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A SHORTENED VERSION OF THE REPORT ON MINIMUM WEIGHT DESIGN OF IMPERFECT ISOGRID-STIFFENED ELLIPSOIDAL SHELLS UNDER UNIFORM EXTERNAL PRESSURE

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ABSTRACT

GENOPT, a program that can be used to optimize anything, and BIGBOSOR4, a program for stress, buckling, and vibration analysis of segmented, branched, stiffened, elastic shells of revolution, are combined to create a capability to optimize a specific kind of shell of revolution: an internally isogrid-stiffened elastic ellipsoidal shell subjected to uniform external pressure. Optimum designs are obtained for isogrid-stiffened and unstiffened axisymmetrically imperfect and perfect titanium 2:1 ellipsoidal shells. The decision variables are the shell skin thickness at several user-selected meridional stations, the height of the isogrid stiffeners at the same meridional stations, the spacing of the isogrid stiffeners (constant over the entire shell), and the thickness of the isogrid stiffeners (also constant over the entire shell). The design constraints involve maximum stress in the isogrid stiffeners, maximum stress in the shell skin, local buckling of an isogrid stiffener, local buckling of the shell skin between isogrid stiffeners, general nonlinear bifurcation buckling, nonlinear axisymmetric collapse, and maximum normal displacement at the apex of the dome. Optimum designs first obtained by GENOPT are subsequently evaluated by the use of STAGS, a general-purpose finite element computer program. It is found that in order to obtain reasonably good agreement between predictions from BIGBOSOR4 and STAGS it is necessary to model the ellipsoidal shell as an "equivalent" ellipsoidal shell consisting of a spherical cap and a series of toroidal shell segments that closely approximates the true ellipsoidal meridional shape. The equivalent ellipsoidal shell is optimized with up to four axisymmetric buckling modal imperfections, each imperfection shape assumed to be present by itself. Computations include both plus and minus axisymmetric buckling modal imperfection shapes. At each design cycle and for the plus and minus version of each axisymmetric imperfection shape the following analyses are conducted: 1. linear general axisymmetric bifurcation buckling analysis (in order to obtain the axisymmetric linear buckling modal imperfection shapes), 2. nonlinear axisymmetric stress analysis at the design pressure, 3. nonlinear axisymmetric collapse analysis, and 4. nonlinear non-axisymmetric bifurcation buckling analysis. For each axisymmetric imperfection shape the design margins include an axisymmetric collapse margin, a general buckling margin, a margin involving the normal displacement of the apex of the shell, and local skin and stiffener stress margins and local skin and stiffener buckling margins within two approximately equal meridional regions of the equivalent ellipsoidal shell. There is

generally good agreement of the predictions from STAGS and from BIGBOSOR4 for the elastic behavior of the perfect stiffened and unstiffened optimized shells and for the behavior of the imperfect stiffened optimized shells with axisymmetric buckling modal imperfections. Optimization with the use of only axisymmetric buckling modal imperfections has a disadvantage in the case of the unstiffened imperfect shell under certain conditions: the optimum design of the axisymmetrically imperfect unstiffened shell evolves in such a way that, according to predictions from STAGS, a non-axisymmetric buckling modal imperfection with the same amplitude as an axisymmetric buckling modal imperfection causes collapse of the shell at an external pressure far below the design pressure. This disadvantage is easily overcome if, during optimization cycles, the unstiffened shell wall in the neighborhood of the apex is forced to remain thick enough so that local axisymmetric buckling does not occur primarily at and near the apex but instead occurs primarily in the remainder of the shell. An extensive study of some of the previously optimized elastic shells is conducted with STAGS including elastic-plastic material properties. The effect on collapse pressure of initial imperfections in the form of off-center residual dents produced by load cycles applied before application of the uniform external pressure is determined and compared with the effect on collapse pressure of imperfections in the form of non-axisymmetric and axisymmetric linear buckling modes, especially the non-axisymmetric linear buckling modal imperfection with n=1 circumferential wave, which seems to be the most harmful imperfection shape for optimized externally pressurized ellipsoidal shells. For the optimized unstiffened shell it is found that a residual dent that locally resembles the n=1 linear buckling modal imperfection shape is just as harmful as the entire n=1 linear buckling modal imperfection shape.

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1.0 INTRODUCTION

Cohen and Haftka [1] were the first to create a capability that could be used for the automated design of imperfect shells of revolution. In this paper a further step is taken by combination of GENOPT [2-7], which incorporates the optimizer ADS written by Vanderplaats and his colleagues [8,9], with a version of BOSOR4 [10-12] called "BIGBOSOR4" [7] to permit optimization of a certain class of shells of revolution: an elastic isogrid-stiffened ellipsoidal shell of revolution subjected to uniform external pressure. BIGBOSOR4 requires the same input data and performs the same analyses as BOSOR4, but BIGBOSOR4 will handle shells of revolution with more segments and more degrees of freedom than can be handled by BOSOR4.

GENOPT is described in detail in [2]. It has previously been used to obtain optimum designs of various systems [3-7]. Optimum designs are obtained via the optimizer, ADS, created many years ago by Vanderplaats and his colleagues [8,9]. In GENOPT the optimizer, ADS, is "hardwired" in the "0-5-7" mode, which is a modified method of steepest descent. This optimization method requires as input the gradients of the design constraints (stress, buckling, collapse, displacement) with respect to each of the decision variables.

As described in [2] and [7], GENOPT creates a system of processors called "BEGIN", "DECIDE", "MAINSETUP", "OPTIMIZE", "SUPEROPT", "CHANGE", "CHOOSEPLOT", "DIPLOT", by means of which optimum designs can be obtained. The architecture of this system of processors is analogous to that previously generated for specific applications [13,14]. "SUPEROPT" is a script by means of which "global" optimum designs can be obtained, as described in [7] and [15] and briefly on the second page of Table 34. “Global” is enclosed in quotation marks because SUPEROPT does not actually find the global optimum design but, with repeated executions, will find a design that is very likely to have an objective that is very close to the global objective.

2.0 PURPOSE AND SUMMARY OF THIS PAPER AND THE LONG REPORT ON WHICH THIS PAPER IS BASED

This paper is a shortened version of the long report [26].

2.1 Purpose of this paper and the long report on which this paper is based

The author was motivated to create a program to optimize an elastic shell of revolution **the behavior of which is significantly nonlinear**. In this application the nonlinearity is entirely caused by moderately large axisymmetric prebuckling meridional rotations of the elastic externally pressurized 2:1 ellipsoidal (or "equivalent" ellipsoidal) shell. (NOTE: some of the STAGS models used to evaluate the optimum designs produced by GENOPT include plastic flow.)

The author wanted to generate another application of GENOPT. **He hopes that in the future GENOPT will be used by others to obtain optimum designs of entirely different systems**. In the long version of this paper (called “report” in the four file folders and names for text, figures, tables, and appendix), the text, the figures, the tables, and the appendix are stored electronically in four separate folders:

text = sdm50.report.pdf;
figures = sdm50pdf.report.figures;
tables = sdm50pdf.report.tables;
appendix = sdm50pdf.report.appendix.

The electronic report [26] is long. In particular there are many, many figures and tables. Some of the tables are very long. **They are all included in [26] in order that a researcher or designer will be able to use this information to obtain, by analogy, the optimum design of any different system.**

The analogous electronic files in this paper are called:
text = sdm50.paper.pdf;
figures = sdm50pdf.paper.figures;
tables = sdm50pdf.paper.tables;
appendix = sdm50pdf.paper.appendix.
NOTE: In the AIAA version of this work the tables and figures are appended to the text.

The captions of the figures and tables are unusually long. The intention is to minimize the need for the reader to flip back and forth from text to figure or from text to table to learn the meaning of the data presented there. A significant amount of the textual material in this paper and in the long report on which this paper is based is contained in those captions. A nomenclature section is not included in this paper because there are few equations, the equations are simple, and the meanings of the symbols in them are explained with them.

NOTE: The table and figure numbers used in this paper are the same as those for the corresponding tables and figures in the long report [26] on which this paper is based. Therefore, in this paper the numbering for tables and figures is not consecutive since many of the tables and figures in the long report are not present in this paper.

2.2 Summary of this paper and of the long report on which this paper is based

GENOPT [2, 7] is used to obtain optimum designs of externally pressurized, perfect or imperfect, isogrid-stiffened or unstiffened, elastic titanium 2:1 ellipsoidal shells subjected to uniform external pressure, p = 460 psi (called the "design pressure").

GENOPT [2, 7] is described in Section 3. **BIGBOSOR4** [7] and **STAGS** [20 – 23] are described in Section 4.

The necessity to use an "**equivalent**" ellipsoidal shell profile rather than a **true** ellipsoidal shell profile is explained in Section 5.

Minimum-weight optimum designs are obtained in the presence of **stress, collapse, bifurcation buckling and displacement design constraints** derived from the various analyses described in Section 6.

Numerical results for **optimized isogrid-stiffened and unstiffened perfect and imperfect elastic titanium 2:1 equivalent ellipsoidal shells** are presented in Sections 7 and 8. The shells are first optimized by GENOPT in the presence of **axisymmetric buckling modal imperfections**. Then the optimum designs are evaluated by means of STAGS models that include both axisymmetric and non-axisymmetric buckling modal imperfection shapes.

It turns out that the pressure-carrying capacity of the optimum design of the **unstiffened, imperfect** shell is extremely sensitive to non-axisymmetric buckling modal imperfections, a type of imperfection that cannot be accounted for in the GENOPT model, which can only handle axisymmetric buckling modal imperfections because the BIGBOSOR4 computer program can only handle axisymmetric imperfections. Therefore, the optimized unstiffened shell is severely under-designed. **This deficiency is avoided by a simple reformulation of the optimization problem in which a higher lower bound is specified for the shell wall thickness in the neighborhood of the apex of the shell.**

Improved optimum designs of **unstiffened** axisymmetrically imperfect equivalent ellipsoidal shells are derived in Section 9. These improved optimum designs, the so-called "**thick-apex**" optimum designs, are evaluated by means of STAGS [20 – 24]. The STAGS models account for elastic-plastic material, axisymmetric and non-axisymmetric buckling modal imperfections, and imperfections in the form of **off-center residual dents** produced via a "Load Set B" load cycle involving concentrated normal inward-directed loads or imposed displacements. By "**off-center**" is meant dents located at some radius from the axis of revolution of the shell. Collapse of the dented shells is determined after completion of the Load Set B load cycle by subsequent application of uniform external pressure in Load Set A.

A "**thick-apex**" optimum design of the unstiffened, imperfect shell is found which survives the design pressure in the presence of either axisymmetric or non-axisymmetric buckling modal imperfections or off-center residual dents.

The optimum design of the **isogrid-stiffened** shell derived in Section 8.1 is evaluated in Section 10 by means of STAGS models that include elastic-plastic material, axisymmetric and non-axisymmetric buckling modal imperfections, and imperfections in the form of off-center residual dents.

It is emphasized that STAGS is not used within the optimization "loop", but only AFTER the optimum design has been obtained by GENOPT.

3.0 ABOUT GENOPT (GENeral OPTimization)

The purpose of GENOPT [2] is to enable an engineer or researcher to create a user-friendly system of computer programs for analyzing and/or optimizing anything. **One of the main advantages of GENOPT is that it provides a way in which an engineer or researcher can extend an EXISTING ANALYSIS CAPABILITY to a capability to obtain OPTIMUM DESIGNS based on that existing analysis capability.** The application of GENOPT is not limited to the field of structural mechanics. In [2] the purpose, properties, and operational details of GENOPT are described. The reader is urged to read [2] and [7] in order to obtain a more complete understanding of the work described in this paper and in the long report [26] on which this paper is based.

In **Sub-section 3.1** the GENOPT processors, GENTEXT, GENPROGRAMS, BEGIN, DECIDE, MAINSETUP, OPTIMIZE, SUPEROPT, CHOOSEPLOT, CHANGE, and AUTOCHANGE are briefly described. In **Sub-section 3.2** the concept is introduced that GENOPT automatically creates FORTRAN code some of which is complete and some of which is in **skeletal** form, to be "**fleshed out**" by the GENOPT user for application to a particular generic system chosen by the GENOPT user. In **Sub-section 3.3** the terms "design gradients", "design constraints", and "design margins" are defined. In **Sub-section 3.4** two types of user, the GENOPT user and the "end" user, are identified. **Sub-section 3.5** is long. In **Sub-section 3.5.1** the optimization problem for the generic case, "**equivellipse**" (equivalent ellipsoidal shell of revolution) is formulated with respect to configuration, boundary conditions, shell wall construction, loading, and imperfections (Sub-section 3.5.1.1); the "behaviors" such as stress, displacement, buckling, and collapse that govern the evolution of the design during optimization cycles are defined (Sub-section 3.5.1.2); and the fact that the GENOPT user has to create "user-friendly" variable names, one-line definitions, and "help" paragraphs is explained (Sub-section 3.5.1.3). In **Sub-section 3.5.2** the seven roles that GENOPT-user-established variables play are defined. In **Sub-section 3.5.3** an example of part of a "GENTEXT" interactive session is given in which the GENOPT user creates variable names, one-line definitions, and "help" paragraphs for the generic case, "equivellipse". In **Sub-section 3.5.4** the completed and skeletal FORTRAN libraries automatically created by GENOPT are briefly described. In **Sub-sections 3.6 and 3.7** details are presented corresponding to two parts of the "GENTEXT" interactive "equivellipse" session; exactly what FORTRAN coding GENOPT automatically generates is listed in several tables and suggestions are given relating to the provision of "user-friendly" "help" paragraphs (Sub-section 3.7.2), automatic creation by GENOPT of the skeletal "behavior" subroutines BEHXi (Sub-section 3.7.3), and whether the GENOPT user should "flesh out" the "behavior" subroutines BEHXi or the "STRUCT" subroutine (Sub-section 3.7.4). Finally, in **Sub-section 3.8** some details are provided relative to "fleshing out" SUBROUTINE STRUCT.

3.1 GENOPT processors

GENOPT is executed via the following commands:

GENOPTLOG	(The GENOPT command set is activated.)
GENTEXT	(The GENOPT user responds interactively to prompts by GENOPT in order to provide names, definitions, and roles of variables to be used during execution of the user-friendly system of programs described next.)
GENPROGRAMS	(GENOPT compiles and creates executable processors called "BEGIN", "DECIDE", "OPTIMIZE", "CHOOSEPLOT", "CHANGE", "AUTOCHANGE", described next.)

During the interactive execution of "GENTEXT" by the GENOPT user, GENOPT creates a system of computer programs consisting of the following independently executable processors:

BEGIN	(The user supplies the starting design, material properties, loads, allowables, factors of safety, etc.)

DECIDE	(The user chooses decision variables, lower and upper bounds, linked variables, and inequality constraints.)
MAINSETUP	(The user chooses strategy parameters, which design constraints to ignore during program execution, and analysis type: 1. optimization or 2. analysis of a fixed design or 3. design sensitivity.)
OPTIMIZE or SUPEROPT	(The program system performs the analysis type specified by the user in MAINSTUP. SUPEROPT is described in [15] and briefly on the second page of Table 34.)
CHOOSEPLOT	(The user chooses which quantities to plot vs design iterations or vs the value of a user-selected design sensitivity variable.)
DIPLOT	(The user obtains postscript files, *.ps, which can be used to obtain plots of objective, margins, decision variables vs design iterations or vs a user-selected design sensitivity variable.)
CHANGE	(The user changes selected problem variables. CHANGE is most often used as a device by means which to save a previously obtained optimum design.)
AUTOCHANGE	(The program system changes all decision variables randomly, in a manner consistent with user-specified bounds, linking constraints, and inequality constraints. AUTOCHANGE and OPTIMIZE are executed repeatedly as part of the SUPEROPT script [15] described briefly on the second page of Table 34.)

3.2 Some software is written by GENOPT, some software is written by the GENOPT user

Certain parts of some of these processors (BEGIN, OPTIMIZE, CHANGE) are written in FORTRAN by the GENOPT program system during the interactive "GENTEXT" execution [2,7]. For example, certain subroutines called by the processor, OPTIMIZE (which is named “MAIN” internally), are partly written by GENOPT. These subroutines are named SUBROUTINE STRUCT and SUBROUTINEs BEHXi, i = 1,2,3… and SUBROUTINE OBJECT. (See [7]). SUBROUTINEs BEHXi, i = 1,2,3… are called by SUBROUTINE STRUCT. As created by GENOPT, these subroutines are "**skeletons**"; they have automatically generated argument lists, automatically generated labeled common blocks, and automatically generated "RETURN" and END" statements. They must be supplemented (“**fleshed out**”) by the GENOPT user, whose responsibility it is to add the coding that computes the behavior (for example, stress, buckling, vibration, clearance, etc.) of the generic class of items to be optimized.

The labeled common blocks generated automatically during the GENTEXT interactive session contain all the variables that define the class of objects to be optimized. The body of each of the "skeletal" subroutines STRUCT and/or BEHXi must be "**fleshed out**" by the GENOPT user. See [2,7,16] for examples of how this is done. Also see Tables a30 and a31 in the appendix of [26]. In the present application, which has the generic name, "**equivellipse**" (meaning "equivalent ellipsoidal shell"), only SUBROUTINE STRUCT is "fleshed out" by the GENOPT user; the SUBROUTINEs BEHXi, i = 1,2,3,..14, are not modified by the GENOPT user but are left as automatically created by GENOPT. In other applications [2 - 6] SUBROUTINEs BEHXi are "fleshed out" by the GENOPT user ([2] and Table a31 of [26], for example) in order to compute the "behavior", that is, stress, buckling, etc. SUBROUTINE OBJECT, which is part of the "behavior.new" library, computes the objective function, which in this application is the weight of the ellipsoidal or "equivalent" ellipsoidal shell. In this generic case, "**equivellipse**", the "fleshed out" version of SUBROUTINE STRUCT is very long. A complete list of it is provided in Table a16 of the appendix of [26]. Complete lists of the skeletal SUBROUTINE STRUCT (Table a14 of [26]) and SUBROUTINEs BEHXi, i = 1,2,3… and SUBROUTINE OBJECT (Table a13 of [26]) are also given in the appendix of [26] for the generic case called "**equivellipse**".

3.3 Design gradients, design constraints, design margins

During each optimization cycle, SUBROUTINE STRUCT is called to evaluate the "current" design and each "perturbed" design. A "perturbed" design is the same as the "current" design except that one of the decision variables has been perturbed a small amount (usually 5 per cent) in order to obtain gradients of the responses or "behaviors" (stress, buckling, collapse, apex deflection), which are needed by the optimization software, ADS [8,9]. ADS is embedded in the GENOPT system. The gradients are obtained by simple finite difference:

gradient=[(response for perturbed design) - (response for current design)]/DX (1)

in which DX is the change (perturbation) in one of the decision variables. "Response", which is a "behavior" such as stress, buckling, collapse, apex deflection, etc., is closely related to what in the optimization literature is called a "design constraint". Design constraints usually have one of the following three forms:

Form 1: (not used in this paper or in the long report [26] on which this paper is based; see Table 16)

Form 2: (design constraint) = [(response)/(allowable response)]/(factor of safety) (2)
Form 2 is used for responses such as **bifurcation buckling** or **nonlinear collapse** that must be greater than a user-specified minimum allowable amount.

Form 3: (design constraint) = [(allowable response)/(response)]/(factor of safety) (3)
Form 3 is used for maximum **stress** or maximum **deflection** because the response (stress or deflection) must be less than a user-specified maximum allowable amount.

Design "margins" are given by

(design margin) = (design constraint) – 1.0 (4)

In an academic sense a design is considered feasible only if all design constraints exceed unity or design margins exceed zero. However, for certain practical reasons GENOPT accepts a design as “FEASIBLE” provided that no margin is less than –0.01. GENOPT accepts a design as “ALMOST FEASIBLE” provided that no margin is less than –0.05. GENOPT accepts a design as “MILDLY UNFEASIBLE” provided that no margin is less than –0.1. Which quality of design is accepted by GENOPT is governed by a user-selected index, IDESIGN, an input datum prompted for during the MAINSETUP interactive session. (See Item 725 in Table a24 of [26]).

3.4 Two types of user

There are two types of user referred to in [2] and [7] and in this paper:

1. the GENOPT user

2. the "end" user or simply “the user”.

The roles of the two types of user are defined in [2] and briefly in [7]. In brief, the GENOPT user decides what **generic class of objects** is to be optimized and, using GENTEXT and GENPROGRAMS, "sets up" the processors just listed (BEGIN, DECIDE, etc.) for the "end” user to use for a **specific member** of that generic class. The "end" user establishes, for the specific member of the generic class: 1. the starting design (BEGIN), 2. decision variables and bounds (DECIDE), and 3. analysis type and strategy for the specific object to be optimized (MAINSETUP). Then the "end" user performs the optimization (OPTIMIZE or SUPEROPT). Often the GENOPT user and the "end" user are the same person. Two types of user are identified here and in [2] because the activities required of each differ.

3.5 What the GENOPT user creates and what GENOPT creates

3.5.1 Formulation of the optimization problem for the generic case, “equivellipse”

Before working with the computer the GENOPT user must formulate the optimization problem.

3.5.1.1 Configuration, boundary conditions, loading

The GENOPT user must decide (in this particular application of GENOPT, “equivellipse”) what shell of revolution or class of shells of revolution is to be optimized:

1. shape of the shell (ellipsoidal or **"equivalent" ellipsoidal** or torispherical)
2. boundary conditions (symmetry conditions at the equator)
3. shell wall (internally isogrid stiffened, isotropic elastic material)
4. imperfections (axisymmetric linear buckling modal imperfections)
5. loading (uniform external pressure)

In the generic case, **equivellipse**, the GENOPT user (the writer) decided to consider the imperfections as part of the "environment", that is, part of the loading. Therefore, the GENOPT user decided to introduce multiple load sets even though there is only one type of physical loading: uniform external pressure. The GENOPT user established the following load sets:

Load Set 1 = uniform external pressure and +mode 1 axisymmetric buckling modal imperfection and +mode 2 axisymmetric buckling modal imperfection, in which "mode 1" means the first axisymmetric linear buckling eigenvector and "mode 2" means the second axisymmetric linear buckling eigenvector. The "mode 1" and "mode 2" imperfections are applied one at a time, each in its own turn. The GENOPT user established "behavioral" variables (also called "response" variables in this paper such as variables for collapse, bifurcation buckling, stress, and displacement), pertaining to the "mode 1" environment that are different from those behavioral variables pertaining to the "mode 2" environment. For example, the GENOPT user decided to name the behavioral variable for collapse in the presence of a "mode 1" imperfection shape CLAPS1 and the behavioral variable for collapse in the presence of a "mode 2" imperfection shape CLAPS2. The GENOPT user established analogous "1" and "2" names for the behavioral variables for bifurcation buckling, stress, and displacement. These GENOPT-user-established names are listed in Table 2, which will be discussed later.

Load Set 2 = uniform external pressure and –mode 1 axisymmetric buckling modal imperfection and –mode 2 axisymmetric buckling modal imperfection. Hence, Load Set 1 and Load Set 2 are the same except for the sign of the "mode 1" and the sign of the "mode 2" axisymmetric linear buckling modal imperfection shapes.

In cases for which the optimization included the effect of the first four axisymmetric linear buckling imperfection shapes, that is, mode 1, mode 2, mode 3, and mode 4, the GENOPT user established four load sets. Load Sets 1 and 2 pertain to the presence of plus and minus mode 1 and mode 2 imperfections as just listed. Load Sets 3 and 4 are as follows:

Load Set 3 = uniform external pressure and +mode 3 axisymmetric buckling modal imperfection and +mode 4 axisymmetric buckling modal imperfection. In Load Set 3 the digit "1" in the behavioral variable name denotes "odd-numbered imperfection mode shape" and the digit "2" in the behavioral variable name denotes "even-numbered imperfection mode shape".

Load Set 4 = uniform external pressure and –mode 3 axisymmetric buckling modal imperfection and –mode 4 axisymmetric buckling modal imperfection.

3.5.1.2 Which behaviors (stress, displacement, buckling, collapse) constrain the design

The GENOPT user must decide what behaviors may constrain the design:

1. stress (maximum effective stress in the skin and in the stiffeners of the imperfect shell)
2. displacement (normal displacement at the apex of the imperfect shell)
3. buckling (local buckling of skin and stiffeners, general buckling of the imperfect shell)

4. nonlinear collapse (axisymmetric collapse)

3.5.1.3 The GENOPT user creates variable names, definitions, and "help" paragraphs

The GENOPT user must identify all variables in the problem, create user-friendly names for these variables, create user-friendly one-line definitions for each of the variables, and create supporting "HELP" paragraphs for some or all of the variables. The variable names (8 characters or less) and one-line definitions (60 characters or less) are especially important because they appear in the output data and therefore should be easy to understand by the "end" user, who may not be as familiar with the jargon of the field as is the GENOPT user. The GENOPT-user-established variable names, one-line definitions, and "HELP" paragraphs are what make the system of processors created by GENOPT "user-friendly" if the GENOPT user has done his or her job well. (NOTE: In the "equivellipse" example provided here the GENOPT user (the writer) did **not** do his job very well because he did not provide enough "help" paragraphs. He was a bit sloppy about this because he also planned to be the "end" user. See Sub-section 3.7.2 for examples of where additional "help" should probably have been provided.)

3.5.2 Various roles that variables governing the generic problem play

As described in [2], GENOPT requires that each of the variables be categorized as performing one of the seven roles listed in Table 1. Variables that perform roles 4, 5, and 6 are always "bundled" together. For example, if the GENOPT user selects a variable with Role No. 4 to have the name, "SKNST1", meaning "maximum stress in the shell skin, mode 1 axisymmetric imperfection shape", then the next variable name he or she must provide during the GENTEXT interactive session is an "allowable". The "allowable" that corresponds to the behavior called "SKNST1" might well have the name, "SKNST1A", meaning "**allowable** stress in the shell skin, mode 1 axisymmetric imperfection shape". The third variable in the same "Role 4,5,6" bundle might well have the name, "SKNST1F", meaning "**factor of safety** for maximum stress in the shell skin, mode 1 axisymmetric imperfection shape". All "responses" (also called "behaviors" in this paper) such as stress, buckling, displacement, etc. are treated in this manner. GENOPT requires the GENOPT user to provide all input relating to variables with Roles 1 and 2 before variables with Role 3. All variables with Role 3 must be provided before variables with Roles 4, 5, and 6. All "Role 4,5,6" bundles must be provided before the objective, which is the only Role 7 variable.

Table 2, taken from the GENOPT output file called "equivellipse.DEF" (Table a2), lists the variable names and one-line definitions established by the GENOPT user for the generic case explored here: the "equivalent" ellipsoidal shell. Table 2 also identifies the role number of each variable and whether or not the variable is an array. Notice especially the sequence or "bundle", (Role 4,5,6) = (response, allowable response, factor of safety), that appears repeatedly for each type of response (each type of behavior). During the GENTEXT interactive session the GENOPT user (the writer in this case) "invented" the variable names, such as "CLAPS" for "collapse", "SKNBK" for "local skin buckling", "STFBK" for "stiffener buckling", "SKNST" for "maximum effective stress in the skin", "STFST" for "maximum stress in the stiffeners", and

"WAPEX" for "maximum normal displacement **w** at the apex of the shell". The GENOPT user also supplied the phrases (one-line definitions of the variables) that follow the equals symbols on the right-hand half of Table 2. In this case Table 2 lists **seven** "Role 4,5,6" bundles pertaining to the behavior in the presence of an axisymmetric "mode 1" buckling modal imperfection shape (names ending with the digit "1", such as CLAPS1) and **seven** "Role 4,5,6" bundles pertaining to the behavior in the presence of an axisymmetric "mode 2" buckling modal imperfection shape (names ending with the digit "2", such as CLAPS2). The last variable listed in Table 2, the only Role 7 variable, is called by the GENOPT user WEIGHT. WEIGHT is the objective.

3.5.3 The "GENTEXT" interactive session

In order to establish user-friendly variable names, one-line definitions, and "help" paragraphs, the GENOPT user executes GENTEXT. **Table 3** lists the GENOPT user's input (bold face) for the **first part** of the interactive GENTEXT session pertaining to the equivalent ellipsoidal shell, that is, the generic class called by the GENOPT user "**equivellipse**". The complete input file for GENTEXT for "equivellipse" is listed in the appendix (Table a1). This complete file is called "**equivellipse.INP**". If, during a rather long GENTEXT interactive session, the GENOPT user makes a mistake, he or she can terminate the GENTEXT session, suitably edit the end of the *.INP file where the mistake occurs, and re-execute GENTEXT, indicating that he/she is restarting a partly completed interactive session. GENTEXT will read input from the existing *.INP file until the end of that file, then return to the interactive mode of execution. Hence, the GENOPT user does not interactively have to repeat all his/her input up to the point where he/she made the mistake. This mode of operation is a characteristic of all the computer programs created by the writer over the years.

Table a1-b in the appendix of [26] reproduces **what the GENOPT user actually sees on his/her computer screen during an interactive GENTEXT session**. The GENOPT user's responses are in bold face. Some comments in connection with this table are:
1. The lines that contain the string, "PART 1 …" and "PART 2 …" and "PART 3 …" do not appear on the computer screen.
2. In the middle of the first page of Table a1-b of [26] GENTEXT informs the GENOPT user that one of his/her tasks is "To complete subroutines BEHX1, BEHX2, BEHX3,…BEHXn which calculate equivellipse behavior for a given design;" Actually, GENOPT is more general than implied by that statement, since the GENOPT user may choose to "flesh out" SUBROUTINE STRUCT either instead of or in addition to "fleshing out" (completing) the "behavior" subroutines, BEHXi. In the generic case "equivellipse" the GENOPT user decided to "flesh out" SUBROUTINE STRUCT instead of completing the skeletal BEHXi routines automatically created by GENOPT.
3. On the second page of Table a1-b of [26] there occurs the instruction, "Hit RETURN". Do that.
4. On pages 3 and 4 and later in Table a1-b of [26] there occur the lines, "(lines skipped to save space)". Table a1-b of [26] would be very long if all those "lines skipped" were included. The material that has been skipped is analogous to the material included in the table.
5. GENTEXT echoes some of the GENOPT user's input data. For example, when the GENOPT user typed, "this is explanatory text", GENOPT echoed that phrase in the next line.

6. Where, in Table a1-b of [26], the GENOPT user responded, “this is explanatory text” and “one more line”, in the actual case listed in Table a1 the GENOPT user typed the multi-lined INTRODUCTORY EXPLANATORY TEXT listed near the beginning of Table a1 that begins with the string, “OPTIMUM DESIGN OF ISOGRID-STIFFENED ELLIPSOIDAL HEAD”.

Table 4 is the part of the glossary produced by GENTEXT corresponding to the GENOPT user’s partial interactive input for the generic case “equivellipse” reproduced in Table 3. The complete glossary becomes part of the file called “equivellipse.DEF”. The complete glossary is listed in Table 2. This complete glossary is produced by GENTEXT after the GENOPT user finishes the GENTEXT interactive session. The entire input data file, “equivellipse.INP”, is reproduced in the appendix (Table a1). Also, the entire file, “equivellipse.DEF”, appears in the appendix (Table a2).

Table 5 is the part of the prompting file, “equivellipse.PRO”, produced by GENTEXT corresponding to the GENOPT user’s partial interactive input for the generic case “equivellipse” listed in Table 3. The complete prompting file, “equivellipse.PRO”, appears in Table 6. The prompting file is arranged automatically by GENTEXT. This file contains the following information.

1. prompting numbers, such as **5.0, 10.1, 10.2, 15.1, 20.1, 20.2**, etc.

2. the GENOPT-user-selected variable names:

npoint, xinput, ainput, binput, nodes, xlimit, THKSKN, HIGHST, SPACNG, THSTIF, THKCYL, RADCYL, etc.

3. corresponding one-line definitions of the variables created by the GENOPT user and just listed. NOTE: GENOPT automatically adds the string, “: <variable name>”, to the one-line definition supplied by the GENOPT user, resulting in the following modified one-line definitions corresponding to **npoint**, **xinput**, **ainput**, etc:

number of x-coordinates: npoint
x-coordinates for ends of segments: xinput
length of semi-major axis: ainput
length of semi-minor axis of ellipse: binput
number of nodal points per segment: nodes
max. x-coordinate for x-coordinate callouts: xlimit
skin thickness at xinput: THKSKN
height of isogrid members at xinput: HIGHST
spacing of the isogrid members: SPACNG
thickness of an isogrid stiffening member: THSTIF
thickness of the cylindrical shell: THKCYL
radius of the cylindrical shell: RADCYL
etc.

The GENOPT user’s one-line definitions are in bold face in the items just listed. The one-line definitions with the added string, ":<variable name>", are what is seen by the "end" user.

4. "help" paragraphs created by the GENOPT user, such as:

10.2
"**The ellipse is simulated by a number of shell segments (try 10) each of which has constant meridional curvature (toroidal). npoint is the number of x-coordinates corresponding to the ends of the toroidal segments that make up the equivalent ellipse. You might try to simulate the ellipse by using 10 toroidal segments. Then the value of npoint would be 11 npoint includes the apex of the ellipse (x = 0) and the equator of the ellipse (x = a, in which a = semimajor axis length).**"

as a "help" paragraph for the variable, **npoint**

and

20.2
"**Please make sure to include x = 0 and x = a (equator) when you provide values for xinput**."

as a "help" paragraph for the variable, **xinput**

and

25.2
"**ainput is the maximum "x=dimension" of the ellipse. The equation for the ellipse is x^2/a^2 + y^2/b^2 = 1.0**"

as a "help" paragraph for the variable, **ainput**

and

30.2
"**binput is the y-dimension of the ellipse, the equation for which is x^2/a^2 + y^2/b^2 = 1.0**."

as a "help" paragraph for the variable, **binput**

and

35.2
"**If you have about 10 segments, use a number less than 31. Use an odd number, greater than or equal to 11**"

as a “help” paragraph for the variable, **nodes**

and

40.2

“**xlimit has two functions:**
1. a delimiter for the definition of callouts:
for x < xlimit callouts are x-coordinates.
for x > xlimit callouts are y-coordinates.
Set xlimit equal to about a/2, where a = length of the
semi-major axis of the ellipse.
2. a delimiter for the boundary between Region 1
and Region 2, Design margins for maximum stress and
minimum buckling load in the shell skin and in the
isogrid stiffeners can be computed in two regions,
Region 1: 0 < x < xlimit, and
Region 2: xlimit < x < semi-major axis.”

as a “help” paragraph for the variable, **xlimit**

and

45.2

“**xinput is the vector of x-coordinate callouts for**
thickness of the shell skin and height of the
isogrid stiffeners.”

as a “help” paragraph for the variable, **THKSKN**

and

50.2

“**xinput is the vector of x-coordinate callouts for**
thickness of the shell skin and height of the
isogrid stiffeners.”

as a “help” paragraph for the variable, **HIGHST**.

and

55.2

“**SPACNG = altitude of the equilateral triangle between adjacent**
isogrid members, measured to middle surfaces of isogrid members.
SPACNG = (length of side of triangle)*sqrt(3)/2.
SPACNG is constant over the entire shell.”

as a “help” paragraph for the variable, **SPACNG**

and

60.2
“**THSTIF is constant over the entire shell**.”

as a “help” paragraph for the variable, **THSTIF**.

GENOPT automatically provides the prompting numbers, such as **50.1** for the one line definition of the variable **HIGHST** and **50.2** for the corresponding “help” paragraph.

3.5.4 Completed and “skeletal” FORTRAN libraries created by GENOPT

Table 7 lists the names of FORTRAN libraries created by GENOPT during the GENTEXT interactive session. BEGIN.NEW, STOGET.NEW, and CHANGE.NEW are entirely written by GENOPT. Lists of these three “*.NEW” FORTRAN libraries are given in the appendix of [26] (Tables a3, a4, and a5, respectively, of [26]). The GENOPT user should not modify them in any way. As previously mentioned, STRUCT.NEW and BEHAVIOR.NEW, as created automatically by GENOPT, are **skeletal** libraries either or both of which must be “**fleshed out**” by the GENOPT user. These **skeletal** libraries are listed in the appendix of [26] (Tables a14 and a13, respectively, of [26]). In this particular generic case, called “equivellipse” by the GENOPT user, only the **skeletal** library, **struct.new** (Table a14 of [26]), is “**fleshed out**” by the GENOPT user (Table a16 of [26]). The **skeletal** library, **behavior.new** (Table a13 of [26]) remains unmodified in this case. Table a31 in the appendix of [26] provides an example from the GENOPT “literature” in which the **skeletal** behavior.new library is “**fleshed out**” by the GENOPT user for a generic case called “cylinder”. Another case in which the behavior.new library is “fleshed out” is described in [2].

3.6 What GENOPT creates corresponding to the GENTEXT input listed in Table 3

Tables 8 – 14 pertain to this sub-section.

Table 8 lists the names and functions of several files, “equivellipse”.xxx, automatically created by GENOPT during the GENTEXT interactive session. GENOPT uses these files:

1. to provide information to the user (equivellipse.PRO, equivellipse.DEF), and

2. to save the interactively provided input data (equivellipse.DAT, equivellipse.INP), and

3. to create the FORTRAN libraries listed in Table 7 and the FORTRAN files listed in Table 8 (equivellipse.NEW, equivellipse.COM, equivellipse.WRI, equivellipse.REA, equivellipse.SET, equivellipse.CON, equivellipse.SUB, equivellipse.CHA).

Corresponding to the GENOPT-user-provided input listed in Table 3, GENOPT automatically creates the FORTRAN fragments listed in Tables 9 – 14.

The file, equivellipse.CON, and the skeletal libraries, STRUCT.NEW (Table a14 of [26]) and BEHAVIOR.NEW (Table a13 of [26]), are not "worked on" by GENOPT until the GENOPT user starts defining the "bundles" of variables with Roles 4, 5, and 6 (Role 4 = behavioral variable, Role 5 = allowable variable, Role 6 = factor-of-safety variable). These Role 4, 5, and 6 variable names are used to construct behavioral constraints [Eqs.(2,3)]. This is described in the next sub-section.

The entire files that exist after the GENOPT user has completed the "GENTEXT" interactive session and that are identified in Table 8 are listed in the appendix of [26] (except for equivellipse.PRO, a complete list of which appears in Table 6, and equivellipse.DAT, which contains the same information as equivellipse.INP). The "equivellipse.xxx" files indicated in Table 8 appear in the appendix of [26] as follows: equivellipse.CHA = Table a7 of [26], equivellipse.COM = Table a6 of [26], equivellipse.CON = Table a12 of [26], equivellipse.DEF = Table a2, equivellipse.INP = Table a1, equivellipse.NEW = Table a10 of [26], equivellipse.REA = Table a8 of [26], equivellipse.SET = Table a11 of [26], equivellipse.SUB = Table a28 of [26], equivellipse.WRI = Table a9 of [26].

3.7 What GENOPT creates corresponding to the GENTEXT input listed in Table 15

3.7.1 General information

Tables 15 – 26 pertain to this sub-section, which is analogous to the previous sub-section.

Table 15 lists the GENOPT user's input (**bold face**) during the interactive GENTEXT session relating to

1. buckling of an isogrid member (STFBK1) in the presence of a "mode 1" axisymmetric imperfection and

2. stress in the skin of the stiffened shell (SKNST1) in the presence of a "mode 1" axisymmetric imperfection.

Table 16 identifies three types of behavioral constraints from which the GENOPT user can choose one type for each "bundle" of Role 4, 5, and 6 variables. Only Types 2 and 3 (called Form 2 and Form 3 in sub-section 3.3) are used in the application described in this paper.

Table 17 is analogous to Table 9. Table 18 is analogous to Table 4. Table 19 is analogous to Table 5. Table 21 is analogous to Table 10. Table 22 is analogous to Table 11. Table 23 is analogous to Table 12. Table 24 is analogous to Table 13.

3.7.2 There should be more "help" paragraphs

Note that there are no "help" paragraphs in Table 19. In order to make the "equivellipse" optimization system more user-friendly, the GENOPT user (the writer) should have included some "help" paragraphs as described next.

3.7.2.1 Additional "help" paragraph option 1

In the GENTEXT interactive session immediately following where the GENOPT user provides input for the Role 3 variable, "uniform external pressure: PRESS" (see Table a1 and Table 6), he should have included a general "help" paragraph concerning the Role 4,5,6 "bundles". Without any additional "help" paragraph Table a1 now contains the following lines (GENOPT user's responses in **bold face**):

```
      1  $ Type of prompt: 0="help" paragraph, 1=one-line prompt
PRESS    $ Name of a variable in the users program (defined below)
      3  $ Role of the variable in the users program
uniform external pressure      $ (one line definition of PRESS)
n        $ Do you want to include a "help" paragraph?
n        $ Any more variables for role type  3 ?              $
      1  $ Type of prompt: 0="help" paragraph, 1=one-line prompt
CLAPS1   $ Name of a variable in the users program (defined below)
```

During the interactive GENTEXT session the GENOPT user **should have included** something like the following material immediately after he answers the GENOPT prompt, "`Any more variables for role type 3 ?`" The GENOPT user's additional "**should have included**" responses to GENTEXT prompting are in **bold face**:

```
      0   $ Type of prompt: 0="help" paragraph, 1=one-line prompt
Next, you supply input for the allowables
y         $ Any more lines in the "help" paragraph?
for every load case, followed by the factors
y         $ Any more lines in the "help" paragraph?
of safety for every load case. See Table 35
y         $ Any more lines in the "help" paragraph?
in the report "sdm50.report.pdf" for an example.
y         $ Any more lines in the "help" paragraph?
See Section 3.5.2 in "sdm50.report.pdf" for the
y         $ Any more lines in the "help" paragraph?
meanings of the behavioral array names and
y         $ Any more lines in the "help" paragraph?
subscripts. See Tables 31 and 32 in "sdm50.report.pdf"
y         $ Any more lines in the "help" paragraph?
for how the margins appear.
n         $ Any more lines in the "help" paragraph?
```

The next two lines in the interactive GENTEXT input would remain as before:

```
       1  $ Type of prompt: 0="help" paragraph, 1=one-line prompt
  CLAPS1   $ Name of a variable in the users program (defined below)
```

The new "help" paragraph would have appeared in a modified equivellipse.PRO file (Table 6) as follows:

```
 115.0
     Next, you supply input for the allowables
     for every load case, followed by the factors
     of safety for every load case. See Table 35
     in the report "sdm50.report.pdf" for an example.
     See Section 3.5.2 in "sdm50.report.pdf" for the
     meanings of the behavioral array names and
     subscripts. See Tables 31 and 32 in "sdm50.report.pdf"
     for how the margins appear.
```

and the prompting numbers now given as 115.0, 120.1, 125.1, etc. would all have been increased by 5 .

3.7.2.2 Additional "help" paragraph option 2

Without any additional "help" paragraph Table 15 currently includes the following (GENOPT users responses in **bold face**):

```
  y        $ Any more variables for role type  4 ?             $160
       1  $ Type of prompt: 0="help" paragraph, 1=one-line prompt
  STFBK1   $ Name of a variable in the users program (defined below)
       4  $ Role of the variable in the users program
  n        $ Do you want to reset the number of columns in STFBK1 ?
  buckling load factor, isogrid member,mode 1 $ one-line def.,STFBK1
  n        $ Do you want to include a "help" paragraph?
```

The GENOPT user **should have included** a "help" paragraph immediately following his answer to the GENOPT prompt, "`$ Any more variables for role type  4 ?`" He **should have included** something like the following responses to GENOPT prompting. The GENOPT user's additional "**should have included**" responses to GENTEXT prompting are in **bold face:**

```
       0   $ Type of prompt: 0="help" paragraph, 1=one-line prompt
  Next, you will be asked to supply allowables
  y         $ Any more lines in the "help" paragraph?
  for STFBK1 (STFBK1A) for every load case, followed
  y         $ Any more lines in the "help" paragraph?
  by factors of safety (STFBK1F) for every load case.
  y         $ Any more lines in the "help" paragraph?
  "STFBK" means "isogrid-stiffener buckling". The
  y         $ Any more lines in the "help" paragraph?
  buckling load factor is computed as described
  y         $ Any more lines in the "help" paragraph?
```

```
in Table 27 of the report, “sdm50.report.pdf”.
y         $ Any more lines in the “help” paragraph?
The digit, “1”, in the name STFBK1 means “isogrid-
y         $ Any more lines in the “help” paragraph?
stiffener buckling in the presence of an imperfect
y         $ Any more lines in the “help” paragraph?
shell with a plus or minus “mode 1” (or “mode 3”)
y         $ Any more lines in the “help” paragraph?
axisymmetric imperfection shape. Please see Section
y         $ Any more lines in the “help” paragraph?
3.5.2 of “sdm50.report.pdf” for more information about
y         $ Any more lines in the “help” paragraph?
the naming of behavioral variables, allowables, and
y         $ Any more lines in the “help” paragraph?
factors of safety.
n         $ Any more lines in the “help” paragraph?
```

The new “help” paragraph would have appeared in a modified equivellipse.PRO file (Table 6) as follows:

```
165.0
     Next, you will be asked to supply allowables
     for STFBK1 (STFBK1A) for every load case, followed
     by factors of safety (STFBK1F) for every load case.
     “STFBK” means “isogrid-stiffener buckling”. The
     buckling load factor is computed as described
     in Table 27 of the report, “sdm50.report.pdf”.
     The digit, “1”, in the name STFBK1 means “isogrid-
     stiffener buckling in the presence of an imperfect
     shell with a plus or minus “mode 1” (or “mode 3”)
     axisymmetric imperfection shape. Please see Section
     3.5.2 of “sdm50.report.pdf” for more information about
     the naming of behavioral variables, allowables, and
     factors of safety.
```

The next several lines in the interactive GENTEXT input would remain as before:

```
      1  $ Type of prompt: 0="help" paragraph, 1=one-line prompt
STFBK1   $ Name of a variable in the users program (defined below)
      4  $ Role of the variable in the users program
n        $ Do you want to reset the number of columns in STFBK1 ?
buckling load factor, isogrid member,mode 1 $ one-line def.,STFBK1
n        $ Do you want to include a "help" paragraph?
```

and the prompting numbers now given as 165.0, 170.1, 175.1, etc. would all have been increased by 5.

With the GENOPT user’s “**should have included**” material, the modified Table 19 (and Table 6) would have the following entries:

```
165.0
     Next, you will be asked to supply allowables
     for STFBK1 (STFBK1A) for every load case, followed
     by factors of safety (STFBK1F) for every load case.
     “STFBK” means “isogrid-stiffener buckling”. The
     buckling load factor is computed as described
     in Table 27 of the report, “sdm50.report.pdf”.
     The digit, “1”, in the name STFBK1 means “isogrid-
     stiffener buckling in the presence of an imperfect
     shell with a plus or minus “mode 1” (or “mode 3”)
     axisymmetric imperfection shape. Please see Section
     3.5.2 of “sdm50.report.pdf” for more information about
     the naming of behavioral variables, allowables, and
     factors of safety.

 170.0 buckling load factor, isogrid member, mode 1: STFBK1
 175.1 allowable for isogrid stiffener buckling (Use 1.): STFBK1A
 180.1 factor of safety for isogrid stiffener buckling: STFBK1F
 185.0 maximum stress in the shell skin, mode 1: SKNST1
 190.1 allowable stress for the shell skin: SKNST1A
 195.1 factor of safety for skin stress: SKNST1F
```

3.7.2.3 Additional “help” paragraph option 3

The GENOPT user could have added the same “help” paragraph as that listed under the prompting number 165.0 above at a slightly different point in the interactive GENTEXT session. Without any additional “help” paragraph two of the existing lines in Table 15 are:

```
buckling load factor, isogrid member,mode 1 $ one-line def.,STFBK1
 n        $ Do you want to include a "help" paragraph?
```

The GENOPT user could have answered the GENOPT prompt,

“Do you want to include a "help" paragraph?”

with a “**y**” instead of a “**n**”, then provided the same “help” paragraph as that listed above. In that case the new Table 19 (and Table 6) would have the following entries:

```
165.0 buckling load factor, isogrid member, mode 1: STFBK1
165.2
     Next, you will be asked to supply allowables
     for STFBK1 (STFBK1A) for every load case, followed
     by factors of safety (STFBK1F) for every load case.
     “STFBK” means “isogrid-stiffener buckling”. The
     buckling load factor is computed as described
     in Table 27 of the report, “sdm50.report.pdf”.
     The digit, “1”, in the name STFBK1 means “isogrid-
     stiffener buckling in the presence of an imperfect
     shell with a plus or minus “mode 1” (or “mode 3”)
     axisymmetric imperfection shape. Please see Section
     3.5.2 of “sdm50.report.pdf” for more information about
```

```
     the naming of behavioral variables, allowables, and
     factors of safety.

  170.1 allowable for isogrid stiffener buckling (Use 1.): STFBK1A
  175.1 factor of safety for isogrid stiffener buckling: STFBK1F
  180.0 maximum stress in the shell skin, mode 1: SKNST1
  185.1 allowable stress for the shell skin: SKNST1A
  190.1 factor of safety for skin stress: SKNST1F
```

This last choice, **Additional "help" paragraph option 3**, is not as good as the previous two choices, **Additional "help" paragraph option 1** and **Additional "help" paragraph option 2**, because the user of the BEGIN processor would never see the "help" paragraph with **Additional "help" paragraph option 3**. The "help" paragraph would be listed in the new version of Table 6 (the new equivellipse.PRO file) but would not appear on the screen as the user provides input for BEGIN in an interactive mode. That is because BEGIN does not prompt for the behavior such as STFBK1 but only for its allowable STFBK1A and for its factor of safety STFBK1F. **The behavior itself cannot be prompted for because its value is unknown, of course. The behavior such as STFBK1 is what is calculated during the execution of OPTIMIZE.**

The discussion above about additional "help" paragraphs applies in an analogous way to each of the 14 Role 4,5,6 "bundles" listed in Table 2 and the corresponding prompting file, equivellipse.PRO, listed in Table 6.

3.7.3 "Behavior" subroutines, constraints, and margins

Table 20 lists a GENOPT-created FORTRAN fragment: the part of the equivellipse.CON file that is directly related to the GENTEXT input listed in Table 15. The complete equivellipse.CON file **is automatically created by GENOPT and is automatically inserted later in the skeletal library STRUCT.NEW by GENOPT**. The complete GENOPT-created equivellipse.CON file corresponding to the entire GENTEXT input file, equivellipse.INP, is listed in Table a12 of the appendix of [26]).

The particular GENOPT-created FORTRAN fragment listed in Table 20 is generated automatically by GENOPT specifically in association with the GENOPT user's input listed in Table 15. In this particular example this is where SUBROUTINEs BEHX4 and BEHX5 are called. For example, in connection with SUBROUTINE BEHX4, see the GENOPT-created statement,

```
 IF (IBEHV(4  ).EQ.0) CALL BEHX4
1     (IFILE8,NPRINX,IMODX,IFAST,ILOADX,J,
1     'buckling load factor, isogrid member, mode 1')
```

which pertains to isogrid stiffener buckling in the presence of a "mode 1" axisymmetric linear buckling modal imperfection shape.

(The indices, IBEHV(i), are all pre-set to zero. For example, the index, IBEHV(4), is either 0 or

1. This index and the other IBEHV(i) are determined by the "end" user for each load set during the MAINSETUP interactive session. See Table 37. If the "end" user has, for some reason, decided that for load set ILOADX he or she does NOT want to let isogrid member buckling in the presence of a "mode 1" imperfection constrain the design, then he or she can respond appropriately during the MAINSETUP interactive session. In that case IBEHV(4) will be set to 1 instead of 0. Usually the "end" user will want to have all the design constraints calculated. That is so in this report. However, there may be complicated cases in which, for one reason or another, the "end" user wants to omit certain design constraints. See [7] for examples.)

The following two GENOPT-created statements are where the wording (WORDCX) is constructed for the design constraint corresponding to buckling of an isogrid stiffening member (STFBK1, STFBK1A, STFBK1F) and where the value of this design constraint is computed (CALL CONX):

```
 WORDCX='(STFBK1('//CIX//','//CJX//')/STFBK1A('//CIX//','//CJX//
1  ')) / STFBK1F('//CIX//','//CJX//')'
 CALL CONX(STFBK1(ILOADX,J),STFBK1A(ILOADX,J),STFBK1F(ILOADX,J)
1,'buckling load factor, isogrid member, mode 1',
1 'allowable for isogrid stiffener buckling (Use 1.)',
1 'factor of safety for isogrid stiffener buckling',
1 2,INUMTT,IMODX,CONMAX,ICONSX,IPOINC,CONSTX,WORDCX,
1 WORDMX,PCWORD,CPLOTX,ICARX)
```

The ICONSXth design constraint, CONSTX, is calculated in SUBROUTINE CONX. SUBROUTINE CONX is located in the library, …/genopt/sources/main.src and is invariable, that is, CONX is not created or modified by GENOPT. It is the "CALL CONX(…)" statement that is automatically created by GENOPT, not SUBROUTINE CONX.

As explained above, in Tables 16, and as listed in Tables 31 and 32, **design margins** are automatically constructed by GENOPT using the Role 4,5,6 variable names such as STFBK1, STFBK1A, and STFBK1F (local isogrid stiffener buckling) as follows (from Table 31):

```
Mar.
 No.     Margin              definition of margin
 5   1.919E+00 (STFBK1(1,1)/STFBK1A(1,1))/STFBK1F(1,1)-1;F.S.=1.00
```

and using Role 4,5,6 variable names such as SKNST1, SKNST1A, and SKNST1F (local skin stress) as follows (from Table 32):

```
Mar.
 No.     Margin              definition of margin
 8   4.979E-02 (SKNST1A(2,2)/SKNST1(2,2))/SKNST1F(2,2)-1;F.S.=1.00
```

In the FORTRAN code fragments listed above (especially the fragment that defines **WORDCX**) and in the definitions of the margins just listed, there are two array indexes. These and other symbols are defined in the next two paragraphs.

The Role 5 variables with names ending in the letter "A" in this particular generic example are **allowables**. The Role 6 variables with the names ending in the letter "F" in this particular generic example are the **factors of safety**. In the two-dimensional arrays such as STFBK1A(i, j) the integer i denotes the **load set number** (called **ILOADX** in the FORTRAN code fragments listed above), and the integer j denotes the **region number** (called **J** in the FORTRAN code fragments listed above). Region 1 is the meridional domain between the pole and **xlimit** (Tables 3 and 4 and Item 40 in Tables 5 and 6), and Region 2 is the meridional domain between **xlimit** and the equator of the shell (Fig. 2).

The variable names are all defined in Table 2. If a shell is to be optimized in the presence of the first two axisymmetric buckling modal imperfections, mode 1 and mode 2, then the number "1" in the variable name, such as CLAPS1A, indicates "mode 1 axisymmetric imperfection" and the number "2" in the variable name indicates "mode 2 axisymmetric imperfection". For example, the name, **SKNBK1A(2,1)**, means "local **SK**i**N** **B**uc**K**ling, axisymmetric mode **1** imperfection shape, **A**llowable, load set **2** (which is for a –mode 1 imperfection shape), region **1** of the meridian of the equivalent ellipsoidal shell". If a shell is to be optimized in the presence of the first four axisymmetric buckling modal imperfections, mode 1, mode 2, mode 3, and mode 4, then the number "1" in the variable name indicates "odd-numbered modal axisymmetric imperfection" (mode 1 or mode 3) and the number "2" in the variable name indicates "even-numbered modal axisymmetric imperfection" (mode 2 or mode 4).

Table 25 lists the part of the **skeletal** BEHAVIOR.NEW library specifically associated with the GENOPT user's input listed in Table 15. The skeletal BEHAVIOR.NEW library is entirely created **automatically** by GENOPT. Listed in Table 25 are the **skeletal** subroutines SUBROUTINE BEHX4, which is associated with buckling of an isogrid member (STFBK1) in the presence of a "mode 1" axisymmetric imperfection, and SUBROUTINE BEHX5, which is associated with maximum stress in the shell skin (SKNST1) in the presence of a "mode 1" axisymmetric imperfection.

Were the GENOPT user to "**flesh out**" either or both of the two **skeletal** SUBROUTINE BEHXi, i = 4 or 5 in Table 25, he or she would insert his or her new material after the line that reads, "INSERT SUBROUTINE STATEMENTS HERE". Presumably this theoretical GENOPT user would find formulas or find existing or create computer code that would compute the "buckling load factor, isogrid member, mode 1", STFBK1(ILOADX, JCOL), in SUBROUTINE BEHX4 and the "maximum stress in the shell skin, mode 1", SKNST1(ILOADX, JCOL), in SUBROUTINE BEHX5. The array indices, (ILOADX, JCOL) mean (load set number, region number).

The entire **skeletal** BEHAVIOR.NEW library corresponding to the entire input file, equivellipse.INP, is listed in Table a13 of the appendix of [26]. This **skeletal** BEHAVIOR.NEW library exists upon the GENOPT user's completion of the "GENTEXT" interactive session. As noted in the footnote in Table 25, the GENOPT user (the writer) in this case decided to do all the calculations in SUBROUTINE STRUCT rather than "**flesh out**" SUBROUTINEs BEHXi, i = 1, 14. Listed in Table a13 of [26] there are 14 **skeletal** "behavioral" subroutines. In this "**equivellipse**" application of GENOPT the skeletal "behavioral" subroutines remain unmodified by the GENOPT user, that is, **not "fleshed out".**

The first **seven** BEHXi, i = 1,7, correspond to the first seven bundles of Role 4,5,6 variables listed in Table 2 (behaviors in the presence of an axisymmetric mode 1 imperfection shape associated with variable names that contain the digit "1", such as CLAPS1). The second **seven** BEHXi, i = 8,14, correspond to the second seven bundles of Role 4,5,6 variables listed in Table 2 (behaviors in the presence of an axisymmetric mode 2 imperfection shape associated with names that contain the digit "2", such as CLAPS2).

3.7.4 Should the BEHXi routines be "fleshed out" or should STRUCT be "fleshed out"?

In this particular application of GENOPT, the GENOPT user decided **not** to "flesh out" any of the BEHXi, i=1,14 subroutines, but instead to perform all the computations in SUBROUTINE STRUCT. The reason for this decision is that the "behaviors" (such as buckling, stress, displacement) are computed by BIGBOSOR4, and **one execution of BIGBOSOR4 yields more than one "behavior"**. For example, one execution of BIGBOSOR4 generates skin and stiffener stresses and buckling load factors for both Region 1 and Region 2. It would take much more computer time if BIGBOSOR4 had to be re-executed inside each of the 14 BEHXi subroutines to yield a particular "behavior" that is the "responsibility" of that particular BEHXi subroutine.

The question arises: **In general, for what kinds of problems should the GENOPT user choose to "flesh out" the BEHXi routines as opposed to or in addition to "fleshing out" SUBROUTINE STRUCT?** In general, if the computation of a behavior is from a relatively simple formula or subroutine or system of subroutines that is independent of other subroutines used for the computation of other behaviors, then it is probably best to "flesh out" whatever BEHXi routine is "responsible" for computing that behavior. A detailed example of this strategy is presented in [2]. On the other hand, if the computation of the behavior occurs within an elaborate system of subroutines that computes several different behaviors, such as is the case with BIGBOSOR4, then it is probably best to compute that or those behavior(s) in SUBROUTINE STRUCT or in a subroutine or subroutines called by SUBROUTINE STRUCT. The GENOPT user must then make sure that in SUBROUTINE STRUCT the value of the behavior is copied to a variable or an array with the correct, **GENOPT-user-established name**.

For example, the very complicated "**fleshed out**" version of SUBROUTINE STRUCT applicable to the generic case, **equivellipse**, is listed in Table a16 of the appendix of [26]. Within this "**fleshed out**" SUBROUTINE STRUCT certain quantities, `bskin1, bstif1, sknmx1, stfmx1, bskin2, bstif2, sknmx2, stfmx2,` and `ENDUV` are computed. (See Tables 26, 30 and Tables 42 – 45). These quantities are are defined as:

`bskin1` = local buckling load factor of the shell skin in Region 1
`bstif1` = local buckling of a meridionally oriented isogrid member in Region 1
`sknmx1` = maximum effective stress of the shell skin in Region 1
`stfmx1` = maximum isogrid stiffener stress in Region 1
`bskin2` = local buckling load factor of the shell skin in Region 2
`bstif2` = local buckling of a meridionally oriented isogrid member in Region 2
`sknmx2` = maximum effective stress of the shell skin in Region 2

`stfmx2` = maximum isogrid stiffener stress in Region 2
`ENDUV` = axial displacement of the apex of the shell

At some point in SUBROUTINE STRUCT (before any of the BEHXi subroutines are called) the following statements appear:

```
SKNBK1(ILOADX,1) = bskin1
STFBK1(ILOADX,1) = bstif1
SKNST1(ILOADX,1) = sknmx1
STFST1(ILOADX,1) = stfmx1
SKNBK1(ILOADX,2) = bskin2
STFBK1(ILOADX,2) = bstif2
SKNST1(ILOADX,2) = sknmx2
STFST1(ILOADX,2) = stfmx2
WAPEX1(ILOADX) = ABS(ENDUV)
```

The names, SKNBK1, STFBK1, SKNST1, STFST1, WAPEX1, are **the GENOPT-user-established names** listed in Table 2 for several of the behaviors generated in connection with a "mode 1" axisymmetric buckling modal imperfection shape. There are analogous statements that occur later in SUBROUTINE STRUCT involving SKNBK2, STFBK2, SKNST2, STFST2, WAPEX2, which are the GENOPT-user-established names listed in Table 2 for several of the behaviors generated in connection with a "mode 2" axisymmetric buckling modal imperfection shape. (`ILOADX` is the load set number, and the second array index is the region number).

Whenever SUBROUTINE STRUCT is "fleshed out" rather than SUBROUTINES BEHXi, the variables or arrays with the **GENOPT-user-established names** must be filled with the correct behavior values before any of the BEHXi subroutines are called by SUBROUTINE STRUCT.

3.8 "Fleshing out" SUBROUTINE STRUCT

The **skeletal** SUBOUTINE STRUCT, produced entirely by GENOPT after the GENOPT user's completion of the GENTEXT interactive session, is listed in Table a14 of the appendix of [26]. The appendix also provides another example of a **skeletal** version of SUBROUTINE STRUCT for a different generic case, "cylinder". (See Table a30 of [26]). The **skeletal** SUBROUTINE STRUCT, as produced automatically by GENTEXT, is part of the library called **struct.new**. It resides in the same directory where GENTEXT has been executed. It is the library, **struct.new**, that should be "**fleshed out**" in this particular generic case, "equivellipse".

It has been mentioned that in this particular application of GENOPT (the application for which the generic case name is "**equivellipse**") the GENOPT user (the writer in this case) must "**flesh out**" SUBROUTINE STRUCT (called **struct.new** as generated by GENTEXT). Table 26 lists a small section of SUBROUTINE STRUCT that has been written by the GENOPT user, not produced automatically by GENOPT. In this small section of SUBROUTINE STRUCT (**struct.new** library) local buckling and local stress quantities are computed as follows:

1. local skin buckling (between isogrid members: SKNBK1) and local isogrid stiffener buckling (buckling along a meridionally oriented side of the equilateral triangle formed by adjacent

isogrid members: STFBK1) are computed for Load Set Number ILOADX for Region 1 (pole to x = xlimit) and Region 2 (x = xlimit to equator) in the presence of an axisymmetric “mode 1” linear buckling modal imperfection with amplitude Wimp.

2. maximum extreme fiber effective stress in the shell skin (SKNST1) and maximum longitudinal extreme fiber stress in a meridionally oriented isogrid member (STFST1) in the presence of a “mode 1” axisymmetric linear buckling modal imperfection with amplitude Wimp.

(Analogous quantities, SKNBK2, STFBK2, SKNST2, and STFST2, are computed in the presence of a “mode 2” axisymmetric linear buckling modal imperfection with amplitude Wimp in another analogous section of SUBROUTINE STRUCT via coding not listed in Table 26 but analogous to that listed in Table 26. See Table a16 in the appendix of [26].)

BIGBOSOR4 is used to compute these quantities for each segment in the multi-segment BIGBOSOR4 model (Fig. 2). This is accomplished via the calls to SUBROUTINES BOSDEC, B4READ, and B4MAIN, as listed in Table 26. SUBROUTINE BOSDEC, **which must be written by the GENOPT user**, generates a valid input file for the BIGBOSOR4 preprocessor, SUBROUTINE B4READ. A complete list of SUBROUTINE BOSDEC for the generic case “equivellipse” is provided in the appendix (Table a15). Guidelines for how to go about generating a valid SUBROUTINE BOSDEC are provided for a different (simpler) generic case, “cylinder”, in Table a29 of the appendix of [26].

Part of the output from the BIGBOSOR4 mainprocessor, B4MAIN, consists of the four arrays:

1. minimum local buckling load of the triangular piece of skin between adjacent isogrid stiffeners in shell segment number iseg: BUCMIN(iseg),

2. minimum local buckling load of the most critical isogrid stiffening member in shell segment number iseg: BUCMNS(iseg),

3. maximum extreme fiber effective stress in the shell skin in shell segment number iseg: SKNMAX(iseg), and

4. maximum extreme fiber longitudinal stress in the most critical isogrid member in shell segment number iseg: STFMXS(iseg).

IMPORTANT NOTE: **It is assumed that the most critical buckling load and stress in an isogrid member are associated with an isogrid member that runs in the meridional direction. This assumption is based on the fact that the imperfect shell is axisymmetric, since both the perfect shell and the imperfection shape are axisymmetric. This assumption lies behind the new FORTRAN coding in BIGBOSOR4 listed in Table 27, in which the most critical isogrid member is treated as if it were a stringer (meridionally oriented stiffener).**

Table 26 lists only a small section of SUBROUTINE STRUCT. The entire SUBROUTINE STRUCT is provided in Table a16 of the appendix of [26]. Also listed in the appendix of [26] is the **skeletal** SUBROUTINE STRUCT (Table a14 of [26]), which is produced entirely automatically by GENOPT upon the GENOPT user's completion of the GENTEXT interactive session. The skeletal "STRUCT" library is called "**struct.new**".

The "**fleshed out**" version of SUBROUTINE STRUCT must be part of the library called **struct.new**. The **"fleshed out"** version of **struct.new** must reside in the same directory (e.g. **genoptcase**) in which GENTEXT was executed, and it must be there, along with the possibly "fleshed out" file, **behavior.new**, before the GENOPT processor, GENPROGRAMS, is executed. Also, the correct version of the GENOPT-user-written SUBROUTINE BOSDEC must exist in a certain directory (not the directory, "**genoptcase**", but a different directory, …/bosdec/sources, that is specified in the file, …/genopt/doc/getting.started, before GENPROGRAMS is executed.

NOTE: IT IS VERY IMPORTANT THAT THE GENOPT USER SAVE THE "FLESHED OUT" FILE, struct.new. SAVE IT WITH THE USE SOME OTHER NAME, SUCH AS struct.equivellipse. THE "FLESHED OUT" FILE SHOULD BE SAVED BY THE GENOPT USER BECAUSE struct.new IS OVER-WRITTEN WHENEVER GENTEXT IS RE-EXECUTED. THIS WARNING APPLIES ALSO TO A POSSIBLY "FLESHED OUT" VERSION OF behavior.new. The GENOPT user must also save valid versions of SUBROUTING BOSDEC. For example, in the generic case, "equivellipse", bosdec.src should be saved in a file called "bosdec.equivellipse", or some such name.

The reader should consult Table a30 in the appendix of [26]. Table a30 of [26] gives more information about "fleshing out" SUBROUTINE STRUCT and provides complete lists for a simple generic case called "cylinder", including "diff" files that show the difference between skeletal and "fleshed out" versions, etc.

Additional guidance for both the GENOPT user and the "end" user is provided in [16], a file called "**getting.started**" that describes how to set up GENOPT at a facility different from that used by the author and how to solve problems with GENOPT. "**getting.started**" is located in the directory, …/genopt/doc .

4.0 ABOUT BIGBOSOR4 AND STAGS

4.1 About BIGBOSOR4 (BIG Buckling Of Shells Of Revolution, 4th version of BOSOR)

BOSOR4 [10-12] (or its latest version, BIGBOSOR4 [7]) is a program for the static and dynamic analysis of any shell of revolution. Input files valid for BOSOR4 are also valid for BIGBOSOR4. BIGBOSOR4 is essentially the same as BOSOR4 except that BIGBOSOR4 will solve bigger problems (more shell segments, more degrees of freedom). The shell can be loaded axisymmetrically or non-axisymmetrically by line loads, distributed loads, temperature, and acceleration. BOSOR4 (BIGBOSOR4) computes static equilibrium states, axisymmetric and nonaxisymmetric bifurcation buckling, nonlinear axisymmetric collapse, modal vibration, and linear response to lateral and axial base excitation. In BOSOR4 (BIGBOSOR4) a complex, branched, stiffened elastic shell of revolution is modeled as an assemblage of shell segments or branches, each with its own geometry (flat, conical, cylindrical, spherical, toroidal), loading, wall construction, and linear elastic material properties. Laminated composite wall construction can be handled. The user of BOSOR4 (BIGBOSOR4) provides input data in an interactive mode on a segment-by-segment basis. These input data are automatically stored in a fully annotated file, one input datum and a phrase defining it on each record of the file. (See Table A.7 in the appendix of [7] for an example of such a file. Also, see Table a18 in the appendix of [26].) The meridian of each shell segment is discretized [12]. Variation in the circumferential coordinate direction is assumed to be trigonometric. For more details about BOSOR4 see [10-12] and [7].

In BOSOR4 (and BIGBOSOR4) the type of analysis to be performed is controlled by an index called INDIC, as follows:

INDIC= -2: stability determinant for axisymmetric or for non-axisymmetric nonlinear bifurcation buckling calculated for increasing load, nonlinear axisymmetric prebuckling analysis

INDIC= -1: axisymmetric or non-axisymmetric bifurcation buckling with nonlinear axisymmetric prebuckling analysis

INDIC= 0: nonlinear axisymmetric stress (and axisymmetric collapse) analysis

INDIC= 1: bifurcation buckling with "linear" axisymmetric prebuckling analysis. (Actually the prebuckling analysis is the same as for INDIC = -1. However, the portion of the applied load that affects the stiffness matrix is never changed during a case. Linear behavior is exhibited provided that the user applies a load that is very small compared to the design load.)

INDIC= 2: axisymmetric or non-axisymmetric modal vibration with axisymmetric nonlinear prestress

INDIC= 3: linear axisymmetric and linear non-axisymmetric stress analysis

INDIC= 4: bifurcation buckling with linear non-axisymmetric prebuckling. The INDIC=4 branch is a combination of the INDIC=3 and INDIC=1 branches. INDIC=3 computations are first executed followed by INDIC=1 computations. The user selects the circumferential coordinate, theta, of the meridian and BOSOR4 (BIGBOSOR4) uses the prebuckled stress state along that meridian in a bifurcation buckling analysis that is identical to that in the INDIC=1 branch, that is, the fact that the prebuckled state may be non-axisymmetric is ignored. This is a conservative approximation provided that the user has chosen the meridian (the value of the circumferential coordinate, theta) for which the prebuckled state is the most destabilizing. Note that BOSOR4 (and BIGBOSOR4) cannot handle buckling of shells with significant in-plane shear resultant, Nxy.

BOSOR4 (BIGBOSOR4) will also compute peak response to loads that vary either harmonically or randomly in time. Buckling under harmonic or random axial or lateral base excitation can also be calculated.

As described in [7], BOSOR4 was modified (advanced to BIGBOSOR4) in order to work in the context of automated optimization.

In 2005 BIGBOSOR4 was further modified (Table 27) to compute local skin buckling between meridionally oriented stiffeners ("stringers") and to compute approximately local buckling between stiffeners that form an isogrid. Also, BIGBOSOR4 was modified to compute the maximum stress in a stringer or isogrid that has been "smeared out" and to compute approximately the local buckling load factor of an isogrid stiffening member that is assumed to run in the meridional coordinate direction. In the case of isogrid stiffening the isogrid members must have rectangular cross sections only the height of which varies within any single shell segment. BIGBOSOR4 was further modified to permit axisymmetric imperfection shapes that are to be provided by the user for every nodal point along the meridian of each shell segment. These modifications are described in [17]. They are required for optimization of the isogrid-stiffened, imperfect ellipsoidal shell and imperfect "equivalent" ellipsoidal shell.

Table 27 lists the modifications made to SUBROUTINEs WALLCF, CFB1, and PLOCAL in BIGBOSOR4 to compute the maximum stiffener stress and minimum stiffener and skin buckling load factors in an isogrid-stiffened shell segment. Comments are added in the FORTRAN coding to explain the variables and equations. The formula for local buckling of the triangular piece of skin between adjacent isogrid stiffeners is from Gerard and Becker [18]. This triangular piece of skin is assumed to be flat and uniformly compressed in both the meridional and circumferential coordinate directions. The formula for local buckling of an isogrid member that comprises one side of the equilateral triangle formed by adjacent isogrid stiffeners is from Roark [19]. **It is assumed that the most critical isogrid stiffening member with regard to both buckling and stress runs in the meridional coordinate direction. Therefore, in Table 27, the most critical isogrid member is treated as if it were a stringer (a meridionally oriented stiffener).**

4.2 ABOUT STAGS (STructural Analysis of General Shells)

In this paper and in the long report [26] on which this paper is based optimum designs obtained by GENOPT are evaluated later via STAGS models. **NOTE: STAGS is not used inside the optimization loop**.

STAGS [20 – 23] is a finite element code for the **general-purpose nonlinear analysis of stiffened shell structures of arbitrary shape and complexity**. Its capabilities include stress, stability, vibration, and transient analyses with both material and geometric nonlinearities permitted in all analysis types. STAGS includes enhancements, such as a higher order thick shell element, more advanced nonlinear solution strategies, and more comprehensive post-processing features such as a link with the STAGS postprocessor, STAPL.

Research and development of STAGS by Brogan, Almroth, Rankin, Stanley, Cabiness, Stehlin and others of the Computational Mechanics Department of the Lockheed Palo Alto Research Laboratory has been under continuous sponsorship from U.S. government agencies and internal Lockheed funding for the past 40 years. During this time particular emphasis has been placed on improvement of the capability to solve difficult nonlinear problems such as the prediction of the behavior of axially compressed stiffened panels loaded far into their locally postbuckled states. STAGS has been extensively used worldwide for the evaluation of stiffened panels and shells loaded well into their locally postbuckled states.

A large rotation algorithm that is independent of the finite element library has been incorporated into STAGS. With this algorithm there is no artificial stiffening due to large rotations. The finite elements in the STAGS library do not store energy under arbitrary rigid-body motion and the first and second variations of the strain energy are consistent. These properties lead to quadratic convergence during Newton iterations.

Solution control in nonlinear problems includes specification of load levels or use of the **advanced Riks-Crisfield path parameter** that enables traversal of limit points into the post-buckling regime. Two load systems with different histories (Load Sets A and B) can be defined and controlled separately during the solution process. Flexible restart procedures permit switching from one strategy to another during an analysis. This includes shifts from bifurcation buckling to nonlinear collapse analyses and back and shifts from static to transient and transient to static analyses with modified boundary conditions and loading. STAGS provides solutions to the generalized eigenvalue problem for **buckling** and **vibration from a linear or nonlinear stress state.**

Quadric surfaces can be modeled with minimal user input as individual substructures called "**shell units**" in which the analytic geometry is represented exactly. "Shell units" can be connected along edges or internal grid lines with partial or complete compatibility. In this way complex structures can be assembled from relatively simple units. Alternatively, a structure of arbitrary shape can be modeled with use of "element units".

Geometric imperfections can be generated automatically in a variety of ways, thereby permitting imperfection-sensitivity studies to be performed. For example, **imperfections can be generated by superposition of several buckling modes determined from previous STAGS analyses of a given case**.

A variety of material models is available, including both plasticity and creep. STAGS handles isotropic and anisotropic materials, including composites consisting of up to 60 layers of arbitrary orientation. Four plasticity models are available, including isotropic strain hardening, the White Besseling (mechanical sublayer model), kinematic strain hardening, and deformation theory.

Two independent load sets, each composed from simple parts that may be specified with minimal input, define a spatial variation of loading. Any number of point loads, prescribed displacements, line loads, surface tractions, thermal loads, and "live" pressure (hydrostatic pressure which remains normal to the shell surface throughout large deformations) can be combined to make a load set. For transient analysis the user may select from a menu of loading histories, or a general temporal variation may be specified in a user-written subroutine.

Boundary conditions (B.C.) may be imposed either by reference to certain standard conditions or by the use of single- and multi-point constraints. Simple support, symmetry, antisymmetry, clamped, or user-defined B.C. can be defined on a "shell unit" edge. Single-point constraints which allow individual freedoms to be free, fixed, or a prescribed non-zero value may be applied to grid lines and surfaces in "shell units" or "element units". A useful feature for buckling analysis allows these constraints to differ for the prestress and eigenvalue analyses. Langrangian constraint equations containing up to 100 terms may be defined to impose multi-point constraints.

STAGS has a variety of finite elements suitable for the analysis of stiffened plates and shells. Simple four node quadrilateral plate elements with a cubic lateral displacement field (called "410" and "411" elements) are effective and efficient for the prediction of postbuckling thin shell response. A linear (410) or quadratic (411) membrane interpolation can be selected. For thicker shells in which transverse shear deformation is important, STAGS provides the Assumed Natural Strain (ANS) nine node element (called "480" element). A two node beam element compatible with the four node quadrilateral plate element is provided to simulate stiffeners and beam assemblies. Other finite elements included in STAGS are described in the STAGS literature [20 – 23].

5.0 "TRUE" ELLIPSOIDAL SHELL versus "EQUIVALENT" ELLIPSOIDAL SHELL

5.1 "True" ellipsoidal shell

Figure 1 shows predictions of elastic collapse of an optimized **true** unstiffened 2:1 titanium ellipsoidal shell under uniform external pressure. The ellipsoidal shell has a semi-major axis length of 24.75 inches and semi-minor axis length of 12.375 inches. The inner surface is the reference surface, which has the ellipsoindal profile. The design external pressure is 460 psi and the minimum allowable pressure at which the shell collapses axisymmetrically is 550 psi. The unstiffened ellipsoidal shell has thickness that varies along the meridian. The decision variables of the optimization problem are the values of wall thickness at 13 stations on the meridian including that at the pole and that at the equator. The shell is optimized in the presence of any one of four possible initial buckling modal imperfections, each with amplitude, Wimp = 0.2 inch. The four imperfections are all in the shape of linear axisymmetric bifurcation buckling modes as follows:

Imperfection no. 1: positive first axisymmetric eigenmode, called "+mode 1"
Imperfection no. 2: positive second axisymmetric eigenmode, called "+mode 2"
Imperfection no. 3: negative first axisymmetric eigenmode, called "–mode 1"
Imperfection no. 4: negative second axisymmetric eigenmode, called "–mode 2"

The optimization is conducted in such a way that, according to predictions by BIGBOSOR4, the final optimum design will survive (not exhibit any significantly negative margins) in the presence of any **one** of the four imperfection shapes just listed. The four curves in Fig. 1 with labels, "GENOPT results…", correspond to the predictions by BIGBOSOR4 of nonlinear axisymmetric collapse of the optimized **true** ellipsoidal pressure vessel head in the presence of each of the 4 axisymmetric linear bifurcation buckling modal imperfection shapes, +mode 1, –mode 1, +mode 2, –mode2, taken one at a time corresponding to each curve.

