specify (*via* the **SLOC** input parameter) that he wants the information that he is requesting for the centroid (if **SLOC** = `'C'`), or for the integration points (if **SLOC** = `'I'`) or for the node points (if **SLOC** = `'N'`) of each of the elements for which that information is available. If the user does not respond to this prompt by setting **SLOC** equal to one of those three characters, **PITRANS** will return to **PX9a** and prompt him to specify **SLOC** again.
>
> Then, with a valid **SLOC** specification in hand, **PITRANS** will examine (a) the **plasx** parameter that it retrieves from *case.sav* to determine whether or not plasticity effects are taken into account in the user’s model and (b) a logical-type variable called **makeplas** that **PITRANS** initializes by making it .false. and changes under the conditions that are described at the end of this sub-paragraph. If **PITRANS** finds that plasticity effects exist and that the user has never answered or has given a negative answer to the program’s prompt for him to specify whether or not he wants plastic stains output for a previously selected load step, **PITRANS** will pause at its **PX9b** control point and prompt the user to specify (*via* the **IPLAST** input parameter) whether or not he wants **PITRANS** to give him plastic strains output for the current **STEP**: if the user responds to this prompt by setting **IPLAST** = `'N'`, **PITRANS** will set **makeplas** = .false. and will not extract plastic strains information from the solutions database; if the user responds by not setting **IPLAST** or by setting it to anything other than `'N'`, **PITRANS** will set **makeplas** = .true. and will extract plastic strains information from the solutions database.

In any event, **PITRANS** will then go to its **PX9c** control point, where it will prompt the user to specify (*via* the **FRAME** input parameter) that he wants **PITRANS** to generate and give him the information that he wants using each element's "material" coordinates reference frame (by setting **FRAME** = 'M') or that he wants **PITRANS** to generate and give it to him using each element's "fabrication" coordinates reference frame (by not setting **FRAME** or by setting it equal to anything other than 'M').

Then, with **STEP**, **LAYER** & **FRAME** in hand (and with **SLOC** & **IPLAST** also in hand, if they are needed), **PITRANS** will extract the nodal stress and strain results (and the plastic strains, if any) that the user requested from the **STAGS** solutions database and give him the nodal stresses in an output file called *case.elmT.**N.LAYER*** (and the plastic strains in a second output file called *case.elmP.**N.LAYER***, if he asked for them). With that done, **PITRANS** will return to its **PX8** control point and prompt the user for his next instruction(s).

If the user has set **ISTEP** = 'Q' at **PX8**, then **PITRANS** will "quit" its **PX8** activities and return to the program's **PX3** control point to prompt the user for his next instruction(s).

Last (but far from least), if the user responds to **PITRANS**' **PX3** prompt by setting **ODATA** equal to 'Q' or 'q', **PITRANS** will close all active files and terminate the current execution.

Example # 1

In this example, the analyst used **PITRANS** to generate a **PATRAN**-compatible displacements vector for **STAGS**' tiny "pcats" test case, demonstrating that it was much easier for him to generate that output file using **PITRANS** in its "interview" operating mode than it was for him to read about how to do so. The following "listing" shows **PITRANS**' output to his screen (in blue type) and his keyboard input into the program (in **Red** type) when he executed the program *via* the OS-level **pitrans** command in a working directory that contained the *pcats.sav* model file and the *pcats.res* and *pcats.rst* solution files:

```
[working directory] > pitrans

PITRANS - STAGS Plot File Reformat Utility Mar 21, 2002
Enter output type: (P)ATRAN, (I)DEAS = Patran
Enter Stags Case Name = pcats

Data: (M)odel only data (nodes, elements, bc, etc)
      (V)ector results  (displ, veloc, accel, forces)
      (I)ntegrated Stresses -or-  Mid-Surface Strains
      (S)tress and Strains  (equivalent nodal values)
      (Q)uit making STAGS plot files ................ = Vector
```

```
12: Data Type: (D)isplacement, (V)elocity, (A)cceleration, Reaction-(F)orces = Displ
13: Enter model type: (F)ull or (C)ondensed: Full
14:
15: the load/time step list has been stored in the file: pcats.step
16:
17: there are 12 loadsteps for this case
18: ==============================================================================
19: loadstep of initial plastic yield: 8
20:
21: Loadstep       Load Factor A      Load Factor B         time         # of modes
22:      0         1.000000E-02       0.000000E+00      0.000000E+00          0
23:      1         1.000000E-02       0.000000E+00      0.000000E+00          0
24:      2         2.000000E-02       0.000000E+00      0.000000E+00          0
25:      3         2.572181E-02       0.000000E+00      0.000000E+00          0
26:      4         3.286878E-02       0.000000E+00      0.000000E+00          0
27:      5         4.301969E-02       0.000000E+00      0.000000E+00          0
28:      6         5.709739E-02       0.000000E+00      0.000000E+00          0
29:      7         7.361708E-02       0.000000E+00      0.000000E+00          0
30:      8         9.189031E-02       0.000000E+00      0.000000E+00          0
31:      9         1.091103E-01       0.000000E+00      0.000000E+00          0
32:     10         1.240358E-01       0.000000E+00      0.000000E+00          0
33:     11         1.280000E-01       0.000000E+00      0.000000E+00          0
34:
35: (P)revious Group, (Q)uit, (S)tart Over or Load-Step No.: 10
36: File: pcats.dis.10 successfully created.
37:
38: there are 12 loadsteps for this case
39: ==============================================================================
40:
41: Loadstep       Load Factor A      Load Factor B         time         # of modes
42:      0         1.000000E-02       0.000000E+00      0.000000E+00          0
43:      1         1.000000E-02       0.000000E+00      0.000000E+00          0
44:      2         2.000000E-02       0.000000E+00      0.000000E+00          0
45:      3         2.572181E-02       0.000000E+00      0.000000E+00          0
46:      4         3.286878E-02       0.000000E+00      0.000000E+00          0
47:      5         4.301969E-02       0.000000E+00      0.000000E+00          0
48:      6         5.709739E-02       0.000000E+00      0.000000E+00          0
49:      7         7.361708E-02       0.000000E+00      0.000000E+00          0
50:      8         9.189031E-02       0.000000E+00      0.000000E+00          0
51:      9         1.091103E-01       0.000000E+00      0.000000E+00          0
52:     10         1.240358E-01       0.000000E+00      0.000000E+00          0
53:     11         1.280000E-01       0.000000E+00      0.000000E+00          0
54:
55: (P)revious Group, (Q)uit, (S)tart Over or Load-Step No.: Q
56:
57: Data: (M)odel only data (nodes,  elements,  bc,  etc)
58:       (V)ector results  (displ, veloc, accel, forces)
59:       (I)ntegrated Stresses -or-  Mid-Surface Strains
60:       (S)tress and Strains  (equivalent nodal values)
61:       (Q)uit making STAGS plot files ................ = Q
62: [working directory] >
```

Note that the user’s responses on lines 4, 11, 12 and 13 of this “interview session” are character strings that have more than a single character in them. **PITRANS** reads and prints the user’s complete answer to most of its prompts, but it only uses the first character (in most cases). The input descriptions on the preceding pages do not indicate where **PITRANS** does that, so the interested reader should rely on the more complete descriptions of the program's input records in the "batch mode input requirements" part of this Appendix. The printouts on lines 15 and 36 of this listing informed our user that **PITRANS** generated two text output files during his execution of the program—the *pcats.step* file that contains the same information that the program printed to the screen on lines 17–33 of the listing (and again on lines 38–53), and the **PATRAN**-compatible *pcats.dis.10* file that contains the displacement results that he requested for load step # 10.

Example # 2

In this example, the analyst used **PITRANS** to generate an **IDEAS**-compatible output file containing mid-surface strains and curvatures for the same (pcats) test case—demonstrating again how much easier it was for him to generate that output using **PITRANS** in its "interview" operating mode than it was for him to read about how to do so. The following "listing" shows **PITRANS**' output to his screen (in `blue` type) and his keyboard input into the program (in **`Red`** type) when he executed the program *via* the OS-level **`pitrans`** command in a working directory that contained the *pcats.sav* model file and the *pcats.res* and *pcats.rst* solution files:

```
 1: [working directory] > pitrans
 2:
 3: PITRANS - STAGS Plot File Reformat Utility Mar 21, 2002
 4: Enter output type: (P)ATRAN, (I)DEAS = IDEAS
 5: Enter Stags Case Name = pcats
 6:
 7: Data: (M)odel only data (nodes,  elements,  bc,  etc)
 8:       (V)ector results  (displ, veloc, accel, forces)
 9:       (I)ntegrated Stresses -or-  Mid-Surface Strains
10:       (S)tress and Strains  (equivalent nodal values)
11:       (Q)uit making STAGS plot files ................ = Integrated S or M
12: Integrated Type: (S)treses  =  Resultants & Moments
13:                  (M)id-Surface Strains & Curvatures = M
14:
15: the load/time step list has been stored in the file: pcats.step
16:
17: there are 12 loadsteps for this case
18: ==============================================================================
19: loadstep of initial plastic yield: 8
20:
21: Loadstep       Load Factor A      Load Factor B         time         # of modes
22:      0         1.000000E-02       0.000000E+00      0.000000E+00          0
23:      1         1.000000E-02       0.000000E+00      0.000000E+00          0
24:      2         2.000000E-02       0.000000E+00      0.000000E+00          0
25:      3         2.572181E-02       0.000000E+00      0.000000E+00          0
26:      4         3.286878E-02       0.000000E+00      0.000000E+00          0
```

```
27:      5         4.301969E-02       0.000000E+00      0.000000E+00          0
28:      6         5.709739E-02       0.000000E+00      0.000000E+00          0
29:      7         7.361708E-02       0.000000E+00      0.000000E+00          0
30:      8         9.189031E-02       0.000000E+00      0.000000E+00          0
31:      9         1.091103E-01       0.000000E+00      0.000000E+00          0
32:     10         1.240358E-01       0.000000E+00      0.000000E+00          0
33:     11         1.280000E-01       0.000000E+00      0.000000E+00          0
34:
35: (P)revious Group, (Q)uit, (S)tart Over or Load-Step No.: 10
36: Please wait for additional computation...
37: File: pcats.elmR.10 successfully created.
38:
39: there are 12 loadsteps for this case
40: ===============================================================================
41:
42: Loadstep       Load Factor A      Load Factor B        time        # of modes
43:      0         1.000000E-02       0.000000E+00      0.000000E+00          0
44:      1         1.000000E-02       0.000000E+00      0.000000E+00          0
45:      2         2.000000E-02       0.000000E+00      0.000000E+00          0
46:      3         2.572181E-02       0.000000E+00      0.000000E+00          0
47:      4         3.286878E-02       0.000000E+00      0.000000E+00          0
48:      5         4.301969E-02       0.000000E+00      0.000000E+00          0
49:      6         5.709739E-02       0.000000E+00      0.000000E+00          0
50:      7         7.361708E-02       0.000000E+00      0.000000E+00          0
51:      8         9.189031E-02       0.000000E+00      0.000000E+00          0
52:      9         1.091103E-01       0.000000E+00      0.000000E+00          0
53:     10         1.240358E-01       0.000000E+00      0.000000E+00          0
54:     11         1.280000E-01       0.000000E+00      0.000000E+00          0
55:
56: (P)revious Group, (Q)uit, (S)tart Over or Load-Step No.: Q
57:
58: Data: (M)odel only data (nodes,  elements,  bc,  etc)
59:       (V)ector results  (displ, veloc, accel, forces)
60:       (I)ntegrated Stresses -or-  Mid-Surface Strains
61:       (S)tress and Strains  (equivalent nodal values)
62:       (Q)uit making STAGS plot files ................ = Q
63: [working directory] >
```

Note that the user’s responses on lines 4 and 11 of this “interview session” are multi-character strings. For these responses, **PITRANS** reads and prints the full character string, extracts the first character from it, and uses that character to determine what the user wants and to do what it has to do next. Note that this is not the “case” on line 5 (pun intended) where the program assumes that the user’s *case* name is whatever he gives the program on that line—all of it. The printouts on lines 15 and 37 of this listing informed our user that **PITRANS** generated two output files during his execution of the program—the *pcats.step* file that contains the same information that the program printed to the screen on lines 17–33 of the listing (and again on lines 39–54), and the **IDEAS**-compatible *pcats.elmR.10* file that contains the mid-surface strain and curvature results that he requested for load step # 10.

Input records (for interview- and batch-mode operations)

On this and on the following eleven pages, we give “formal” descriptions of the twelve input records (user responses) that were referenced in the flow chart on page C-3 and in the Input requirements and output files discussions part of this Appendix—in the traditional input record format that is used throughout this and other **STAGS** user manuals. Some of these records are required whenever the user executes the **PITRANS** program, and others are only needed when the user asks the program to do certain things. All of that will be clear from the description of each of these records and from the “navigation” instructions that appear at the end of it.

PX-1 Output Format record

The first thing that **PITRANS** does when the user executes the program is to print a short program-version header followed by its initial (station **PX1**) prompt that asks the user to specify the format that he wants the program to use for all of the output files that it generates for him during the current execution (where **PX1** is the first of the twelve prompt and control addresses in the flow chart on page C-3). The following PX-1 input record documents the answer—a character string called **FORM** that may contain up to but not more than 72 alphanumeric characters—that **PITRANS** expects the user to give it in his response to that prompt:

FORM

FORM output format (72 characters or less); see the note, below

Note: **PITRANS** reads and displays the complete **FORM** string, extracts the first character from it, and uses that character to set its internal control parameters to generate all of the output files that it produces in **PATRAN**-compatible formatted files (if the first character is `‘P’` or `‘p’`) or in **IDEAS**-compatible formatted files (if the first character is `‘I’` or `‘i’`). If the first character is anything other than one of those four possibilities, **PITRANS** will reissue its **PX1** control point prompt and wait for the user’s next response to the same question. Then—after the user’s valid response has been read and processed—**PITRANS** will move forward to its next prompt station (and input record).

✦ *go to* PX-2

PX-2 Stags Case Name record

This record specifies the case name for the case at hand.

CASE

CASE case name (an alphanumeric character string that identifies the *case* at hand); see the important **Notes**, below

Note 1: In **PITRANS**, the **CASE** character string is long enough to contain up to (but not more than) 72 characters. Some analysts who are using **PITRANS** with cases that have names that are much shorter than that might be tempted to respond to the program's **PX2** control station prompt with a short case name followed by one or more blank characters followed by comments or other things. The **PITRANS** program is not "smart" enough to realize that the user might give it a short case name (which cannot contain any blank characters) followed by other stuff, and it tries to use the entire character string instead of the short substring that the user wants it to use. Please do not let **PITRANS** do that.

Note 2: **PITRANS** will need the *case.sav* file that **s1** generated for the user's case to produce any output files for the case at hand—and it will need the *case.res* and *case.rst* files that **s2** generated to produce any output files that contain displacements, velocities, reaction forces, stresses, strains and/or other results that are contained in those files or that must be generated with information that those files contain. The *case.sav* file must be present in the user's working directory under any circumstances. The *case.res* and *case.rst* files must also be there when they are needed. **PITRANS** will read each of these files when and if it needs to do so—but will not change any of them under any circumstances.

Note 3: **PITRANS** will terminate its execution prematurely (stop) if it does not find the *case.sav* file that it expects (and needs) in the user's working directory. If **PITRANS** finds and opens that file successfully, it will move on to its central **PX3** control station, where it expects the user to respond with the following (PX-3) program-control input record.

go to PX-3

PX-3 Output Data Option record

This record is requested and read at **PITRANS**' central control point—the **PX3** control station in the flow chart on page C-3 to initiate one or another of the program's data extraction, translation and output activities—or to quit the **PITRANS** program. This is where **PITRANS** displays its

```
Data: (M)odel only data (nodes,  elements,  bc,  etc)
      (V)ector results  (displ, veloc, accel, forces)
      (I)ntegrated Stresses -or-  Mid-Surface Strains
      (S)tress and Strains  (equivalent nodal values)
      (Q)uit making STAGS plot files ................ = >
```

prompt and waits for the user's answer to the what do you want me to do next question that it poses—*via* the very first character in his specification of the 72-character-long **OPTION** answer string on this input record:

OPTION

OPTION(1:1) **primary program-control input parameter:**

= 'M' or 'm' – generate a **PATRAN**- or an **IDEAS**-compatible output file containing information about the **STAGS** model

= 'V' or 'v' – generate one or more **PATRAN**- or **IDEAS**-compatible output files that contain displacement, velocity or reaction force results for the specified load step(s)

= 'I' or 'i' – generate one or more **PATRAN**- or **IDEAS**-compatible output files that contain integrated stress results for the specified load step(s)

= 'S' or 's' – generate one or more **PATRAN**- or **IDEAS**-compatible output files that contain nodal stress/strain results for the specified load step(s)

= 'Q' or 'q' – stop generating output files!!!

```
if      ( OPTION(1:1) = 'M' or 'm' )  then
        go to PX-7
elseif  ( OPTION(1:1) = 'V' or 'v' )  then
        go to PX-4
elseif  ( OPTION(1:1) = 'I' or 'i' )  then
        go to PX-5
elseif  ( OPTION(1:1) = 'S' or 's' )  then
        go to PX-8
elseif  ( OPTION(1:1) = 'Q' or 'q' )  then
        finished!!!
else
        go to PX-3
endif
```

PX-4 Vector Type record

This record is read at **PITRANS**' **PX4** control station (in the flow chart on page C-3), which **PITRANS** reaches if and only if the user has specified that **ODATA(1:1)** = 'V' or 'v' on his most recent PX-3 record.

VTYPE

VTYPE(1:1) **vector-type control parameter:**

= 'D' or 'd' – generate one or more **PATRAN**- or **IDEAS**-compatible output files that contain displacement results for the specified load step(s)

= 'V' or 'v' – generate one or more **PATRAN**- or **IDEAS**-compatible output files that contain velocity results for the specified load step(s)

= 'F' or 'f' – generate one or more **PATRAN**- or **IDEAS**-compatible output files that contain reaction forces for the specified load step(s)

```
if       ( VTYPE(1:1) = 'D' or 'd' )   then
         go to PX-7
elseif   ( VTYPE(1:1) = 'V' or 'v' )   then
         go to PX-7
elseif   ( VTYPE(1:1) = 'F' or 'f' )   then
         go to PX-7
else
         go to PX-4
endif
```

PX-5 Integrated Stress Type record

This record is read at **PITRANS**’ **PX5** control station, which **PITRANS** reaches if and only if the user has specified that **ODATA(1:1)** = `‘I’` or `‘i’` on his most recent PX-3 record.

STYPE

STYPE(1:1) **integrated-stress-type control parameter:**

= `‘S’` or `‘s’` – generate one or more **PATRAN**- or **IDEAS**-compatible output files that contain integrated stresses in each element for the specified load step(s)

= `‘M’` or `‘m’` – generate one or more **PATRAN**- or **IDEAS**-compatible output files that contain mid-surface strains in each element for the specified load step(s)

```
if ( STYPE(1:1) = 'S' or 'M' or 's' or 'm' ) then
    go to PX-6
else
    go to PX-5
endif
```

PX-6 Next Step record

This record is read at **PITRANS**’ **PX6** control station, which **PITRANS** reaches if and only if the user has specified that **ODATA(1:1)** = ‘I’ or ‘i’ on his most recent PX-3 record and if the user has specified that **STYPE(1:1)** = ‘S’ or ‘M’ (or ‘S’ or ‘M’) on his most recent PX-5 record. This is where the user selects a valid step number from the “load table” for the analysis (or analyses) that produced the *case.res* and *case.rst* files in his working directory. This is a little bit tricky because the **ISTEP** input parameter can contain an integer step number (**N**, say) or a character string (**A**, say)—the first of these being the case where the user wants to specify a valid load step for which he wants output of the type that he requested on his PX-5 record, and the second of these being the case when he wants to direct **PITRANS** to do something.

ISTEP = N or A

ISTEP **next step number or action string:**

= **N** – generate a **PATRAN**- or an **IDEAS**-compatible output file that contains integrated stresses or mid-surface strains in each element for load step # **N**

= **A(1:1)** = ‘P’ display an earlier section of the “load table” than is currently being displayed on **PITRANS**’ output screen

= **A(1:1)** = ‘S’ display the very first section of the “load table” instead of the section that is currently being displayed

= **A(1:1)** = ‘Q’ quit generating integrated stress or mid-surface strains output files; return to **PX3** to prompt and wait for further instructions,

```
if      ( ISTEP = N  )  then
        go to PX-6
elseif  ( ISTEP = S(1:1) = ‘P’or ‘S’ )  then
        go to PX-6
elseif  ( ISTEP = S(1:1) = ‘Q’ )  then
        go to PX-3
else
        go to PX-6
endif
```

PX-7 Model Type record

This record is read at **PITRANS**’ **PX7** control station, which **PITRANS** reaches if and only if the user has specified that **ODATA(1:1)** = ‘**M**’ or ‘**m**’ on his most recent PX-3 record—or if he has specified that **ODATA(1:1)** = ‘**V**’ or ‘**v**’ there and that he has specified that **VTYPE(1:1)** = ‘**D**’ or ‘**V**’ or ‘**F**’ (or ‘**d**’ or ‘**v**’ or ‘**f**’) on his most recent PX-4 record. At **PX7**, **PITRANS** prompts the user to specify (*via* the **MTYPE** input parameter) that he wants **PITRANS** to do any calculations that it needs to do using his **STAGS** model in the program’s “full model” computational mode or in the program’s “condensed model” mode when it calculates forces, stresses and other results. When the user specifies that he wants the “full model” option, **PITRANS** will perform its computations keeping nodes that occupy the same locations as other nodes in-place as “doubled” nodes. When the user specifies that he wants the “condensed model” option, **PITRANS** will coalesce each “doubled” node into a single “master” node. This is important when downstream processors cannot handle “doubled” node situations properly. **STAGS** and its utility programs can handle those situations correctly, so it is rarely (if ever) necessary for **STAGS** users to choose the “condensed model” option.

PITRANS expects to read the following (Model Type) input record in response to this **PX7** prompt:

MTYPE

MTYPE(1:1) **model type parameter:**

= ‘**F**’ – perform force, stress and other calculations using the program’s “full model” computation mode (the usual situation); or

= ‘**C**’ – perform force, stress and other calculations using the program’s “condensed model” mode

```
if  ( MTYPE(1:1) = 'F' or 'C' or 'f' or 'c' )  then
    if ( ODATA(1:1) = 'M' or 'm' ) go to PX-3
    if ( ODATA(1:1) = 'V' or 'v' ) go to PX-8
else
    go to PX-7
endif
```

PX-8 Next Step record

This record is read at **PITRANS**’ **PX8** control station, which **PITRANS** reaches if and only if the user has specified that

> **ODATA(1:1)** = ‘S’ or ‘s’ on his most recent PX-3 record, or that
>
> **ODATA(1:1)** = ‘V’ or ‘v’ at **PX3**, and that **VTYPE(1:1)** = ‘D’ or ‘V’ or ‘F’ (or ‘d’ or ‘v’ or ‘f’) at **PX4**, and that **MTYPE(1:1)** = ‘F’ or ‘C’ (or ‘f’ or ‘c’) at **PX7**

Under these circumstances, this is where the user selects a valid step number from the “load table” for the analysis (or analyses) that produced the *case.res* and *case.rst* files in his working directory. The **STEP** input parameter can contain an integer step number (**N**, say) or a character string (**A**, say)—the first of these being the case where the user wants to specify a valid load step for which he wants output of the requested type, and the second of these being the case when he wants to direct **PITRANS** to do something.

STEP = N or A

STEP **next step number or action string:**

= **N**	–	generate a **PATRAN**- or an **IDEAS**-compatible output file that contains the requested information for load step # **N**
= **A(1:1)** = ‘P’		display an earlier section of the “load table” than is currently being displayed on **PITRANS**’ output screen
= **A(1:1)** = ‘S’		display the first section of the “load table” instead of the section that is currently being displayed
= **A(1:1)** = ‘Q’		quit generating output files of the requested type

```
if      ( STEP = N   )  then
        if ( ODATA(1:1) = ‘V’ or ‘v’ )    go to PX-8
        if ( ODATA(1:1) = ‘S’ or ‘s’ )    go to PX-9
elseif  ( STEP = A(1:1) = ‘P’ or ‘S’ )    then
        go to PX-8
elseif  ( STEP = A(1:1) = ‘Q’ )   then
        go to PX-3
else
        go to PX-8
endif
```

PX-9 Layer record

This record is read at **PITRANS**' **PX9** control station, which **PITRANS** reaches if and only if the user has specified that **ODATA(1:1)** = 'S' or 's' on his most recent PX-3 input record (at **PX3**) and that he has selected a valid step number in his most recent PX-8 input record (at **PX8**). This is where **PITRANS** prompts the user to specify the layer number (in the **LAYER** input parameter) for which he wants the program to give him the output that he has requested for each laminated element in the model that has a layer with that number—in which case a valid **LAYER** number will be in the range $1 \le$ **LAYER** $\le$ **maxlayer**, where **maxlayer** is the highest layer number in the model (a parameter that **PITRANS** determines by examining all of the elements in the model)—or that he wants the program to give him the output that he has requested at layer number "0" (*i.e.*, for the top and bottom laminates) in each element:

LAYER

LAYER **layer number:**

> 0 – generate a **PATRAN**- or an **IDEAS**-compatible output file that contains the requested information for the current load step for each element that has a layer # **LAYER**

= 0 generate a **PATRAN**- or an **IDEAS**-compatible output file that contains the requested information for the current load step for the top and bottom laminates of each element in the model

```
if      ( LAYER is a valid layer number )          then
        if ( nr840 > 0  or nr880 > 0 )             then
                go to PX-9a
        elseif ( plasx and .not. makeplas )        then
                go to PX-9b
        else
                go to PX-9c
        endif
else
        go to PX-9
endif
```

PX-9a Output Point Location record

This record is read at **PITRANS**’ **PX9a** control station, which **PITRANS** reaches if and only if the user has specified a valid **LAYER** number in the preceding PX-9 record at the program’s **PX9** control point AND if the user’s model contains one or more sandwich or solid elements in it. This is where **PITRANS** prompts the user to specify the location(s) at which he wants it to generate the output that he has requested in each sandwich or solid element for which **LAYER** is a valid layer number (when **LAYER** > 0) or for the top and bottom laminates (when **LAYER** = 0)—in the single-character **SLOC** input parameter that the program expects the user to specify here:

SLOC

SLOC **location(s) where output is wanted:**

= ‘C’ or ‘c’ – generate output at the centroid of the selected layer(s)

= ‘I’ or ‘i’ – generate output at each integration point of the selected layer(s)

= ‘N’ or ‘n’ – generate output at each node point of the selected layer(s)

```
if    ( SLOC = ‘C’ or ‘I’ or ‘N’ or ‘c’ or ‘i’ or ‘n’)   then
      if    ( plasx and .not. makeplas )   then
            go to PX-9b
      else
            go to PX-9c
      endif
else
      go to PX-9a
endif
```

PX-9b Plastic Strains record

This record is read at **PITRANS**' **PX9b** control station, which **PITRANS** reaches if and only if the user has specified a valid output location (**SLOC**) number in the preceding PX-9a record at the program's **PX9a** control point AND if the user's model takes plasticity into account AND if **PITRANS**' internal logical variable **makeplas** is .false. when the user reaches this control point—where **PITRANS** asks the user the question "Do you want to examine plastic strains? (y or n)" and waits for him to respond (*via* the single-character **IPLAST** input parameter) on the PX-9b input record that is described here:

IPLAST

IPLAST **do I want plastic strains output???**

= `'N'` or `'n'` – No, I do not: do not give me a plastic strains output file for this loading step

≠ `'N'` or `'n'` – Yes, I do: please give me a plastic strains output file for this and for all subsequent load steps; and do not ask me this question again

Note: PITRANS initializes **makeplas** to be .false. at the outset of each execution of the program—and will refrain from extracting plastic strains from the user's *case.res/case.rst* database (and from giving the user output files containing that information) until the user changes **makeplas** to be .true. by giving **PITRANS** anything other than an `'N'` or `'n'` response to this **PX9b** prompt.

go to PX-9c

PX-9c Reference Frame record

This record is read at **PITRANS**’ **PX9c** control station, which the program reaches if and only if the user has selected a valid **LAYER** number at **PX9** (and has specified the **SLOC** and/or **IPLAST** parameters successfully at **PX9a** and **PX9b**, as and if necessary). This is where **PITRANS** asks the user to specify the (fabrication or material) reference coordinate frame that he wants the program to use for all of the stress and strain computations has to do in each element, *via* the single-character **FRAME** parameter on the following input record:

FRAME

FRAME **Reference coordinate frame:**

= **‘M’** or **‘m’** – use the layer’s (or element’s) material coordinates frame

≠ **‘M’** or **‘m’** – use the layer’s (or element’s) fabrication coordinates frame

Note: PITRANS sets **FRAME** = **‘F’** if the user does not set it equal to **‘M’** or **‘m’**.

go to PX-8

Example # 3

In this example, the analyst decided that he wanted resultants and moments (instead of mid-surface strains and curvatures) for his pcats test case—at load steps 9, 10 and 11. Not wanting to plow through another of **PITRANS**' painful interview sessions—and remembering what he did in the second example (above)—he constructed the following *pcats.pix* "script" file that answer's **PITRANS**' prompts in the way that he needs to do so to get the output that he wants:

```
1: I                    $ PX-1 IDEAS-compatible output desired
2: pcats
3: Integrated S or M    $ PX-3 Output Data OPTION
4: R                    $ PX-5 Resultants and moments
5: 9                    $ PX-6 ISTEP =  9
6: 10                   $ PX-6 ISTEP = 10
7: 11                   $ PX-6 ISTEP = 11
8: Q                    $ PX-6 Quit specifying steps
9: Q                    $ PX-3 Quit PITRANS !!!
```

The **Red** items in this text file are our analyst's answers to the prompts that he expects **PITRANS** to make, and the **Black** items are in-line comments that he expects the program to ignore. Note that he has been careful not to put anything other than his *case* name on the second line of this input script.