The overall dimensions of the shell, the external uniform design pressure loading, the allowable maximum external pressure for collapse, and the four axisymmetric linear bifurcation buckling modal imperfection shapes taken one at a time also govern the behavior and optimization of the "**equivalent**" ellipsoidal shells that are the subject of most of this paper.

Figure 1 also shows the prediction from STAGS [20-23] for the optimized **true** unstiffened ellipsoidal shell with Imperfection No. 3: "–mode 1". There is a huge difference between the BIGBOSOR4 (GENOPT) and STAGS predictions for the pressure-carrying capability of this optimized axisymmetrically imperfect unstiffened shell. The predictions from BIGBOSOR4 are unacceptably unconservative. This result is caused by finite element "lockup" in the BIGBOSOR4 model. **BOSOR4 [10-12] and BIGBOSOR4 [7] should be applied only to shells for which the meridional radius of curvature is constant within each perfect shell segment of a multi-segment model of a shell of revolution**. For a **true** perfect ellipsoidal shell the meridional radius of curvature of the reference surface decreases monotonically from the pole to the equator.

5.2 "Equivalent" ellipsoidal shell

The BIGBOSOR4 finite element "lockup" problem is essentially solved by representation of the "true" ellipsoidal shell as an "**equivalent**" ellipsoidal shell consisting of a shallow spherical cap plus multiple toroidal segments connected in series, each segment of which has **constant meridional radius of curvature** and each segment of which closely approximates the local meridional shape of the "true" ellipsoidal shell at the location of that segment. In the present analysis the "equivalent" ellipsoidal shell consists of 12 shell segments: a spherical cap (Segment 1) and 11 toroidal segments (Segments 2 – 12) the radial (x-coordinate) end points of which are located as listed in **Table 28**. The input data required by BIGBOSOR4 for each shell segment are the (x,y) coordinates of the two end points of that segment, (x_1,y_1) and (x_2,y_2), and the (x,y) coordinates of the center of meridional curvature, (x_3,y_3), of that segment. The coordinates, (x_1,y_1) and (x_2,y_2), lie on the profile of the true ellipsoid.

Table 29 lists how the location, (x_3,y_3), of the center of meridional curvature of the "equivalent" toroidal segment is derived for a typical toroidal segment. Figure 2 shows the meridional profile of the 12-segment "equivalent" ellipsoidal shell. The (x,y) coordinates of the end points of each toroidal shell segment, (x_1,y_1) and (x_2,y_2), lie on the meridional profile of the true ellipsoidal shell, of course.

6.0 ANALYSES INCLUDED IN THE "FLESHED OUT" SUBROUTINE STRUCT

As previously mentioned, in this work only the "**skeletal**" SUBROUTINE STRUCT (part of the library called **struct.new** in the **genoptcase** directory immediately following the GENOPT user's execution of GENTEXT) automatically produced during the interactive GENTEXT session of GENOPT (Table a14 of [26]) was "**fleshed out**" (Table a16 of [26]) by the GENOPT user (the writer). The 14 **skeletal** "behavioral" subroutines, SUBROUTINE BEHXi, i = 1,14, remain unchanged from the versions created automatically by GENTEXT. (See Table a13 in the appendix of [26]). **Much of the effort in this project was spent on creating a final correct version of SUBROUTINE STRUCT**. The long final ("**fleshed out**") version of SUBROUTINE STRUCT (part of the **struct.new** library) is listed in the appendix (Table a16 of [26]). For each "current" (unperturbed) design and for each perturbed design virtually all the computations take place in SUBROUTINE STRUCT.

SUBROUTINE STRUCT consists essentially of seven analyses. These analyses have the following two most significant elements:

1. A call to SUBROUTINE BOSDEC (Table a15) creates a file that is valid as input to BIGBOSOR4 (or BOSOR4). This is done for each of the seven analyses in SUBROUTINE STRUCT. An example has already been provided for one of the seven analyses in Table 26. For any application that involves the use of BIGBOSOR4 (or BOSOR4), the GENOPT user **must** create a SUBROUTINE BOSDEC, that is, a subroutine that when executed creates a valid input file, *.ALL, for BIGBOSOR4 (or BOSOR4). A list of SUBROUTINE BOSDEC valid for the "equivalent" ellipsoidal shell is given in Table a15 of the appendix. An example of a valid *.ALL file as created by BOSDEC is also listed in Table a17 of the appendix of [26]. This file does not have the usual complete annotations for each input datum typical of BOSOR4 (BIGBOSOR4) input files; it is none-the-less valid. The "complete annotation" format can easily be produced by execution of "**bigbosorall**" followed by execution of "**cleanup**". An example of the valid *.ALL file in the "complete annotation" format after execution of "bigbosorall" followed by execution of "cleanup" is listed in Table a18 of the appendix of [26].

2. Calls to BIGBOSOR4 software in SUBROUTINE STRUCT perform typical BIGBOSOR4 computations for:

a. axisymmetric linear bifurcation buckling analysis (INDIC = 1) with a very small applied pressure: one thousanth of the design pressure, or p = 0.460 psi, in order to ensure linear behavior. This is **analysis number 1**. The purpose is to obtain axisymmetric buckling modes that are used in Items b, c, d as imperfection shapes.

b. nonlinear axisymmetric stress analysis of the shell with an axisymmetric linear bifurcation buckling modal imperfection (INDIC = 0) with the applied pressure equal to the design pressure, p = 460 psi. This is **analysis number 2** (axisymmetric mode 1 imperfection shape) and **analysis number 3** (axisymmetric mode 2 imperfection shape).

c. nonlinear axisymmetric collapse analysis of the shell with an axisymmetric linear bifurcation buckling modal imperfection (INDIC = 0) for a series of monotonically increasing pressure p until axisymmetric collapse occurs or until p reaches a maximum value of 920 psi. This is **analysis number 4** (axisymmetric mode 1 imperfection shape) and **analysis number 5** (axisymmetric mode 2 imperfection shape). The upper limit on applied external pressure, p = 920 psi, is arbitrarily set by the GENOPT user to be equal to twice the design pressure, p = 460 psi.

d. partially nonlinear bifurcation buckling analysis of the shell with an axisymmetric linear bifurcation buckling modal imperfection (INDIC = 1) with pressure in Load Set B (Load Set B means "not eigenvalue load": affects only the stiffness matrix), p = 460 psi, and "dp" the pressure increment in Load Set A (Load Set A means "yes eigenvalue load": affects only the load-geometric matrix), dp = 0.46 psi. This is **analysis number 6** (axisymmetric mode 1 imperfection shape) and **analysis number 7** (axisymmetric mode 2 imperfection shape). The analysis is called "partially nonlinear" because the static response to the applied design pressure, p = 460 psi, treated as "Load Set B", a load that affects the stiffness matrix but not the load-geometric matrix, is obtained from nonlinear theory but the eigenvalue is obtained from the linear equation,

$$\mathbf{K_1}(\text{at p=460 psi}) \times \mathbf{q} = (\text{eigenvalue})\mathbf{K_2}(\text{dp}) \times \mathbf{q} \tag{5}$$

in which **q** is the eigenvector, $\mathbf{K_1}$ is the stiffness matrix of the structure as loaded by p = 460 psi, and $\mathbf{K_2}$ is the load-geometric matrix which is proportional to the pressure increment, dp. The "nonlinear" bifurcation buckling pressure, p(critical) is given by

$$\text{p(critical)} = 460 + (\text{eigenvalue}) \times \text{dp} \quad \text{psi} \tag{6}$$

If, for the current design, the applied external pressure, p = 460 psi, happens to exceed the pressure at which the shell collapses axisymmetrically, there is a strategy to avoid numerical problems. (That is one of the reasons SUBROUTINE STRUCT is so long: the need for strategies to avoid numerical problems in the face of nonlinear behavior).

Table 30 presents a summary of results from each of the seven analyses for the case of an optimized titanium axisymmetrically imperfect, internally isogrid-stiffened, "equivalent" ellipsoidal shell with skin thickness and isogrid stiffener height that vary along the meridian. The amplitude of the linear axisymmetric bifurcation buckling modal imperfection is Wimp = 0.2 inch. The inner surface of the shell skin is the reference surface, has the "equivalent" ellipsoidal shape, and has semi-major axis of length 24.75 inches and semi-minor axis of length 12.375 inches. The decision variables are the skin thicknesses, THKSKN(i), and isogrid stiffener heights, HIGHST(i), at the 13 radial (x-coordinate, xinput(i)) locations listed in Table 28, plus the isogrid stiffener spacing, SPACNG, (constant along the meridian) and the isogrid stiffener thickness, THSTIF, (constant along the meridian). The optimum design to which the results in Table 30 correspond is listed in Table 33 under the heading, **"isogrid-stiffened, imperfect"**.

The computations listed in Table 30 are for Load Set 1 (+mode 1 and + mode 2 imperfections). They are repeated for Load Set 2, which corresponds to use of the negatives of the first and second axisymmetric bifurcation buckling modal imperfection shapes, that is, with the use of –mode 1 and –mode 2 linear axisymmetric bifurcation buckling modal imperfection shapes.

A complete list of the output file, eqellipse.OPM, corresponding to the **optimized imperfect isogrid-stiffened equivalent ellipsoidal shell** generated with use of the ITYPE = 2 choice of analysis type (ITYPE = 2 means "fixed design", not optimization; see Table 37) appears in Table a19 of the appendix.

If the shell is optimized with the use of the **four** lowest axisymmetric buckling modal imperfections rather than only the **two** lowest axisymmetric buckling modal imperfections, then the seven analyses are conducted, not only for +mode 1 and +mode 2 axisymmetric imperfection shapes (Load Set 1) and for –mode 1 and –mode 2 axisymmetric imperfection shapes (Load Set 2), but also for +mode 3 and +mode 4 axisymmetric imperfection shapes (Load Set 3) and for –mode 3 and –mode 4 axisymmetric imperfection shapes (Load Set 4). The results from such an extensive "4-mode" treatment are presented for axisymmetrically imperfect **isogrid-stiffened** and for axisymmetrically imperfect **unstiffened** optimized equivalent ellipsoidal shells in Sub-sections 8.1.8 and 8.2.8, respectively, of [26]. The "4-mode" (4 load set) optimization of the isogrid-stiffened equivalent ellipsoidal shell requires a run time of about eight days on the very efficient LINUX-based workstation on which the work reported here was performed.

Table 31 lists the design margins corresponding to Load Set 1 (+mode 1 and +mode 2 axisymmetric linear bifurcation buckling modal imperfection shapes) and Table 32 lists the design margins corresponding to Load Set 2 (–mode 1 and –mode 2 axisymmetric linear bifurcation buckling modal imperfection shapes). The GENOPT-user-selected variable names that appear in the margins, such as "CLAPS1", "CLAPS1A", "CLAPS1F", are defined in Table 2. The optimum design is deemed by GENOPT to be acceptable even though there are several small negative margins because the design is "ALMOST FEASIBLE", that is, all margins are greater than –0.05. If small negative margins were not permitted many, many executions of SUPEROPT might be required to find a "global" minimum-weight design that is either FEASIBLE or ALMOST FEASIBLE. It is best, therefore, to allow small negative margins and to compensate for them, if one really thinks it is necessary, by raising the factors of safety by a correspondingly small amount. For GENOPT to accept a design as FEASIBLE rather than ALMOST FEASIBLE all margins must be greater than –0.01. For GENOPT to accept a design that is "MILDLY UNFEASIBLE" all margins must be greater than –0.10. (See Item no. 725 in Table a24 of [26]).

In Table 31 Margin No. 1 is developed from Analysis No. 4 (nonlinear axisymmetric collapse); Margin No. 2 is developed from Analysis No. 6 ("nonlinear" bifurcation buckling); Margin Nos. 3-11 are developed from Analysis No. 2 (nonlinear axisymmetric stress). Margins 1 – 11 are developed with the use of the axisymmetric +mode 1 linear bifurcation buckling modal imperfection shape.

Margin No. 12 is developed from Analysis No. 5 (nonlinear axisymmetric collapse); Margin No. 13 is developed from Analysis No. 7 ("nonlinear" bifurcation buckling); Margin Nos. 14 – 22 are developed from Analysis No. 3 (nonlinear axisymmetric stress). Margins 12 – 22 are developed with use of the axisymmetric +mode 2 linear bifurcation buckling modal imperfection shape.

The margins in Table 32 are developed in an analogous manner. They are based on –mode 1 and –mode 2 axisymmetric linear bifurcation buckling modal imperfection shapes (Load Set 2).

7.0 NUMERICAL RESULTS FOR SEVERAL CASES

The isotropic titanium material has a modulus, E = 16 x 10^6 psi, Poisson ratio = 0.25, weight density = 0.16 lb/in^3. The amplitude of the linear axisymmetric buckling modal imperfection shapes is Wimp = (+ or –) 0.2 inch, unless otherwise noted. All of these cases have the "equivalent" ellipsoidal shape with semi-major and semi-minor axes lengths, 24.75 inches and 12.375 inches, respectively. The reference surface is always the inner surface of the shell skin. It is this surface that has the shape of the "equivalent" ellipsoid. The value of "xlimit" (radial, that is, x-coordinate) where Regions 1 and 2 join is xlimit = 17.63477 inches, which is the same as the location of the junction between shell segments 6 and 7 (Fig. 2). As listed in Tables 31 and 32, Region 1 is 0 < x < xlimit, and Region 2 is xlimit < x < 24.75 inches.

Optimum designs from several cases are listed in Table 33 of [26]. The values of xinput are the same as those listed in Table 28: xinput are the radial coordinate locations of the ends of the 12 segments of the "equivalent" ellipsoidal shell. For an isogrid-stiffened shell the decision variables are the shell skin thicknesses, THKSKN(i), at the 13 "xinput" points, plus the heights, HIGHST(i), (dimension measured normal to the shell reference surface) of the isogrid stiffeners at the same 13 points, plus the isogrid spacing, SPACNG, (altitude of the equilateral triangle formed by three adjacent isogrid stiffeners), which is constant over the entire shell, plus the thickness, THSTIF, of each isogrid member, which is constant over the entire shell. This makes a total of 28 decision variables for the isogrid-stiffened shell. The isogrid members have rectangular cross sections. The shell skin thickness and height (depth) of the isogrid stiffening system vary linearly with meridional arc length between the shell segment ends. The isogrid member spacing and isogrid member thickness are constant over the entire shell. The isogrid is attached to the inner surface of the shell skin, which is selected as the shell reference surface.

IMPORTANT NOTE: Note that in this research no attempt was made to determine if a doubly-curved shell of this type could actually be manufactured with isogrid stiffening of the type specified in this paper.

Perfect and imperfect, isogrid-stiffened and unstiffened "equivalent" ellipsoidal shells were optimized with GENOPT, that is, based on BIGBOSOR4 models. Some of the optimum designs were obtained only after multiple executions of SUPEROPT. **All of the results listed in Table 33 of [26] correspond to the use of only two axisymmetric linear bifurcation buckling modal imperfection shapes, mode 1 and mode 2, with the plus and minus version of each imperfection shape included in the model.** The amplitude of each imperfection shape is Wimp = 0.2 inches. A single execution of SUPEROPT for the "two-mode" isogrid-stiffened imperfect shell requires approximately 95 hours of CPU time on the efficient LINUX workstation on which this work was done.

Table 33 of this paper is the same as Table 33 of [26] **except for the column with the heading, "unstiffened, imperfect"**. The shell wall thicknesses and the shell weight listed in that column are derived from the "**thick apex**" optimization formulation described in Section 9.3.

The optimum designs obtained with GENOPT were evaluated with the use of STAGS, a general-purpose, nonlinear, finite element code [20-24].

Table 34 lists a typical run stream for obtaining an optimum design with GENOPT. This table forms part of the *.DEF file (called "equivellipse.DEF" for the generic case, "equivellipse"). The complete equivellipse.DEF file is listed in Table a2 of the appendix. The best way to optimize something is to use the "global" optimization scheme launched by the command SUPEROPT. (See the second page of Table 34).

Table 47 is analogous to Table 33 in that it pertains to all the four optimum designs listed in Table 33 of [26]. Table 47 lists the maximum extreme fiber stresses predicted by BIGBOSOR4, BOSOR5 [25], and STAGS for the optimized stiffened and unstiffened, perfect and imperfect equivalent ellipsoidal shells the dimensions of which are listed in Table 33 of [26]. Note that the column in Table 47 with the heading, "**unstiffened, imperfect**" corresponds to the optimum design listed in the version of Table 33 given in [26], not to the optimum design listed in the version of Table 33 given in this paper.

8.0 DETAILS FOR EACH OF THE FOUR CASES LISTED IN TABLE 33 OF [26]

Sub-section 8.1: Tables 30, 31, 32, and 35 – 55 and Figures 3 – 68 of [26] and Tables 30, 31, 32, and 35 – 45 and 47 and Figs. 3 – 17 and 20, 36, 37, 38, 47, and 48 here pertain to the **isogrid-stiffened, imperfect** equivalent ellipsoidal shell. **Sub-section 8.2:** Tables 56 – 66 and Figs. 69 – 114 of [26] and Figs. 74, 75, 77, and 94 here pertain to the **unstiffened, imperfect** equivalent ellipsoidal shell. **Sub-section 8.3:** Tables 67 – 71 and Figs. 115 – 128 of [26] pertain to the **isogrid-stiffened, "perfect"** equivalent ellipsoidal shell. **Sub-section 8.4:** Tables 72 – 76 and Figs. 129 – 142 of [26] pertain to the **unstiffened, "perfect"** equivalent ellipsoidal shell. "Perfect" is in quotes because the "perfect" shells were actually optimized in the presence of very, very small +mode 1 and +mode 2 axisymmetric buckling modal imperfections. (imperfection amplitude, Wimp = 0.0001 inch).

8.1 Details pertaining to the isogrid-stiffened, imperfect equivalent ellipsoidal shell

Tables 30, 31, 32, and 35 – 55 and Figures 3 – 68 of [26] and Tables 30, 31, 32, and 35 – 45 and 47 and Figs. 3 – 17 and 20, 36, 37, 38, 47, and 48 in this paper pertain to this sub-section.

8.1.1 Input data

Table 35 lists the input data for the BEGIN processor for the specific case, "eqellipse", which is a member of the GENOPT user's generic class, "equivellipse". (Both the generic case name, "equivellipse", and the specific case name, "eqellipse", stand for "equivalent ellipsoidal shell".) The name of the input file for BEGIN is "eqellipse.BEG". The decision variables in this specific case are the "skin thickness at xinput: THKSKN"(i), i = 1,13, the "height of isogrid members at xinput: HIGHST"(i), i = 1,13, the "spacing of the isogrid members: SPACNG", and "thickness of an isogrid stiffening member: THSTIF". Note that the names of these decision variables, THKSKN, HIGHST, SPACNG, and THSTIF, are the GENOPT-user-selected variable names, and the one-line definitions, "skin thickness at xinput", etc. are those chosen by the GENOPT user (Table 2).

"NCASES" is the number of load sets: two in this example, Load Set 1 for the shells with +mode 1 and +mode 2 axisymmetric linear bifurcation buckling modal imperfection shapes and Load Set 2 for the shells with –mode 1 and –mode 2 axisymmetric linear bifurcation buckling modal imperfection shapes. If the user had set NCASES equal to 4, Load Sets 1 and 2 would have been as just defined, Load Set 3 would have been for shells with +mode 3 and + mode 4 axisymmetric linear buckling modal imperfection shapes, and Load Set 4 would have been for shells with –mode 3 and –mode 4 axisymmetric linear bifurcation buckling modal imperfection shapes.

The indexes, JSKNBK1 and JSKNBK2, in Table 35 are the number of **regions** for computing local stress and local buckling of the shell skin and isogrid stiffeners. See the next paragraph and

Item No. 40.2 in Table 5, which is the "help" paragraph associated with the variable **xlimit**, for the meaning of "**regions**" as used in this context.

The GENOPT-user-specified variables with names ending in the letter "A" are **allowables**. The variables with the names ending in the letter "F" are the **factors of safety**. In the two-dimensional arrays such as SKNBK1A(i, j) the integer i denotes the **load set number** and the integer j denotes the **region number** (Fig. 2). Region 1 is the meridional domain between the pole and xlimit=17.63477 inches, and Region 2 is the meridional domain between xlimit=17.63477 inches and the equator.

The variable names are all defined in Table 2. If a shell is to be optimized in the presence of the first two axisymmetric buckling modal imperfections, mode 1 and mode 2, then the number "1" in the variable name, such as CLAPS1A, indicates "in the presence of the mode 1 axisymmetric imperfection" and the number "2" in the variable name indicates "in the presence of the mode 2 axisymmetric imperfection". For example, the name, **SKNBK1A(2,1)**, means "local **SK**i**N** **B**uc**K**ling, axisymmetric mode **1** imperfection shape, **A**llowable, load set **2** (which is for a –mode 1 imperfection shape), region **1** of the meridian of the equivalent ellipsoidal shell". If a shell is to be optimized in the presence of the first four axisymmetric buckling modal imperfections, mode 1, mode 2, mode 3, and mode 4, then the number "1" in the variable name indicates "odd-numbered modal axisymmetric imperfection" (mode 1 or mode 3) and the number "2" in the variable name indicates "even-numbered modal axisymmetric imperfection" (mode 2 or mode 4).

Note from Table 35 that the Role 3 variable, PRESS, and each of the "behavioral" allowables (Role 5 variable) and factors of safety (Role 6 variable) are provided in **loops over the number of load sets**. Role 4 variables are not prompted for in BEGIN because they are unknown values, such as collapse load factor (CLAPS1), general buckling load factor (GENBK1), local skin buckling load factor (SKNBK1), local stiffener buckling load factor (STFBK1) maximum stress in the shell skin (SKNST1), maximum stress in the stiffeners (STFST1), and apex displacement (WAPEX1). **The user provides only the allowables and factors of safety corresponding to these "behaviors".** Where Region 1 and Region 2 apply (local stress and buckling in shell skin and stiffener in Regions 1 and 2) the inner loop is the loop over load set number, and the outer loop is the loop over region number. The allowables and factors of safety corresponding to shells with mode 2 axisymmetric buckling modal imperfection shapes (CLAPS2A, CLAPS2F, etc.) are provided by the user after all the "mode 1" quantities have been provided.

Table a47 in the appendix of [26] lists **what the "end" user actually sees on his or her computer screen during the interactive "BEGIN" session** corresponding to Table 35. The "end" user's responses are in bold face. Some comments on Table a47 are:
1. The first line, "GENOPT = /home/progs/genopt" refers to the location of the GENOPT material on the writer's computer where this work was done. At another user's facility the string, "/home/progs" would be replaced by wherever the GENOPT material is located at that facility.
2. In response to the query, "Are you correcting, adding to, or using an existing file?", the "end" user responds "n" in Table a47. The "n" response leads to an interactive session. If the "end" user wanted to use as input the existing eqellipse.BEG file listed in Table 35, he would have

responded “y” to this prompt. GENOPT would then have read the input data from the eqellipse.BEG file instead of requiring interactive input from the “end” user.
3. On the computer screen GENOPT echoes the “end” user’s data entries. These echoes are not listed in Table a47 in order to save space.
4. GENOPT does not require any input from the “end” user for the “behavioral” variables (collapse, buckling, apex deflection, etc) such as CLAPS1, GENBK1, SKNBK1, WAPEX1, CLAPS2, STFST2, WAPEX2, etc. No values yet exist for the “behavioral” variables. Values for them are computed later in SUBROUTINE STRUCT (or possibly in the “behavior” subroutines BEHXi if the GENOPT user has decided on that strategy). During the “BEGIN” interactive session GENOPT only requires values for the allowable and the factor of safety that correspond to each “behavioral” variable. For example, the several lines on page 3 of Table a47 that begin with the line, “DEFINITION OF THE ROW INDEX OF THE ARRAY, CLAPS1 =” and end with the second line that reads, “collapse pressure with imperfection mode 1: CLAPS1” do not require any response from the “end” user. The “end” user is first required to respond when the prompt, “allowable pressure for axisymmetric collapse: CLAPS1A(1)=” appears on the computer screen. The same holds for the rather long series of lines having to do with the “behavioral” variable, SKNBK1. GENOPT presents all those “SKNBK1” lines on the screen but waits for a response from the end user only after presentation of the prompt, “allowable buckling load factor: SKNBK1A(1, 1)=”.
5. Where there are two-dimensional arrays for allowable and factor of safety, GENOPT requires responses from the user over the “load case loop” as the inner loop and over the “region loop” as the outer loop.
6. Where the line, “(many lines skipped to save space)”, occurs the input is analogous to that which is included in Table a47.

As explained in Sub-section 3.7.3 and in Tables 16 and 31 and 32, **design margins** are automatically constructed by GENOPT using the Role 4,5,6 variable names such as STFBK1, STFBK1A, and STFBK1F (local isogrid stiffener buckling) as follows (from Table 31):

```
(STFBK1(1,1)/STFBK1A(1,1))/STFBK1F(1,1)-1; F.S.= 1.00
```

or using Role 4,5,6 variable names such as SKNST1, SKNST1A, and SKNST1F (local skin effective stress) as follows (from Table 32):

```
(SKNST1A(2,2)/SKNST1(2,2))/SKNST1F(2,2)-1; F.S.= 1.00
```

Table 36 lists the input file, eqellipse.DEC, for the DECIDE processor for the specific case, “eqellipse”. The writer has added the names, THKSKN(1), THKSKN(2), etc. on the right-hand side in Table 36 so that the reader knows the correspondence between decision variable number and name of that decision variable. (Actual *.DEC files do not include the decision variable names). “Escape” variables are those variables that when increased drive the design toward the feasible region. Typically a wall thickness is an escape variable because a thicker wall almost always leads to higher buckling loads, lower stresses, and smaller deformations. “Escape” variables are needed for instances during optimization cycles when a design is so far in the unfeasible region that it is impractical to rely on ADS to drive it toward the feasible region. In such instances, instead of using ADS, the main processor, OPTIMIZE, drives the design toward the feasible region by cyclically increasing all of the user-selected or default-selected escape variables by 10 per cent per cycle until ADS resumes control of the optimization process. The default selection chooses a decision variable as an escape variable if the string, "thick" occurs in the one-line definition of that decision variable.

Table 37 lists the input file, eqellipse.OPT, for the MAINSETUP/OPTIMIZE processors for the specific case, "eqellipse". The response to the prompt, "Choose an analysis you DON'T want (1, 2,…), IBEHAV" is repeated NCASES times, that is, for the number of load sets, in this example 2 load sets. See Sub-section 3.7.3 for more on IBEHAV (spelled IBEHV there). IDESIGN = 2, the preferred choice, means that an "ALMOST FEASIBLE" design will be accepted by GENOPT, that is, a design for which all margins are greater than –0.05. IMOVE = 1, the preferred choice, means that the move limit for each decision variable during an optimization cycle is ten per cent. These and other inputs are explained via "help" paragraphs in the file, /home/progs/genopt/execute/URPROMPT.DAT. The complete file, URPROMPT.DAT, is listed in Table a24 of the appendix of [26]. Unlike the GENOPT-generated prompting file, called "equivellipse.PRO" for the generic case "equivellipse", the prompting file called URPROMPT.DAT, remains the same for all GENOPT generic cases. This prompting file is used during the execution of the GENOPT processors called CHANGE, DECIDE, MAINSETUP, and CHOOSEPLOT.

8.1.2 Optimization

Figure 3 shows the objective vs design iterations for the last of a series of four executions of SUPEROPT (Table 39). Each "spike" in the plot corresponds to a new starting design, obtained randomly as described in [15]. The presence of the three "dense" or "quiet" regions starting approximately at Iteration Numbers 150, 325, and 440 in this particular case, is explained in Section 9 on p. 10 of [24] as follows:

"During a SUPEROPT run the 'starting' design is set equal to the best design determined so far at or near Design Iteration Numbers. 150, 300, and 450, and the maximum permitted 'move limits' are reduced temporarily from 0.1 to 0.02 at or near each of these same three Iteration Numbers. (See Items 730 and 740 in Table a24 of [26] for more information about the index, IMOVE). This new strategy helps PANDA2 'close in' on a FEASIBLE or ALMOST FEASIBLE local minimum-weight design. The 'move limits' are re-expanded to 0.1 at the next execution of AUTOCHANGE." (For "next execution of AUTOCHANGE" see the second page of Table 34).

The optimum design is listed in Table 33 under the heading, "**isogrid-stiffened, imperfect**".

Table 38 lists an input file, eqellipse.CHG, for the processor called CHANGE. In this instance **CHANGE is used as a means to preserve the optimum design** electronically so that in the future that same optimum design can easily be re-established by execution of BEGIN with use of the file listed in Table 35 followed immediately by execution of CHANGE with use of the file listed in Table 38. **Over the years the writer has found that it is always a good idea to use CHANGE to "save" previously obtained optimum designs.**

Table 39 lists the run stream used to produce, in this particular case, the optimum design of the isogrid-stiffened imperfect equivalent ellipsoidal shell and to produce the plots from BIGBOSOR4 of axisymmetric linear bifurcation buckling modes 1 and 2 corresponding to the optimum design. The plots of +mode 1 and +mode 2 axisymmetric buckling modes are displayed in Figs. 4 and 5. The –mode 1 and –mode 2 imperfection shapes are simply the negatives of the deformed shapes exhibited in Figs. 4 and 5, respectively.

In Table 39 notice that each execution of SUPEROPT is followed immediately by executions of CHOOSEPLOT and DIPLOT before SUPEROPT is executed again. After successful completion of a SUPEROPT run, execution of CHOOSEPLOT causes the total number of design iterations to be reset to zero so that the next execution of SUPEROPT begins at Design Iteration Number zero. If the user does not execute CHOOSEPLOT after successful completion of a SUPEROPT run, but instead tries immediately to execute SUPEROPT again, the second SUPEROPT run will terminate after only a few design iterations because the total number of design iterations (a number greater than 465, probably between 468 and 474) will exceed the number that automatically "tells" SUPEROPT to stop.

PART 2 of Table 39 briefly instructs the user how to run BIGBOSOR4 using one of the files (eqellipse.ALL1) as input data. The long footnote at the bottom of Table 30 gives more details about how to use independent BIGBOSOR4 runs to obtain results for each of the seven analyses listed in the body of Table 30. The reader should study the footnote of Table 30 carefully.

8.1.3 Design margins

Tables 31 and 32 list the design margins for the **optimized isogrid-stiffened imperfect equivalent ellipsoidal shell**. In each table a line is skipped between Margins 11 and 12 to emphasize that the first 11 margins correspond to the shell with the axisymmetric mode 1 imperfection shape and Margins 12 – 22 correspond to the shell with the axisymmetric mode 2 imperfection shape. (This skipped line is not present in the actual *.OPM file from which the margins listed in Tables 31 and 32 are abstracted; see Table a19). For this particular case general nonlinear bifurcation buckling margins (GENBK) and local skin buckling margins (SKNBK) are not critical or nearly critical, as can be seen from inspection of Tables 31 and 32. The –mode 1 and –mode 2 imperfections (Load Set 2 = Table 32 = imperfection causes flattening near the apex of the shell as seen in Figs. 14 and 15) generate more critical and near-critical margins than do the +mode 1 and +mode 2 imperfections (Load Set 1 = Table 31 = imperfection causes local bulging near the apex of the shell as seen in Figs. 12 and 13). The isogrid stiffener local buckling margins for –mode 1 and –mode 2 in Region 1 [STFBK1(2,1) and STFBK2(2,1)] are near-critical (Table 32, margins 5 and 16). Several of the skin and isogrid stiffener stress margins (SKNST and STFST) are critical or near-critical. The collapse margin corresponding to the –mode 1 imperfection shape [CLAPS1(2)] is critical. (Design margin no. 1 in Table 32 is near zero). Margin 12 in Table 32 is identical to Margin 12 in Table 31 (CLAPS2). This is not a coincidence but indicates that no axisymmetric collapse occurs for an external pressure less than 920 psi, which is twice the design pressure, p = 460 psi, and which is the maximum external pressure used in the collapse analyses conducted in SUBROUTINE STRUCT. (See Analysis No. 5 in Table 30, for example).

Figures 4 and 5 display the axisymmetric buckling modes, +mode 1 in Fig. 4 and +mode 2 in Fig. 5, obtained for the optimized design by BIGBOSOR4 as described in Part 2 of Table 39, in the long footnote in Table 30, and in the next paragraph.

When the GENOPT processor called "OPTIMIZE" is executed **with the use of "type of analysis", ITYPE = 2 (fixed design, Table 37)**, several files are produced, the name of each file starting with the string, "eqellipse" (the user-selected name for the specific case). Most of these files have names of the form, eqellipse.ALLxxx. Each of these *.ALL* files is valid input for BIGBOSOR4 (or BOSOR4). One can use each of these files to obtain results directly from BIGBOSOR4 (or BOSOR4). For example, the file called "eqellipse.ALL1" can be used to obtain the axisymmetric linear buckling modes shown in Figs. 4 and 5 by means of the statements listed in Part 2 of Table 39 and as described in the long footnote to Table 30. The other *.ALL* files produced by OPTIMIZE **running in the ITYPE=2 mode** are described in the file, /home/progs/genopt/case/torisph/readme.equivellipse. (Note: the string, "/home/progs/genopt" points to the location of the GENOPT material stored on the writer's computer. To find the same file at your facility, replace the string, "/home/progs", with whatever string corresponds to the appropriate location on your computer.) The processor, OPTIMIZE, **running in the ITYPE=2 mode** also produces a file called "eqellipse.STAGS". The eqellipse.STAGS file corresponding to the optimized isogrid-stiffened shell is listed in Table a23 of the appendix. This file, with its name changed to **WALLTHICK.STAGS**, is used in connection with STAGS models described in the next and in other sub-sections. (See Table 40 for more on WALLTHICK.STAGS).

8.1.4 Evaluation of the optimum design with the use of STAGS

We have an optimum design derived from GENOPT by means of repeated executions of SUPEROPT/CHOOSEPLOT/DIPLOT, and we wish now to check this optimum design through the use of a general-purpose finite element computer program. **Here we choose STAGS [20 – 24] to evaluate the optimum design obtained by GENOPT.** We choose STAGS because STAGS is very good at solving difficult nonlinear shell problems and because the developer of STAGS, Dr. Charles Rankin, is close by.

Table 40, many pages long, instructs the user how to generate STAGS input files and how to obtain results. Because the thickness of the optimized shell varies over the surface of the shell, STAGS requires that a user-written subroutine called "WALL" or that a user-written subroutine called "USRFAB" be available. Versions of SUBROUTINE WALL are listed in Tables a20 – a22 of [26] and Tables a32 and a33 of [26]. Versions of SUBROUTINE USRFAB are listed in Tables a34 – a36 of [26]. (Table a36 is also included in the appendix of this paper).

In this section only SUBROUTINE WALL is used. Four copies of SUBROUTINE WALL are listed in the appendix of [26]:

1. a skeletal ("template") version of WALL that is provided with the STAGS software (Table a20 of [26]),

2. a complete version of WALL valid for elastic material (Table a21 of [26]),

3. a complete version of WALL valid for elastic-plastic material (Table a22 of [26]), and

4. a complete version of WALL valid for a 180-degree STAGS “soccerball” model of the equivalent ellipsoidal shell (Table a32 of [26]).

There are also several versions of USRFAB listed in the appendix (Tables a34 – a36 of [26]).

The complete versions of WALL or USRFAB require that a file called “**WALLTHICK.STAGS**” be available. WALLTHICK.STAGS contains the meridional distributions of shell skin thickness, isogrid height, and certain other information. A copy of WALLTHICK.STAGS (called “eqellipse.STAGS” for the specific case, “eqellipse”, because it is generated by execution of the mainprocessor, OPTIMIZE for the specific case called “eqellipse”) is listed in the appendix (Table a23). Lists of the two input files required for STAGS, eqellipse.bin and eqellipse.inp, are included on pages 3 – 8 of Table 40. From the list of eqellipse.inp (pages 4 – 8 of Table 40) one sees that the STAGS finite element called “410” is used in the 360-degree STAGS model (Fig. a1). (The favored STAGS 480 finite element does not work in connection with the 360-degree STAGS model displayed in Fig. a1, probably because of the greatly elongated finite elements shown in the insert at the top of Fig. a1).

Also included in Table 40 are input and output for the sequence of STAGS runs and “post-processing” by the STAGS processors, STAPL and XYTRANS, needed to obtain the maximum pressure-carrying capability of the optimized isogrid-stiffened equivalent ellipsoidal shell with axisymmetric or non-axisymmetric linear buckling modal imperfections.

STAGS is used:

1. to obtain the axisymmetric mode 1 and mode 2 and non-axisymmetric linear bifurcation buckling modal imperfection shapes from an INDIC=1 STAGS analysis (pp. 3 – 11 of Table 40 and Table 41, and Figs. 6 – 10),

2. to obtain plots of the axisymmetric and the non-axisymmetric linear buckling modes (pp. 11, 12 of Table 40 and Figs. 6 – 10),

3. to modify the eqellipse.bin and eqellipse.inp files in order to run nonlinear equilibrium and nonlinear bifurcation buckling analyses (INDIC = 3) of the optimized shell with plus and minus mode 1 and mode 2 initial axisymmetric imperfection shapes and other non-axisymmetric buckling modal imperfection shapes (pp. 12 – 17 of Table 40 and Figs. 16 and 17),

4. to obtain the maximum pressure-carrying capabilities of the imperfect shells (pp. 17 – 19 of Table 40 and Figs. 16 and 17), and

5. to obtain “x,y” plots of external pressure versus normal deflection of the apex of the shell for various axisymmetric and non-axisymmetric linear buckling modal imperfection shapes (pp. 18, 19 of Table 40 and Figs. 16 and 17).

A typical 12-shell-unit 360-degree STAGS model of the equivalent ellipsoidal shell is displayed in the appendix (Fig. a1). The 12 shell units shown in Fig. a1 correspond exactly to the 12 shell segments in the BIGBOSOR4 model displayed in Fig. 2.

Table 41 lists a small part of the STAGS output file, eqellipse.out2, corresponding to a linear bifurcation buckling STAGS execution (INDIC=1). In this case the fundamental buckling mode, displayed in Fig. 6, is axisymmetric. It is analogous to the "+mode 1" axisymmetric imperfection shape predicted by BIGBOSOR4 and depicted in Fig. 4. Axisymmetric "+mode 2" corresponds to the sixth eigenvalue computed by STAGS (Fig. 9). It is analogous to the "+mode 2" axisymmetric imperfection shape predicted by BIGBOSOR4 and depicted in Fig. 5.

STAGS eigenvalues 2 – 5 correspond to non-axisymmetric eigenvectors (buckling modes), as displayed in Figs. 7 and 8. Note from Table 41 that in the 360-degree STAGS model the STAGS eigenvalues corresponding to non-axisymmetric buckling modes occur in pairs. The corresponding eigenmodes are the same in each member of the pair except that one mode is rotated circumferentially with respect to the other in the pair. Figure 9 shows the axisymmetric "+mode 2" from STAGS, and Fig. 10 shows the non-axisymmetric mode corresponding to the next higher eigenvalue.

NOTE: BIGBOSOR4 is capable of computing linear and nonlinear buckling modal eigenvalues and eigenvectors (buckling modes) corresponding to non-axisymmetric buckling modes as well as axisymmetric buckling modes. However, no comparison is made here for linear bifurcation buckling between the predictions of STAGS and BIGBOSOR4 for linear non-axisymmetric buckling modes because non-axisymmetric initial linear buckling modal imperfections cannot be used in the GENOPT models described in this paper or in the long report [26] on which this paper is based. BIGBOSOR4 (AND BOSOR4) CANNOT HANDLE PREDICTION OF THE BEHAVIOR OF SHELLS OF REVOLUTION WITH NON-AXISYMMETRIC INITIAL IMPERFECTION SHAPES.

8.1.5 Some predictions from BIGBOSOR4 (GENOPT), BOSOR5, and STAGS

Figure 11 demonstrates that there is excellent agreement between BIGBOSOR4 and STAGS for the axisymmetric linear bifurcation buckling modes 1 and 2. This agreement leads to the reasonably good agreement between STAGS and BIGBOSOR4 predictions of maximum pressure-carrying capability of the optimized axisymmetrically imperfect isogrid-stiffened equivalent ellipsoidal shells, as displayed in Fig. 16.

Figures 12 – 15 show the axisymmetric deformed states (according to BOSOR5 [25] with the use of elastic material) of the optimized isogrid-stiffened equivalent ellipsoidal shells with +mode 1 (Fig. 12), +mode 2 (Fig. 13), –mode 1 (Fig. 14), and –mode 2 (Fig. 15) axisymmetric linear buckling modal imperfections with amplitude, Wimp = 0.2 inch. The axisymmetrically imperfect shells are loaded by the external design pressure, p = 460 psi.

These axisymmetrically deformed states predicted by BIGBOSOR4 give rise to the maximum local stress and minimum buckling load factors of shell skin and isogrid stiffeners listed in

Tables 42 – 45 for the shells with the axisymmetric +mode 1 imperfection (Table 42), +mode 2 imperfection (Table 43), –mode 1 imperfection (Table 44), and –mode 2 imperfection (Table 45). The results in Tables 42 – 45 are produced by BIGBOSOR4. They are included in the output file, *.OPM, which is produced by the GENOPT mainprocessor, "OPTIMIZE", run in the ITYPE=2 mode and with NPRINT = 2 in the *.OPT file (Table a19). In Tables 42 – 45 the local maximum effective stress in the shell skin (SKNMAX) in each of the 12 segments of the equivalent ellipsoidal shell (Fig. 2) are computed taking into account the comparison of the effective stresses at both the inner and outer extreme fibers of the skin. Output for the inner fiber effective stress and outer fiber effective stress are not available as separate quantities in the data produced by BIGBOSOR4 as processed by GENOPT. Similarly, the maximum absolute value of the stress (STFMXS) along the axis of a **MERIDIONALLY ORIENTED** isogrid stiffener (assumed here to be the most critical orientation of an isogrid member) is obtained from comparison of the stresses both at the root and tip of the stiffener. The stiffener root and tip stresses are not available as separate quantities in the output produced by BIGBOSOR4 as processed by GENOPT. There are no "rings" (circumferentially running stiffeners independent of the isogrid). Hence the (nonexistent) ring buckling load (BUCMNR) is arbitrarily set equal to a very high value and the maximum stress in the (nonexistent) ring (STFMXR) is arbitrarily set equal to zero so that these irrelevant quantities will not produce critical margins that affect the evolution of the design during optimization cycles.

Figure 16 shows plots of load-apex-deflection curves from GENOPT (BIGBOSOR4, elastic material), STAGS (elastic material), and BOSOR5 (elastic-plastic material)[25] for the optimized isogrid-stiffened imperfect equivalent ellipsoidal shell. There is reasonably good agreement between BIGBOSOR4 and STAGS predictions of maximum pressure-carrying capabilities of the elastic shells. Note that BIGBOSOR4 and BOSOR5 cannot obtain solutions "beyond" the maximum pressure because the BOSOR programs do not have the Riks nonlinear continuation algorithm [22], whereas STAGS does [22]. The most critical case is that with the –mode 1 axisymmetric buckling modal imperfection. There is no effect of plasticity below or at the design pressure, 460 psi. Plastic flow (BOSOR5) affects the behavior only above the design pressure, p = 460 psi. Sample input data for the BOSOR5 preprocessor (BOSORREAD) and the BOSOR5 mainprocessor (BOSORMAIN) are listed in Tables a25 and a26, respectively, of the appendix of [26].

Figure 17 demonstrates that for this particular optimized isogrid-stiffened imperfect shell the axisymmetric –mode 1 imperfection is more critical than any of the non-axisymmetric linear buckling modal imperfection shapes displayed in Figs. 7, 8, and 10 (last three traces in Fig. 17). **As we will see in Sub-section 8.2 this is not true for the optimized UNSTIFFENED imperfect equivalent ellipsoidal shell.**

Figures 18 and 19 of [26] display a spurious nonlinear bifurcation buckling mode from the 360-degree STAGS model that affects the region near the pole of the optimized isogrid-stiffened imperfect equivalent ellipsoidal shell. The presence of this spurious nonlinear bifurcation (eigenvalue) on the primary nonlinear equilibrium path at a pressure close to 300 psi (well below the design pressure, p = 460 psi) does not seem to affect the prediction by STAGS of nonlinear behavior of the shell in this case.

Section 10.0 gives STAGS results for the same optimized isogrid-stiffened shell including plastic flow in the shells with both axisymmetric and non-axisymmetric imperfections.

8.1.6 Predictions of extreme fiber stress

In the long report [26] Figs. 20 – 35 show the distributions of meridional stress, sigma1 or sxx, at the inner fiber of the isogrid "layer" (layer number 1 in the STAGS model) and the inner and outer fiber effective stress, seff, in the shell skin (layer number 2 in the STAGS model) generated for the axisymmetrically imperfect shells with a +mode 1 imperfection (Figs. 20 – 23 of [26], Fig. 20 in this paper), a +mode 2 imperfection (Figs. 24 – 27 of [26]), a –mode 1 imperfection (Figs. 28 – 31 of [26]), and a –mode 2 imperfection (Figs. 32 – 35 of [26]). Compare the +mode1 STAGS predictions with those from GENOPT (BIGBOSOR4) listed in Table 42. Compare the +mode 2 STAGS predictions in [26] with those from GENOPT (BIGBOSOR4) listed in Table 43. Compare the –mode 1 STAGS predictions in [26] with those from GENOPT (BIGBOSOR4) listed in Table 44. Compare the –mode 2 STAGS predictions in [26] with those from GENOPT (BIGBOSOR4) listed in Table 45.

Note that the STAGS predictions for meridional inner fiber stress, sigma1 or sxx, in the isogrid "layer" may not agree very well with those from BIGBOSOR4, especially in the immediate neighborhood of the pole. This is to be expected. It is because the isogrid "layer" in the STAGS model is treated as an isotropic material with Poisson's ratio equal 1/3 both in the computation of overall shell wall stiffness (the 6 x 6 integrated constitutive matrix C_{ij}) and in the computation of stress at a point in that layer. In contrast, in the BIGBOSOR4 model, although the same "smeared" stiffener model is used for computation of the overall stiffness C_{ij} of the shell wall, the maximum stress in a single isogrid member is calculated **as if that member were oriented in the meridional coordinate direction** and as if it were not affected by any other neighboring isogrid members. Therefore, in the STAGS model the meridional stress at a point in the isogrid isotropic "layer" is computed from

$$\text{sigma1(meridional)} = [E/(1\text{-nu}^2)](\text{eps}_1 + \text{nu}*\text{eps}_2) \qquad (7)$$

in which E is the elastic modulus, nu is the Poisson ratio, eps_1 is the strain in the meridional direction and eps_2 is the strain in the circumferential direction at any point through the thickness of the shell wall layer. In contrast, in the BIGBOSOR4 model the stress at a point in the meridionally oriented isogrid stiffener is computed from

$$\text{sigma1(meridional)} = E*\text{eps}_1 \qquad (8)$$

At the pole, where $\text{eps}_1 = \text{eps}_2$, STAGS predicts

$$\text{sigma(meridional)} = E*\text{eps}_1/(1\text{-nu}) \qquad (9)$$

which for nu = 1/3 is 50 per cent greater than the value, $E*\text{eps}_1$ predicted by the BIGBOSOR4 model.

The value predicted by the BIGBOSOR4 model is the correct value to use for optimization of an actual isogrid-stiffened shell for the isogrid members that are oriented in the meridional coordinate direction, WHICH IS ASSUMED HERE TO BE THE MOST CRITICAL DIRECTION for axisymmetrically deformed, perfect or axisymmetrically imperfect, equivalent ellipsoidal shells.

The maximum stresses predicted from the axisymmetric (360-degree) STAGS models displayed in Fig. a1 of the appendix and in Figs. 20 – 35 in [26] and Fig. 20 in this paper may not represent converged values. Therefore, a much more refined 12-shell-unit STAGS model was set up. The STAGS input data for this refined model are listed in Table 46a of [26]. The model subtends only 10 degrees of circumference. Symmetry conditions are applied along the two meridionally oriented edges. These symmetry conditions simulate axisymmetric deformations.

Table 46b in [26] lists the first eight eigenvalues from both the STAGS "10-degree" model and the first eight eigenvalues from BIGBOSOR4 all of which correspond to axisymmetric mode shapes. (See the BIGBOSOR4 predictions listed under the heading, Analysis no. 1, in Table 30). In this narrow 10-degree "slice" STAGS model with symmetry conditions applied on the two meridionally oriented edges, all the eigenvalues correspond to axisymmetric buckling modes. Compare eigenvalues 1 and 2 in Table 46b in [26] with eigenvalues 1 and 6 in Table 41, which applies to the 360-degree STAGS model.

Figures 36 and 37 show +mode 1 and +mode 2 linear bifurcation buckling modes from the 10-degree refined STAGS model. These figures are analogous to Figs. 6 and 9, respectively. Figure 38 displays nonlinear load-apex-deflection curves from GENOPT (BIGBOSOR4) and from STAGS for the 360-degree STAGS model and for the 10-degree STAGS model. Figures 39 – 46 in [26] show the inner fiber meridional stress in the isogrid "layer" for the +mode 1 imperfection (Figs. 39, 40 in [26]), for the +mode 2 imperfection (Figs. 41, 42 in [26]), for the –mode 1 imperfection (Figs. 43, 44 in [26]), and for the –mode 2 imperfection (Figs. 45, 46 in [26]). Compare the stresses displayed in these figures with those from the 360-degree STAGS models shown in Figs. 20 and 21 in [26] for the +mode 1 imperfection, in Figs. 24 and 25 in [26] for the +mode 2 imperfection, in Figs. 28 and 29 in [26] for the –mode 1 imperfection, and in Figs. 32 and 33 in [26] for the –mode 2 imperfection. Compare with those from GENOPT (BIGBOSOR4) listed in Tables 42 – 45, respectively.

Figure 47 shows the extreme fiber meridional stress in the isogrid "layer" for the optimized isogrid-stiffened imperfect equivalent ellipsoidal shell at the design external pressure, p=460 psi. The shell has a –mode 1 axisymmetric linear bifurcation buckling modal imperfection with amplitude, Wimp = –0.2 inch. The BOSOR5 (with the use of elastic material) and STAGS predictions are from similar models in that the meridional stress is computed from a model in which the isogrid "layer" is treated as an isotropic layer with smeared stiffeners [Eq.(7)] and in both models the material remains elastic. Most of the BOSOR5 data points correspond to the extreme inner fiber of the isogrid "layer". The BOSOR5 data points corresponding to the root of the isogrid "layer" (the extreme outer fiber of the isogrid "layer") are plotted only over part of the meridian, from about 8 inches to about 27 inches of the meridional reference surface arc length. No STAGS data points are plotted for the root of the isogrid "layer". The BIGBOSOR4 points are taken directly from Table 44 (maximum STFMXS in each shell segment, except for the sign of the stress; only absolute values are listed in Table 44). As has been mentioned previously, the BIGBOSOR4 data entries in Table 44 represent the maximum absolute values of inner and outer fiber meridional stresses in each shell segment; inner and outer fiber meridional stresses are not both listed. (Outer fiber of the isogrid "layer" is the same location as the root of the isogrid "layer"). The BOSOR5 (with use of elastic material) and STAGS predictions are in very good agreement because they are based on the same type of model [Eq.(7)]. The BIGBOSOR4 predictions differ because the maximum axial stress in a meridionally oriented isogrid member is computed from a different formula [Eq.(8)] in BIGBOSOR4, as previously explained, than that used for computation of the meridional stress from the BOSOR5 and STAGS models in which the isotropic stiffeners are replaced by a uniform homogenous isotropic material (smeared isotropic "layer" model).

Figure 48 is analogous to Fig. 47. It corresponds to the same shell with a –mode 2 imperfection shape instead of a –mode 1 imperfection shape.

Note that at the pole the meridional stress from both the BOSOR5 (elastic) and STAGS models is approximately 1.5 = 1/(1 – nu) times the meridional stress from the BIGBOSOR4 model. That difference is as it should be for a Poisson's ratio equal to 1/3, as previously explained [Eq.(9)]. In Fig. 47 the STAGS prediction is a bit low, possibly due to the relative crudeness of the 360-degree STAGS model or possibly due to the extremely elongated shape of the finite elements nearest the pole, as seen in the insert at the top of Fig. a1.

The most critical stresses from the BIGBOSOR4, STAGS, and BOSOR5 models for all four axisymmetric imperfection shapes (+mode 1, +mode 2, –mode 1, and –mode 2, are listed in the two columns in Table 47 headed, **"isogrid-stiffened, imperfect"**.

See Section 10.0 and Figs. 254 – 276 of [26] for more results relating to the optimized isogrid-stiffened shell for various STAGS analyses in which the effect of plastic flow is included.

Table 47 is analogous to Table 33 of [26] in that it pertains to all the four optimum designs: Table 47 lists the maximum extreme fiber stresses predicted by BIGBOSOR4, BOSOR5 [25], and STAGS for the optimized stiffened and unstiffened, perfect and imperfect equivalent ellipsoidal shells, the optimum designs of which are listed in the version of Table 33 in [26].

8.1.7 Use of plus and minus axisymmetric modes 1 – 4 (4 load sets)

See [26] for results corresponding to this sub-section.

8.1.8 Optimization with the use of plus and minus modes 1 – 4

See [26] for results corresponding to this sub-section.

8.2 Details pertaining to the unstiffened, imperfect equivalent ellipsoidal shell

Tables 56 – 66 and Figs. 69 – 114 of [26] and Figs. 74, 75, 77, and 94 in this paper pertain to the **unstiffened, imperfect** equivalent ellipsoidal shell as discussed in this sub-section. There is more in Section 9.0. As is seen in this important sub-section in [26], the optimized unstiffened shell analyzed in this sub-section in [26] is severely under-designed, in the author's opinion, because the collapse pressure of this optimized design turns out to be extremely sensitive to **non-axisymmetric** buckling modal imperfections, imperfection types not present during the optimization cycles. Non-axisymmetric buckling modal imperfections are not present in the GENOPT model used here because the GENOPT model is based on BIGBOSOR4 and **BIGBOSOR4 can handle only axisymmetric** imperfections. This inadequacy is eliminated in a simple way, as described later in Section 9.0.

Although the shell is termed "**unstiffened**", in this section (as in Section 9.0) the shell is modeled as if it has two layers: an isogrid "layer" and the shell skin. To represent an unstiffened shell the height of the isogrid is set equal to a very, very small value, HIGHST(i) = 0.000001 inch, and the thickness of each isogrid member is also set equal to a very, very small number, 0.00001 inch (Table 56 of [26]). Therefore, the presence of the isogrid layer has no effect on the behavior of the shell. In STAGS models the isogrid layer is Layer No. 1 and the shell skin is Layer No. 2.

8.2.1 Input data

See [26] for data corresponding to this sub-section.

8.2.2 Optimization

See [26] for results corresponding to this sub-section.

8.2.3 Design margins

See [26] for results corresponding to this sub-section.

8.2.4 Some predictions from BIGBOSOR4 (GENOPT), BOSOR5, and STAGS

Figures 74 and 75 show the axisymmetric linear bifurcation buckling modes 1 and 2, respectively, of the **optimized unstiffened equivalent ellipsoidal shell** as predicted by BIGBOSOR4. Comparing Fig. 74 with Fig. 4, which pertains to the optimized isogrid-stiffened shell, we see that the characteristic meridional wavelength of the axisymmetric mode 1 buckle in the unstiffened shell is much shorter than that in the isogrid-stiffened shell. The shape of the mode 1 buckle in the neighborhood of the pole (Fig. 74) is almost identical to that of the mode 2 buckle in the neighborhood of the pole (Fig. 75), and the shape of the mode 1 buckle far from the pole is similar to the negative of the mode 2 buckle far from the pole.

The fact that both the mode 1 and mode 2 axisymmetric imperfection shapes exhibit rather small deflections everywhere except in the neighborhood of the pole has a significant consequence with respect to the suitability of the optimum design of the axisymmetrically imperfect unstiffened equivalent ellipsoidal shell developed with use of the decision variables and their lower bounds as listed in Table 57 of [26]. It is found from STAGS models that the pressure-carrying capability of the unstiffened shell optimized in the presence of only **axisymmetric** linear buckling modal imperfection shapes turns out to be especially sensitive to **non-axisymmetric** linear buckling modal imperfections, imperfections that have shapes for which the maximum buckling modal normal deflection is maximum some distance away from the pole rather than at the pole. We will see this later in connection with STAGS predictions. A simple way to avoid this difficulty is to force the spherical cap (Shell Segment 1 in Fig. 2) to be relatively thick. Results for "**thick apex**" optimized unstiffened shells are presented in Section 9.0 in Figs. 143 – 254 and Tables 77 – 95 of [26] and in Figs. 148, 161 and 188 here.

8.2.5 Predictions of extreme fiber stress

See [26] for results corresponding to this sub-section. The most critical stresses from the BIGBOSOR4, STAGS, and BOSOR5 models for all four axisymmetric imperfection shapes (+mode 1, +mode 2, –mode 1, and –mode 2, are listed in the column in Table 47 headed, **"unstiffened, imperfect"**. NOTE: The stresses listed in Table 47 for the "unstiffened, imperfect" shell correspond to the optimum design listed in the version of Table 33 given in [26], not the version of Table 33 listed in this paper.

8.2.6 The inadequacy of the optimized unstiffened axisymmetrically imperfect shell

Figure 94 (a very important figure!) displays load-apex-deflection curves for axisymmetric –mode 1, –mode 2, +mode 3, and –mode 3 imperfection shapes and non-axisymmetric imperfection shapes corresponding to the linear bifurcation buckling modes shown in Fig. 77 (n=1 circumferential wave), Fig. 79 of [26] (n=2 circumferential waves), and Fig. 81 of [26] (n=3 circumferential waves). **Note that the sensitivities of the maximum pressure-carrying capability to NON-AXISYMMETRIC imperfections are much greater than those to axisymmetric imperfections, especially greater than those corresponding to the mode 1 and mode 2 axisymmetric imperfections in the presence of which the shell was designed. The non-axisymmetric buckling modal imperfection with n=1 circumferential wave is the most harmful imperfection, given its amplitude, Wimp = 0.2 inch.**

8.2.7 Important Note!

The most significant results in Fig. 94 are the extremely low maximum pressure-carrying capabilities of the **non-axisymmetrically imperfect unstiffened shells** optimized with the use of only the two axisymmetric linear buckling modal imperfection shapes, mode 1 and mode 2.

The lowest collapse load of a non-axisymmetrically imperfect shell is at an external pressure of about 215 psi (trace with Xs), less than half the specified design pressure, p = 460 psi. **The non-axisymmetric imperfections are far more harmful than the axisymmetric mode 1 and mode 2 imperfections, indicating that the optimized unstiffened shell is probably an impractical design. A small dent anywhere on the surface of the shell except in the immediate neighborhood of the pole will probably cause collapse at a pressure far below the design pressure, p = 460 psi.**

What appears to be occurring here is that the optimization "tailors" the axisymmetric mode shapes, mode 1 and mode 2, so that these modes exhibit relatively small deflections away from the pole, where the contribution of wall thickness to the total weight of the shell is most significant. This characteristic of the axisymmetric linear buckling modal imperfection shapes of the optimized unstiffened shell can be seen in Figs. 74 and 75.

The local nature of the axisymmetric buckling modal imperfection shapes displayed in Figs. 74 and 75 is a consequence of a certain peculiarity of the meridional distribution of shell wall thickness that evolves during the optimization process. In the optimized shells there is a thick and rather local circumferential band centered at xinput(3)= 5.66645 inches (Table 28). This locally thickened circumferential band is exhibited in Table 33 of [26] (the column with the heading "**unstiffened, imperfect**" in Table 33 of [26]). (Also, see the footnote to the version of Table 33 given in this paper). The thick band, THKSKN(3) = **0.5991** inch, acts very much as a ring stiffener that isolates the apex region from the rest of the shell. Essentially we have a shallow axisymmetrically imperfect spherical cap clamped at its edge and connected to an almost perfect remainder of the shell. If, during the fabrication and handling process, an off-center dent with depth, Wimp, approaching 0.2 inch, is somehow produced in the remainder of the shell, there is a high probability that under uniform external pressure the dented shell will collapse at a pressure significantly below the design pressure, p = 460 psi.

The following questions arise:

1. Would the axisymmetric buckling modal imperfection shapes depicted in Figs. 74 and 75 be typical of imperfections in actual fabricated optimized unstiffened shells?

2. Is it safe to use only the axisymmetric mode 1 and mode 2 linear buckling modal imperfection shapes in designing and evaluating the unstiffened shell?

The answers to both questions, in the writer's opinion, is, "Almost certainly not."

In the writer's opinion the method as described up to this point to obtain optimum designs of UNSTIFFENED ellipsoidal shells is faulty. This weakness in the approach does not seem to exist in the case of isogrid-stiffened shells, as is seen from Fig. 17. Hence, the method is most likely a reasonable one for that class of shells. The method as described so far probably will not work well if a shell is only weakly stiffened.

HOWEVER, THERE IS A SIMPLE "FIX". Since the inadequacy of the optimum design of the unstiffened imperfect shell is related to the shapes of the axisymmetric buckling modal

imperfections displayed in Figs. 74 and 75 (significant local deviation from perfect only in the immediate neighborhood of the apex of the shell), one should obtain optimum designs of unstiffened shells in which the apex region is forced to remain thick enough during optimization cycles so that the maximum axisymmetric buckling modal deflection will not occur there. This has been done, and the results are presented in Section 9.0 in Figs. 143 – 253 and Tables 77 – 95 of [26] and in Section 9.0 and Figs. 148, 161 and 188 in this paper.

8.2.8 Optimization with the use of plus and minus modes 1 – 4

See [26] for results corresponding to this sub-section.

8.3 Details pertaining to the isogrid-stiffened, "perfect" equivalent ellipsoidal shell

Tables 67 – 71 and Figs. 115 – 128 of [26] pertain to the **isogrid-stiffened, "perfect"** equivalent ellipsoidal shell. "Perfect" is in quotes because in fact a very small axisymmetric initial imperfection amplitude is used: Wimp = 0.0001 inch in the eqellperf.BEG file. (For the perfect shells the user has chosen the specific case name, "eqellperf" instead of "eqellipse").

8.3.1 Input data

See [26] for data corresponding to this sub-section.

8.3.2 Optimization

See [26] for results corresponding to this sub-section.

8.3.3 Design margins

See [26] for results corresponding to this sub-section.

8.3.4 Some predictions from BIGBOSOR4 (GENOPT), BOSOR5, and STAGS

See [26] for results corresponding to this sub-section.

8.3.5 Predictions of extreme fiber stress

See [26] for results corresponding to this sub-section. The most critical stresses from the BIGBOSOR4, STAGS, and BOSOR5 are listed in the two columns in Table 47 headed, **"isogrid-stiffened, perfect"**.

8.4 Details pertaining to the unstiffened, “perfect” equivalent ellipsoidal shell

Tables 72 – 76 and Figs. 129 – 142 of [26] pertain to the **unstiffened, “perfect”** equivalent ellipsoidal shell. “Perfect” is in quotes because in fact a very small axisymmetric initial imperfection amplitude is used: Wimp = 0.0001 inch.

8.4.1 Input data

See [26] for data corresponding to this sub-section.

8.4.2 Optimization

See [26] for results corresponding to this sub-section.

8.4.3 Design margins

See [26] for results corresponding to this sub-section.

8.4.4 Some predictions from BIGBOSOR4 (GENOPT), BOSOR5, and STAGS

See [26] for results corresponding to this sub-section.

8.4.5 Predictions of extreme fiber stress

See [26] for results corresponding to this sub-section. The most critical stresses from the BIGBOSOR4, STAGS, and BOSOR5 are listed in the column in Table 47 headed, **“unstiffened, perfect”**.

9.0 OPTIMIZATION AND ANALYSIS OF IMPERFECT UNSTIFFENED EQUIVALENT ELLIPSOIDAL SHELLS WITH A THICK APEX

In the previous section we learned that the optimum design of an axisymmetrically imperfect **unstiffened** equivalent ellipsoidal shell would fail at an external pressure far lower than the design pressure, p = 460 psi, if the shell happened to have, instead of the axisymmetric linear buckling modal imperfections in the presence of which it was optimized, a **non-axisymmetric** linear buckling modal imperfection of approximately the same amplitude, Wimp = 0.2 inch (Fig. 94). The worst non-axisymmetric imperfection has n=1 circumferential waves (trace 5, the trace with the X symbol, in Fig. 94).

In the presence of only **axisymmetric** linear buckling modal imperfections and if the wall thickness in the neighborhood of the shell apex is given a **low lower bound**, the meridional thickness distribution of the optimized shell evolves during optimization cycles so that the axisymmetric linear buckling modes (the imperfection shapes) have profiles such as those displayed in Figs. 74 and 75 for the unstiffened shell optimized with plus and minus mode 1 and mode 2 axisymmetric imperfection shapes. **Note that with these axisymmetric buckling modal imperfection shapes there is significant deviation of the profile of the imperfect shell from that of the perfect shell only in a rather small neighborhood of the apex of the shell. This property of the optimized, axisymmetrically imperfect shell causes the collapse pressure of the optimized shell to be especially sensitive to NON-AXISYMMETRIC linear buckling modal imperfections of the type displayed in Fig. 77 (n=1 circumferential wave).**

The local nature of the axisymmetric buckling modal imperfection shapes displayed in Figs. 74 and 75 is a consequence of a certain peculiarity of the meridional distribution of shell wall thickness that evolves during the optimization process. In the optimized shells there is a thick and rather local circumferential band centered at xinput(3)= 5.66645 inches (Table 28) where the local thickness of the shell wall is THKSKN(3) = **0.5991** inch. This locally thickened circumferential band is exhibited in Table 33 of [26] (the column with the heading "**unstiffened, imperfect in Table 33 of [26]**) and in the footnote of Table 33 in this paper. **The thick band acts very much as a ring stiffener that isolates the apex region from the rest of the shell.** Essentially we have a shallow axisymmetrically imperfect spherical cap clamped at its edge and connected to an almost perfect remainder of the shell. If, during the fabrication and handling process, an off-center dent is somehow produced in the remainder of the shell, there is a high probability that under uniform external pressure the dented shell will collapse at a pressure significantly below the design pressure, p = 460 psi, especially if the off-center dent has a depth approaching Wimp = 0.2 inch.

The purpose of this section is to demonstrate a formulation of the optimization problem by means of which the optimum design of the unstiffened imperfect shell will survive the design pressure of 460 psi even if there exist non-axisymmetric linear buckling modal imperfections or non-axisymmetric imperfections in the form of off-center residual dents generated either by a single normal inward-directed concentrated load or by a number of normal inward-directed concentrated loads applied along a circumferential line and distributed over half of the circumference of the shell as cos(theta), where theta is the circumferential coordinate.

Tables 77 – 95 and Figs. 143 – 253 in [26] and Figs. 148, 161 and 188 in this paper pertain to this section. By "**thick apex**", a phrase used in the heading of this section, is meant the uniform thickness, **t(apex)**, of the spherical cap, that is, the uniform thickness of Shell Segment No. 1 in the BIGBOSOR4 model shown in Fig. 2. Optimization is performed with use of the starting design listed in Table 56 of [26] and with the 12 decision variables listed in Table 77 of [26]: THKSKN(1) and THKSKN(3), THKSKN(4),…, THKSKN(13). The thickness at the junction between Shell Segment 1 and Shell Segment 2, THKSKN(2), is linked to the thickness at the apex of the shell, THKSKN(1), with a linking constant equal to unity, that is, THKSKN(2) = THKSKN(1). In other words, the thickness of the spherical cap (Shell Segment 1 in Fig. 2) is uniform and equal to **t(apex)**. See Table 77 of [26], which lists the input file, *.DEC, for the "DECIDE" processor where the linking relationship, THKSKN(2) = THKSKN(1), is set up by the user.

This section has the following three sub-sections:

1. **sub-section 9.1:** optimization and analysis of the "**thick-apex**" shell with the lower bound of **t(apex)** = THKSKN(1) set equal to **0.4 inch** and the amplitude of the axisymmetric linear buckling modal imperfection, **Wimp = 0.2 inch** (Figs. 143 – 200, Tables 77 – 88 of [26] and Figs. 148, 161, and 188 here),

2. **sub-section 9.2:** optimization and analysis of the "**thick-apex**" shell with the lower bound of **t(apex)** = THKSKN(1) set equal to **0.4 inch** and the amplitude of the axisymmetric linear buckling modal imperfection, **Wimp = 0.1 inch** (Figs. 201 – 225, Tables 89 – 91 of [26]), and

3. **sub-section 9.3:** optimization and analysis of the "**thick-apex**" shell with the lower bound of **t(apex)** = THKSKN(1) set equal to **0.6 inch** and the amplitude of the axisymmetric linear buckling modal imperfection, **Wimp = 0.2 inch** (Figs. 226 – 253, Tables 92 – 95 of [26] and Fig. 237 here).

In each of these three sub-sections the STAGS computer program [20 – 23] is used to determined the **elastic-plastic** collapse loads of the optimized shells with axisymmetric and non-axisymmetric **linear buckling modal imperfection** shapes and with imperfection shapes in the form of **off-center residual dents** produced by an elastic-plastic load cycle in what in STAGS jargon is called "Load Set B". The external uniform pressure is applied in Load Set A. For shells with an imperfection in the form of an off-center residual dent the Load Set B cycle is first applied with zero external uniform pressure (zero loads in Load Set A). Then, with zero loads in Load Set B, the pressure-carrying capacity of the dented shell is determined by application of Load Set A, the uniform external pressure. By "**off-center residual dent**" is meant a dent the maximum depth of which occurs at some distance from the axis of revolution of the perfect shell.

The purpose of computing collapse pressures of shells with residual dents is to compare the harmfulness of a residual dent with the harmfulness of the "worst" (most harmful) linear buckling modal imperfection. In Fig. 94 it is demonstrated that the most harmful linear buckling modal imperfection is the non-axisymmetric buckling modal imperfection shape with n=1 circumferential wave.

Although the shell is termed "**unstiffened**", in this section (as in Section 8.2) the shell is modeled as if it has two layers: an isogrid "layer" and the shell skin. As in Section 8.2, the height of the isogrid is set equal to a very, very small value, HIGHST(i) = 0.000001 inch, and the thickness of each isogrid member is also set equal to a very, very small number, 0.00001 inch (Table 56 of [26]). Therefore, the presence of the isogrid layer has no effect on the behavior of the shell. In STAGS models the isogrid layer is Layer No. 1 and the shell skin is Layer No. 2.

9.1 "Thick-apex" unstiffened shell with lower bound of t(apex) = 0.4 inch and Wimp = 0.2 inch

The purpose of this sub-section is to find and evaluate an optimum design that may or may not survive the external design pressure, p = 460 psi provided that the amplitude of any imperfection, **axisymmetric or non-axisymmetric**, does not exceed 0.2 inch.

Figures 143 – 200 and Tables 77 – 88 of [26] and Figs. 148, 161 and 188 in this paper pertain to this sub-section. First, **in sub-section 9.1.1** a "**thick-apex**" optimum design is found by GENOPT via two executions of SUPEROPT (Tables 77 and 78 and Figs. 143 and 144 of [26]). Next, **in sub-section 9.1.2** linear buckling modes by BIGBOSOR4 and STAGS are presented for the optimized design (Tables 79 and 80 and Figs. 145 – 151 of [26]). Then, **in sub-section 9.1.3** extreme fiber effective stress distributions from BIGBOSOR4 and STAGS are presented for the optimized design (Table 81 and Figs. 152 – 160 of [26]). Then, **in sub-section 9.1.4** collapse of the shells with axisymmetric mode 1 and mode 2 imperfection shapes are determined for the optimized design by BIGBOSOR4 for elastic material and by STAGS for either axisymmetric or non-axisymmetric linear buckling modal imperfections and for either elastic or elastic-plastic material (Figs 161 – 163 of [26] and Fig. 161 here). Finally, **in sub-section 9.1.5** a rather long series of STAGS models is used to determine the pressure-carrying capabilities of the optimized shell with **residual dents** of various depths, one residual dent for each collapse analysis (Tables 82 – 88 and Figs. 164 – 200 of [26] and Figs. 148, 161, and 188 here). In this final long sub-section the STAGS **180-degree "soccerball" model** of the optimized equivalent ellipsoidal shell is introduced (Fig. 169, Figs. a2 – a13 of [26] and Fig. a2 here). Each residual dent is produced by application of a load cycle that is included in the *.inp and *.bin files as what is called in STAGS jargon, "Load Set B". The external uniform pressure is subsequently introduced in Load Set A. This external pressure is applied to each of the dented shells that exist after completion of a Load Set B load cycle, that is, following the load cycle in which a single residual dent is generated.

9.1.1 Optimization

See [26] for results corresponding to this sub-section. The "**thick apex**" shell is much heavier than the optimized unstiffened shell listed in Table 33 of [26] because the mode 1 and mode 2 axisymmetric buckling modal imperfection shapes for the optimized "**thick apex**" shell (Figs. 145 and 146 of [26]) exhibit much greater amplitude in the region away from the neighborhood of the apex of the shell (the shell remainder) than is exhibited in Figs. 74 and 75. This much greater imperfection amplitude in the shell remainder gives rise to the need for greater thickness in the shell remainder in order to avoid unacceptably high extreme fiber stresses there and an unacceptably low overall collapse pressure than would result from mode 1 and mode 2 imperfection shapes of the type shown in Figs. 74 and 75. An increase of the wall thickness in the shell remainder leads to an increase in shell weight that is much more significant than an increase of the wall thickness only in the neighborhood of the shell apex.

9.1.2 Linear buckling from BIGBOSOR4 and from STAGS

See [26] for results corresponding to this sub-section.

9.1.3 Extreme fiber distributions of effective stress in the shell skin

See [26] for results corresponding to this sub-section.

9.1.4 Collapse of the optimized shell with linear buckling modal imperfections

See [26] for results corresponding to this sub-section.

9.1.5 Collapse pressures of the optimized shell with various off-center residual dents

See [26] for results corresponding to this sub-section.

9.1.5.1 360-degree STAGS model of the optimized shell with a residual dent produced by a single concentrated load (normal pressure applied to a single finite element)

The purpose of this sub-section is to determine the collapse load of the optimized shell with an "off-center" residual dent compared to the collapse load of the optimized shell with a non-axisymmetric linear buckling modal imperfection with n=1 circumferential wave (Fig. 148). The n=1 imperfection shape shown in Fig. 148 is the most harmful of the buckling modal imperfection shapes, as is demonstrated in Fig. 161. Therefore, it is assumed that a residual dent at the location indicated in Fig. 148 would be more harmful than a residual dent of the same amplitude at any other location in the shell.

Table 79, Tables 82 – 86, and Table a22 and Figs. 164 – 168, Figs. 175 and 176, and Fig. a1 of [26] pertain to this sub-section. The residual dent is produced by a single concentrated **load** applied as normal inward-directed pressure over a single finite element at the location indicated in Fig. 148. The dent-production phase of the nonlinear elastic-plastic STAGS analysis consists of a Load Set B (PB) load cycle.

9.1.5.1.1 Results obtained with the use of SUBROUTINE WALL

See [26] for results corresponding to this sub-section.

9.1.5.1.2 Results obtained with the use of SUBROUTINE USRFAB

See [26] for results corresponding to this sub-section. **The residual dent produced by a single concentrated normal inward-directed load is not as harmful an imperfection as the linear buckling modal imperfection with n=1 circumferential wave, as is demonstrated in Figs 161 and 188. (For example, compare trace 1 with trace 4 in Fig. 188).**

9.1.5.2 STAGS 180-degree "soccerball" model of the optimized shell

Figure a2 here and Figs. a3 – a13 and Tables a32 and a36 – a39 of [26] pertain to this sub-section. The STAGS "soccerball" model avoids the singularity at the pole associated with the 360-degree STAGS model shown in Fig. a1. Also, there are no oddly shaped finite elements in the neighborhood of the pole, such as those displayed at the top of Fig. a1. Those oddly shaped elements in the 360-degree STAGS model prevent the productive use of the STAGS 480 finite element for this particular geometry, even for elastic material properties. (The writer prefers the STAGS 480 finite element because it seldom produces spurious behavior).

Figure a2 shows the STAGS 180-degree "soccerball" finite element model. The entire model contains 50 shell units (Table a37): six shell units for the "soccerball" spherical cap (Shell Segment 1 in the BIGBOSOR4 model shown in Fig. 2 and Shell unit 1 in the 360-degree STAGS model shown in Fig. a1), and four shell units for each of what are called "Shell Segments 2 –12" in Fig. a2. In this paper the term "Shell Segment" used in connection with STAGS models denotes one of the twelve shell segments displayed in Fig. 2 or in Fig. a1. In the 360-degree STAGS model shown in Fig. a1 "Shell Segment" and "Shell Unit" have the same meaning.

Whenever the STAGS "soccerball" model is used STAGS must be compiled with the subroutines listed in Tables a32, a36, and a39 of [26]. Directions for re-compiling STAGS in the presence of user-written (or user-modified) subroutines are given in Items 6 and 7 on page 2 of Table 40.

9.1.5.3 STAGS 180-degree "soccerball" model of the optimized shell with an off-center residual dent produced by a single concentrated load

See [26] for results corresponding to this sub-section. **It is seen from Fig. 176 of [26] and from Figs. 161 and 188 in this paper that the residual dents produced by a single concentrated load at the location indicated in Fig. 148 are significantly less harmful than a non-axisymmetric linear buckling modal imperfection with n=1 circumferential wave and with amplitude, Wimp = 0.2 inch.**

9.1.5.4 STAGS 180-degree "soccerball" model of the optimized shell with a residual dent produced by a "cos(theta)" distribution of normal loads or imposed displacements

See [26] for results corresponding to this sub-section.

9.1.5.4.1 Residual dent produced by a vector of normal inward-directed concentrated LOADS that vary as cos(theta) from theta = 0 to 90 degrees along the circumference at the junction between Shell Segment 3 and Shell Segment 4 (Figs 2, 169, 190, 191 of [26])

See [26] for results corresponding to this sub-section. **It is seen that, as we expected, the "cos(theta)" residual dent is significantly more harmful than the residual dent produced by**

a single concentrated load. In fact, from traces 2 and 4 of Fig. 188, we see that the "cos(theta)" residual dent is just as harmful as the n=1 linear buckling modal imperfection of essentially the same amplitude.