Then, with *pcats.sav*, *pcats.res*, *pcats.rst* and *pcats.pix* in his working directory, our analyst executed **PITRANS** with the following OS-level command:

```
% pitrans < pcats.pix
```

When **PITRANS** was finished with this job, our happy analyst found the following output files in his working directory:

pcats.step	load step table
pcats.elmI.9	IDEAS-compatible resultant & moment results for step # 9
pcats.elmI.10	IDEAS-compatible resultant & moment results for step # 10
pcats.elmI.11	IDEAS-compatible resultant & moment results for step # 11
pcats.sot.0	**PITRANS** "journal" file for this run

K
STAGS Shell Surface Differential Geometry

Definition of Basic Differential Geometry Terms

Slope information to be used to generate higher-order shell imperfections can be computed from the relationships defining the shell surface.* The basic relationships, given in (4.1) on page 4-8, are repeated here:

$$x = x(X, Y) \qquad y = y(X, Y) \qquad z = z(X, Y) \tag{K.1}$$

where (x, y, z) are branch coordinates of the position vector **r** of a point defined by functions of the (X, Y) surface coordinates (see Section 4.2 “Shell Unit” on page 4-8). Such functions are defined for each of the standard shell surfaces in “Standard Shell Surfaces” on page 6-2. Slope information required by user-written subroutine DIMP can be expressed as a function of the *bending numbers* β_x, β_y, and γ, which in turn depend on the knowledge of the Lamé coefficients (the First Fundamental Form) of the shell. It is possible to compute the Lamé coefficients by differentiation of the functional form provided in “Standard Shell Surfaces” for each shell unit. Without delving into shell theory, we present here a short summary of the required information for each **STAGS** shell type. Only the leading terms are presented for LAME and the elliptic cylinder (**ISHELL** = 9). In most situations, the leading terms involving derivatives of the displacement normal to the surface are sufficient to define the higher-order imperfection field to better precision than can be measured. The user should note that the imperfection field for the coordinates (the translations) is always expressed in units of distance (as opposed to angles or other generalized curvilinear coordinates). One

* See, for example:
Kraus, H., “Thin Elastic Shells,” John Wiley & Sons, Inc., New York, 1967; and/or
Dym, C.L., “Introduction to the Theory of Shells (revised printing),” Hemisphere Publishing Corp., New York, 1990; and/or
Vinson, J.R., “The Behavior of Shells Composed of Isotropic and Composite Materials,” Kluwer Academic Publishers, Dordrecht, 1993*; and/or*
Struik, D.J., “Lectures on Classical Differential Geometry, second edition,” Dover Publications, Inc., New York, 1988

should also note that although for some shell units formulas for the drilling freedom γ are included, this is a small quantity that could without harm be set to zero.

Note that in what follows, the perturbed coordinates are labeled (u, v, w), and are always expressed in the (X', Y', Z') shell coordinate system. The most important coordinate for thin shell imperfections is w, which points in the direction of the shell normal.

Bending Numbers for Arbitrary Shell

Omitting details that can be found in most texts on shell theory or differential geometry, we define the in-plane bending numbers β_i by the following relationship:

$$\begin{aligned} \zeta_j &= w,_j + \sum_k \frac{\mathbf{n} \cdot \mathbf{r},_{kj} u_k}{\sqrt{\mathbf{r},_k \cdot \mathbf{r},_k}} \\ \beta_j &= \frac{\zeta_j}{\sqrt{\mathbf{r},_j \cdot \mathbf{r},_j}} \end{aligned} \tag{K.2}$$

The comma notation indicates differentiation; for example, $\mathbf{r},_i \equiv \frac{\partial \mathbf{r}}{\partial i}$.

$\hat{\mathbf{n}}$ is a unit vector pointing in the direction of the outward normal to the shell, and u_k are the components of the in-plane displacements expressed in a system tangent to the coordinate lines. This equation applies to arbitrary tangent lines, including those that are not orthogonal. The user will discover in practice that only the term involving the normal coordinate w will contribute to the imperfection (in fact, it is very difficult to measure anything else). The drilling freedom γ can be ignored.

For the shell types orthogonalized by **STAGS**, the user must express his imperfection displacements and rotations in the orthogonal system. However, the imperfection displacements are still expressed as functions of the original (X, Y) surface coordinates. To express the new direction in terms of the original (X, Y), we make a change of variables that orthogonalizes the system, and apply that to (K.2). The final result is

$$\begin{aligned}
\beta_1 &= \frac{\hat{\mathbf{n}} \cdot [\mathbf{r},_{11} u_1/\alpha_1 + (\mathbf{r},_{12} - c\mathbf{r},_{11}) u_2/\alpha_2] + w,_1}{\alpha_1} \\
\beta_2 &= (\xi + \eta + \varsigma)/\alpha_2 \\
\xi &= w,_2 - c w,_1 \\
\eta &= \hat{\mathbf{n}} \cdot [\mathbf{r},_{12} - c\mathbf{r},_{11}] u_1/\alpha_1 \\
\varsigma &= \hat{\mathbf{n}} \cdot [\mathbf{r},_{11} c^2 - 2\mathbf{r},_{12} c + \mathbf{r},_{22}] u_2/\alpha_2 \\
c &= \frac{\mathbf{r},_1 \cdot \mathbf{r},_2}{\mathbf{r},_1 \cdot \mathbf{r},_1} \\
\alpha_1 &= \sqrt{\mathbf{r},_1 \cdot \mathbf{r},_1} \\
\alpha_2 &= \sqrt{\mathbf{r},_2 \cdot \mathbf{r},_2 - c(\mathbf{r},_1 \cdot \mathbf{r},_2)}
\end{aligned} \tag{K.3}$$

Again, note that only the terms involving the undeformed surface and the normal coordinate are important. This fact will be reflected in the next section.

ISHELL = 1 (LAME) Option

This option permits the user to define his own shell type, with the possibility that the tangent coordinate line do not form an orthogonal set. The Lamé coefficients α_i^2 for an orthogonal system are defined by the following relationships:

$$\begin{aligned}
\alpha_i &= \sqrt{g_{ii}} \\
g_{ii} &= \mathbf{r},_i \cdot \mathbf{r},_i
\end{aligned} \tag{K.4}$$

The comma notation indicates differentiation; for example, $\mathbf{r},_i \equiv \frac{\partial \mathbf{r}}{\partial i}$.

If the system is not orthogonal, the user is asked to choose which shell coordinate is aligned with the tangent line (see “LAME Reference Surface Geometry” on page 12-19). If we assign i to be the coordinate selected from the tangent line, then the following relationship can be derived from (K.3):

$$\begin{aligned}
\alpha_i &= \sqrt{g_{ii}} = \sqrt{\mathbf{r},_i \cdot \mathbf{r},_i} \\
\alpha_j &= \sqrt{\mathbf{r},_j \cdot \mathbf{r},_j - \frac{(\mathbf{r},_i \cdot \mathbf{r},_j)^2}{\mathbf{r},_i \cdot \mathbf{r},_i}}
\end{aligned} \tag{K.5}$$

Note that all these quantities are easily computed given (K.1). The bending numbers for LAME are

$$\begin{aligned}
\beta_i &= \frac{w,_i}{\alpha_i} \\
\beta_j &= \frac{\bar{w},_j}{\alpha_j} \\
\gamma &= 0 \\
\bar{w},_j &= w,_j - w,_i\left(\frac{\mathbf{r},_i \cdot \mathbf{r},_j}{\alpha_i^2}\right)
\end{aligned} \tag{K.6}$$

where the value of i and j range from 1 to 2, and where no summation is implied by repeated indices.

Flat Plates (ISHELL = 2 or 3)

Please see “RECTANGULAR PLATE” and “QUADRILATERAL PLATE” on page 6-4 for the defining equations. The bending numbers are

$$\beta_i = w,_i \tag{K.7}$$

and (this is almost never necessary)

$$\gamma = \frac{1}{2}(v,_1 - u,_2) \tag{K.8}$$

Annular Plate (ISHELL = 4)

Please refer to “ANNULAR PLATE” on page 6-5 for the notation and defining equations. The bending numbers are

$$\begin{aligned}
\beta_1 &= w,_1 \\
\beta_2 &= \frac{w,_2}{X} \\
\gamma &= \frac{1}{2}\left(v,_1 - \frac{u,_2 - v}{X}\right)
\end{aligned} \tag{K.9}$$

where X is the radial position coordinate within the annular plate segment.

Cylinder (ISHELL = 5)

Please refer to “CYLINDER” on page 6-5 for the notation and defining equations. The bending numbers are

$$\begin{aligned}\beta_1 &= w,_1 \\ \beta_2 &= \frac{w,_2 - v}{R} \\ \gamma &= \frac{1}{2}\left(v,_1 - \frac{u,_2}{R}\right)\end{aligned} \tag{K.10}$$

Cone (ISHELL = 6)

Please refer to “CONE” on page 6-6 for the notation and defining equations. The bending numbers are

$$\begin{aligned}\beta_1 &= \frac{w,_1}{\alpha_1} \\ \beta_2 &= \frac{w,_2 - v/\alpha_1}{\alpha_2} \\ \gamma &= \frac{1}{2}\left(\frac{v,_1}{\alpha_1} - \frac{u,_2}{\alpha_2} + \frac{v\tan\varphi}{\alpha_1\alpha_2}\right)\end{aligned} \tag{K.11}$$

where the Lamé coefficients are defined by

$$\begin{aligned}\alpha_1 &= 1/\cos\varphi \\ \alpha_2 &= r\end{aligned} \tag{K.12}$$

Sphere (ISHELL = 7)

Please refer to “SPHERE” on page 6-6 for the notation and defining equations. The bending numbers are

$$\begin{aligned}
\beta_1 &= \frac{w,_1 - u}{R} \\
\beta_2 &= \frac{w,_2 - v\sin X}{R\sin X} \\
\gamma &= \frac{1}{2}\left(\frac{v,_1}{R} - \frac{u,_2 - v\cos X}{R\sin X}\right)
\end{aligned} \tag{K.13}$$

Torus (ISHELL = 8)

Please refer to “TORUS” on page 6-7 for the notation and defining equations. The bending numbers are

$$\begin{aligned}
\beta_1 &= \frac{w,_1 - u}{\alpha_1} \\
\beta_2 &= \frac{w,_2 - v\sin X}{\alpha_2} \\
\gamma &= \frac{1}{2}\left(\frac{v,_1}{\alpha_1} - \frac{u,_2 - v\cos X}{\alpha_2}\right)
\end{aligned} \tag{K.14}$$

where the Lamé coefficients are defined by

$$\begin{aligned}
\alpha_1 &= R_b \\
\alpha_2 &= R_a + R_b\sin X
\end{aligned} \tag{K.15}$$

Elliptic Cylinder (ISHELL = 9)

This is a special case where the shell coordinates are orthogonalized, as discussed above. Approximate formulas for the in-plane bending numbers will be given, and the drilling freedom γ will be ignored. Please refer to “ELLIPTIC CONE/CYLINDER” on page 6-8 for the notation and defining equations. The bending numbers are

$$\begin{aligned}
\beta_1 &= \frac{w,_1 - cw,_2}{\alpha_1} \\
\beta_2 &= \frac{w,_2}{\alpha_2} \\
\gamma &= 0
\end{aligned} \tag{K.16}$$

with constants in (K.16) defined as follows:

$$
\begin{aligned}
g_{22} &= X_{ap}^2(\tan\varphi)^2(\xi^3\cos^2 Y + \sin^2 Y) \\
g_{12} &= \sin Y\cos Y(\tan\varphi)^2 X_{ap}(\xi^2 - 1) \\
g_{11} &= 1 + (\tan\varphi)^2(\xi^2\sin^2 Y + \cos^2 Y) \\
c &= g_{12}/g_{22} \\
\alpha_1 &= \sqrt{g_{11} - c g_{12}} \\
\alpha_2 &= \sqrt{g_{22}}
\end{aligned}
\tag{K.17}
$$

Paraboloid (ISHELL = 10)

Please refer to “PARABOLOID” on page 6-9 for the notation and defining equations. The bending numbers are

$$
\begin{aligned}
\beta_1 &= \frac{w,_1}{\alpha_1} - u\frac{4R_a^2}{(\alpha_1\alpha_2)^3} \\
\beta_2 &= \frac{w,_2 - v/\alpha_1}{\alpha_2} \\
\gamma &= \frac{1}{2}\left(\frac{v,_1}{\alpha_1} - \frac{u,_2 - v/[\alpha_1\alpha_2]}{\alpha_2}\right)
\end{aligned}
\tag{K.18}
$$

where the Lamé coefficients are defined by

$$
\begin{aligned}
\alpha_1 &= \sqrt{1 + \eta^2} \\
\alpha_2 &= \bar{R}(x) \\
\eta &= \frac{R_a}{X + R_b}
\end{aligned}
\tag{K.19}
$$

Ellipsoid (ISHELL = 11)

Please refer to “ELLIPSOID” on page 6-10 for the notation and defining equations. The bending numbers are

$$
\begin{aligned}
\beta_1 &= \frac{w,_1 - uR_xR_{yz}/\alpha_1^2}{\alpha_1} \\
\beta_2 &= \frac{w,_2}{\alpha_2} - v\frac{R_x}{\alpha_1 R_{yz}} \\
\gamma &= \frac{1}{2}\left(\frac{v,_1}{\alpha_1} - \frac{u,_2 - vR_{yz}\cos X_e/\alpha_1}{\alpha_2}\right)
\end{aligned}
\tag{K.20}
$$

where the Lamé coefficients are defined by

$$
\begin{aligned}
\alpha_1 &= \sqrt{R_x^2(\sin X_e)^2 + R_{yz}^2(\cos X_e)^2} \\
\alpha_2 &= R_{yz}\sin X_e
\end{aligned}
\tag{K.21}
$$

Hyperboloid (ISHELL = 12)

Please refer to “HYPERBOLOID” on page 6-11 for the notation and defining equations. The bending numbers are

$$
\begin{aligned}
\beta_1 &= \frac{w,_1}{\alpha_1} - u\frac{R_a^4}{R_b^2(\alpha_2\alpha_2)^3} \\
\beta_2 &= \frac{w,_2 - v/\alpha_1}{\alpha_2} \\
\gamma &= \frac{1}{2}\left(\frac{v,_1}{\alpha_1} - \frac{u,_2 - v\eta/\alpha_1}{\alpha_2}\right)
\end{aligned}
\tag{K.22}
$$

where the Lamé coefficients are defined by

$$
\begin{aligned}
\alpha_1 &= \sqrt{1 + \eta^2} \\
\alpha_2 &= \bar{R}(x) \\
\eta &= \frac{R_a^2(x - x_1 + R_c)}{R_b^2\bar{R}(x)}
\end{aligned}
\tag{K.23}
$$

L
Design Parameter Derivatives

Displacement gradients

The objective is to determine how the system unknowns change as a function of changes in model parameters that govern system behavior. The starting point for such an analysis is the governing equation that determines the system state:

$$\mathbf{f}(\mathbf{u},\lambda) = 0 \tag{L.1}$$

where **f** is the nodal residual vector (internal minus external forces), and **u** are the nodal displacements and the system unknowns to be determined by application of (L.1). Equation (L.1) is a statement of Newton's second law in a very general sense; such a system is usually nonlinear in its unknowns, and may require sophisticated solution techniques and considerable resources to solve. The system has a number of independent parameters that determine response, such as nodal positions and element topology, shell wall fabrication, and material data. In principle, any of these parameters can change as a design evolves. Our objective is to determine how the system unknowns change when such *design parameters* λ change. We assume at the outset that we have a solution at a given reference state (our current design and environment), and that we wish to see how these unknowns evolve for small changes in our current system definition. We obtain the governing equations by differentiating (L.1) to yield

$$\begin{gathered}\frac{\partial\mathbf{f}(\mathbf{u},\lambda)}{\partial\mathbf{u}}\mathbf{u}_{,\lambda} + \frac{\partial\mathbf{f}(\mathbf{u},\lambda)}{\partial\lambda} = 0 \\ \mathbf{K}\mathbf{u}_{,\lambda} = -\mathbf{f}_{,\lambda}\end{gathered} \tag{L.2}$$

where $\mathbf{u}_{,\lambda}$ is the displacement gradient vector field that we wish to compute, and where a subscripted comma followed by a variable denotes a derivative with respect to that variable. The first partial derivative is shorthand for the derivative of the residual with respect to each unknown in turn, with all others held constant. The second term is the partial derivative of the residual with respect to the design variable with all other unknowns and parameters held constant; this derivative is almost always *local* to each element, *i.e.*, the total derivative is a sum of a contribution from each element taken independent of all the others. **K** is the stiffness matrix that is readily identified with the first partial derivative in (L.2); it is already available in FEM software. The second equation in (L.2) consists of a factoring of the stiffness matrix followed by one or more “solve” operations with right hand sides $-\mathbf{f}_{,\lambda}$. Thus, the task is divided neatly into two independent parts:

- Computation of local partial derivatives of the residual and assembly into $\mathbf{f}_{,\lambda}$.
- The solution of a system of linear equations with the same structure as the normal “systems matrix” in an ordinary FEM analysis.

The first task can be very complex—especially if element shape, topology, and nodal locations are involved. For the time being, we shall concentrate on a very important subset of design variables that yields a simplified analysis. We shall admit for variation all components of a wall fabrication, such as layer thickness, material orientation angles and material properties. Any number of such variations can be combined so that a very large class of design gradients can be computed. It is fortuitous that no matter how complex a fabrication is in a shell analysis, it all comes down in the end to the **ABD** matrix that relates reference surface strains and curvatures to force resultants and moments. Furthermore, the residual is a *linear* function of the **ABD** matrix for the class of problems we are interested in; in what follows, we shall call this matrix **C** with components *ij*. **C** is symmetric and positive definite, and has either 21 or 24 independent components depending on the type of element used (the last three are transverse shear terms). Since the entire response of the system to changes in λ comes from **C**, we can express $\mathbf{f}_{,\lambda}$ as follows by using the chain rule:

$$\mathbf{f}_{,\lambda} = \frac{\partial \mathbf{f}}{\partial \lambda} = \sum_{ij} \frac{\partial \mathbf{f}}{\partial \mathrm{C}_{ij}} \frac{\partial \mathrm{C}_{ij}}{\partial \lambda} \tag{L.3}$$

where we remove the bold face for *components* of **C** to emphasize that they are treated one-by-one. One can see readily that $\mathbf{f}_{,\lambda}$ is a linear combination of partials with respect to each individual member of **C**. In addition, since the FEM analysis is a strictly linear function of **C**, one can compute these partials by setting all the **C** matrices in the system to zero, and replacing each component in turn by unity for fabrications affected by the design parameter. One must be careful to preserve the symmetry of **C**: unity in the *ij* slot must be matched by unity in the *ji* slot. Subsequently, one has to call a simple internal force calculation to obtain each of the 21 or 24 partials in (L.3). Clearly, if (L.3) holds, then

$$\begin{gathered} \mathbf{u}_{,\lambda} = \sum_{ij} \mathbf{u}_{,ij} \frac{\partial \mathrm{C}_{ij}}{\partial \lambda} \\ \mathbf{K}\mathbf{u}_{,ij} = -\frac{\partial \mathbf{f}}{\partial \mathrm{C}_{ij}} \end{gathered} \tag{L.4}$$

must also be true. The advantage of solving for the independent $\mathbf{u}_{ij}$ vectors is that this particular operation needs to be done only once, no matter what contributes to changes in **C**. In fact, the second equation in (L.4) is the only part that has to be done with the full FEM machinery; the sum in the first of (L.4) can be performed in a post-processing environment. This is how it is done in **STAGS**. The user selects the fabrications to vary, computes the 21 or 24 *gradient basis vectors* $\mathbf{u}_{,ij}$, and stores them away. In a **stapl** or a **star** application, these vectors are multiplied by the coefficients of variation of **C** with respect to a particular design variable to yield the final result. The variation coefficients of **C** can be computed with simple software independent of **STAGS**. We have provided an example of such software, called `GradC`, which is described below. This `GradC` program allows linked variation with respect to material properties, layup thickness and orientation angles. The post-processing operation can be repeated for the variation of any different design parameter that affects the same **C**—and this can include a group of **C’**s that form multiple fabrications. In that case, there will be a set of basis vectors for each different fabrication. The user can obtain additional flexibility by assigning more fabrications to the model, even though they may have the same initial composition.

Strain gradients

Two ingredients are required to compute strain gradients as a function of some design variable λ. First, we must have the displacement gradients computed from the governing equations (L.2); this subject was covered in full in the previous section. The second requirement for the strain variation is the partial derivative or variation of the strain as a function of nodal displacements. For a linear analysis, this is easy to obtain, since one only has to turn off the nonlinearity in the strain-displacement relationship, and compute strain as a function of $\mathbf{u}_{,\lambda}$ instead of **u**. This is the same requirement as that expressed by the formula

$$\mathbf{B}_L(X)\mathbf{u} = \varepsilon \tag{L.5}$$

where we have emphasized that **B** depends only on the undeformed geometry X. For nonlinear analysis, we would require the relationship

$$\mathbf{B}_{NL}(X, \mathbf{u})\mathbf{u} = \varepsilon \tag{L.6}$$

Unfortunately, this expression is *not* equivalent to substituting the displacement gradient for the displacements in the existing strain routines because **B** itself is a function of the actual displacements of the problem. This is especially true of corotation software that is applied well before strains are computed.

Fortunately, there is an entirely different approach that can be used. We note that the internal force routines compute the first variation of the energy *via*

$$\begin{aligned} \delta\mathbf{u}^T\mathbf{f}_{in} &= \int(\sigma \;\; \delta\varepsilon)\delta A \\ &= \delta\mathbf{u}^T\left(\sum_l w_l \mathbf{B}_{NL}^T \sigma_l\right) \end{aligned} \tag{L.7}$$

where we have arranged the stresses into a “vector” defined by a particular element. A corresponding vector exists for the strains, so that when “engineering” strains are used, the energy is the inner product of the stress and the strain. The *w* above are integration weights. If we examine (L.7) closely, we see that the integral of the gradient we desire is already in place, so long as we replace the stress vector with a one in the desired slot, and zero elsewhere. For example, in the E410 arrangement of strains, we have the ordering $N_x, N_y, N_{xy}, M_x, M_y, M_{xy}$ for the stresses, and $\varepsilon_x^0, \varepsilon_y^0, \varepsilon_{xy}^0, \kappa_x^0, \kappa_y^0, \kappa_{xy}^0$ are the corresponding strains. If we wish to obtain ε_{xy}^0 , then our “stress” vector would be zero except for a one for component N_{xy} for each integration point *l*. The resulting “internal force” vector $\bar{f}_k$ provides the integral of the gradient of strain over the element as a function of a *unit* variation of a given displacement component. This relationship holds even in the presence of corotation and projection; in fact, results are improved when both are applied. The output of the internal force calculation is of course a nodal vector of the same length and structure as the internal force; we can call this vector $\bar{f}_k$ the strain gradient coefficient vector. We summarize these operations by the following:

$$\begin{aligned} \bar{\sigma}^{(k)} &= \mathbf{e}_k \\ \delta\mathbf{u}^T\bar{\mathbf{f}}_k &= \int\bar{\sigma}^{(k)}\delta\varepsilon dA \\ &= \delta\mathbf{u}^T\left(\sum_l w_l \mathbf{B}_{NL}^T \bar{\sigma}^{(k)}\right) \end{aligned} \tag{L.8}$$

where $\mathbf{e}_k$ is an array with the same structure as stress, but with unity in position *k* and zero elsewhere. Now we see the significance of the subscript *k* on the force vector: it is the base variation of strain component *k* with respect to the displacement field. The integral of the strain variation with respect to a *particular* displacement gradient becomes

$$\int\varepsilon_{k,\,\lambda}dA = \left(\frac{\delta\mathbf{u}}{\delta\lambda}\right)^T\bar{\mathbf{f}}_k = \bar{\mathbf{f}}_k^T\mathbf{u}_{,\lambda} \tag{L.9}$$

where the total derivative can be substituted for the ratio of variations since these variations in **u** are restricted to those satisfying the equilibrium equation (L.1). The average (centroidal) gradient for the element is

$$\bar{\varepsilon}_{k,\,\lambda} = \frac{\int \varepsilon_{k,\,\lambda}\, dA}{A} = \frac{\bar{\mathbf{f}}_k^T \mathbf{u}_{,\lambda}}{A} \tag{L.10}$$

where *A* is the area of the element. These calculations can be done with existing software with a minimum of effort. For values at the integration points, one can set only that component corresponding to point *l* to unity. Then the divisor in (L.10) becomes the integration weight w_l instead of *A*, and the operations above are repeated for each integration point.

Strain gradients with corotation

The displacement gradient above refers to the deformational displacements in the local element frame. The inner product (L.10) is valid only when both $\bar{\mathbf{f}}_k$ and $\mathbf{u}_{,\lambda}$ are in the same coordinate frame. However, the displacement gradient available from **STAGS** is in the usual computational system. They first must be transformed to the element frame as a variation in total displacements, and then converted by the corotational projector into the local deformational system:

$$\mathbf{u}_{,\lambda} = \mathbf{P}\mathbf{u}^E_{,\lambda} \tag{L.11}$$

where **P** is the corotational projector, and $\mathbf{u}^E_{,\lambda}$ are the displacements taken from the **STAGS** archive and transformed into the element frame. This transforms the product in (L.7) to

$$\bar{\varepsilon}_{k,\,\lambda} = \frac{\bar{\mathbf{f}}_k^T \mathbf{P}\mathbf{u}^E_{,A}}{A} \tag{L.12}$$

This is the final result needed for display of the strain gradients in the element frame. The usual transformations apply for display of strain gradients in shell/fabrication coordinate frames.

Gradient computation in STAGS

Let us now summarize how **STAGS** accomplishes our objective to determine the gradient of the system displacement unknowns **u**. First, we must have a solution at the desired load and boundary environment for the reference design. Most often, such a solution is accomplished by solving (L.1) at a series of increasing load steps using all the solution tools available in **STAGS**. If the user desires to follow with a gradient analysis, he will specify this in the solution **.bin* input file. One can request that the solution will stop at a given set of load steps, and instead of an eigenanalysis, perform a gradient analysis. Or one can elect the option to compute gradients at a successful conclusion of the analysis at a given load step. In either case, **STAGS** will compute the second equation in (L.4): it will in turn examine the fabrications involved in the gradient definition, and zero out the **C** matrix for all non-involved fabrications. For those involved in the variation, only a given {*ij*,*ji*} pair of **C** matrix components will be nonzero, and their values will be set to unity. An internal force calculation will be done (our system first variation), and a right hand side belonging to component *ij* will be the result. After we have all 21 or 24 independent right hand sides, we compute their *gradient basis vector* $\mathbf{u}_{,ij}$ counterparts with the previously factored stiffness matrix **K**. If a current stiffness matrix is not available, one will be computed and factored. The basis vectors will be archived, along with the gradient of the displacements with respect to the load, something already required for path-following algorithms. At that point, S2 has finished its business.

The user now has the option of computing a *particular* displacement gradient by applying the first equation in (L.4). Let us for the moment assume that he has at hand the full set of coefficients of variation of **C** with respect to his particular choice of design variables. We currently have an option in **stapl** to permit the user to input these coefficients as part of his interview or his.*pin* input stream. **stapl** will then sum up the contributions from each gradient basis vector and display the result. The user also has the option to display the gradient of strain resulting from this displacement gradient. In addition, one can display the displacement or strain gradient with respect to load. This latter information can be very revealing to an engineer wishing to determine what margins exist at a critical load, for instance. The plot will show where in the structure displacements or strains are most sensitive and perhaps critical in determining the outcome of a design. Lastly, we have the option of using previously computed eigenvectors as displacement gradients. In a very real sense, eigenvectors show alternative load paths that might be important should the stability of the structure go critical. The strain gradients from such an analysis will point out where strain is most likely to grow if stability is lost.

The GradC Program

For illustrative and reference purposes, a FORTRAN-language program (called `GradC`) that computes a **C** matrix and its partial derivatives is listed in the following paragraphs—along with 6 subroutines that are called by it and with a FORTRAN header file (`gccom.h`) that is used by `GradC` and most of its subordinate routines. The logic and usage of this program are discussed after those listings. Output from `GradC` can be plotted by **STAGS**' **stapl** processor and used as input for other applications.