In a later sub-section (Sub-section 9.3) collapse pressures are computed by STAGS for shells with residual dents centered at three different radii from the axis of revolution (one dent for each collapse analysis). This extra work is performed because the optimized shell described in Sub-section 9.3 comes acceptably close to surviving the design pressure, p = 460 psi, in the presence of any axisymmetric or non-axisymmetric imperfection the amplitude of which is at least 0.2 inch. It is this "Section 9.3" optimum design of the "thick apex" unstiffened shell that is listed in the version of Table 33 given in this paper.

9.1.5.4.2 Residual dent produced by a vector of normal inward-directed IMPOSED DISPLACEMENTS w that vary as cos(theta) from theta = 0 to 90 degrees along the circumference at the junction between Shell Segment 3 and Shell Segment 4 (Figs 2, 169, 190, 191 of [26])

See [26] for results corresponding to this sub-section.

9.2 "Thick-apex" unstiffened shell with lower bound of t(apex) = 0.4 inch and Wimp = 0.1 inch

See [26] for results corresponding to this sub-section. The purpose of this sub-section is to find and evaluate an optimum design that will most likely survive the external design pressure, p = 460 psi provided that the amplitude of any imperfection, **axisymmetric or non-axisymmetric**, does not exceed **Wimp = 0.1 inch**.

Figures 201 – 225 and Tables 89 – 91 of [26] pertain to this sub-section. First, **in sub-section 9.2.1** a "**thick-apex**" optimum design is found by GENOPT via one execution of SUPEROPT (Table 89 and Fig. 201 of [26]). Next, **in sub-section 9.2.2** linear buckling modes by BIGBOSOR4 and STAGS are presented for the optimized design (Table 90 and Figs. 202 – 207 of [26]). Then, **in sub-section 9.2.3** extreme fiber effective stress distributions from BIGBOSOR4 are presented for the optimized design (Table 91 and Fig. 208 of [26]). Then, **in sub-section 9.2.4** elastic-plastic collapse of the shells with either axisymmetric or non-axisymmetric (n=1 circumferential wave) linear buckling modal imperfection shapes are determined for the optimized design by STAGS (Figs 209 – 215 of [26]). Finally, **in sub-section 9.2.5** elastic-plastic STAGS models are used to determine the pressure-carrying capabilities of the optimized shell with **residual dents** of various depths, one residual dent for each collapse analysis (Figs. 216 – 225 of [26]). A summary conclusion is given **in sub-section 9.2.6**.

9.2.1 Optimization

See [26] for results corresponding to this sub-section.

9.2.2 Linear buckling from BIGBOSOR4 and from STAGS

See [26] for results corresponding to this sub-section. **Only SUBROUTINE USRFAB and only the STAGS 180-degree "soccerball" model are used to generate the results in sub-section 9.2 and in the remaining sections and sub-sections of this paper and in [26]. Previous experience during this study has demonstrated conclusively that this is the preferred STAGS model to be used for cases of the type explored in this paper and in [26]. The STAGS finite element E480 is the preferred choice.**

9.2.3 Extreme fiber distributions of effective stress in the shell skin

See [26] for results corresponding to this sub-section.

9.2.4 Collapse of the optimized shell with linear buckling modal imperfections

See [26] for results corresponding to this sub-section.

9.2.5 Collapse pressures of the optimized shell with various "cos(theta)" residual dents

See [26] for results corresponding to this sub-section.

9.2.6 Conclusion from the results obtained in Section 9.2

The optimum design listed in Table 89 of [26] will most likely survive the external design pressure, p = 460 psi provided that the amplitude of any imperfection, axisymmetric or non-axisymmetric, does not exceed 0.1 inch. (See Figs. 209 and 211 of [26]).

9.3 "Thick-apex" unstiffened shell with lower bound of t(apex) = 0.6 inch and Wimp = 0.2 inch

The purpose of this sub-section is to find and evaluate an optimum design that will most likely survive the external design pressure, p = 460 psi provided that the amplitude of any imperfection, **axisymmetric or non-axisymmetric**, does not exceed 0.2 inch.

Figures 226 – 253 and Tables 92 – 95 of [26] and Fig. 237 here pertain to this sub-section. First, **in sub-section 9.3.1** the uniform thickness of the optimized "**thick-apex**" shell in sub-section 9.1 (Table 78 of [26]) is arbitrarily increased from 0.4 inch to 0.6 inch, and design margins and axisymmetric linear buckling mode 1 and mode 2 are computed from GENOPT and BIGBOSOR4 (Table 92, Figs. 226 and 227 of [26]) without any optimization. Next, **in sub-section 9.3.2** a new "**thick-apex**" optimum design is found by GENOPT via one execution of SUPEROPT (Table 93 and Fig. 228 of [26]). Then, **in sub-section 9.3.3** linear buckling modes by BIGBOSOR4 and STAGS are presented for the optimized design (Tables 94 and 95 and Figs.

229 – 236 of [26]). Then, **in sub-section 9.3.4** elastic-plastic collapse of the shells with either axisymmetric or non-axisymmetric (n=1 circumferential wave) linear buckling modal imperfection shapes are determined for the optimized design by STAGS (Figs 237 – 239 of [26] and Fig. 237 in this paper). Finally, **in sub-section 9.3.5** elastic-plastic STAGS models are used to determine the pressure-carrying capabilities of the optimized shell with **residual dents** of various depths centered at three different radial coordinates, one residual dent for each collapse analysis (Figs. 240 – 253 of [26]). The STAGS 180-degree "soccerball" model (Fig. a2) with the 480 finite element is used in all the STAGS runs.

9.3.1 Same design as that listed in Table 78 of [26] except t(apex) = 0.6 inch instead of 0.4 inch

Table 92 of [26] lists the design and the design margins. Note that several of the design margins are significantly negative even though all we did was increase the thickness, **t(apex)**, of the spherical cap (Shell Segment No. 1 in Fig. 2) from 0.4 inch to 0.6 inch. Earlier, in sub-section 8.1.1, we wrote the following:

"'Escape' variables are those variables that when increased drive the design toward the feasible region. Typically a wall thickness is an escape variable because a thicker wall almost always leads to higher buckling loads, lower stresses, and smaller deformations."

Here is one of those rare examples in which increasing a wall thickness has the opposite effect. This non-intuitive result follows from the difference in the axisymmetric linear buckling modal imperfection shapes for the shell with **t(apex)** = 0.6 inch (Figs. 226 and 227 of [26]) and for the shell with **t(apex)** = 0.4 inch (Figs. 145 and 146 of [26]). The axisymmetric buckling modal imperfection shapes for the shell with the thicker apex exhibit maximum deflections in the region away from the apex, deflections that are significantly larger than those displayed in the same region for the shell with the thinner apex. Therefore, under the uniform external pressure the axisymmetrically imperfect shell with the thicker apex may collapse (CLAPS) earlier, experience nonlinear bifurcation buckling (GENBK) earlier, and exhibit higher maximum shell skin effective stress (SKNST) than the imperfect shell with the thinner apex.

The same phenomenon occurs for other optimum designs. If one changes the optimum design of the unstiffened, imperfect shell listed in Table 33 of [26] by increasing THKSKN(1) and THKSKN(2) from 0.2269 inch and 0.1575 inch, respectively, to 0.4 inch, most of the design margins become significantly negative for the same reason as that given in the previous paragraph.

9.3.2 Optimization

A new optimum design is found for the unstiffened, imperfect shell by a single execution of SUPEROPT. The evolution of the objective is shown in Fig. 228 of [26]. The input for the "BEGIN" processor, eqellipse.BEG, is the same as that listed in Table 56 of [26] (Section 8.2). The input for the "DECIDE" processor, eqellipse.DEC, is the same as that listed in Table 77 of

[26] (Section 9.1) **except the lower bound of THKSKN(1) is equal to 0.6 inch instead of 0.4 inch.** The starting design is the optimum design listed in Table 78 of [26] (Section 9.1), corresponding to which the objective is equal to 127.1 lb.

The optimum design, design objective, and design margins are listed in Table 93 of Section 9.3 of [26] and in the column headed "**unstiffened, imperfect**" in the **version of Table 33 given in this paper**. Note that the objective has increased from 127.1 lb to 132.5 lb, not nearly as dramatic a change as that from the unstiffened, imperfect optimum design listed in the version of Table 33 given in [26] (weight = 96.461 lb) to that listed in Table 78 of Section 9.1 of [26] (127.1 lb). Note from Table 93 of Section 9.3 of [26] and in the version of Table 33 given in this paper that there is no locally thick circumferential band, THKSKN(3).

9.3.3 Linear buckling of the optimum design listed in Table 93

See [26] for results corresponding to this sub-section.

9.3.4 Collapse of the optimized shell with buckling modal imperfections

See [26] for more results corresponding to this sub-section. Figure 237 shows pressure-deflection curves for the shells with plus and minus "mode 1" and "mode 2" axisymmetric buckling modal imperfections and for the shell with the non-axisymmetric n=1 buckling modal imperfection shape displayed in Fig. 232 of [26]. The shell with the n=1 buckling modal imperfection shape collapses at a pressure slightly below the design pressure, p = 460 psi. However, its collapse pressure is close enough to the design pressure to qualify the shell as ALMOST FEASIBLE (all design margins greater than –0.05). The shell was optimized such that ALMOST FEASIBLE designs were accepted by GENOPT.

Figure 237 also shows the pressures at which nonlinear bifurcation buckling occurs according to GENOPT (BIGBOSOR4) and according to STAGS. One of the nonlinear bifurcation buckling mode shapes is displayed in Fig. 238 of [26]. No post-nonlinear-bifurcation-buckling analyses were conducted for this optimum design. Hence, there are no traces in Fig. 237 with legends that contain the string, "trigger", such as exist in Fig. 211 of [26], for example.

9.3.5 Collapse of the optimized shell with residual "cos(theta)" dents produced by imposed loads

Figures 240 – 253 of [26] pertain to this sub-section. There are three "cases". (See Figs. 232 and 233 of [26]):

Case 1: residual dent centered at theta = 0, Row No. 2 of Shell Segment No. 3
Case 2: residual dent centered at theta = 0, Row No. 3 of Shell Segment No. 5
Case 3: residual dent centered at theta = 0, Row No. 4 of Shell Segment No. 7

In all three cases the dents are generated by "cos(theta)" normal inward-directed **loads**, not by imposed displacements. Each dent is produced by a Load Set B load cycle. Collapse pressures are subsequently computed by application of the uniform external normal pressure (Load Set A) to each shell with its residual dent.

9.3.5.1 Case 1:

See [26] for results corresponding to this sub-section.

9.3.5.2 Case 2:

See [26] for results corresponding to this sub-section.

9.3.5.3 Case 3:

See [26] for results corresponding to this sub-section.

9.3.6 Conclusion from the results obtained in Section 9.3

The shell optimized with a lower bound of apex thickness, t(apex) = 0.6 inch, will most likely survive at the design pressure, p = 460 psi, in the presence of either axisymmetric or non-axisymmetric imperfections with amplitude less than or equal to Wimp = 0.2 inch.

10.0 ELASTIC-PLASTIC ANALYSIS WITH USE OF THE STAGS 180-DEGREE "SOCCERBALL" MODEL OF THE PRESSURE-CARRYING CAPABILITY OF THE OPTIMIZED ISOGRID-STIFFENED SHELL WITH LINEAR BUCKLING MODAL IMPERFECTIONS OR WITH RESIDUAL DENTS

Figures 254 – 276 of [26] and Figs. 254, 258, 262, 263, 268, 270, 275, and 276 in this paper pertain to this section. The various elastic-plastic STAGS models all pertain to the optimum design listed in the two columns of Table 33 headed, **"isogrid-stiffened, imperfect"**. First, **in sub-section 10.1** the pressure-carrying capacities of both elastic and elastic-plastic shells are determined for almost perfect and imperfect shells in which the imperfections are n=0 and n=1 **linear buckling modal imperfections** with amplitude, Wimp = 0.2 inch (Figs. 254 – 262 of [26] and Figs. 254, 258, and 262 here). Then, **in sub-section 10.2** the pressure-carrying capacities of elastic-plastic imperfect shells are determined for shells with **off-center residual dents** produced by Load Set B load cycles (Figs. 263 – 276 of [26] and Figs. 263, 268, 270, 275, and 276 here).

10.1 Elastic-plastic collapse of the optimized isogrid-stiffened shell with n=0 and n=1 buckling modal imperfections with amplitude, Wimp = 0.2 inch

Figures 254 – 262 of [26] and Figs. 254, 258, and 262 in this paper pertain to this sub-section. The geometry of the optimized isogrid-stiffened shell is listed in Table 33 in the two columns under the heading, "**isogrid-stiffened, imperfect**". The STAGS 180-degree "soccerball" model (Fig. a2) is used to generate most of the results. The user-written SUBROUTINE USRFAB is employed with the associated file, WALLTHICK.STAGS, that is listed in Table a23. For the 360-degree models the version of SUBROUTINE USRFAB listed in Table a35 of [26] is used if the material is elastic-plastic. For the 180-degree "soccerball" models the version of SUBROUTINE USRFAB listed in Table a36 is used if the material is elastic-plastic. For elastic material the index, iplas, near the end of SUBROUTINE USRFAB must be changed from 1 to 0.

Figure 254 shows pressure-apex-deflection curves corresponding to STAGS 360-degree models (Fig. a1) and STAGS 180-degree "soccerball" models (Fig. a2). The "worst" (most harmful) imperfection is the first non-axisymmetric linear buckling modal imperfection with n=1 circumferential wave. (See the second-to-last curve in Fig. 254, the curve pointed to by the arrow from the box containing the text, "Load Step 12…"). The elastic-plastic collapse of this imperfect shell occurs at a pressure slightly in excess of the design pressure, p = 460 psi.

Figures 255 and 256 of [26] show the inner and outer fiber meridional plastic strains in the isogrid-stiffened shell at a pressure slightly above the design pressure (Load Step 12). The meridional plastic strains have the localized distribution shapes because the n=1 linear buckling modal imperfection has the shape displayed in Fig. 258.

Figures 257 – 262 of [26] and Figs. 258 and 262 here show the linear buckling modes for the optimized isogrid-stiffened shell. The first six curves in Fig. 254 corresponding to the legends that contain the string, "n=0", are for the shell with the **negative** of the axisymmetric linear buckling modal imperfection shape displayed in Fig. 257 of [26]. The next six curves in Fig. 254 corresponding to the legends that contain the string, "n=1", are for the shell with the non-axisymmetric linear buckling modal imperfection shape displayed in Fig. 258. The last curve in Fig. 254, the curve with the legend that contains the string, "2nd n=1", is for the shell with the non-axisymmetric buckling modal imperfection shape displayed in Fig. 262.

In the next sub-section the behavior of the optimized isogrid-stiffened shell with "cos(theta)" residual dents at two radial locations (one residual dent at one location for each collapse analysis) is explored. The first location is at Row 2 of Shell Segment 2, as indicated in Fig. 258. The second location is at Row 5 of Shell Segment 4, as indicated in Fig. 262. These residual dents **locally** resemble the n=1 linear buckling modal imperfection shapes displayed in Figs. 258 and 262, respectively.

10.2 Collapse of the optimized isogrid-stiffened shell with "cos(theta)" residual dents

Figures 263 – 276 in [26] and Figs. 263, 268, 270, 275, and 276 here pertain to this sub-section. Figures 263 – 269 in [26] and Figs. 263 and 268 here and Figs. 275 and 276 pertain to the case in which residual dents are centered at Row 2 of Shell Segment 2 (Fig. 258). Figures 270, 275, and

276 pertain to the case in which residual dents are centered at Row 5 of Shell Segment 4.

10.2.1 Residual dent centered at Row 2 in Shell Segment 2

Figure 263 is analogous to Fig 240 of [26], which applies to the unstiffened optimized shell. Residual "cos(theta)" dents of three depths are produced by three Load Set B load cycles in which the dents are generated by the application of a cos(theta) distribution of normal inward-directed **loads** rather than normal inward-directed imposed displacements. The smallest residual dent is taken to be the imperfection present in the collapse analysis under Load Set A, the uniform external pressure, results from which are displayed as the **first** trace in Fig. 275.

Figure 268, analogous to Fig. 193 of [26], shows the Load Set B load cycle in which a "cos(theta)" residual dent is produced by a cos(theta) distribution of normal inward-directed imposed **displacements** from circumferential coordinate theta = 0 to 90 degrees along Row 2 of Shell Segment 2. The residual dent at Load Step 55 is taken to be the imperfection present in the collapse analysis under Load Set A, the uniform external pressure, results from which are displayed as the **second** trace in Fig. 275. The collapse pressure is lower than that corresponding to the first trace in Fig. 275 because the residual dent is deeper.

Figure 276 shows the state of the shell at a load step in the post-collapse phase of the Load Set A analysis.

10.2.2 Residual dent centered at Row 5 in Shell Segment 4

Figure 270, analogous to Fig. 268, shows two Load Set B load cycles in which "cos(theta)" residual dents of two depths are produced by a cos(theta) distribution of normal inward-directed imposed **displacements** from circumferential coordinate theta = 0 to 90 degrees along Row 5 of Shell Segment 4. The residual dent at Step 158 is taken to be the imperfection present in the collapse analysis under Load Set A, the uniform external pressure, results from which are displayed as the **third** trace in Fig. 275.

10.3 Conclusion from the results obtained in Section 10.0

The optimized isogrid-stiffened shell, the design of which is listed in Columns 2 and 3 of Table 33, will most likely survive at the design pressure, p = 460 psi, in the presence of either axisymmetric or non-axisymmetric imperfections with amplitude less than or equal to Wimp = 0.2 inch. For the optimized isogrid-stiffened shell off-center residual dents produced by "cos(theta)" Load Set B load cycles are not as harmful (Fig. 275) as the linear buckling modal imperfection with n=1 circumferential wave (second-to-last trace in Fig. 254), given the amplitude of the imperfection.

11.0 CONCLUSIONS

1. GENOPT can be used in combination with BIGBOSOR4 to obtain minimum-weight designs of isogrid-stiffened or unstiffened perfect or imperfect ellipsoidal shells provided that the "**equivalent" ellipsoid model** (Table 29, Fig. 2) is used and provided that the **imperfection shapes are axisymmetric**.

2. **UNSTIFFENED imperfect shells should be optimized with relatively high lower bounds set on the thicknesses of the shell wall in the neighborhood of the shell apex** (Table 77 of [26]). In the case of the unstiffened, imperfect shell, if the lower bound of the wall thickness in the neighborhood of the shell apex is set too low the thickness distribution in the neighborhood of the shell apex evolves during optimization cycles in a way that essentially isolates the apex from the remainder of the shell. This produces optimum designs the collapse pressures of which are **especially sensitive to non-axisymmetric imperfection shapes**, **a type of imperfection that cannot be modeled with BIGBOSOR4 and therefore cannot be accommodated during the GENOPT optimization process.**

3. It is generally found from STAGS models that for optimized shells the **"worst" imperfections are non-axisymmetric linear buckling modal imperfections with n=1 circumferential wave** (Figs. 94, 109, 161, 176, 209, 211, 237 and 254 of [26] and Figs. 94, 161, and 254 here).

4. For the optimized **unstiffened imperfect** shell it is found that imperfections in the form of **off-center residual dents** produced by a distribution of normal inward-directed concentrated loads that vary as the cos(theta) over a circumferential line from circumferential coordinate, theta = 0 to 90 degrees applied at a radius from the axis of revolution that corresponds to the first pronounced "valley" or "ridge" in the non-axisymmetric linear buckling mode shape with n=1 circumferential wave are approximately as harmful as the n=1 linear buckling modal imperfection shapes (Figs. 188, 190, 205, 211, 217, 232, 237, 241 in [26] and Figs. 148 and 188 here).

5. **Off-center residual dents produced by a single normal inward-directed concentrated load are significantly less harmful than off-center "cos(theta)" residual dents** (Figs. 176, 188, 200 in [26] and Figs. 148 and 188 here).

6. **A STAGS "soccerball" model (Figs. 169, a2 – a13 in [26] and Fig. a2 here) of the optimized shells is better than a 360-degree STAGS model based on polar coordinates** (Fig. a1) because the STAGS 480 finite element, which fails when used for nonlinear analysis in connection with the 360-degree model, works well when used in connection with the "soccerball" model, which has no singularity at the apex of the shell. Also, spurious buckling modes such as that shown in Figs 18 and 19 of [26] are avoided when the STAGS "soccerball" model is used.

7. The STAGS user should **rely on user-written SUBROUTINE USRFAB** rather than on user-written SUBROUTINE WALL for providing wall properties that vary within a shell unit (Fig.

175 in [26]).

8. Sections 3.0 – 6.0 of this paper contain enough detail about how GENOPT works so that the **reader can use it as a guide for setting up user-friendly optimization software** for other structural or even non-structural applications.

9. The material about STAGS models in [26] is extensive enough so that the **reader should be able to set up other STAGS models** without too much trouble.

12.0 ACKNOWLEDGMENTS

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Table 1 **Seven roles that user-established GENOPT variables play**. This list is included as part of the **equivellipse.DEF** file, in which "equivellipse" is the GENOPT user's **generic name** for the optimization case. The complete equivellipse.DEF file is listed in the appendix as Table a2. In the GENTEXT interactive session the GENOPT user must create names, one-line definitions, and “help” paragraphs for all Role 1 and Role 2 variables first, followed by the same for all Role 3 variables, followed by the same for all Role 4,5,6 “bundles”, followed by the same for the Role 7 variable. See Tables 2 & 6.

```
===========================================================
    A variable can have one of the following roles:

    1 = a possible decision variable for optimization,
        typically a dimension of a structure.
    2 = a constant parameter (cannot vary as design evolves),
        typically a control integer or material property,
        but not a load, allowable, or factor of safety,
        which are asked for later.
    3 = a parameter characterizing the environment, such
        as a load component or a temperature.
    4 = a quantity that describes the response of the
        structure, (e.g. stress, buckling load, frequency)
    5 = an allowable, such as maximum allowable stress,
        minimum allowable frequency, etc.
    6 = a factor of safety
    7 = the quantity that is to be minimized or maximized,
        called the "objective function" (e.g. weight).
 ===========================================================
```

Table 2 **A complete glossary of variables established and defined by the GENOPT user during the GENTEXT interactive session.** This list is included as part of the equivellipse.DEF file after the GENOPT user's completion of the GENTEXT interactive session. The complete equivellipse.DEF file is listed in Table a2 of the appendix. ("**equivellipse**" is the GENOPT user's generic **name** for the class of objects to be optimized in this case). An example of part of the GENTEXT interactive session that automatically generates the first part of this list is given in the next table. See Table 1 for definitions of Roles 1 – 7. See Table 6 for more on PROMPT NUMBER.

TABLE 2 GLOSSARY OF VARIABLES USED IN "equivellipse"

ARRAY ?	NUMBER OF (ROWS,COLS)	ROLE	PROMPT NUMBER (equivellipse.PRO)	NAME	DEFINITION OF VARIABLE
n	(0, 0)	2	10	npoint	= number of x-coordinates
n	(0, 0)	2	15	Ixinpu	= vector element number for xinput in xinput(Ixinpu)
y	(21, 0)	2	20	xinput	= x-coordinates for ends of segments
n	(0, 0)	2	25	ainput	= length of semi-major axis
n	(0, 0)	2	30	binput	= length of semi-minor axis of ellipse
n	(0, 0)	2	35	nodes	= number of nodal points per segment
n	(0, 0)	2	40	xlimit	= max. x-coordinate for x-coordinate callouts
y	(21, 0)	1	45	THKSKN	= skin thickness at xinput
y	(21, 0)	1	50	HIGHST	= height of isogrid members at xinput
n	(0, 0)	1	55	SPACNG	= spacing of the isogrid members
n	(0, 0)	1	60	THSTIF	= thickness of an isogrid stiffening member
n	(0, 0)	2	65	THKCYL	= thickness of the cylindrical shell
n	(0, 0)	2	70	RADCYL	= radius of the cylindrical shell
n	(0, 0)	2	75	LENCYL	= length of the cylindrical segment
n	(0, 0)	2	80	WIMP	= amplitude of the axisymmetric imperfection
n	(0, 0)	2	85	EMATL	= elastic modulus
n	(0, 0)	2	90	NUMATL	= Poisson ratio of material
n	(0, 0)	2	95	DNMATL	= mass density of material
n	(0, 0)	2	100	IMODE	= strategy control for imperfection shapes
n	(0, 0)	2	105	NCASES	= Number of load cases (number of environments)
y	(20, 0)	3	110	PRESS	= uniform external pressure
y	(20, 0)	4	115	CLAPS1	= collapse pressure with imperfection mode 1
y	(20, 0)	5	120	CLAPS1A	= allowable pressure for axisymmetric collapse
y	(20, 0)	6	125	CLAPS1F	= factor of safety for axisymmetric collapse
y	(20, 0)	4	130	GENBK1	= general buckling load factor, mode 1
y	(20, 0)	5	135	GENBK1A	= allowable general buckling load factor (use 1.0)
y	(20, 0)	6	140	GENBK1F	= factor of safety for general buckling
n	(0, 0)	2	145	JSKNBK1	= number of regions for computing behavior
y	(20, 10)	4	150	SKNBK1	= local skin buckling load factor, mode 1
y	(20, 10)	5	155	SKNBK1A	= allowable buckling load factor
y	(20, 10)	6	160	SKNBK1F	= factor of safety for skin buckling
y	(20, 10)	4	165	STFBK1	= buckling load factor, isogrid member, mode 1
y	(20, 10)	5	170	STFBK1A	= allowable for isogrid stiffener buckling (Use 1.)
y	(20, 10)	6	175	STFBK1F	= factor of safety for isogrid stiffener buckling
y	(20, 10)	4	180	SKNST1	= maximum stress in the shell skin, mode 1
y	(20, 10)	5	185	SKNST1A	= allowable stress for the shell skin
y	(20, 10)	6	190	SKNST1F	= factor of safety for skin stress
y	(20, 10)	4	195	STFST1	= maximum stress in isogrid stiffener, mode 1
y	(20, 10)	5	200	STFST1A	= allowable stress in isogrid stiffeners
y	(20, 10)	6	205	STFST1F	= factor of safety for stress in isogrid member

```
 y   (  20,    0)    4     210   WAPEX1   = normal (axial) displacement at apex, mode 1
 y   (  20,    0)    5     215   WAPEX1A  = allowable normal (axial) displacement at apex
 y   (  20,    0)    6     220   WAPEX1F  = factor of safety for WAPEX
 y   (  20,    0)    4     225   CLAPS2   = collapse pressure with imperfection mode 2
 y   (  20,    0)    5     230   CLAPS2A  = allowable pressure for axisymmetric collapse
 y   (  20,    0)    6     235   CLAPS2F  = factor of safety for axisymmetric collapse
 y   (  20,    0)    4     240   GENBK2   = general buckling load factor, mode 2
 y   (  20,    0)    5     245   GENBK2A  = allowable general buckling load factor (use 1.0)
 y   (  20,    0)    6     250   GENBK2F  = factor of safety for general buckling
 n   (   0,    0)    2     255   JSKNBK2  = number of regions for computing behavior
 y   (  20,   10)    4     260   SKNBK2   = local skin buckling load factor, mode 2
 y   (  20,   10)    5     265   SKNBK2A  = allowable skin buckling load factor (use 1.0)
 y   (  20,   10)    6     270   SKNBK2F  = factor of safety for local skin buckling
 y   (  20,   10)    4     275   STFBK2   = buckling load factor for isogrid member, mode 2
 y   (  20,   10)    5     280   STFBK2A  = allowable for isogrid stiffener buckling (Use 1.)
 y   (  20,   10)    6     285   STFBK2F  = factor of safety for isogrid stiffener buckling
 y   (  20,   10)    4     290   SKNST2   = maximum stress in the shell skin, mode 2
 y   (  20,   10)    5     295   SKNST2A  = allowable stress for the shell skin
 y   (  20,   10)    6     300   SKNST2F  = factor of safety for skin stress
 y   (  20,   10)    4     305   STFST2   = maximum stress in isogrid stiffener, mode 2
 y   (  20,   10)    5     310   STFST2A  = allowable stress in isogrid stiffeners
 y   (  20,   10)    6     315   STFST2F  = factor of safety for stress in isogrid member
 y   (  20,    0)    4     320   WAPEX2   = normal (axial) displacement at apex, mode 2
 y   (  20,    0)    5     325   WAPEX2A  = allowable normal (axial) displacement at apex
 y   (  20,    0)    6     330   WAPEX2F  = factor of safety for WAPEX
 n   (   0,    0)    7     335   WEIGHT   = weight of the equivalent ellipsoidal head
==========================================================================================
```

Table 3 Portion of the **equivellipse.DAT** file relating to some Role 1 and Role 2 variables established and defined and explained in "help" paragraphs by the GENOPT user during the first part of **interactive "GENTEXT" session.** ("**equivellipse**" is the generic name selected by the GENOPT user for the class of objects to be optimized). After the GENOPT user has completed the "GENTEXT" interactive session the completed equivellipse.DAT file becomes a file that is called **equivellipse.INP.** See the appendix for a list of equivellipse.INP (Table a1). In the following list in this table the GENOPT user's **responses** to the prompting phrases issued by GENOPT are in **boldface.** The part of the glossary of variables that corresponds to the GENOPT user's input listed here appears in Table 4, and the part of the prompting file automatically generated by GENOPT during this partial GENTEXT interactive session appears in Table 5. See Table 1 for definitions of "Role of the variable in the users program".

```
========================================================================
       1  $ Type of prompt: 0="help" paragraph, 1=one-line prompt
 npoint   $ Name of a variable in the users program (defined below)
       2  $ Role of the variable in the users program
       1  $ type of variable:  1 =integer,  2 =floating point
 n         $ Is the variable  npoint  an array?
 number of x-coordinates             $ one-line definition of npoint
 y         $ Do you want to include a "help" paragraph?
 The ellipse is simulated by a number of shell segments (try 10)
 y         $ Any more lines in the "help" paragraph?
 each of which has constant meridional curvature (toroidal).
 y         $ Any more lines in the "help" paragraph?
 npoint is the number of x-coordinates corresponding to the
 y         $ Any more lines in the "help" paragraph?
 ends of the toroidal segments that make up the equivalent
 y         $ Any more lines in the "help" paragraph?
 ellipse. You might try to simulate the ellipse by using 10
 y         $ Any more lines in the "help" paragraph?
 toroidal segments. Then the value of npoint would be 11
 y         $ Any more lines in the "help" paragraph?
 npoint includes the apex of the ellipse (x = 0) and the equator
 y         $ Any more lines in the "help" paragraph?
 of the ellipse (x = a, in which a = semimajor axis length).
 n         $ Any more lines in the "help" paragraph?
 y         $ Any more variables for role types  1  or  2   ?    $10
       1  $ Type of prompt: 0="help" paragraph, 1=one-line prompt
 xinput    $ Name of a variable in the users program (defined below)
       2  $ Role of the variable in the users program
       2  $ type of variable:  1 =integer,  2 =floating point
 y         $ Is the variable  xinput  an array?
 y         $ Do you want to establish new dimensions for xinput ?
       1  $ Number of dimensions in the array,  xinput
 vector element number for xinput
      21  $ Max. allowable number of rows NROWS in the array, xinput
 x-coordinates for ends of segments  $ one-line definition of xinput
 y         $ Do you want to include a "help" paragraph?
 Please make sure to include x = 0 and x = a (equator) when
 y         $ Any more lines in the "help" paragraph?
 you provide values for xinput.
 n         $ Any more lines in the "help" paragraph?
 y         $ Any more variables for role types  1  or  2   ?    $20
       1  $ Type of prompt: 0="help" paragraph, 1=one-line prompt
```

```
ainput    $ Name of a variable in the users program (defined below)
      2  $ Role of the variable in the users program
      2  $ type of variable:  1 =integer,  2 =floating point
n         $ Is the variable  ainput  an array?
length of semi-major axis          $ one-line definition of ainput
y         $ Do you want to include a "help" paragraph?
ainput is the maximum "x=dimension" of the ellipse.
y         $ Any more lines in the "help" paragraph?
The equation for the ellipse is x^2/a^2 + y^2/b^2 = 1.0
n         $ Any more lines in the "help" paragraph?
y         $ Any more variables for role types  1  or  2   ?    $25
      1  $ Type of prompt: 0="help" paragraph, 1=one-line prompt
binput    $ Name of a variable in the users program (defined below)
      2  $ Role of the variable in the users program
      2  $ type of variable:  1 =integer,  2 =floating point
n         $ Is the variable  binput  an array?
length of semi-minor axis of ellipse      $ one-line definition of binput
y         $ Do you want to include a "help" paragraph?
binput is the y-dimension of the ellipse, the equation for which
y         $ Any more lines in the "help" paragraph?
is x^2/a^2 + y^2/b^2 = 1.0.
n         $ Any more lines in the "help" paragraph?
y         $ Any more variables for role types  1  or  2   ?    $30
      1  $ Type of prompt: 0="help" paragraph, 1=one-line prompt
nodes     $ Name of a variable in the users program (defined below)
      2  $ Role of the variable in the users program
      1  $ type of variable:  1 =integer,  2 =floating point
n         $ Is the variable  nodes  an array?
number of nodal points per segment  $ one-line definition of nodes
y         $ Do you want to include a "help" paragraph?
If you have about 10 segments, use a number less than 31.
y         $ Any more lines in the "help" paragraph?
Use an odd number, greater than or equal to 11
n         $ Any more lines in the "help" paragraph?
y         $ Any more variables for role types  1  or  2   ?    $35
      1  $ Type of prompt: 0="help" paragraph, 1=one-line prompt
xlimit    $ Name of a variable in the users program (defined below)
      2  $ Role of the variable in the users program
      2  $ type of variable:  1 =integer,  2 =floating point
n         $ Is the variable  xlimit  an array?
max.x-coordinate for x-coordinate callouts $one-line definition of xlimit
y         $ Do you want to include a "help" paragraph?
xlimit has two functions:
y         $ Any more lines in the "help" paragraph?
1. a delimiter for the definition of callouts:
y         $ Any more lines in the "help" paragraph?
for x < xlimit callouts are x-coordinates.
y         $ Any more lines in the "help" paragraph?
for x > xlimit callouts are y-coordinates.
y         $ Any more lines in the "help" paragraph?
Set xlimit equal to about a/2, where a = length of the
y         $ Any more lines in the "help" paragraph?
semi-major axis of the ellipse.
y         $ Any more lines in the "help" paragraph?
2. a delimiter for the boundary between Region 1
y         $ Any more lines in the "help" paragraph?
and Region 2. Design margins for maximum stress and
```

```
y         $ Any more lines in the "help" paragraph?
minimum buckling load in the shell skin and in the
y         $ Any more lines in the "help" paragraph?
isogrid stiffeners can be computed in two regions,
y         $ Any more lines in the "help" paragraph?
Region 1: 0 < x < xlimit, and
y         $ Any more lines in the "help" paragraph?
Region 2: xlimit < x < semi-major axis.
n         $ Any more lines in the "help" paragraph?
y         $ Any more variables for role types  1  or  2   ?    $40
      1  $ Type of prompt: 0="help" paragraph, 1=one-line prompt
THKSKN    $ Name of a variable in the users program (defined below)
      1  $ Role of the variable in the users program
y         $ Is the variable  THKSKN  an array?
n         $ Do you want to establish new dimensions for THKSKN ?
skin thickness at xinput           $ one-line definition of THKSKN
y         $ Do you want to include a "help" paragraph?
xinput is the vector of x-coordinate callouts for
y         $ Any more lines in the "help" paragraph?
thickness of the shell skin and height of the
y         $ Any more lines in the "help" paragraph?
isogrid stiffeners.
n         $ Any more lines in the "help" paragraph?
y         $ Any more variables for role types  1  or  2   ?    $45
      1  $ Type of prompt: 0="help" paragraph, 1=one-line prompt
HIGHST    $ Name of a variable in the users program (defined below)
      1  $ Role of the variable in the users program
y         $ Is the variable  HIGHST  an array?
n         $ Do you want to establish new dimensions for HIGHST ?
height of isogrid members at xinput      $ one-line definition of HIGHST
y         $ Do you want to include a "help" paragraph?
xinput is the vector of x-coordinate callouts for
y         $ Any more lines in the "help" paragraph?
thickness of the shell skin and height of the
y         $ Any more lines in the "help" paragraph?
isogrid stiffeners.
n         $ Any more lines in the "help" paragraph?
y         $ Any more variables for role types  1  or  2   ?    $50
      1  $ Type of prompt: 0="help" paragraph, 1=one-line prompt
SPACNG    $ Name of a variable in the users program (defined below)
      1  $ Role of the variable in the users program
n         $ Is the variable  SPACNG  an array?
spacing of the isogrid members      $ one-line definition of SPACNG
y         $ Do you want to include a "help" paragraph?
SPACNG = altitude of the equilateral triangle between adjacent
y         $ Any more lines in the "help" paragraph?
isogrid members, measured to middle surfaces of isogrid members.
y         $ Any more lines in the "help" paragraph?
SPACNG = (length of side of triangle)*sqrt(3)/2.
y         $ Any more lines in the "help" paragraph?
SPACNG is constant over the entire shell.
n         $ Any more lines in the "help" paragraph?
y         $ Any more variables for role types  1  or  2   ?    $55
      1  $ Type of prompt: 0="help" paragraph, 1=one-line prompt
THSTIF    $ Name of a variable in the users program (defined below)
      1  $ Role of the variable in the users program
n         $ Is the variable  THSTIF  an array?
```

```
thickness of an isogrid stiffening member $one-line definition of THSTIF
y         $ Do you want to include a "help" paragraph?
THSTIF is constant over the entire shell.
n         $ Any more lines in the "help" paragraph?
y         $ Any more variables for role types  1  or  2   ?    $60
      1  $ Type of prompt: 0="help" paragraph, 1=one-line prompt
THKCYL    $ Name of a variable in the users program (defined below)
      2  $ Role of the variable in the users program
      2  $ type of variable:  1 =integer,  2 =floating point
n         $ Is the variable  THKCYL  an array?
thickness of the cylindrical shell  $ one-line definition of THKCYL
n         $ Do you want to include a "help" paragraph?
y         $ Any more variables for role types  1  or  2   ?    $65
      1  $ Type of prompt: 0="help" paragraph, 1=one-line prompt
RADCYL    $ Name of a variable in the users program (defined below)
      2  $ Role of the variable in the users program
      2  $ type of variable:  1 =integer,  2 =floating point
n         $ Is the variable  RADCYL  an array?
radius of the cylindrical shell    $ one-line definition of RADCYL
n         $ Do you want to include a "help" paragraph?
======================================================================
```

Table 4 **Glossary of variables** used in the generic case called "**equivellipse**" corresponding to the GENOPT user's interactive input to "GENTEXT" listed in Table 3. The complete glossary generated by GENOPT upon the GENOPT user's completion of the entire "GENTEXT" interactive session is listed in Table 2 and forms part of the file, equivellipse.DEF, which is listed in Table a2 in the appendix. ("**equivellipse**" is the generic name selected by the GENOPT user for the class of objects to be optimized). See Table 1 for definitions of "ROLE", and see the next table for more on "PROMPT NUMBER" (the partial equivellipse.PRO file).

ARRAY ?	NUMBER OF (ROWS,COLS)	ROLE	PROMPT NUMBER (equivellipse.PRO)	NAME	DEFINITION OF VARIABLE
n	(0, 0)	2	10	npoint	= number of x-coordinates
n	(0, 0)	2	15	Ixinpu	= vector element number for xinput in xinput(Ixinpu)
y	(21, 0)	2	20	xinput	= x-coordinates for ends of segments
n	(0, 0)	2	25	ainput	= length of semi-major axis
n	(0, 0)	2	30	binput	= length of semi-minor axis of ellipse
n	(0, 0)	2	35	nodes	= number of nodal points per segment
n	(0, 0)	2	40	xlimit	= max. x-coordinate for x-coordinate callouts
y	(21, 0)	1	45	THKSKN	= skin thickness at xinput
y	(21, 0)	1	50	HIGHST	= height of isogrid members at xinput
n	(0, 0)	1	55	SPACNG	= spacing of the isogrid members
n	(0, 0)	1	60	THSTIF	= thickness of an isogrid stiffening member
n	(0, 0)	2	65	THKCYL	= thickness of the cylindrical shell
n	(0, 0)	2	70	RADCYL	= radius of the cylindrical shell

Table 5 Portion of the prompting file, **equivellipse.PRO**, generated automatically by "GENTEXT" that corresponds to the GENOPT user's interactive input listed in Table 3. The complete equivellipse.PRO file generated after the GENOPT user completes the "GENTEXT" interactive session is listed in Table 6. The variable names, the one-line definitions of the variables, and the "help" paragraphs, created by the GENOPT user during the GENTEXT interactive session, **will be seen by the "end" user.** If the GENOPT user has done his or her job well, the program system created by GENOPT (BEGIN, DECIDE, MAINSETUP, OPTIMIZE, CHOOSEPLOT, etc.), that is, the program system for the generic case, "**equivellipse**", to be used later by the "end" user for specific cases (such as a specific case called "eqellipse"), will be user-friendly. The numbering (e.g. 10.1) of the one-line prompting phrases and of the "help" paragraphs (e.g. 10.2) is created automatically by GENOPT. The "end" user always sees the one-line prompting phrases (e.g. "number of x-coordinates: npoint") during his or her interactive input session in "BEGIN". The "end" user will see the corresponding "help" paragraph if he or she types "h"(elp) in response to the one-line prompting phrase. If there is no "help" paragraph "BEGIN" will respond to the user's "h" with the phrase, "There is no help."

```
=======================================================================

  10.1 number of x-coordinates: npoint
  10.2
       The ellipse is simulated by a number of shell segments (try 10)
       each of which has constant meridional curvature (toroidal).
       npoint is the number of x-coordinates corresponding to the
       ends of the toroidal segments that make up the equivalent
       ellipse. You might try to simulate the ellipse by using 10
       toroidal segments. Then the value of npoint would be 11
       npoint includes the apex of the ellipse (x = 0) and the equator
       of the ellipse (x = a, in which a = semimajor axis length).

  15.1 Number Ixinpu  of rows in the array  xinput: Ixinpu
  20.1 x-coordinates for ends of segments: xinput
  20.2
       Please make sure to include x = 0 and x = a (equator) when
       you provide values for xinput.

  25.1 length of semi-major axis: ainput
  25.2
       ainput is the maximum "x=dimension" of the ellipse.
       The equation for the ellipse is x^2/a^2 + y^2/b^2 = 1.0

  30.1 length of semi-minor axis of ellipse: binput
  30.2
       binput is the y-dimension of the ellipse, the equation for which
       is x^2/a^2 + y^2/b^2 = 1.0.

  35.1 number of nodal points per segment: nodes
  35.2
       If you have about 10 segments, use a number less than 31.
       Use an odd number, greater than or equal to 11

  40.1 max. x-coordinate for x-coordinate callouts: xlimit
  40.2
       xlimit has two functions:
```

```
     1. a delimiter for the definition of callouts:
     for x < xlimit callouts are x-coordinates.
     for x > xlimit callouts are y-coordinates.
     Set xlimit equal to about a/2, where a = length of the
     semi-major axis of the ellipse.
     2. a delimiter for the boundary between Region 1
     and Region 2, Design margins for maximum stress and
     minimum buckling load in the shell skin and in the
     isogrid stiffeners can be computed in two regions,
     Region 1: 0 < x < xlimit, and
     Region 2: xlimit < x < semi-major axis.

45.1 skin thickness at xinput: THKSKN
45.2
     xinput is the vector of x-coordinate callouts for
     thickness of the shell skin and height of the
     isogrid stiffeners.

50.1 height of isogrid members at xinput: HIGHST
50.2
     xinput is the vector of x-coordinate callouts for
     thickness of the shell skin and height of the
     isogrid stiffeners.

55.1 spacing of the isogrid members: SPACNG
55.2
     SPACNG = altitude of the equilateral triangle between adjacent
     isogrid members, measured to middle surfaces of isogrid members.
     SPACNG = (length of side of triangle)*sqrt(3)/2.
     SPACNG is constant over the entire shell.

60.1 thickness of an isogrid stiffening member: THSTIF
60.2
     THSTIF is constant over the entire shell.

65.1 thickness of the cylindrical shell: THKCYL
70.1 radius of the cylindrical shell: RADCYL
=====================================================================
```

Table 6 The complete prompting file, **equivellipse.PRO**, corresponding to the generic case called "equivellipse". This file is automatically created by "GENTEXT" once the GENOPT user has provided all variable names, one-line definitions, and "help" paragraphs during the entire "GENTEXT" interactive session. The variable names, the one-line definitions of the variables, and the "help" paragraphs, created by the GENOPT user during the GENTEXT interactive session, **will be seen by the "end" user**. If the GENOPT user has done his or her job well, the program system created by GENOPT (BEGIN, DECIDE, MAINSETUP, OPTIMIZE, CHOOSEPLOT, etc.), that is, the program system for the generic case, "**equivellipse**", to be used later by the "end" user for specific cases (such as a specific case called "eqellipse"), will be user-friendly. The prompting numbers (e.g. 10) corresponding to each prompt for input data (e.g. "number of x coordinates: npoint") are listed with the variable names (e.g. "npoint") and one-line definitions (e.g. "number of x-coordinates") in Table 2.

```
=====================================================================
   5.0
       OPTIMUM DESIGN OF ISOGRID-STIFFENED ELLIPSOIDAL HEAD
       David Bushnell, retired (formerly with Lockheed Martin)
       ABSTACT: The externally pressurized head is elastic, has
       internal isogrid stiffening, and is attached to a short,
       unstiffened cylindrical shell of uniform thickness.
       The BIGBOSOR4 computer program is used for the structural
       analysis and GENOPT is used to set up the user-friendly
       optimization program. Please read the following papers
       for descriptions of BIGBOSOR4 and GENOPT:
       [1] Bushnell, D., "Automated optimum design of shells of
       revolution with application to ring-stiffened cylindrical
       shells with wavy walls", Proc. AIAA 41st SDM Meeting, AIAA
       Paper No. AIAA-2000-1663, April 2000. (Also see the Lockheed
       Martin report, LMMS P525674, November, 1999 for more details).
       [2] Bushnell, D., "GENOPT - a program that writes user-friendly
       optimization code", Int. J. Solids Structures, Vol. 26, No. 9/10
       pp. 1173-1210, 1990

  10.1 number of x-coordinates: npoint
  10.2
       The ellipse is simulated by a number of shell segments (try 10)
       each of which has constant meridional curvature (toroidal).
       npoint is the number of x-coordinates corresponding to the
       ends of the toroidal segments that make up the equivalent
       ellipse. You might try to simulate the ellipse by using 10
       toroidal segments. Then the value of npoint would be 11
       npoint includes the apex of the ellipse (x = 0) and the equator
       of the ellipse (x = a, in which a = semimajor axis length).

  15.1 Number Ixinpu  of rows in the array  xinput: Ixinpu
  20.1 x-coordinates for ends of segments: xinput
  20.2
       Please make sure to include x = 0 and x = a (equator) when
       you provide values for xinput.

  25.1 length of semi-major axis: ainput
  25.2
       ainput is the maximum "x=dimension" of the ellipse.
       The equation for the ellipse is x^2/a^2 + y^2/b^2 = 1.0
```

```
30.1 length of semi-minor axis of ellipse: binput
30.2
     binput is the y-dimension of the ellipse, the equation for which
     is x^2/a^2 + y^2/b^2 = 1.0.

35.1 number of nodal points per segment: nodes
35.2
     If you have about 10 segments, use a number less than 31.
     Use an odd number, greater than or equal to 11

40.1 max. x-coordinate for x-coordinate callouts: xlimit
40.2
     xlimit has two functions:
     1. a delimiter for the definition of callouts:
     for x < xlimit callouts are x-coordinates.
     for x > xlimit callouts are y-coordinates.
     Set xlimit equal to about a/2, where a = length of the
     semi-major axis of the ellipse.
     2. a delimiter for the boundary between Region 1
     and Region 2, Design margins for maximum stress and
     minimum buckling load in the shell skin and in the
     isogrid stiffeners can be computed in two regions,
     Region 1: 0 < x < xlimit, and
     Region 2: xlimit < x < semi-major axis.

45.1 skin thickness at xinput: THKSKN
45.2
     xinput is the vector of x-coordinate callouts for
     thickness of the shell skin and height of the
     isogrid stiffeners.

50.1 height of isogrid members at xinput: HIGHST
50.2
     xinput is the vector of x-coordinate callouts for
     thickness of the shell skin and height of the
     isogrid stiffeners.

55.1 spacing of the isogrid members: SPACNG
55.2
     SPACNG = altitude of the equilateral triangle between adjacent
     isogrid members, measured to middle surfaces of isogrid members.
     SPACNG = (length of side of triangle)*sqrt(3)/2.
     SPACNG is constant over the entire shell.

60.1 thickness of an isogrid stiffening member: THSTIF
60.2
     THSTIF is constant over the entire shell.

65.1 thickness of the cylindrical shell: THKCYL
70.1 radius of the cylindrical shell: RADCYL
75.1 length of the cylindrical segment: LENCYL
80.1 amplitude of the axisymmetric imperfection: WIMP
80.2
     Use a positive value greater than zero.
     For a perfect shell, use a value of WIMP that is
     very, very small compared to the skin thickness.
```

The imperfections are in the shapes of the axisymmetric
buckling modes obtained from linear theory for the
PERFECT shell. The actual imperfections are equal to
WIMP*WSHAPE(i), i = 1,NUMB,
in which NUMB = number of nodes in a shell segment.
In the paper about optimization of ellipsoidal shells
the axisymmetric buckling modal imperfections are
called "mode 1", "mode 2", "mode 3", "mode 4",
corresponding to the number of the linear buckling
eigenvalue corresponding to axisymmetric buckling.
Optimization can be performed with the use of
two modes, "mode 1" and "mode 2" or with the use
of four modes, "mode 1", "mode 2", "mode 3", "mode 4".
The shell is optimized with the plus and minus
version of each axisymmetric buckling modal
imperfection present by itself. In other words,
the shell is optimized such that it will survive
if any ONE of up to eight axisymmetric buckling
modal imperfections of amplitude WIMP is present.
The plus and minus versions of the axisymmetric
buckling modal imperfections are processed as
different load sets "applied" to the shell:
Load set 1 has plus "mode 1" and plus "mode 2";
Load set 2 has minus "mode 1" and minus "mode 2";
Load set 3 has plus "mode 3" and plus "mode 4";
Load set 4 has minus "mode 3" and minus "mode 4.
Usually, optimization should be performed with use
of only "mode 1" and "mode 2" imperfection shapes.

85.1 elastic modulus: EMATL
90.1 Poisson ratio of material: NUMATL
95.1 mass density of material: DNMATL
95.2
For example, the mass density of aluminum in English units is
0.000259

100.1 strategy control for imperfection shapes: IMODE
100.2
IMODE governs the strategy used to generate axisymmetric
buckling modal imperfection shapes.
IMODE = 1 means use Strategy 1 (Do not use this)
IMODE = 2 means use Strategy 2 (Use this choice)

In Strategy 1 axisymmetric buckling modes are
scanned until a mode is found in which the normal
modal displacement amplitude at the apex of the shell
is at least 0.7. (All buckling modes are normalized so that
the maximum buckling modal displacement is 1.0. The
buckling modal imperfection is the user-specified amplitude,
WIMP, multiplied by the normalized buckling modal displacement
distribution WSHAPE along the meridian of the shell.)
The remaining n (n = 2 or n = 4) modes are selected without
regard to the imperfection amplitude at the apex.

In Strategy 2 the first n axisymmetric buckling
modes (n = 2 or n = 4) are selected regardless of their
amplitude at the apex of the shell.

It is best to try Strategy 2 first.

105.1 Number NCASES of load cases (environments): NCASES
110.1 uniform external pressure: PRESS
115.0 collapse pressure with imperfection mode 1: CLAPS1
120.1 allowable pressure for axisymmetric collapse: CLAPS1A
125.1 factor of safety for axisymmetric collapse: CLAPS1F
130.0 general buckling load factor, mode 1: GENBK1
135.1 allowable general buckling load factor (use 1.0): GENBK1A
135.2

GENBK1 is defined as a "buckling load FACTOR", not as a "buckling LOAD". Therefore, you should always use a value of the "allowable general buckling load factor" equal to unity. This point holds for the treatment of all buckling allowables in this application.

140.1 factor of safety for general buckling: GENBK1F
140.2

Remember, this program already includes the effect of an axisymmetric buckling modal imperfection. If you use an imperfection amplitude, WIMP, significantly greater than zero you should accordingly use a factor of safety closer to unity than you would for an almost perfect shell.

145.1 Number JSKNBK1 of columns in the array, SKNBK1: JSKNBK1
150.0 local skin buckling load factor, mode 1: SKNBK1
155.1 allowable buckling load factor: SKNBK1A
160.1 factor of safety for skin buckling: SKNBK1F
165.0 buckling load factor, isogrid member, mode 1: STFBK1
170.1 allowable for isogrid stiffener buckling (Use 1.): STFBK1A
175.1 factor of safety for isogrid stiffener buckling: STFBK1F
180.0 maximum stress in the shell skin, mode 1: SKNST1
185.1 allowable stress for the shell skin: SKNST1A
190.1 factor of safety for skin stress: SKNST1F
195.0 maximum stress in isogrid stiffener, mode 1: STFST1
200.1 allowable stress in isogrid stiffeners: STFST1A
205.1 factor of safety for stress in isogrid member: STFST1F
210.0 normal (axial) displacement at apex, mode 1: WAPEX1
215.1 allowable normal (axial) displacement at apex: WAPEX1A
220.1 factor of safety for WAPEX: WAPEX1F
225.0 collapse pressure with imperfection mode 2: CLAPS2
230.1 allowable pressure for axisymmetric collapse: CLAPS2A
235.1 factor of safety for axisymmetric collapse: CLAPS2F
240.0 general buckling load factor, mode 2: GENBK2
245.1 allowable general buckling load factor (use 1.0): GENBK2A
250.1 factor of safety for general buckling: GENBK2F
250.2

Remember, this program already includes the effect of an axisymmetric buckling modal imperfection. If you use an imperfection amplitude, WIMP, significantly greater than zero you should accordingly use a factor of safety closer to unity than you would for an almost perfect shell.

255.1 Number JSKNBK2 of columns in the array, SKNBK2: JSKNBK2

```
260.0 local skin buckling load factor, mode 2: SKNBK2
265.1 allowable skin buckling load factor (use 1.0): SKNBK2A
270.1 factor of safety for local skin buckling: SKNBK2F
275.0 buckling load factor for isogrid member, mode 2: STFBK2
280.1 allowable for isogrid stiffener buckling (Use 1.): STFBK2A
285.1 factor of safety for isogrid stiffener buckling: STFBK2F
290.0 maximum stress in the shell skin, mode 2: SKNST2
295.1 allowable stress for the shell skin: SKNST2A
300.1 factor of safety for skin stress: SKNST2F
305.0 maximum stress in isogrid stiffener, mode 2: STFST2
310.1 allowable stress in isogrid stiffeners: STFST2A
315.1 factor of safety for stress in isogrid member: STFST2F
320.0 normal (axial) displacement at apex, mode 2: WAPEX2
325.1 allowable normal (axial) displacement at apex: WAPEX2A
330.1 factor of safety for WAPEX: WAPEX2F
335.0 weight of the equivalent ellipsoidal head: WEIGHT
335.2
      You can get the weight of just the head (no cylindrical shell
      by setting the density of the cylindrical segment equal to 0.
      NOTE: This is done in SUBROUTINE BOSDEC for you.
999.0 DUMMY ENTRY TO MARK END OF FILE
==================================================================
```

Table 7 **Source code libraries generated by "GENTEXT".** This list forms part of the **equivellipse.DEF** file, in which "equivellipse" is the GENOPT user's generic name for the case. The complete equivellipse.DEF file is listed in Table a2 of the appendix. **BEGIN.NEW** is listed in Table a3 of [26]; **STOGET.NEW** is listed in Table a4 of [26]; **STRUCT.NEW:** skeletal form is listed in Table a14 of [26], the GENOPT-user-completed final version for the generic case equivellipse, is listed in Table a16 of [26]; **BEHAVIOR.NEW:** skeletal version before inclusion of the GENOPT-created labeled common blocks is listed in Table a28 of [26] (where it has the name eqellipse.SUB), skeletal version after inclusion of the GENOPT-created labeled common blocks is listed in Table a13 of [26]; **CHANGE.NEW** is listed in Table a5 of [26].

```
==============================================================

 BEGIN.NEW   = source library for FORTRAN program which will
               be used to set up the starting design, material
               properties, and any other data you wish.

 STOGET.NEW  = source library for FORTRAN subroutines which
               are used to transfer labelled common blocks.
               These labelled common blocks are the data base.

 STRUCT.NEW  = source library for FORTRAN subroutines that
               perform the analysis for each iterate in the
               set of optimization iterations.  You may have
               to complete this routine (add dimension state-
               ments, subroutine calls, output statements,
               etc.).  The library, STRUCT.NEW, also contains
               a skeletal routine, SUB. TRANFR, that you can
               complete in order to translate data names from
               from those just established by you (TABLE 2) to
               other names used by the developer of previously
               written code that you may plan to incorporate
               into SUBROUTINE STRUCT and/or SUBROUTINES
               BEHX1, BEHX2, BEHX3,...BEHXn (described next).


 BEHAVIOR.NEW= a library of subroutine skeletons, BEHX1,BEHX2,
               BEHX3,...BEHXn, that, upon completion by you,
               will calculate behavior for a given design or
               design perturbation.  Skeletal subroutines for
               a user-written constraint condition, USRCON,
               and a skeletal routine for the objective func-
               tion, OBJECT, are also generated and are
               included in the BEHAVIOR.NEW library.

 CHANGE.NEW  = FORTRAN program that permits you to change
               certain program parameters without having to
               go back to BEGIN and run a case from scratch.
==============================================================
```

Table 8 **Contents of small files created by "GENTEXT".** This list forms part of the **equivellipse.DEF** file, in which "equivellipse" is the GENOPT user's generic name for the case. The complete equivellipse.DEF file is listed in Table a2 of the appendix. The completed files for the GENOPT user's generic case, "equivellipse", are included in the report [26] as follows: **equivellipe.PRO** is listed in Table 6; **equivellipse.NEW** is listed in Table a10 of [26]; **equivellipse.INP** is listed in Table a1; **equivellipse.COM** is listed in Table a6 of [26]; **equivellipse.WRI** is listed in Table a9 of [26]; **equivellipse.REA** is listed in Table a8 of [26]; **equivellipse.SET** is listed in Table a11 of [26]; **equivellipse.CON** is listed in Table a12 of [26]; **equivellipse.SUB** is listed in Table a28 of [26]; **equivellipse.DEF** is listed in Table a2 of [26]; **equivellipse.CHA** is listed in Table a7 of [26]; **equivellipse.DAT** is the same as the file **equivellipse.INP** and is listed in Table a1. Several of these small files are FORTRAN fragments. The FORTRAN small files are incorporated automatically by GENOPT into the appropriate places in the libraries listed in the previous table. The files that are FORTRAN fragments are: equivellipse.NEW, equivellipse.COM, equivellipse.WRI, equivellipse.REA, equivellipse.SET, equivellipse.CON, and equivellipse.CHA.

FILE NAME	DEFINITION OF FILE CONTENTS
equivellipse.PRO	Prompts and help paragraphs for interactive input to the user-developed optimization code.
equivellipse.NEW	Part of BEGIN.NEW that contains calls to SUBROUTINE DATUM and SUBROUTINE GETVAR. This coding sets up the interactive input for the starting design in the user-generated design code.
equivellipse.INP	Image of interactive input for user-developed program, generated to save time in case you make a mistake during input.
equivellipse.COM	Labelled common blocks generated specifically for the user-developed class of problems.
equivellipse.WRI	Part of subroutine for writing labelled common blocks in SUBROUTINE STORCM (in Library STOGET).
equivellipse.REA	Part of subroutine for reading labelled common blocks in SUBROUTINE GETCOM (in Library STOGET).
equivellipse.SET	Part of SUBROUTINE SETUPC in which new values are installed in labelled common blocks from the array VAR(I), which contains the latest values of all candidates for decision variables.
equivellipse.CON	Calls to subroutines, BEHX1, BEHX2, BEHX3,..., which calculate behavior such as stresses modal frequencies, buckling loads, etc. Also, calls to CON, which generate the value of the behavioral constraints corresponding

```
                         to BEHX1, BEHX2, BEHX3,...
                         Also, generates phrases that identify, in the
                         output of the user-generated program, the
                         exact meaning of each behavioral constraint.

equivellipse.SUB     Skeletal subroutines, BEHX1, BEHX2, ..., and the
                         skeletal objective function, OBJECT.

equivellipse.DEF     List of user-established variable names,
                         definitions, and roles that these variables
                         play in the user-generated program.  Also,
                         contains list of files created by GENTEXT
                         and the functions of these files.

equivellipse.CHA     Part of SUBROUTINE NEWPAR (called in the CHANGE
                         processor) in which labelled common values
                         are updated.

equivellipse.DAT     Image of interactive input for user-developed
                         program, generated to save time in case you
                         make a mistake during input. This file is used
                         by the INSERT processor.
=======================================================================
```

Table 9 Portion of the **equivellipse.COM** file generated automatically by "GENTEXT" that corresponds to the GENOPT user's input listed in Table 3. GENOPT inserts these labeled common blocks and variable declarations in all the FORTRAN libraries listed in Table 7. This list forms part of the complete equivellipse.COM file that appears in Table a6 of the appendix of [26]. The complete equivellipse.COM file exists when the GENOPT user has completed the interactive "GENTEXT" session.

```
===============================================================
      COMMON/FV01/xinput(21),Ixinpu
      REAL xinput
      COMMON/FV02/ainput,binput,xlimit,SPACNG,THSTIF,THKCYL,RADCYL
      REAL ainput,binput,xlimit,SPACNG,THSTIF,THKCYL,RADCYL
      COMMON/FV05/THKSKN(21),HIGHST(21)
      REAL THKSKN,HIGHST
      COMMON/IV01/npoint,nodes,IMODE
      INTEGER npoint,nodes,IMODE
================================================================
```

Table 10 Portion of the **equivellipse.CHA** file generated automatically by "GENTEXT" that corresponds to the GENOPT user's input listed in Table 3. This list forms part of the complete equivellipse.CHA file that appears in Table a7 of the appendix of [26]. The complete equivellipse.CHA file exists when the GENOPT user has completed the interactive "GENTEXT" session. This FORTRAN fragment forms part the FORTRAN library, change.new, in particular, part of SUBROUTINE NEWPAR.

```
=========================================================
      IF (Ixinpu .EQ.0) GO TO  21
      DO  20 I=1,Ixinpu
      xinput(I) =   PAR ( IPAR )
       IPAR  =  IPAR  + 1
   20 CONTINUE
   21 CONTINUE
      ainput   =   PAR ( IPAR )
       IPAR  =  IPAR  + 1
      binput   =   PAR ( IPAR )
       IPAR  =  IPAR  + 1
      xlimit   =   PAR ( IPAR )
       IPAR  =  IPAR  + 1
      IF (Ixinpu .EQ.0) GO TO  46
      DO  45 I=1,Ixinpu
      THKSKN(I) =   VAR ( IVAR )
       IVAR  =  IVAR  + 1
   45 CONTINUE
   46 CONTINUE
      IF (Ixinpu .EQ.0) GO TO  51
      DO  50 I=1,Ixinpu
      HIGHST(I) =   VAR ( IVAR )
       IVAR  =  IVAR  + 1
   50 CONTINUE
   51 CONTINUE
      SPACNG   =   VAR ( IVAR )
       IVAR  =  IVAR  + 1
      THSTIF   =   VAR ( IVAR )
       IVAR  =  IVAR  + 1
      THKCYL   =   PAR ( IPAR )
       IPAR  =  IPAR  + 1
      RADCYL   =   PAR ( IPAR )
       IPAR  =  IPAR  + 1
=========================================================
```

Table 11 Portion of the **equivellipse.REA** file generated automatically by "GENTEXT" that corresponds to the GENOPT user's input listed in Table 3. This list forms part of the complete equivellipse.REA file that appears in Table a8 of the appendix of [26]. The complete equivellipse.REA file exists when the GENOPT user has completed the interactive "GENTEXT" session. This FORTRAN fragment forms part the FORTRAN library, stoget.new, in particular, part of SUBROUTINE GETCOM.

```
================================================================
       READ(IFILE) npoint
       READ(IFILE) (xinput(I), I=1,21),Ixinpu
       READ(IFILE) ainput
       READ(IFILE) binput
       READ(IFILE) nodes
       READ(IFILE) xlimit
       READ(IFILE) (THKSKN(I), I=1,21)
       READ(IFILE) (HIGHST(I), I=1,21)
       READ(IFILE) SPACNG
       READ(IFILE) THSTIF
       READ(IFILE) THKCYL
       READ(IFILE) RADCYL
================================================================
```

Table 12 Portion of the **equivellipse.WRI** file generated automatically by "GENTEXT" that corresponds to the GENOPT user's input listed in Table 3. This list forms part of the complete equivellipse.WRI file that appears in Table a9 of the appendix of [26]. The complete equivellipse.WRI file exists when the GENOPT user has completed the interactive "GENTEXT" session. This FORTRAN fragment forms part the FORTRAN library, stoget.new, in particular, part of SUBROUTINE STORCM.

```
===============================================================
      WRITE(IFILE) npoint
      WRITE(IFILE) (xinput(I), I=1,21),Ixinpu
      WRITE(IFILE) ainput
      WRITE(IFILE) binput
      WRITE(IFILE) nodes
      WRITE(IFILE) xlimit
      WRITE(IFILE) (THKSKN(I), I=1,21)
      WRITE(IFILE) (HIGHST(I), I=1,21)
      WRITE(IFILE) SPACNG
      WRITE(IFILE) THSTIF
      WRITE(IFILE) THKCYL
      WRITE(IFILE) RADCYL
===============================================================
```

Table 13 Portion of the **equivellipse.NEW** file generated automatically by "GENTEXT" that corresponds to the GENOPT user's input listed in Table 3. This list forms part of the complete equivellipse.NEW file that appears in Table a10 of the appendix of [26]. The complete equivellipse.NEW file exists when the GENOPT user has completed the interactive "GENTEXT" session. This FORTRAN fragment forms part the FORTRAN library, begin.new, in particular, part of SUBROUTINE INPUT.

===

```
      CALL DATUM(IFILE, 10,1,2,npoint  , REALL,CHARAC,IOUT,0,0,0,IPROMP)
      WRITE(6,'(A)')'   '
      WRITE(6,'(A)')
     1 ' DEFINITION OF THE ROW INDEX OF THE ARRAY, xinput = '
      WRITE(6,'(A)')
     1 '  vector element number for xinput'
      WRITE(6,'(A)')'   '
      IF (IPROMP.GT.1) THEN
         WRITE(IFILE8,'(A)')'   '
         WRITE(IFILE8,'(A)')
     1 ' DEFINITION OF THE ROW INDEX OF THE ARRAY, xinput = '
         WRITE(IFILE8,'(A)')
     1 '  vector element number for xinput'
         WRITE(IFILE8,'(A)')'   '
      ENDIF
      REWIND IFILE
      CALL DATUM(IFILE, 15,1,1,Ixinpu ,REALL,CHARAC,IOUT,0,0,0,IPROMP)
      IF (Ixinpu .EQ.0) GO TO  16
      DO  15  I=1,Ixinpu
      REWIND IFILE
      CALL DATUM(IFILE, 20,1,2,
     1    INT,xinput(I),CHARAC,  IOUT,I,0,1,IPROMP)
      CALL GETVAR(I,0,     xinput(I),   IPAR,  PAR,WORDP)
   15 CONTINUE
   16 CONTINUE
      CALL DATUM(IFILE, 25,1,2,   INT,ainput  ,CHARAC,IOUT,0,0,0,IPROMP)
      CALL GETVAR(0,0,     ainput  ,    IPAR,  PAR,WORDP)
      CALL DATUM(IFILE, 30,1,2,   INT,binput  ,CHARAC,IOUT,0,0,0,IPROMP)
      CALL GETVAR(0,0,     binput  ,    IPAR,  PAR,WORDP)
      CALL DATUM(IFILE, 35,1,2,nodes   , REALL,CHARAC,IOUT,0,0,0,IPROMP)
      CALL DATUM(IFILE, 40,1,2,   INT,xlimit  ,CHARAC,IOUT,0,0,0,IPROMP)
      CALL GETVAR(0,0,     xlimit  ,    IPAR,  PAR,WORDP)
      WRITE(6,'(A)')'   '
      WRITE(6,'(A)')
     1 ' DEFINITION OF THE ROW INDEX OF THE ARRAY, THKSKN = '
      WRITE(6,'(A)')
     1 '  vector element number for xinput'
      WRITE(6,'(A)')'   '
      IF (IPROMP.GT.1) THEN
         WRITE(IFILE8,'(A)')'   '
         WRITE(IFILE8,'(A)')
     1 ' DEFINITION OF THE ROW INDEX OF THE ARRAY, THKSKN = '
         WRITE(IFILE8,'(A)')
     1 '  vector element number for xinput'
         WRITE(IFILE8,'(A)')'   '
      ENDIF
      IF (Ixinpu .EQ.0) GO TO  46
```

```
      DO  45  I=1,Ixinpu
      REWIND IFILE
      CALL DATUM(IFILE, 45,1,2,
     1    INT,THKSKN(I),CHARAC,  IOUT,I,0,1,IPROMP)
      CALL GETVAR(I,0,     THKSKN(I),   IVAR,  VAR,WORDV)
   45 CONTINUE
   46 CONTINUE
      WRITE(6,'(A)')'   '
      WRITE(6,'(A)')
     1 ' DEFINITION OF THE ROW INDEX OF THE ARRAY, HIGHST = '
      WRITE(6,'(A)')
     1 '  vector element number for xinput'
      WRITE(6,'(A)')'   '
      IF (IPROMP.GT.1) THEN
         WRITE(IFILE8,'(A)')'   '
         WRITE(IFILE8,'(A)')
     1 ' DEFINITION OF THE ROW INDEX OF THE ARRAY, HIGHST = '
         WRITE(IFILE8,'(A)')
     1 '  vector element number for xinput'
         WRITE(IFILE8,'(A)')'   '
      ENDIF
      IF (Ixinpu .EQ.0) GO TO  51
      DO  50  I=1,Ixinpu
      REWIND IFILE
      CALL DATUM(IFILE, 50,1,2,
     1    INT,HIGHST(I),CHARAC,  IOUT,I,0,1,IPROMP)
      CALL GETVAR(I,0,     HIGHST(I),   IVAR,  VAR,WORDV)
   50 CONTINUE
   51 CONTINUE
      CALL DATUM(IFILE, 55,1,2,   INT,SPACNG  ,CHARAC,IOUT,0,0,0,IPROMP)
      CALL GETVAR(0,0,     SPACNG  ,    IVAR,  VAR,WORDV)
      CALL DATUM(IFILE, 60,1,2,   INT,THSTIF  ,CHARAC,IOUT,0,0,0,IPROMP)
      CALL GETVAR(0,0,     THSTIF  ,    IVAR,  VAR,WORDV)
      CALL DATUM(IFILE, 65,1,1,   INT,THKCYL  ,CHARAC,IOUT,0,0,0,IPROMP)
      CALL GETVAR(0,0,     THKCYL  ,    IPAR,  PAR,WORDP)
      CALL DATUM(IFILE, 70,1,1,   INT,RADCYL  ,CHARAC,IOUT,0,0,0,IPROMP)
      CALL GETVAR(0,0,     RADCYL  ,    IPAR,  PAR,WORDP)
========================================================================
```

Table 14 Portion of the **equivellipse.SET** file generated automatically by "GENTEXT" that corresponds to the GENOPT user's input listed in Table 3. This list forms part of the complete equivellipse.SET file that appears in Table a11 of the appendix of [26]. The complete equivellipse.SET file exists when the GENOPT user has completed the interactive "GENTEXT" session. This FORTRAN fragment forms part the FORTRAN library, begin.new, in particular, part of SUBROUTINE SETUPC.

```
=========================================================
      IF (Ixinpu .EQ.0) GO TO  46
      DO  45 I=1,Ixinpu
      THKSKN(I) = VAR(IVAR)
      IVAR = IVAR + 1
   45 CONTINUE
   46 CONTINUE
      IF (Ixinpu .EQ.0) GO TO  51
      DO  50 I=1,Ixinpu
      HIGHST(I) = VAR(IVAR)
      IVAR = IVAR + 1
   50 CONTINUE
   51 CONTINUE
      SPACNG   = VAR(IVAR)
      IVAR = IVAR + 1
      THSTIF   = VAR(IVAR)
      IVAR = IVAR + 1
==========================================================
```

Table 15 Portion of the **equivellipse.DAT** file relating to some Role 4, 5, and 6 variables established and defined by the GENOPT user during the interactive GENTEXT session. When the GENOPT user has completed the GENTEXT interactive session the complete equivellipse.DAT file becomes a file that is called **equivellipse.INP**. See Table a1 of the appendix for a list of equivellipse.INP. The GENOPT user's **responses** to the prompts are in **bold face** in this table. The variable names, the one-line definitions of the variables, and the "help" paragraphs, created by the GENOPT user during the GENTEXT interactive session, **will be seen by the "end" user**. If the GENOPT user has done his or her job well, the program system created by GENOPT (BEGIN, DECIDE, MAINSETUP, OPTIMIZE, CHOOSEPLOT, etc.), that is, the program system for the generic case, "**equivellipse**", to be used later by the "end" user for specific cases (such as a specific case called "eqellipse"), will be user-friendly. Note that the GENOPT user (the writer) did not create any "help" paragraphs here. It would have been better if he had. See Section 3.7 for suggestions for typical "help" paragraphs that the GENOPT user should probably have included.

```
==========================================================================
 y         $ Any more variables for role type  4 ?             $160
       1  $ Type of prompt: 0="help" paragraph, 1=one-line prompt
 STFBK1    $ Name of a variable in the users program (defined below)
       4  $ Role of the variable in the users program
 n         $ Do you want to reset the number of columns in STFBK1 ?
 buckling load factor, isogrid member,mode 1 $ one-line definition,STFBK1
 n         $ Do you want to include a "help" paragraph?
       1  $ Type of prompt: 0="help" paragraph, 1=one-line prompt
 STFBK1A   $ Name of a variable in the users program (defined below)
       5  $ Role of the variable in the users program
 allowable for isogrid stiffener buckling (Use 1.)$ definition, STFBK1A
 n         $ Do you want to include a "help" paragraph?
       1  $ Type of prompt: 0="help" paragraph, 1=one-line prompt
 STFBK1F   $ Name of a variable in the users program (defined below)
       6  $ Role of the variable in the users program
 factor of safety for isogrid stiffener buckling      $ definition, STFBK1F
 n         $ Do you want to include a "help" paragraph?
       2  $ Indicator (1 or 2 or 3) for type of constraint
 y         $ Any more variables for role type  4 ?             $175
       1  $ Type of prompt: 0="help" paragraph, 1=one-line prompt
 SKNST1    $ Name of a variable in the users program (defined below)
       4  $ Role of the variable in the users program
 n         $ Do you want to reset the number of columns in SKNST1 ?
 maximum stress in the shell skin, mode 1  $ one-line definition, SKNST1
 n         $ Do you want to include a "help" paragraph?
       1  $ Type of prompt: 0="help" paragraph, 1=one-line prompt
 SKNST1A   $ Name of a variable in the users program (defined below)
       5  $ Role of the variable in the users program
 allowable stress for the shell skin       $ one-line definition, SKNST1A
 n         $ Do you want to include a "help" paragraph?
       1  $ Type of prompt: 0="help" paragraph, 1=one-line prompt
 SKNST1F   $ Name of a variable in the users program (defined below)
       6  $ Role of the variable in the users program
 factor of safety for skin stress          $ one-line definition, SKNST1F
n         $ Do you want to include a "help" paragraph?
       3  $ Indicator (1 or 2 or 3) for type of constraint
======================================================================
NOTE: See Table 16 for the meaning of
      "Indicator (1 or 2 or 3) for type of constraint".
```

Table 16 Explanation of three types of behavioral constraints corresponding to the prompt in the previous table:
"Indicator (1 or 2 or 3) for type of constraint".
In the “equivellipse” application of GENOPT only Indicators 2 and 3 are used. See Tables 31 and 32 for typical margins.

```
===============================================================
 There are three types of behavioral constraint
 conditions in an optimization problem:

  1  For a feasible design the allowable response, ALLOW
     must be greater than the product of the actual
     response, BEHAV, times its factor of safety, FSAFE.'
     EXAMPLE: Allowable stress must be greater than the actual
              stress x the factor of safety for stress.
     For example, a design margin of this type is expressed as:
     1 - [BEHAVIOR)/(ALLOWABLE BEHAVIOR)] X (FACTOR OF SAFETY)

  2  For a feasible design the actual response, BEHAV,
     must be greater than the product of the allowable
     response, ALLOW, times its factor of safety, FSAFE.
     EXAMPLES: (a) buckling load factor must be greater than
                   the allowable value x the factor of safety
                   for buckling.
               (b) lowest natural frequency must be greater
                   than the allowable value x the factor of
                   safety for natural frequency.
     For example, a design margin of this type is expressed as:
     [(BEHAVIOR)/(ALLOWABLE BEHAVIOR)] /(FACTOR OF SAFETY) - 1

  3  For a feasible design the allowable response, ALLOW
     must be greater than the product of the actual
     response, BEHAV, times its factor of safety, FSAFE. (same
     as for INDX = 1). However, the margin has a different form
     EXAMPLE: Allowable stress must be greater than the actual
              stress x the factor of safety for stress.
     For example, a design margin of this type is expressed as:
     [(ALLOWABLE BEHAVIOR)/(BEHAVIOR)] /(FACTOR OF SAFETY) - 1
===============================================================
```

Table 17 Portion of the **equivellipse.COM** file generated automatically by "GENTEXT" that corresponds to the GENOPT user's input listed in Table 15. GENOPT inserts these labeled common blocks and variable declarations in all the FORTRAN libraries listed in Table 7. This list forms part of the complete equivellipse.COM file that appears in Table a6 of the appendix of [26]. The complete equivellipse.COM file exists when the GENOPT user has completed the interactive "GENTEXT" session. This table is analogous to Table 9.

```
===============================================================
      COMMON/FV28/STFBK1(20,10),STFBK1A(20,10),STFBK1F(20,10)
      REAL STFBK1,STFBK1A,STFBK1F
      COMMON/FV31/SKNST1(20,10),SKNST1A(20,10),SKNST1F(20,10)
      REAL SKNST1,SKNST1A,SKNST1F
===============================================================
```

Table 18 Glossary of variables used in the generic case called **"equivellipse"** corresponding to the GENOPT user's interactive input to "GENTEXT" listed in Table 15. The complete glossary generated by GENOPT upon the GENOPT user's completion of the "GENTEXT" interactive session is listed in Table 2 and forms part of the file, equivellipse.DEF, which is listed in Table a2 in the appendix. This table is analogous to Table 4.

ARRAY ?	NUMBER OF (ROWS,COLS)	ROLE	PROMPT NUMBER (equivellipse.PRO)	NAME	DEFINITION OF VARIABLE
y	(20, 10)	4	165	STFBK1	= buckling load factor, isogrid member, mode 1
y	(20, 10)	5	170	STFBK1A	= allowable for isogrid stiffener buckling
y	(20, 10)	6	175	STFBK1F	= factor of safety for isogrid stiffener buckling
y	(20, 10)	4	180	SKNST1	= maximum stress in the shell skin, mode 1
y	(20, 10)	5	185	SKNST1A	= allowable stress for the shell skin
y	(20, 10)	6	190	SKNST1F	= factor of safety for skin stress

Table 19 Portion of the **equivellipse.PRO** file generated automatically by "GENTEXT" that corresponds to the GENOPT user's interactive input listed in Table 15. The complete equivellipse.PRO file generated after the GENOPT user completes the "GENTEXT" interactive session is listed in Table 6. This table is analogous to Table 5. Note: The GENOPT user (the writer) should have provided "help" paragraphs. See Section 3.7 for suggestions for "help" paragraphs.

```
=================================================================
 165.0 buckling load factor, isogrid member, mode 1: STFBK1
 170.1 allowable for isogrid stiffener buckling (Use 1.): STFBK1A
 175.1 factor of safety for isogrid stiffener buckling: STFBK1F
 180.0 maximum stress in the shell skin, mode 1: SKNST1
 185.1 allowable stress for the shell skin: SKNST1A
 190.1 factor of safety for skin stress: SKNST1F
 ================================================================
```

Table 20 Portion of the **equivellipse.CON** file generated automatically by "GENTEXT" that corresponds to the GENOPT user's input listed in Table 15. This list forms part of the complete equivellipse.CON file that appears in Table a12 of the appendix of [26]. The complete equivellipse.CON file exists when the GENOPT user has completed the interactive "GENTEXT" session. This FORTRAN fragment forms part the FORTRAN library, struct.new, which contains the GENOPT-created **skeletal** version of SUBROUTINE STRUCT. The complete **skeletal** version of SUBROUTINE STRUCT is included in Table a14 of the appendix of [26]. See Section 3.7 for more on subroutines BEHXi, construction of design constraints, typical forms which the design margins have, and the meanings of array subscripts.

```
=================================================================
C
C  Behavior and constraints generated next for STFBK1:
C  STFBK1 = buckling load factor, isogrid member, mode 1
C
      IF (JSKNBK1.EQ.0) GO TO 176
      IF (NPRINX.GT.0) THEN
         IF (JSKNBK1.GT.1) THEN
            WRITE(IFILE8,'(1X,A)')'  '
            WRITE(IFILE8,'(1X,A,$)')' BEHAVIOR OVER J = '
            WRITE(IFILE8,'(1X,A)')
     1      'number of regions for computing behavior'
         ENDIF
      ENDIF
      DO 175  J=1,JSKNBK1
      CALL CONVR2(J,CJX)
      PHRASE =
     1 'buckling load factor, isogrid member, mode 1'
      CALL BLANKX(PHRASE,IENDP4)
      IF (IBEHV(4  ).EQ.0) CALL BEHX4
     1 (IFILE8,NPRINX,IMODX,IFAST,ILOADX,J,
     1 'buckling load factor, isogrid member, mode 1')
      IF (STFBK1(ILOADX,J).EQ.0.)  STFBK1(ILOADX,J) = 1.E+10
      IF (STFBK1A(ILOADX,J).EQ.0.)  STFBK1A(ILOADX,J) = 1.0
      IF (STFBK1F(ILOADX,J).EQ.0.)  STFBK1F(ILOADX,J) = 1.0
      KCONX = KCONX + 1
      CARX(KCONX) =STFBK1(ILOADX,J)
      WORDCX= '(STFBK1('//CIX//','//CJX//')/STFBK1A('//CIX//','//CJX//
     1  ')) / STFBK1F('//CIX//','//CJX//')'
      CALL CONX(STFBK1(ILOADX,J),STFBK1A(ILOADX,J),STFBK1F(ILOADX,J)
     1,'buckling load factor, isogrid member, mode 1',
     1 'allowable for isogrid stiffener buckling (Use 1.)',
     1 'factor of safety for isogrid stiffener buckling',
     1 2,INUMTT,IMODX,CONMAX,ICONSX,IPOINC,CONSTX,WORDCX,
     1 WORDMX,PCWORD,CPLOTX,ICARX)
      IF (IMODX.EQ.0) THEN
         CODPHR =
     1 '  buckling load factor, isogrid member, mode 1: '
         IENDP4 =48
         CODNAM ='STFBK1('//CIX//','//CJX//')'
         MLET4 =6 + 7
         WORDBX(KCONX)= CODPHR(1:IENDP4)//CODNAM(1:MLET4)
         IF (NPRINX.GT.0) WRITE(IFILE8,'(I5,6X,G14.7,A,A)')
```

```
     1    KCONX,CARX(KCONX),CODPHR(1:IENDP4),CODNAM(1:MLET4)
      ENDIF
  175 CONTINUE
  176 CONTINUE
C
C  Behavior and constraints generated next for SKNST1:
C  SKNST1 = maximum stress in the shell skin, mode 1
C
      IF (JSKNBK1.EQ.0) GO TO 191
      IF (NPRINX.GT.0) THEN
         IF (JSKNBK1.GT.1) THEN
            WRITE(IFILE8,'(1X,A)')'  '
            WRITE(IFILE8,'(1X,A,$)')' BEHAVIOR OVER J = '
            WRITE(IFILE8,'(1X,A)')
     1      'number of regions for computing behavior'
         ENDIF
      ENDIF
      DO 190  J=1,JSKNBK1
      CALL CONVR2(J,CJX)
      PHRASE =
     1 'maximum stress in the shell skin, mode 1'
      CALL BLANKX(PHRASE,IENDP4)
      IF (IBEHV(5  ).EQ.0) CALL BEHX5
     1 (IFILE8,NPRINX,IMODX,IFAST,ILOADX,J,
     1 'maximum stress in the shell skin, mode 1')
      IF (SKNST1(ILOADX,J).EQ.0.)  SKNST1(ILOADX,J) = 1.E-10
      IF (SKNST1A(ILOADX,J).EQ.0.)  SKNST1A(ILOADX,J) = 1.0
      IF (SKNST1F(ILOADX,J).EQ.0.)  SKNST1F(ILOADX,J) = 1.0
      KCONX = KCONX + 1
      CARX(KCONX) =SKNST1(ILOADX,J)
      WORDCX= '(SKNST1A('//CIX//','//CJX//')/SKNST1('//CIX//','//CJX//
     1  ')) / SKNST1F('//CIX//','//CJX//')'
      CALL CONX(SKNST1(ILOADX,J),SKNST1A(ILOADX,J),SKNST1F(ILOADX,J)
     1,'maximum stress in the shell skin, mode 1',
     1 'allowable stress for the shell skin',
     1 'factor of safety for skin stress',
     1 3,INUMTT,IMODX,CONMAX,ICONSX,IPOINC,CONSTX,WORDCX,
     1 WORDMX,PCWORD,CPLOTX,ICARX)
      IF (IMODX.EQ.0) THEN
         CODPHR =
     1 '  maximum stress in the shell skin, mode 1: '
         IENDP4 =44
         CODNAM ='SKNST1('//CIX//','//CJX//')'
         MLET4 =6 + 7
         WORDBX(KCONX)= CODPHR(1:IENDP4)//CODNAM(1:MLET4)
         IF (NPRINX.GT.0) WRITE(IFILE8,'(I5,6X,G14.7,A,A)')
     1    KCONX,CARX(KCONX),CODPHR(1:IENDP4),CODNAM(1:MLET4)
      ENDIF
  190 CONTINUE
  191 CONTINUE
=====================================================================
```

Table 21 Portion of the **equivellipse.CHA** file generated automatically by "GENTEXT" that corresponds to the GENOPT user's input listed in Table 15. This list forms part of the complete equivellipse.CHA file that appears in Table a7 of the appendix of [26]. The complete equivellipse.CHA file exists when the GENOPT user has completed the interactive "GENTEXT" session. This FORTRAN fragment forms part the FORTRAN library, change.new, in particular part of SUBROUTINE NEWPAR. This table is analogous to Table 10.

```
================================================================
      IF (JSKNBK1.EQ.0) GO TO 171
      IF (NCASES .EQ.0) GO TO 171
      DO 170 J=1,JSKNBK1
      DO 170 I=1,NCASES
      STFBK1A(I,J) =  ALLOW(IALLOW)
      IALLOW = IALLOW + 1
  170 CONTINUE
  171 CONTINUE
      IF (JSKNBK1.EQ.0) GO TO 176
      IF (NCASES .EQ.0) GO TO 176
      DO 175 J=1,JSKNBK1
      DO 175 I=1,NCASES
      STFBK1F(I,J) = FSAFE (IFACT )
      IFACT  = IFACT  + 1
  175 CONTINUE
  176 CONTINUE
      IF (JSKNBK1.EQ.0) GO TO 186
      IF (NCASES .EQ.0) GO TO 186
      DO 185 J=1,JSKNBK1
      DO 185 I=1,NCASES
      SKNST1A(I,J) =  ALLOW(IALLOW)
      IALLOW = IALLOW + 1
  185 CONTINUE
  186 CONTINUE
      IF (JSKNBK1.EQ.0) GO TO 191
      IF (NCASES .EQ.0) GO TO 191
      DO 190 J=1,JSKNBK1
      DO 190 I=1,NCASES
      SKNST1F(I,J) = FSAFE (IFACT )
      IFACT  = IFACT  + 1
  190 CONTINUE
  191 CONTINUE
================================================================
```

Table 22 Portion of the **equivellipse.REA** file generated automatically by "GENTEXT" that corresponds to the GENOPT user's input listed in Table 15. This list forms part of the complete equivellipse.REA file that appears in Table a8 of the appendix of [26]. The complete equivellipse.REA file exists when the GENOPT user has completed the interactive "GENTEXT" session. This FORTRAN fragment forms part the FORTRAN library, stoget.new, in particular, part of SUBROUTINE GETCOM. This table is analogous to Table 11.

```
===============================================================
       READ(IFILE) ((STFBK1(I,J), I=1,20),    J=1,10)
       READ(IFILE) ((STFBK1A(I,J), I=1,20),    J=1,10)
       READ(IFILE) ((STFBK1F(I,J), I=1,20),    J=1,10)
       READ(IFILE) ((SKNST1(I,J), I=1,20),    J=1,10)
       READ(IFILE) ((SKNST1A(I,J), I=1,20),    J=1,10)
       READ(IFILE) ((SKNST1F(I,J), I=1,20),    J=1,10)
==============================================================
```

Table 23 Portion of the **equivellipse.WRI** file generated automatically by "GENTEXT" that corresponds to the GENOPT user's input listed in Table 15. This list forms part of the complete equivellipse.WRI file that appears in Table a9 of the appendix of [26]. The complete equivellipse.WRI file exists when the GENOPT user has completed the interactive "GENTEXT" session. This FORTRAN fragment forms part the FORTRAN library, stoget.new, in particular, part of SUBROUTINE STORCM. This table is analogous to Table 12.

```
================================================================
      WRITE(IFILE) ((STFBK1(I,J), I=1,20),    J=1,10)
      WRITE(IFILE) ((STFBK1A(I,J), I=1,20),    J=1,10)
      WRITE(IFILE) ((STFBK1F(I,J), I=1,20),    J=1,10)
      WRITE(IFILE) ((SKNST1(I,J), I=1,20),    J=1,10)
      WRITE(IFILE) ((SKNST1A(I,J), I=1,20),    J=1,10)
      WRITE(IFILE) ((SKNST1F(I,J), I=1,20),    J=1,10)
================================================================
```

Table 24 Portion of the **equivellipse.NEW** file generated automatically by "GENTEXT" that corresponds to the GENOPT user's input listed in Table 15. This list forms part of the complete equivellipse.NEW file that appears in Table a10 of the appendix of [26]. The complete equivellipse.NEW file exists when the GENOPT user has completed the interactive "GENTEXT" session. This FORTRAN fragment forms part the FORTRAN library, begin.new, in particular, part of SUBROUTINE INPUT. This table is analogous to Table 13.

```
===================================================================
      IF (JSKNBK1.EQ.0) GO TO 166
      DO 165  J=1,JSKNBK1
      IF (JSKNBK1.GT.1) THEN
         WRITE(6,'(A)')'   '
         WRITE(6,'(A)')
     1    ' DEFINITION OF THE COLUMN INDEX OF THE ARRAY, STFBK1 = '
         WRITE(6,'(A)')
     1 '  number of regions for computing behavior'
         WRITE(6,'(A)')'   '
         CALL CONVR2(J,CJ)
         WRITE(6,'(A,A,A)')
     1 '   INPUT FOR COL. NO. ',CJ,' OF THE ARRAY STFBK1'
         IF (IPROMP.GT.1) THEN
          WRITE(IFILE8,'(A)')'  '
          WRITE(IFILE8,'(A)')
     1    ' DEFINITION OF THE COLUMN INDEX OF THE ARRAY, STFBK1 = '
          WRITE(IFILE8,'(A)')
     1 '  number of regions for computing behavior'
          WRITE(IFILE8,'(A)')'  '
          WRITE(IFILE8,'(A,A,A)')
     1 '   INPUT FOR COL. NO. ',CJ,' OF THE ARRAY STFBK1'
         ENDIF
      ENDIF
      WRITE(6,'(A)')'   '
      WRITE(6,'(A)')
     1 ' DEFINITION OF THE ROW INDEX OF THE ARRAY, STFBK1 = '
      WRITE(6,'(A)')
     1 '  Number of load cases (number of environments) '
      WRITE(6,'(A)')'   '
      IF (IPROMP.GT.1) THEN
         WRITE(IFILE8,'(A)')'   '
         WRITE(IFILE8,'(A)')
     1 ' DEFINITION OF THE ROW INDEX OF THE ARRAY, STFBK1 = '
         WRITE(IFILE8,'(A)')
     1 '  Number of load cases (number of environments) '
         WRITE(IFILE8,'(A)')'   '
      ENDIF
      IF (NCASES .EQ.0) GO TO 166
      DO 165  I=1,NCASES
      REWIND IFILE
      CALL DATUM(IFILE,165,0,0,
     1    INT,STFBK1(I,J),CHARAC,IOUT,I,J,2,IPROMP)
      PHRASE =
     1 'buckling load factor, isogrid member, mode 1: STFBK1'
      CALL BLANKX(PHRASE,IBLANK)
      CALL GETVAR(I,J,   STFBK1(I,J),   ICAR,  CAR,WORDB)
```

```
165 CONTINUE
166 CONTINUE
    IF (JSKNBK1.EQ.0) GO TO 171
    DO 170  J=1,JSKNBK1
    IF (JSKNBK1.GT.1) THEN
       WRITE(6,'(A)')'   '
       WRITE(6,'(A)')
   1    ' DEFINITION OF THE COLUMN INDEX OF THE ARRAY, STFBK1A = '
       WRITE(6,'(A)')
   1 '  number of regions for computing behavior'
       WRITE(6,'(A)')'   '
       CALL CONVR2(J,CJ)
       WRITE(6,'(A,A,A)')
   1 '   INPUT FOR COL. NO. ',CJ,' OF THE ARRAY STFBK1A'
       IF (IPROMP.GT.1) THEN
        WRITE(IFILE8,'(A)')'  '
        WRITE(IFILE8,'(A)')
   1    ' DEFINITION OF THE COLUMN INDEX OF THE ARRAY, STFBK1A = '
        WRITE(IFILE8,'(A)')
   1 '  number of regions for computing behavior'
        WRITE(IFILE8,'(A)')'  '
        WRITE(IFILE8,'(A,A,A)')
   1 '   INPUT FOR COL. NO. ',CJ,' OF THE ARRAY STFBK1A'
       ENDIF
    ENDIF
    WRITE(6,'(A)')'   '
    WRITE(6,'(A)')
   1 ' DEFINITION OF THE ROW INDEX OF THE ARRAY, STFBK1A = '
    WRITE(6,'(A)')
   1 '  Number of load cases (number of environments) '
    WRITE(6,'(A)')'   '
    IF (IPROMP.GT.1) THEN
       WRITE(IFILE8,'(A)')'   '
       WRITE(IFILE8,'(A)')
   1 ' DEFINITION OF THE ROW INDEX OF THE ARRAY, STFBK1A = '
       WRITE(IFILE8,'(A)')
   1 '  Number of load cases (number of environments) '
       WRITE(IFILE8,'(A)')'   '
    ENDIF
    IF (NCASES .EQ.0) GO TO 171
    DO 170  I=1,NCASES
    REWIND IFILE
    CALL DATUM(IFILE,170,1,1,
   1    INT,STFBK1A(I,J),CHARAC,IOUT,I,J,2,IPROMP)
    CALL GETVAR(I,J,   STFBK1A(I,J),IALLOW,ALLOW,WORDA)
170 CONTINUE
171 CONTINUE
    IF (JSKNBK1.EQ.0) GO TO 176
    DO 175  J=1,JSKNBK1
    IF (JSKNBK1.GT.1) THEN
       WRITE(6,'(A)')'   '
       WRITE(6,'(A)')
   1    ' DEFINITION OF THE COLUMN INDEX OF THE ARRAY, STFBK1F = '
       WRITE(6,'(A)')
   1 '  number of regions for computing behavior'
       WRITE(6,'(A)')'   '
       CALL CONVR2(J,CJ)
```

```
        WRITE(6,'(A,A,A)')
    1 '   INPUT FOR COL. NO. ',CJ,' OF THE ARRAY STFBK1F'
        IF (IPROMP.GT.1) THEN
         WRITE(IFILE8,'(A)')'  '
         WRITE(IFILE8,'(A)')
    1    ' DEFINITION OF THE COLUMN INDEX OF THE ARRAY, STFBK1F = '
         WRITE(IFILE8,'(A)')
    1 '  number of regions for computing behavior'
         WRITE(IFILE8,'(A)')'  '
         WRITE(IFILE8,'(A,A,A)')
    1 '   INPUT FOR COL. NO. ',CJ,' OF THE ARRAY STFBK1F'
        ENDIF
     ENDIF
     WRITE(6,'(A)')'   '
     WRITE(6,'(A)')
    1 ' DEFINITION OF THE ROW INDEX OF THE ARRAY, STFBK1F = '
     WRITE(6,'(A)')
    1 '  Number of load cases (number of environments) '
     WRITE(6,'(A)')'   '
     IF (IPROMP.GT.1) THEN
        WRITE(IFILE8,'(A)')'   '
        WRITE(IFILE8,'(A)')
    1 ' DEFINITION OF THE ROW INDEX OF THE ARRAY, STFBK1F = '
        WRITE(IFILE8,'(A)')
    1 '  Number of load cases (number of environments) '
        WRITE(IFILE8,'(A)')'   '
     ENDIF
     IF (NCASES .EQ.0) GO TO 176
     DO 175  I=1,NCASES
     REWIND IFILE
     CALL DATUM(IFILE,175,1,1,
    1    INT,STFBK1F(I,J),CHARAC,IOUT,I,J,2,IPROMP)
     CALL GETVAR(I,J,   STFBK1F(I,J), IFACT,FSAFE,WORDS)
 175 CONTINUE
 176 CONTINUE
     IF (JSKNBK1.EQ.0) GO TO 181
     DO 180  J=1,JSKNBK1
     IF (JSKNBK1.GT.1) THEN
        WRITE(6,'(A)')'   '
        WRITE(6,'(A)')
    1    ' DEFINITION OF THE COLUMN INDEX OF THE ARRAY, SKNST1 = '
        WRITE(6,'(A)')
    1 '  number of regions for computing behavior'
        WRITE(6,'(A)')'   '
        CALL CONVR2(J,CJ)
        WRITE(6,'(A,A,A)')
    1 '   INPUT FOR COL. NO. ',CJ,' OF THE ARRAY SKNST1'
        IF (IPROMP.GT.1) THEN
         WRITE(IFILE8,'(A)')'  '
         WRITE(IFILE8,'(A)')
    1    ' DEFINITION OF THE COLUMN INDEX OF THE ARRAY, SKNST1 = '
         WRITE(IFILE8,'(A)')
    1 '  number of regions for computing behavior'
         WRITE(IFILE8,'(A)')'  '
         WRITE(IFILE8,'(A,A,A)')
    1 '   INPUT FOR COL. NO. ',CJ,' OF THE ARRAY SKNST1'
        ENDIF
```

```
      ENDIF
      WRITE(6,'(A)')'    '
      WRITE(6,'(A)')
     1 ' DEFINITION OF THE ROW INDEX OF THE ARRAY, SKNST1 = '
      WRITE(6,'(A)')
     1 '  Number of load cases (number of environments) '
      WRITE(6,'(A)')'    '
      IF (IPROMP.GT.1) THEN
         WRITE(IFILE8,'(A)')'    '
         WRITE(IFILE8,'(A)')
     1 ' DEFINITION OF THE ROW INDEX OF THE ARRAY, SKNST1 = '
         WRITE(IFILE8,'(A)')
     1 '  Number of load cases (number of environments) '
         WRITE(IFILE8,'(A)')'    '
      ENDIF
      IF (NCASES .EQ.0) GO TO 181
      DO 180  I=1,NCASES
      REWIND IFILE
      CALL DATUM(IFILE,180,0,0,
     1    INT,SKNST1(I,J),CHARAC,IOUT,I,J,2,IPROMP)
      PHRASE =
     1 'maximum stress in the shell skin, mode 1: SKNST1'
      CALL BLANKX(PHRASE,IBLANK)
      CALL GETVAR(I,J,   SKNST1(I,J),   ICAR,  CAR,WORDB)
  180 CONTINUE
  181 CONTINUE
      IF (JSKNBK1.EQ.0) GO TO 186
      DO 185  J=1,JSKNBK1
      IF (JSKNBK1.GT.1) THEN
         WRITE(6,'(A)')'    '
         WRITE(6,'(A)')
     1    ' DEFINITION OF THE COLUMN INDEX OF THE ARRAY, SKNST1A = '
         WRITE(6,'(A)')
     1 '  number of regions for computing behavior'
         WRITE(6,'(A)')'    '
         CALL CONVR2(J,CJ)
         WRITE(6,'(A,A,A)')
     1 '   INPUT FOR COL. NO. ',CJ,' OF THE ARRAY SKNST1A'
         IF (IPROMP.GT.1) THEN
          WRITE(IFILE8,'(A)')'   '
          WRITE(IFILE8,'(A)')
     1    ' DEFINITION OF THE COLUMN INDEX OF THE ARRAY, SKNST1A = '
          WRITE(IFILE8,'(A)')
     1 '  number of regions for computing behavior'
          WRITE(IFILE8,'(A)')'   '
          WRITE(IFILE8,'(A,A,A)')
     1 '   INPUT FOR COL. NO. ',CJ,' OF THE ARRAY SKNST1A'
         ENDIF
      ENDIF
      WRITE(6,'(A)')'    '
      WRITE(6,'(A)')
     1 ' DEFINITION OF THE ROW INDEX OF THE ARRAY, SKNST1A = '
      WRITE(6,'(A)')
     1 '  Number of load cases (number of environments) '
      WRITE(6,'(A)')'    '
      IF (IPROMP.GT.1) THEN
         WRITE(IFILE8,'(A)')'    '
```

```
         WRITE(IFILE8,'(A)')
     1 ' DEFINITION OF THE ROW INDEX OF THE ARRAY, SKNST1A = '
         WRITE(IFILE8,'(A)')
     1 '  Number of load cases (number of environments) '
         WRITE(IFILE8,'(A)')'   '
      ENDIF
      IF (NCASES .EQ.0) GO TO 186
      DO 185  I=1,NCASES
      REWIND IFILE
      CALL DATUM(IFILE,185,1,1,
     1    INT,SKNST1A(I,J),CHARAC,IOUT,I,J,2,IPROMP)
      CALL GETVAR(I,J,   SKNST1A(I,J),IALLOW,ALLOW,WORDA)
  185 CONTINUE
  186 CONTINUE
      IF (JSKNBK1.EQ.0) GO TO 191
      DO 190  J=1,JSKNBK1
      IF (JSKNBK1.GT.1) THEN
         WRITE(6,'(A)')'   '
         WRITE(6,'(A)')
     1     ' DEFINITION OF THE COLUMN INDEX OF THE ARRAY, SKNST1F = '
         WRITE(6,'(A)')
     1 '  number of regions for computing behavior'
         WRITE(6,'(A)')'   '
         CALL CONVR2(J,CJ)
         WRITE(6,'(A,A,A)')
     1 '   INPUT FOR COL. NO. ',CJ,' OF THE ARRAY SKNST1F'
         IF (IPROMP.GT.1) THEN
          WRITE(IFILE8,'(A)')'  '
          WRITE(IFILE8,'(A)')
     1     ' DEFINITION OF THE COLUMN INDEX OF THE ARRAY, SKNST1F = '
          WRITE(IFILE8,'(A)')
     1 '  number of regions for computing behavior'
          WRITE(IFILE8,'(A)')'  '
          WRITE(IFILE8,'(A,A,A)')
     1 '   INPUT FOR COL. NO. ',CJ,' OF THE ARRAY SKNST1F'
         ENDIF
      ENDIF
      WRITE(6,'(A)')'   '
      WRITE(6,'(A)')
     1 ' DEFINITION OF THE ROW INDEX OF THE ARRAY, SKNST1F = '
      WRITE(6,'(A)')
     1 '  Number of load cases (number of environments) '
      WRITE(6,'(A)')'   '
      IF (IPROMP.GT.1) THEN
         WRITE(IFILE8,'(A)')'   '
         WRITE(IFILE8,'(A)')
     1 ' DEFINITION OF THE ROW INDEX OF THE ARRAY, SKNST1F = '
         WRITE(IFILE8,'(A)')
     1 '  Number of load cases (number of environments) '
         WRITE(IFILE8,'(A)')'   '
      ENDIF
      IF (NCASES .EQ.0) GO TO 191
      DO 190  I=1,NCASES
      REWIND IFILE
      CALL DATUM(IFILE,190,1,1,
     1    INT,SKNST1F(I,J),CHARAC,IOUT,I,J,2,IPROMP)
      CALL GETVAR(I,J,   SKNST1F(I,J), IFACT,FSAFE,WORDS)
```

```
  190 CONTINUE
  191 CONTINUE
====================================================================
```

Table 25 Portion of the **behavior.new** file generated automatically by GENTEXT that corresponds to the GENOPT user's input listed in Table 15. The complete behavior.new file, available after the GENOPT user has completed the interactive "GENTEXT" session, is listed in Table a13 of the appendix of [26]. The behavior.new file created by GENTEXT contains the **skeletal** version of SUBROUTINES BEHXi, I = 1, 2, 3... In the present application of GENOPT the GENOPT user does not modify these **skeletal** subroutines, but instead **"fleshes out"** only SUBROUTINE STRUCT. The file, **equivellipse.SUB**, contains similar FORTRAN coding as behavior.new after the GENOPT user's completion of the "GENTEXT" interactive session. equivellipse.SUB lacks a copy of the file, equivellipse.DEF and lacks the labeled common blocks generated automatically by "GENTEXT" and added to each BEHXi, i=1,14, in the skeletal behavior.new file. equivellipse.SUB is listed in Table a28 of the appendix of [26].

```
=================================================================
C=DECK      BEHX4
      SUBROUTINE BEHX4
     1 (IFILE,NPRINX,IMODX,IFAST,ILOADX,JCOL,PHRASE)
C
C   PURPOSE: OBTAIN buckling load factor, isogrid member, mode 1
C
C   YOU MUST WRITE CODE THAT, USING
C   THE VARIABLES IN THE LABELLED
C   COMMON BLOCKS AS INPUT, ULTIMATELY
C   YIELDS THE RESPONSE VARIABLE FOR
C   THE ith LOAD CASE, ILOADX:
C
C     STFBK1(ILOADX,JCOL)
C
C   AS OUTPUT. THE ith CASE REFERS
C   TO ith ENVIRONMENT (e.g. load com-
C   bination).
C   THE jth COLUMN  (JCOL)
C   INDEX IS DEFINED AS FOLLOWS:
C     number of regions for computing behavior
C
C   DEFINITIONS OF INPUT DATA:
C    IMODX  = DESIGN CONTROL INTEGER:
C     IMODX = 0 MEANS BASELINE DESIGN
C     IMODX = 1 MEANS PERTURBED DESIGN
C     IFAST = 0 MEANS FEW  SHORTCUTS FOR PERTURBED DESIGNS
C     IFAST = 1 MEANS MORE SHORTCUTS FOR PERTURBED DESIGNS
C    IFILE = FILE FOR OUTPUT LIST:
C    NPRINX= OUTPUT CONTROL INTEGER:
C     NPRINX=0 MEANS SMALLEST AMOUNT
C     NPRINX=1 MEANS MEDIUM AMOUNT
C     NPRINX=2 MEANS LOTS OF OUTPUT
C
C     ILOADX = ith LOADING COMBINATION
C     JCOL   = jth column of STFBK1
C     JCOL   = number of regions for computing behavior
C     PHRASE = buckling load factor, isogrid member, mode 1
C
C   OUTPUT:
C
```

```
C     STFBK1(ILOADX,JCOL)
C
        CHARACTER*80 PHRASE
C  INSERT ADDITIONAL COMMON BLOCKS:
       (lines skipped to save space)
      COMMON/FV28/STFBK1(20,10),STFBK1A(20,10),STFBK1F(20,10)
      REAL STFBK1,STFBK1A,STFBK1F
      COMMON/FV31/SKNST1(20,10),SKNST1A(20,10),SKNST1F(20,10)
      REAL SKNST1,SKNST1A,SKNST1F
       (lines skipped to save space)
C
C  INSERT SUBROUTINE STATEMENTS HERE.
C
C
      RETURN
      END
C
C
C=DECK      BEHX5
      SUBROUTINE BEHX5
     1 (IFILE,NPRINX,IMODX,IFAST,ILOADX,JCOL,PHRASE)
C
C   PURPOSE: OBTAIN maximum stress in the shell skin, mode 1
C
C   YOU MUST WRITE CODE THAT, USING
C   THE VARIABLES IN THE LABELLED
C   COMMON BLOCKS AS INPUT, ULTIMATELY
C   YIELDS THE RESPONSE VARIABLE FOR
C   THE ith LOAD CASE, ILOADX:
C
C     SKNST1(ILOADX,JCOL)
C
C   AS OUTPUT. THE ith CASE REFERS
C   TO ith ENVIRONMENT (e.g. load com-
C   bination).
C   THE jth COLUMN  (JCOL)
C   INDEX IS DEFINED AS FOLLOWS:
C     number of regions for computing behavior
C
C   DEFINITIONS OF INPUT DATA:
    (lines skipped to save space)
C     ILOADX = ith LOADING COMBINATION
C     JCOL   = jth column of SKNST1
C     JCOL   = number of regions for computing behavior
C     PHRASE = maximum stress in the shell skin, mode 1
C
C   OUTPUT:
C
C     SKNST1(ILOADX,JCOL)
C
        CHARACTER*80 PHRASE
C  INSERT ADDITIONAL COMMON BLOCKS:
       (lines skipped to save space)
      COMMON/FV28/STFBK1(20,10),STFBK1A(20,10),STFBK1F(20,10)
      REAL STFBK1,STFBK1A,STFBK1F
      COMMON/FV31/SKNST1(20,10),SKNST1A(20,10),SKNST1F(20,10)
      REAL SKNST1,SKNST1A,SKNST1F
```

```
      (lines skipped to save space)
C
C  INSERT SUBROUTINE STATEMENTS HERE.
C
C
      RETURN
      END
=================================================================
```

NOTE: IN THIS PARTICULAR APPLICATION OF GENOPT THE GENOPT USER (THE WRITER) DECIDED THAT THE "BEHAVIOR" SUBROUTINES, SUBROUTINE BEHXi, i = 1, 2, 3, 4,...14, WERE NOT TO BE MODIFIED. INSTEAD, THE GENOPT USER DECIDED FOR VARIOUS REASONS THAT THE OUTPUT ORDINARILY TO BE GENERATED BY "BEHXi" WOULD INSTEAD BE COMPUTED IN SUBROUTINE STRUCT. THE SKELETAL "BEHXi" SUBROUTINES THEREFORE DO NOTHING IN THIS APPLICATION. HOWEVER, TWO OF THEM ARE LISTED HERE IN ORDER TO INFORM THE READER THAT IN DIFFERENT APPLICATIONS OF GENOPT, SUCH AS THOSE DESCRIBED IN REFS. [2 - 7], THE GENOPT USER MAY DECIDE TO "FLESH OUT" THE "BEHXi" SUBROUTINES INSTEAD OF CREATING AN ELABORATE SUBROUTINE STRUCT, AS WAS DONE HERE. SEE TABLE a31 IN THE APPENDIX OF [26] FOR A RELATIVELY SIMPLE EXAMPLE IN WHICH THE SKELETAL "BEHXi" SUBROUTINES ARE "FLESHED OUT" BY THE GENOPT USER.

Table 26 The **GENOPT-user-written** abridged part of **SUBROUTINE STRUCT** in which the maximum effective stress and minimum buckling load factors are computed for the shell skin and for the isogrid stiffeners. This part of SUBROUTINE STRUCT was written by the GENOPT user. Both the GENOPT-created skeletal version of SUBROUTINE STRUCT and the complete version of SUBROUTINE STRUCT are listed in the appendix of [26] as Tables a14 of [26] and Table a16 of [26], respectively. The complete version of SUBROUTINE STRUCT is very long and constitutes a major part of the work on this project. This table presents only a short segment of SUBROUTINE STRUCT.

```
=====================================================================
C  Find axisymmetric nonlinear equilibrium (INDIC=0) of imperfect shell
C  at the design load, PRESS(ILOADX), with use of axisymmetric buckling
C  modal imperfection mode 1.
C
  (many lines skipped to save space)

NOTE: SUBROUTINE BOSDEC generates a valid input file for BOSOR4
      (or BIGBOSOR4) for an INDIC = 0 type of analysis:

      CALL BOSDEC(4,ILOADX,INDIC,IMPERF,24,IFILE8,
     1                  npoint,ainput,binput,LENCYL,nodes,WIMP,
     1                  WMODEX,xinput,xlimit,EMATL,NUMATL,DNMATL,
     1                  THKSKN,HIGHST,SPACNG,THSTIF,THKCYL,
     1                  PRESS,PMAX,N0BX,NMINBX,NMAXBX,INCRBX)

  (many lines skipped to save space)
c
      CALL B4READ       (execution of the BIGBOSOR4 preprocessor)
      CALL B4MAIN       (execution of the BIGBOSOR4 mainprocessor.
                         B4MAIN computes BUCMIN, BUCMNS, SKNMAX,
                         and STFMXS. bskin1, etc. are defined in
                         a footnote at the end of this table.)
c
  (lines skipped to save space)

      do 363 iseg = 1,NSEG
         ipoint = iseg + 1
         if (xinput(ipoint).lt.xlimit) then
            bskin1 = min(bskin1,BUCMIN(iseg))
            bstif1 = min(bstif1,BUCMNS(iseg))
            sknmx1 = max(sknmx1,SKNMAX(iseg))
            stfmx1 = max(stfmx1,STFMXS(iseg))
         else
            bskin2 = min(bskin2,BUCMIN(iseg))
            bstif2 = min(bstif2,BUCMNS(iseg))
            sknmx2 = max(sknmx2,SKNMAX(iseg))
            stfmx2 = max(stfmx2,STFMXS(iseg))
         endif
  363 continue
c
  (many lines skipped to save space)

      IF (PMAX01.GE.0.90*PRESS(ILOADX)) THEN
         SKNBK1(ILOADX,1) = bskin1
         STFBK1(ILOADX,1) = bstif1
         SKNST1(ILOADX,1) = sknmx1
```

```
      STFST1(ILOADX,1) = stfmx1
      SKNBK1(ILOADX,2) = bskin2
      STFBK1(ILOADX,2) = bstif2
      SKNST1(ILOADX,2) = sknmx2
      STFST1(ILOADX,2) = stfmx2
      WAPEX1(ILOADX) = ABS(ENDUV)
   ENDIF
```

NOTES ON THIS TABLE

DEFINITION OF VARIABLES:
ILOADX = load set number
ENDUV = normal displacement at the apex of the shell
bskin1 = local skin buckling in Region 1
bstif1 = local isogrid stiffener buckling in Region 1
sknmx1 = maximum effective stress in shell skin in Region 1
stfmx1 = maximum stress in isogrid stiffener in Region 1
The same quantities with a "2" pertain to Region 2.
The quantities, SKNBK1, STFBK1, etc. are used in the computation of behavioral constraints and design margins that are computed in SUBROUTINE CONX, which is part of the file, ..genopt/sources/main.src.

SUBROUTINE BOSDEC must be created by the GENOPT user. BOSDEC produces a valid input file for BIGBOSOR4, such as that listed in Table a17 of [26], for example. SUBROUTINE BOSDEC for the "equivellipse" application is listed in Table a15.

SEE TABLE a30 IN THE APPENDIX OF [26] FOR A RELATIVELY SIMPLE EXAMPLE IN WHICH THE SKELETAL "STRUCT" SUBROUTINE IS "FLESHED OUT" BY THE GENOPT USER.

Table 27 **2005 modifications to BIGBOSOR4** to compute maximum stress in a stringer or isogrid member and minimum local buckling load factors for skin and smeared stiffeners. For the purposes of computing maximum stress and minimum buckling load in an isogrid member the isogrid is modeled as a stringer, that is, a stiffener that runs in the meridional coordinate direction. For the purpose of modeling the stiffness of the shell wall, that is, the computation of the 6 x 6 integrated constitutive matrix, C_{ij}, the isogrid is modeled as an isotropic shell wall layer with Poisson ratio equal to 1/3 and modulus equal to the actual material modulus multiplied by the isogrid stiffener wall thickness divided by the isogrid member spacing, which is taken to be the altitude of the equilateral triangle formed by adjacent three sets of isogrid stiffening members.

```
=================================================================  bigbosor4
was modified to permit computation of the following
 additional behaviors:
```

a. Local buckling of the small triangular piece of skin of a shell when that skin is stiffened by an isogrid. The small triangular piece of skin is assumed to be flat.

b. Buckling of a stiffener in a model in which the set of like stiffeners (stringers or isogrid or rings) is smeared out in the BIGBOSOR4 model.

c. Maximum stress in a stiffener in a manner analogous to **b**

```
 For each shell segment BIGBOSOR4 now computes the minimum
 skin buckling load factor, the minimum stiffener buckling load
 factor, and the maximum effective stress in a smeared stiffener.
 NOTE: BIGBOSOR4 does this ONLY FOR AXISYMMETRICALLY LOADED SHELLS:
       (Analysis types, INDIC = -2, -1, 0, 1, 2). The smeared
       stiffeners (stringers, rings, isogrid) MUST HAVE RECTANGULAR
       CROSS SECTIONS.
 The new output (for an externally pressurized isogrid-stiffened
 torispherical head, for example) in the *.OUT file appears as follows:
----------------------------------------------------------------------
 ISEG,ISOGRD(IS)=    1    1
 Segment no.1 Minimum skin buckling load factor,BUCMIN(IS)=  2.4114E+01
 Segment no.1 Minimum isogrid member buckling load factor,
                                               BUCMNS(IS)=  9.8306E-01
 Segment no.1 Maximum stringer (or isogrid member) stress,
                                               STFMXS(IS)=  2.0268E+05
 ISEG,ISOGRD(IS)=    2    1
 Segment no.2 Minimum skin buckling load factor,BUCMIN(IS)=  8.2028E+00
 Segment no.2 Minimum isogrid member buckling load factor,
                                               BUCMNS(IS)=  3.0349E-01
 Segment no.2 Maximum stringer (or isogrid member) stress,
                                               STFMXS(IS)=  4.2003E+05

 Minimum local skin buckling load factor      BUCSKN=  8.2028E+00
 Minimum local stiffener buckling load factor BUCSTF=  3.0349E-01
 Maximum local stiffener stress               STRSTF=  4.2003E+05
 ---------------------------------------------------------------------
```

This modification was implemented by adding new code to SUBROUTINES **WALLCF**, **CFB1**, and **PLOCAL**, as follows:

```
C=DECK      WALLCF              (Integrated constitutive matrix,
(lines skipped to save space)   Cij, i=1,6, j=1,6 computed here)
----------------------------------------------------------------------
C=DECK      CFB1                (smeared stiffener stiffness is
C                                added to the shell skin stiffness)
     STFPRP(1,1,I) = T1 (stringer or isogrid stiffener thickness)
     STFPRP(2,1,I) = H1 (stringer or isogrid stiffener height)
     STFPRP(3,1,I) = D1 (stringer or isogrid stiffener spacing)
     STFPRP(4,1,I) = E1 (stringer or isogrid stiffener modulus)
C
     STFPRP(1,2,I) = T2 (  ring   or isogrid stiffener thickness)
     STFPRP(2,2,I) = H2 (  ring   or isogrid stiffener height)
     STFPRP(3,2,I) = D2 (  ring   or isogrid stiffener spacing)
     STFPRP(4,2,I) = E2 (  ring   or isogrid stiffener modulus)
C
     CSKIN(1,1,I) = C11 (CSKIN = 6 x 6 Cij for shell skin) (I=nodal pt.)
(lines skipped to save space)
C
     IF (ISOGRD(ISEGMT).EQ.0) THEN        (ISOGRD = 1 for isogrid
(lines skipped to save space)                          stiffening)
     ELSE                          (isogrid branch of "IF" follows)
        EEFF = E1*T1/D1            (EEFF = "effective" modulus)
        FNUEFF = 0.3               (Poisson's ratio)
        FNUDEN = 1. - FNUEFF**2
        C11ISO = EEFF*H1/FNUDEN    (CijISO = added wall stiffness from
        C12ISO = FNUEFF*C11ISO               the isogrid stiffeners)
        C22ISO = C11ISO
        C33ISO = EEFF*H1/(2.*(1.+FNUEFF))
        C44ISO = EEFF*H1**3/(12.*FNUDEN)
        C55ISO = C44ISO
        C45ISO = FNUEFF*C44ISO
        C66ISO = C33ISO*H1**2/12.
        SMPA = SMPA + 3.0*STIFMD*A1/D1 + RGMD*A2/D2  (wall mass/area)
        IF (K1.EQ.1) DSHIFT = -(H1/2. + TD - Z)      (internal stiff.)
        IF (K1.EQ.0) DSHIFT = H1/2. + Z              (external stiff.)
        C11 = C11 + C11ISO                (Cij = wall stiffness with
        C22 = C22 + C22ISO                       smeared isogrid)
        C12 = C12 + C12ISO
        C33 = C33 + C33ISO
        C14 = C14 + DSHIFT*C11ISO
        C15 = C15 + DSHIFT*C12ISO
        C24 = C24 + DSHIFT*C12ISO
        C25 = C25 + DSHIFT*C22ISO
        C36 = C36 - DSHIFT*C33ISO
        C44 = C44 + C44ISO + DSHIFT*DSHIFT*C11ISO
        C45 = C45 + C45ISO + DSHIFT*DSHIFT*C12ISO
        C55 = C55 + C55ISO + DSHIFT*DSHIFT*C22ISO
        C66 = C66 + C66ISO + DSHIFT*DSHIFT*C33ISO
      ENDIF
C END SEP 2005
     RETURN
     END

---------------------------------------------------------------------
C=DECK      PLOCAL             (local skin and stiffener stress
(lines skipped to save space)  and buckling load factors are computed
C BEG SEP 2005                 for axisymmetrically deformed shell)
```

```
C new stuff when there are smeared stiffeners...
      IF (I.EQ.1.AND.(ISTSMR(1,IS).NE.0.OR.ISTSMR(2,IS).NE.0)) THEN
         BUCMIN(IS) = 10.E+16        (IS = segment no.; I = nodal pt.)
         BUCMNS(IS) = 10.E+16
         BUCMNR(IS) = 10.E+16
         STFMXS(IS) = 0.
         STFMXR(IS) = 0.
         CALL GASP(STFPRP,800,3,ISTFPR(IS)) (retrieve stiffener
                                             properties and shell skin
         CALL GASP(CSKIN,3600,3,ICSKIN(IS))  stiffnesses)
      ENDIF
C
      IF (I.EQ.1) CALL MOVER(0.,0,FNSKIN,1,200)
      IF (ISTSMR(1,IS).NE.0.OR.ISTSMR(2,IS).NE.0) THEN (IS=segment no.)
C       N1SKIN, N2SKIN are meridional, hoop resultants in the skin...
C       I=nodal point number; EPS1, EPS2, K1, K2 = reference surface
C       meridional and circumferential strains and curvature changes.
         N1SKIN = CSKIN(1,1,I)*EPS1 + CSKIN(1,2,I)*EPS2
     1           +CSKIN(1,4,I)*K1   + CSKIN(1,5,I)*K2
         N2SKIN = CSKIN(1,2,I)*EPS1 + CSKIN(2,2,I)*EPS2
     1           +CSKIN(2,4,I)*K1   + CSKIN(2,5,I)*K2
         FNSKIN(1,I) = N1SKIN
         FNSKIN(2,I) = N2SKIN
         IF (I.EQ.I5.AND.IFIX.EQ.0) CALL GASP(FNSKIN,200,1,INSKIN(1,IS))
         IF (I.EQ.I5.AND.IFIX.EQ.1) CALL GASP(FNSKIN,200,1,INSKIN(2,IS))
C
         STRSTR = 0.
         STRRNG = 0.
         BUCLOD = 10.E+16
         BUCSTR = 10.E+16
         BUCRNG = 10.E+16
C
         IF (ISOGRD(IS).EQ.1.AND.(N1SKIN.LT.0.0.OR.N2SKIN.LT.0.0)) THEN
C
C  Following section is for buckling of shell skin between isogrid.
C  Get buckling load factor for flat equilateral triangular piece of
C  skin. Formula is from NACA TN-3781, July 1957 by Gerard & Becker,
C  "Handbook of Structural Stability, Part I - Buckling of Flat Plates".
C  Formula is for buckling of equilateral flat plate with
C          N1SKIN = N2SKIN (compression).
C  NOTE: result is approximate here because in general N1SKIN is not
C  equal to N2SKIN, and in general the skin is not isotropic.
C
            FCOEF = 5.0
            SIDE = STFPRP(3,1,I)*2./SQRT(3.) (SIDE=length of side of
            PI = 3.1415927                 isogrid equilateral triangle)
C       The critical buckling resultant is NSCRIT.
C                                        BUCLOD = buckling load factor:
            NSCRIT = FCOEF*PI**2*CSKIN(4,4,I)/SIDE**2
            NSMAX  = MIN(N1SKIN,N2SKIN)
            BUCLOD = NSCRIT/ABS(NSMAX)
            BUCMIN(IS) = MIN(BUCMIN(IS),BUCLOD)
(lines skipped to save space)
         ENDIF
C
C  STRSTR = maximum stress in a (smeared) stringer
C           or isogrid member..
```

```
C  BUCMNS = minimum buckling load factor in (smeared) stringer
C           or isogrid member
C  INTEXT(1,IS) = 0 means internal stiffener; 1 means external stif.)
C
        IF (ISTSMR(1,IS).EQ.1.AND.IRECT(1,IS).EQ.1) THEN
           IF (INTEXT(1,IS).EQ.0) ZTIP = -(STFPRP(2,1,I) + Z(I))
           IF (INTEXT(1,IS).EQ.1) ZTIP = STFPRP(2,1,I) + T(I) - Z(I)
           STRTIP = STFPRP(4,1,I)*(EPS1 - ZTIP*K1)  (stress at tip
                                                          of stiff.)
C  Critical buckling load of stiffener. Use formulas from ROARK:
C  FORMULAS FOR STRESS AND STRAIN, 3rd Edition, McGraw-Hill, 1954,
C  Table XVI, p. 312, Formulas 4 (s.s.,free) and 5 (clamped,free).
C  Roark gives: SIGCR = k*[ESTIFF/(1-NUSTIF**2)]*(TSTIFF/HEIGHT)**2
C  in which k is a coefficient that depends on the aspect ratio of the
C  plate (stiffener), For long, uniformly axially compressed plates:
C  a. k= 0.375 if the plate is s.s.( MDC G4295, 4.1.7)
C  b. k= 1.1 if the plate is clamped,free (Roark, Table XVI, Formula 5)
C
           EDGSTF = 0.5
           NUSTIF = 0.3
           SIGCR = (0.375+0.7*EDGSTF)*(STFPRP(4,1,I)/(1.-NUSTIF**2))*
    1                             (STFPRP(1,1,I)/STFPRP(2,1,I))**2
           IF (STRTIP.LT.0.0) THEN
              BUCSTR = SIGCR/ABS(STRTIP)
              BUCMNS(IS) = MIN(BUCMNS(IS),BUCSTR)
           ENDIF
C  INTEXT(1,IS) = 0 means internal stiffener; 1 means external stif.)
           IF (INTEXT(1,IS).EQ.0) ZROOT = -Z(I)
           IF (INTEXT(1,IS).EQ.1) ZROOT =  T(I) - Z(I)
           STRROT = STFPRP(4,1,I)*(EPS1 - ZROOT*K1)
           STRSTR = MAX(ABS(STRTIP),ABS(STRROT))
           STFMXS(IS) = MAX(STFMXS(IS),STRSTR)  (maximum stress in
(lines skipped to save space)                     shell segment IS)
        ENDIF
C
C      STRRNG = maximum stress in a (smeared) ring...
C      BUCMNR = minimum buckling load factor in (smearee) ring
        IF (ISTSMR(2,IS).EQ.1.AND.IRECT(2,IS).EQ.1) THEN
           IF (INTEXT(2,IS).EQ.0) ZTIP = -(STFPRP(2,2,I) + Z(I))
           IF (INTEXT(2,IS).EQ.1) ZTIP = STFPRP(2,2,I) + T(I) - Z(I)
           STRTIP = STFPRP(4,2,I)*(EPS2 - ZTIP*K2)
C
C  Critical buckling load of stiffener. Use formulas from ROARK:
C  FORMULAS FOR STRESS AND STRAIN, 3rd Edition, McGraw-Hill, 1954,
C  Table XVI, p. 312, Formulas 4 (s.s.,free) and 5 (clamped,free).
C  Roark gives: SIGCR = k*[ESTIFF/(1-NUSTIF**2)]*(TSTIFF/HEIGHT)**2
C  in which k is a coefficient that depends on the aspect ratio of the
C  plate (stiffener), For long, uniformly axially compressed plates:
C  a. k= 0.375 if the plate is s.s.( MDC G4295, 4.1.7)
C  b. k= 1.1 if the plate is clamped,free (Roark, Table XVI, Formula 5)
C
           EDGSTF = 0.5
           NUSTIF = 0.3
           SIGCR = (0.375+0.7*EDGSTF)*(STFPRP(4,2,I)/(1.-NUSTIF**2))*
    1                             (STFPRP(1,2,I)/STFPRP(2,2,I))**2
           IF (STRTIP.LT.0.0) THEN
              BUCRNG = SIGCR/ABS(STRTIP)
```

```
              BUCMNR(IS) = MIN(BUCMNR(IS),BUCRNG)
           ENDIF
           IF (INTEXT(2,IS).EQ.0) ZROOT = -Z(I)
           IF (INTEXT(2,IS).EQ.1) ZROOT =  T(I) - Z(I)
           STRROT = STFPRP(4,2,I)*(EPS2 - ZROOT*K2)
           STRRNG = MAX(ABS(STRTIP),ABS(STRROT))
           STFMXR(IS) = MAX(STFMXR(IS),STRRNG)
(lines skipped to save space)
        ENDIF
     ENDIF
C END SEP 2005
=======================================================================
```

Table 28 **Radial coordinates** of shell segment meridional ends (Fig. 2) for the generation of an **"equivalent" ellipsoidal shell** and for the specification of shell skin thicknesses and isogrid stiffener heights for a BIGBOSOR4 model of the shell.

```
=====================================================================
     n         $ Do you want a tutorial session and tutorial output?
       13      $ number of x-coordinates: npoint
       13      $ Number Ixinpu  of rows in the array  xinput: Ixinpu
   0.000000    $ x-coordinates for ends of segments: xinput( 1)
   2.554500    $ x-coordinates for ends of segments: xinput( 2)
   5.666450    $ x-coordinates for ends of segments: xinput( 3)
   8.753630    $ x-coordinates for ends of segments: xinput( 4)
   11.79770    $ x-coordinates for ends of segments: xinput( 5)
   14.77232    $ x-coordinates for ends of segments: xinput( 6)
   17.63477    $ x-coordinates for ends of segments: xinput( 7)
   19.63631    $ x-coordinates for ends of segments: xinput( 8)
   21.26065    $ x-coordinates for ends of segments: xinput( 9)
   22.70426    $ x-coordinates for ends of segments: xinput(10)
   23.86535    $ x-coordinates for ends of segments: xinput(11)
   24.54286    $ x-coordinates for ends of segments: xinput(12)
   24.75000    $ x-coordinates for ends of segments: xinput(13)
   24.75000    $ length of semi-major axis: ainput
   12.37500    $ length of semi-minor axis of ellipse: binput
       11      $ number of nodal points per segment: nodes
   17.63477    $ max. x-coordinate for x-coordinate callouts: xlimit
=====================================================================
```

NOTE: The variable in the last line, xlimit, serves also as the x-coordinate of the junction between meridional Region 1 and Region 2, the two regions where local shell skin stress and local stiffener buckling are computed. (See Fig. 2).

Table 29 Generation of an **"equivalent" ellipsoidal** meridional shape for a BIGBOSOR4 model of this multi-segment shell of revolution (Fig.2). These computations are carried out in SUBROUTINE **x3y3**, which is included with the **bosdec** library listed in Table a15.

```
=====================================================================
c This version of SUBROUTINE BOSDEC is for an "equivalent" ellipsoidal
c head. The "equivalent" ellipsoidal head is constructed because BOSOR4
c (bigbosor4) finite elements tend to "lock up" for shells of revolution
c in which the meridional curvature varies significantly within a single
c shell segment.
c
c The "equivalent" ellipsoidal head consists of a user-defined number of
c toroidal segments that match as well as possible the contour of the
c ellipsoidal head. The meridional curvature of each toroidal segment
c is constant in that segment. Therefore, there is no problem of finite
c element "lock up" in a segmented model of this type.
c
c For each toroidal segment, bigbosor4 needs three points for input:
c (x1,y1), (x2,y2), and (x3,y3). (x1,y1) and (x2,y2) lie on the
c ellipsoidal contour and are the (x,y) coordinates at the two ends of
c the toroidal segment. (x3,y3) is the center of meridional curvature
c of the toroidal segment. The trick is to obtain (x3,y3) so that the
c toroidal segment best fits the ellipsoidal contour in that segment.
c
c We use the following procedure to get (x3,y3):
c
c 1. The equation of the ellipse is
c
c     x^2/a^2 + y^2/b^2 = 1.0                                    (1)
c
c 2. The equation for the normal to the ellipse at (x1,y1) is:
c
c     y - y1 = (y1/x1)(a^2/b^2)(x - x1)                          (2)
c
c 3. The equation for the normal to the ellipse at (x2,y2) is:
c
c     y - y2 = (y2/x2)(a^2/b^2)(x - x2)                          (3)
c
c 4. These two straight lines in (x,y) space intersect at (x03,y03),
c    with (x03,y03) are given by:
c    x03 = (b2 - b1)/(a1 - a2);   y03 = (a2*b1 - a1*b2)/(a2 - a1) (4)
c    in which a1, b1 and a2, b2 are:
c
c     a1 = (y1/x1)(a^2/b^2);      b1 = -a1*x1 + y1               (5)
c     a2 = (y2/x2)(a^2/b^2);      b2 = -a2*x2 + y2               (6)
c
c 5. For an ellipse the distance from the point (x03,y03) to (x1,y1) is
c    different than the distance from the point (x03,y03) to (x2,y2)
c    because the meridional curvature varies along the contour of the
c    ellipse. We wish to find a new point (x3,y3) in the neighborhood
c    of (x03,y03) for which the distance from (x3,y3) to (x1,y1) equals
c    the distance from (x3,y3) to (x2,y2). For such a point the
c    "equivalent" segment will be a toroidal segment in which the
c    meridional curvature is constant along the segment arc.
c
c 6. The square of the distances from (x03,y03) to (x1,y1) and to (x2,y2)
```

```
c    are:
c
c     d1sq = (x1 - x03)**2 + (y1 - y03)**2                        (7)
c     d2sq = (x2 - x03)**2 + (y2 - y03)**2                        (8)
c
c    and the difference of these is:
c
c     delsq = d1sq - d2sq                                          (9)
c
c 7. We determine the location of the center of meridional curvature of
c    the "equivalent" torioidal segment by allocating half of delsq to
c    each (distance)**2, d1sq and d2sq. We then have two (distance)^2
c    that are equal:
c
c     (x1 - x03)**2 + (y1 - y03)**2 - delsq/2                     (10)
c     (x2 - x03)**2 + (y2 - y03)**2 + delsq/2                     (11)
c
c 8. Suppose we let
c
c     x3 = x03 + dx  ;             y3 = y03 + dy                  (12)
c
c    Then we have two nonlinear equations for the unknowns (dx,dy):
c
c    [x1 - (x03+dx)]**2 + [y1 - (y03+dy)]**2 =
c                         (x1 - x03)**2 +(y1 - y03)**2 -delsq/2  (13)
c
c    [x2 - (x03+dx)]**2 + [y2 - (y03+dy)]**2 =
c                         (x2 - x03)**2 +(y2 - y03)**2 +delsq/2  (14)
c
c    These two equations say that the square of the distance from
c    (x3,y3) to (x1,y1) Eq.(13) is equal to that from (x3,y3) to (x2,y2)
c    Eq.(14).
c
c 9. We use Newton's method to solve the two simultaneous nonlinear
c    equations for (dx,dy):
c
c    For the ith Newton iteration, let
c
c     dx(i) = dx(i-1) + u                                         (15)
c     dy(i) = dy(i-1) + v                                         (16)
c
c    Then we develop two linear equations for u and v for the ith
c    Newton iteration:
c
c     u*2.*(x03-x1+dx(i-1)) +v*2.*(y03-y1 +dy(i-1)) = f1pp       (17)
c     u*2.*(x03-x2+dx(i-1)) +v*2.*(y03-y2 +dy(i-1)) = f2pp       (18)
c
c    in which the right-hand sides, f1pp and f2pp, are rather long
c    expressions given in SUBROUTINE x3y3, where the Newton iterations
c    occur.
========================================================================
```

Table 30 Analyses performed in **SUBROUTINE STRUCT** for generation of the behavioral design constraints. This list is abstracted from the file, **eqellipse.OPM**, which presents results for the optimized isogrid-stiffened equivalent ellipsoidal shell: the design identified by the heading, "**isogrid-stiffened**, **imperfect**" in Table 33. The complete eqellipse.OPM file, called "eqellipse.stiffened.opm4", is listed in Table a19 of the appendix. "**eqellipse**" is the "end" user's **specific name** for the case that is a member of the **generic class** called by the GENOPT user: "**equivellipse**".

```
=====================================================================
 ============ Analysis No. 1 for Load Set No. 1 ============
 **** Start linear axisymmetric bifurcation buckling of perfect shell.
 **** The purpose is to get two axisymmetric buckling modal
 **** imperfection shapes: mode 1 and mode 2.
 BIGBOSOR4 input file for linear buckling,perfect shell=
 eqellipse.ALL1
 Input file for SUBROUTINE WALL for STAGS models=
 eqellipse.STAGS
 Linear buckling eigenvalues from BIGBOSOR4, EGV(i)=
  2.8386E+03  3.5262E+03  4.1902E+03  4.3751E+03  5.8141E+03
  6.9852E+03  9.0675E+03  1.0883E+04  1.2440E+04  1.3618E+04
 Linear axisymmetric buckling pressure of perfect shell=  1.3057E+03
 Buckling modal normal displacement w at apex of shell,=  1.0000E+00


 ============ Analysis No. 2 for Load Set No. 1 ============
 *** Start nonlinear axisymmetric stress,+(mode 1) imperfection
 BIGBOSOR4 input file for nonlinear stress,+(mode 1) imperfect=
 eqellipse.ALL2P

 The following quantities are used to generate
 behavioral constraint conditions and margins:
 Region 1 skin buckling load factor,        bskin1=  2.6863E+00
 Region 1 stiffener buckling load factor,   bstif1=  2.9187E+00
 Region 1 skin maximum effective stress,    sknmx1=  8.9086E+04
 Region 1 stiffener max. effective stress,  stfmx1=  8.6190E+04
 Region 2 skin buckling load factor,        bskin2=  2.6893E+00
 Region 2 stiffener buckling load factor,   bstif2=  1.5813E+00
 Region 2 skin maximum effective stress,    sknmx2=  1.0543E+05
 Region 2 stiffener max. effective stress,  stfmx2=  1.2476E+05
 Normal displacement of shell at apex,       ENDUV=  2.8842E-01


 ============ Analysis No. 3 for Load Set No. 1 ============
 *** Start nonlinear axisymmetric stress,+(mode 2) imperfection
 BIGBOSOR4 input file for nonlinear stress,+(mode 2) imperfect=
 eqellipse.ALL4P

 The following quantities are used to generate
 behavioral constraint conditions and margins:
 Region 1 skin buckling load factor,        bskin1=  2.9925E+00
 Region 1 stiffener buckling load factor,   bstif1=  1.8143E+00
 Region 1 skin maximum effective stress,    sknmx1=  8.3974E+04
 Region 1 stiffener max. effective stress,  stfmx1=  1.2255E+05
 Region 2 skin buckling load factor,        bskin2=  3.1488E+00
 Region 2 stiffener buckling load factor,   bstif2=  1.7200E+00
```

```
Region 2 skin maximum effective stress,    sknmx2=  1.1438E+05
Region 2 stiffener max. effective stress,  stfmx2=  1.2331E+05
Normal displacement of shell at apex,       ENDUV=  3.1743E-01
```

============ **Analysis No. 4 for Load Set No. 1** ============

```
** Start nonlinear axisymmetric collpse,+(mode 1) imperfection
BIGBOSOR4 input file, axisymmetric collpse, +mode 1 imperfect=
```
eqellipse.ALL6P

```
Pressure multiplier, P, for all load steps=
 4.6000E+01  9.2000E+01  1.3800E+02  1.8400E+02  2.3000E+02
 2.7600E+02  3.2200E+02  3.6800E+02  4.1400E+02  4.6000E+02
 5.0600E+02  5.5200E+02  5.9800E+02  6.4400E+02  6.9000E+02
 7.3600E+02  7.8200E+02  8.2800E+02  8.3260E+02  8.3720E+02
 8.4180E+02  8.4640E+02  8.5100E+02  8.5560E+02  8.6020E+02
 8.6480E+02  8.6940E+02  8.7400E+02  8.7860E+02  8.8320E+02
 8.8780E+02  8.8826E+02  8.8872E+02  8.8918E+02  8.8964E+02
 8.9010E+02  8.9056E+02  8.9102E+02  8.9148E+02

Collapse pressure with +(mode 1): PSTEP(ISTEP)= 8.9148E+02

The following quantity is used to generate the
behavioral constraint condition and margin:
Collapse pressure with mode 1: CLAPS1(ILOADX)=  8.9148E+02
```

============ **Analysis No. 5 for Load Set No. 1** ============

```
** Start nonlinear axisymmetric collpse,+(mode 2) imperfection
BIGBOSOR4 input file, axisymmetric collpse, +mode 2 imperfect=
```
eqellipse.ALL7P

```
Pressure multiplier, P, for all load steps=
 4.6000E+01  9.2000E+01  1.3800E+02  1.8400E+02  2.3000E+02
 2.7600E+02  3.2200E+02  3.6800E+02  4.1400E+02  4.6000E+02
 5.0600E+02  5.5200E+02  5.9800E+02  6.4400E+02  6.9000E+02
 7.3600E+02  7.8200E+02  8.2800E+02  8.7400E+02  9.2000E+02

Collapse pressure with +(mode 2): PSTEP(ISTEP)= 9.2000E+02

The following quantity is used to generate the
behavioral constraint condition and margin:
Collapse pressure with mode 2: CLAPS2(ILOADX)=  9.2000E+02
```

============ **Analysis No. 6 for Load Set No. 1** ============

```
** Start nonlinear bifurcation buckling,+(mode 1) imperfection
BIGBOSOR4 input file, bifurcation buckling, +(mode 1) imperf.=
```
eqellipse.ALL8P

```
Overall buckling, +(mode 1) imperfection shape;
Applied pressure, PMAX =  4.6000E+02
Nonlinear bifurcation buckling pressure,
                                  BUCPRSP(circ.waves)=1.1908E+03(2)
General bifurcation buckling load factor, GENBK1(ILOADX)=2.5888E+00
```

```
============ Analysis No. 7 for Load Set No. 1 ============
** Start nonlinear bifurcation buckling,+(mode 2) imperfection
BIGBOSOR4 input file, bifurcation buckling, +(mode 2) imperf.=
eqellipse.ALL9P

Overall buckling, +(mode 2) imperfection shape;
Applied pressure, PMAX =  4.6000E+02
Nonlinear bifurcation buckling pressure,
                                  BUCPRSP(circ.waves)=1.2336E+03(2)
General bifurcation buckling load factor, GENBK2(ILOADX)=2.6818E+00
====================================================================
```

TO BE ESPECIALLY NOTED: The file names in bold face, such as **eqellipse.ALL1** (in general *.**ALL***) are valid input files for BIGBOSOR4 (or BOSOR4). Any of these *.**ALL*** files can be used as input to BIGBOSOR4 (or BOSOR4) in independent BIGBOSOR4 executions to produce results corresponding to the type of analysis under which they were created. For example, **after completion of a GENOPT mainprocessor run (command = "OPTIMIZE" and only with analysis type, ITYPE = 2 in the *.OPT file),** corresponding to Analysis No. 1 the user can copy the **eqellipse.ALL1** file from the directory where the user is running GENOPT to a different directory where he or she wants to run BIGBOSOR4 (or BOSOR4), for example:

cp …/genoptcase/**eqellipse.ALL1** …/bigbosor4case/**eqellipse.ALL**

The user then types the commands: **bigbosor4log** and **bigbosorall** with the use of the file, **eqellipse.ALL**, as the input data. In this way one can obtain bigbosor4 type output and plots. The **eqellipse.ALL1** file used in the example just given contains input data for Analysis No. 1 (linear axisymmetric bifurcation buckling of perfect shell). After the execution of **bigbosorall**, one can then type **bosorplot** to obtain plots such as those shown in Figs. 4 and 5. Any of the other *.**ALL*** files works the same way.

The file, **eqellipse.STAGS**, is the same as the **WALLTHICK.STAGS** file, such as that listed in Table a23. WALLTHICK.STAGS must be used as input data for any STAGS models that require the user-written **SUBROUTINE WALL** (Tables a20 – a22 of [26]) or the user-written **SUBROUTINE USRFAB** (Tables a34 – a36 of [26]). (See Table a36 in the appendix of this paper, for example).

Table 31 Optimized **imperfect isogrid-stiffened** equivalent elliposidal shell. Design margins from Load Set 1 **(+mode 1 and +mode 2 imperfection shapes)** corresponding to the design optimized with the use of only mode 1 and mode 2 imperfection shapes. These margins are developed via the seven analyses of the type listed in the previous table. Critical margins = **bold**

```
 A typical margin with the meanings of the indices, a, b, c, d, e,
 explained:
                                  a             b
 5  1.919E+00  (STFBK1(1,1)/STFBK1A(1,1))/STFBK1F(1,1)-1; F.S.= 1.00
                    c d e       c  d e        c  d e

         "STFBK" means "Stiffener buckling"
     a = "A" means "Allowable value"
     b = "F" means "Factor of safety"
     c = Imperfection mode number, (1 or 2 in the cases explored here)
     d = Load set number (1 or 2 in the cases explored here)
          Load set 1 means "use +mode 1 and +mode 2 imperfection shapes"
          Load set 2 means "use -mode 1 and -mode 2 imperfection shapes"
     e = Region number:
           (1 or 2 Region 1 is from the axis of revolution to xlimit,
                            that is, 0 < x < xlimit.
                   Region 2 is from xlimit to the equator,
                            that is, xlimit < x < semi-major axis.)
```

*** RESULTS FOR LOAD SET NO. 1 (+mode 1 and +mode 2 imperfections) ***
MARGINS CORRESPONDING TO CURRENT DESIGN (F.S.= FACTOR OF SAFETY)

MARGIN NO.	CURRENT VALUE	DEFINITION
1	6.209E-01	(CLAPS1(1)/CLAPS1A(1)) / CLAPS1F(1)-1; F.S.= 1.00
2	1.589E+00	(GENBK1(1)/GENBK1A(1)) / GENBK1F(1)-1; F.S.= 1.00
3	1.686E+00	(SKNBK1(1,1)/SKNBK1A(1,1))/SKNBK1F(1,1)-1; F.S.= 1.00
4	1.689E+00	(SKNBK1(1,2)/SKNBK1A(1,2))/SKNBK1F(1,2)-1; F.S.= 1.00
5	1.919E+00	(STFBK1(1,1)/STFBK1A(1,1))/STFBK1F(1,1)-1; F.S.= 1.00
6	5.813E-01	(STFBK1(1,2)/STFBK1A(1,2))/STFBK1F(1,2)-1; F.S.= 1.00
7	3.470E-01	(SKNST1A(1,1)/SKNST1(1,1))/SKNST1F(1,1)-1; F.S.= 1.00
8	**1.382E-01**	**(SKNST1A(1,2)/SKNST1(1,2))/SKNST1F(1,2)-1; F.S.= 1.00**
9	3.923E-01	(STFST1A(1,1)/STFST1(1,1))/STFST1F(1,1)-1; F.S.= 1.00
10	**-3.816E-02**	**(STFST1A(1,2)/STFST1(1,2))/STFST1F(1,2)-1; F.S.= 1.00**
11	1.427E+00	(WAPEX1A(1)/WAPEX1(1)) / WAPEX1F(1)-1; F.S.= 1.00
12	6.727E-01	(CLAPS2(1)/CLAPS2A(1)) / CLAPS2F(1)-1; F.S.= 1.00
13	1.682E+00	(GENBK2(1)/GENBK2A(1)) / GENBK2F(1)-1; F.S.= 1.00
14	1.992E+00	(SKNBK2(1,1)/SKNBK2A(1,1))/SKNBK2F(1,1)-1; F.S.= 1.00
15	2.149E+00	(SKNBK2(1,2)/SKNBK2A(1,2))/SKNBK2F(1,2)-1; F.S.= 1.00
16	8.143E-01	(STFBK2(1,1)/STFBK2A(1,1))/STFBK2F(1,1)-1; F.S.= 1.00
17	7.200E-01	(STFBK2(1,2)/STFBK2A(1,2))/STFBK2F(1,2)-1; F.S.= 1.00
18	4.290E-01	(SKNST2A(1,1)/SKNST2(1,1))/SKNST2F(1,1)-1; F.S.= 1.00
19	**4.917E-02**	**(SKNST2A(1,2)/SKNST2(1,2))/SKNST2F(1,2)-1; F.S.= 1.00**
20	**-2.078E-02**	**(STFST2A(1,1)/STFST2(1,1))/STFST2F(1,1)-1; F.S.= 1.00**
21	**-2.687E-02**	**(STFST2A(1,2)/STFST2(1,2))/STFST2F(1,2)-1; F.S.= 1.00**
22	1.205E+00	(WAPEX2A(1)/WAPEX2(1)) / WAPEX2F(1)-1; F.S.= 1.00

Table 32 Optimized imperfect isogrid-stiffened equivalent elliposidal shell. Design margins from Load Set 2 **(-mode 1 and -mode 2 imperfection shapes)** corresponding to the design optimized with the use of only mode 1 and mode 2 imperfection shapes. These margins are developed via the seven analyses of the type listed in Table 30. Critical margins are in **bold.**

```
=======================================================================
 A typical margin with the meanings of the indices, a, b, c, d, e,
 explained:
                      a                          b
 8  4.979E-02  (SKNST1A(2,2)/SKNST1(2,2))/SKNST1F(2,2)-1; F.S.= 1.00
                     c  d e       c d e        c  d e

         "SKNST" means "Skin effective stress"
     a = "A" means "Allowable value"
     b = "F" means "Factor of safety"
     c = Imperfection mode number, (1 or 2 in the cases explored here)
     d = Load set number (1 or 2 in the cases explored here)
          Load set 1 means "use +mode 1 and +mode 2 imperfection shapes"
          Load set 2 means "use -mode 1 and -mode 2 imperfection shapes"
     e = Region number:
           (1 or 2 Region 1 is from the axis of revolution to xlimit,
                            that is, 0 < x < xlimit.
                   Region 2 is from xlimit to the equator,
                            that is, xlimit < x < semi-major axis.)

 *** RESULTS FOR LOAD SET NO. 2 (-mode 1 and -mode 2 imperfections) ***
 MARGINS CORRESPONDING TO CURRENT DESIGN (F.S.= FACTOR OF SAFETY)
 MARGIN CURRENT
 NO.     VALUE           DEFINITION
  1    2.455E-02  (CLAPS1(2 )/CLAPS1A(2 )) / CLAPS1F(2 )-1; F.S.=  1.00
  2    5.860E-01  (GENBK1(2 )/GENBK1A(2 )) / GENBK1F(2 )-1; F.S.=  1.00
  3    2.168E+00  (SKNBK1(2,1)/SKNBK1A(2,1))/SKNBK1F(2,1)-1; F.S.= 1.00
  4    2.298E+00  (SKNBK1(2,2)/SKNBK1A(2,2))/SKNBK1F(2,2)-1; F.S.= 1.00
  5    1.477E-01  (STFBK1(2,1)/STFBK1A(2,1))/STFBK1F(2,1)-1; F.S.= 1.00
  6    3.683E-01  (STFBK1(2,2)/STFBK1A(2,2))/STFBK1F(2,2)-1; F.S.= 1.00
  7   -4.325E-03  (SKNST1A(2,1)/SKNST1(2,1))/SKNST1F(2,1)-1; F.S.= 1.00
  8    4.979E-02  (SKNST1A(2,2)/SKNST1(2,2))/SKNST1F(2,2)-1; F.S.= 1.00
  9    2.005E-02  (STFST1A(2,1)/STFST1(2,1))/STFST1F(2,1)-1; F.S.= 1.00
 10   -1.268E-02  (STFST1A(2,2)/STFST1(2,2))/STFST1F(2,2)-1; F.S.= 1.00
 11    3.043E-01  (WAPEX1A(2 )/WAPEX1(2 )) / WAPEX1F(2 )-1; F.S.=  1.00

 12    6.727E-01  (CLAPS2(2 )/CLAPS2A(2 )) / CLAPS2F(2 )-1; F.S.=  1.00
 13    1.151E+00  (GENBK2(2 )/GENBK2A(2 )) / GENBK2F(2 )-1; F.S.=  1.00
 14    1.790E+00  (SKNBK2(2,1)/SKNBK2A(2,1))/SKNBK2F(2,1)-1; F.S.= 1.00
 15    1.791E+00  (SKNBK2(2,2)/SKNBK2A(2,2))/SKNBK2F(2,2)-1; F.S.= 1.00
 16    7.854E-02  (STFBK2(2,1)/STFBK2A(2,1))/STFBK2F(2,1)-1; F.S.= 1.00
 17    1.232E+00  (STFBK2(2,2)/STFBK2A(2,2))/STFBK2F(2,2)-1; F.S.= 1.00
 18    1.558E-01  (SKNST2A(2,1)/SKNST2(2,1))/SKNST2F(2,1)-1; F.S.= 1.00
 19    1.423E-01  (SKNST2A(2,2)/SKNST2(2,2))/SKNST2F(2,2)-1; F.S.= 1.00
 20   -1.639E-02  (STFST2A(2,1)/STFST2(2,1))/STFST2F(2,1)-1; F.S.= 1.00
 21   -3.856E-02  (STFST2A(2,2)/STFST2(2,2))/STFST2F(2,2)-1; F.S.= 1.00
 22    5.771E-01  (WAPEX2A(2 )/WAPEX2(2 )) / WAPEX2F(2 )-1; F.S.=  1.00
=======================================================================
```

Table 33 Four optimized “equivalent” ellipsoidal shells: values of the decision variables and the weight of the shells after possibly multiple executions of SUPEROPT. Dimensions are in inches. The optimum designs listed here were obtained with the use of only mode 1 and mode 2 axisymmetric imperfections.

	isogrid-stiffened, imperfect		**isogrid-stiffened, perfect**		**unstiffened, imperfect***	**unstiffened, perfect**
xinput Table 28	skin thickness	isogrid height	skin thickness	isogrid height	skin thickness	skin thickness
0.	0.12453	0.66766	0.14020	0.59807	0.61996	0.35820
2.554500	0.16641	0.60783	0.14166	0.85281	0.61996	0.28972
5.666450	0.14460	0.97928	0.10000	0.50387	0.41122	0.34052
8.753630	0.16082	1.2562	0.11349	0.79681	0.40594	0.21352
11.79770	0.10412	1.1540	0.10000	0.68664	0.39622	0.26590
14.77232	0.10000	0.80422	0.10160	1.0421	0.37653	0.20147
17.63477	0.10162	1.2686	0.10000	0.55000	0.29665	0.25367
19.63631	0.13795	0.88339	0.11191	0.55488	0.28323	0.19872
21.26065	0.10201	0.70560	0.10000	0.39187	0.30991	0.18310
22.70426	0.10411	0.58445	0.11417	0.35828	0.27282	0.15937
23.86535	0.19869	0.51581	0.10569	0.23963	0.24117	0.14621
24.54286	0.10000	0.34417	0.15146	0.33231	0.16825	0.13888
24.75000	0.19779	0.46660	0.10822	0.27718	0.28315	0.14864
	isogrid stiffener thickness	isogrid spacing	isogrid stiffener thickness	isogrid spacing	NOTE: This is the “**thick apex**” shell	
	0.090531	2.9154	0.05834	2.8884	(Section 9.3)	
shell weight	86.101 lb		60.952 lb		132.5 lb	85.352 lb

* These are the thicknesses and shell weight for the optimum design with the **thick apex**, t(apex) = 0.61996 inch, taken from **Table 93** in the long report [26]. The optimum design was obtained with use of a **lower bound** for the thickness at the shell apex, THKSKN(1) **equal to 0.6 inch** and the thickness at the junction between Shell Segment 1 and Shell Segment 2, THKSKN(2), linked to THKSKN(1), so that the thickness of Shell Segment 1 (Fig. 2) is uniform. In contrast, Table 33 in the long report [26] has for this column, “unstiffened, imperfect”, the thickness distribution and shell weight for the optimized shell for which the thicknesses at the shell apex, THKSKN(1), and the thickness at the junction between Shell Segment 1 and Shell Segment 2, THKSKN(2), are both decision variables and both have a **lower bound equal to 0.1 inch.** The thicknesses, THKSKN(i), i=1,13 (in inches), of the optimum design in Table 33 of [26] are as follows:
0.2269, 0.1575, **0.5991**, 0.3050, 0.2672, 0.2456, 0.2553, 0.1862, 0.2059, 0.1646, 0.1789, 0.1437, 0.1771. The **unstiffened, imperfect** shell listed in Table 33 of the long report [26] is significantly **under-designed** because it will collapse at a very low external pressure (Fig. 94) if it happens to have a **non-axisymmetric** initial imperfection, a type of imperfection for which it was not designed in the particular application of GENOPT described in this paper. In this paper optimum designs of shells with **only axisymmetric imperfections** can be obtained because **BIGBOSOR4 cannot handle shells of revolution with non-axisymmetric initial imperfections.** In the presence of only axisymmetric imperfections the unstiffened, imperfect shell optimized as dictated by the input for the “DECIDE” processor listed in Table 57 of [26] develops a locally thick circumferential band at xinput = 5.666 inches, THKSKN(3)=**0.5991** inch. The effect of this thick circumferential band is to isolate the apex from the remainder of the shell, leading to axisymmetric buckling modal imperfection shapes such as those displayed in Figs. 74 and 75.