Main Program (`GradC`):

```
*************************************************************************
                              Program GradC
*************************************************************************

#include “keydefs.h”

       _implicit_none_

#      include “gccom.h”
#      include “pie.h”

       Logical   prompt


       pi   = 3.141592653589793d0
       dtr = pi/180.d0
       rtd = 180.d0/pi

       tol = 1.e-5

*      GET MATERIAL DATA
*      =================
10     print 100
20     print 200
       read*, nmat

       if (nmat.le.0) then
          print 300
          stop
       endif

       if (nmat.gt.MAXMAT) then
          print 400, MAXMAT
          goto 20
       endif

       do 30 i=1,nmat
          print 500, i
          read*, e1(i), nu12(i), g12(i), e2(i)
30     continue

*      GET LAYER DATA
*      ==============
40     print 600
       read*, layers

       if (layers.lt.1 .or. layers.gt.MAXLAYER) then
          print 700, MAXLAYER
          goto 40
       endif

       do 60 i=1,layers

50         print 800, i
           read*, imat(i), t(i), angle(i)

           if (imat(i).lt.1 .or. imat(i).gt.nmat) then
               print 900, imat(i)
               goto 50
           endif

60     continue

       print 1000
       read*, ecz

*      COMPUTE AND PRINT C MATRIX
*      ==========================
       call compcc (e1,      nu12, g12, e2,     ecz,
     &                 layers, imat, t,    angle, cct)

       print 1100
       call out

*      COMPUTE C MATRIX MATERIAL DERIVATIVE
*      ====================================
70     if (prompt(‘Compute a C matrix material derivative? ‘)) then

           call MatDeriv
           goto 70

       endif

*      COMPUTE C MATRIX THICKNESS DERIVATIVE
*      =====================================
80     if (prompt(‘Compute a C matrix thickness derivative? ‘)) then

           call ThickDeriv
           goto 80

       endif

*      COMPUTE C MATRIX ANGLE DERIVATIVE
*      =================================
90     if (prompt(‘Compute a C matrix angle derivative? ‘)) then

           call AngleDeriv
           goto 90

       endif
```

```
*      CHECK FOR ANOTHER C MATRIX COMPUTATION
*      =====================================
       goto 10

100   format(/'---------------'
     &        /'Welcome to GradC'
     &        /'----------------')
200   format(/'Number of materials (zero to exit)? ',$)
300   format(/'---------------'
     &        /'GradC Completed'
     &        /'---------------')
400   format('>>>  Number of materials limited to:',i4)
500   format('Material',i3,':  E1, Nu12, G12, E2? ',$)
600   format(/'Number of layers? ',$)
700   format('>>>  Number of layers limited to:',i4)
800   format('Layer',i4,':  Material, Thickness, Angle? ',$)
900   format('>>>  Bad material number:',i4)
1000  format(/'Eccentricity? ',$)
1100  format(/'C Matrix'/)

       end
```

Subroutine AngleDeriv:

```
**********************************************************************
                      Subroutine AngleDeriv
**********************************************************************

       _implicit_none_

#      include "gccom.h"

*      COMPUTE C MATRIX ANGLE DERIVATIVE
*      ================================
       call zerof (MAXLAYER, dthick)
       call zerof (MAXLAYER, dangle)

       rtol = tol

       do 10 i=1,layers

           print 100, i
           read*, dangle(i)

           if (dangle(i).ne.0) then
               rtol = max( rtol, abs(angle(i))*tol )
           endif
```

```
10    continue

      print 200

      call LayerDeriv

100   format('Layer',i4,':  dAngle? ',$)
200   format(/'C Matrix Angle Derivative'/)

      end
```

Subroutine LayerDeriv:

```
*********************************************************************
                     Subroutine LayerDeriv
*********************************************************************

      _implicit_none_

#     include "gccom.h"

*     COMPUTE A LAYER (THICKNESS OR ANGLE) DERIVATIVE
*     =============================================

      do 10 i=1,layers
          tp(i)     = t(i)     + dthick(i) * rtol
          anglep(i) = angle(i) + dangle(i) * rtol
10    continue

      call compcc (e1,     nu12, g12, e2,     ecz,
     &                layers, imat, tp,  anglep, cctp)

      do 20 i=1,layers
          tp(i)     = t(i)     - dthick(i) * rtol
          anglep(i) = angle(i) - dangle(i) * rtol
20    continue

      call compcc (e1,     nu12, g12, e2,     ecz,
     &                layers, imat, tp,  anglep, cctm)

      do 30 i=1,21
          cct(i) = (cctp(i)-cctm(i)) / (2.d0*rtol)
30    continue

      call out

      end
```

Subroutine MatDeriv:

```
**********************************************************************
                       Subroutine MatDeriv
**********************************************************************

       _implicit_none_

#      include “gccom.h”

       Character  eg*3

*      COMPUTE C MATRIX MATERIAL (E1, E2, OR G12) DERIVATIVE
*      ===================================================

       call zerof (MAXMAT, de1 )
       call zerof (MAXMAT, de2 )
       call zerof (MAXMAT, dg12)

10     print 100
       read*, mat

       if (mat.lt.1 .or. mat.gt.nmat) then
           print 200, mat
           goto 10
       endif

20     print 300
       read*, eg

       call upper (3,eg,eg)

       if (eg.eq.’E1’) then
           de1(mat) = 1.d0
           print 400
       elseif (eg.eq.’E2’) then
           de2(mat) = 1.d0
           print 500
       elseif (eg.eq.’G12’) then
           dg12(mat) = 1.d0
           print 600
       else
           print 700
           goto 20
       endif

*      COMPUTE C MATRIX FINITE DIFFERENCE
*      =================================
       rtol = e1(mat) * tol

       do 30 i=1,nmat
```

```
            e1p (i) = e1 (i) + de1 (i) * rtol
            e2p (i) = e2 (i) + de2 (i) * rtol
            g12p(i) = g12(i) + dg12(i) * rtol
30       continue

         call compcc (e1p,     nu12, g12p, e2p,    ecz,
        &                layers, imat, t,     angle, cctp)

         do 40 i=1,nmat
            e1p (i) = e1 (i) - de1 (i) * rtol
            e2p (i) = e2 (i) - de2 (i) * rtol
            g12p(i) = g12(i) - dg12(i) * rtol
40       continue

         call compcc (e1p,     nu12, g12p, e2p,    ecz,
        &                layers, imat, t,     angle, cctm)

         do 50 i=1,21
            cct(i) = (cctp(i)-cctm(i)) / (2.d0*rtol)
50       continue

         call out

100      format('Material number? ',$)
200      format('>>>  Bad material number:',i4)
300      format('Derivative with respect to: E1, E2, or G12? ',$)
400      format(/'C Matrix E1 Derivative'/)
500      format(/'C MAtrix E2 Derivative'/)
600      format(/'C Matrix G12 Derivative'/)
700      format('>>>  Enter: E1, E2, or G12')

         end
```

Subroutine Out:

```
***********************************************************************
                          Subroutine Out
***********************************************************************

         _implicit_none_

#        include "gccom.h"

         Integer ij
         Integer j

*        ----------------------
         ij(i,j) = i*(i-1)/2 + j
*        ----------------------
```

```
       do 10 i=1,6
           print 100, (cct(ij(i,j)),j=1,i)
10     continue

100    format(1x,1p6e13.5)

       end
```

Logical Function Prompt:

```
************************************************************************
                       Logical Function Prompt( msg)
************************************************************************

       _implicit_none_

       Character msg*(*)

       Character answer*3
       Logical   cmatch

       print 10, msg
       read*, answer

       prompt = cmatch(answer,’Y^ES’)

10     format(/a,$)

       end
```

Subroutine ThickDeriv:

```
************************************************************************
                                Subroutine ThickDeriv
************************************************************************

       _implicit_none_

#      include “gccom.h”

       call zerof (MAXLAYER, dthick)
       call zerof (MAXLAYER, dangle)

       rtol = tol
       do 10 i=1,layers

           print 100, i
           read*, dthick(i)

           if (dthick(i).ne.0) then
               rtol = max( rtol, abs(t(i))*tol )
           endif

10     continue

       print 200

       call LayerDeriv

100    format(‘Layer’,i4,’:  dThickness? ‘,$)
200    format(/’C Matrix Thickness Derivative’/)

       end
```

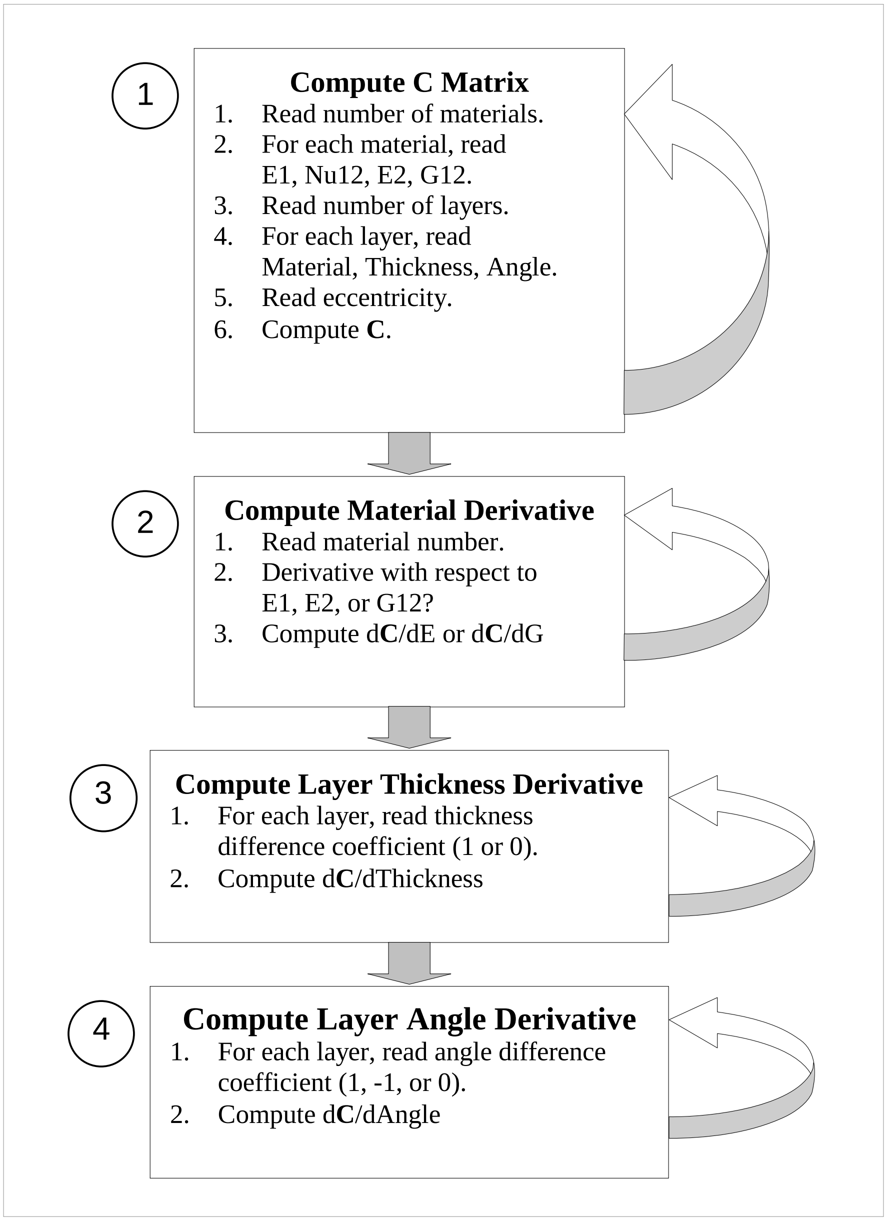
Fortran Header File gccom.h:

```
*      ====================
*      GLOBAL DATA: gccom.h
*      ====================

       Integer     MAXMAT
       Parameter (MAXMAT = 10)

       Integer     MAXLAYER
       Parameter (MAXLAYER = 100)

       _float_  angle (MAXLAYER)
       _float_  anglep(MAXLAYER)
       _float_  cct (21)
       _float_  cctm(21)
       _float_  cctp(21)
       _float_  dangle(MAXLAYER)
       _float_  de1 (MAXMAT)
       _float_  de2 (MAXMAT)
       _float_  dg12(MAXMAT)
       _float_  dthick(MAXLAYER)
       _float_  e1 (MAXMAT)
       _float_  e1p(MAXMAT)
       _float_  e2 (MAXMAT)
       _float_  e2p(MAXMAT)
       _float_  ecz
       _float_  g12 (MAXMAT)
```

```
      _float_   g12p(MAXMAT)
      _float_   nu12(MAXMAT)
      _float_   rtol
      _float_   t(100)
      _float_   tol
      _float_   tp(MAXLAYER)

      Common  /gccom1/  angle,   anglep,
     &                     cct,     cctm,    cctp,
     &                     dangle, de1,     de2,     dg12, dthick,
     &                     e1,      e1p,     e2,      e2p,   ecz,
     &                     g12,     g12p,    nu12,    rtol,
     &                     t,        tol,   tp

      Integer   i
      Integer   imat(MAXLAYER)
      Integer   layers
      Integer   mat
      Integer   nmat

      Common  /gccom2/  i,  imat,  layers,  mat,  nmat

*      ============
*      END: gccom.h
*      ============
```

Using the GradC Program

The `GradC` program allows users to compute a **C** matrix and the partial derivatives of a **C** matrix with respect to one of the material properties: E1, E2, and G12, or one of the laminate properties: thickness and orientation angles. The four logical stages provided by `GradC` are shown the following Figure:



Compute C Matrix

1. Read number of materials.
2. For each material, read E1, Nu12, E2, G12.
3. Read number of layers.
4. For each layer, read Material, Thickness, Angle.
5. Read eccentricity.
6. Compute **C**.

Compute Material Derivative

1. Read material number.
2. Derivative with respect to E1, E2, or G12?
3. Compute d**C**/dE or d**C**/dG

Compute Layer Thickness Derivative

1. For each layer, read thickness difference coefficient (1 or 0).
2. Compute d**C**/dThickness

Compute Layer Angle Derivative

1. For each layer, read angle difference coefficient (1, -1, or 0).
2. Compute d**C**/dAngle

Logical flow of program `GradC`.

Computation of a C Matrix

A **C** matrix is computed during the first stage of the `GradC` program. As shown in this Figure, during this stage the user supplies material and fabrication properties for a composite laminate. For each material in the laminate, the user supplies `E1`, `Nu12`, `E2`, and

G12. This version of GradC permits up to 10 materials to be specified. This limit can be modified easily by changing the **MAXMAT** parameter in the gccom.h header file. Laminate geometry is next given by specifying the thickness and material principle axis orientation angle for each layer. This version of GradC permits up to 100 layers to be specified. This limit can be modified easily by changing the **MAXLAYER** parameter in the gccom.h header file. Next, the eccentricity of the shell middle surface from the element reference surface, as defined by the element nodes, is specified. GradC computes a **C** matrix using these data.

After a **C** matrix is computed, the user is asked if another **C** matrix computation is desired. If the response is yes, then the data just described are entered for another laminate. Otherwise, the user is moved along to the second stage of GradC.

Computation of a C Matrix Material Partial Derivative

A **C** matrix material partial derivative is computed during the second stage of the GradC program. As shown in the Figure, during this stage the user identifies a material (as a number that identifies one of the materials entered during stage one) and the material property for the partial derivative. To identify the material property, the user enters one of the case insensitive values: ‘E1’, E2’, or ‘G12’ (without quotes). Using these data, GradC computes the partial derivative of the **C** matrix computed in stage one with respect to the specified material property.

After a **C** matrix material partial derivative is computed, the user is asked if another material partial derivative computation is desired. If the response is yes, then the data just described are entered to specify another material and material property. Otherwise, the user is moved along to the third stage of GradC.

Computation of a C Matrix Thickness Partial Derivative

A **C** matrix thickness partial derivative is computed during the third stage of the GradC program. As shown in the Figure, during this stage the user identifies each layer that is to be considered during the derivative computation. If a thickness difference coefficient (referred to by the code as dThickness) is specified (usually as 1), then the layer thickness is considered during the derivative computation. However, if a thickness difference coefficient is specified as 0, then the layer thickness is not considered during the derivative computation. Using these data, `GradC` computes the partial derivative of the **C** matrix computed in stage one with respect to the specified layer thicknesses.