Table 34 A possible **run stream** for obtaining an optimum design and other information. This information appears in the file called *.DEF, in which "*" represents the generic case name, for example, "equivellipse", in this application of GENOPT. A list of the equivellipse.DEF file appears in Table a2 of the appendix. Note: **The preferred method to obtain optimum designs is to use SUPEROPT rather than multiple executions of OPTIMIZE.**

```
===============================================================
     A typical runstream is:
C       GENOPTLOG   (activate command set)
C       BEGIN       (provide starting design, loads, etc.)
C       DECIDE      (choose decision variables and bounds)
C       MAINSETUP   (choose print option and analysis type)
C       OPTIMIZE    (launch batch run for n design iterations)
C       OPTIMIZE    (launch batch run for n design iterations)
C       OPTIMIZE    (launch batch run for n design iterations)
C       OPTIMIZE    (launch batch run for n design iterations)
C       OPTIMIZE    (launch batch run for n design iterations)
C       CHANGE      (change some variables for new starting pt)
C       OPTIMIZE    (launch batch run for n design iterations)
C       OPTIMIZE    (launch batch run for n design iterations)
C       OPTIMIZE    (launch batch run for n design iterations)
C       OPTIMIZE    (launch batch run for n design iterations)
C       OPTIMIZE    (launch batch run for n design iterations)
C       CHOOSEPLOT  (choose which variables to plot)
C       DIPLOT      (plot variables v. iterations)
C       CHOOSEPLOT  (choose additional variables to plot)
C       DIPLOT      (plot more variables v design iterations)
C       CLEANSPEC   (delete extraneous files for specific case)

C  IMPORTANT:  YOU MUST ALWAYS GIVE THE COMMAND "OPTIMIZE"
C              SEVERAL TIMES IN SUCCESSION IN ORDER TO OBTAIN
C              CONVERGENCE! AN EXPLANATION OF WHY YOU MUST DO
C              THIS IS GIVEN ON P 580-582 OF THE PAPER "PANDA2,
C              PROGRAM FOR MINIMUM WEIGHT DESIGN OF STIFFENED,
C              COMPOSITE LOCALLY BUCKLED PANELS", Computers and
C              Structures, Vol. 25, No. 4, pp 469-605 (1987).

C Due to introduction of a "global" optimizer, SUPEROPT,
C described in the paper, Bushnell, D., "Recent enhancements to
C PANDA2", AIAA paper 96-1337-CP, Proc. 37th AIAA SDM Meeting,
C April 1996 pp. 126-182, in particular, pp. 127-130, you can
C now use the runstream

C      BEGIN       (provide starting design, loads, etc.)
C      DECIDE      (choose decision variables and bounds)
C      MAINSETUP   (choose print option and analysis type)
C      SUPEROPT    (launch batch run for "global" optimization)
C      CHOOSEPLOT  (choose which variables to plot)
C      DIPLOT      (plot variables v. iterations)

C "Global" is in quotes because SUPEROPT does its best to find
C a true global optimum design. The user is strongly urged to
C execute SUPEROPT/CHOOSEPLOT several times in succession in
C order to determine an optimum that is essentially just as
C good as the theoretical true global optimum. Each execution
```

```
C of the series,
C
C      SUPEROPT
C      CHOOSEPLOT

C does the following:

C 1. SUPEROPT executes many sets of the two processors,
C    OPTIMIZE and AUTOCHANGE (AUTOCHANGE gets a new random
C    "starting" design), in which each set does the following:

C      OPTIMIZE          (perform k design iterations)
C      OPTIMIZE          (perform k design iterations)
C      OPTIMIZE          (perform k design iterations)
C      OPTIMIZE          (perform k design iterations)
C      OPTIMIZE          (perform k design iterations)
C      AUTOCHANGE        (get new starting design randomly)

C    SUPEROPT keeps repeating the above sequence until the
C    total number of design iterations reaches about 470.
C    The number of OPTIMIZEs per AUTOCHANGE is user-provided.

C 2. CHOOSEPLOT allows the user to plot stuff and resets the
C    total number of design iterations from SUPEROPT to zero.
C    After each execution of SUPEROPT the user MUST execute
C    CHOOSEPLOT: before the next execution of SUPEROPT the
C    total number of design iterations MUST be reset to zero.
=================================================================
```

Table 35 Input file, ***.BEG**, for the "**BEGIN**" processor for an **imperfect isogrid-stiffened equivalent ellipsoidal shell** in which there are two load sets:
Load set 1=+mode 1 and +mode 2 axisymmetric imperfections, one at a time
Load set 2=-mode 1 and -mode 2 axisymmetric imperfections, one at a time
In the directory, /home/progs/genopt/case/torisph, the input file name is "eqellipse.stiffened.BEG". Copy this file to /home/progs/genoptcase and change the case name from "eqellipse.stiffened" to "eqellipse" before processing. The shell has an initial imperfection with amplitude, Wimp= (+ or -) 0.2 inch. **(/home/progs = the directory where the GENOPT system is stored on the writer's computer).**

```
=============================================================================
     n      $ Do you want a tutorial session and tutorial output?
       13   $ number of x-coordinates: npoint
       13   $ Number Ixinpu  of rows in the array  xinput: Ixinpu
  0.000000  $ x-coordinates for ends of segments: xinput( 1)
  2.554500  $ x-coordinates for ends of segments: xinput( 2)
  5.666450  $ x-coordinates for ends of segments: xinput( 3)
  8.753630  $ x-coordinates for ends of segments: xinput( 4)
  11.79770  $ x-coordinates for ends of segments: xinput( 5)
  14.77232  $ x-coordinates for ends of segments: xinput( 6)
  17.63477  $ x-coordinates for ends of segments: xinput( 7)
  19.63631  $ x-coordinates for ends of segments: xinput( 8)
  21.26065  $ x-coordinates for ends of segments: xinput( 9)
  22.70426  $ x-coordinates for ends of segments: xinput(10)
  23.86535  $ x-coordinates for ends of segments: xinput(11)
  24.54286  $ x-coordinates for ends of segments: xinput(12)
  24.75000  $ x-coordinates for ends of segments: xinput(13)
  24.75000  $ length of semi-major axis: ainput
  12.37500  $ length of semi-minor axis of ellipse: binput
       11   $ number of nodal points per segment: nodes
  17.63477  $ max. x-coordinate for x-coordinate callouts: xlimit
 0.4000000  $ skin thickness at xinput: THKSKN( 1)
 0.4000000  $ skin thickness at xinput: THKSKN( 2)
 0.4000000  $ skin thickness at xinput: THKSKN( 3)
 0.4000000  $ skin thickness at xinput: THKSKN( 4)
 0.4000000  $ skin thickness at xinput: THKSKN( 5)
 0.4000000  $ skin thickness at xinput: THKSKN( 6)
 0.4000000  $ skin thickness at xinput: THKSKN( 7)
 0.4000000  $ skin thickness at xinput: THKSKN( 8)
 0.4000000  $ skin thickness at xinput: THKSKN( 9)
 0.4000000  $ skin thickness at xinput: THKSKN(10)
 0.4000000  $ skin thickness at xinput: THKSKN(11)
 0.4000000  $ skin thickness at xinput: THKSKN(12)
 0.4000000  $ skin thickness at xinput: THKSKN(13)
  1.000000  $ height of isogrid members at xinput: HIGHST( 1)
  1.000000  $ height of isogrid members at xinput: HIGHST( 2)
  1.000000  $ height of isogrid members at xinput: HIGHST( 3)
  1.000000  $ height of isogrid members at xinput: HIGHST( 4)
  1.000000  $ height of isogrid members at xinput: HIGHST( 5)
  1.000000  $ height of isogrid members at xinput: HIGHST( 6)
  1.000000  $ height of isogrid members at xinput: HIGHST( 7)
  1.000000  $ height of isogrid members at xinput: HIGHST( 8)
  1.000000  $ height of isogrid members at xinput: HIGHST( 9)
  1.000000  $ height of isogrid members at xinput: HIGHST(10)
  1.000000  $ height of isogrid members at xinput: HIGHST(11)
  1.000000  $ height of isogrid members at xinput: HIGHST(12)
```

```
 1.000000  $ height of isogrid members at xinput: HIGHST(13)
 3.000000  $ spacing of the isogrid members: SPACNG
0.1000000  $ thickness of an isogrid stiffening member: THSTIF
0.2000000  $ thickness of the cylindrical shell: THKCYL
 24.75000  $ radius of the cylindrical shell: RADCYL
 0.000000  $ length of the cylindrical segment: LENCYL
0.2000000  $ amplitude of the axisymmetric imperfection: WIMP
0.1600E+08 $ elastic modulus: EMATL
0.2500     $ Poisson ratio of material: NUMATL
0.4155E-03 $ mass density of material: DNMATL
       2   $ strategy control for imperfection shapes: IMODE
       2   $ Number NCASES  of load cases (environments): NCASES
 460.0000  $ uniform external pressure: PRESS( 1)
 460.0000  $ uniform external pressure: PRESS( 2)
 550.0000  $ allowable pressure for axisymmetric collapse: CLAPS1A(1)
 550.0000  $ allowable pressure for axisymmetric collapse: CLAPS1A(2)
 1.000000  $ factor of safety for axisymmetric collapse: CLAPS1F(1)
 1.000000  $ factor of safety for axisymmetric collapse: CLAPS1F(2)
 1.000000  $ allowable general buckling load factor (use 1.0):GENBK1A(1)
 1.000000  $ allowable general buckling load factor (use 1.0):GENBK1A(2)
 1.000000  $ factor of safety for general buckling: GENBK1F( 1)
 1.000000  $ factor of safety for general buckling: GENBK1F( 2)
       2   $ Number JSKNBK1 of columns in the array, SKNBK1: JSKNBK1
 1.000000  $ allowable buckling load factor: SKNBK1A( 1, 1)
 1.000000  $ allowable buckling load factor: SKNBK1A( 2, 1)
 1.000000  $ allowable buckling load factor: SKNBK1A( 1, 2)
 1.000000  $ allowable buckling load factor: SKNBK1A( 2, 2)
 1.000000  $ factor of safety for skin buckling: SKNBK1F( 1, 1)
 1.000000  $ factor of safety for skin buckling: SKNBK1F( 2, 1)
 1.000000  $ factor of safety for skin buckling: SKNBK1F( 1, 2)
 1.000000  $ factor of safety for skin buckling: SKNBK1F( 2, 2)
 1.000000  $ allowable for isogrid stiffener buckling: STFBK1A( 1, 1)
 1.000000  $ allowable for isogrid stiffener buckling: STFBK1A( 2, 1)
 1.000000  $ allowable for isogrid stiffener buckling: STFBK1A( 1, 2)
 1.000000  $ allowable for isogrid stiffener buckling: STFBK1A( 2, 2)
 1.000000  $ factor of safety, isogrid stiffener buckling: STFBK1F(1,1)
 1.000000  $ factor of safety, isogrid stiffener buckling: STFBK1F(2,1)
 1.000000  $ factor of safety, isogrid stiffener buckling: STFBK1F(1,2)
 1.000000  $ factor of safety, isogrid stiffener buckling: STFBK1F(2,2)
 120000.0  $ allowable stress for the shell skin: SKNST1A( 1, 1)
 120000.0  $ allowable stress for the shell skin: SKNST1A( 2, 1)
 120000.0  $ allowable stress for the shell skin: SKNST1A( 1, 2)
 120000.0  $ allowable stress for the shell skin: SKNST1A( 2, 2)
 1.000000  $ factor of safety for skin stress: SKNST1F( 1, 1)
 1.000000  $ factor of safety for skin stress: SKNST1F( 2, 1)
 1.000000  $ factor of safety for skin stress: SKNST1F( 1, 2)
 1.000000  $ factor of safety for skin stress: SKNST1F( 2, 2)
 120000.0  $ allowable stress in isogrid stiffeners: STFST1A( 1, 1)
 120000.0  $ allowable stress in isogrid stiffeners: STFST1A( 2, 1)
 120000.0  $ allowable stress in isogrid stiffeners: STFST1A( 1, 2)
 120000.0  $ allowable stress in isogrid stiffeners: STFST1A( 2, 2)
 1.000000  $ factor of safety for stress in isogrid member: STFST1F(1,1)
 1.000000  $ factor of safety for stress in isogrid member: STFST1F(2,1)
 1.000000  $ factor of safety for stress in isogrid member: STFST1F(1,2)
 1.000000  $ factor of safety for stress in isogrid member: STFST1F(2,2)
0.7000000  $ allowable normal (axial) displacement at apex: WAPEX1A( 1)
0.7000000  $ allowable normal (axial) displacement at apex: WAPEX1A( 2)
```

```
 1.000000  $ factor of safety for WAPEX: WAPEX1F( 1)
 1.000000  $ factor of safety for WAPEX: WAPEX1F( 2)
 550.0000  $ allowable pressure for axisymmetric collapse: CLAPS2A( 1)
 550.0000  $ allowable pressure for axisymmetric collapse: CLAPS2A( 2)
 1.000000  $ factor of safety for axisymmetric collapse: CLAPS2F( 1)
 1.000000  $ factor of safety for axisymmetric collapse: CLAPS2F( 2)
 1.000000  $ allowable general buckling load factor (use 1.0):GENBK2A(1)
 1.000000  $ allowable general buckling load factor (use 1.0):GENBK2A(2)
 1.000000  $ factor of safety for general buckling: GENBK2F( 1)
 1.000000  $ factor of safety for general buckling: GENBK2F( 2)
       2   $ Number JSKNBK2 of columns in the array, SKNBK2: JSKNBK2
 1.000000  $ allowable skin buckling load factor (use 1.0):SKNBK2A(1,1)
 1.000000  $ allowable skin buckling load factor (use 1.0):SKNBK2A(2,1)
 1.000000  $ allowable skin buckling load factor (use 1.0):SKNBK2A(1,2)
 1.000000  $ allowable skin buckling load factor (use 1.0):SKNBK2A(2,2)
 1.000000  $ factor of safety for local skin buckling: SKNBK2F( 1, 1)
 1.000000  $ factor of safety for local skin buckling: SKNBK2F( 2, 1)
 1.000000  $ factor of safety for local skin buckling: SKNBK2F( 1, 2)
 1.000000  $ factor of safety for local skin buckling: SKNBK2F( 2, 2)
 1.000000  $ allowable for isogrid stiffener buckling: STFBK2A(1,1)
 1.000000  $ allowable for isogrid stiffener buckling: STFBK2A(2,1)
 1.000000  $ allowable for isogrid stiffener buckling: STFBK2A(1,2)
 1.000000  $ allowable for isogrid stiffener buckling: STFBK2A(2,2)
 1.000000  $ factor of safety, isogrid stiffener buckling: STFBK2F(1,1)
 1.000000  $ factor of safety, isogrid stiffener buckling: STFBK2F(2,1)
 1.000000  $ factor of safety, isogrid stiffener buckling: STFBK2F(1,2)
 1.000000  $ factor of safety, isogrid stiffener buckling: STFBK2F(2,2)
 120000.0  $ allowable stress for the shell skin: SKNST2A( 1, 1)
 120000.0  $ allowable stress for the shell skin: SKNST2A( 2, 1)
 120000.0  $ allowable stress for the shell skin: SKNST2A( 1, 2)
 120000.0  $ allowable stress for the shell skin: SKNST2A( 2, 2)
 1.000000  $ factor of safety for skin stress: SKNST2F( 1, 1)
 1.000000  $ factor of safety for skin stress: SKNST2F( 2, 1)
 1.000000  $ factor of safety for skin stress: SKNST2F( 1, 2)
 1.000000  $ factor of safety for skin stress: SKNST2F( 2, 2)
 120000.0  $ allowable stress in isogrid stiffeners: STFST2A( 1, 1)
 120000.0  $ allowable stress in isogrid stiffeners: STFST2A( 2, 1)
 120000.0  $ allowable stress in isogrid stiffeners: STFST2A( 1, 2)
 120000.0  $ allowable stress in isogrid stiffeners: STFST2A( 2, 2)
 1.000000  $ factor of safety for stress in isogrid member: STFST2F(1,1)
 1.000000  $ factor of safety for stress in isogrid member: STFST2F(2,1)
 1.000000  $ factor of safety for stress in isogrid member: STFST2F(1,2)
 1.000000  $ factor of safety for stress in isogrid member: STFST2F(2,2)
0.7000000  $ allowable normal (axial) displacement at apex: WAPEX2A( 1)
0.7000000  $ allowable normal (axial) displacement at apex: WAPEX2A( 2)
 1.000000  $ factor of safety for WAPEX: WAPEX2F( 1)
 1.000000  $ factor of safety for WAPEX: WAPEX2F( 2)
```

Table 36 Input data, ***.DEC**, for "**DECIDE**" for the **isogrid-stiffened equivalent ellipsoidal shell.** This file is called "eqellipse.stiffened.DEC". In the directory, /home/progs/genopt/case/torisph, the input file name is "eqellipse.stiffened.DEC". Copy this file to /home/progs/genoptcase and change the case name from "eqellipse.stiffened" to "eqellipse" before processing. **(/home/progs = the directory where the GENOPT system is stored on the writer's computer).**

NOTE: In the case of an **unstiffened, imperfect** shell, the optimization problem as formulated here leads to a severely under-designed shell, as is demonstrated by the results shown in Fig. 94. A much better formulation of the optimization problem for **unstiffened, imperfect** shells is listed in Table 77 of [26], in particular, see Section 9.3 where the lower bound of THKSKN(1) = 0.6 inch and where THKSKN(2) is linked to THKSKN(1). **THIS NOTE APPLIES ONLY TO UNSTIFFENED, IMPERFECT SHELLS.**

```
=====================================================================
      n         $ Do you want a tutorial session and tutorial output?
         1      $ Choose a decision variable (1,2,3,...)     THKSKN( 1)
  0.1000000     $ Lower bound of variable no.( 1)
   1.000000     $ Upper bound of variable no.( 1)
      y         $ Any more decision variables (Y or N) ?
         2      $ Choose a decision variable (1,2,3,...)     THKSKN( 2)
  0.1000000     $ Lower bound of variable no.( 2)
   1.000000     $ Upper bound of variable no.( 2)
      y         $ Any more decision variables (Y or N) ?
         3      $ Choose a decision variable (1,2,3,...)     THKSKN( 3)
  0.1000000     $ Lower bound of variable no.( 3)
   1.000000     $ Upper bound of variable no.( 3)
      y         $ Any more decision variables (Y or N) ?
         4      $ Choose a decision variable (1,2,3,...)     THKSKN( 4)
  0.1000000     $ Lower bound of variable no.( 4)
   1.000000     $ Upper bound of variable no.( 4)
      y         $ Any more decision variables (Y or N) ?
         5      $ Choose a decision variable (1,2,3,...)     THKSKN( 5)
  0.1000000     $ Lower bound of variable no.( 5)
   1.000000     $ Upper bound of variable no.( 5)
      y         $ Any more decision variables (Y or N) ?
         6      $ Choose a decision variable (1,2,3,...)     THKSKN( 6)
  0.1000000     $ Lower bound of variable no.( 6)
   1.000000     $ Upper bound of variable no.( 6)
      y         $ Any more decision variables (Y or N) ?
         7      $ Choose a decision variable (1,2,3,...)     THKSKN( 7)
  0.1000000     $ Lower bound of variable no.( 7)
   1.000000     $ Upper bound of variable no.( 7)
      y         $ Any more decision variables (Y or N) ?
         8      $ Choose a decision variable (1,2,3,...)     THKSKN( 8)
  0.1000000     $ Lower bound of variable no.( 8)
   1.000000     $ Upper bound of variable no.( 8)
      y         $ Any more decision variables (Y or N) ?
         9      $ Choose a decision variable (1,2,3,...)     THKSKN( 9)
  0.1000000     $ Lower bound of variable no.( 9)
   1.000000     $ Upper bound of variable no.( 9)
      y         $ Any more decision variables (Y or N) ?
        10      $ Choose a decision variable (1,2,3,...)     THKSKN(10)
```

```
0.1000000      $ Lower bound of variable no.(10)
 1.000000      $ Upper bound of variable no.(10)
    y          $ Any more decision variables (Y or N) ?
      11       $ Choose a decision variable (1,2,3,...)     THKSKN(11)
0.1000000      $ Lower bound of variable no.(11)
 1.000000      $ Upper bound of variable no.(11)
    y          $ Any more decision variables (Y or N) ?
      12       $ Choose a decision variable (1,2,3,...)     THKSKN(12)
0.1000000      $ Lower bound of variable no.(12)
 1.000000      $ Upper bound of variable no.(12)
    y          $ Any more decision variables (Y or N) ?
      13       $ Choose a decision variable (1,2,3,...)     THKSKN(13)
0.1000000      $ Lower bound of variable no.(13)
 1.000000      $ Upper bound of variable no.(13)
    y          $ Any more decision variables (Y or N) ?
      14       $ Choose a decision variable (1,2,3,...)     HIGHST( 1)
0.5000000      $ Lower bound of variable no.(14)
 3.000000      $ Upper bound of variable no.(14)
    y          $ Any more decision variables (Y or N) ?
      15       $ Choose a decision variable (1,2,3,...)     HIGHST( 2)
0.5000000      $ Lower bound of variable no.(15)
 3.000000      $ Upper bound of variable no.(15)
    y          $ Any more decision variables (Y or N) ?
      16       $ Choose a decision variable (1,2,3,...)     HIGHST( 3)
0.5000000      $ Lower bound of variable no.(16)
 3.000000      $ Upper bound of variable no.(16)
    y          $ Any more decision variables (Y or N) ?
      17       $ Choose a decision variable (1,2,3,...)     HIGHST( 4)
0.2000000      $ Lower bound of variable no.(17)
 3.000000      $ Upper bound of variable no.(17)
    y          $ Any more decision variables (Y or N) ?
      18       $ Choose a decision variable (1,2,3,...)     HIGHST( 5)
0.2000000      $ Lower bound of variable no.(18)
 3.000000      $ Upper bound of variable no.(18)
    y          $ Any more decision variables (Y or N) ?
      19       $ Choose a decision variable (1,2,3,...)     HIGHST( 6)
0.2000000      $ Lower bound of variable no.(19)
 3.000000      $ Upper bound of variable no.(19)
    y          $ Any more decision variables (Y or N) ?
      20       $ Choose a decision variable (1,2,3,...)     HIGHST( 7)
0.2000000      $ Lower bound of variable no.(20)
 3.000000      $ Upper bound of variable no.(20)
    y          $ Any more decision variables (Y or N) ?
      21       $ Choose a decision variable (1,2,3,...)     HIGHST( 8)
0.2000000      $ Lower bound of variable no.(21)
 3.000000      $ Upper bound of variable no.(21)
    y          $ Any more decision variables (Y or N) ?
      22       $ Choose a decision variable (1,2,3,...)     HIGHST( 9)
0.2000000      $ Lower bound of variable no.(22)
 3.000000      $ Upper bound of variable no.(22)
    y          $ Any more decision variables (Y or N) ?
      23       $ Choose a decision variable (1,2,3,...)     HIGHST(10)
0.2000000      $ Lower bound of variable no.(23)
 3.000000      $ Upper bound of variable no.(23)
    y          $ Any more decision variables (Y or N) ?
      24       $ Choose a decision variable (1,2,3,...)     HIGHST(11)
0.2000000      $ Lower bound of variable no.(24)
```

```
  3.000000     $ Upper bound of variable no.(24)
     y         $ Any more decision variables (Y or N) ?
       25      $ Choose a decision variable (1,2,3,...)     HIGHST(12)
 0.2000000     $ Lower bound of variable no.(25)
  3.000000     $ Upper bound of variable no.(25)
     y         $ Any more decision variables (Y or N) ?
       26      $ Choose a decision variable (1,2,3,...)     HIGHST(13)
 0.2000000     $ Lower bound of variable no.(26)
  3.000000     $ Upper bound of variable no.(26)
     y         $ Any more decision variables (Y or N) ?
       27      $ Choose a decision variable (1,2,3,...)     SPACNG
  1.000000     $ Lower bound of variable no.(27)
  3.000000     $ Upper bound of variable no.(27)
     y         $ Any more decision variables (Y or N) ?
       28      $ Choose a decision variable (1,2,3,...)     THSTIF
 0.5000000E-01 $ Lower bound of variable no.(28)
  1.000000     $ Upper bound of variable no.(28)
     n         $ Any more decision variables (Y or N) ?
     n         $ Any linked variables (Y or N) ?
     n         $ Any inequality relations among variables? (type H)
     y         $ Any escape variables (Y or N) ?
     y         $ Want to have escape variables chosen by default?
====================================================================
```

Table 37 Input data, ***.OPT**, for "MAINSETUP" for the **isogrid-stiffened** equivalent ellipsoidal shell. In the directory, /home/progs/genopt/case/torisph, the input file name is "eqellipse.stiffened.OPT". Copy this file to /home/progs/genoptcase and change the case name from "eqellipse.stiffened" to "eqellipse" before processing. **(/home/progs = the directory where the GENOPT system is stored on the writer's computer).**

```
======================================================================
   n       $ Do you want a tutorial session and tutorial output?
      0    $ Choose an analysis you DON'T want (1, 2,..), IBEHAV
      0    $ Choose an analysis you DON'T want (1, 2,..), IBEHAV
      0    $ NPRINT= output index (0=GOOD, 1=ok, 2=debug, 3=too much)
      1    $ Choose type of analysis (1=opt., 2=fixed, 3=sensit.) ITYPE
      5    $ How many design iterations in this run (3 to 25)?
   n       $ Take "shortcuts" for perturbed designs (Y or N)?
      2    $ Choose 1 or 2 or 3 or 4 or 5 for IDESIGN
      1    $ Choose 1 or 2 or 3 or 4 or 5 for move limits, IMOVE
   y       $ Do you want default (RATIO=10) for initial move limit jump?
   y       $ Do you want the default perturbation (dx/x = 0.05)?
   y       $ Do you want to have dx/x modified by GENOPT?
   n       $ Do you want to reset total iterations to zero (Type H)?
======================================================================
```

NOTES:

1. The input line for IBEHAV is repeated NCASES times, where NCASES = the number of load sets. In this case there are two 1oad sets, the first corresponding to shells with +mode 1 and +mode 2 axisymmetric imperfection shapes and the second corresponding to shells with –mode 1 and -mode 2 axisymmetric imperfection shapes.

2. For definitions of IDESIGN, IMOVE, and RATIO see the file URPROMPT.DAT, which is listed in Table a24 of the appendix of [26].

Table 38 Input data, ***.CHG**, for "**CHANGE**" for the **isogrid-stiffened** equivalent ellipsoidal shell. In the directory, /home/progs/genopt/case/torisph, the input file name is "eqellipse.stiffened.CHG". Copy this file to /home/progs/genoptcase and change the case name from "eqellipse.stiffened" to "eqellipse" before processing. **(/home/progs = the directory where the GENOPT system is stored on the writer's computer).** The writer routinely uses "CHANGE" as a device by means of which to preserve an optimum design that has previously been obtained. Then the data base, margins, etc. for that optimum design can easily be re-computed by executing BEGIN followed immediately by an execution of CHANGE with use of a file such as that listed here for input to CHANGE (tedious interactive mode of input not necessary).

```
=====================================================================
     n      $ Do you want a tutorial session and tutorial output?
     y      $ Do you want to change any values in Parameter Set No.1?
        1   $ Number of parameter to change (1, 2, 3, . .)        THKSKN( 1)
  0.1245300  $ New value of the parameter
     y      $ Want to change any other parameters in this set?
        2   $ Number of parameter to change (1, 2, 3, . .)        THKSKN( 2)
  0.1664100  $ New value of the parameter
     y      $ Want to change any other parameters in this set?
        3   $ Number of parameter to change (1, 2, 3, . .)        THKSKN( 3)
  0.1446000  $ New value of the parameter
     y      $ Want to change any other parameters in this set?
        4   $ Number of parameter to change (1, 2, 3, . .)        THKSKN( 4)
  0.1608200  $ New value of the parameter
     y      $ Want to change any other parameters in this set?
        5   $ Number of parameter to change (1, 2, 3, . .)        THKSKN( 5)
  0.1041200  $ New value of the parameter
     y      $ Want to change any other parameters in this set?
        6   $ Number of parameter to change (1, 2, 3, . .)        THKSKN( 6)
  0.1000000  $ New value of the parameter
     y      $ Want to change any other parameters in this set?
        7   $ Number of parameter to change (1, 2, 3, . .)        THKSKN( 7)
  0.1016200  $ New value of the parameter
     y      $ Want to change any other parameters in this set?
        8   $ Number of parameter to change (1, 2, 3, . .)        THKSKN( 8)
  0.1379500  $ New value of the parameter
     y      $ Want to change any other parameters in this set?
        9   $ Number of parameter to change (1, 2, 3, . .)        THKSKN( 9)
  0.1020100  $ New value of the parameter
     y      $ Want to change any other parameters in this set?
       10   $ Number of parameter to change (1, 2, 3, . .)        THKSKN(10)
  0.1041100  $ New value of the parameter
     y      $ Want to change any other parameters in this set?
       11   $ Number of parameter to change (1, 2, 3, . .)        THKSKN(11)
  0.1986900  $ New value of the parameter
     y      $ Want to change any other parameters in this set?
       12   $ Number of parameter to change (1, 2, 3, . .)        THKSKN(12)
  0.1000000  $ New value of the parameter
     y      $ Want to change any other parameters in this set?
       13   $ Number of parameter to change (1, 2, 3, . .)        THKSKN(13)
  0.1977900  $ New value of the parameter
     y      $ Want to change any other parameters in this set?
       14   $ Number of parameter to change (1, 2, 3, . .)        HIGHST( 1)
```

```
  0.6676600  $ New value of the parameter
     y       $ Want to change any other parameters in this set?
       15    $ Number of parameter to change (1, 2, 3, . .)       HIGHST( 2)
  0.6078300  $ New value of the parameter
     y       $ Want to change any other parameters in this set?
       16    $ Number of parameter to change (1, 2, 3, . .)       HIGHST( 3)
  0.9792800  $ New value of the parameter
     y       $ Want to change any other parameters in this set?
       17    $ Number of parameter to change (1, 2, 3, . .)       HIGHST( 4)
  1.256200   $ New value of the parameter
     y       $ Want to change any other parameters in this set?
       18    $ Number of parameter to change (1, 2, 3, . .)       HIGHST( 5)
  1.154000   $ New value of the parameter
     y       $ Want to change any other parameters in this set?
       19    $ Number of parameter to change (1, 2, 3, . .)       HIGHST( 6)
  0.8042200  $ New value of the parameter
     y       $ Want to change any other parameters in this set?
       20    $ Number of parameter to change (1, 2, 3, . .)       HIGHST( 7)
  1.2686000  $ New value of the parameter
     y       $ Want to change any other parameters in this set?
       21    $ Number of parameter to change (1, 2, 3, . .)       HIGHST( 8)
  0.8833900  $ New value of the parameter
     y       $ Want to change any other parameters in this set?
       22    $ Number of parameter to change (1, 2, 3, . .)       HIGHST( 9)
  0.7056000  $ New value of the parameter
     y       $ Want to change any other parameters in this set?
       23    $ Number of parameter to change (1, 2, 3, . .)       HIGHST(10)
  0.5844500  $ New value of the parameter
     y       $ Want to change any other parameters in this set?
       24    $ Number of parameter to change (1, 2, 3, . .)       HIGHST(11)
  0.5158100  $ New value of the parameter
     y       $ Want to change any other parameters in this set?
       25    $ Number of parameter to change (1, 2, 3, . .)       HIGHST(12)
  0.3441700  $ New value of the parameter
     y       $ Want to change any other parameters in this set?
       26    $ Number of parameter to change (1, 2, 3, . .)       HIGHST(13)
  0.4666000  $ New value of the parameter
     y       $ Want to change any other parameters in this set?
       27    $ Number of parameter to change (1, 2, 3, . .)       SPACNG
   2.915400  $ New value of the parameter
     y       $ Want to change any other parameters in this set?
       28    $ Number of parameter to change (1, 2, 3, . .)       THSTIF
  0.0905310  $ New value of the parameter
     n       $ Want to change any other parameters in this set?
     n       $ Do you want to change values of any "fixed" parameters?
     n       $ Do you want to change any loads?
     n       $ Do you want to change values of allowables?
     n       $ Do you want to change any factors of safety?
======================================================================
```

Table 39 **Run stream** to produce the results for the **imperfect, isogrid-stiffened** equivalent ellipsoidal shell, which is the case called "eqellipse.stiffened" in the directory, /home/progs/genopt/case/torisph.
The GENOPT case is run in the directory, /home/progs/genoptcase.
(/home/progs = the directory where the GENOPT system is stored on the writer's computer).

```
=================================================================

COMMAND          PURPOSE OF THE COMMAND              FILES
                                                 input    output
(PART 1 First generate results from GENOPT...)

begin       establish the starting design      *.BEG    *.OPB
decide      choose decision variables, bounds  *.DEC    *.OPD
mainsetup   choose analysis type, strategy     *.OPT    -----
superopt    96-hour "batch" run.               *.OPT    *.OPP
            five OPTIMIZEs per AUTOCHANGE
chooseplot  choose what to plot vs design      *.CPL    -----
            iterations.
diplot      get plot file, *.5.ps             various   *.5.ps

superopt    96-hour "batch" run.               *.OPT    *.OPP
            five OPTIMIZEs per AUTOCHANGE
chooseplot  choose what to plot vs design      *.CPL    -----
            iterations.
diplot      get plot file, *.5.ps             various   *.5.ps

superopt    96-hour "batch" run.               *.OPT    *.OPP
            five OPTIMIZEs per AUTOCHANGE
chooseplot  choose what to plot vs design      *.CPL    -----
            iterations.
diplot      get plot file, *.5.ps             various   *.5.ps

superopt    96-hour "batch" run.               *.OPT    *.OPP
            five OPTIMIZEs per AUTOCHANGE
chooseplot  choose what to plot vs design      *.CPL    -----
            iterations.
diplot      get plot file, *.5.ps             various   *.5.ps
  (The results from the last SUPEROPT run appear in
   Fig. 3)

  (In the *.OPT file, change NPRINT from 0 to 1 and
   ITYPE from 1 to 2, that is, analysis of fixed design).
mainsetup   choose analysis type, strategy     *.OPT    -----
optimize    run fixed design analysis in       *.OPT    *.OPM
            the foreground - about 50 seconds
            are required.

  (The optimum design and margins, etc. are listed in
   the file, eqellipse.stiffened.opm4 in the directory,
   ../genopt/case/torisph. See Table 33, in particular the
   two columns headed "isogrid-stiffened, imperfect", and
   see Tables 30 - 32. See Table a19 in the appendix.)

  (Next, save the optimum design by using "CHANGE". This
```

```
   is always a good practice. Then, should you want to
   rerun the case without optimization but using the
   optimum design as a "starting" design, you can easily
   do this by first executing "BEGIN" immediately followed
   by an execution of "CHANGE" with use of the input file
   for "CHANGE", that is, the file called *.CHG. See Table 38.)

change      run the processor called "CHANGE"  *.CHG   *.OPC
            As input, provide the latest
            optimum design, in this case the
            design that is listed in the file,
            eqellipse.stiffened.opm4 (see the
            previous table for the input data.
              See Table 38 for a list of *.CHG)
--------------------------------------------------------------


(PART 2 Next, generate results from BIGBOSOR4 for the optimum
        design. See the footnote in Table 30 for more info...)

cp eqellipse.ALL1 /home/progs/bigbosor4/work/eqellipse.ALL
cd /home/progs/bigbosor4/work
bigbosor4log activate bigbosor4 command set    -----    -----
bigbosorall  run bigbosor4 in foreground.      *.ALL    *.OUT
bosorplot    get plots of mode 1 and mode 2
             buckling of perfect, optimized
             isogrid-stiffened torispherical
             shell.
  (The plots are in Figs. 4 (mode 1) and 5 (mode 2))
--------------------------------------------------------------

(PART 3 Results from STAGS FOR THE OPTIMUM DESIGN...)

(Please see the next table.)
=================================================================
```

Table 40 How to run **STAGS** to obtain results such as those displayed in the next table and in Figs. 6 - 10 and Figs. 16 and 17 and Figs. 20 – 23, etc.

==

The following steps are taken in order to run STAGS cases involving the user-written SUBROUTINE WALL or SUBROUTINE USRFAB. A user-written SUBROUTINE WALL or **a user-written SUBROUTINE USRFAB is required whenever the thickness of the shell varies over the surface of the shell.**

I have written three versions of SUBROUTINE WALL, one for elastic material (wall.elastic.src), one for elastic-plastic material (wall.plastic.src), and one for the "soccerball" STAGS model (wall.soccerball.plastic.src. See Tables a20 – a22 and a32 in the Appendix [26]for lists of SUBROUTINE WALL.

I have written two versions of SUBROUTINE USRFAB, one for a 360-degree STAGS model (usrfab.plastic.src) and one for the "soccerball" STAGS model (usrfab.soccerball.plastic.src). See Tables a34 – a36 and a39 in the Appendix [26] for lists of SUBROUTINE USRFAB and SUBROUTINE LAME (Table a39). (SUBROUTINE LAME must be used in connection with "soccerball" STAGS models.)

To set up STAGS for running a case, we do the following:

1. Run GENOPT (OPTIMIZE) **with a fixed design (ITYPE=2 in the *.OPT file)** in order to generate the file called "*.STAGS" (eqellipse.STAGS in the specific case called "eqellipse". In general: <casename>.STAGS).

2. Go to the directory from which you want to run STAGS.

3a.**For the use of STAGS with SUBROUTINE WALL:**
   Copy SUBROUTINE WALL into the directory where you want to run STAGS:
   Example: cp /home/progs/genopt/case/torisph/wall.elastic.src wall.F
   NOTE: You must ALWAYS use the name, "wall.F".

3b.**For the 360-degree elastic-plastic STAGS model:**
   Copy SUBROUTINE USRFAB into the directory where you want to run STAGS:
   Example: cp /home/progs/genopt/case/torisph/usrfab.plastic.src usrfab.F
   NOTE: You must ALWAYS use the name, "usrfab.F".

3c.**For the 180-degree elastic-plastic "soccerball" STAGS model:**
   Copy SUBROUTINE USRFAB into the directory where you want to run STAGS:
   Example:
 cp /home/progs/genopt/case/torisph/usrfab.soccerball.plastic.src usrfab.F
   NOTE: You must ALWAYS use the name, "usrfab.F".
   Copy SUBROUTINE LAME into the directory where you want to run STAGS:
   Example: cp /home/progs/genopt/case/torisph/lame.src lame.F
   NOTE: You must ALWAYS use the name, "lame.F".

4. Copy <casename>.STAGS in an analogous manner:
   Example: cp /home/progs/genoptcase/eqellipse.STAGS WALLTHICK.STAGS
   NOTE: You must ALWAYS use the name, "WALLTHICK.STAGS". WALLTHICK.STAGS
         is "called" by both SUBROUTINE WALL and SUBROUTINE USRFAB .

5. We must "**source**" the STAGS code now. At the writer's facility:
   source /home/weiler/stags5/prc/initialize (for feynman computer)
   source /home/stag5/prc/initialize   (for teller computer)

6. We must **"make"** both s1 (STAGS preprocessor) and s2 (STAGS mainprocessor) in the directory where we want to run STAGS cases. The appropriate commands are:

```
makeuser s1  (generates an executable element called us1)
makeuser s2  (generates an executable element called us2)
```

7. We must **"make"** the utilities STAPL and XYTRANS (STAGS postprocessors) in the directory where we want to run STAGS cases. The appropriate commands are:

```
makeuser stapl    (generates an executable element called ustapl)
makeuser xytrans  (generates an executable element called uxytrans)
```

************* NOTE ***
When we use STAPL and XYTRANS with the new us1 and us2, we must type "ustapl <casename>" and "uxytrans" instead of "stapl" and "xytrans".
****

8. **Generate the *.inp and *.bin input files for STAGS.** These files are called here <casename>.inp1 and <casename>.bin1 (for linear buckling) and <casename>.inp2 and <casename>.bin2 (for nonlinear collapse) here. See the discussion below for some tips on generating a valid *.inp file. Examples are given of *.inp & *.bin in this table.

9. cp /home/progs/genopt/case/torisph/<casename>.{bin1,inp1} <casename.{bin,inp} and later, after completion of the linear buckling run or runs, cp /home/progs/genopt/case/torisph/<casename>.{bin2,inp2} <casename>.{bin,inp} for the nonlinear collapse analysis of the shell with one or more buckling modal imperfections.

10. Run STAGS via the command:

    stags <casename> -1 <path-to-us1> -2 <path-to-us2> -b

    Example: stags eqellipse -1 /home/bush/us1 -2 /home/bush/us2 -b

    NOTE: In order to run STAGS you have to have two valid input files, <casename>.bin and <casename>.inp . Examples are listed below.

NOTE; Whether STAGS runs an ELASTIC model or an ELASTIC-PLASTIC model depends on SUBROUTINE WALL (or SUBROUTINE USRFAB).

There are three SUBROUTINE WALL files included in the directory, /home/progs/genopt/case/torisph :

```
wall.elastic.src              (listed in Table a21 of [26])
wall.plastic.src              (listed in Table a22 of [26])
wall.soccerball.plastic.src   (listed in Table a32 of [26])
```

There are two SUBROUTINE USRFAB files included in the directory, /home/progs/genopt/case/torisph :

For the 360-degree STAGS models:

```
usrfab.plastic.src                  (listed in Table a35 of [26])
```

For the 180-degree STAGS “soccerball” models:
usrfab.soccerball.plastic.src (listed in Table a36 of [26])

The STAGS “soccerball” models require also the presence of
SUBROUTINE LAME.   (listed in Table a39 of [26])

HOW TO RUN STAGS AND GET PLOTS

To run STAGS you need a <casename>.bin file and a <casename>.inp file. For example, for this case (eqellipse) the <casename>.bin file for linear bifurcation buckling analysis is called :

/home/progs/genopt/case/torisph/eqellipse.stiffened.stags.bin1

in which /home/progs/genopt/case/torisph is the directory where the "bin1" file is located.

The "bin1" file, eqellipse.stiffened.stags.bin1, contains the following STAGS input data:

```
---------------------------------------------------------------
 eqellipse.bin: linear bifurcation buckling
 1, $ INDIC=1 is bifur.buckling; INDIC=3 is nonlinear BEGIN B-1
 1, $ IPOST=1 means save displacements every IPOSTth step
 0, $ ILIST =0 means normal batch-oriented output
 0, $ ICOR  =0 means projection in; 1 means not in.
 1, $ IMPTHE=index for imperfection theory.
 0, $ ICHIST=index for crack archive option
 0, $ IFLU  =0 means no fluid interaction.
 -1 $ ISOLVR= 0 means original solver; -1 new solver.END B-1 rec
 1.000E+00, $ STLD(1) = starting load factor, System A. BEGIN C-1 rec.
 0.000E+00, $ STEP(1) = load factor increment, System A
 1.000E+00, $ FACM(1) = maximum load factor, System A
 0.000E+00, $ STLD(2) = starting load factor, System B
 0.000E+00, $ STEP(2) = load factor increment, System B
 0.000E+00, $ FACM(2) = maximum load factor, System B
 0  $ ITEMP =0 means no thermal loads. END C-1 rec.
 10000, $ NSEC= number of CPU seconds before run termination
 0., $ DELEV is eigenvalue error tolerance (0=.00001)
 0  $ IPRINT=0 means print modes, iteration data, END D-2 rec.
  8, $ NEIGS= number of eigenvalues sought.  BEGIN D-3 rec.
 2.83, $ SHIFT=initial eigenvalue shift
 0.000E+00, $ EIGA =lower bound of eigenvalue range
 0.000E+00  $ EIGB =upper bound of eigenvalue range.    END D-3 rec.
---------------------------------------------------------------------
```

The corresponding STAGS input file, <casename>.inp, is called here,

/home/progs/genopt/case/torisph/eqellipse.stiffened.stags.inp1

For the optimized isogrid-stiffened equivalent ellipse, this file contains the following input data:

```
---------------------------------------------------------------------
perfect isogrid-stiffened equivalent ellipsoidal head X_320
  0  0  0  0  0  0  0   $B-1 IGRAV,ICHECK,ILIST,INCBC,NRUNIT,NROTS,KDEV
  12  1  0  23  0,  $B-2 NUNITS,NUNITE,NSTFS,NINTS,NPATS,
```

```
  0  0  0  0  0  0  $B-2 NCONST,NIMPFS,INERT,NINSR,NPATX,NSTIFS
  2  0  0  0  0  0  $B-3 NTAM,NTAB,NTAW,NTAP,NTAMT,NGCP
  5 91,             $F-1 NROWS(1),NCOLS(1)
  5 91,             $F-1 NROWS(1),NCOLS(1)
  5 91,             $F-1 NROWS(1),NCOLS(1)
  5 91,             $F-1 NROWS(1),NCOLS(1)
  5 91,             $F-1 NROWS(1),NCOLS(1)
  5 91,             $F-1 NROWS(1),NCOLS(1)
  5 91,             $F-1 NROWS(1),NCOLS(1)
  5 91,             $F-1 NROWS(1),NCOLS(1)
  5 91,             $F-1 NROWS(1),NCOLS(1)
  5 91,             $F-1 NROWS(1),NCOLS(1)
  5 91,             $F-1 NROWS(1),NCOLS(1)
  5 91              $F-1 NROWS(2),NCOLS(1)
  1  3  2  1        $G-1 MUNIT,MBOUND,NUNIT,NBOUND
  2  3  3  1        $G-1 MUNIT,MBOUND,NUNIT,NBOUND
  3  3  4  1        $G-1 MUNIT,MBOUND,NUNIT,NBOUND
  4  3  5  1        $G-1 MUNIT,MBOUND,NUNIT,NBOUND
  5  3  6  1        $G-1 MUNIT,MBOUND,NUNIT,NBOUND
  6  3  7  1        $G-1 MUNIT,MBOUND,NUNIT,NBOUND
  7  3  8  1        $G-1 MUNIT,MBOUND,NUNIT,NBOUND
  8  3  9  1        $G-1 MUNIT,MBOUND,NUNIT,NBOUND
  9  3 10  1        $G-1 MUNIT,MBOUND,NUNIT,NBOUND
 10  3 11  1        $G-1 MUNIT,MBOUND,NUNIT,NBOUND
 11  3 12  1        $G-1 MUNIT,MBOUND,NUNIT,NBOUND
  1  2  1  4        $G-1 unit 1 is a closed shell
  2  2  2  4        $G-1 unit 2 is a closed shell
  3  2  3  4        $G-1 unit 2 is a closed shell
  4  2  4  4        $G-1 unit 2 is a closed shell
  5  2  5  4        $G-1 unit 2 is a closed shell
  6  2  6  4        $G-1 unit 2 is a closed shell
  7  2  7  4        $G-1 unit 2 is a closed shell
  8  2  8  4        $G-1 unit 2 is a closed shell
  9  2  9  4        $G-1 unit 2 is a closed shell
 10  2 10  4        $G-1 unit 2 is a closed shell
 11  2 11  4        $G-1 unit 2 is a closed shell
 12  2 12  4        $G-1 unit 2 is a closed shell
  -1   -1           $H-1 For pole, rigid links (-1's let computer do the
$                        counting for you!)
  1  7  1  1  0  0  $I-1 ITAM,NESP,IPLST,ITANST,ICREEP,IPLANE
 16.E+06  0.25  0.0  0.16  0.0  16.E+06  0. $I-2 E1,U12,G,RHO,A1,E2,A2
  .0075 120000.,    $I-3 E(i), S(i)
  .0088 138000.,    $I-3 E(i), S(i)
  .0102 148000.,    $I-3 E(i), S(i)
  .0122 156000.,    $I-3 E(i), S(i)
  .0156 164000.,    $I-3 E(i), S(i)
  .0200 165000.,    $I-3 E(i), S(i)
  .0400 166000.     $I-3 E(i), S(i)
  2  7  1  1  0  0  $I-1 ITAM,NESP,IPLST,ITANST,ICREEP,IPLANE
 496894.4 .333 0. .004969 496894.4 0. $I-2 E1,U12,G,RHO,A1,E2,A2
  .0075 3726.710,    $I-3 E(i), S(i)
  .0088 4285.710,    $I-3 E(i), S(i)
  .0102 4596.270,    $I-3 E(i), S(i)
  .0122 4844.720,    $I-3 E(i), S(i)
  .0156 5093.170,    $I-3 E(i), S(i)
  .0200 5124.220,    $I-3 E(i), S(i)
  .0400 5155.280     $I-3 E(i), S(i)
```

```
C unit 1 = the spherical cap
  7  0  0  0  0  0  $M-1 ISHELL,IGLOBE,NROWS,NCOLS,NLAYS,NFABS
  0.00 2.958103 0.0  360.0  49.5 $M-2 PHI1, PHI2, THETA1, THETA2, R
  0  0              $M-5 IWALL,IWIMP
  410               $N-1 KELT
  0  6  6  6  0     $P-1 IBLN(i), i=1,4, IBOND
 111  111           $P-2 ITRA, IROT (conditions at pole)
  1  0  0  0  0  0  0 $Q-1 NSYS,NICS,NAMS,NUSS,NHINGE,etc.
  1  1  0           $Q-2 ISYS,NN,IFLG
 -460.  5  3  0  0  0 $Q-3 P,LT,LD,LI,LJ,LAX
  0  0  0  0  0     $R-1 IPRD,IPRR,IPRE,IPRS,IPRP
C unit 2 = toroidal
  8  0  0  0  0  0  $M-1 ISHELL,IGLOBE,NROWS,NCOLS,NLAYS,NFABS
  2.957441 6.69448 0. 360. .08364234 47.890324 $M-2 PH1,PH2,THET1,THET2,
                                               $    Ra,Rb
  0  0              $M-5 IWALL,IWIMP
  410               $N-1 KELT
  6  6  6  6  0     $P-1 IBLN(i), i=1,4, IBOND
  1  0  0  0  0  0  0 $Q-1 NSYS,NICS,NAMS,NUSS,NHINGE,etc.
  1  1  0           $Q-2 ISYS,NN,IFLG
 -460.  5  3  0  0  0 $Q-3 P,LT,LD,LI,LJ,LAX
  0  0  0  0  0     $R-1 IPRD,IPRR,IPRE,IPRS,IPRP
C unit 3 = toroidal
  8  0  0  0  0  0  $M-1 ISHELL,IGLOBE,NROWS,NCOLS,NLAYS,NFABS
  6.67782 10.67682 0. 360. .4623073 44.752884 $M-2 PH1,PH2,THET1,THET2,
                                              $    Ra,Rb
  0  0              $M-5 IWALL,IWIMP
  410               $N-1 KELT
  6  6  6  6  0     $P-1 IBLN(i), i=1,4, IBOND
  1  0  0  0  0  0  0 $Q-1 NSYS,NICS,NAMS,NUSS,NHINGE,etc.
  1  1  0           $Q-2 ISYS,NN,IFLG
 -460.  5  3  0  0  0 $Q-3 P,LT,LD,LI,LJ,LAX
  0  0  0  0  0     $R-1 IPRD,IPRR,IPRE,IPRS,IPRP
C unit 4 = toroidal
  8  0  0  0  0  0  $M-1 ISHELL,IGLOBE,NROWS,NCOLS,NLAYS,NFABS
  10.65673 15.12016 0. 360. 1.338907 40.095947 $M-2 PH1,PH2,THET1,THET2,
                                               $    Ra,Rb
  0  0              $M-5 IWALL,IWIMP
  410               $N-1 KELT
  6  6  6  6  0     $P-1 IBLN(i), i=1,4, IBOND
  1  0  0  0  0  0  0 $Q-1 NSYS,NICS,NAMS,NUSS,NHINGE,etc.
  1  1  0           $Q-2 ISYS,NN,IFLG
 -460.  5  3  0  0  0 $Q-3 P,LT,LD,LI,LJ,LAX
  0  0  0  0  0     $R-1 IPRD,IPRR,IPRE,IPRS,IPRP
C unit 5 = toroidal
  8  0  0  0  0  0  $M-1 ISHELL,IGLOBE,NROWS,NCOLS,NLAYS,NFABS
  15.08829 20.32144 0. 360. 2.895449 34.199043 $M-2 PH1,PH2,THET1,THET2,
                                               $    Ra,Rb
  0  0              $M-5 IWALL,IWIMP
  410               $N-1 KELT
  6  6  6  6  0     $P-1 IBLN(i), i=1,4, IBOND
  1  0  0  0  0  0  0 $Q-1 NSYS,NICS,NAMS,NUSS,NHINGE,etc.
  1  1  0           $Q-2 ISYS,NN,IFLG
 -460.  5  3  0  0  0 $Q-3 P,LT,LD,LI,LJ,LAX
  0  0  0  0  0     $R-1 IPRD,IPRR,IPRE,IPRS,IPRP
C unit 6 = toroidal
  8  0  0  0  0  0  $M-1 ISHELL,IGLOBE,NROWS,NCOLS,NLAYS,NFABS
```

```
  20.26536 26.78145 0. 360. 5.259145 27.465466 $M-2 PH1,PH2,THET1,THET2,
                                               $    Ra,Rb
  0  0              $M-5 IWALL,IWIMP
  410               $N-1 KELT
  6  6  6  6  0     $P-1 IBLN(i), i=1,4, IBOND
  1  0  0  0  0  0  0 $Q-1 NSYS,NICS,NAMS,NUSS,NHINGE,etc.
  1  1  0           $Q-2 ISYS,NN,IFLG
 -460.  5  3  0  0  0 $Q-3 P,LT,LD,LI,LJ,LAX
  0  0  0  0  0     $R-1 IPRD,IPRR,IPRE,IPRS,IPRP
C unit 7 = toroidal
  8  0  0  0  0  0  $M-1 ISHELL,IGLOBE,NROWS,NCOLS,NLAYS,NFABS
  26.79548 32.96853 0. 360. 7.971097 21.436380 $M-2 PH1,PH2,THET1,THET2,
                                               $    Ra,Rb
  0  0              $M-5 IWALL,IWIMP
  410               $N-1 KELT
  6  6  6  6  0     $P-1 IBLN(i), i=1,4, IBOND
  1  0  0  0  0  0  0 $Q-1 NSYS,NICS,NAMS,NUSS,NHINGE,etc.
  1  1  0           $Q-2 ISYS,NN,IFLG
 -460.  5  3  0  0  0 $Q-3 P,LT,LD,LI,LJ,LAX
  0  0  0  0  0     $R-1 IPRD,IPRR,IPRE,IPRS,IPRP
C unit 8 = toroidal
  8  0  0  0  0  0  $M-1 ISHELL,IGLOBE,NROWS,NCOLS,NLAYS,NFABS
  32.94721 39.85107 0. 360. 10.52211 16.758169 $M-2 PH1,PH2,THET1,THET2,
                                               $    Ra,Rb
  0  0              $M-5 IWALL,IWIMP
  410               $N-1 KELT
  6  6  6  6  0     $P-1 IBLN(i), i=1,4, IBOND
  1  0  0  0  0  0  0 $Q-1 NSYS,NICS,NAMS,NUSS,NHINGE,etc.
  1  1  0           $Q-2 ISYS,NN,IFLG
 -460.  5  3  0  0  0 $Q-3 P,LT,LD,LI,LJ,LAX
  0  0  0  0  0     $R-1 IPRD,IPRR,IPRE,IPRS,IPRP
C unit 9 = toroidal
  8  0  0  0  0  0  $M-1 ISHELL,IGLOBE,NROWS,NCOLS,NLAYS,NFABS
  39.77901 48.82777 0. 360. 13.07984 12.785950 $M-2 PH1,PH2,THET1,THET2,
                                               $    Ra,Rb
  0  0              $M-5 IWALL,IWIMP
  410               $N-1 KELT
  6  6  6  6  0     $P-1 IBLN(i), i=1,4, IBOND
  1  0  0  0  0  0  0 $Q-1 NSYS,NICS,NAMS,NUSS,NHINGE,etc.
  1  1  0           $Q-2 ISYS,NN,IFLG
 -460.  5  3  0  0  0 $Q-3 P,LT,LD,LI,LJ,LAX
  0  0  0  0  0     $R-1 IPRD,IPRR,IPRE,IPRS,IPRP
C unit 10 = toroidal
  8  0  0  0  0  0  $M-1 ISHELL,IGLOBE,NROWS,NCOLS,NLAYS,NFABS
  48.74254 60.90592 0. 360. 15.55374 9.5117826 $M-2 PH1,PH2,THET1,THET2,
                                               $    Ra,Rb
  0  0              $M-5 IWALL,IWIMP
  410               $N-1 KELT
  6  6  6  6  0     $P-1 IBLN(i), i=1,4, IBOND
  1  0  0  0  0  0  0 $Q-1 NSYS,NICS,NAMS,NUSS,NHINGE,etc.
  1  1  0           $Q-2 ISYS,NN,IFLG
 -460.  5  3  0  0  0 $Q-3 P,LT,LD,LI,LJ,LAX
  0  0  0  0  0     $R-1 IPRD,IPRR,IPRE,IPRS,IPRP
C unit 11 = toroidal
  8  0  0  0  0  0  $M-1 ISHELL,IGLOBE,NROWS,NCOLS,NLAYS,NFABS
  60.95361 75.15099 0. 360. 17.45365 7.3341379 $M-2 PH1,PH2,THET1,THET2,
                                               $    Ra,Rb
```

```
  0  0               $M-5 IWALL,IWIMP
  410                $N-1 KELT
  6  6  6  6  0      $P-1 IBLN(i), i=1,4, IBOND
  1  0  0  0  0  0  0 $Q-1 NSYS,NICS,NAMS,NUSS,NHINGE,etc.
  1  1  0            $Q-2 ISYS,NN,IFLG
 -460.  5  3  0  0  0 $Q-3 P,LT,LD,LI,LJ,LAX
  0  0  0  0  0      $R-1 IPRD,IPRR,IPRE,IPRS,IPRP
C unit 12 = toroidal
  8  0  0  0  0  0  $M-1 ISHELL,IGLOBE,NROWS,NCOLS,NLAYS,NFABS
  75.3152 89.91051 0.0 360.0 18.40842 6.3415871 $M-2 PH1,PH2,THET1,THET2,
                                                $    Ra,Rb
  0  0               $M-5 IWALL,IWIMP
  410                $N-1 KELT
  6  6  0  6  0      $P-1 IBLN(i), i=1,4, IBOND
 001  000            $P-2 ITRA, IROT (conditions at pole)
  1  0  0  0  0  0  0 $Q-1 NSYS,NICS,NAMS,NUSS,NHINGE,etc.
  1  1  0            $Q-2 ISYS,NN,IFLG
 -460.  5  3  0  0  0 $Q-3 P,LT,LD,LI,LJ,LAX
  0  0  0  0  0      $R-1 IPRD,IPRR,IPRE,IPRS,IPRP
$
$      ELEMENT UNIT for RIGID LINKS
$
$ S-1 records...
$USRPT unit row col  ignore coords  freedoms  AUX  #defs  layer
  1     1    1   1   3*0.           2*111     0     90      0
  1     0    0   1   $ Increment variable above by value
END                  $ Computer does the counting for you!
$
$ Element records, "command method"
E120_ELEMENTS        $ Ask for rigid link element
$N1 N2 N3 Kelt Ndefs, increment N1,N2,N3. N3 must be unity.
 1  2  1  120   89    1  1  0  $  See T1 record. Want 89 elements
 1. $ SCALE
END  $ Computer did the counting, incrementation
0   $ No loads
0   $ No printed output
-------------------------------------------------------------
```

NOTE: We must provide input data for each shell segment.
For example, for Shell Segment No. 8 (Unit 8 in STAGS jargon),
we must supply the following geometrical input data:

```
32.94721 39.85107 0. 360. 10.52211 16.758169 $M-2 PH1,PH2,THET1,THET2,
                                             $    Ra,Rb
```

Where do we obtain the numerical values for PH1, PH2, THET1, THET2, Ra, Rb?

THET1 and THET2 are easy: in the 360-degree STAGS model the shell is a closed shell of revolution so that THET1 = 0 and THET2 = 360 degrees.

For a toroidal segment the quantities, Ra and Rb, are defined as follows:

Ra= radius from axis of revolution to the center of meridional curvature
Rb= meridional radius of curvature

The angles, PH1 and PH2, are measured in degrees from the axis of revolution to the beginning (PH1) and to the end (PH2) of the shell segment.

The four quantities, PH1, PH2, Ra, Rb, can be read from BIGBOSOR4 output. For example, for Shell Segment No. 8, BIGBOSOR4 lists the following in the <casename>.OUT file:

```
-----------------------------------------------------------------
 SEGMENT NO.  8 IS SPHERICAL OR TOROIDAL.
  END POINT COORDINATES (0.196363E+02,-.753289E+01) AND
                        (0.212607E+02,-.633536E+01)
  AND CENTER (  0.1052211E+02,  0.6530096E+01)
 RADIUS =    1.6758169E+01 ALPHA1 =    3.2947208E+01
 ALPHA2 =   3.9851074E+01  INCREASING ARC LENGTH ANTICLOCKWISE
-----------------------------------------------------------------
```

In the above output, the **first of the two** (r,z) "**CENTER**" coordinates, (**0.1052211E+02**, 0.6530096E+01), is the same as Ra. The other BIGBOSOR4 variables correspond to the STAGS required input data as follows:
RADIUS = Rb;   **ALPHA1** = PH1;   **ALPHA2** = PH2
NOTE: The string, "INCREASING ARC LENGTH ANTICLOCKWISE" refers to the BIGBOSOR4 (BOSOR4) model, not to the STAGS model.

Assume that now we have valid <casename>.bin and <casename>.inp files in the directory from which we want to run STAGS.

The appropriate command to run STAGS at the writer's facility is:

```
stags <casename> -1 /home/bush/us1 -2 /home/bush/us2 -b
```

If during execution a STAGS case fails, look at the <casenam>.log file first. Then look at the <casename>.out2 file. Often, almost nothing will be in the <casename>.out2 file because the error occurs during execution of "s1", that is, the error will be noted in the file <casename>.out1. If that is so, inspect the <casename>.out1 file. Search for the words, "ERROR" or "WARNING". Inspect the end of the <casename>.out1 file first.

If the STAGS execution is satisfactory, look at the <casename>.out2 file. If it is a buckling analysis, search for the string, "roots". Then search for the string, "CONVERGENCE HAS", to find the eigenvalue(s). If you ask for 8 eigenvalues and STAGS fails to find all 8, then you can set SHIFT (near the end of the <casename>.bin file) to some value that will probably lead to convergence to all 8 requested eigenvalues. Set SHIFT to a value near the center of the cluster of eigenvalues successfully determined by STAGS. Look at the value of "roots" to make sure that you haven't missed any lower eigenvalues.

You may set the initial eigenvalue "SHIFT" too high. You can sometimes tell if you have done this by searching for the string, "roots" and seeing if, in factoring the stability matrix, STAGS counts more "roots" than the number given upon the first occurrence of the string, "roots", in the <casename>.out2 file.

The most significant output from STAGS (<casename>.out2 file) is the following (in the particular case of linear bifurcation buckling, that is, **INDIC = 1** in the <casename>.bin file):

```
Output from STAGS (abridged) eqellipse.stiffened.stags.linearbuck.out2
----------------------------------------------------------------------
CONVERGENCE HAS BEEN OBTAINED FOR EIGENVALUES  1 THROUGH   8
                     CRITICAL LOAD FACTOR COMBINATION
NO. EIGENVALUE   LOAD SYSTEM A  LOAD SYSTEM B  @DOF (writer's comments)
1  2.835021E+00  2.835021E+00  0.000000E+00     3 <--axisymmetric mode1
2  3.004836E+00  3.004836E+00  0.000000E+00  3795 <-- n = 1 circ. wave
3  3.004836E+00  3.004836E+00  0.000000E+00  3393 <-- n = 1 circ. wave
4  3.483754E+00  3.483754E+00  0.000000E+00  8277 <-- n = 2 circ. waves
5  3.483755E+00  3.483755E+00  0.000000E+00  8211 <-- n = 2 circ. waves
6  3.505017E+00  3.505017E+00  0.000000E+00     3 <--axisymmetric mode2
7  3.551819E+00  3.551819E+00  0.000000E+00  5241 <-- n = 1 circ. wave
8  3.551820E+00  3.551820E+00  0.000000E+00  5109 <-- n = 1 circ. wave
------------------------------------------------------------------------
```

NOTE: The comments on the right-hand side of the above list were added by the writer and are not part of the STAGS output. This abridged list of eqellipse.out2 is also contained in Table 41.

The eigenvectors (buckling mode shapes) corresponding to EIGENVALUEs 1, 2, 4, 6, and 7 are displayed in Figs. 6, 7, 8, 9, and 10, respectively, of the paper, sdm50.report.pdf.

Eigenvalues 2 and 3 correspond to non-axisymmetric buckling with n = 1 circumferential wave. These two modes are the same, except that one mode is rotated about the axis of revolution with respect to the other. Eigenvalue 1 corresponds to axisymmetric buckling and is, in GENOPT jargon, called "(mode 1)".
This first mode from STAGS is the one we want to use as an imperfection shape in the nonlinear equilibrium (**INDIC=3**) STAGS run that follows (described below). We use this lowest AXISYMMETRIC mode first because we want to compare load-deflection curves of an axisymmetrically imperfect equivalent ellipsoidal shell from STAGS with those from BIGBOSOR4 and BOSOR5 where only axisymmetric imperfections can be handled. Later, we also use the second axisymmetric mode (EIGENVALUE no. 6).

To get a plot of an eigenvector (<casename>.pdf file), generate a <casename>.pin file using "ustapl". A typical <casename>.pin file for plotting the first eigenvector in a linear buckling analysis (**INDIC=1**) is as follows:

```
--------------------------------------------------------------
linear buckling of perfect shell from STAGS
  1  0  1  0  $PL-2  NPLOT,IPREP,IPRS,KDEV
     1     0     4     0     1  $PL-3  KPLOT,NUNIT,ITEM,STEP,MODE
    0.0   3  $PL-5  DSCALE,NROTS
  1   -35.84   $PL-6  IROT,ROT
  2   -13.14   $PL-6  IROT,ROT
  3    35.63   $PL-6  IROT,ROT
----------------------------------------------------------------
```

For the 2nd eigenvector, set "MODE" in the third line to 2 , and so on for eigenvectors corresponding to higher eigenvalues.

To get a plot of the prebuckling distribution of axial resultant, Nx, use the following <casename>.pin file:

```
---------------------------------------------------------------
eqellipse plot of prebuckling Nx
 1  0  1  0  $PL-2  NPLOT,IPREP,IPRS,KDEV
 2   0  5   0  0  0  0  1 $PL-3 KPLOT,VIEW,ITEM,STEP,
                          $     MODE,IFRNG,COLOR,ICOMP
 0.0   0  0.0  0.0  0.0 $PL-5 DSCALE,NROTS,LWSCALE,RNGMIN,RGMAX
----------------------------------------------------------------
```

To get a plot of Ny change ICOMP to 2 ; to get a plot of Nxy set ICOMP = 3 .

If we already have a valid <casename>.pin (input data for ustapl) file, we type the command:

```
ustapl <casename>
```

This command, if completed successfully, generates a <casename>.pdf file, which you can view on the screen by typing the command:

```
acroread <casename>.pdf
```

If the <casename>.pdf file looks too short, meaning that ustapl failed, then inspect the <casename>.pout file for error messages.

In this particular case we generate several "pdf" files of the linear buckling modes obtained from STAGS (Figs. 6, 7, 8, 9, 10 in the paper called sdm50.report.pdf).

Figure 6 shows the first AXISYMMETRIC mode shape, which is called "mode 1" in the paper, sdm50.report.pdf. This "mode 1" corresponds to the first eigenvalue (IMMODE = 1) in the STAGS analysis. This axisymmetric mode from STAGS is plotted in Fig. 6. The 2nd axisymmetric mode from STAGS (called "mode 2" in GENOPT jargon) corresponds to the sixth eigenvalue. It is plotted in Fig. 7. Figure 16 shows the STAGS prediction of nonlinear axisymmetric static response of an imperfect isogrid-stiffened equivalent ellipsoidal shell in which the axisymmetric imperfection shapes are (+ and -) "mode 1" and (+ and -) "mode 2", each of the 4 buckling modal imperfections having an amplitude, Wimp = 0.2 inch. Only one imperfection shape is used at a time.

Next, we wish to conduct a nonlinear equilibrium analysis with STAGS (**INDIC=3** in the *.bin file), including an axisymmetric imperfection shape similar to the "-(mode 1)" imperfection shape used in the nonlinear stress and collapse analyses in the GENOPT case enumerated in the file, sdm50.report.pdf.

First, we want to use the NEGATIVE of the buckling modal shape displayed in Fig. 6 as an imperfection shape because that is the most critical case (Fig.16). In the GENOPT jargon this is analogous to the "-(mode 1)" axisymmetric imperfection shape. Therefore, in the <casename>.inp file (called "eqellipse.stiffened.stags.inp2" here), the amplitude of the buckling modal imperfection corresponding to STAGS datum, IMMODE = 1, is set to WIMPFA = -0.2 inches.

NOTE: The only differences between the file, eqellipse.stiffened.stags.inp1

and the file,

eqellipse.stiffened.stags.inp2

are:

1. NIMPFS is equal to zero in the eqellipse.stiffened.stags.inp1 file.
   NIMPFS is equal to one in the eqellipse.stiffened.stags.inp2 file.

2. There is a new "B5" record. In the eqellipse.stiffened.stags.inp1
   file we have:

```
-----------------------------------------------------------------------
perfect isogrid-stiffened equivalent ellipsoidal head X_320
  0  0  0  0  0  0  0   $B-1 IGRAV,ICHECK,ILIST,INCBC,NRUNIT,NROTS,KDEV
  12  1  0  23  0,  $B-2 NUNITS,NUNITE,NSTFS,NINTS,NPATS,
  0  0  0  0  0  0  $B-2 NCONST,NIMPFS,INERT,NINSR,NPATX,NSTIFS
  2  0  0  0  0  0  $B-3 NTAM,NTAB,NTAW,NTAP,NTAMT,NGCP
  5 91,             $F-1 NROWS(1),NCOLS(1)
------------------------------------------------------------------------
```

and in the eqellipse.stiffened.stags.inp2 file we have:

```
------------------------------------------------------------------------
imperfect isogrid-stiffened equivalent ellipsoidal head X_320
  0  0  0  0  0  0  0   $B-1 IGRAV,ICHECK,ILIST,INCBC,NRUNIT,NROTS,KDEV
  12  1  0  23  0,  $B-2 NUNITS,NUNITE,NSTFS,NINTS,NPATS,
  0  1  0  0  0  0  $B-2 NCONST,NIMPFS,INERT,NINSR,NPATX,NSTIFS
  2  0  0  0  0  0  $B-3 NTAM,NTAB,NTAW,NTAP,NTAMT,NGCP
 -0.200   0  1  1   $B-5 WIMPFA, IMSTEP, IMMODE, IMRUN
  5 91,             $F-1 NROWS(1),NCOLS(1)
------------------------------------------------------------------------
```

We copy the two files,

 eqellipse.stiffened.stags.inp2
 eqellipse.stiffened.stags.bin2

into the directory where we are running STAGS and we rename them

 eqellipse.inp
 eqellipse.bin

First we edit the eqellipse.bin file (making the highest
load factor, FACM(1), equal to unity instead of 2.5 and asking
for zero eigenvalues), so that we have for the eqellipse.bin file
the following:

```
-----------------------------------------------------------------
optimized imperfect shell, nonlinear theory (INDIC=3)
 3, $ INDIC=1 is bifur.buckling; INDIC=3 is nonlinear BEGIN B-1
 1, $ IPOST=1 means save displacements every IPOSTth step
 0, $ ILIST =0 means normal batch-oriented output
 0, $ ICOR  =0 means projection in; 1 means not in.
 1, $ IMPTHE=index for imperfection theory.
 0, $ IOPTIM=0 means bandwith optimization will be performed
 0, $ IFLU  =0 means no fluid interaction.
```

```
 -1 $ ISOLVR= 0 means original solver; -1 new solver.END B-1 rec
 5.000E-02, $ STLD(1) = starting load factor, System A. BEGIN C-1 rec.
 5.000E-02, $ STEP(1) = load factor increment, System A
 1.000E+00, $ FACM(1) = maximum load factor, System A
 0.000E+00, $ STLD(2) = starting load factor, System B
 0.000E+00, $ STEP(2) = load factor increment, System B
 0.000E+00, $ FACM(2) = maximum load factor, System B
 0   $ ITEMP =0 means no thermal loads. END C-1 rec.
   0, $ ISTART=restart from ISTARTth load step.   BEGIN D-1 rec.
 500,$ NSEC= number of CPU seconds before run termination
 15,$ NCUT = number of times step size may be cut
  -20, $ NEWT = number of refactorings allowed
-1,$ NSTRAT=-1 means path length used as independent parameter
 0.00005,$ DELX=convergence tolerance
 0. $ WUND = 0 means initial relaxation factor =1.END D-1 rec.
 0,  0, 0  $ NPATH=0: Riks method, NEIGS=no.of eigs, NSOL=0: contin.ET-1
------------------------------------------------------------------------
```

Then we launch the nonlinear equilibrium STAGS run via the command:

```
stags eqellipse -1 /home/bush/us1 -2 /home/bush/us2 -b
```

The results appear in the new eqellipse.out2 file. The most important part of this file is the list of load steps for which a converged solution was determined. Search for the string, "LIST", to find the following output in the file called “eqellipse.out2”:

```
--------------------------------------------
 LIST OF LOAD STEPS AND LOAD FACTORS
 STEP      PA            PB            PX
    0  0.500000E-01  0.000000E+00
    1  0.500000E-01  0.000000E+00
    2  0.100000E+00  0.000000E+00
    3  0.137106E+00  0.000000E+00
    4  0.192128E+00  0.000000E+00
    5  0.273220E+00  0.000000E+00
    6  0.391567E+00  0.000000E+00
    7  0.561420E+00  0.000000E+00
    8  0.797259E+00  0.000000E+00
    9  0.100000E+01  0.000000E+00
---------------------------------------------
```

PA = 1.0 corresponds to the external design pressure, p = 460 psi.

If we wish to find the meridional stress distribution at the inner fiber of the isogrid layer in Shell Units 8, 9, 10, 11, and 12 of the STAGS model (isogrid layer = layer no. 1 in the STAGS model, shell skin = layer number 2 in the STAGS model), we execute "ustapl" with use of the following eqellipse.pin input file:

```
-------------------------------------------------------------------
STAGS: nonlinear meridional stress isogrid inner fiber
  1  0  1  0  $PL-2  NPLOT,IPREP,IPRS,KDEV
  2   5  7   9  0  0  0  1  1  1 $PL-3  KPLOT,VIEW,ITEM,STEP,MODE,
                                 $   IFRNG,COLOR,ICOMP,LAYER,FIBR
  8  9  10  11  12               $ include only Units 8 - 12
   0.0   3  0.0  0.0  0.0 $PL-5  DSCALE,NROTS,LWSCALE,RNGMIN,RGMAX
  1  -0.35840000E+02   $PL-6  IROT,ROT
  2  -0.13140000E+02   $PL-6  IROT,ROT
  3   0.35630001E+02   $PL-6  IROT,ROT
```

```
----------------------------------------------------------------------
```

The execution of ustapl with the input data just listed generates a *.pdf file which shows contour plots of the meridional stress at the inner fiber of the isogrid “layer”. The *.pdf file is plotted in Fig. 29 in the report, sdm50.report.pdf.

In order to try to find the axisymmetric collapse load, we must continue the nonlinear equilibrium (**INDIC=3**) STAGS analysis. We edit the eqellipse.bin file so that we can start where the previous nonlinear run left off, at Load Step No. 9. The new eqellipse.bin file is as follows:

```
-----------------------------------------------------------------------
optimized imperfect shell, nonlinear theory (INDIC=3)
 3, $ INDIC=1 is bifur.buckling; INDIC=3 is nonlinear BEGIN B-1
 1, $ IPOST=1 means save displacements every IPOSTth step
 0, $ ILIST =0 means normal batch-oriented output
 0, $ ICOR  =0 means projection in; 1 means not in.
 1, $ IMPTHE=index for imperfection theory.
 0, $ IOPTIM=0 means bandwith optimization will be performed
 0, $ IFLU  =0 means no fluid interaction.
 -1 $ ISOLVR= 0 means original solver; -1 new solver.END B-1 rec
 1.0, $ STLD(1) = starting load factor, System A. BEGIN C-1 rec.
 1.000E-01, $ STEP(1) = load factor increment, System A
 1.200E+00, $ FACM(1) = maximum load factor, System A
 0.000E+00, $ STLD(2) = starting load factor, System B
 0.000E+00, $ STEP(2) = load factor increment, System B
 0.000E+00, $ FACM(2) = maximum load factor, System B
 0   $ ITEMP =0 means no thermal loads. END C-1 rec.
   9, $ ISTART=restart from ISTARTth load step.   BEGIN D-1 rec.
 300,$ NSEC= number of CPU seconds before run termination
 15,$ NCUT = number of times step size may be cut
  -20, $ NEWT = number of refactorings allowed
-1,$ NSTRAT=-1 means path length used as independent parameter
 0.00005,$ DELX=convergence tolerance
 0. $ WUND = 0 means initial relaxation factor =1.END D-1 rec.
 0,  0, 0  $ NPATH=0: Riks method, NEIGS=no.of eigs, NSOL=0: contin.ET-1
---------------------------------------------------------------------------
```

The eqellipse.inp file remains unchanged. We launch another STAGS run via the command:

```
stags eqellipse -1 /home/bush/us1 -2 /home/bush/us2 -b
```

After this run finishes we have a new eqellipse.out2 file, the most significant part of which is as follows:

```
--------------------------------------------
 LIST OF LOAD STEPS AND LOAD FACTORS
 STEP      PA            PB            PX
    9  0.100000E+01  0.000000E+00
   10  0.101816E+01  0.000000E+00
   11  0.104443E+01  0.000000E+00
   12  0.108156E+01  0.000000E+00
   13  0.113111E+01  0.000000E+00
   14  0.118720E+01  0.000000E+00
   15  0.120000E+01  0.000000E+00
```

```
--------------------------------------------
```

Again, we must launch a new nonlinear equilibrium STAGS run (INDIC=3) with use of a new eqellipse.bin file, as follows:

```
--------------------------------------------------------------------
optimized imperfect shell, nonlinear theory (INDIC=3)
 3, $ INDIC=1 is bifur.buckling; INDIC=3 is nonlinear BEGIN B-1
 1, $ IPOST=1 means save displacements every IPOSTth step
 0, $ ILIST =0 means normal batch-oriented output
 0, $ ICOR  =0 means projection in; 1 means not in.
 1, $ IMPTHE=index for imperfection theory.
 0, $ IOPTIM=0 means bandwith optimization will be performed
 0, $ IFLU  =0 means no fluid interaction.
 -1 $ ISOLVR= 0 means original solver; -1 new solver.END B-1 rec
 1.2, $ STLD(1) = starting load factor, System A. BEGIN C-1 rec.
 1.000E-01, $ STEP(1) = load factor increment, System A
 1.400E+00, $ FACM(1) = maximum load factor, System A
 0.000E+00, $ STLD(2) = starting load factor, System B
 0.000E+00, $ STEP(2) = load factor increment, System B
 0.000E+00, $ FACM(2) = maximum load factor, System B
 0   $ ITEMP =0 means no thermal loads. END C-1 rec.
  15, $ ISTART=restart from ISTARTth load step.   BEGIN D-1 rec.
 300,$ NSEC= number of CPU seconds before run termination
 15,$ NCUT = number of times step size may be cut
  -20, $ NEWT = number of refactorings allowed
-1,$ NSTRAT=-1 means path length used as independent parameter
 0.00005,$ DELX=convergence tolerance
 0. $ WUND = 0 means initial relaxation factor =1.END D-1 rec.
 0,  0, 0  $ NPATH=0: Riks method, NEIGS=no.of eigs, NSOL=0: contin.ET-1
------------------------------------------------------------------------
```

Again, we launch the new STAGS run via the command:

```
stags eqellipse -1 /home/bush/us1 -2 /home/bush/us2 -b
```

After this third nonlinear run finishes we have a new eqellipse.out2 file, the most significant part of which is as follows:

```
--------------------------------------------------------------------
 LIST OF LOAD STEPS AND LOAD FACTORS
 STEP      PA             PB            PX
   15  0.120000E+01  0.000000E+00
   16  0.120107E+01  0.000000E+00
   17  0.120262E+01  0.000000E+00
   18  0.120546E+01  0.000000E+00
   19  0.121019E+01  0.000000E+00
   20  0.121590E+01  0.000000E+00
   21  0.121596E+01  0.000000E+00 <--This is the collapse load.
   22  0.120181E+01  0.000000E+00    The collapse pressure in psi is
   23  0.116407E+01  0.000000E+00    given by PA x 460
   24  0.110760E+01  0.000000E+00
   25  0.103917E+01  0.000000E+00
   26  0.965515E+00  0.000000E+00
   27  0.892909E+00  0.000000E+00
   28  0.828470E+00  0.000000E+00
   29  0.781610E+00  0.000000E+00
   30  0.763487E+00  0.000000E+00
   31  0.778943E+00  0.000000E+00
```

```
   32  0.816120E+00  0.000000E+00
-----------------------------------------------------------------
```

To obtain the external pressure in psi, we use the product,

PA*(applied pressure in each shell segment in the <casename>.inp file).

The maximum pressure for which converged results were obtained is at Load Step 21, and is:

```
             load      $ Q-3
 pressure   factor    pressure, P
  in psi            in each segment
                     of *.inp file
  p(max)   =  PA   *   (-460)      = 1.21596 * (-460) = -559.34 psi.
```

To obtain the load-deflection plot we execute **uxytrans** with the following input (stored in the <casename>.pxy file, a list of which follows):

```
--------------------------------------------------------------
 P              $ (P)lotps or (S)pread_Sheet output
 eqellipse      $ STAGS solution 'Case Name'
 F              $ (F)ull or (C)ondensed Model
 Y              $ (Y)es-(N)o: setup data for another plot
  5             $ x-axis variable = choice (1 to 15)
      1         $ node no. (0 = ask for Unit,Row,Col)
 3              $ comp no., dis,vel,acc (1-6) = u,v,w,ru,rv,rw
 S              $ (G)lobal or (S)hell ref surface
 Y              $ (Y)es-(N)o: specify x-variable scale factor
 -1.0           $ x-variable scale factor
  2             $ y-axis variable = choice (1 to 15)
 Y              $ (Y)es-(N)o: specify x-variable scale factor
  0.460000E+03  $ y-variable scale factor
 N              $ (Y)es-(N)o: specify subrange of loadsteps
 Y              $ (Y)es-(N)o: plotted points start at origin
 N              $ (Y)es-(N)o: setup data for another plot
--------------------------------------------------------------
```

The output, <casename>.plt. from **uxytrans** is:

```
----------------------------------------
"Disp(1,w,L) vs. load_PA
   0.000000E+00    0.000000E+00
   2.109927E-02    2.300000E+01
   4.254400E-02    4.600000E+01
   5.869397E-02    6.306869E+01
   8.303329E-02    8.837901E+01
   1.198239E-01    1.256814E+02
   1.757387E-01    1.801207E+02
   2.616668E-01    2.582531E+02
   3.973414E-01    3.667389E+02
   5.436194E-01    4.600000E+02
   5.593396E-01    4.683524E+02
   5.833589E-01    4.804367E+02
   6.206204E-01    4.975161E+02
   6.797398E-01    5.203097E+02
   7.770769E-01    5.461098E+02
   8.126104E-01    5.520000E+02
```

```
   8.161874E-01    5.524943E+02
   8.215648E-01    5.532043E+02
   8.323741E-01    5.545132E+02
   8.541937E-01    5.566884E+02
   8.984855E-01    5.593120E+02
   9.657895E-01    5.593420E+02
   1.066471E+00    5.528304E+02
   1.213734E+00    5.354706E+02
   1.397812E+00    5.094970E+02
   1.626016E+00    4.780168E+02
   1.906073E+00    4.441367E+02
   2.247330E+00    4.107383E+02
   2.662107E+00    3.810960E+02
   3.166491E+00    3.595404E+02
   3.781092E+00    3.512041E+02
   4.475360E+00    3.583138E+02
   5.327549E+00    3.754154E+02
----------------------------------------
```

The data in the <casename>.plt file is in a form that makes it very easy to incorporate into the files:

```
eqellipse.stiffened.bosor4andstags.input
eqellipse.stiffened.mode1mode2.collapse.input
```

We then obtain postscript files for plotting via the commands:

```
/home/progs/bin/plotps.linux
     < eqellipse.stiffened.bosor4andstags.input
     > eqellipse.stiffened.bosor4andstags.ps

/home/progs/bin/plotps.linux
     < eqellipse.stiffened.mode1mode2.collapse.input
     > eqellipse.stiffened.mode1mode2.collapse.ps
```

We obtain plots on the screen via the commands:

```
gv eqellipse.stiffened.bosor4andstags.ps
gv eqellipse.stiffened.mode1mode2.collapse.ps
```

Next, we wish to run essentially the same STAGS model, but this time we want to include plasticity. The runstream is analogous to that described above. Briefly, we type the following commands:

```
cp wall.plastic.src wall.F
makeuser s1
makeuser s2
makeuser stapl
makeuser xytrans
'rm' *.out2*

(First, execute the linear bifurcation [INDIC=1] analysis)
cp <casename>.stiffened.stags.bin1 <casename>.bin
cp <casename>.stiffened.stags.inp1 <casename>.inp
stags <casename> -1 /home/bush/us1 -2 /home/bush/us2 -b
```

```
(inspect the <casename>.out2 file)
(set up the proper <casename>.pin file)
ustapl <casename>
acroread <casename>.pdf

(Next, execute the nonlinear equilibrium [INDIC=3] analysis)
cp <casename>.stiffened.stags.bin2 <casename>.bin
cp <casename>.stiffened.stags.inp2 <casename>.inp
stags <casename> -1 /home/bush/us1 -2 /home/bush/us2 -b
(inspect the <casename>.out2 file; search for "LIST")
```
(Unfortunately in this case STAGS bombed for an unknown reason, probably because of the greatly elongated finite elements next to the pole. To run elastic-plastic cases successfully you must use the "soccerball" model.)

```
(If STAGS had run successfully to completion, we would have done
 the following)
uxytrans <casename> (use the input data listed above in <casename>.pxy)
(inspect the output from uxytrans in the <casename>.plt file)
(include the "x,y" values as an additional trace in the
 file called "eqellipse.bosor4andbosor5andstags.plotps.input"
 and obtain a new eqellipse.bosor4andbosor5andstags.plotps.ps file
 from the command,
/home/progs/bin/plotps.linux
   < eqellipse.bosor4andbosor5andstags.plotps.input
   > eqellipse.bosor4andbosor5andstags.plotps.ps
```

Please see Fig. 169 and Figs. a2 – a13 in the appendix of [26] for the STAGS model called "soccerball". Unlike the STAGS model based on polar coordinates, the "soccerball" model has no singularity at the apex of the shell. Therefore, one can successfully use the 480 finite element and one can obtain good results for domes in which elastic-plastic material behavior is included. Figures 169 – 276 of [26] are results generated with use of the "soccerball" STAGS model.

==

Table 41 Optimized **isogrid-stiffened** equivalent ellipsoidal shell. **Output from STAGS** (abridged). This is part of the **eqellipse.out2** file generated during a linear bifurcation buckling STAGS run (**INDIC=1**). The comments on the right-hand-side about mode shapes were added by the author.

```
=======================================================================
CONVERGENCE HAS BEEN OBTAINED FOR EIGENVALUES  1 THROUGH   8
                     CRITICAL LOAD FACTOR COMBINATION
NO. EIGENVALUE  LOAD SYSTEM A  LOAD SYSTEM B @DOF      (writer's comments)
 1 2.835021E+00  2.835021E+00  0.000000E+00    3 <--axisymmetric mode 1
 2 3.004836E+00  3.004836E+00  0.000000E+00 3795 <-- n = 1 circ. wave
 3 3.004836E+00  3.004836E+00  0.000000E+00 3393 <-- n = 1 circ. wave
 4 3.483754E+00  3.483754E+00  0.000000E+00 8277 <-- n = 2 circ. waves
 5 3.483755E+00  3.483755E+00  0.000000E+00 8211 <-- n = 2 circ. waves
 6 3.505017E+00  3.505017E+00  0.000000E+00    3 <--axisymmetric mode 2
 7 3.551819E+00  3.551819E+00  0.000000E+00 5241 <-- n = 1 circ. wave
 8 3.551820E+00  3.551820E+00  0.000000E+00 5109 <-- n = 1 circ. wave
========================================================================
```

Table 42 Output from **SUBROUTINE STRUCT** in GENOPT for local buckling and effective stress in the shell skin and in the meridionally oriented isogrid stiffener for the optimized **imperfect isogrid-stiffened** equivalent ellipsoidal shell with an **axisymmetric +mode 1** buckling modal imperfection with amplitude, Wimp = +0.2 inch. The applied external pressure is the design pressure, p = 460 psi. **These are predictions from BIGBOSOR4.** This file has been edited a bit to get each line in the actual GENOPT output to fit on a single line in this table. For a list of the actual and complete eqellipse.OPM file produced by GENOPT see Table a19 in the appendix. Critical and nearly critical stresses are listed in bold face. **The locations of the shell segments are indicated in Fig. 2.**

```
=========================================================================
 ============ Analysis No. 2 for Load Set No. 1 ============
 *** Start nonlinear axisymmetric stress,+(mode 1) imperfection  IMODX=0
 BIGBOSOR4 input file for nonlinear stress,+(mode 1) imperfect=
eqellipse.ALL2P

 Local skin and smeared stiffener buckling and stress, Shell Segment  1
 Skin buckling load factor,                   BUCMIN=9.4633E+00 at pt. 2
 Smeared stringer/isogrid buckling load factor,BUCMNS=2.9187E+00 at pt. 1
 Smeared ring buckling load factor,           BUCMNR=1.0000E+17 at pt.13
 Smeared stringer/isogrid maximum eff. stress, STFMXS=8.6190E+04 at pt. 8
 Smeared ring maximum effective stress,       STFMXR=0.0000E+00 at pt. 0
 Shell skin maximum effective stress,         SKNMAX=4.7007E+04 at pt.13

 Local skin and smeared stiffener buckling and stress, Shell Segment  2
 Skin buckling load factor,                   BUCMIN=8.6543E+00 at pt.13
 Smeared stringer/isogrid buckling load factor,BUCMNS=3.3413E+00 at pt. 1
 Smeared ring buckling load factor,           BUCMNR=1.0000E+17 at pt.13
 Smeared stringer/isogrid maximum eff. stress, STFMXS=8.4631E+04 at pt. 1
 Smeared ring maximum effective stress,       STFMXR=0.0000E+00 at pt. 0
 Shell skin maximum effective stress,         SKNMAX=5.6745E+04 at pt.13

 Local skin and smeared stiffener buckling and stress, Shell Segment  3
 Skin buckling load factor,                   BUCMIN=8.6478E+00 at pt. 1
 Smeared stringer/isogrid buckling load factor,BUCMNS=1.0000E+17 at pt.13
 Smeared ring buckling load factor,           BUCMNR=1.0000E+17 at pt.13
 Smeared stringer/isogrid maximum eff. stress, STFMXS=3.4130E+04 at pt. 1
 Smeared ring maximum effective stress,       STFMXR=0.0000E+00 at pt. 0
 Shell skin maximum effective stress,         SKNMAX=6.1198E+04 at pt.13

 Local skin and smeared stiffener buckling and stress, Shell Segment  4
 Skin buckling load factor,                   BUCMIN=3.0235E+00 at pt.13
 Smeared stringer/isogrid buckling load factor,BUCMNS=1.0000E+17 at pt.13
 Smeared ring buckling load factor,           BUCMNR=1.0000E+17 at pt.13
 Smeared stringer/isogrid maximum eff. stress, STFMXS=6.5071E+04 at pt.13
 Smeared ring maximum effective stress,       STFMXR=0.0000E+00 at pt. 0
 Shell skin maximum effective stress,         SKNMAX=8.7084E+04 at pt.13

 Local skin and smeared stiffener buckling and stress, Shell Segment  5
 Skin buckling load factor,                   BUCMIN=2.6863E+00 at pt.12
 Smeared stringer/isogrid buckling load factor,BUCMNS=1.0000E+17 at pt.13
 Smeared ring buckling load factor,           BUCMNR=1.0000E+17 at pt.13
 Smeared stringer/isogrid maximum eff. stress, STFMXS=6.9978E+04 at pt.13
 Smeared ring maximum effective stress,       STFMXR=0.0000E+00 at pt. 0
 Shell skin maximum effective stress,         SKNMAX=8.9086E+04 at pt. 8
```

```
Local skin and smeared stiffener buckling and stress, Shell Segment  6
Skin buckling load factor,                    BUCMIN=2.6893E+00 at pt. 1
Smeared stringer/isogrid buckling load factor,BUCMNS=1.9258E+01 at pt.13
Smeared ring buckling load factor,            BUCMNR=1.0000E+17 at pt.13
Smeared stringer/isogrid maximum eff. stress, STFMXS=7.0013E+04 at pt. 1
Smeared ring maximum effective stress,        STFMXR=0.0000E+00 at pt. 0
Shell skin maximum effective stress,          SKNMAX=8.7480E+04 at pt. 1

Local skin and smeared stiffener buckling and stress, Shell Segment  7
Skin buckling load factor,                    BUCMIN=3.1890E+00 at pt. 1
Smeared stringer/isogrid buckling load factor,BUCMNS=1.6103E+00 at pt.13
Smeared ring buckling load factor,            BUCMNR=1.0000E+17 at pt.13
Smeared stringer/isogrid maximum eff. stress, STFMXS=8.3139E+04 at pt.13
Smeared ring maximum effective stress,        STFMXR=0.0000E+00 at pt. 0
Shell skin maximum effective stress,          SKNMAX=7.2323E+04 at pt. 1

Local skin and smeared stiffener buckling and stress, Shell Segment  8
Skin buckling load factor,                    BUCMIN=4.2428E+00 at pt.13
Smeared stringer/isogrid buckling load factor,BUCMNS=1.5813E+00 at pt. 2
Smeared ring buckling load factor,            BUCMNR=1.0000E+17 at pt.13
Smeared stringer/isogrid maximum eff. stress, STFMXS=1.1415E+05 at pt.13
Smeared ring maximum effective stress,        STFMXR=0.0000E+00 at pt. 0
Shell skin maximum effective stress,          SKNMAX=7.9991E+04 at pt.13

Local skin and smeared stiffener buckling and stress, Shell Segment  9
Skin buckling load factor,                    BUCMIN=4.2470E+00 at pt. 1
Smeared stringer/isogrid buckling load factor,BUCMNS=1.8018E+00 at pt. 2
Smeared ring buckling load factor,            BUCMNR=1.0000E+17 at pt.13
Smeared stringer/isogrid maximum eff. stress, STFMXS=1.2476E+05 at pt. 7
Smeared ring maximum effective stress,        STFMXR=0.0000E+00 at pt. 0
Shell skin maximum effective stress,          SKNMAX=9.2786E+04 at pt.13

Local skin and smeared stiffener buckling and stress, Shell Segment 10
Skin buckling load factor,                    BUCMIN=4.8516E+00 at pt. 1
Smeared stringer/isogrid buckling load factor,BUCMNS=2.5233E+00 at pt. 2
Smeared ring buckling load factor,            BUCMNR=1.0000E+17 at pt.13
Smeared stringer/isogrid maximum eff. stress, STFMXS=1.2200E+05 at pt. 2
Smeared ring maximum effective stress,        STFMXR=0.0000E+00 at pt. 0
Shell skin maximum effective stress,          SKNMAX=9.2778E+04 at pt. 1

Local skin and smeared stiffener buckling and stress, Shell Segment 11
Skin buckling load factor,                    BUCMIN=4.5458E+00 at pt.13
Smeared stringer/isogrid buckling load factor,BUCMNS=3.7129E+00 at pt. 1
Smeared ring buckling load factor,            BUCMNR=1.0000E+17 at pt.13
Smeared stringer/isogrid maximum eff. stress, STFMXS=1.0622E+05 at pt. 2
Smeared ring maximum effective stress,        STFMXR=0.0000E+00 at pt. 0
Shell skin maximum effective stress,          SKNMAX=1.0543E+05 at pt.13

Local skin and smeared stiffener buckling and stress, Shell Segment 12
Skin buckling load factor,                    BUCMIN=4.5472E+00 at pt. 1
Smeared stringer/isogrid buckling load factor,BUCMNS=5.5937E+00 at pt.13
Smeared ring buckling load factor,            BUCMNR=1.0000E+17 at pt.13
Smeared stringer/isogrid maximum eff. stress, STFMXS=8.5788E+04 at pt.13
Smeared ring maximum effective stress,        STFMXR=0.0000E+00 at pt. 0
Shell skin maximum effective stress,          SKNMAX=1.0541E+05 at pt. 1
```

```
 The following quantities are used to generate behavioral constraint
 conditions and margins:
                                                PERTURBED  UNPERTURBED
 Region 1 skin buckling load factor,      bskin1=  2.6863E+00  2.6863E+00
 Region 1 stiffener buckling load factor, bstif1=  2.9187E+00  2.9187E+00
 Region 1 skin maximum effective stress,  sknmx1=  8.9086E+04  8.9086E+04
 Region 1 stiffener max. effective stress,stfmx1=  8.6190E+04  8.6190E+04
 Region 2 skin buckling load factor,      bskin2=  2.6893E+00  2.6893E+00
 Region 2 stiffener buckling load factor, bstif2=  1.5813E+00  1.5813E+00
 Region 2 skin maximum effective stress,  sknmx2=  1.0543E+05  1.0543E+05
 Region 2 stiffener max. effective stress,stfmx2=  1.2476E+05  1.2476E+05
 Normal displacement of shell at apex,     ENDUV=  2.8842E-01  2.8842E-01
```

NOTE: The values listed under the headings, “PERTURBED” and “UNPERTURBED” are identical here because this list corresponds to the “fixed” design analysis type in MAINSETUP (**ITYPE = 2**). There are no perturbations of the decision variables in an ITYPE = 2 run of OPTIMIZE. The values of bskin1 and bstif1 are the **minimum** values computed for all the segments in Region 1. The values of bskin2 and bstif2 are the **minimum** values computed for all the segments in Region 2. The values of sknmx1 and stfmx1 are the **maximum** values computed for all the segments in Region 1. The values of sknmx2 and stfmx2 are the **maximum** values computed for all the segments in Region 2.
The values of bskin1, bstif1, sknmx1, stfmx1, bskin2, bstif2, sknmx2, stfmx2, and ENDUV are used in the computation of Margins 3, 5, 7, 9, 4, 6, 8, 10, and 11, respectively, listed in Table 31.

Table 43 Output from **SUBROUTINE STRUCT** in GENOPT for local buckling and effective stress in the shell skin and in the meridionally oriented isogrid stiffener for the optimized **imperfect isogrid-stiffened** equivalent ellipsoidal shell with an **axisymmetric +mode 2** buckling modal imperfection with amplitude, Wimp = +0.2 inch. The applied external pressure is the design pressure, p = 460 psi. **These are predictions from BIGBOSOR4.** This file has been edited a bit to get each line in the actual GENOPT output to fit on a single line in this table. For a list of the actual and complete eqellipse.OPM file produced by GENOPT see Table a19 in the appendix. Critical and nearly critical stresses are listed in bold face. **The locations of the shell segments are indicated in Fig. 2.**

```
=========================================================================
 ============ Analysis No. 3 for Load Set No. 1 ============
 *** Start nonlinear axisymmetric stress,+(mode 2) imperfection  IMODX=0
 BIGBOSOR4 input file for nonlinear stress,+(mode 2) imperfect=
eqellipse.ALL4P

 Local skin and smeared stiffener buckling and stress, Seg.   1
 Skin buckling load factor,                     BUCMIN=1.0223E+01 at pt. 2
 Smeared stringer/isogrid buckling load factor,BUCMNS=1.9224E+00 at pt. 1
 Smeared ring buckling load factor,             BUCMNR=1.0000E+17 at pt.13
 Smeared stringer/isogrid maximum eff. stress, STFMXS=1.2255E+05 at pt. 3
 Smeared ring maximum effective stress,         STFMXR=0.0000E+00 at pt. 0
 Shell skin maximum effective stress,           SKNMAX=5.3373E+04 at pt.13

 Local skin and smeared stiffener buckling and stress, Seg.   2
 Skin buckling load factor,                     BUCMIN=7.3064E+00 at pt.13
 Smeared stringer/isogrid buckling load factor,BUCMNS=4.1002E+00 at pt. 1
 Smeared ring buckling load factor,             BUCMNR=1.0000E+17 at pt.13
 Smeared stringer/isogrid maximum eff. stress, STFMXS=6.8967E+04 at pt. 1
 Smeared ring maximum effective stress,         STFMXR=0.0000E+00 at pt. 0
 Shell skin maximum effective stress,           SKNMAX=7.0925E+04 at pt.13

 Local skin and smeared stiffener buckling and stress, Seg.   3
 Skin buckling load factor,                     BUCMIN=7.3011E+00 at pt. 1
 Smeared stringer/isogrid buckling load factor,BUCMNS=1.0000E+17 at pt.13
 Smeared ring buckling load factor,             BUCMNR=1.0000E+17 at pt.13
 Smeared stringer/isogrid maximum eff. stress, STFMXS=4.3008E+04 at pt. 1
 Smeared ring maximum effective stress,         STFMXR=0.0000E+00 at pt. 0
 Shell skin maximum effective stress,           SKNMAX=7.1210E+04 at pt. 4

 Local skin and smeared stiffener buckling and stress, Seg.   4
 Skin buckling load factor,                     BUCMIN=2.9943E+00 at pt.13
 Smeared stringer/isogrid buckling load factor,BUCMNS=1.0000E+17 at pt.13
 Smeared ring buckling load factor,             BUCMNR=1.0000E+17 at pt.13
 Smeared stringer/isogrid maximum eff. stress, STFMXS=6.9629E+04 at pt.13
 Smeared ring maximum effective stress,         STFMXR=0.0000E+00 at pt. 0
 Shell skin maximum effective stress,           SKNMAX=8.3938E+04 at pt.13

 Local skin and smeared stiffener buckling and stress, Seg.   5
 Skin buckling load factor,                     BUCMIN=2.9925E+00 at pt. 1
 Smeared stringer/isogrid buckling load factor,BUCMNS=1.8143E+00 at pt.13
 Smeared ring buckling load factor,             BUCMNR=1.0000E+17 at pt.13
 Smeared stringer/isogrid maximum eff. stress, STFMXS=8.9031E+04 at pt.13
 Smeared ring maximum effective stress,         STFMXR=0.0000E+00 at pt. 0
 Shell skin maximum effective stress,           SKNMAX=8.3974E+04 at pt. 1
```

```
Local skin and smeared stiffener buckling and stress, Seg.   6
Skin buckling load factor,                    BUCMIN=3.1488E+00 at pt. 1
Smeared stringer/isogrid buckling load factor,BUCMNS=1.7834E+00 at pt. 2
Smeared ring buckling load factor,            BUCMNR=1.0000E+17 at pt.13
Smeared stringer/isogrid maximum eff. stress, STFMXS=8.9544E+04 at pt. 1
Smeared ring maximum effective stress,        STFMXR=0.0000E+00 at pt. 0
Shell skin maximum effective stress,          SKNMAX=6.9545E+04 at pt. 1

Local skin and smeared stiffener buckling and stress, Seg.   7
Skin buckling load factor,                    BUCMIN=3.4621E+00 at pt. 1
Smeared stringer/isogrid buckling load factor,BUCMNS=1.7368E+00 at pt.13
Smeared ring buckling load factor,            BUCMNR=1.0000E+17 at pt.13
Smeared stringer/isogrid maximum eff. stress, STFMXS=7.7081E+04 at pt.13
Smeared ring maximum effective stress,        STFMXR=0.0000E+00 at pt. 0
Shell skin maximum effective stress,          SKNMAX=6.6328E+04 at pt. 1

Local skin and smeared stiffener buckling and stress, Seg.   8
Skin buckling load factor,                    BUCMIN=3.9860E+00 at pt.13
Smeared stringer/isogrid buckling load factor,BUCMNS=1.7200E+00 at pt. 2
Smeared ring buckling load factor,            BUCMNR=1.0000E+17 at pt.13
Smeared stringer/isogrid maximum eff. stress, STFMXS=7.8703E+04 at pt. 2
Smeared ring maximum effective stress,        STFMXR=0.0000E+00 at pt. 0
Shell skin maximum effective stress,          SKNMAX=7.0892E+04 at pt.13

Local skin and smeared stiffener buckling and stress, Seg.   9
Skin buckling load factor,                    BUCMIN=3.9885E+00 at pt. 1
Smeared stringer/isogrid buckling load factor,BUCMNS=3.3026E+00 at pt. 2
Smeared ring buckling load factor,            BUCMNR=1.0000E+17 at pt.13
Smeared stringer/isogrid maximum eff. stress, STFMXS=6.7528E+04 at pt.13
Smeared ring maximum effective stress,        STFMXR=0.0000E+00 at pt. 0
Shell skin maximum effective stress,          SKNMAX=8.3523E+04 at pt.13

Local skin and smeared stiffener buckling and stress, Seg.  10
Skin buckling load factor,                    BUCMIN=4.3321E+00 at pt. 1
Smeared stringer/isogrid buckling load factor,BUCMNS=4.2840E+00 at pt.13
Smeared ring buckling load factor,            BUCMNR=1.0000E+17 at pt.13
Smeared stringer/isogrid maximum eff. stress, STFMXS=9.1661E+04 at pt.13
Smeared ring maximum effective stress,        STFMXR=0.0000E+00 at pt. 0
Shell skin maximum effective stress,          SKNMAX=8.6618E+04 at pt.13

Local skin and smeared stiffener buckling and stress, Seg.  11
Skin buckling load factor,                    BUCMIN=4.8141E+00 at pt.13
Smeared stringer/isogrid buckling load factor,BUCMNS=4.2701E+00 at pt. 1
Smeared ring buckling load factor,            BUCMNR=1.0000E+17 at pt.13
Smeared stringer/isogrid maximum eff. stress, STFMXS=1.1479E+05 at pt.13
Smeared ring maximum effective stress,        STFMXR=0.0000E+00 at pt. 0
Shell skin maximum effective stress,          SKNMAX=1.1436E+05 at pt.13

Local skin and smeared stiffener buckling and stress, Seg.  12
Skin buckling load factor,                    BUCMIN=4.8171E+00 at pt. 1
Smeared stringer/isogrid buckling load factor,BUCMNS=4.3387E+00 at pt.13
Smeared ring buckling load factor,            BUCMNR=1.0000E+17 at pt.13
Smeared stringer/isogrid maximum eff. stress, STFMXS=1.2331E+05 at pt. 4
Smeared ring maximum effective stress,        STFMXR=0.0000E+00 at pt. 0
Shell skin maximum effective stress,          SKNMAX=1.1438E+05 at pt. 1
```

```
 The following quantities are used to generate behavioral constraint
 conditions and margins:
                                                  PERTURBED  UNPERTURBED
 Region 1 skin buckling load factor,      bskin1=  2.9925E+00  2.9925E+00
 Region 1 stiffener buckling load factor, bstif1=  1.8143E+00  1.8143E+00
 Region 1 skin maximum effective stress,  sknmx1=  8.3974E+04  8.3974E+04
 Region 1 stiffener max. effective stress,stfmx1=  1.2255E+05  1.2255E+05
 Region 2 skin buckling load factor,      bskin2=  3.1488E+00  3.1488E+00
 Region 2 stiffener buckling load factor, bstif2=  1.7200E+00  1.7200E+00
 Region 2 skin maximum effective stress,  sknmx2=  1.1438E+05  1.1438E+05
 Region 2 stiffener max. effective stress,stfmx2=  1.2331E+05  1.2331E+05
 Normal displacement of shell at apex,     ENDUV=  3.1743E-01  3.1743E-01
=========================================================================
```

NOTE: The values listed under the headings, "PERTURBED" and "UNPERTURBED" are identical here because this list corresponds to the "fixed" design analysis type in MAINSETUP (**ITYPE = 2**). There are no perturbations of the decision variables in an ITYPE = 2 run of OPTIMIZE. The values of bskin1 and bstif1 are the **minimum** values computed for all the segments in Region 1. The values of bskin2 and bstif2 are the **minimum** values computed for all the segments in Region 2. The values of sknmx1 and stfmx1 are the **maximum** values computed for all the segments in Region 1. The values of sknmx2 and stfmx2 are the **maximum** values computed for all the segments in Region 2.
The values of bskin1, bstif1, sknmx1, stfmx1, bskin2, bstif2, sknmx2, stfmx2, and ENDUV are used in the computation of Margins 14, 16, 18, 20, 15, 17, 19, 21, and 22, respectively, listed in Table 31.

Table 44 Output from **SUBROUTINE STRUCT** in GENOPT for local buckling and effective stress in the shell skin and in the meridionally oriented isogrid stiffener for the optimized **imperfect isogrid-stiffened** equivalent ellipsoidal shell with an **axisymmetric -mode 1** buckling modal imperfection with amplitude, Wimp = -0.2 inch. The applied external pressure is the design pressure, p = 460 psi. **These are predictions from BIGBOSOR4.** This file has been edited a bit to get each line in the actual GENOPT output to fit on a single line in this table. For a list of the actual and complete eqellipse.OPM file produced by GENOPT see Table a19 in the appendix. Critical and nearly critical stresses are listed in bold face. **The locations of the shell segments are indicated in Fig. 2.**

```
==========================================================================
 ============ Analysis No. 2 for Load Set No. 2 ============
 *** Start nonlinear axisymmetric stress,-(mode 1) imperfection  IMODX=0
 BIGBOSOR4 input file for nonlinear stress,-(mode 1) imperfect=
eqellipse.ALL2N

 Local skin and smeared stiffener buckling and stress, Seg.   1
 Skin buckling load factor,                    BUCMIN=3.9282E+00 at pt. 2
 Smeared stringer/isogrid buckling load factor,BUCMNS=5.4718E+00 at pt.13
 Smeared ring buckling load factor,            BUCMNR=1.0000E+17 at pt.13
 Smeared stringer/isogrid maximum eff. stress, STFMXS=1.0224E+05 at pt. 2
 Smeared ring maximum effective stress,        STFMXR=0.0000E+00 at pt. 0
 Shell skin maximum effective stress,          SKNMAX=1.2052E+05 at pt. 3

 Local skin and smeared stiffener buckling and stress, Seg.   2
 Skin buckling load factor,                    BUCMIN=6.9070E+00 at pt.13
 Smeared stringer/isogrid buckling load factor,BUCMNS=1.5913E+00 at pt.12
 Smeared ring buckling load factor,            BUCMNR=1.0000E+17 at pt.13
 Smeared stringer/isogrid maximum eff. stress, STFMXS=7.7984E+04 at pt. 7
 Smeared ring maximum effective stress,        STFMXR=0.0000E+00 at pt. 0
 Shell skin maximum effective stress,          SKNMAX=8.9581E+04 at pt. 1

 Local skin and smeared stiffener buckling and stress, Seg.   3
 Skin buckling load factor,                    BUCMIN=6.8926E+00 at pt. 1
 Smeared stringer/isogrid buckling load factor,BUCMNS=1.1519E+00 at pt.13
 Smeared ring buckling load factor,            BUCMNR=1.0000E+17 at pt.13
 Smeared stringer/isogrid maximum eff. stress, STFMXS=6.9503E+04 at pt. 4
 Smeared ring maximum effective stress,        STFMXR=0.0000E+00 at pt. 0
 Shell skin maximum effective stress,          SKNMAX=7.4727E+04 at pt. 1

 Local skin and smeared stiffener buckling and stress, Seg.   4
 Skin buckling load factor,                    BUCMIN=3.1695E+00 at pt.13
 Smeared stringer/isogrid buckling load factor,BUCMNS=1.1477E+00 at pt. 1
 Smeared ring buckling load factor,            BUCMNR=1.0000E+17 at pt.13
 Smeared stringer/isogrid maximum eff. stress, STFMXS=7.1231E+04 at pt.13
 Smeared ring maximum effective stress,        STFMXR=0.0000E+00 at pt. 0
 Shell skin maximum effective stress,          SKNMAX=7.5136E+04 at pt.13

 Local skin and smeared stiffener buckling and stress, Seg.   5
 Skin buckling load factor,                    BUCMIN=3.1685E+00 at pt. 1
 Smeared stringer/isogrid buckling load factor,BUCMNS=1.3509E+00 at pt.10
 Smeared ring buckling load factor,            BUCMNR=1.0000E+17 at pt.13
 Smeared stringer/isogrid maximum eff. stress, STFMXS=1.1764E+05 at pt.13
 Smeared ring maximum effective stress,        STFMXR=0.0000E+00 at pt. 0
 Shell skin maximum effective stress,          SKNMAX=7.5150E+04 at pt. 1
```

```
Local skin and smeared stiffener buckling and stress, Seg.   6
Skin buckling load factor,                    BUCMIN=3.2980E+00 at pt. 4
Smeared stringer/isogrid buckling load factor,BUCMNS=1.3683E+00 at pt. 2
Smeared ring buckling load factor,            BUCMNR=1.0000E+17 at pt.13
Smeared stringer/isogrid maximum eff. stress, STFMXS=1.1803E+05 at pt. 1
Smeared ring maximum effective stress,        STFMXR=0.0000E+00 at pt. 0
Shell skin maximum effective stress,          SKNMAX=6.7917E+04 at pt.12

Local skin and smeared stiffener buckling and stress, Seg.   7
Skin buckling load factor,                    BUCMIN=3.4293E+00 at pt. 1
Smeared stringer/isogrid buckling load factor,BUCMNS=2.6155E+00 at pt.13
Smeared ring buckling load factor,            BUCMNR=1.0000E+17 at pt.13
Smeared stringer/isogrid maximum eff. stress, STFMXS=6.5714E+04 at pt. 1
Smeared ring maximum effective stress,        STFMXR=0.0000E+00 at pt. 0
Shell skin maximum effective stress,          SKNMAX=6.7636E+04 at pt. 1

Local skin and smeared stiffener buckling and stress, Seg.   8
Skin buckling load factor,                    BUCMIN=3.8518E+00 at pt.13
Smeared stringer/isogrid buckling load factor,BUCMNS=2.5826E+00 at pt. 2
Smeared ring buckling load factor,            BUCMNR=1.0000E+17 at pt.13
Smeared stringer/isogrid maximum eff. stress, STFMXS=6.6295E+04 at pt.13
Smeared ring maximum effective stress,        STFMXR=0.0000E+00 at pt. 0
Shell skin maximum effective stress,          SKNMAX=7.1914E+04 at pt.13

Local skin and smeared stiffener buckling and stress, Seg.   9
Skin buckling load factor,                    BUCMIN=3.8540E+00 at pt. 1
Smeared stringer/isogrid buckling load factor,BUCMNS=5.4581E+00 at pt. 2
Smeared ring buckling load factor,            BUCMNR=1.0000E+17 at pt.13
Smeared stringer/isogrid maximum eff. stress, STFMXS=6.6772E+04 at pt.13
Smeared ring maximum effective stress,        STFMXR=0.0000E+00 at pt. 0
Shell skin maximum effective stress,          SKNMAX=8.1601E+04 at pt.13

Local skin and smeared stiffener buckling and stress, Seg.  10
Skin buckling load factor,                    BUCMIN=4.3444E+00 at pt. 1
Smeared stringer/isogrid buckling load factor,BUCMNS=3.9164E+00 at pt.13
Smeared ring buckling load factor,            BUCMNR=1.0000E+17 at pt.13
Smeared stringer/isogrid maximum eff. stress, STFMXS=1.0026E+05 at pt.13
Smeared ring maximum effective stress,        STFMXR=0.0000E+00 at pt. 0
Shell skin maximum effective stress,          SKNMAX=8.6954E+04 at pt.13

Local skin and smeared stiffener buckling and stress, Seg.  11
Skin buckling load factor,                    BUCMIN=4.8340E+00 at pt.13
Smeared stringer/isogrid buckling load factor,BUCMNS=3.9044E+00 at pt. 1
Smeared ring buckling load factor,            BUCMNR=1.0000E+17 at pt.13
Smeared stringer/isogrid maximum eff. stress, STFMXS=1.1834E+05 at pt.11
Smeared ring maximum effective stress,        STFMXR=0.0000E+00 at pt. 0
Shell skin maximum effective stress,          SKNMAX=1.1430E+05 at pt.13

Local skin and smeared stiffener buckling and stress, Seg.  12
Skin buckling load factor,                    BUCMIN=4.8370E+00 at pt. 1
Smeared stringer/isogrid buckling load factor,BUCMNS=4.4899E+00 at pt.13
Smeared ring buckling load factor,            BUCMNR=1.0000E+17 at pt.13
Smeared stringer/isogrid maximum eff. stress, STFMXS=1.2154E+05 at pt. 4
Smeared ring maximum effective stress,        STFMXR=0.0000E+00 at pt. 0
Shell skin maximum effective stress,          SKNMAX=1.1431E+05 at pt. 1
```

```
 The following quantities are used to generate behavioral constraint
 conditions and margins:
                                                  PERTURBED  UNPERTURBED
 Region 1 skin buckling load factor,      bskin1=  3.1685E+00  3.1685E+00
 Region 1 stiffener buckling load factor, bstif1=  1.1477E+00  1.1477E+00
 Region 1 skin maximum effective stress,  sknmx1=  1.2052E+05  1.2052E+05
 Region 1 stiffener max. effective stress,stfmx1=  1.1764E+05  1.1764E+05
 Region 2 skin buckling load factor,      bskin2=  3.2980E+00  3.2980E+00
 Region 2 stiffener buckling load factor, bstif2=  1.3683E+00  1.3683E+00
 Region 2 skin maximum effective stress,  sknmx2=  1.1431E+05  1.1431E+05
 Region 2 stiffener max. effective stress,stfmx2=  1.2154E+05  1.2154E+05
 Normal displacement of shell at apex,     ENDUV=  5.3669E-01  5.3669E-01
========================================================================
```

NOTE: The values listed under the headings, "PERTURBED" and "UNPERTURBED" are identical here because this list corresponds to the "fixed" design analysis type in MAINSETUP (**ITYPE = 2**). There are no perturbations of the decision variables in an ITYPE = 2 run of OPTIMIZE. The values of bskin1 and bstif1 are the **minimum** values computed for all the segments in Region 1. The values of bskin2 and bstif2 are the **minimum** values computed for all the segments in Region 2. The values of sknmx1 and stfmx1 are the **maximum** values computed for all the segments in Region 1. The values of sknmx2 and stfmx2 are the **maximum** values computed for all the segments in Region 2.
The values of bskin1, bstif1, sknmx1, stfmx1, bskin2, bstif2, sknmx2, stfmx2, and ENDUV are used in the computation of Margins 3, 5, 7, 9, 4, 6, 8, 10, and 11, respectively, listed in Table 32.

Table 45 Output from **SUBROUTINE STRUCT** in GENOPT for local buckling and effective stress in the shell skin and in the meridionally oriented isogrid stiffener for the optimized **imperfect isogrid-stiffened** equivalent ellipsoidal shell with an **axisymmetric -mode 2** buckling modal imperfection with amplitude, Wimp = -0.2 inch. The applied external pressure is the design pressure, p = 460 psi. **These are predictions from BIGBOSOR4.** This file has been edited a bit to get each line in the actual GENOPT output to fit on a single line in this table. For a list of the actual and complete eqellipse.OPM file produced by GENOPT see Table a19 in the appendix. Critical and nearly critical stresses are listed in bold face. **The locations of the shell segments are indicated in Fig. 2.**

```
=========================================================================
 ============ Analysis No. 3 for Load Set No. 2 ============
 *** Start nonlinear axisymmetric stress,-(mode 2) imperfection  IMODX=0
 BIGBOSOR4 input file for nonlinear stress,-(mode 2) imperfect=
eqellipse.ALL4N

 Local skin and smeared stiffener buckling and stress, Seg.   1
 Skin buckling load factor,                   BUCMIN=4.8647E+00 at pt. 2
 Smeared stringer/isogrid buckling load factor,BUCMNS=3.6423E+00 at pt.13
 Smeared ring buckling load factor,           BUCMNR=1.0000E+17 at pt.13
 Smeared stringer/isogrid maximum eff. stress, STFMXS=1.2200E+05 at pt. 2
 Smeared ring maximum effective stress,       STFMXR=0.0000E+00 at pt. 0
 Shell skin maximum effective stress,         SKNMAX=1.0383E+05 at pt. 3

 Local skin and smeared stiffener buckling and stress, Seg.   2
 Skin buckling load factor,                   BUCMIN=8.8085E+00 at pt.13
 Smeared stringer/isogrid buckling load factor,BUCMNS=1.1020E+00 at pt.12
 Smeared ring buckling load factor,           BUCMNR=1.0000E+17 at pt.13
 Smeared stringer/isogrid maximum eff. stress, STFMXS=1.2191E+05 at pt. 7
 Smeared ring maximum effective stress,       STFMXR=0.0000E+00 at pt. 0
 Shell skin maximum effective stress,         SKNMAX=7.4042E+04 at pt. 1

 Local skin and smeared stiffener buckling and stress, Seg.   3
 Skin buckling load factor,                   BUCMIN=8.8027E+00 at pt. 1
 Smeared stringer/isogrid buckling load factor,BUCMNS=1.0785E+00 at pt. 5
 Smeared ring buckling load factor,           BUCMNR=1.0000E+17 at pt.13
 Smeared stringer/isogrid maximum eff. stress, STFMXS=9.7738E+04 at pt. 1
 Smeared ring maximum effective stress,       STFMXR=0.0000E+00 at pt. 0
 Shell skin maximum effective stress,         SKNMAX=6.0171E+04 at pt. 1

 Local skin and smeared stiffener buckling and stress, Seg.   4
 Skin buckling load factor,                   BUCMIN=3.1954E+00 at pt.13
 Smeared stringer/isogrid buckling load factor,BUCMNS=1.3035E+00 at pt. 1
 Smeared ring buckling load factor,           BUCMNR=1.0000E+17 at pt.13
 Smeared stringer/isogrid maximum eff. stress, STFMXS=6.5633E+04 at pt.13
 Smeared ring maximum effective stress,       STFMXR=0.0000E+00 at pt. 0
 Shell skin maximum effective stress,         SKNMAX=7.8055E+04 at pt.13

 Local skin and smeared stiffener buckling and stress, Seg.   5
 Skin buckling load factor,                   BUCMIN=2.7898E+00 at pt.12
 Smeared stringer/isogrid buckling load factor,BUCMNS=9.1698E+00 at pt. 2
 Smeared ring buckling load factor,           BUCMNR=1.0000E+17 at pt.13
 Smeared stringer/isogrid maximum eff. stress, STFMXS=6.9813E+04 at pt.12
 Smeared ring maximum effective stress,       STFMXR=0.0000E+00 at pt. 0
 Shell skin maximum effective stress,         SKNMAX=8.2542E+04 at pt.12
```

```
Local skin and smeared stiffener buckling and stress, Seg.   6
Skin buckling load factor,                    BUCMIN=2.7915E+00 at pt. 1
Smeared stringer/isogrid buckling load factor,BUCMNS=3.1585E+01 at pt. 2
Smeared ring buckling load factor,            BUCMNR=1.0000E+17 at pt.13
Smeared stringer/isogrid maximum eff. stress, STFMXS=6.9824E+04 at pt. 1
Smeared ring maximum effective stress,        STFMXR=0.0000E+00 at pt. 0
Shell skin maximum effective stress,          SKNMAX=8.2144E+04 at pt. 1

Local skin and smeared stiffener buckling and stress, Seg.   7
Skin buckling load factor,                    BUCMIN=3.1702E+00 at pt. 1
Smeared stringer/isogrid buckling load factor,BUCMNS=2.3329E+00 at pt.13
Smeared ring buckling load factor,            BUCMNR=1.0000E+17 at pt.13
Smeared stringer/isogrid maximum eff. stress, STFMXS=6.8607E+04 at pt. 1
Smeared ring maximum effective stress,        STFMXR=0.0000E+00 at pt. 0
Shell skin maximum effective stress,          SKNMAX=7.3148E+04 at pt. 1

Local skin and smeared stiffener buckling and stress, Seg.   8
Skin buckling load factor,                    BUCMIN=4.0972E+00 at pt.13
Smeared stringer/isogrid buckling load factor,BUCMNS=2.2758E+00 at pt. 2
Smeared ring buckling load factor,            BUCMNR=1.0000E+17 at pt.13
Smeared stringer/isogrid maximum eff. stress, STFMXS=8.9435E+04 at pt.13
Smeared ring maximum effective stress,        STFMXR=0.0000E+00 at pt. 0
Shell skin maximum effective stress,          SKNMAX=7.6971E+04 at pt.13

Local skin and smeared stiffener buckling and stress, Seg.   9
Skin buckling load factor,                    BUCMIN=4.1011E+00 at pt. 1
Smeared stringer/isogrid buckling load factor,BUCMNS=2.2320E+00 at pt. 5
Smeared ring buckling load factor,            BUCMNR=1.0000E+17 at pt.13
Smeared stringer/isogrid maximum eff. stress, STFMXS=1.1783E+05 at pt.13
Smeared ring maximum effective stress,        STFMXR=0.0000E+00 at pt. 0
Shell skin maximum effective stress,          SKNMAX=9.0706E+04 at pt.13

Local skin and smeared stiffener buckling and stress, Seg.  10
Skin buckling load factor,                    BUCMIN=4.8739E+00 at pt. 1
Smeared stringer/isogrid buckling load factor,BUCMNS=2.5118E+00 at pt. 2
Smeared ring buckling load factor,            BUCMNR=1.0000E+17 at pt.13
Smeared stringer/isogrid maximum eff. stress, STFMXS=1.2481E+05 at pt. 5
Smeared ring maximum effective stress,        STFMXR=0.0000E+00 at pt. 0
Shell skin maximum effective stress,          SKNMAX=9.1319E+04 at pt.13

Local skin and smeared stiffener buckling and stress, Seg.  11
Skin buckling load factor,                    BUCMIN=4.5637E+00 at pt.13
Smeared stringer/isogrid buckling load factor,BUCMNS=3.4244E+00 at pt. 1
Smeared ring buckling load factor,            BUCMNR=1.0000E+17 at pt.13
Smeared stringer/isogrid maximum eff. stress, STFMXS=1.1537E+05 at pt. 2
Smeared ring maximum effective stress,        STFMXR=0.0000E+00 at pt. 0
Shell skin maximum effective stress,          SKNMAX=1.0505E+05 at pt.13

Local skin and smeared stiffener buckling and stress, Seg.  12
Skin buckling load factor,                    BUCMIN=4.5650E+00 at pt. 1
Smeared stringer/isogrid buckling load factor,BUCMNS=5.8590E+00 at pt.13
Smeared ring buckling load factor,            BUCMNR=1.0000E+17 at pt.13
Smeared stringer/isogrid maximum eff. stress, STFMXS=8.1902E+04 at pt.13
Smeared ring maximum effective stress,        STFMXR=0.0000E+00 at pt. 0
Shell skin maximum effective stress,          SKNMAX=1.0503E+05 at pt. 1
```

```
 The following quantities are used to generate behavioral constraint
 conditions and margins:
                                                  PERTURBED  UNPERTURBED
 Region 1 skin buckling load factor,      bskin1=  2.7898E+00  2.7898E+00
 Region 1 stiffener buckling load factor, bstif1=  1.0785E+00  1.0785E+00
 Region 1 skin maximum effective stress,  sknmx1=  1.0383E+05  1.0383E+05
 Region 1 stiffener max. effective stress,stfmx1=  1.2200E+05  1.2200E+05
 Region 2 skin buckling load factor,      bskin2=  2.7915E+00  2.7915E+00
 Region 2 stiffener buckling load factor, bstif2=  2.2320E+00  2.2320E+00
 Region 2 skin maximum effective stress,  sknmx2=  1.0505E+05  1.0505E+05
 Region 2 stiffener max. effective stress,stfmx2=  1.2481E+05  1.2481E+05
 Normal displacement of shell at apex,     ENDUV=  4.4386E-01  4.4386E-01
========================================================================
```

NOTE: The values listed under the headings, "PERTURBED" and "UNPERTURBED" are identical here because this list corresponds to the "fixed" design analysis type in MAINSETUP (**ITYPE = 2**). There are no perturbations of the decision variables in an ITYPE = 2 run of OPTIMIZE. The values of bskin1 and bstif1 are the **minimum** values computed for all the segments in Region 1. The values of bskin2 and bstif2 are the **minimum** values computed for all the segments in Region 2. The values of sknmx1 and stfmx1 are the **maximum** values computed for all the segments in Region 1. The values of sknmx2 and stfmx2 are the **maximum** values computed for all the segments in Region 2. **The values of bskin1, bstif1, sknmx1, stfmx1, bskin2, bstif2, sknmx2, stfmx2, and ENDUV are used in the computation of Margins 14, 16, 18, 20, 15, 17, 19, 21, and 22, respectively, listed in Table 32.**

Table 46 is in [26].

Table 47 Maximum absolute values of stresses in the optimized designs listed in Table 33 of [26] as predicted by BIGBOSOR4 (elastic, Eq.8), BOSOR5 (elastic-plastic, Eq.7), and STAGS (elastic, Eq.7). Units are psi.

	isogrid-stiffened, imperfect (segment, node, fiber)		**isogrid-stiffened, perfect, Wimp=.0001 (segment, node, fiber)**		**unstiffened, imperfect (seg.node,f)**	**unstiffene “perfect” (seg.node,**
Program/Imperfection shape/ Region 1 or Region2 (See Fig. 2 for definition of Region 1 and Region 2).	maximum effective stress in skin	maximum meridional stress in isogrid	maximum effective stress in skin	maximum meridional stress in isogrid	maximum effective stress in skin [26]	maximum effective s in skin
BOSOR4/+mode 1/Region 1	89086 (5,8)	86190 (1,8)	101570 (4,12)	119670 (1,1)	84689 (2,1)	95914 (4,1
BOSOR5/+mode 1/Region 1	89090 (5,8,outer)	127834 (1,9,inner)	101530 (4,12,out)	157442* (1,1,inner)	84630 (2,1,outer)	96050 (4,1,outer)
STAGS /+mode 1/Region 1	89330	126900 (1,9,inner)	100600 (4,12,out)	150510 (1,1,inner)		
BOSOR4/+mode 1/Region 2	105430 (12,1)	124760 (9,7)	121610 (11,2)	122490 (10,2)	117440 (7,13)	118290 (12
BOSOR5/+mode 1/Region 2	105420 (12,1,outer)	115920 (9,7,inner)	121490 (11,2,in)	105456 (10,2,innr)	117840 (7,13,outer)	118260 (12,2,inner
STAGS /+mode 1/Region 2	100300 (12,1,inner)	116532 (9,7,inner)	120600 (11,1,in)	105902 (10,2,innr)	115800 (7,13,outer)	116900 (12,1,inner
BOSOR4/+mode 2/Region 1	83974 (5,1)	122550 (1,3)			116160 (1,13)	
BOSOR5/+mode 2/Region 1	83920 (5,1,outer)	157136* (1,3,inner)			116080 (1,13,outer)	
STAGS /+mode 2/Region 1	83000	176231 (1,3,inner)				
BOSOR4/+mode 2/Region 2	114380 (12,1)	123310 (12,3)			123210 (11,8)	
BOSOR5/+mode 2/Region 2	114450 (12,1,inner)	102718 (12,4,innr)			122780 (11,8,inner)	
STAGS /+mode 2/Region 2	111300 (12,1,inner)	99884 (12,4,innr)			120300 (11,8,inner)	
BOSOR4/-mode 1/Region 1	120520 (1,3)	117640 (5,13)			122840 (1,13)	
BOSOR5/-mode 1/Region 1	120560 (1,3,outer)	145544* (1,2,inner)			122450 (2,7,outer)	
STAGS /-mode 1/Region 1	116500 (1,3,outer)	138524 (1,2,inner)			122900 (2,7,outer)	
BOSOR5/-mode 1/Region 1		134918* (5,13,innr)				
STAGS /-mode 1/Region 1		128414 (5,13,innr)				
BOSOR4/-mode 1/Region 2	114310 (12,1)	121540 (12,4)			115250 (11,9)	
BOSOR5/-mode 1/Region 2	114390 (12,1,inner)	101108 (12,4,innr)			115250 (11,9,inner)	
STAGS /-mode 1/Region 2	111500 (12,1,inner)	100174 (12,4,innr)			116200 (11,9,inner)	
BOSOR4/-mode 2/Region 1	103830 (1,3)	122000 (1,2)			111300 (2,5)	

BOSOR5/-mode 2/Region 1	104210 (1,3,outer)	156492* (1,2,inner)			111360 (2,5,outer)	
STAGS /-mode 2/Region 1	100200 (1,3,outer)	179644 (1,2,inner)			111700 (2,5,outer)	
BOSOR4/-mode 2/Region 1		121910 (2,7)				
BOSOR5/-mode 2/Region 1		138782* (2,7,inner)				
STAGS /-mode 2/Region 1		136689 (2,7,inner)				
BOSOR4/-mode 2/Region 2	105050 (12,1)	124810 (10,5)			122620 (10,2)	
BOSOR5/-mode 2/Region 2	105070 (12,1,outer)	113022 (10,5,innr)			122190 (10,2,inner)	
STAGS /-mode 2/Region 2	100800 (12,1,outer)	113247 (10,5,innr)			115900 (10,2,inner)	

* some plastic flow occurs in the BOSOR5 model

Region 1: 0. < x < 17.63477 inches; Region 2: 17.63477 < x < x(equator), in which x = radial coordinate.

The STAGS results have (segment, node) entrees that are the same as those for the BOSOR5 results because the STAGS contour plots of stress show this approximately to be the case. The nodal point numbers do not apply literally in the case of the listings for STAGS.

BOSOR5 and STAGS agree reasonably well because in both applications the isogrid "layer" is treated as an elastic isotropic layer with smeared stiffeners and Poisson's ratio, nu = 1/3. In the BIGBOSOR4 application the same "smeared" model is used to compute the 6 x 6 constitutive matrix, C_{ij}, but the extreme fiber stress in the isogrid "layer" is calculated as if the most critical isogrid member is oriented in the meridional coordinate direction. The extreme fiber stress in that meridionally oriented member is obtained as described in Table 27 and in Eq.(8).

Where the BOSOR5 and STAGS predictions disagree the difference is caused primarily by plastic flow. The BOSOR5 results listed here account for plastic flow but the STAGS results are for elastic material.

NOTE: The column headed "**unstiffened, imperfect**" lists results corresponding to the optimum design listed in Table 33 of [26], the design from Section 8.2 that is severely under-designed as demonstrated in Fig. 94.

NOTE: The figure numbering here is the same as in [26]. Not all the figures from [26] are included with this "short" version of [26]. Therefore, the figure numbering, while increasing monotonically, is not consecutive in this paper.

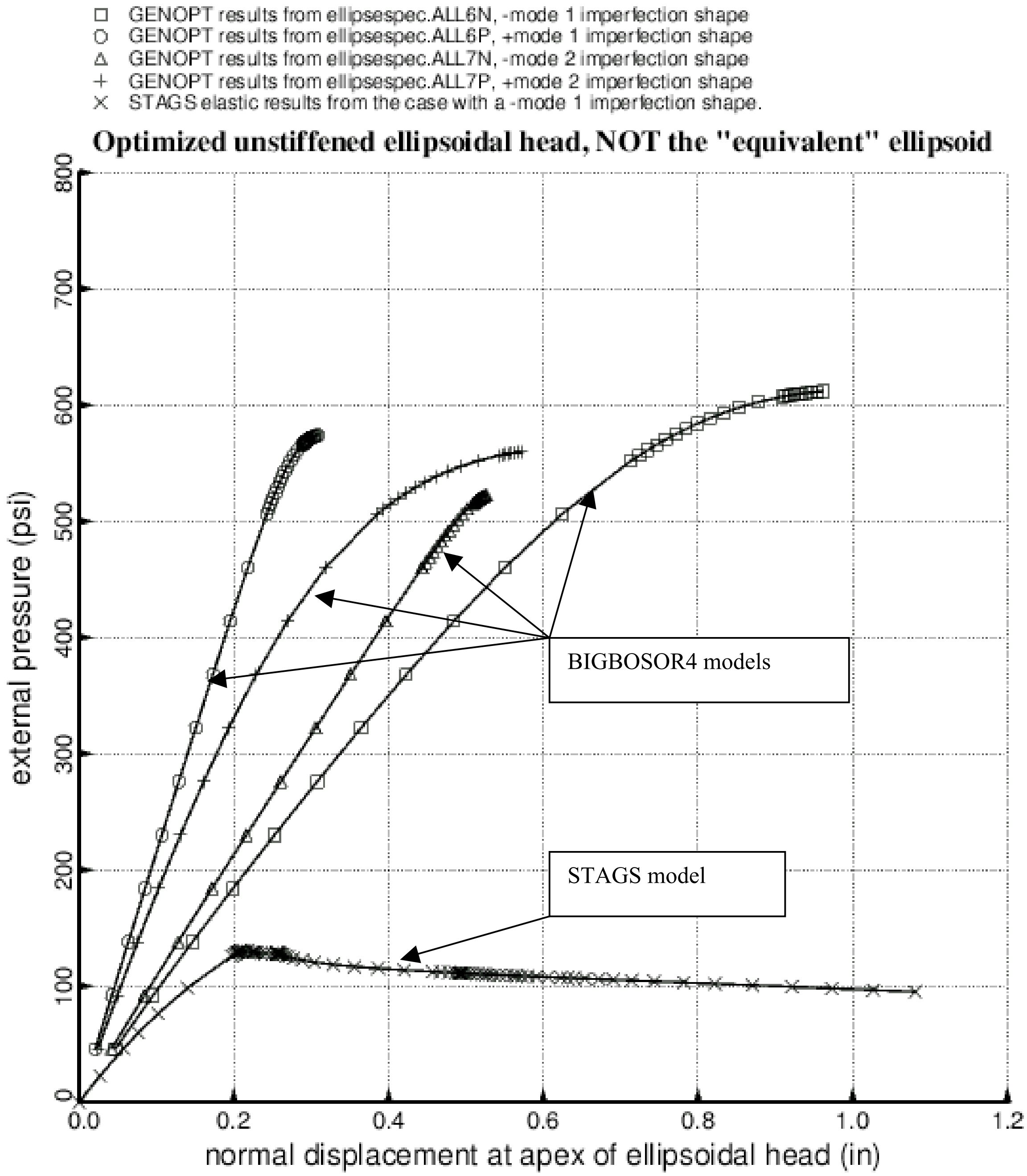

Fig. 1 Load-apex-deflection curves for an optimized, unstiffened, axisymmetrically imperfect, **TRUE** ellipsoidal shell under uniform external pressure. The "mode 1" and "mode 2" imperfection shapes are the first and second axisymmetric buckling modes of the perfect shell. The curves labeled "GENOPT" are obtained from BIGBOSOR4. The STAGS prediction is from a finite element model similar to that displayed in Fig. 6. The "GENOPT" predictions of maximum load-bearing capability are much higher than that from STAGS because of "finite element lockup" in the BIGBOSOR4 model. "Lockup" is avoided by representation of the **TRUE** ellipsoidal profile by an **EQUIVALENT** ellipsoidal profile such as that shown in the next figure, in which the meridional radius of curvature is constant within any one shell segment.

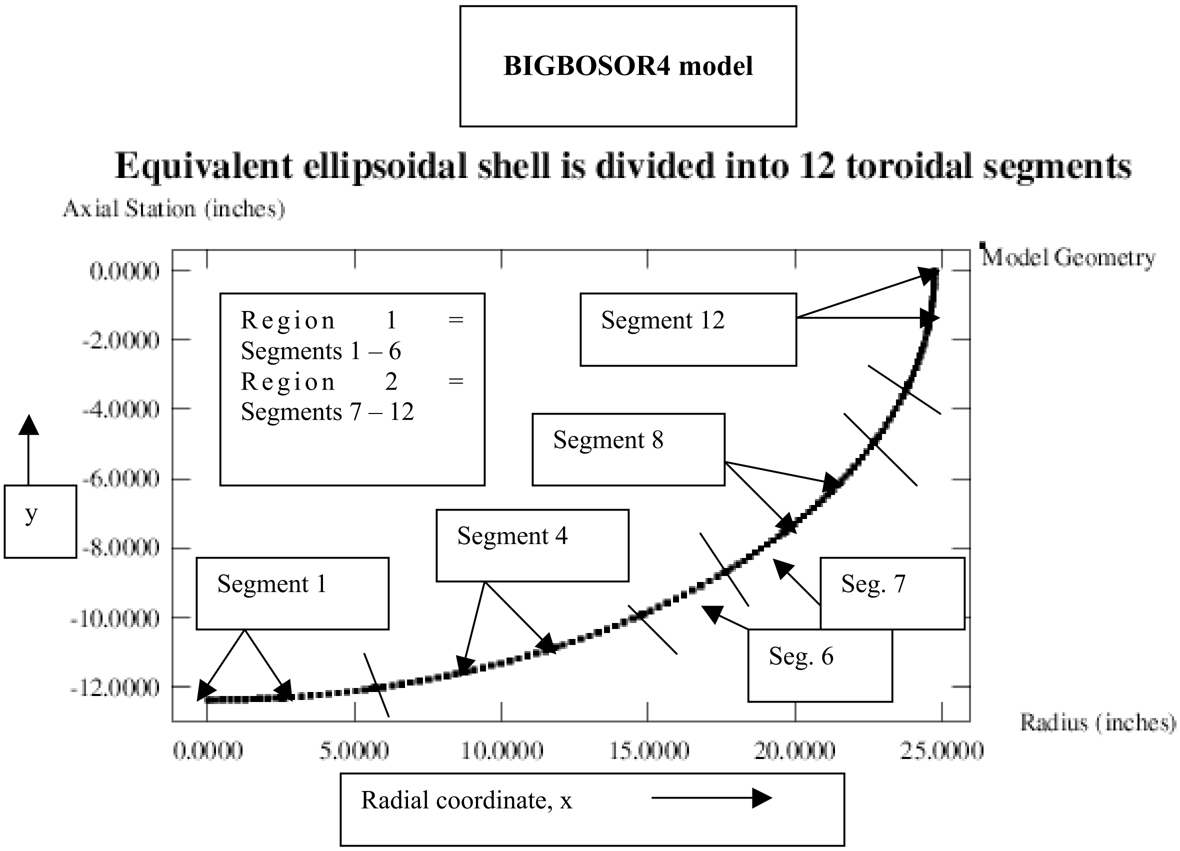

Fig. 2 This is a **BIGBOSOR4** model of the **EQUIVALENT** ellipsoidal shell. The equivalent ellipsoidal shell consists of 12 shell segments: one spherical cap (Segment 1) and 11 toroidal shell segments with end points that fall on the profile of the **TRUE** ellipsoidal shell and that match as closely as possible the local profile of the **TRUE** ellipsoidal shell. Finite element "lockup" is avoided because the meridional radius of curvature within each segment of the perfect **EQUIVALENT** ellipsoidal shell is constant. The (r,z) = (x,y) = (x_3,y_3) = (radius, axial station) location of the center of meridional curvature of each toroidal shell segment is computed as set forth in Table 29. Maximum local shell skin extreme fiber effective stress and minimum local skin buckling load factor and maximum local meridional isogrid member extreme fiber stress and minimum local meridional isogrid member buckling load factor are computed for each of the two regions: Region 1 and Region 2. The corresponding design margins are listed in Tables 31 and 32, for example. The 360-degree STAGS finite element model shown in Fig. a1 of the appendix is analogous to this BIGBOSOR4 model. The 360-degree STAGS finite element model has fewer nodal points along the meridian than the BIGBOSOR4 model shown here.

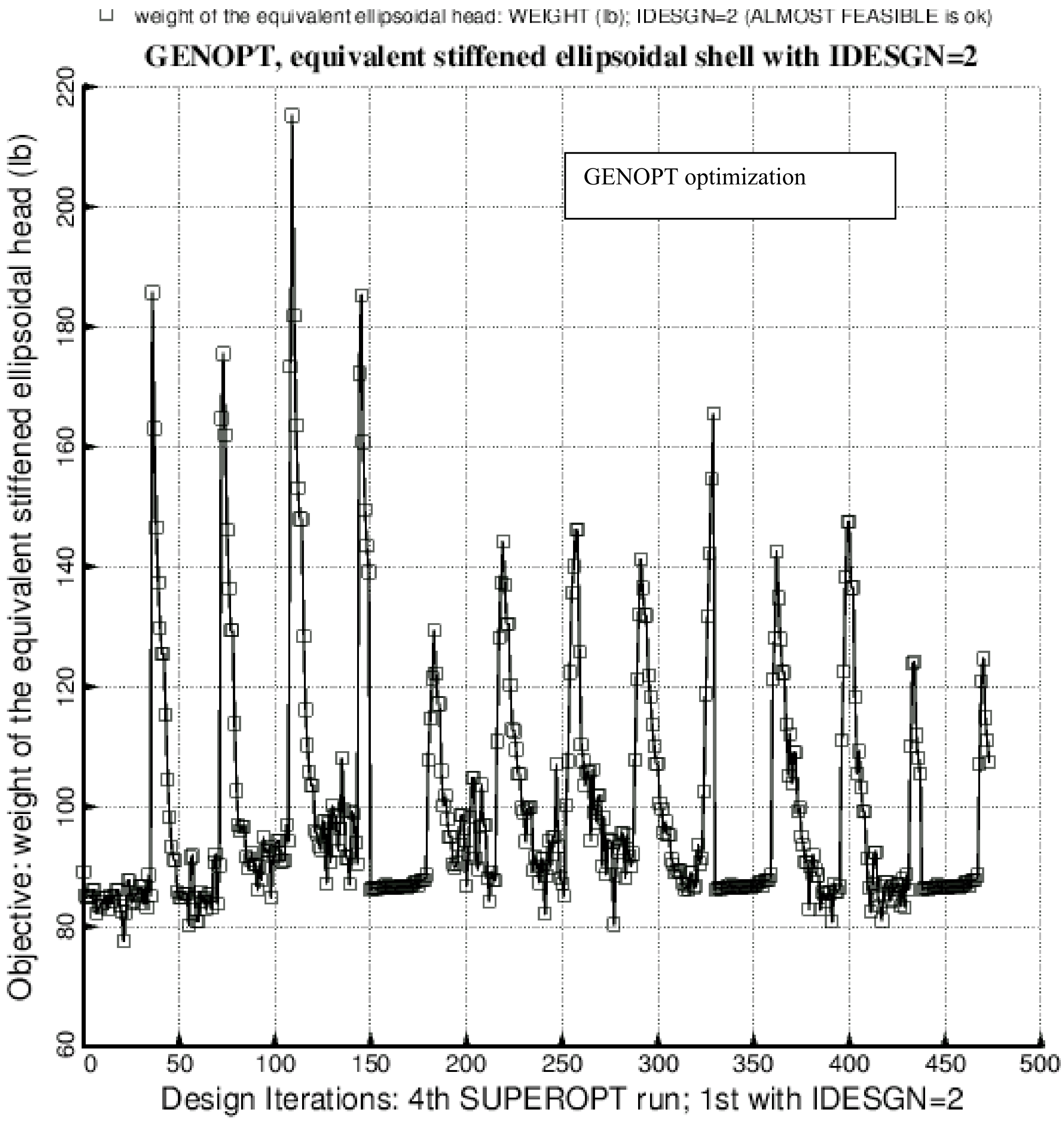

Fig. 3 Objective vs design iterations for the **isogrid-stiffened imperfect** shell for the last of a series of four executions of the GENOPT processor called **SUPEROPT**. Each "spike" in the plot corresponds to a new starting design, obtained randomly as described in [15]. The presence of the three "dense", "quiet" regions starting approximately at Iteration Numbers 150, 325, and 440, is explained in Section 9 on p. 10 of [24] and in sub-section 8.1.2 of this paper. The purpose of these "quiet" regions, within which the move limits of the decision variables are severely restricted, is to close in on a possibly better optimum design in the neighborhood of the "best" design determined previous to that iteration at which the "quiet" region begins. At the end of each "quiet" region the move limits of the decision variables are re-expanded to their values used during the "non-quiet" design iterations, that is, during most of the **SUPEROPT** process, during which in this example the objective is rather "jumpy" from design iteration to iteration. The starting design before the first SUPEROPT is listed in Table 35.

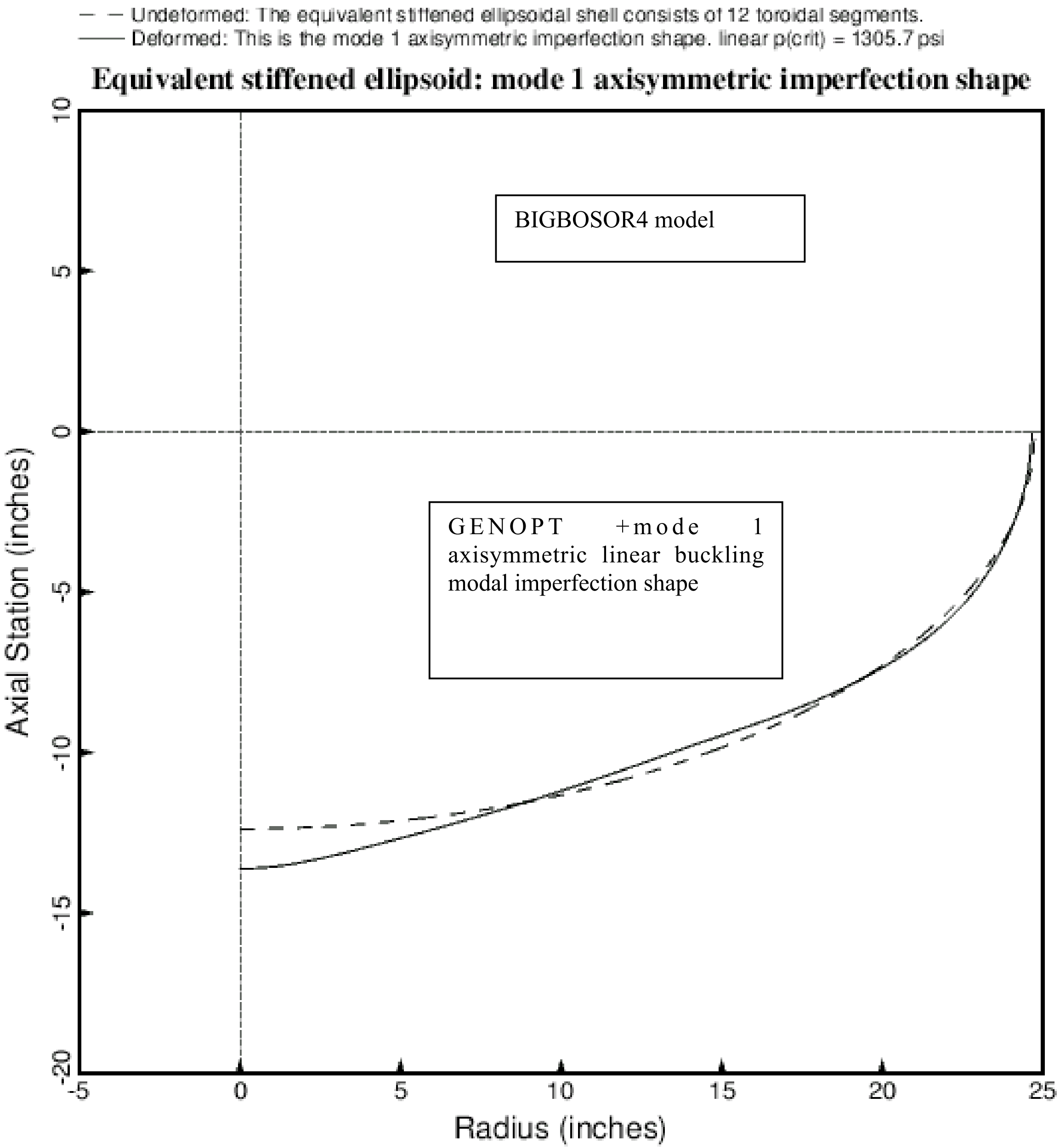

Fig. 4 First **axisymmetric** linear bifurcation buckling mode shape of the optimized **isogrid-stiffened** shell as computed by BIGBOSOR4. The corresponding linear bifurcation buckling pressure according to BIGBOSOR4 is p(crit) = 1305.7 psi. The program STAGS obtains a linear bifurcation buckling pressure of 1304.1 psi for this shell. (See Fig. 6). This axisymmetric mode, predicted by BIGBOSOR4, corresponds to the lowest eigenvalue in the STAGS model, as listed in Table 41. Compare with Fig. 6. This axisymmetric buckling mode is what is called in GENOPT jargon **"mode 1"**. Plus and minus versions of "mode 1" are used as initial axisymmetric imperfection shapes in computations of the local skin and stiffener stresses and buckling load factors, axisymmetric collapse loads, and general nonlinear bifurcation buckling load factors.

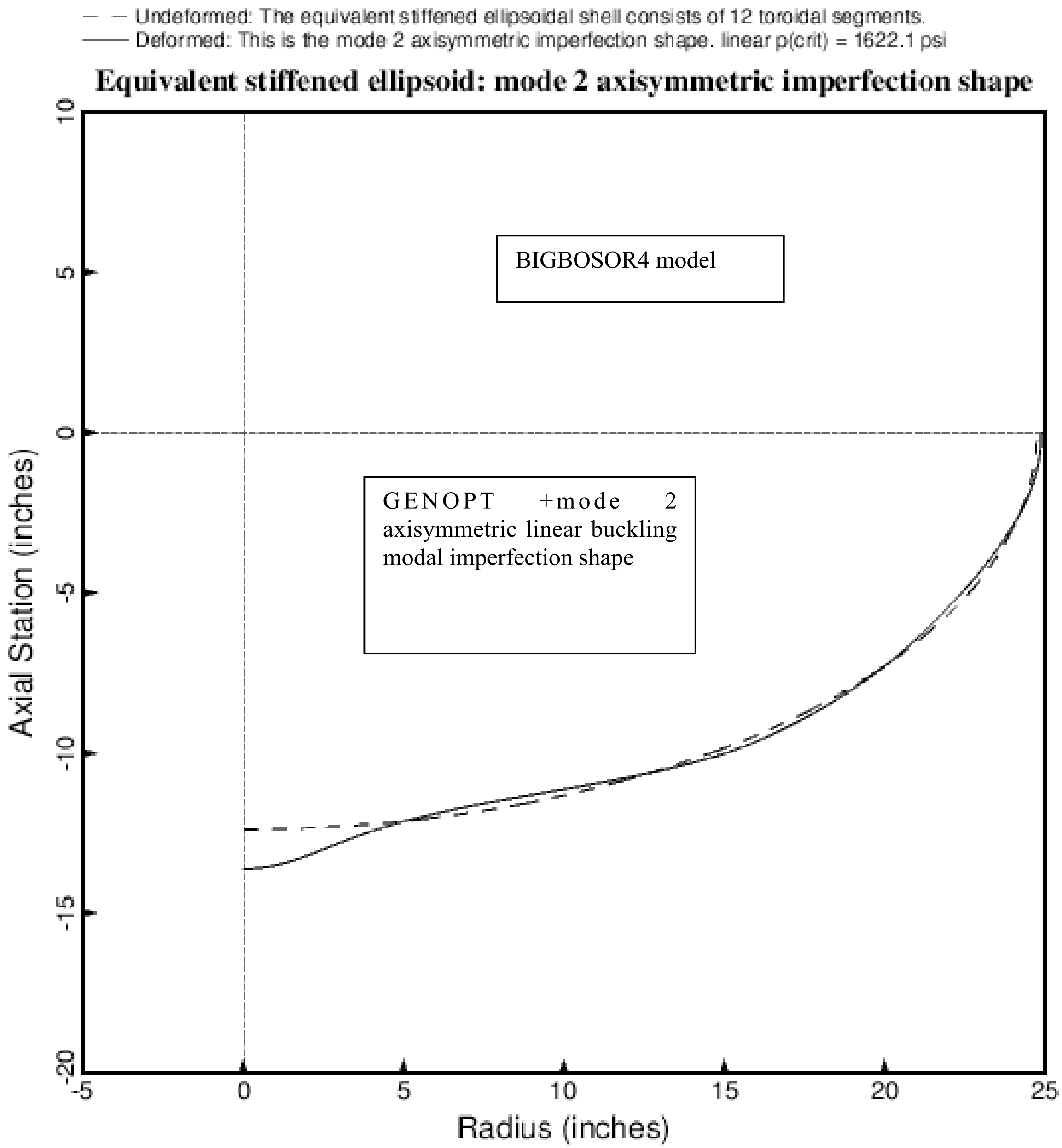

Fig. 5 Second **axisymmetric** bifurcation buckling mode shape of the optimized **isogrid-stiffened** shell as computed by BIGBOSOR4. The corresponding linear bifurcation buckling pressure according to BIGBOSOR4 is p(crit) = 1622.1 psi. The program STAGS obtains a linear bifurcation buckling pressure of 1612.3 psi for this second axisymmetric mode predicted by BIGBOSOR4. (See Fig. 9). In the STAGS model the second axisymmetric mode corresponds to the sixth eigenvalue, as listed in Table 41, following four non-axisymmetric modes, two of which are displayed in Figs. 7 and 8. Compare with Fig. 9. This axisymmetric buckling mode is what is called in GENOPT jargon **"mode 2"**. Plus and minus versions of "mode 2" are used as initial axisymmetric imperfection shapes in computations of the local skin and stiffener stresses and buckling load factors, axisymmetric collapse loads, and general nonlinear bifurcation buckling load factors.