After a **C** matrix thickness partial derivative is computed, the user is asked if another thickness partial derivative computation is desired. If the response is yes, then the data just described are entered to specify another set of thickness difference coefficients. Otherwise, the user is moved along to the fourth stage of `GradC`.

Computation of a C Matrix Angle Partial Derivative

A **C** matrix angle partial derivative is computed during the fourth stage of the `GradC` program. As shown in the Figure, during this stage the user identifies each layer that is to be considered during the derivative computation. If an angle difference coefficient (referred to by the code as `dTheta`) is specified (usually as 1 or -1), then the layer angle is considered during the derivative computation. However, if an angle difference coefficient is specified as 0, then the layer angle is not considered during the derivative computation. Using these data, `GradC` computes the partial derivative of the **C** matrix computed in stage one with respect to the specified layer angles.

After a **C** matrix angle partial derivative is computed, the user is asked if another angle partial derivative computation is desired. If the response is yes, then the data just described are entered to specify another set of angle difference coefficients. Otherwise, the user is moved back to the first stage of `GradC`.

X
PAT2S

This appendix is not up-to-date *vis a viz* version 5.0 of the **STAGS** program. It is included in this document for reference purposes.

Introduction

The **PATRAN** to **STAGS** translator, **PAT2S**, illustrates the use of the **STAR** Data Put (DP) routines. **PAT2S** creates or updates a **STAGS** database. After preparation, the database is suitable input for **STAGS**’ S2 processor. Figure 4 shows the data flow from a **PATRAN** neutral file to a **STAGS** database. The following paragraphs describe the preparation of a **STAGS** database from a **PATRAN** neutral file.

Input File

The user first generates a **PATRAN** model. The user names the neutral file, *case.pat.i*. The user must also proved a user instruction file, *case.usr.i*. The user will replace *case* with a prefix appropriate for his model. *i* is an integer, which distinguishes files with the same prefix. **PAT2S** opens the *case.pat.i* or *case.usr.i* file with the greatest integer suffix. If gaps occur in the list of integer suffixes, **PAT2S** opens the last file before the gap occurs.

Execution

The user runs **PAT2S** in either of the following ways. The user can invoke **STAGS**’ STP processor with the case name as a command line argument and, then, choose the **PATRAN** to **STAGS** translator option. The user can also directly invoke **PAT2S** according to the following command line example,

```
% PAT2S case [debug]
```

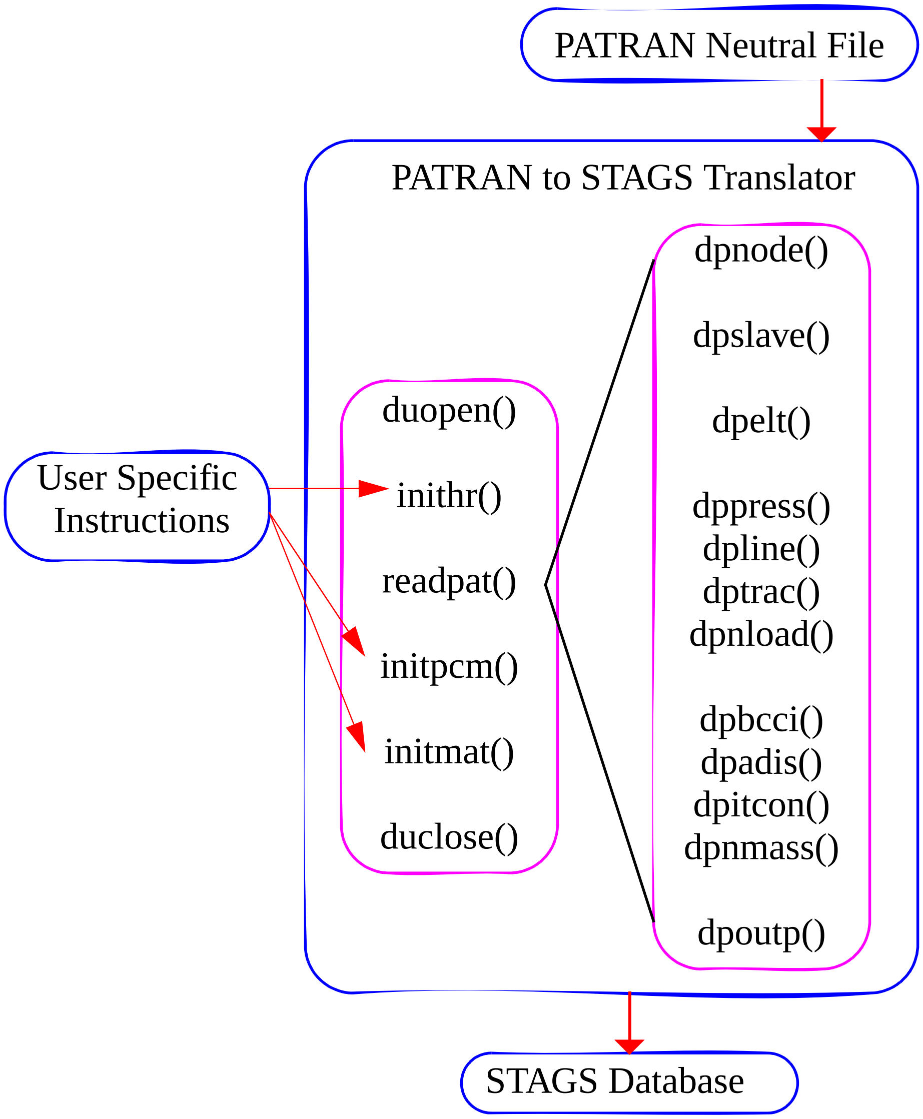


Figure 4. **PATRAN** To **STAGS** Translator.

case is the case name prefix. *debug* is an optional command line argument. If *debug* is present, the file *case.sot.i* contains a complete ASCII representation of data written into the **STAGS** database, *case.sav*. Look at the section, Output Files, for more information on these **PAT2S** output files. However, the ASCII information may be difficult to understand for users not familiar with the format of the **STAGS** database. The main purpose of the *debug* option is to provide a rough trace of the progress of translation in case of translation error.

Output Files

PAT2S uses the **STAGS** Access Routines (**STAR**) to place data into the **STAGS** database. Therefore, the output files for **PAT2S** are the same output files for **STAR**. These files include *case.sot.i* and *case.sav*. The prefix, *case*, and the suffix, *i*, follow the convention of the input files. *case.sot.i* contains diagnostic messages during translation. If the translation from **PATRAN** to **STAGS** is not successful, users should read the end of the *case.sot.i* file. **STAGS**' S2 processor uses the *case.sav* file as input. *case.sav* is the model database. In most cases, **PAT2S** creates a new *case.sav* file. However, **PAT2S** can augment existing *case.sav* files. Because of this feature, the user is responsible for keeping copies of old *case.sav* files before translation.

User Instruction File Format

The user instruction file for **PAT2S** consists of a sequence of logical free-form input records, one logical record corresponding to each FORTRAN input list. In the following, a record is referred to by use of a name, such as “B-1 Element Type Translation”.

A free-form input record contains a number of *numerical data fields*, each separated by one of several *data terminators*, and optional *comments*, placed after the end of input data and ignored by the program. There are two types of numerical data fields, *integer* and *floating point*.

- Unless otherwise noted, an entry on a data record is an integer if the variable name starts with I–N. Otherwise it is to be treated as a floating point number.
- Integer field widths cannot exceed 5 characters, including the optional sign. Leading blanks and a terminating character are not counted.
- Floating point numbers must contain a decimal point; an exponent is optional. The exponent may be in any form allowed by regular FORTRAN “E” type format. Thus, the following data forms are all equivalent

```
1450.   1.45E+03  .145+4   1.45E3
```

- Floating-point decimal field widths are unlimited, however floating-point data are truncated to about 7 or 8 decimal digits.

- A numerical data field may begin with any number of blanks (which are ignored) and is terminated either with the last column for input data (column 80) or with one of the following characters:

`“ ″`	blank
`“,″`	comma
`“/″`	slash
`“$″`	dollar sign

- Blanks are ignored everywhere on records containing numerical data, except when they occur between two numerical data fields; then the first field is terminated by the blank. Thus input integers or floating point numbers may never contain embedded blanks.

  WARNING: A blank line is not ignored; it produces a single logical record.

- A comma is normally used to terminate a data field when the logical record contains additional data. Hence, when the last data field on one line is terminated with a comma, this functions as a continuation character and indicates that the logical record continues with the next input line. Otherwise, the logical record is terminated when the end of data on the line is reached. Successive commas on a line may be used to generate blank values of integer items in a list. For example, `“20,,,10″` is equivalent to `“20, 0, 0, 10″`, which is equivalent to `“20 0 0 10″`.

- A slash terminates a logical record, and means that any following data field begins a new logical record. Thus, several logical records may be constructed with one input line (whereas with the use of commas, several input records might comprise a single logical record). A slash following a comma prevents continuation and the comma then functions as a simple terminator.

- A dollar sign in column 1 indicates a comment card.

  A dollar sign in any other column signals the end of data on a record and means that the remaining information on the line is ignored. This space may be used for comments. A dollar sign may be used also when the data field on a line is terminated by a comma, *i.e.*, when the logical record continues on the following input line.

User Instruction File Records

Because **STAGS** has modeling capabilities which the **PATRAN** neutral file cannot describe, a separate set of user instructions must accompany the **PATRAN** neutral file. The following pages describe the input records in a User Instruction file, which is subject to the above free form guidelines.

A-1 Case Title

The case title is read on the first line, which may contain any alphanumeric character. Subsequently any number of comment records can be added provided they begin with a “$” in column 1. Comments can also be included at the end of a data line, a “$” terminating data, and the comment following. A list of the complete input file, including any comment records, is printed at the beginning of all text output files. The user is urged to use this record as a way to document the analysis.

COMMENT

COMMENT case title

✦ *go to* B-1

B-1 Element Type Translation

The next set of lines map the shape, nodes, and configuration number in the **PATRAN** neutral file (Packet Type 02, Variables **IV**, **NODES**, and **CONFIG**) to a corresponding element type in **STAGS**. There is a default set of mappings as indicated below.

NECODE

NECODE Number of user defined element translation records. 0 means use the default. A 0 indicates that the translation will proceed according to the following map:

Shape	Nodes	Configuration Number	**STAGS** element type
2	2	0	210
2	2	1	211
2	2	2	110
2	2	3	130
2	2	4	250
3	3	0	320
4	4	0	410
4	4	1	411
4	9	0	480
4	9	1	510
4	9	2	710

The elements 130 and 250 are not currently supported.

```
if (NECODE > 0) go to B-1a
else   go to C-1
```

B-1a Element Type List

This record is read **NECODE** times. The following applies only if **NECODE** is not 0. Each line has 4 integers: **ISHAPE**, **INODES**, **IPAT**, and **ISTAGS**.

ISHAPE(i) INODES(i) IPAT(i) ISTAGS(i)

ISHAPE(i) **PATRAN** neutral file (Packet Type 02), variable **IV**.

INODES(i) **PATRAN** neutral file (Packet Type 02), variable **NODES**.

IPAT(i) **PATRAN** neutral file (Packet Type 02), variable **CONFIG**.

ISTAGS(i) **STAGS** element type (e.g. 320, 410, or 480).

✦ *go to* C-1

C-1 Material Translation

The next record associates a **PATRAN** material ID (Packet Type 02, variable **PID**) with a **STAGS** material number. This record is currently not active. Material information in the **PATRAN** neutral file (Packet type 03) is not translated into **STAGS** material properties information. The user should place a 0 for this record.

NMATCD

NMATCD Number of user defined associations between **PATRAN** material properties and **STAGS** material properties. 0 means the **PATRAN** material ID corresponds to the **STAGS** material ID. Since this record is not active, the user should always enter 0.

if (**NMATCD** > 0) *go to* C-1a
else *go to* D-1

C-1a Material List

This record is read **NMATCD** times. The following applies only if **NMATCD** is not 0. Each line has 2 integers: **MPAT** and **MSTAGS**.

MPAT(i) MSTAGS(i)

MPAT(i) **PATRAN** neutral file (Packet Type 02), variable **PID**.

MSTAGS(i) **STAGS** material ID number.

✦ *go to* D-1

D-1 Element Property

PATRAN can associate an arbitrary list (Packet Type 04, Variable **DATA**) of numbers with an element. **PATRAN** tags each element with a property ID (Packet Type 02, Variable **PID**) in order to establish this association. **PAT2S** uses the element property ID to specify mount table ID, Cross Section Table ID, or Wall Fabrication Table ID. The actual mount table, Cross Section Table, or Wall Fabrication Table occur in subsequent lines of the user instruction file. **PAT2S** also uses the **PATRAN** element property list of numbers to specify the parameters normally specified in the **STAGS** T-1a through T-4c records.

NELMCD

NELMCD Number of user defined associations between **PATRAN** element property ID and **STAGS** mount table ID, Cross Section Table ID, or Wall Fabrication Table ID. If this record contains 0, then the default association is **PATRAN** element property ID equals **STAGS** table ID.

if (**NELMCD** > 0) *go to* D-1a
else *go to* E-1

D-1a Element Property List

This record is read **NELMCD** times. The following applies only if **NELMCD** is not 0. Each line has 2 integers: **IEPAT** and **IESTAGS**.

For mount elements, the **PATRAN** element property list (Packet Type 04, variable **DATA**) contains the following:

MATID, **IMNT1**,**IMNT2**, **LINKS**, **RLX1**,**RLY1**,**RLZ1**, **RLX2**,**RLY2**,**RLZ2**

MATID is the **PATRAN** material property ID, which **PAT2S** does not use. **PATRAN** assigns this number. The other variables occur in the **STAGS** T-1a and T-1b input records. The user should consult the **STAGS** user manual for the meaning of these entries. For hyperelastic fastener elements, the **PATRAN** element property list (Packet Type 04, variable **DATA**) contains the following:

MATID, **IMNT1**,**IMNT2**,**IMNT3**,**IMNT4**,**IMNT5**,**IMNT6**

These variables occur in the **STAGS** T-1C input record. For beam elements, the **PATRAN** element property list (Packet Type 04, variable **DATA**) contains:

MATID, **XSI**,**ECY**,**ECZ**, **ILIN**,**IPLAS**

These variables occur in the **STAGS** T-2 input record. For shell elements, the **PATRAN** element property list contains the following:

MATID,**UNUSED**, **ZETA**,**ECZ**, **ILIN**,**IPLAS**,**INTEG**,**IPENL**,**IANG**, **RX**,**RY**,**RZ**

The variable, UNUSED, must contain 0. The other variables correspond to fields in the **STAGS** T-3a through T-4c records for triangles or quadrilaterals. Users should consult the **STAGS** User Manual for the meaning of these records.