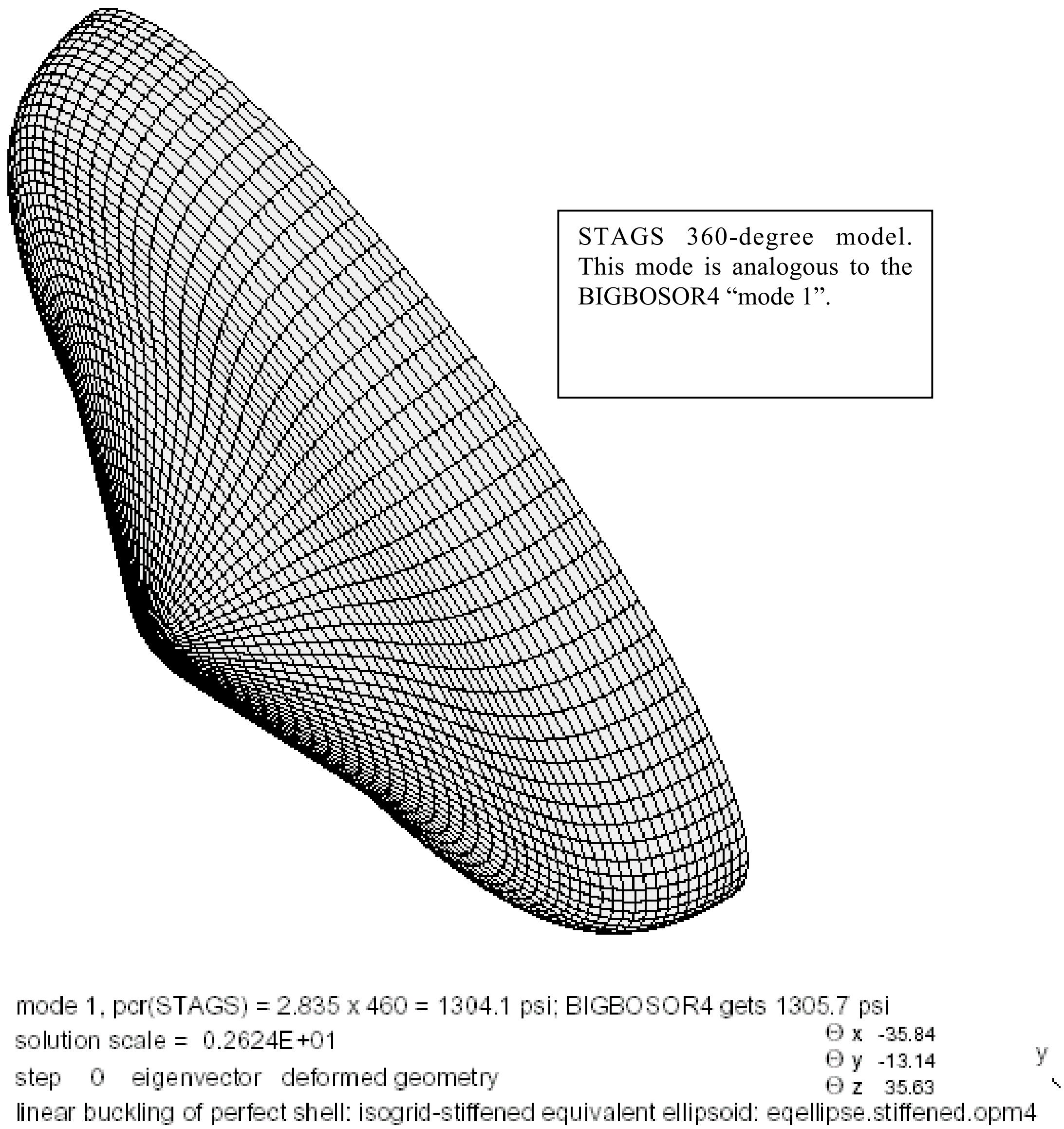

Fig. 6 Fundamental linear bifurcation buckling mode of **the optimized isogrid-stiffened equivalent ellipsoidal shell** according to the STAGS program. The STAGS finite element model is shown in Fig. a1 of the appendix. Compare with the BIGBOSOR4 prediction in Fig. 4. The axisymmetric buckling mode analogous to this one but computed by BIGBOSOR4 (Fig. 4) is what is called in GENOPT jargon “mode 1”. Plus and minus versions of this STAGS linear bifurcation buckling mode are used as initial imperfection shapes in STAGS computations of the local skin and stiffener stresses and buckling load factors, collapse loads, and general nonlinear bifurcation buckling load factors of the optimized isogrid-stiffened shell. Compare with the 10-degree “slice” model in Fig. 36. Compare with the 180-degree STAGS “soccerball” model in Fig. 257 of [26].

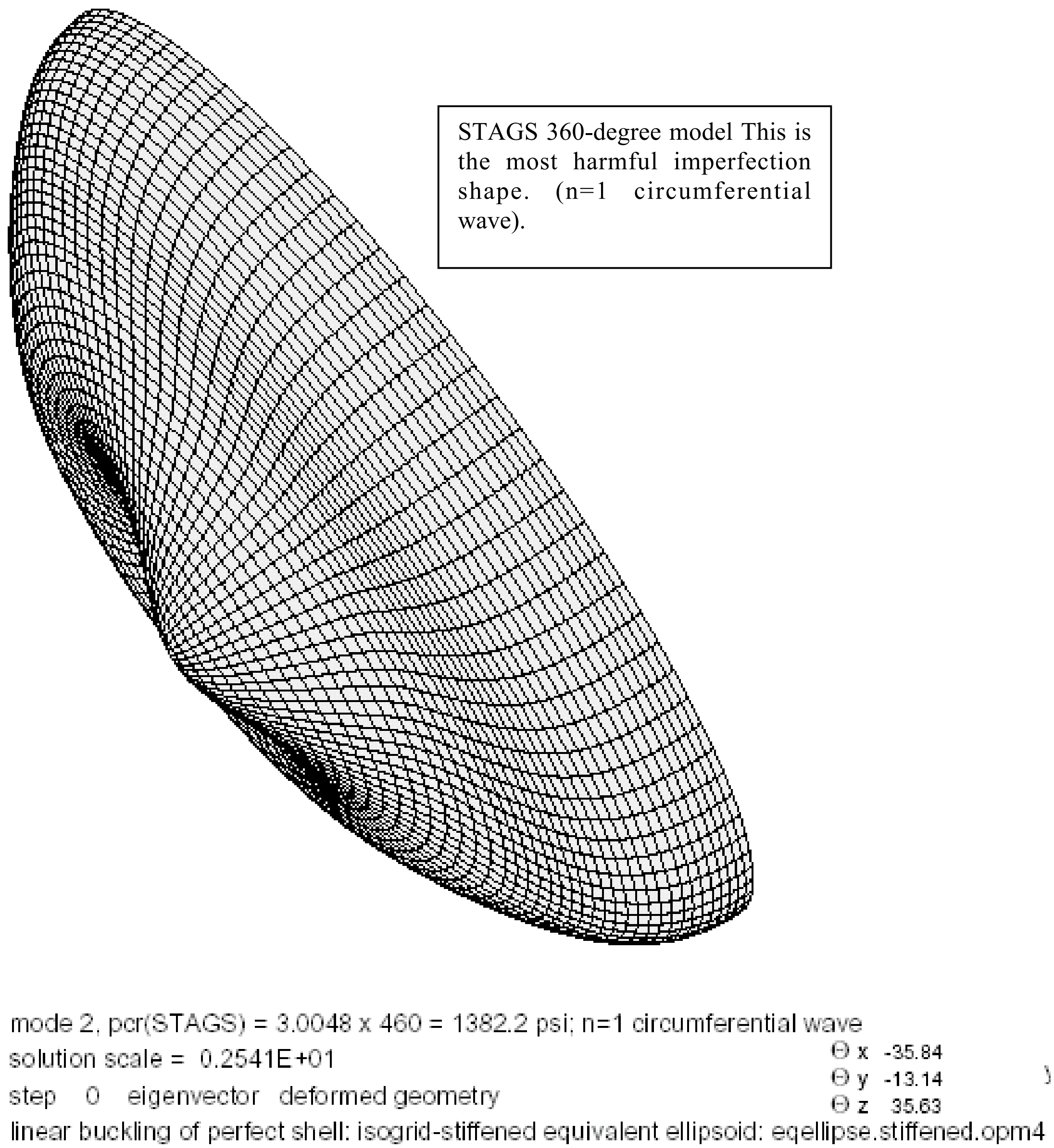

Fig. 7 Second linear bifurcation buckling mode of the optimized **isogrid-stiffened** equivalent ellipsoidal shell according to the STAGS program. This non-axisymmetric (n=1 circumferential wave) mode is the first of a pair of modes with exactly the same eigenvalue. The second non-axisymmetric mode in the pair is the same as the above except that the buckling mode is oriented differently circumferentially. This STAGS linear bifurcation buckling mode is used as an initial imperfection shape with amplitude, Wimp = 0.2 inch, to compute the nonlinear load-apex-deflection curve with upside-down triangles plotted as the seventh trace in Fig. 17. Compare with the 180-degree STAGS "soccerball" model in Fig. 258. **Shells of revolution with imperfections with this non-axisymmetric shape cannot be handled by BIGBOSOR4.** Therefore, GENOPT optimization occurs in the presence of only axisymmetric buckling modal imperfections.

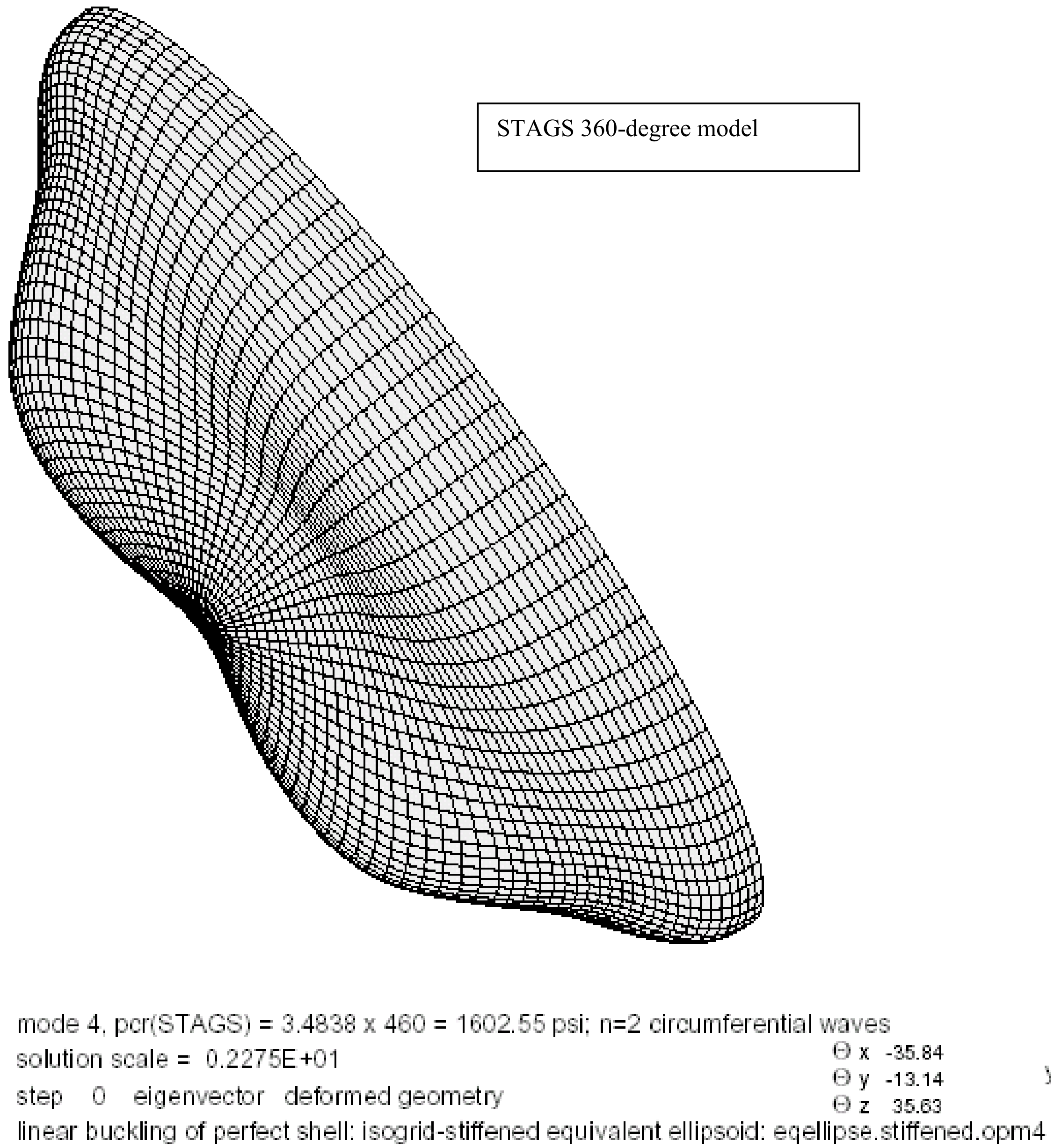

Fig. 8 Fourth linear bifurcation buckling mode of the optimized **isogrid-stiffened** equivalent ellipsoidal shell according to the STAGS program. This non-axisymmetric (n=2 circumferential waves) mode is the first of a pair of modes with exactly the same eigenvalue. The second non-axisymmetric mode in the pair is the same as the above except that the buckling mode is oriented differently circumferentially. This STAGS linear bifurcation buckling mode is used as an initial imperfection shape with amplitude, Wimp = 0.2 inch, to compute the nonlinear load-apex-deflection curve with boxes with internal x plotted as the eighth trace in Fig. 17. Compare with the 180-degree STAGS "soccerball" model in Fig. 261 of [26]. **Shells of revolution with imperfections with this non-axisymmetric shape cannot be handled by BIGBOSOR4.** Therefore, GENOPT optimization occurs in the presence of only axisymmetric buckling modal imperfections.

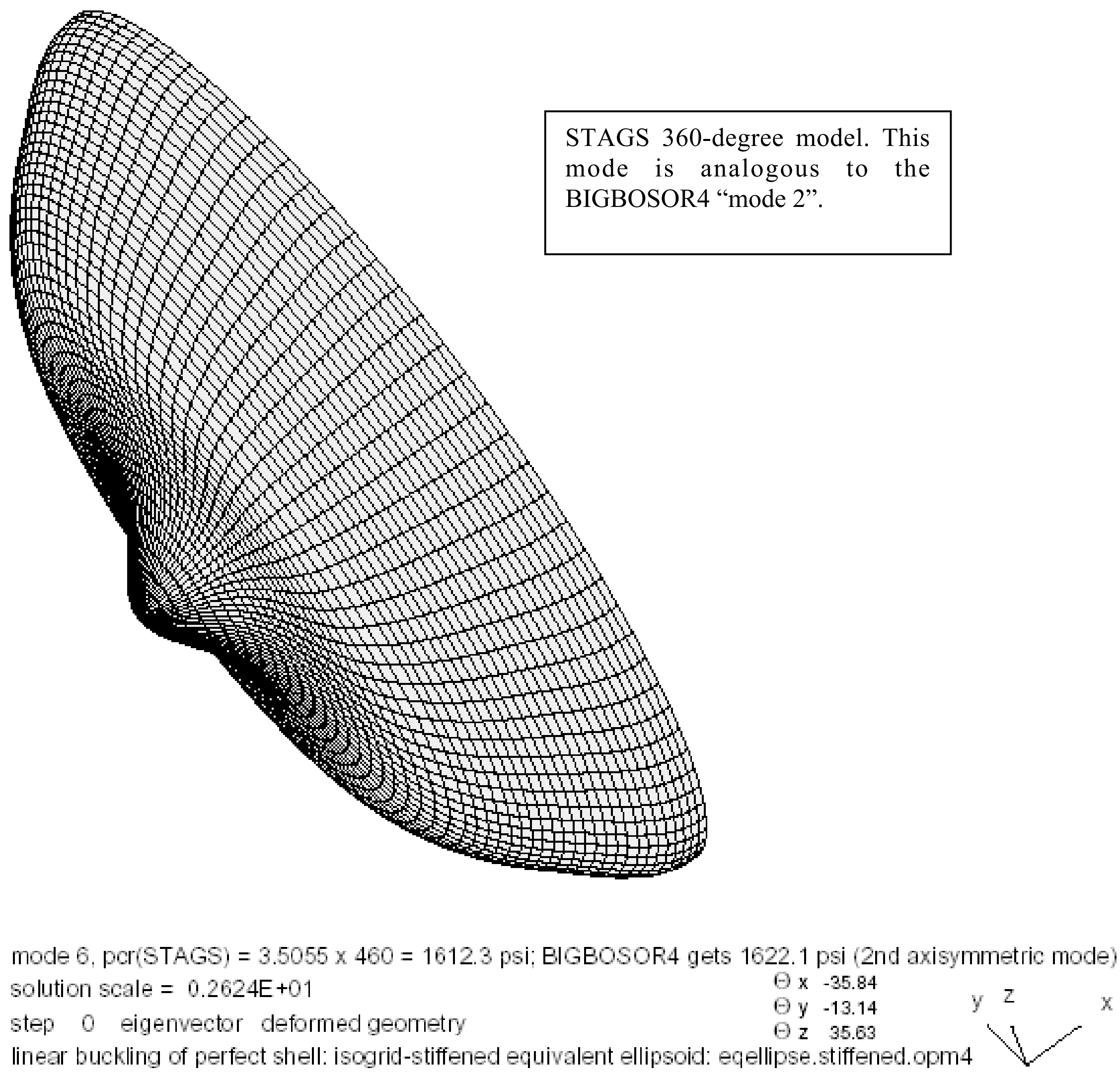

Fig. 9 Sixth linear bifurcation buckling mode of the optimized **isogrid-stiffened** equivalent ellipsoidal shell according to the STAGS program. Compare with the BIGBOSOR4 prediction in Fig. 5. The axisymmetric buckling mode analogous to this one but computed by BIGBOSOR4 (Fig. 5) is what is called in GENOPT jargon “mode 2”. Plus and minus versions of this STAGS linear bifurcation buckling mode are used as initial imperfection shapes in STAGS computations of the local skin and stiffener stresses and buckling load factors, collapse loads, and general nonlinear bifurcation buckling load factors. Compare with the 10-degree “slice” model in Fig. 37. Compare with the 180-degree STAGS “soccerball” model in Fig. 260 of [26].

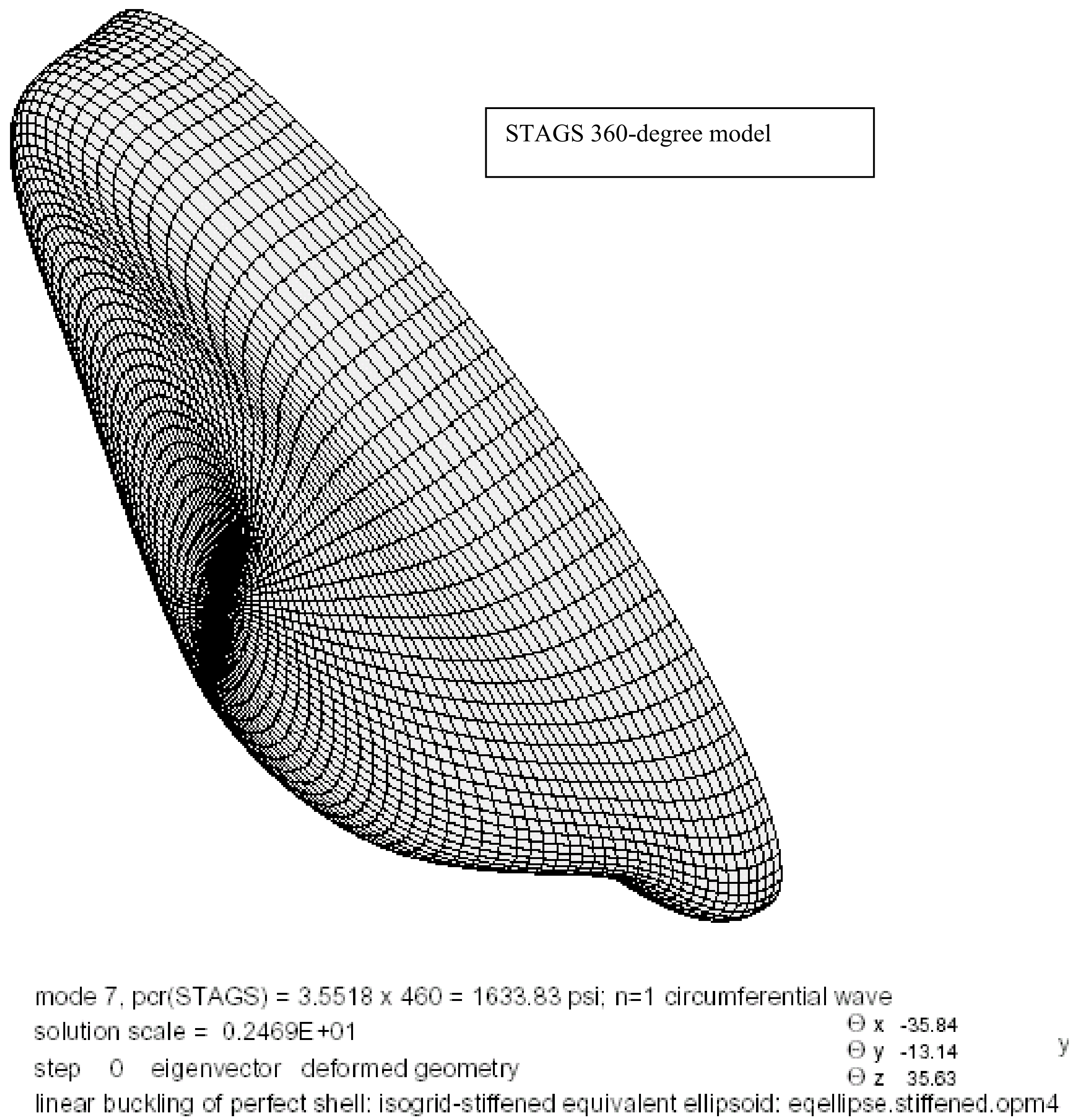

Fig. 10 Seventh linear bifurcation buckling mode of the optimized **isogrid-stiffened** equivalent ellipsoidal shell according to the STAGS program. This STAGS linear bifurcation buckling mode is used as an initial imperfection shape with amplitude, Wimp = 0.2 inch, to compute the nonlinear load-apex-deflection curve plotted as the last trace in Fig. 17. Compare with the 180-degree STAGS "soccerball" model in Fig. 262. **Shells of revolution with imperfections with this non-axisymmetric shape cannot be handled by BIGBOSOR4.** Therefore, GENOPT optimization occurs in the presence of only axisymmetric buckling modal imperfections.

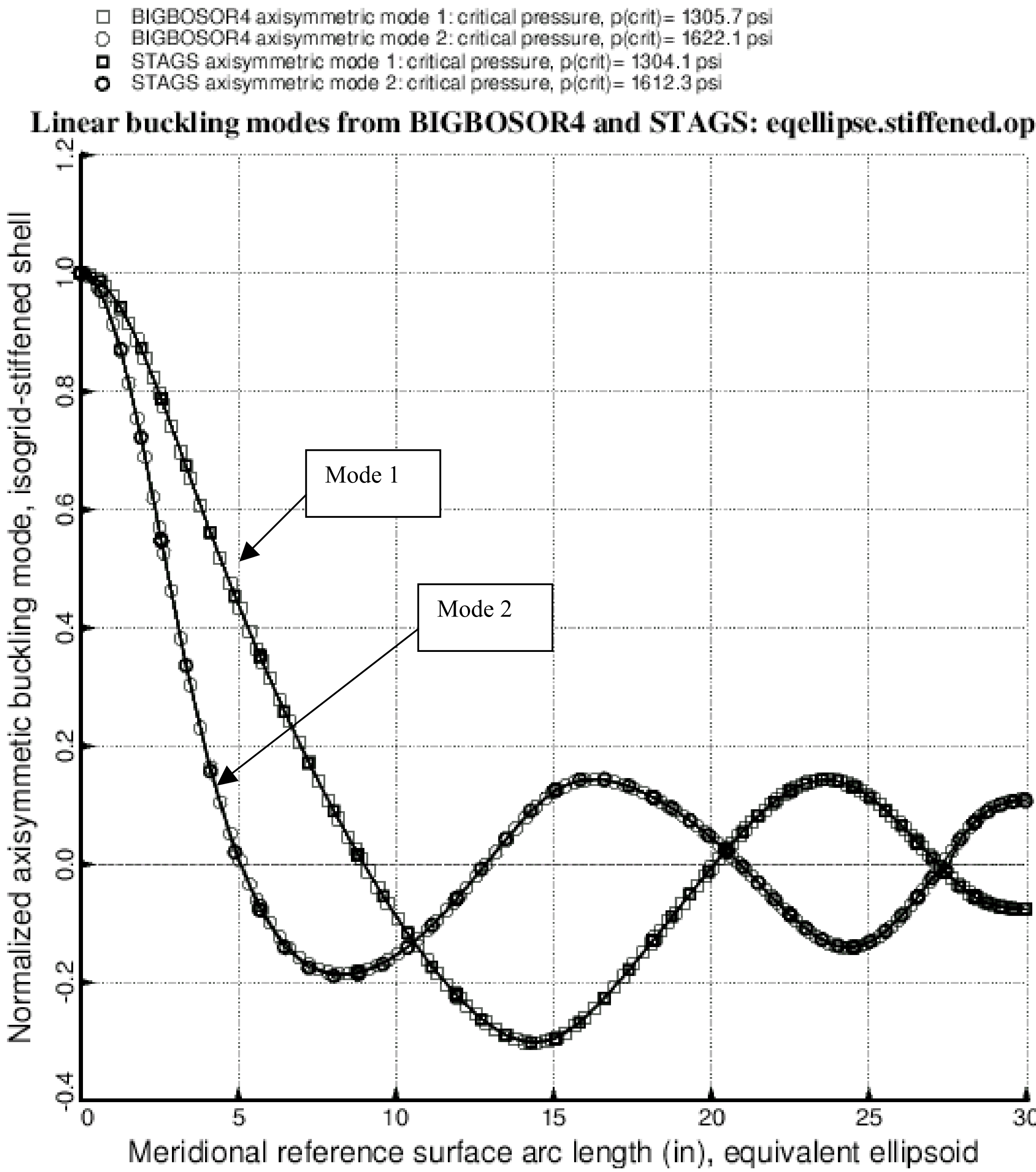

Fig. 11 Comparison of axisymmetric modes 1 and 2 as predicted by BIGBOSOR4 and as predicted by the 360-degree STAGS finite element model shown in Fig. a1 for the optimized **isogrid-stiffened** equivalent ellipsoidal shell. Plotted here is the normal linear buckling modal displacement w along a meridian from pole to equator. The excellent agreement between BIGBOSOR4 and STAGS of these axisymmetric linear bifurcation buckling mode shapes, which are used as initial imperfections in nonlinear analyses by BIGBOSOR4 and STAGS, leads to good agreement between BIGBOSOR4 and STAGS of the maximum load-bearing capability of the imperfect shells with plus and minus axisymmetric mode 1 and mode 2 imperfections. (See Fig. 16).

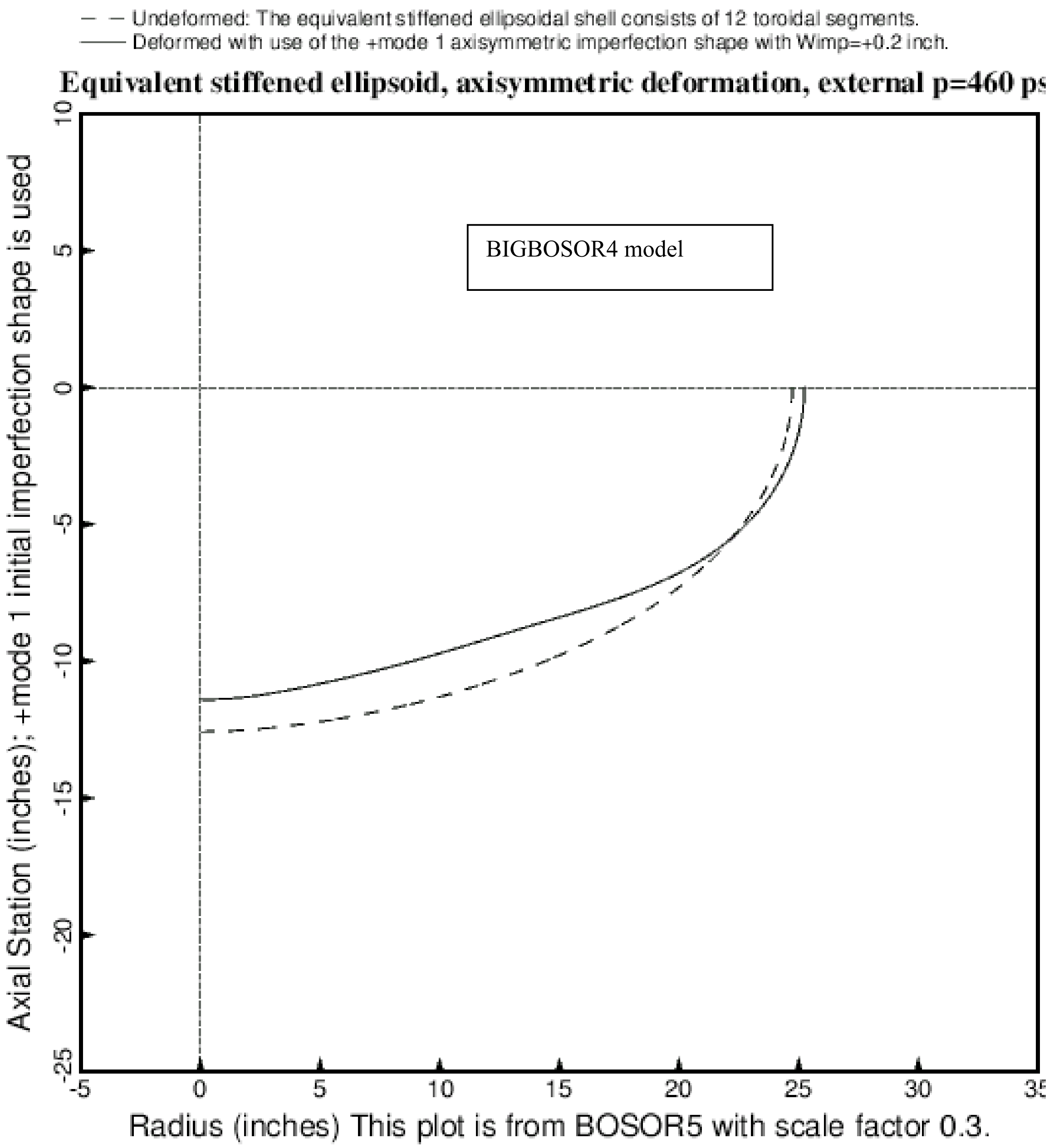

Fig. 12 BIGBOSOR4 prediction of axisymmetric deformation of the optimized **imperfect isogrid-stiffened** equivalent ellipsoidal shell with an axisymmetric +mode 1 linear bifurcation buckling modal imperfection shape with amplitude, Wimp = +0.2 inches. The applied external pressure is the design pressure, p = 460 psi. The shape of the buckling modal imperfection is displayed in Fig. 4. The maximum stresses and local buckling load factors of skin and meridionally oriented isogrid members computed by BIGBOSOR4 and associated with this deformation pattern are listed in Table 42.

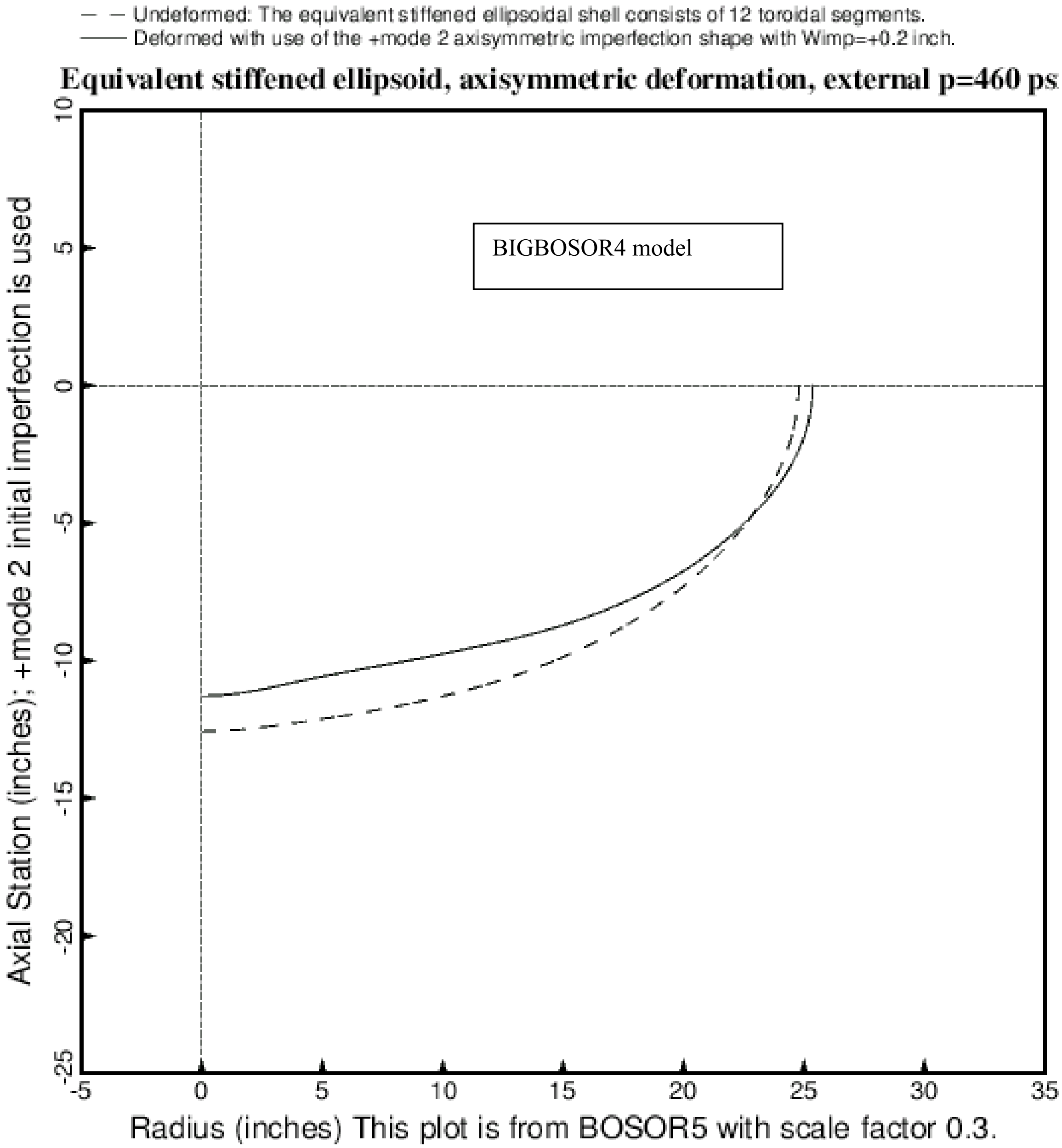

Fig. 13 BIGBOSOR4 prediction of axisymmetric deformation of the optimized **imperfect isogrid-stiffened** equivalent ellipsoidal shell with an axisymmetric +mode 2 linear bifurcation buckling modal imperfection shape with amplitude, Wimp = +0.2 inches. The applied external pressure is the design pressure, p = 460 psi. The shape of the buckling modal imperfection is displayed in Fig. 5. The maximum stresses and local buckling load factors of skin and meridionally oriented isogrid members computed by BIGBOSOR4 and associated with this deformation pattern are listed in Table 43.

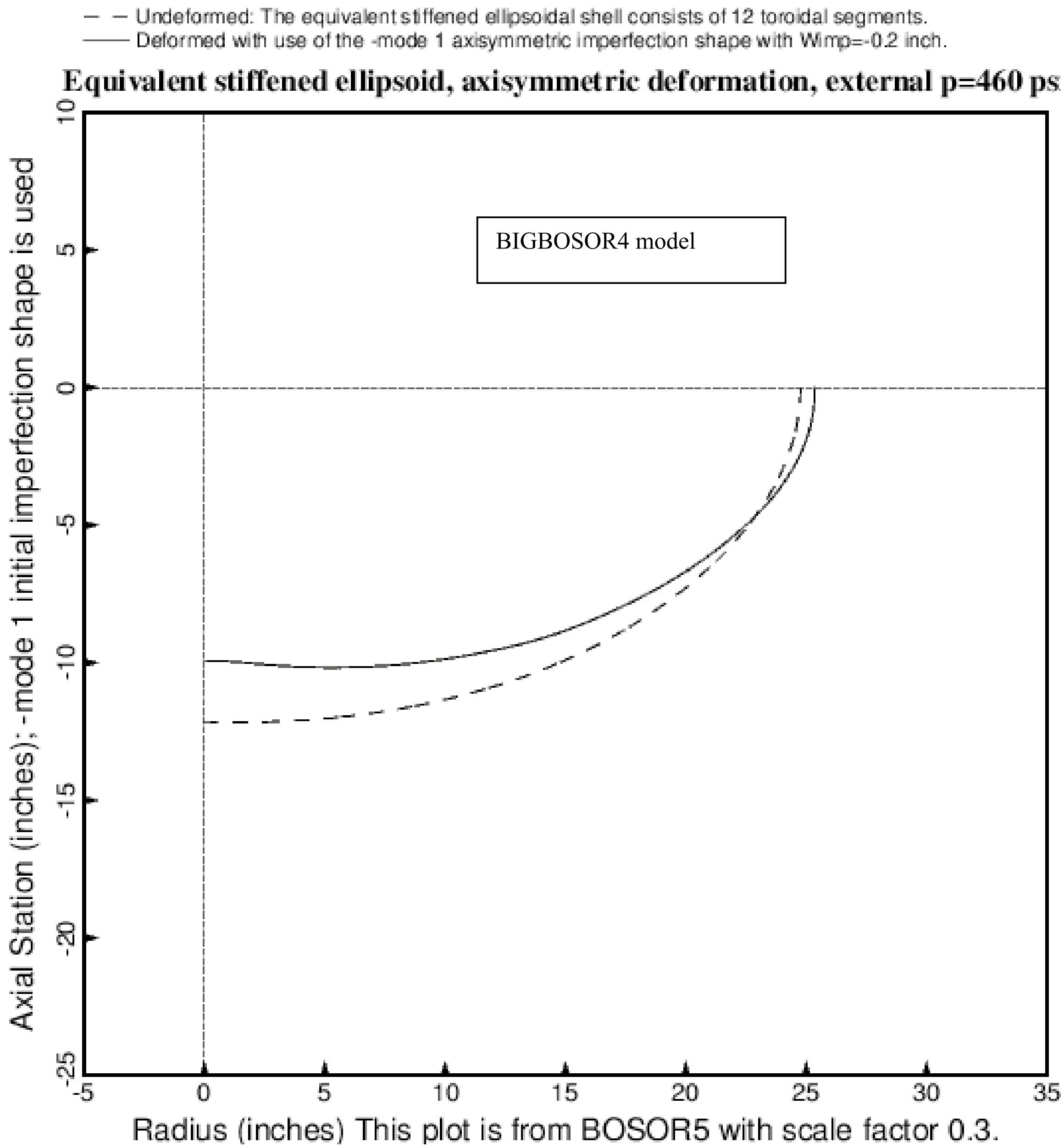

Fig. 14 BIGBOSOR4 prediction of axisymmetric deformation of the optimized **imperfect isogrid-stiffened** equivalent ellipsoidal shell with an axisymmetric –mode 1 linear bifurcation buckling modal imperfection shape with amplitude, Wimp = –0.2 inches. The applied external pressure is the design pressure, p = 460 psi. The shape of the buckling modal imperfection is the **negative** of that displayed in Fig. 4. The maximum stresses and local buckling load factors of skin and meridionally oriented isogrid members computed by BIGBOSOR4 and associated with this deformation pattern are listed for each shell segment in Table 44. The –mode 1 imperfection shape is the most critical with respect to axisymmetric collapse of the shell, as demonstrated in Fig. 16. Compare with Fig. 82 in [26], which pertains to the optimized unstiffened equivalent ellipsoidal shell.

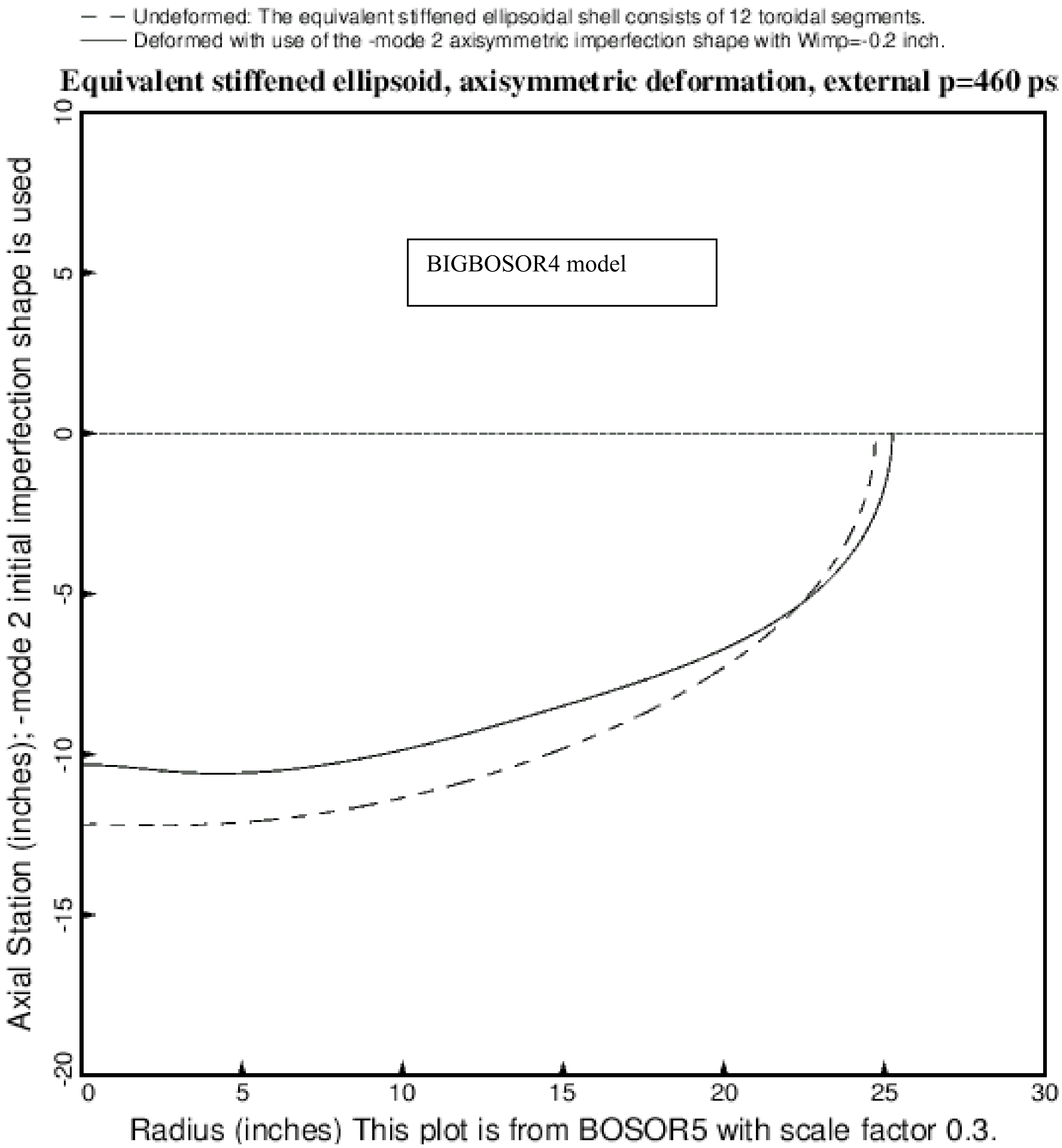

Fig. 15 BIGBOSOR4 prediction of axisymmetric deformation of the optimized **imperfect isogrid-stiffened** equivalent ellipsoidal shell with an axisymmetric –mode 2 linear bifurcation buckling modal imperfection shape with amplitude, Wimp = –0.2 inches. The applied external pressure is the design pressure, p = 460 psi. The shape of the buckling modal imperfection is the **negative** of that displayed in Fig. 5. The maximum stresses and local buckling load factors of skin and meridionally oriented isogrid members computed by BIGBOSOR4 and associated with this deformation pattern are listed in Table 45.

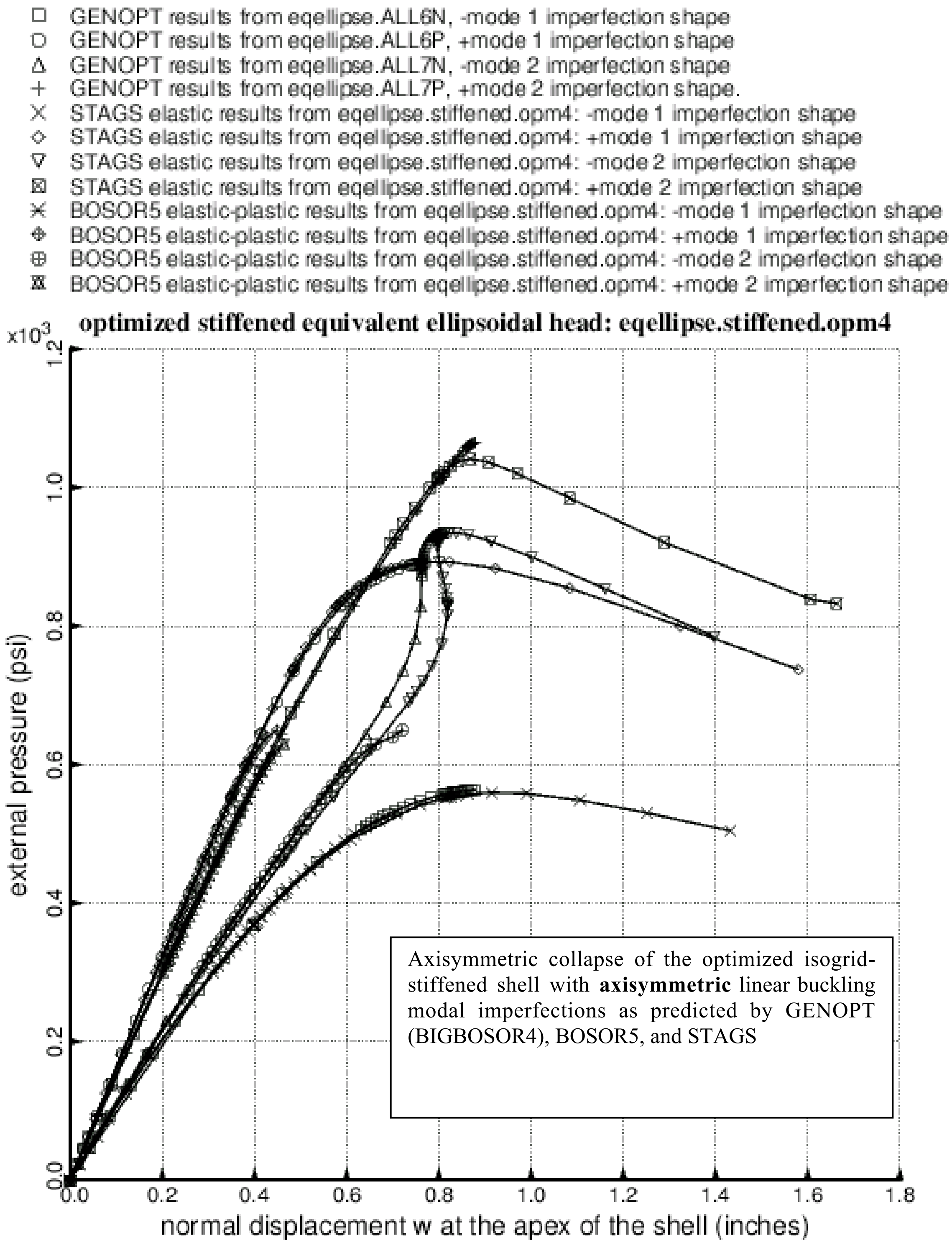

Fig. 16 Axisymmetric collapse of the optimized axisymmetrically **imperfect isogrid-stiffened** equivalent ellipsoidal shell under uniform external pressure from BIGBOSOR4 (elastic material), STAGS (elastic material) and BOSOR5 (elastic-plastic material). Compare with Fig. 83 of [26], which pertains to the optimized unstiffened shell. Compare trace 5 with results plotted in Fig. 254 for several STAGS models.

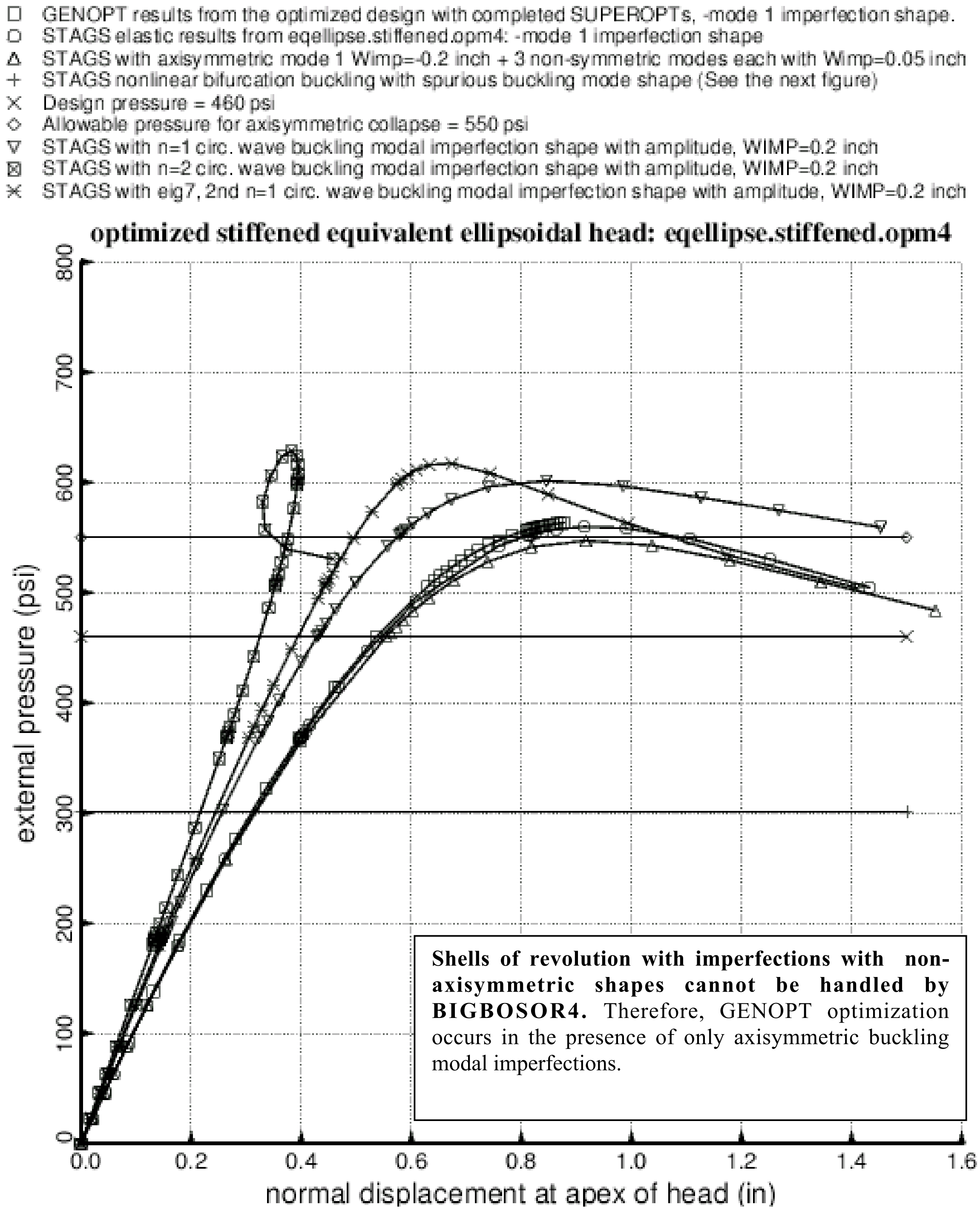

Fig. 17 Axisymmetric and non-axisymmetric collapse of optimized **imperfect isogrid-stiffened** equivalent ellipsoidal shells. The linear bifurcation buckling modal imperfection shapes corresponding to non-axisymmetric collapse (the last three traces) are displayed in Figs. 7, 8, and 10. In this case the –mode 1 (axisymmetric) buckling modal imperfection is predicted to be more harmful than the non-axisymmetric buckling modal imperfections with shapes given in Figs. 7, 8 and 10. This does not hold for the optimized unstiffened imperfect shell, as seen in Fig. 94. Compare with Fig. 254.

NOTE: Figures 18 and 19 in [26].

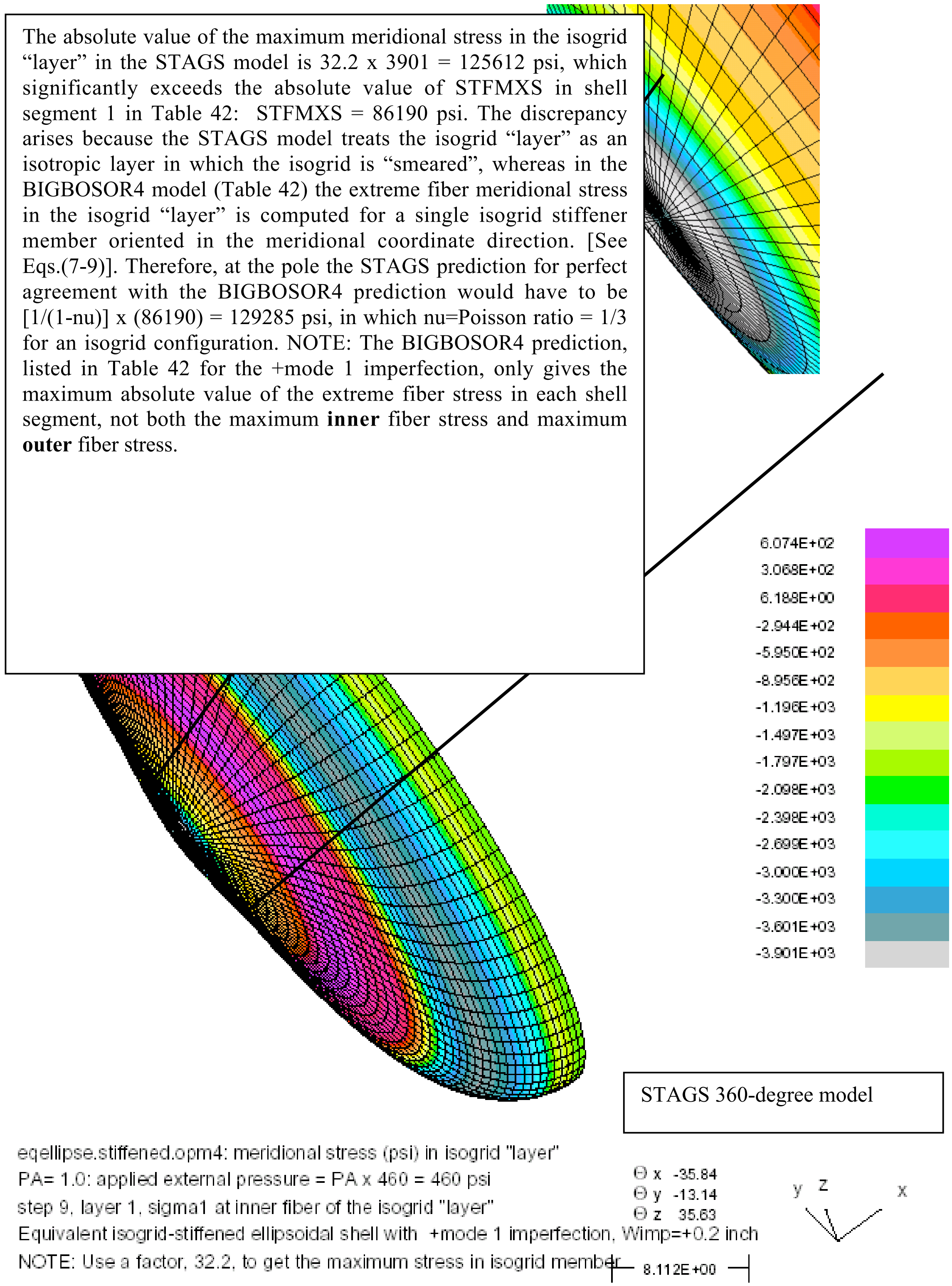

Fig. 20 STAGS prediction of the **inner fiber meridional stress sigma1 (psi) in the isogrid "layer"** of the optimized **+mode 1 imperfect isogrid-stiffened** equivalent ellipsoidal shell subjected to the external design pressure, p = 460 psi. Compare with STFMXS in Table 42. Compare with the 10-degree "slice" model in Fig. 39 of [26].

NOTE: Figures 21 – 35 are in [26].

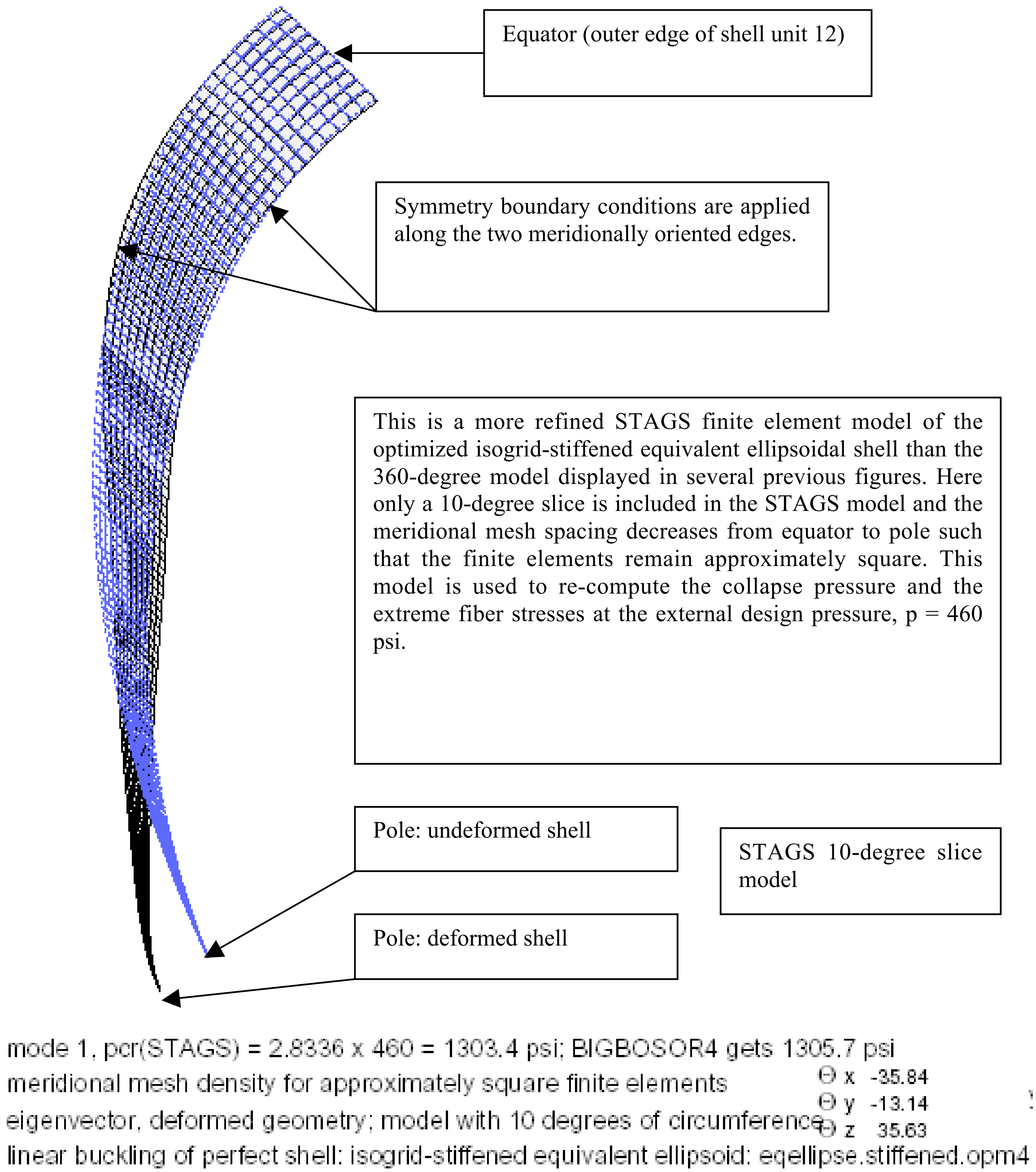

Fig. 36 STAGS prediction of linear bifurcation buckling of the optimized **isogrid-stiffened** equivalent ellipsoidal shell from a refined model that subtends 10 degrees of circumference. This is the fundamental (lowest eigenvalue) buckling mode from STAGS. The analogous axisymmetric mode computed by BIGBOSOR4 (Fig. 4) is called "**mode 1**" in the GENOPT jargon. Compare with Figs. 4 and 6.

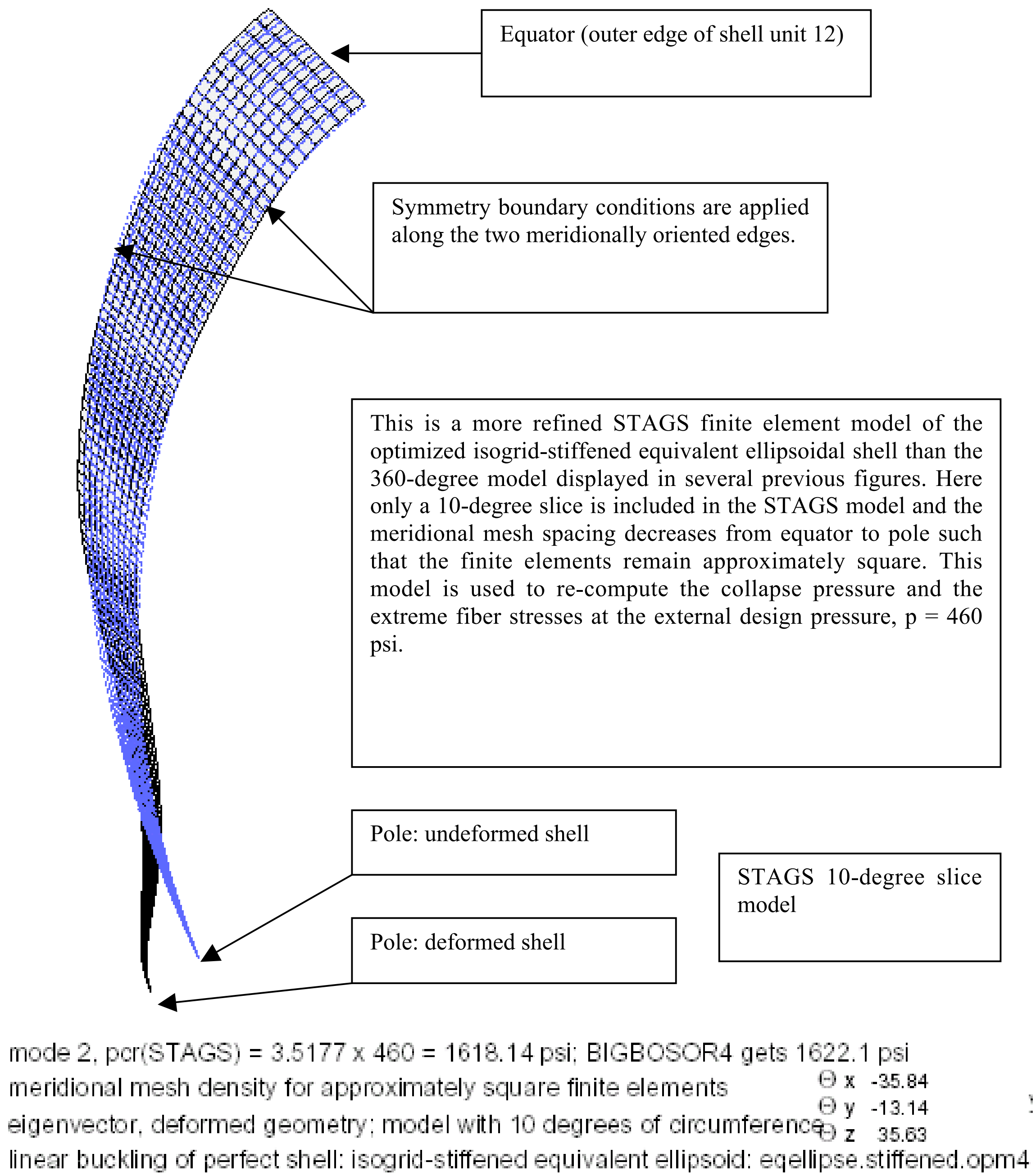

Fig. 37 STAGS prediction of linear bifurcation buckling of the optimized **isogrid-stiffened** equivalent ellipsoidal shell from a refined model that subtends 10 degrees of circumference. For the "slice" STAGS model this is the second buckling mode. The analogous axisymmetric mode computed by BIGBOSOR4 (Fig. 5) is called "**mode 2**" in the GENOPT jargon. Compare with Figs. 5 and 9. In the 360-degree STAGS model this mode corresponds to the sixth eigenvalue (Fig. 9).

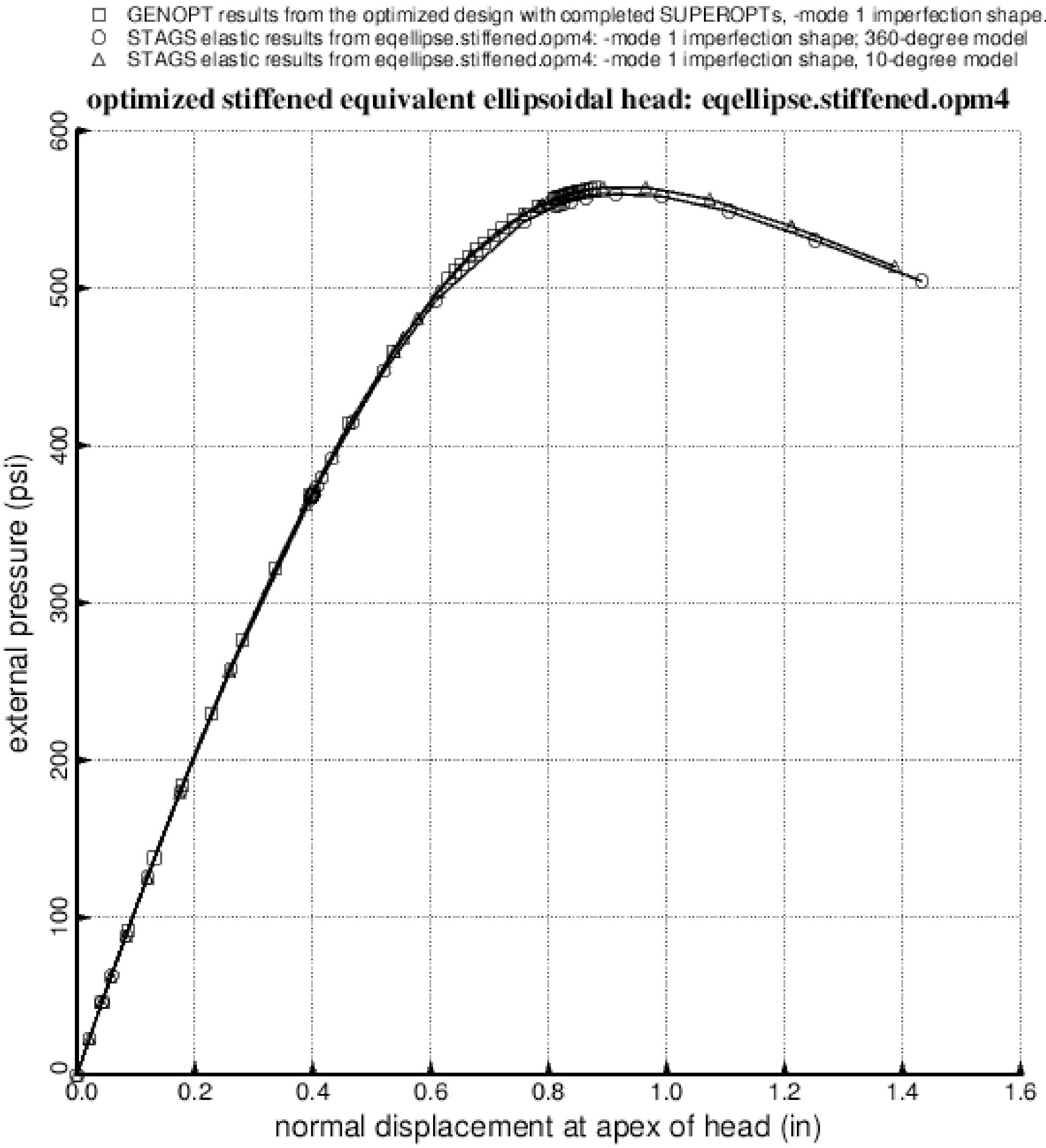

Fig. 38 Prediction of axisymmetric collapse of the optimized **imperfect isogrid-stiffened** equivalent ellipsoidal shell with a **–mode 1** linear axisymmetric buckling modal imperfection shape with amplitude, Wimp = -0.2 inch. The imperfection shape predicted by BIGBOSOR4 is shown in Fig. 4 and that predicted by STAGS is shown in Fig. 6 for the 360-degree STAGS finite element model and in Fig. 36 for the 10-degree "slice" STAGS model.

NOTE: Figures 39 – 46 are in [26].

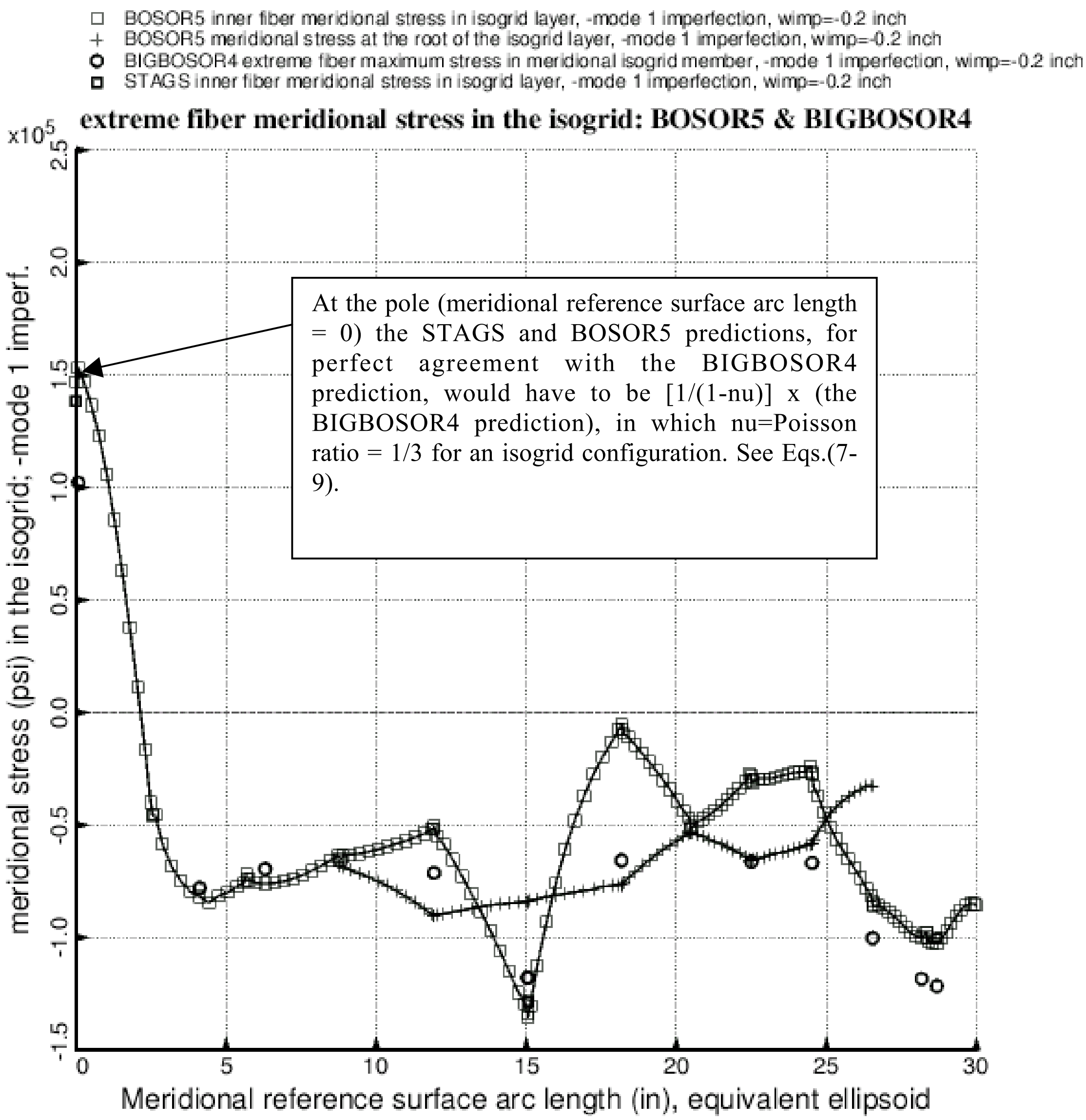

Fig. 47 Comparison of extreme fiber meridional stress distribution in the isogrid "layer" from BOSOR5 (elastic material), BIGBOSOR4, and STAGS for the optimized **imperfect isogrid-stiffened** equivalent ellipsoidal shell with a **–mode 1** imperfection with amplitude, Wimp = -0.2 inch. The applied external pressure is the design pressure, p = 460 psi. BOSOR5 and STAGS agree because in both applications the isogrid "layer" is treated as an elastic isotropic layer with smeared stiffeners and Poisson's ratio, nu = 1/3. In the BIGBOSOR4 application the same "smeared" model is used to compute the 6 x 6 constitutive matrix, C_{ij}, but the extreme fiber stress in the isogrid "layer" is calculated as if the most critical isogrid member is oriented in the meridional coordinate direction. The extreme fiber stress in that meridionally oriented member is obtained as described in Table 27 and in Eq.(8). NOTE: The BIGBOSOR4 prediction, listed in Table 44 for the –mode 1 imperfection, only gives the maximum extreme fiber stress in each shell segment, not both the maximum **inner** fiber stress and maximum **outer** fiber stress.

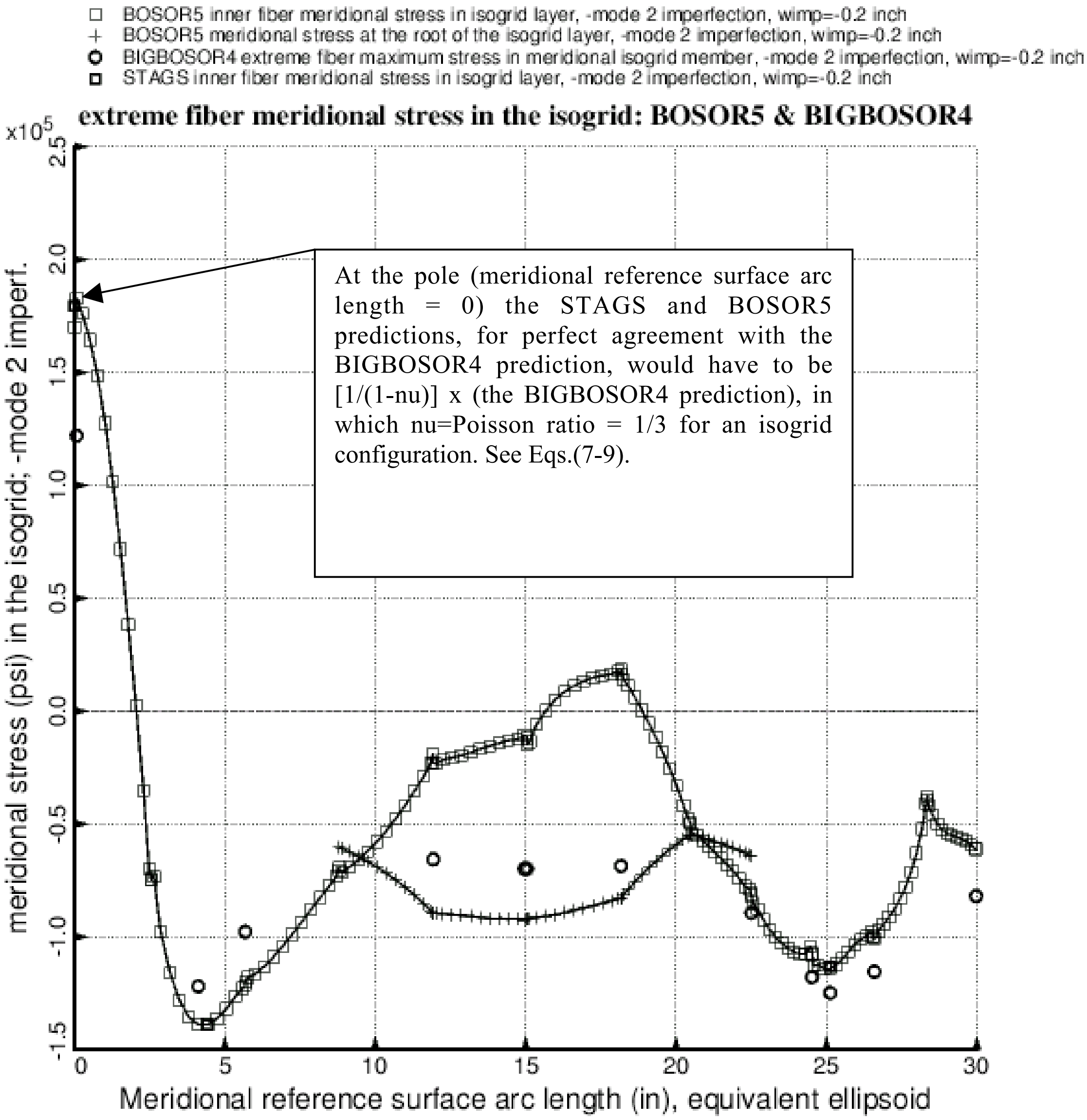

Fig. 48 Comparison of extreme fiber meridional stress distribution in the isogrid "layer" from BOSOR5, BIGBOSOR4, and STAGS for the optimized **imperfect isogrid-stiffened** equivalent ellipsoidal shell with a **–mode 2** imperfection with amplitude, Wimp = -0.2 inch. The applied external pressure is the design pressure, p = 460 psi. BOSOR5 and STAGS agree because in both applications the isogrid "layer" is treated as an elastic isotropic layer with smeared stiffeners and Poisson's ratio, nu = 1/3. In the BIGBOSOR4 application the same "smeared" model is used to compute the 6 x 6 constitutive matrix, C_{ij}, but the extreme fiber stress in the isogrid "layer" is calculated as if the most critical isogrid member is oriented in the meridional coordinate direction. The extreme fiber stress in that meridionally oriented member is obtained as described in Table 27 and in Eq. (8). NOTE: The BIGBOSOR4 prediction, listed in Table 45 for the –mode 2 imperfection, only gives the maximum extreme fiber stress in each shell segment, not both the maximum **inner** fiber stress and maximum **outer** fiber stress.