The wall reference vector, (**RX**,**RY**,**RZ**), may differ from element to element. Each distinct wall reference vector requires a distinct Packet Type 04 in the **PATRAN** neutral file. Because specifying a wall reference vector in this manner is laborious, **PAT2S** offers another method to indicate the wall reference vector. The user triggers this alternate method when **IANG**=1 and (**RX**,**RY**,**RZ**)=(0.0,0.0,0.0) in the element property list for triangles and quadrilaterals.

For this alternate method to work the user must do the following. The user first specifies alternate coordinate systems (Packet Type 05) in **PATRAN** and, then, associates a particular coordinate system with a particular element of the model. **PATRAN** puts the alternate system information in the coordinate frame data (Packet Type 05). **PATRAN** projects the x-axis of a Cartesian frame or the r-axis of a cylindrical or spherical frame onto the plane of the element. This projected axis is the **PATRAN** material axis. The θ_1 angle in the element data (Packet Type 02) is the angle between the **PATRAN** material axis and the vector from node 1 to node 2 of the element. Since we do not know the algorithm used by **PATRAN** to determine this material axis, we assume that this material axis lies in the same plane as the x-y plane of the **STAGS** element frame. **PAT2S** transforms this material axis to the **PATRAN** global frame. The resulting vector is the wall reference vector (**RX**,**RY**,**RZ**). Users should consult the **PATRAN** manual on Mesh Generation for more information.

IEPAT(i) IESTAGS(i)

IEPAT(i) **PATRAN** neutral file (Packet Type 02), variable **PID**.

IESTAGS(i) **STAGS** mount table ID, Cross Section Table ID,
or Wall Fabrication Table ID.

✦ *go to* E-1

E-1 Load Translation

PATRAN allows two types of element loading: line loads and surface tractions. **PATRAN** also allows node forces. In addition to these loads and tractions, **STAGS** also permits live and dead pressure. Live pressure remains normal to the deformed surface throughout geometrically nonlinear deformations. Dead pressure is constant (i.e. normal to the undeformed configuration). Whereas **PATRAN** defines element loading in the parametric directions of the parent geometry, **STAGS** has five options for defining element distributed load directions:

element-edge coordinates (x_e, y_e, z_e)
element-surface coordinates (x_s, y_s, z_s)
shell coordinates (X', Y', Z')
global coordinates (x_g, y_g, z_g)
element normal z'

Stags also defines two point load directions:

computational coordinates (x'', y'', z'')
global coordinates (x_g, y_g, z_g)

In order to resolve these conflicts and to allow full use of **STAGS** element loading features, we established rules for interpreting **PATRAN** distributed loads (Packet Type 06), and **PATRAN** node forces (Packet Type 07).

In order to facilitate distributed loading and point force interpretation, we established six load categories with specific load type and coordinate direction combinations. The load categories with the associated load types and coordinate directions are the following:

Intrinsic:
line loads in element-edge coordinates
surface tractions in element-surface coordinates
node forces in computational coordinates

shell:
line loads and surface tractions in shell coordinates

global:
line loads and surface tractions in global coordinates
node forces in global coordinates

live:
live pressure in the z' (element normal) direction

dead:
dead pressure in the z' (element normal) direction

velocity:
velocity dependent point load.

For the categories live and dead, we treat the z', the 3rd load component as the pressure value. Other load components are irrelevant for those categories.

PATRAN groups distributed loads and node forces into load sets. Each identified by a unique load set ID (LSID). We use the LSID to categorize distributed loads and point forces according to the above six types. By default, all load sets are in the intrinsic category, which permits line loads in element-edge coordinates, surface tractions in element-surface coordinates, and node forces in computational coordinates. The user instruction file provides a means for independently placing each load set into one of the other five categories. Each LSID may appear in only one category.

With this background information, we now return to the next records in the user instruction file. The next lines in the user instruction file are the load specification records.

NSHELL NGLOB NLIVE NDEAD NVELC

NSHELL **NSHELL** must always equal 0. This option is currently not supported. If **NGLOB**, **NLIVE**, **NDEAD**, and **NVELC** are all 0, then **PAT2S** uses the intrinsic designation: line loads in element-edge frame, surface tractions in element-surface frame, node forces in computational frame.

NGLOB **NGLOB** is the number of IDs considered in the global frame. This number includes both distributed load set IDs and node forces IDs.

NLIVE **NLIVE** is the number of IDs considered as live loads. This number includes only distributed load set IDs.

NDEAD **NDEAD** is the number of IDs considered as dead loads. This number includes only distributed load set IDs.

NVELC **NVELC** is the number of IDs considered as velocity dependent loads. This number includes only point force set IDs.

```
if (NGLOB > 0) go to E-1a
else if (NLIVE > 0) go to E-1b
else if (NDEAD > 0) go to E-1c
else if (NVELC > 0) go to E-1d
else go to F-1
```

E-1a Global Frame List

This record is read **NGLOB** times.

NLGLOB(i)

NLGLOB(i) **PATRAN** neutral file (Packet Type 06 or 07), variable **IV**.

✦

```
if (NLIVE > 0) go to E-1b
else if (NDEAD > 0) go to E-1c
else if (NVELC > 0) go to E-1d
else go to F-1
```

E-1b Live Load List

This record is read **NLIVE** times.

NLLIVE(i)

NLLIVE(i) **PATRAN** neutral file (Packet Type 06), variable **IV**.

```
✦   if (NDEAD > 0) go to E-1c
    else if (NVELC > 0) go to E-1d
    else go to F-1
```

E-1c Dead Load List

This record is read **NDEAD** times.

NLDEAD(i)

NLDEAD(i) **PATRAN** neutral file (Packet Type 06), variable **IV**.

✦ if (**NVELC** > 0) *go to* E-1d
else *go to* F-1

E-1d Velocity Dependent List

This record is read **NVELC** times.

NLVELC(i)

NLVELC(i) **PATRAN** neutral file (Packet Type 07), variable **IV**.

✦ *go to* F-1

F-1 Load System

PATRAN groups load data using an arbitrary number of load sets, which **PATRAN** identifies by a unique load set ID (LSID). **STAGS** organizes loads into two load systems, A and B. In this context, “load” includes both distributed (element) loads and point (nodal) forces. By default, we place all loads in load system A. The next user instruction lines allow users to override this default by permitting them to place each LSID in load system B or to omit each LSID from the **STAGS** model.

NSYSB NOMIT

NSYSB **NSYSB** is the number of IDs indicating use of load system B. Load system A is the default.

NOMIT **NOMIT** is the number of IDs omitted from translation.

```
if (NSYSB > 0) go to F-1a
else if (NOMIT > 0) go to F-1b
else go to G-1
```

F-1a System B List

This record is read **NSYSB** times.

NLSYSB(i)

NLSYSB(i) PATRAN neutral file (Packet Type 06 or 07), variable **IV**.

✦ if (**NOMIT** > 0) *go to* F-1b
else *go to* G-1

F-1b Omitted Load List

This record is read **NOMIT** times.

NLOMIT(i)

NLOMIT(i) **PATRAN** neutral file (Packet Type 06 or 07), variable **IV**.

✦ *go to* G-1

G-1 Constraint Translation

Prescribed nodal displacements are translated from **PATRAN** node displacements records (Packets Type 08). **PATRAN** groups this data using an arbitrary number of constraint sets, each identified by a unique constraint set ID (CSID). **STAGS** assembles prescribed nodal displacements into its two load systems, A and B.

Closely related to prescribed nodal displacements are boundary conditions, which are a set of degree-of-freedom (DOF) flags indicating the condition of each DOF as free (unconstrained) or fixed (constrained).

STAGS also recognizes initial conditions, initial displacement, or initial velocity. We make use of the **PATRAN** node displacements record to also specify initial displacement or initial velocity. With these numerous possible interpretations of the **PATRAN** node displacements record, we introduce the constraint translation records in the next lines of the user instruction file.

NDBASC NDINCR NINTDS NINTVL

NDBASC **NDBASC** is the number of IDs indicating basic boundary conditions.

NDINCR **NDINCR** is the number of IDs indicating incremental boundary conditions.

NINTDS **NINTDS** is the number of IDs indicating initial displacement.

NINTVL **NINTVL** is the number of IDs indicating initial velocity.

```
if (NDBASC > 0) go to G-1a
else if (NDINCR > 0) go to G-1b
else if (NINTDS > 0) go to G-1c
else if (NINTVL > 0) go to G-1d
else go to H-1
```

G-1a Basic Boundary Condition List

This record is read **NDBASC** times.

IDBASC(i)

IDBASC(i) **PATRAN** neutral file (Packet Type 08), variable **IV**.

```
if (NDINCR > 0) go to G-1b
else if (NINTDS > 0) go to G-1c
else if (NINTVL > 0) go to G-1d
else go to H-1
```

G-1b Incremental Boundary Condition List

This record is read **NDINCR** times.

IDINCR(i)

IDINCR(i) **PATRAN** neutral file (Packet Type 08), variable **IV**.

```
if (NINTDS > 0) go to G-1c
else if (NINTVL > 0) go to G-1d
else go to H-1
```

G-1c Initial Displacement List

This record is read **NINTDS** times.

IINTDS(i)

IINTDS(i) **PATRAN** neutral file (Packet Type 08), variable **IV**.

✦ if (**NINTVL** > 0) *go to* G-1d
else *go to* H-1

G-1d Initial Velocity List

This record is read **NINTVL** times.

IINTVL(i)

IINTVL(i) **PATRAN** neutral file (Packet Type 08), variable **IV**.

✦ *go to* H-1

H-1 Constraint System Translation

PATRAN groups nodal displacements using an arbitrary number of constraint set IDs (CSID). **STAGS** organizes constraints into two load systems, A and B. By default, we place all constraints in load system A. The next user instruction lines allow users to override this default by permitting them to place each CSID in load system B or to omit each CSID from the **STAGS** model.

NDSYSB NDOMIT

NDSYSB **NDSYSB** is the number of IDs indicating use of load system B. Load system A is the default.

NDOMIT **NDOMIT** is the number of IDs omitted from translation.

if (**NDSYSB** > 0) *go to* H-1a
else if (**NDOMIT** > 0) *go to* H-1b
else *go to* I-1

H-1a System B List

This record is read **NDSYSB** times.

IDSYSB(i)

IDSYSB(i) **PATRAN** neutral file (Packet Type 08), variable **IV**.

✦ if (**NDOMIT** > 0) *go to* H-1b
else *go to* I-1

H-1b Omitted Constraint List

This record is read **NDOMIT** times.

IDOMIT(i)

IDOMIT(i) **PATRAN** neutral file (Packet Type 08), variable **IV**.

✦ *go to* I-1

I-1 Multipoint Constraint Translation

Multiple interpretation of the **PATRAN** multipoint constraint record (Packet Type 14) is also possible. We use the **PATRAN** multipoint constraint record to specify either a **STAGS** multipoint constraint, Lagrangian constraint, or partial compatibility constraint. The next set of lines from the user instruction file removes the ambiguity of interpreting multipoint constraint records.

NCMPC NCLGC NCPCM NCOMIT

NCMPC **NCMPC** is the number of multipoint constraint IDs for interpretation as multipoint constraints.

NCLGC **NCLGC** is the number of multipoint constraint IDs for interpretation as Lagrangian constraint.

NCPCM **NCPCM** is the number of multipoint constraint IDs for interpretation as partial compatibility constraints.

NCOMIT **NCOMIT** is the number of multipoint constraint IDs omitted from translation.

```
if (NCMPC > 0) go to I-1a
else if (NCLGC > 0) go to I-1b
else if (NCPCM > 0) go to I-1c
else if (NCOMIT > 0) go to I-1d
else go to J-1
```

I-1a Multipoint Constraint List

This record is read **NCMPC** times.

MCMPC(i)

MCMPC(i) **PATRAN** neutral file (Packet Type 14), variable **IV**.

✦ if (**NCLGC** > 0) *go to* I-1b
else if (**NCPCM** > 0) *go to* I-1c
else if (**NCOMIT** > 0) *go to* I-1d
else *go to* J-1

I-1b Lagrangian Constraint List

This record is read **NCLGC** times.

MCLGC(i)

MCLGC(i) **PATRAN** neutral file (Packet Type 14), variable **IV**.

✦ if (**NCPCM** > 0) *go to* I-1c
else if (**NCOMIT** > 0) *go to* I-1d
else *go to* J-1

I-1c Partial Compatibility Constraint List

This record is read **NCPCM** times.

MCPCM(i)

MCPCM(i) **PATRAN** neutral file (Packet Type 14), variable **IV**.

```
if (NCOMIT > 0) go to I-1d
else go to J-1
```

I-1d Omitted Multipoint Constraint List

This record is read **NCOMIT** times.

MCOMIT(i)

MCOMIT(i) **PATRAN** neutral file (Packet Type 14), variable **IV**.

✦ *go to* J-1

J-1 Master-Slave Translation

Since **PATRAN** cannot specify master-slave node relationships, we use the user instruction file to establish these relationships between nodes. The next set of lines in the user instruction file is for master slave relationships.

NMASLAV

NMASLAV **NMASLAV** is the number of master-slave relationships between nodes.

✦ if (**NMASLAV** > 0) *go to* J-1a
else *go to* K-1

J-1a Master-Slave List

This record is read **NMASLAV** times.

NSUNT(i) NSNODE(i) NMUNT(i) NMNODE(i)

NSUNT(i) **NSUNT(i)** is the unit number of the slave node. If **NSUNT(i)** = 0, then **NSNODE(i)** is a global node number.

NSNODE(i) **NSNODE(i)** is slave node number in the unit. If **NSUNT(i)** = 0, then slave node number is a global node number.

NMUNT **NMUNT(i)** is the unit number of the master node. If **NMUNT(i)** = 0, then **NMNODE(i)** is a global node number.

NMNODE **NMNODE(i)** is master node number in the unit. If **NMUNT(i)** = 0, then master node number is a global node number.

go to K-1

K-1 Tables Translation

Because we currently do not translate the material property data records (packet type 03) in **PATRAN** to a **STAGS** database, we use the user instruction file to specify the material properties of the model. We make use of the format in the B-3, I-1, I-2, I-3, I-3a, I-4a, I-4b, I-4c, I-4d, J-1, J-2a, J-2b, J-3a, J-3b, K-1, K-2, K-5a, K-5b, and K-5c **STAGS** input records to specify the material properties, plasticity, creep, mount element force tables, beam element Cross Section Tables, and shell Wall Fabrication Tables. Users should consult the **STAGS** User Manual for more information on these input records.

NTAM NTAB NTAW NTAP NTAMT

NTAM Refer to record B-3, Data Table Summary, in the **STAGS** User Manual for the meaning of these variables.

NTAB

NTAW

NTAP Although this variable is used in record B-3, it has no meaning for **PAT2S**. Users should set it to 0.

NTAMT

```
if (NTAM > 0) go to L-1
else if (NTAB > 0) go to M-1
else if (NTAW > 0) go to N-1
else if (NTAMT > 0) go to O-1
else go to P-1
```

L-1–L-4 Material Properties

These records are read **NTAM** times. The subsequent input records are identical with **STAGS**' I-1, I-2, I-3, and I-3a input records which specify the material elastic, plastic, and creep properties. Users should consult the **STAGS** User Manual for more information on these input records.

```
if (NTAB > 0) go to M-1
else if (NTAW > 0) go to N-1
else if (NTAMT > 0) go to O-1
else go to P-1
```

M-1–M-4 Table Information

These records are read **NTAB** times. The subsequent input records are identical with **STAGS**' I-4a, I-4b, I-4c, and I-4d input records which specify the mount element table information. Users should consult the **STAGS** User Manual for more information on these input records.

```
if (NTAW > 0) go to N-1
else if (NTAMT > 0) go to O-1
else go to P-1
```

N-1–N-5 Beam Cross Section Properties

These records are read **NTAW** times. The subsequent input records are identical with **STAGS**’ J-1, J-2a, J-2b, J-3a, and J-3b input records which specify the beam cross section information. Records J-4a and J-4b are not supported by **PAT2S**. Users should consult the **STAGS** User Manual for more information on these input records.

if (**NTAMT** > 0) *go to* O-1
else *go to* P-1

O-1–O-5 Shell Wall Properties

These records are read **NTAMT** times. The subsequent input records are identical with **STAGS**’ K-1, K-2, K-5a, K-5b, and K-5c input records which specify the beam cross section information. Records K-3a, K-3b, K-4a, K-4b, and K-6 are not supported by **PAT2S**. Users should consult the **STAGS** User Manual for more information on these input records.

✦ *go to* P-1

P-1 Output Control

The final line in the user instruction file is identical to the **STAGS** V-1 input record, the element unit output control record. The variables **NSELD** and **NSELS** are not active. The user should set these variables to 0. Users should consult the **STAGS** User Manual for more information on these input records.

End of user instructions

Translation Details

The following gives additional details on the translation of a **PATRAN** neutral file to a **STAGS** database. Figure 5 and Figure 6 associate **PATRAN** data records to **STAR** put routines. The user instruction file which directs **PAT2S** in processing a **PATRAN** neutral file determines some of the parameters to these **STAR** put routines. The tail of each arrow in the figures is a **PATRAN** data packet. The head of each arrow point to the associated **STAR** put routine, which we used to create an entry in the **STAGS** database.

Node Data Translation

Figure 5 indicates that the translation of node data (Packet Type 01) also utilizes coordinate frame information (Packet Type 05). A node references an alternate coordinate frame using the **PATRAN** variable, **CID** (Packet Type 01). The **PATRAN** alternate coordinate frame is a rectangular, cylindrical, or spherical frame. This frame serves the same function as the **STAGS** branch coordinate frame for shells. This frame determines a node's computational frame to global frame transformation. If **IV** = 0 (Packet Type 05), then **PATRAN** does not specify an alternate frame. The nodes's computational to global frame transformation is the identity transformation. If **IV** = 1, then **PATRAN** specifies a rectangular alternate frame. The node's computational to global frame transformation is the variable, **R** (Packet Type 05). If **IV** = 2, then **PATRAN** specifies a cylindrical frame. The computational frame at the node has the **PATRAN** convention with the x-axis as the radial axis, the y-axis as the circumferential axis, and the z-axis as the axial axis. We construct a transformation from the **PATRAN** alternate frame to this computational frame. The node's computational to global transformation combines the transformation from computational to alternate frame with the alternate to global frame transformation in the variable, **R**. If **IV** = 3, then **PATRAN** specifies

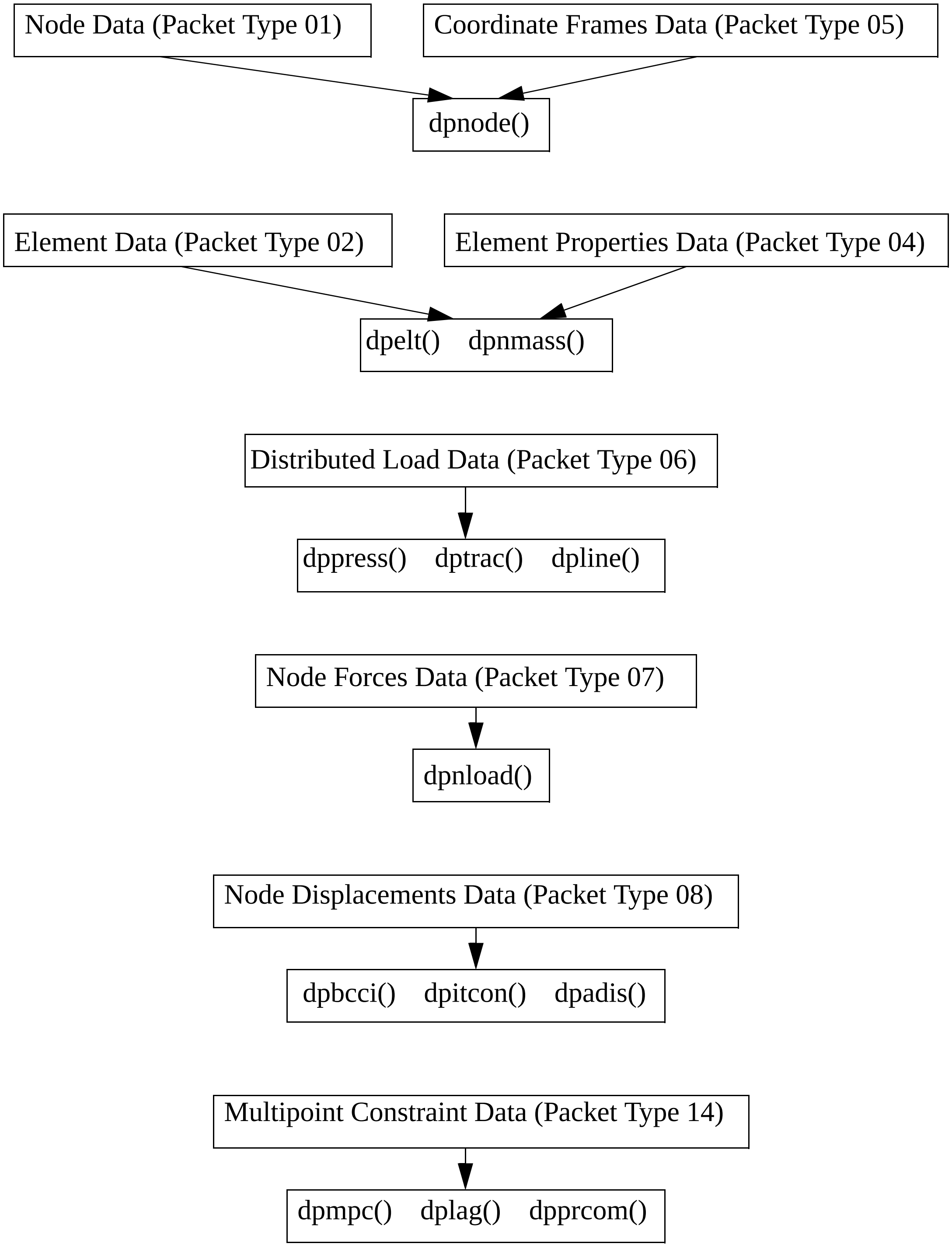

Node Data (Packet Type 01)
Coordinate Frames Data (Packet Type 05)
dpnode()
Element Data (Packet Type 02)
Element Properties Data (Packet Type 04)
dpelt() dpnmass()
Distributed Load Data (Packet Type 06)
dppress() dptrac() dpline()
Node Forces Data (Packet Type 07)
dpnload()
Node Displacements Data (Packet Type 08)
dpbcci() dpitcon() dpadis()
Multipoint Constraint Data (Packet Type 14)
dpmpc() dplag() dpprcom()

Figure 5. **STAR** Routines Accessed During **PATRAN** Neutral File Translation.

a spherical frame. The computational frame at the node has the **PATRAN** convention with the x-axis as the radial axis, the y-axis as the azimuthal axis, and the z-axis as the longitudinal

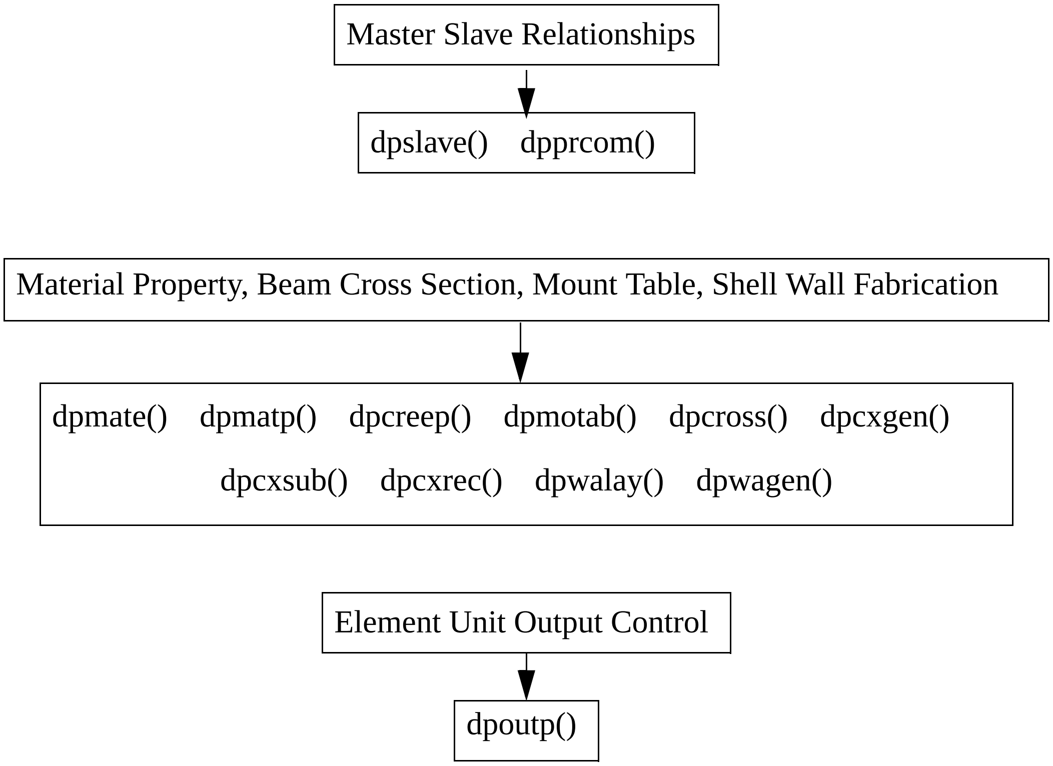

Master Slave Relationships
dpslave() dpprcom()
Material Property, Beam Cross Section, Mount Table, Shell Wall Fabrication
dpmate() dpmatp() dpcreep() dpmotab() dpcross() dpcxgen()
dpcxsub() dpcxrec() dpwalay() dpwagen()
Element Unit Output Control
dpoutp()

Figure 6. **STAR** Routines Accessed for User Instruction File.

axis. We construct a transformation from the **PATRAN** alternate frame to this computational frame. The computational to global frame transformation for the node combines the computational to alternate frame transformation with the alternate to global frame transformation in the variable, **R**.

Element Data Translation

Figure 5 indicates that the translation of element data (Packet Type 02) also uses the element properties information (packet type 04). The description of input record B-1 in the user instruction file explains the default interpretation of the **CONFIG** variable (Packet Type 02). This interpretation maps **PATRAN** element types to **STAGS** element types. In the D-1A input record, we described the necessary information for the **DATA** field of the element properties packet (Packet Type 04), which gives attributes of individual elements.

There are a few special elements which the user can describe by a **PATRAN** neutral file. If the element shape equals 2, **IV** = 2 (Packet Type 02), and the element configuration equals

7, **CONFIG** = 7, then the element is an added mass element. The first node in **LNODES** array is the location of the added mass and the second entry in **DATA** (Packet Type 04) is the added mass value. If **IV** = 4, **NODES** = 9, and **CONFIG** = 1, then the element is the **STAGS** 510 transition element. If **IV** = 4, **NODES** = 9, and **CONFIG** = 2, then the element is the **STAGS** 710 transition element. For these two elements, some entries in **LNODES** have values less then or equal to 0 in order to reflect node pattern in the transition element. Since these elements are not part of the standard **PATRAN** element libraries, interactive use of **PATRAN** cannot generate these elements. However, other programs generating **PATRAN** neutral files can easily generate a 510 or 710 element entry.

Distributed Load Translation

Depending on the entries in the user instruction file, the translator interprets the distributed loads (Packet Type 06) in the **PATRAN** neutral file. If the user instructs **PAT2S** to interpret a distributed load as a live pressure, then **PAT2S** uses only every third component in **PDATA**. **PAT2S** calls the routine *dppress*. If the user instructs **PAT2S** to interpret a distributed load as a dead pressure, then **PAT2S** uses only every third component in **PDATA**. **PAT2S** puts a distributed line load in the **STAGS** database with a call to *dpline* and a distributed surface load in the **STAGS** database with a call to *dptrac*. Although these translation mechanisms are in place, **STAGS** S2 processor currently does not recognize distributed traction loads. Any attempt to interpret distributed surface loads will invoke *dptrac*. *dptrac* will then exit with an error.

Node Displacement Translation

Depending on the entries in the user instruction file, the translator interprets the node displacement (Packet Type 08) in the **PATRAN** neutral file. If the user instructs **PAT2S** to interpret a node displacement as a basic boundary condition or incremental boundary condition, then **PAT2S** ignores the load values in **DDATA** and uses only the displacement component flags in **ICOMP**. The **PATRAN** convention for the displacement component flags is 0 for free degrees of freedom and 1 for constrained degrees of freedom. The **STAGS** convention is the opposite. Therefore, **PAT2S** changes the contents of the **ICOMP** variable from the **PATRAN** convention to the **STAGS** convention. The contents of the **ICOMP** variable adds to the single point constraint specified by the **PSPC** variable in the node data packet (Packet Type 01). **PAT2S** then calls the routine *dpbcci* to create an entry in the **STAGS** database.

If the user instructs **PAT2S** to interpret a node displacement as an initial displacement or an initial velocity, **PAT2S** uses the value in **DDATA** and calls the routine *dpitcon* to create an entry in the **STAGS** database. **PAT2S** calls *dpadis* for the default action of applying a specified displacement at the node.

Multipoint Constraint Translation

Depending on the entries in the user instruction file, the translator interprets the multipoint constraint data (Packet Type 14) in the **PATRAN** neutral file. If the user instructs **PAT2S** to interpret a multipoint constraint data set as a Lagrangian constraint, then **PAT2S** calls the routine *dplag*. If the user instructs **PAT2S** to interpret a multipoint constraint data set as a partial compatibility constraint, then **PAT2S** calls the routine *dpprcom*. The **PATRAN** dependent node becomes the **STAGS** slave node and the **PATRAN** independent node becomes the **STAGS** master node. **PAT2S** ignores all but the first independent node. If the user does not provide a translation interpretation, **PAT2S**' default action is to translate **PATRAN**'s multipoint constraint packet into a **STAGS** multipoint constraint and by calling the routine, *dpmpc*.