NOTE: Figures 49 – 73 are in [26].

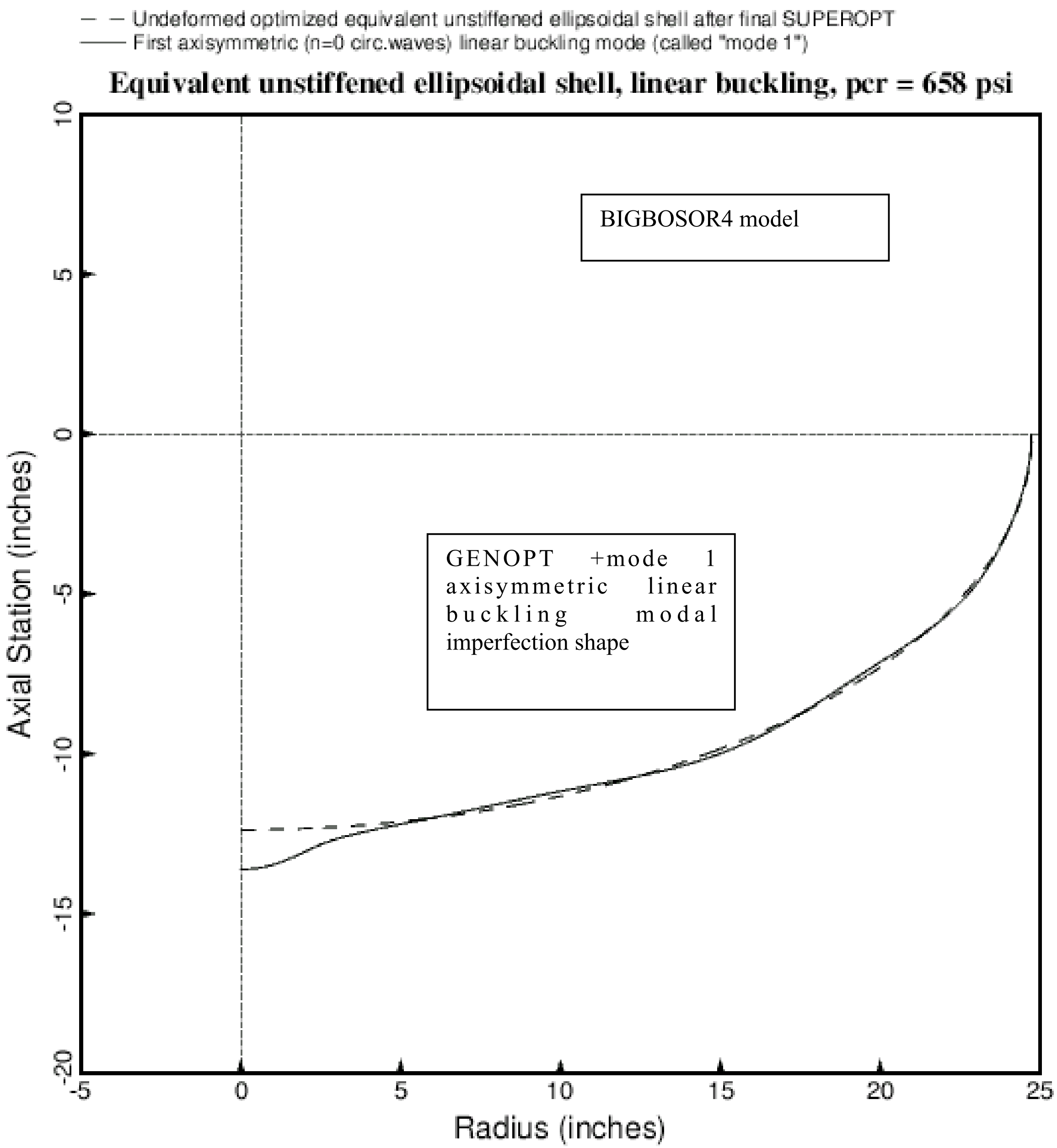

Fig. 74 First **axisymmetric** linear bifurcation buckling mode shape of the optimized **unstiffened** shell as computed by BIGBOSOR4. The corresponding linear bifurcation buckling pressure according to BIGBOSOR4 is p(crit) = 658 psi. The program STAGS obtains a linear bifurcation buckling pressure of 666 psi for this shell. (See Fig. 76 of [26]). This axisymmetric mode corresponds to the lowest eigenvalue in the STAGS model, as listed in Table 60 of [26]. Compare with Fig. 76 of [26]. Plus and minus versions of "**mode 1**" are used as initial axisymmetric imperfection shapes in computations of the local skin and stiffener stresses and buckling load factors, axisymmetric collapse loads, and general nonlinear bifurcation buckling load factors. Compare with the axisymmetric buckling modes for the "thick apex" optimum designs shown in Figs. 145 and 229 of [26].

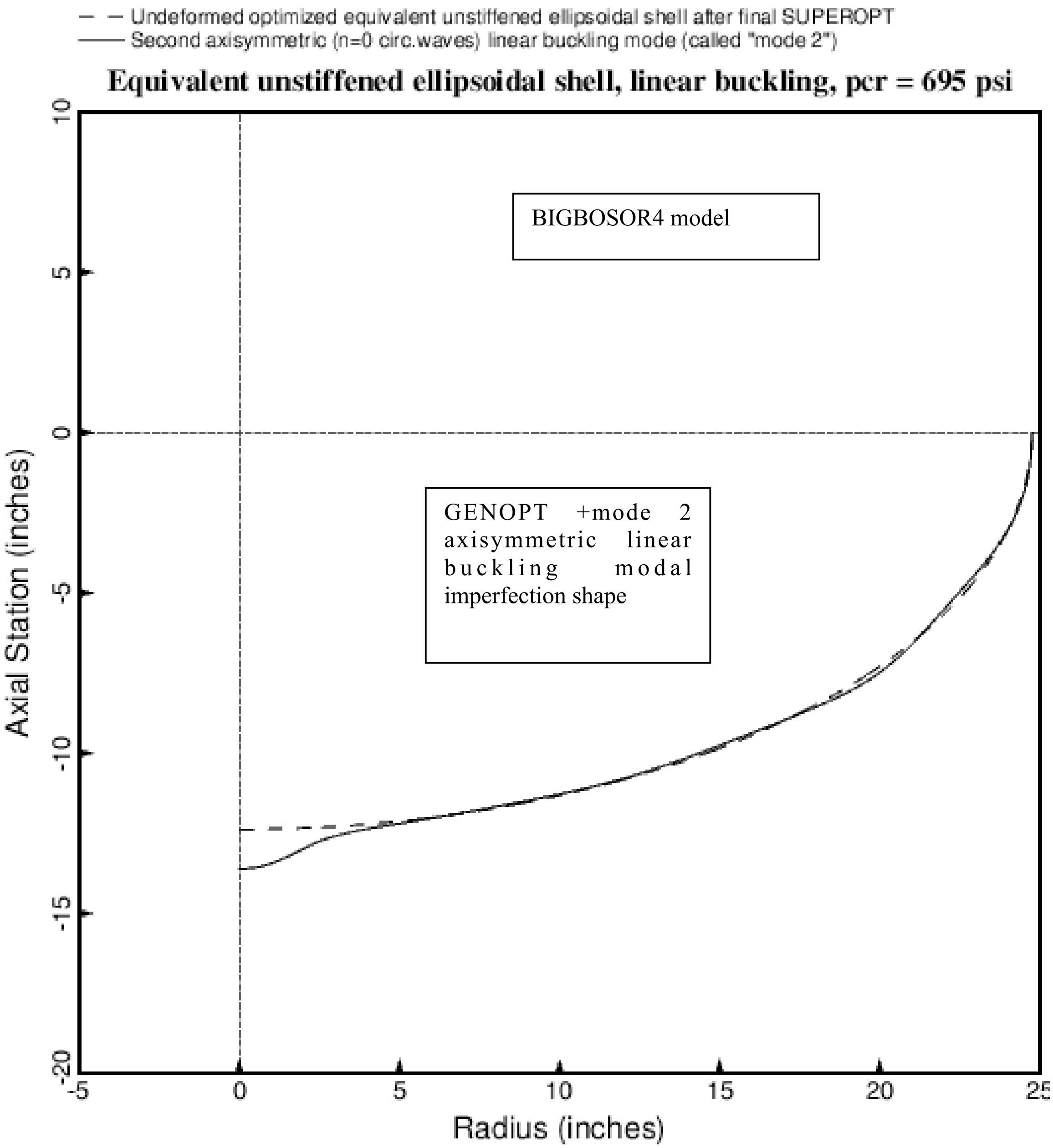

Fig. 75 Second **axisymmetric** bifurcation buckling mode shape of the optimized **unstiffened** shell as computed by BIGBOSOR4. The corresponding linear bifurcation buckling pressure according to BIGBOSOR4 is p(crit) = 695 psi. The program STAGS obtains a linear bifurcation buckling pressure of 708 psi for this second axisymmetric mode. (See Fig. 78 of [26]). In the STAGS model the second axisymmetric mode corresponds to the fourth eigenvalue, as listed in Table 60 of [26], following two nonsymmetric modes, one of which is displayed in Fig. 77. Compare with Fig. 78 of [26]. Plus and minus versions of "**mode 2**" are used as initial axisymmetric imperfection shapes in computations of the local skin and stiffener stresses and buckling load factors, axisymmetric collapse loads, and general nonlinear bifurcation buckling load factors. Compare with the axisymmetric buckling modes for the "thick apex" optimum designs shown in Figs. 146 and 230 of [26].

NOTE: Figure 76 is in [26].

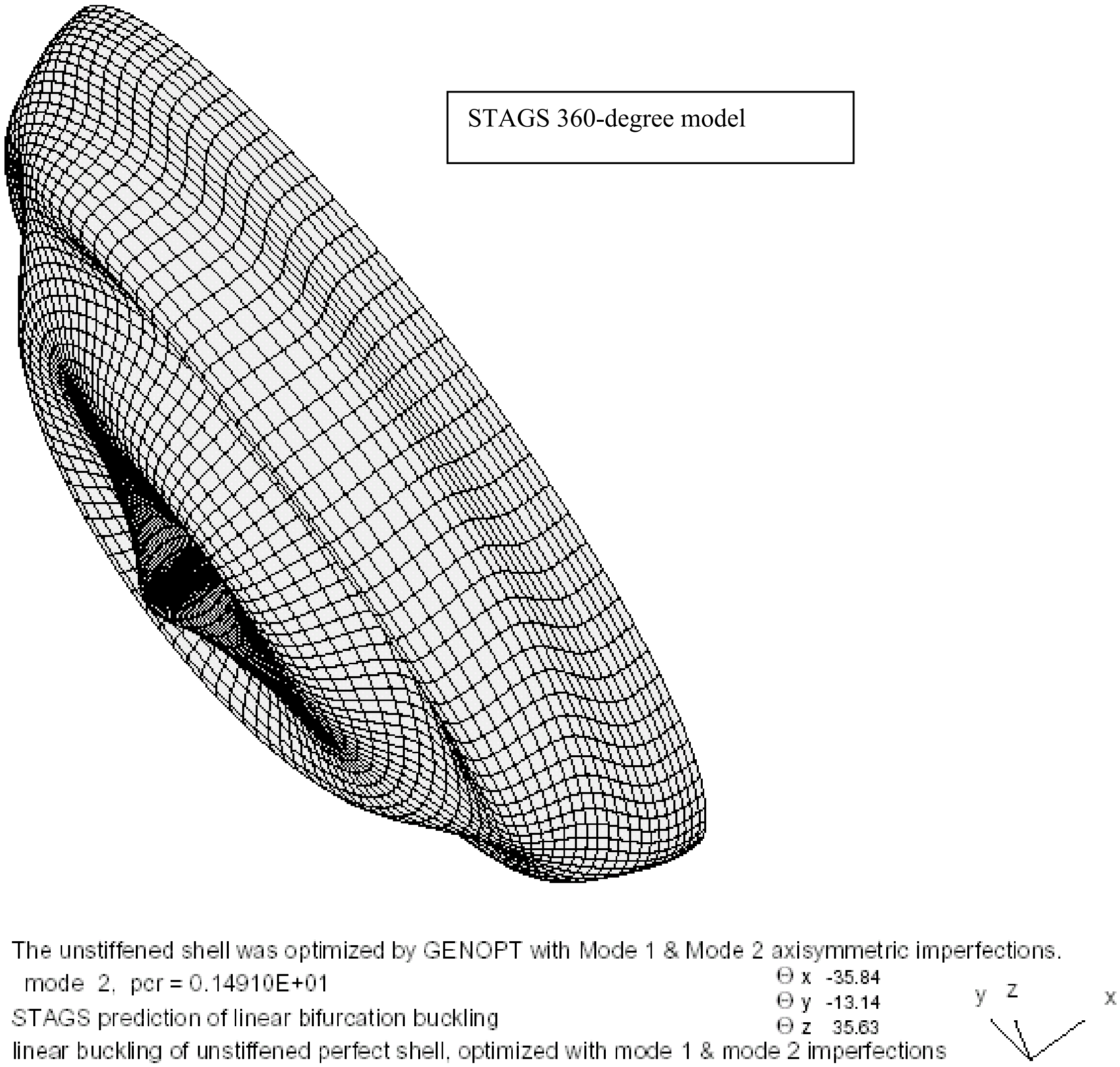

Fig. 77 Second linear bifurcation buckling mode of the optimized **unstiffened** equivalent ellipsoidal shell according to the STAGS program. This non-axisymmetric (n=1 circumferential wave) mode is the first of a pair of modes with exactly the same eigenvalue. The second non-axisymmetric mode in the pair is the same as the above except that the buckling mode is oriented differently circumferentially. This STAGS linear bifurcation buckling mode is used as an initial imperfection shape with amplitude, Wimp = 0.2 inch, to compute the nonlinear load-apex-deflection curve with x symbols plotted as the fifth trace in Fig. 94. **Shells of revolution with imperfections with this non-axisymmetric shape cannot be handled by BIGBOSOR4.** Therefore, GENOPT optimization occurs in the presence of only axisymmetric buckling modal imperfections.

NOTE: Figures 78 – 93 are in [26].

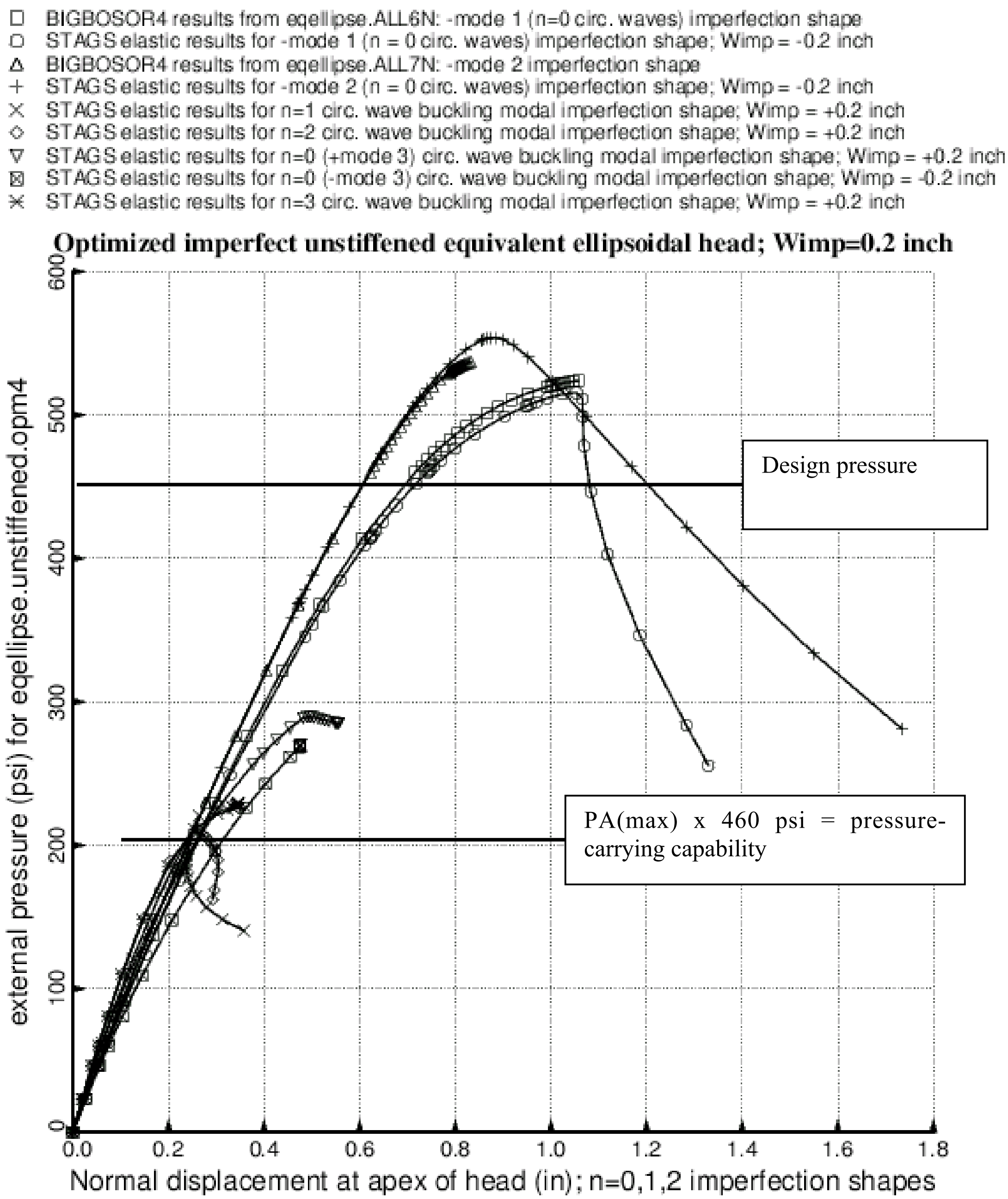

Fig. 94 Nonlinear elastic load-deflection curves for the optimized **imperfect unstiffened** equivalent ellipsoidal shell from BIGBOSOR4 (axisymmetric deformation) and from STAGS (both axisymmetric and non-axisymmetric deformation). The most significant point to be emphasized with regard to this figure is that the pressure-carrying capability of the shell, which is optimized with regard to mode 1 and mode 2 **axisymmetric** imperfections (BIGBOSOR4 models in Figs. 74 and 75), is much more sensitive to non-axisymmetric imperfections (buckling modal imperfections with n = 1 and n = 2 circumferential waves) with the same amplitude, Wimp = 0.2 inch. **The optimized unstiffened shell is therefore under-designed.** Compare with the results for the "thick apex" optimized unstiffened shells plotted in Figs. 161 of [26] and 237.

NOTE: Figures 95 – 147 are in [26].

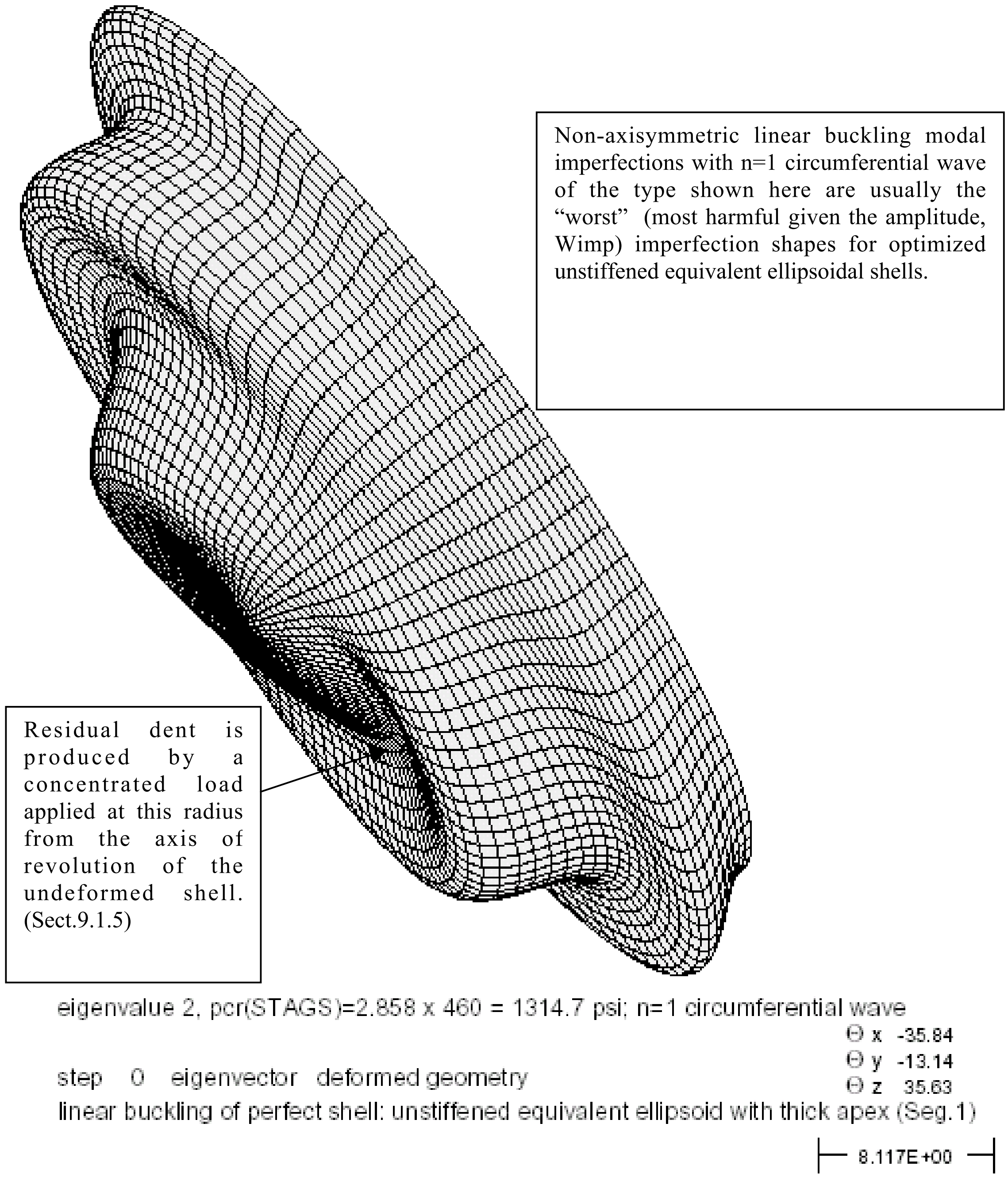

Fig. 148 Non-axisymmetric (**n=1 circumferential wave**) linear buckling mode from STAGS that corresponds to the second eigenvalue for the **optimized unstiffened equivalent ellipsoidal shell with the thick apex with t(apex) = 0.4 inch; the optimum design is listed in Table 78 of [26].** Compare this mode with that obtained from the STAGS "soccerball" models displayed in Figs. 179 and 190 of [26] for the same shell. **Shells of revolution with imperfections with this non-axisymmetric shape cannot be handled by BIGBOSOR4.** Therefore, GENOPT optimization occurs in the presence of only axisymmetric buckling modal imperfections.

NOTE: Figures 149 – 160 are in [26].

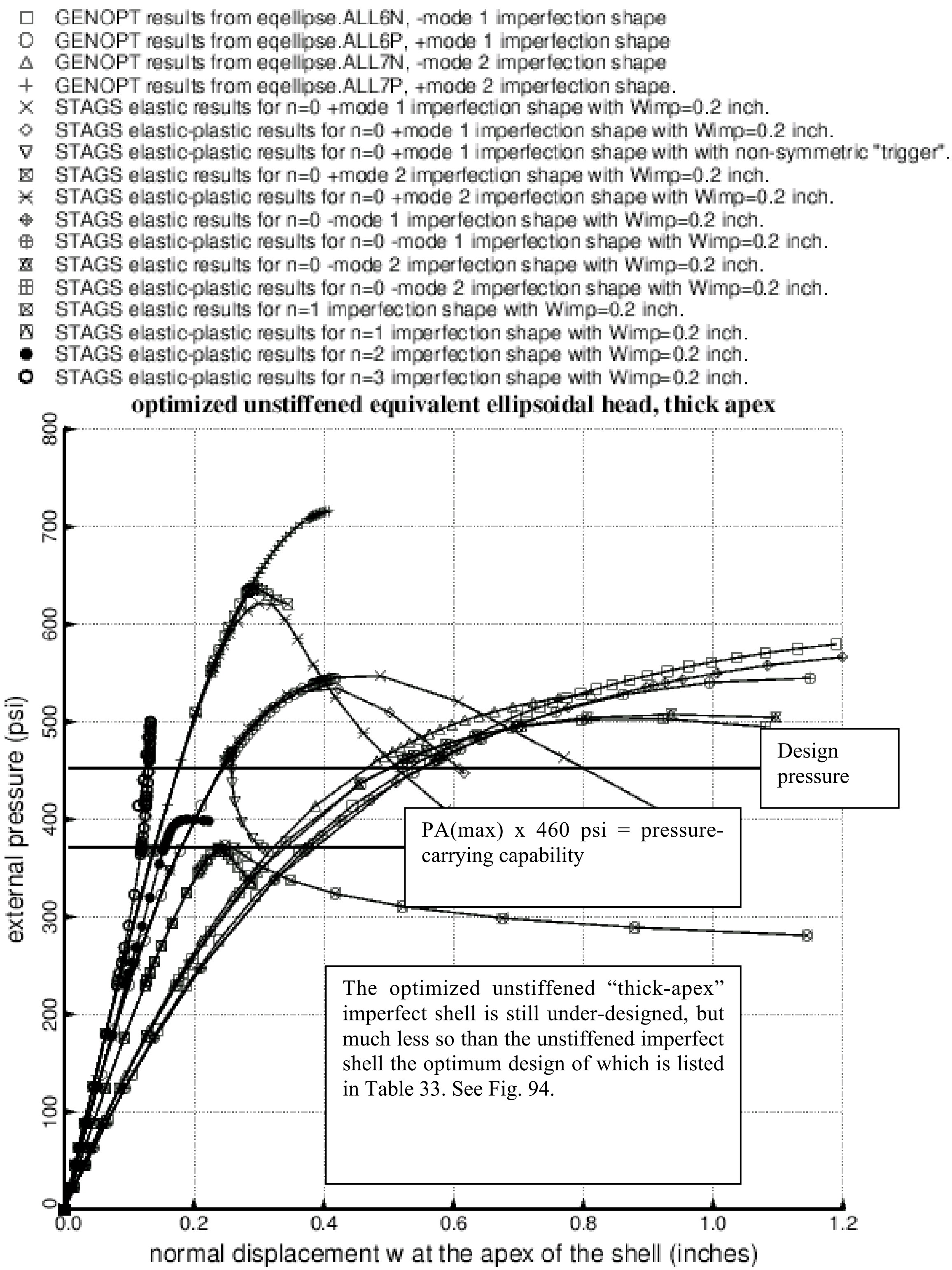

Fig. 161 **Optimized unstiffened equivalent ellipsoidal shell with thick apex, t(apex)=0.4 inch; Wimp=0.2 inch; the optimum design is listed in Table 78 of [26].** Load-displacement curves for various buckling modal imperfection shapes. Amplitude of each buckling modal imperfection, Wimp = 0.2 inch. Compare with Fig. 94.

NOTE: Figures 162 – 187 are in [26].

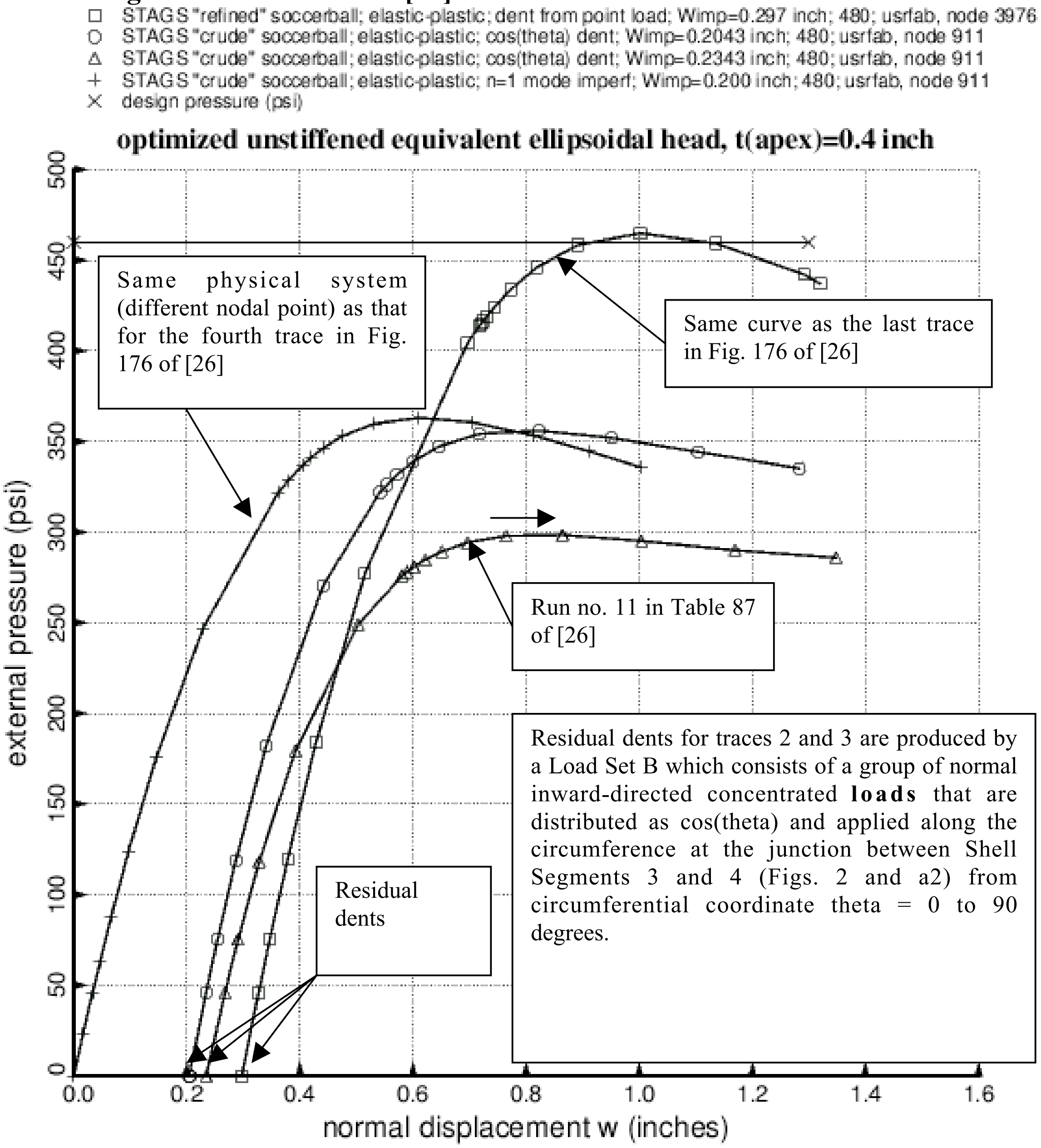

Fig. 188 Elastic-plastic analysis of the **optimized unstiffened equivalent ellipsoidal shell with the thick apex with t(apex) = 0.4 inch; Wimp=0.2 inch; the optimum design is listed in Table 78 of [26].** Collapse of the imperfect shell with three different kinds of imperfections. trace 1= imperfection is a residual dent caused by a single concentrated load (Fig. 171 of [26]); traces 2 and 3 = imperfections are residual dents caused by a "cos(theta)" distribution of concentrated loads along a circumferential line from theta = 0 to 90 degrees (Figs. 184 and 186 of [26]), and trace 4 = a linear buckling modal imperfection with n=1 circumferential wave (Fig. 190 of [26]). Notice the similarity between traces 2 and 4. These two curves differ mostly by a horizontal shift of w= 0.2 inch, which represents the depth of the residual dent created by the "cos(theta)" distribution of concentrated loads. The "cos(theta)" residual dent is just as harmful as the n=1 buckling modal imperfection.

NOTE: Figures 189 – 236 are in [26].

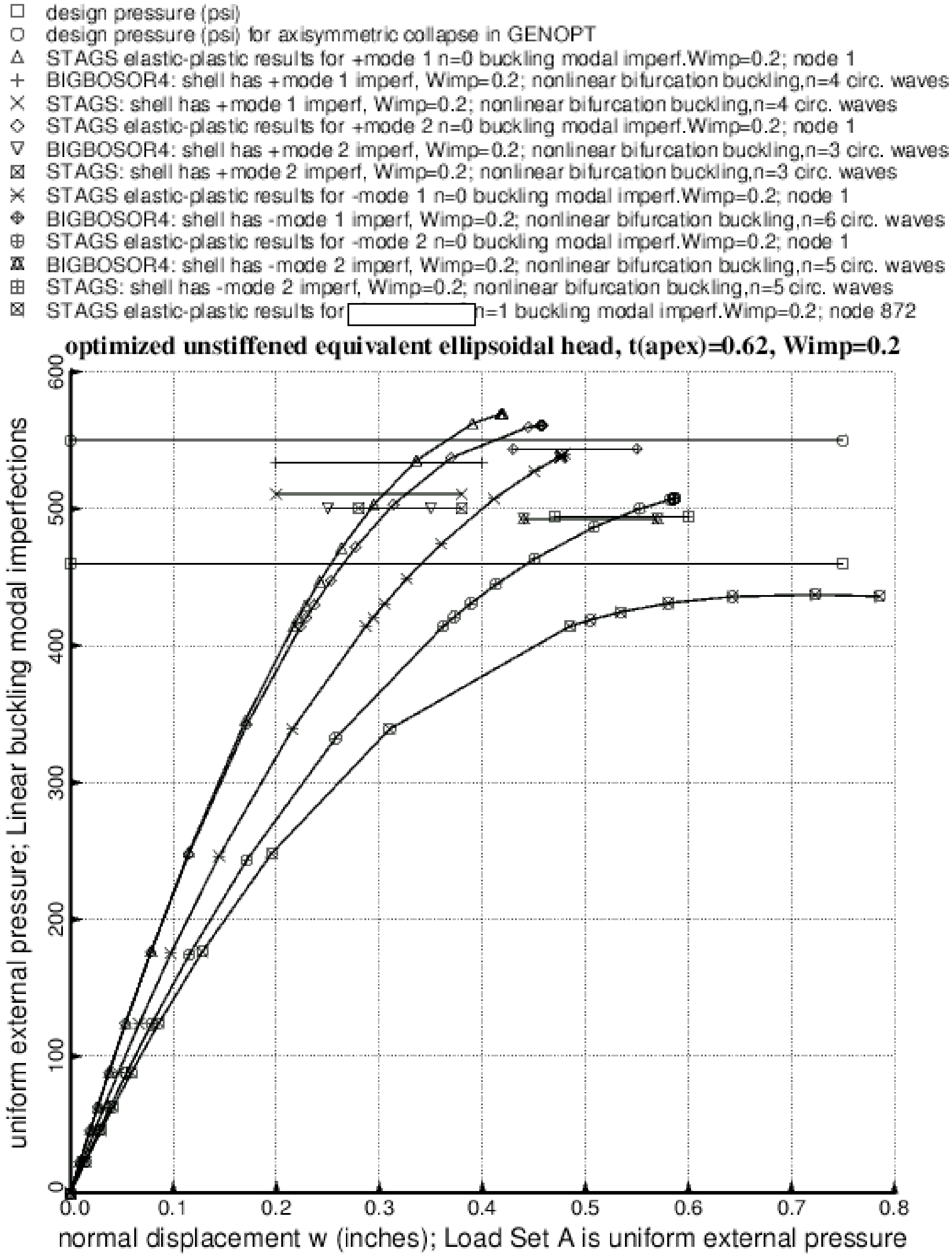

Fig. 237 **Optimized unstiffened equivalent ellipsoidal shell with thick apex, t(apex)=0.61996 inch; Wimp=0.2 inch; the optimum design is listed in Table 93 of [26].** STAGS elastic-plastic load-displacement curves and nonlinear bifurcation buckling loads and BIGBOSOR4 elastic nonlinear bifurcation buckling loads for various buckling modal imperfection shapes. Amplitude of each buckling modal imperfection, Wimp = 0.2 inch. Compare with Fig. 161 of [26], for which the optimum design is listed in Table 78 of [26], and compare with Figs. 209 and 211 of [26], for which Wimp=0.1 and optimum design is listed in Table 89 of [26].

NOTE: Figures 238 – 253 are in [26].

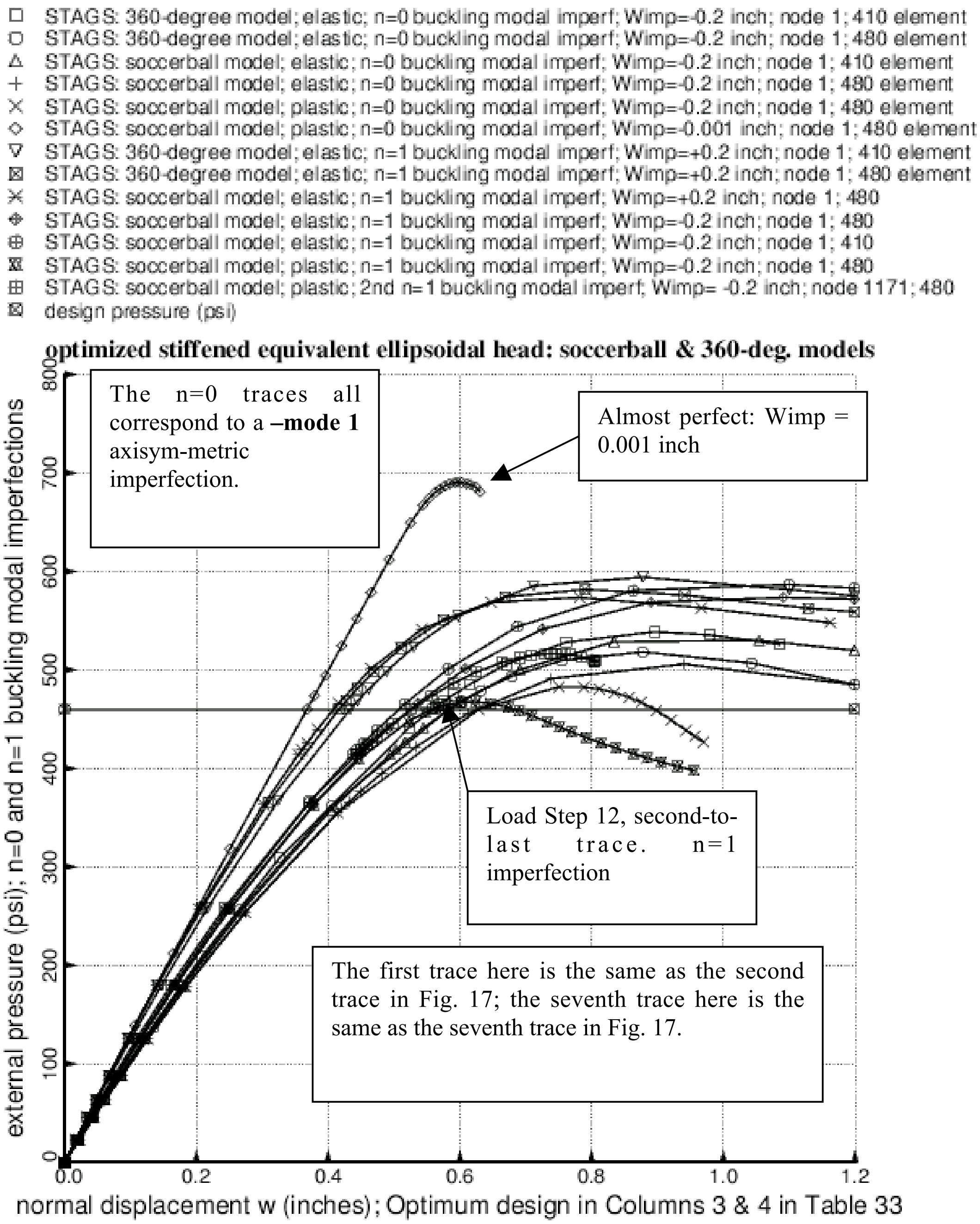

Fig. 254 Axisymmetric and non-axisymmetric collapse of optimized almost perfect (trace 6) and **imperfect isogrid-stiffened equivalent ellipsoidal shells. The optimum design, listed in columns 2 and 3 of Table 33, was obtained with linear axisymmetric (n=0) buckling modal imperfections with amplitude, Wimp = 0.2 inch.** For the 180-degree "soccerball" model the linear bifurcation buckling modal imperfection shape corresponding to axisymmetric (n=0) collapse (the first 6 traces) is shown in Fig. 257 of [26]. The linear bifurcation buckling modal imperfection shapes corresponding to non-axisymmetric (n=1) collapse (the last 7 traces) are displayed in Figs. 258 and 262. For the 360-degree models the linear bifurcation buckling modal imperfection shapes are shown for n=0 in Fig. 6 and for n=1 in Figs. 7 and 10. Compare this figure with Fig. 17.

NOTE: Figures 255 – 257 are in [26].

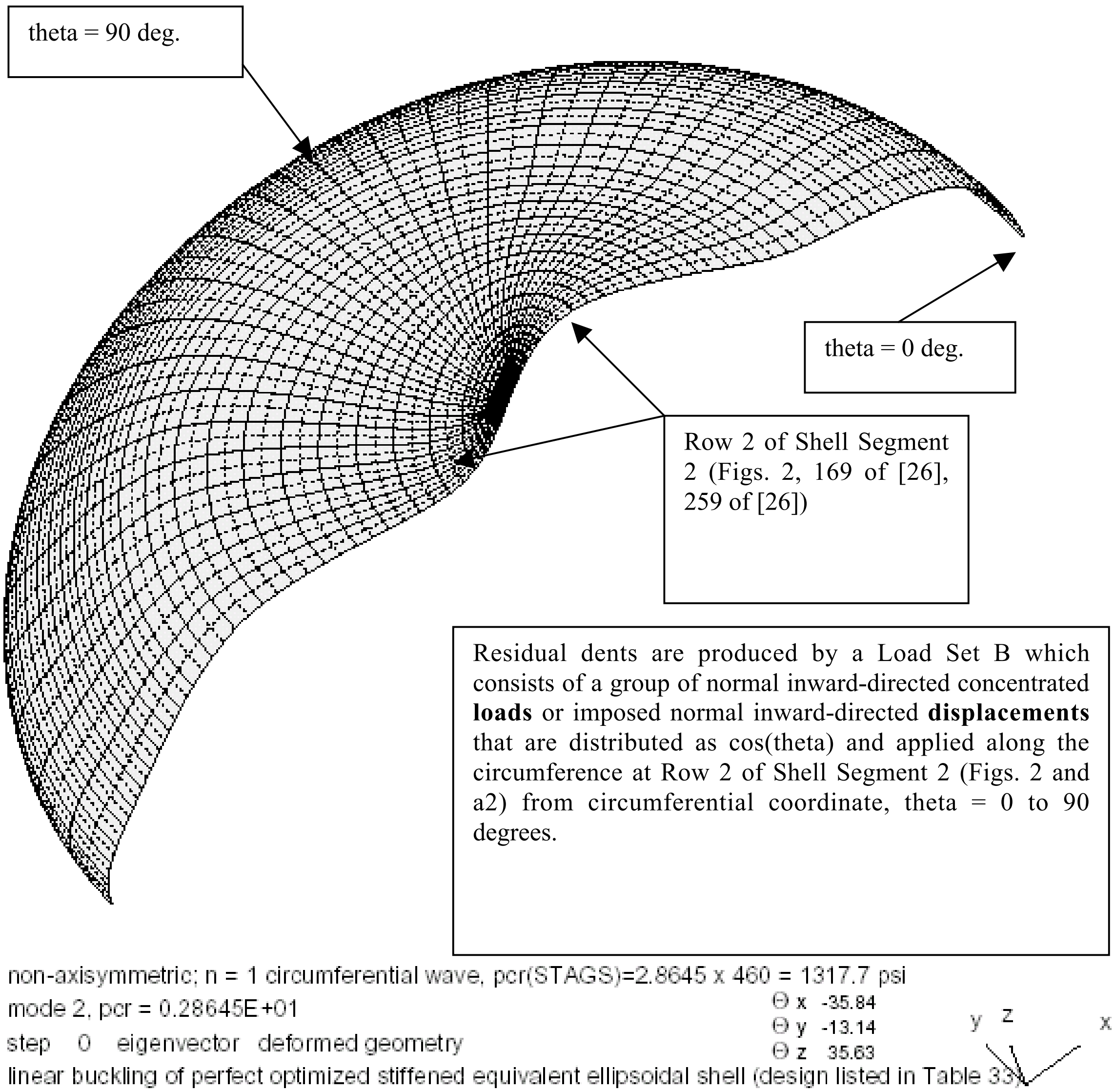

Fig. 258 **STAGS "soccerball" model of the optimized imperfect isogrid-stiffened equivalent ellipsoidal shell. The optimum design, listed in columns 2 and 3 of Table 33, was obtained with plus and minus axisymmetric (n=0) mode 1 and mode 2 linear buckling modal imperfection shapes with amplitude, Wimp = 0.2 inch.** This is the non-axisymmetric (n=1 circumferential wave) linear buckling modal imperfection shape used as the n = 1 imperfection corresponding to the second six traces (traces 7-12) in Fig. 254. Compare with the 360-degree STAGS model displayed in Fig. 7. The difference in the eigenvalue, 2.8645 here vs 3.0048 in Fig. 7, is caused primarily by the difference in the finite element used in the STAGS model: STAGS Element 480 here vs STAGS Element 410 in Fig. 7. Indicated in this figure is the location where normal inward-directed concentrated loads or displacements are imposed in a "cos(theta)" distribution in order to produce a dent that **locally** resembles the negative of this linear buckling mode shape.

NOTE: Figures 259 – 261 are in [26].

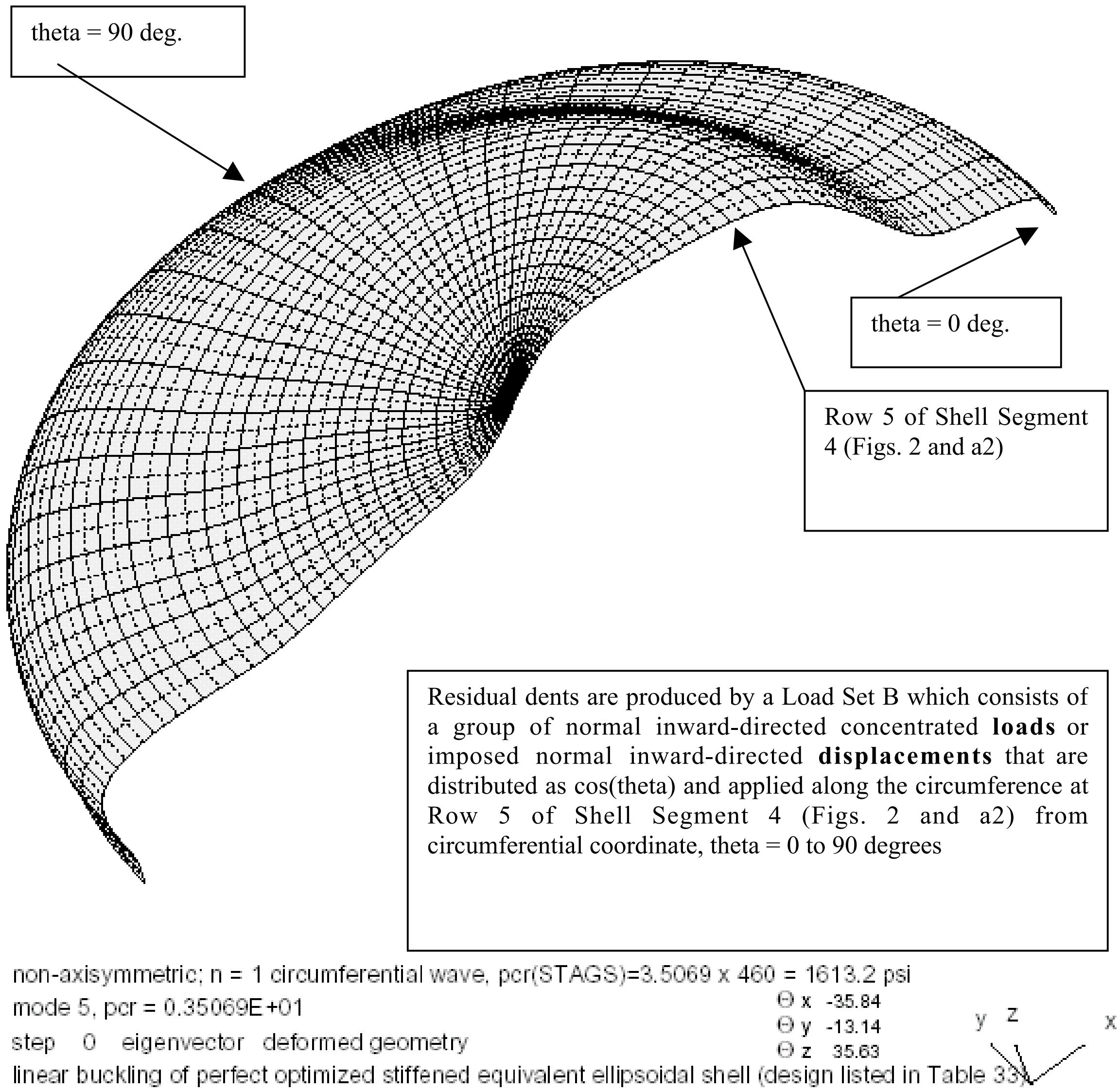

Fig. 262 **STAGS "soccerball" model of the optimized imperfect isogrid-stiffened equivalent ellipsoidal shell. The optimum design, listed in columns 2 and 3 of Table 33, was obtained with plus and minus axisymmetric (n=0) mode 1 and mode 2 linear buckling modal imperfection shapes with amplitude, Wimp = 0.2 inch.** This is the non-axisymmetric (2nd n=1 circumferential wave) linear buckling modal imperfection shape used as the n = 1 imperfection corresponding to the last trace in Fig. 254. Compare with the 360-degree STAGS model displayed in Fig. 10. The difference in the eigenvalue, 3.5069 here vs 3.5518 in Fig. 10, is caused primarily by the difference in the finite element used in the STAGS model: STAGS Element 480 here vs STAGS Element 410 in Fig. 10. Indicated in this figure is the location where normal inward-directed concentrated loads or displacements are imposed in a "cos(theta)" distribution in order to produce a dent that **locally** resembles the negative of this linear buckling mode shape.

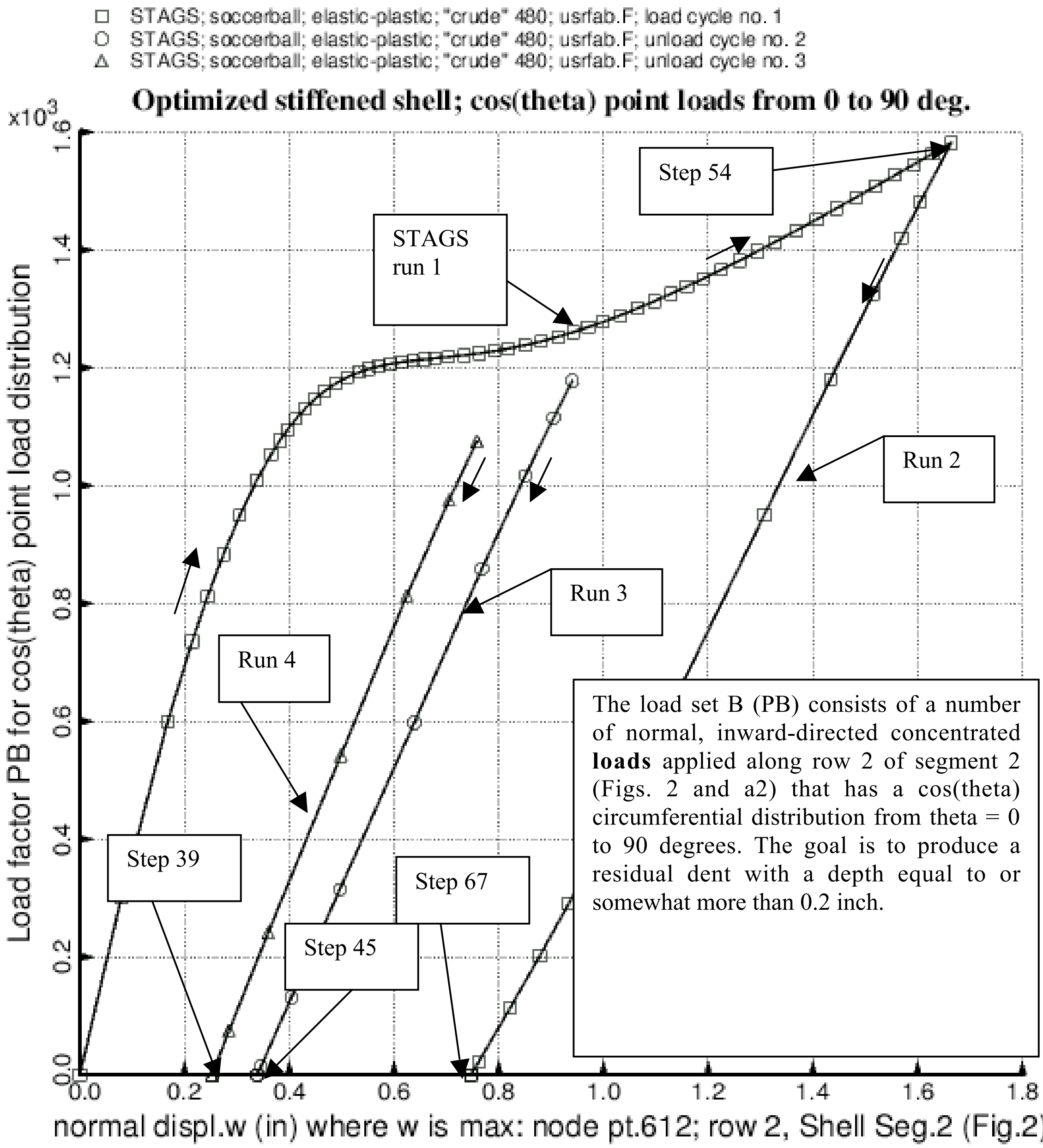

Fig. 263 STAGS results for the **optimized isogrid-stiffened equivalent ellipsoidal shell; Wimp=0.2 inch; this figure pertains to the shell design listed in columns 2 and 3 of Table 33.** Shown here are the load cycles for load set B (load factor PB) that produce residual "cos(theta)" dents of various depths. Compare with Fig. 237. These results correspond to the "cos(theta)" line load applied along Row 2 of Shell Segment 2 from circumferential coordinate, theta = 0 to 90 degrees. This "cos(theta)" load distribution is used because it generates a residual dent that **locally** resembles the negative of the buckling modal deformation in Figs. 258, that is, the negative of the linear buckling modal imperfection with n = 1 circumferential wave.

NOTE: Figures 264 – 267 are in [26].

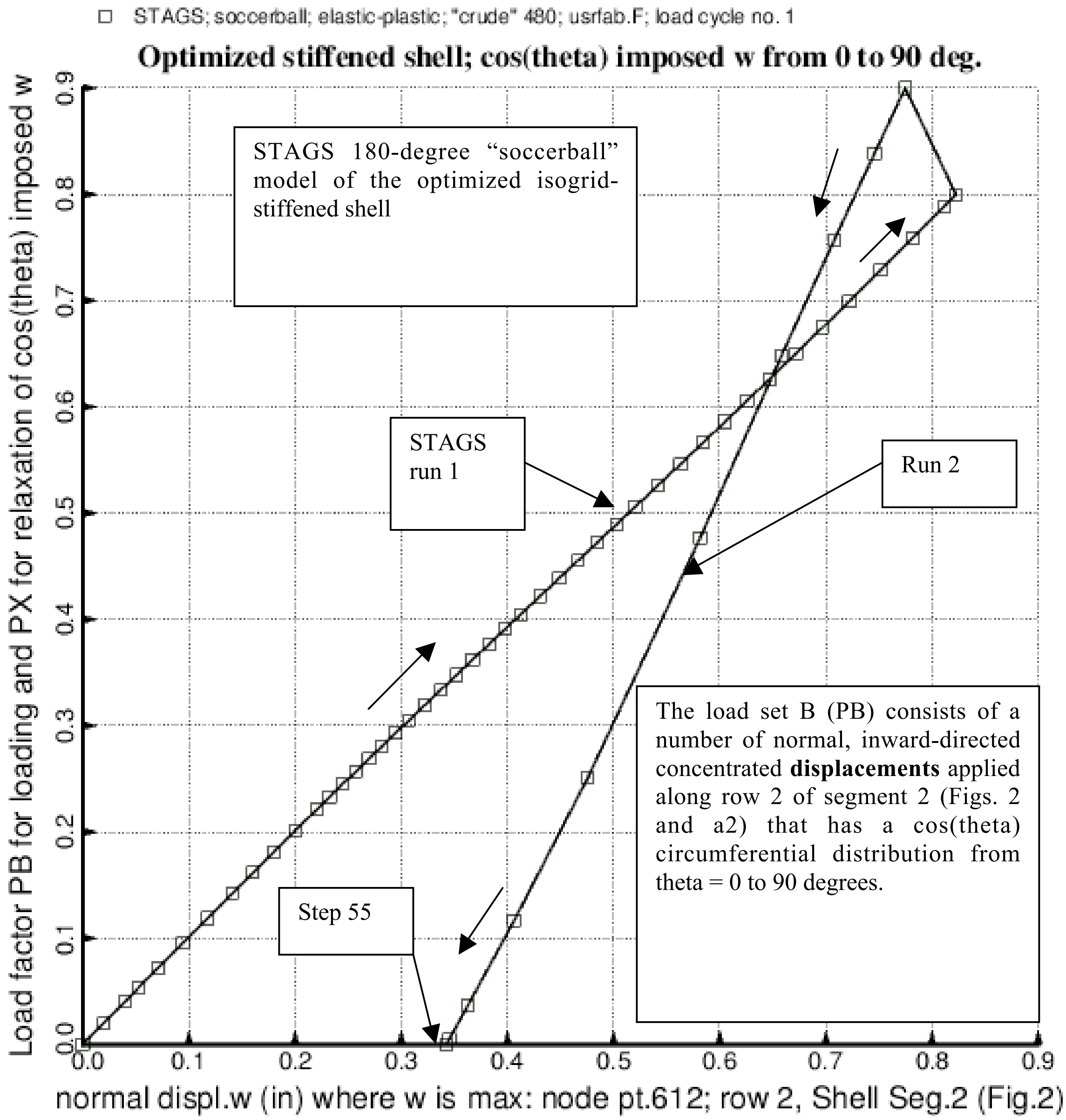

Fig. 268 STAGS results for the **optimized isogrid-stiffened equivalent ellipsoidal shell; Wimp=0.2 inch; this figure pertains to the shell design listed in columns 2 and 3 of Table 33.** Shown here is the load cycle for load set B (load factor PB) that produces a residual "cos(theta)" dent of depth 0.347 inch. Compare with Fig. 193 of [26]. These results correspond to the "cos(theta)" line imposed normal inward-directed **displacement** applied along Row 2 of Shell Segment 2 from circumferential coordinate, theta = 0 to 90 degrees. (See Fig. 258). Here the residual dent is significantly deeper than the depth, Wimp=0.2 inch, of each of the two axisymmetric buckling modal imperfections, mode 1 and mode 2, for which the optimum design was obtained.

NOTE: Figure 269 is in [26].

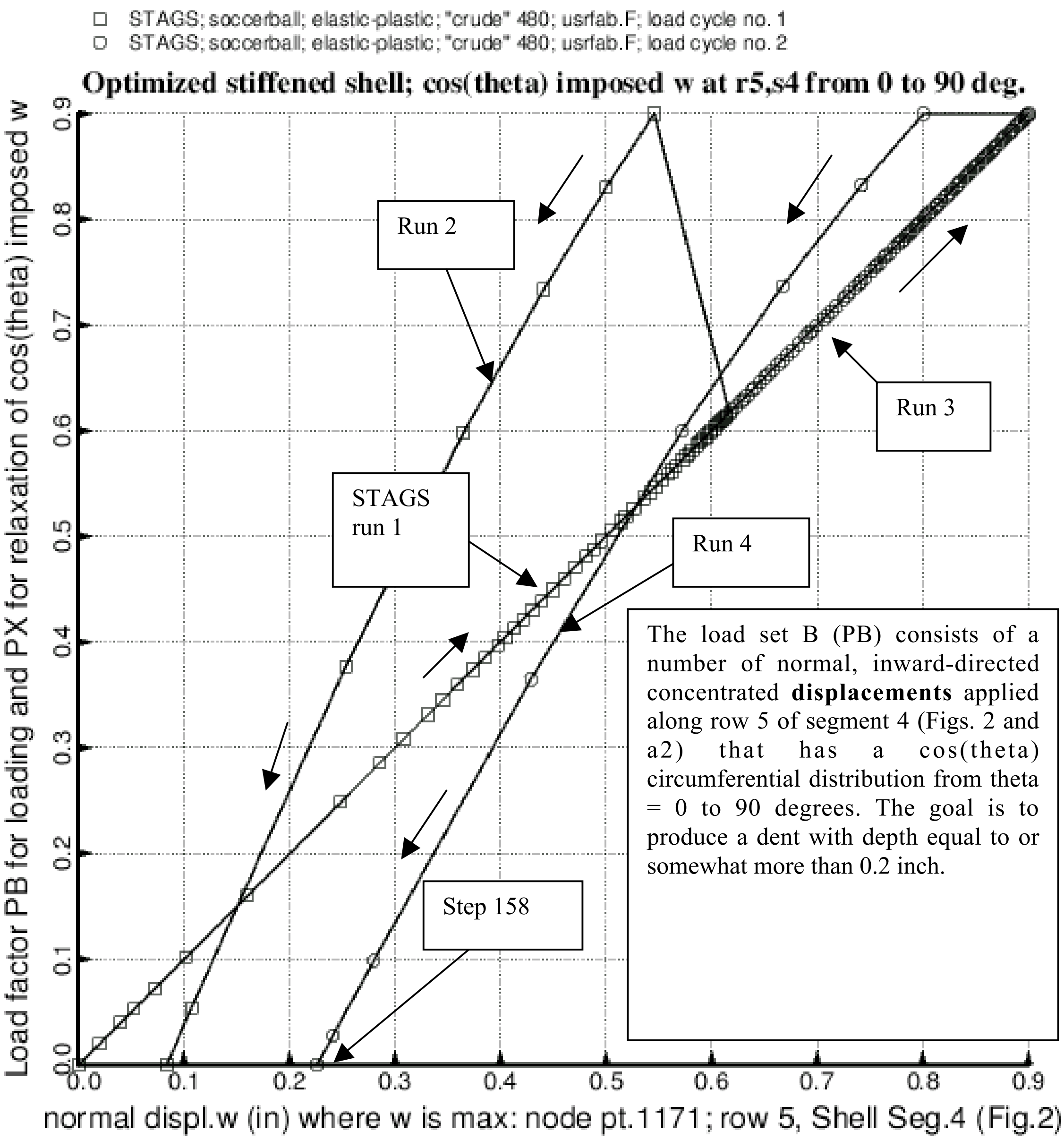

Fig. 270 STAGS results for the **optimized isogrid-stiffened equivalent ellipsoidal shell; Wimp=0.2 inch; this figure pertains to the shell design listed in columns 2 and 3 of Table 33.** Shown here are the load cycles for load set B (load factor PB) that produce two different residual "cos(theta)" dents, the biggest of depth 0.2278 inch. Compare with Fig. 268. These results correspond to the "cos(theta)" line imposed normal inward-directed **displacement** applied along Row 5 of Shell Segment 4 from circumferential coordinate, theta = 0 to 90 degrees. This "cos(theta)" displacement distribution is used because it generates a residual dent that **locally** resembles the negative of the buckling modal deformation in Fig. 262, that is, the negative of the second linear buckling modal imperfection with n = 1 circumferential wave. Here the residual dent is somewhat deeper than the depth, Wimp=0.2 inch, of each of the two axisymmetric buckling modal imperfections, mode 1 and mode 2, for which the optimum design was obtained.

NOTE: Figures 271 – 274 are in [26].

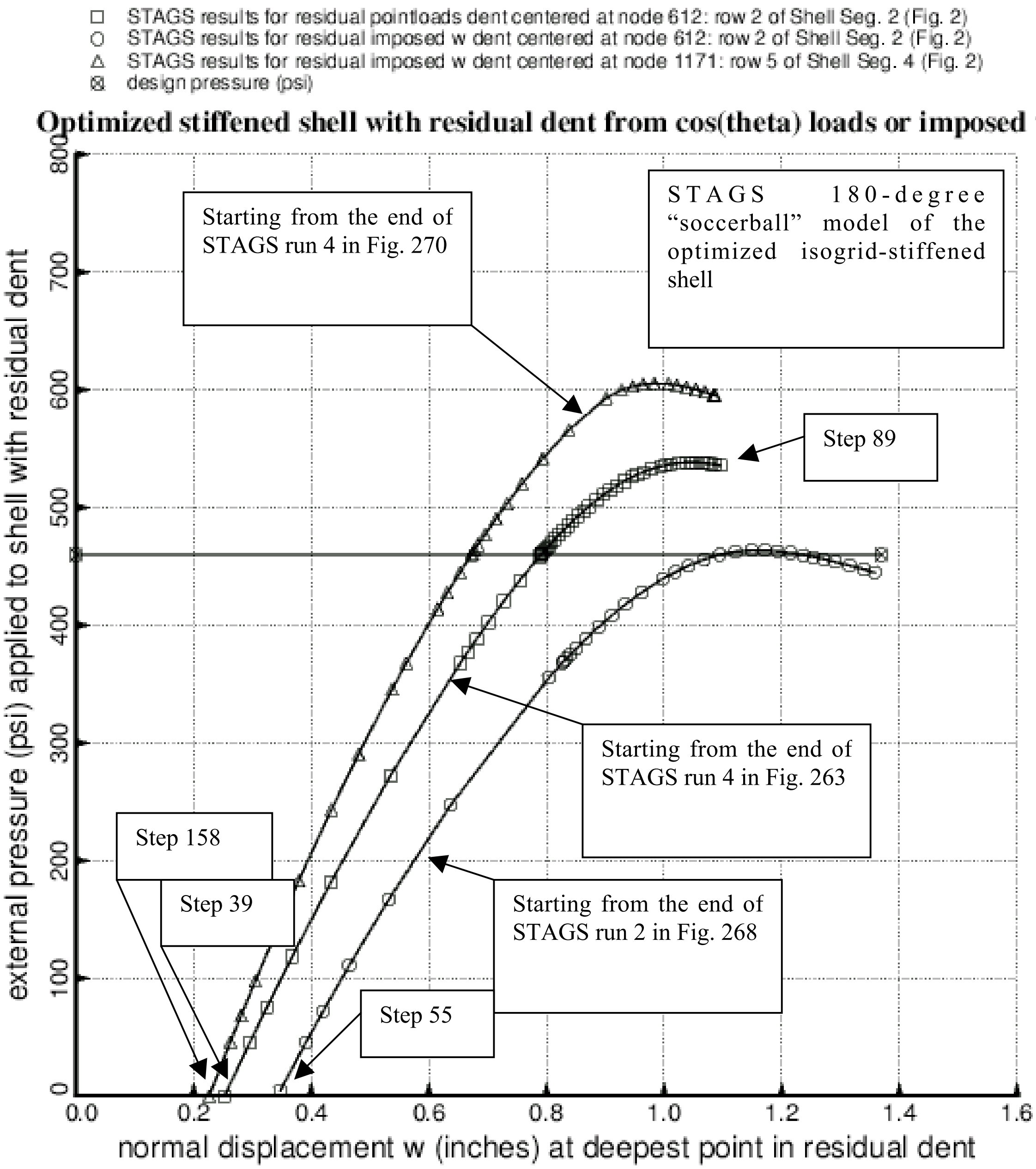

Fig. 275 The **optimized isogrid-stiffened equivalent ellipsoidal shell; Wimp=0.2 inch; the optimum design is listed in columns 2 and 3 of Table 33.** Shown here are load-deflection curves for the optimized stiffened shell with various residual dents loaded by uniform external normal pressure (Load Set A). Notice that in each of the three cases the depth of the residual "cos(theta)" dent is greater than the depth, Wimp = 0.2 inch, of each of the axisymmetric linear buckling mode 1 or mode 2 imperfection shapes, in the presence of which the shell was optimized. Therefore, these curves represent conservative estimates of the load-carrying capability of the dented shells, the optimum design of which is listed in columns 2 and 3 of Table 33.

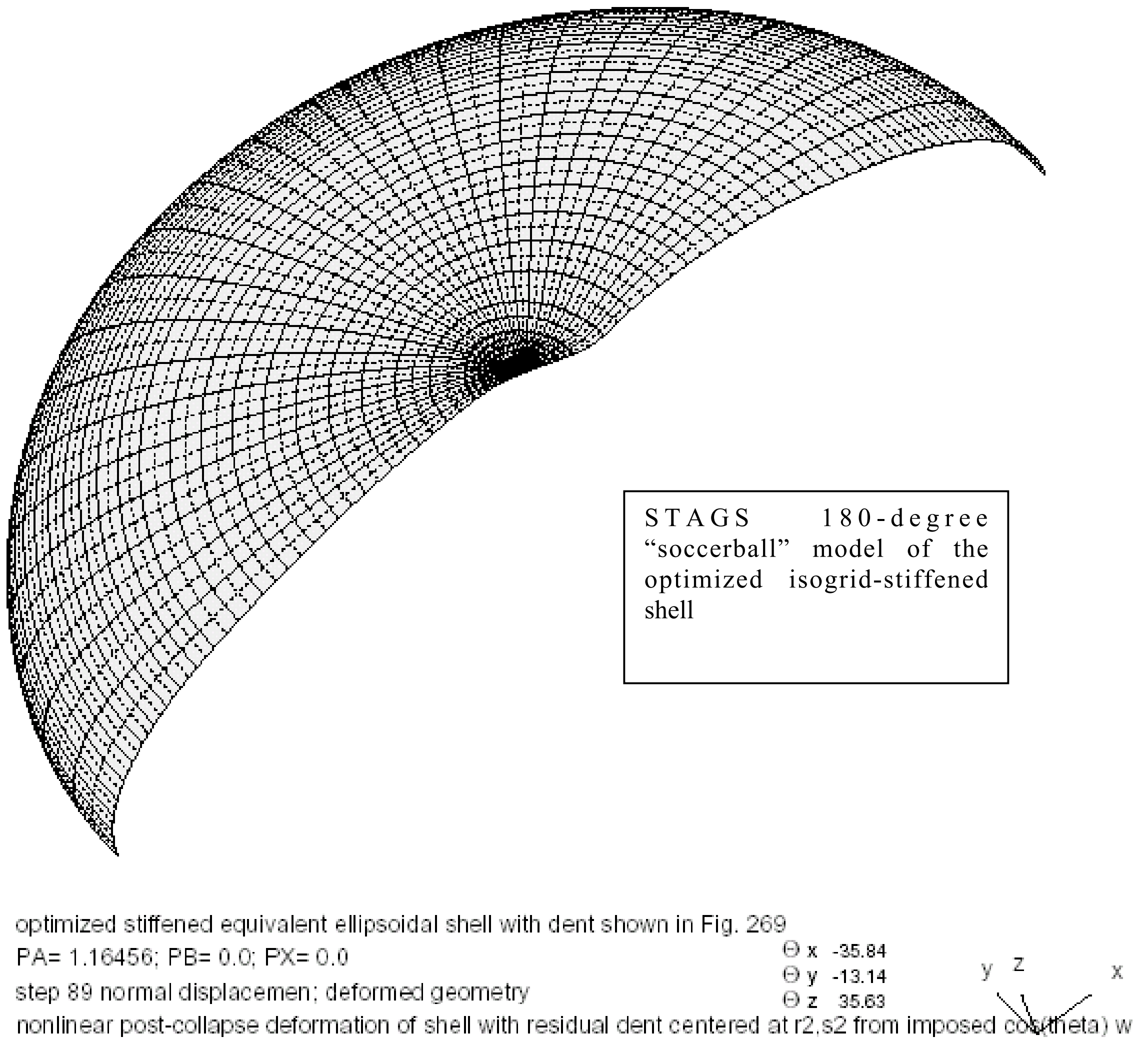

Fig. 276 The **optimized isogrid-stiffened equivalent ellipsoidal shell; Wimp=0.2 inch; the optimum design is listed in columns 2 and 3 of Table 33.** Shown here is the **post-collapse** deformation of the uniformly externally pressurized shell with the residual dent that exists at the STAGS load step labeled "Step 39" in the previous figure and in Fig. 263 and that is displayed in Fig. 267 of [26]. The residual dent is produced by a cos(theta) distribution of normal inward-directed concentrated **loads** applied along Row 2 of Shell Segment 2 from circumferential coordinate, theta = 0 to 90 degrees (Figs. 2 and a2). This "cos(theta)" load distribution is used because it generates a residual dent that **locally** resembles the negative of the buckling modal deformation in Fig. 262, that is, the negative of the first linear buckling modal imperfection with n = 1 circumferential wave.

APPENDIX

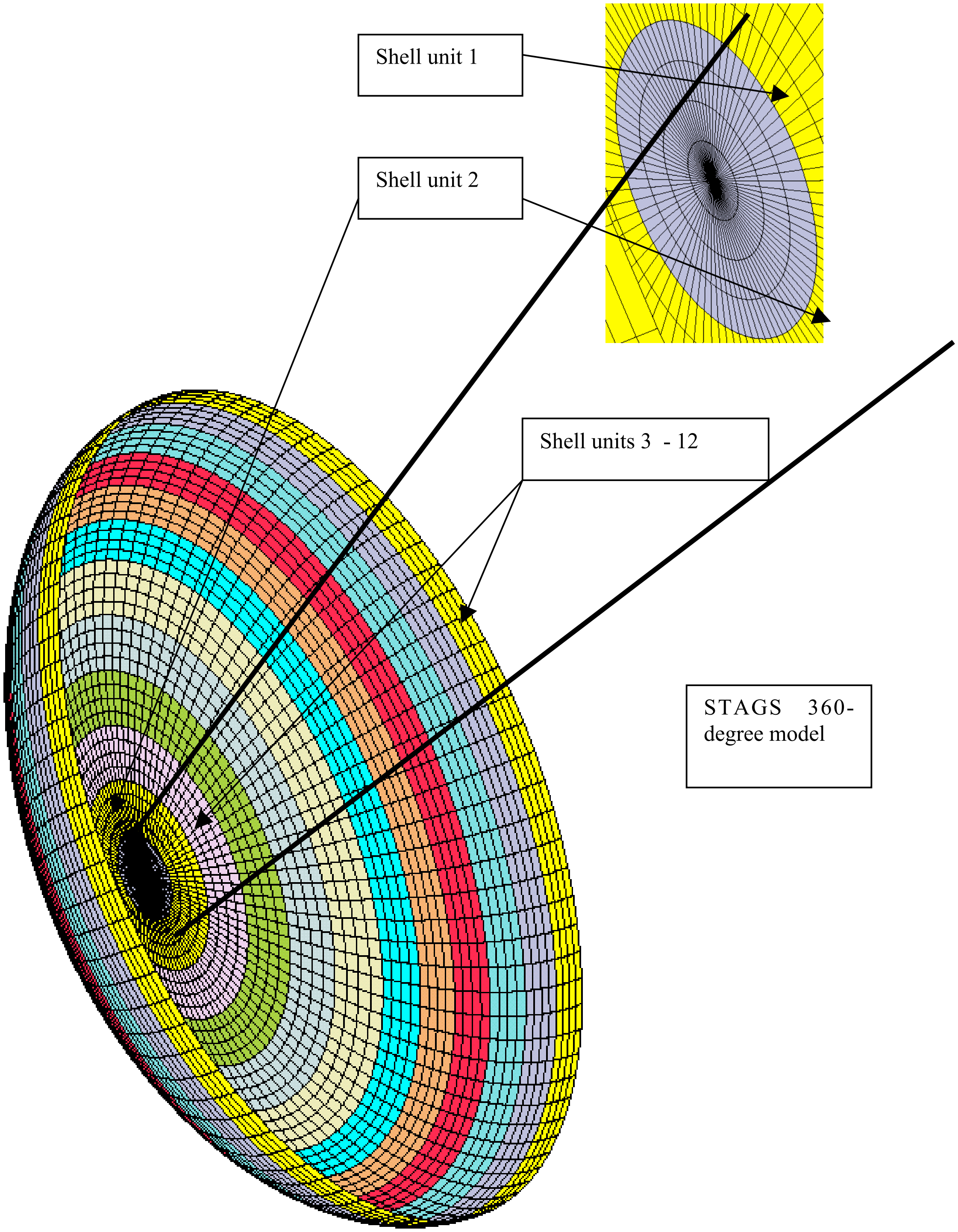

Fig. a1 STAGS 360-degree model of the **equivalent ellipsoidal** shell with a spherical cap (shell unit 1) and 11 toroidal segments (shell units 2 – 12). Each of the twelve axisymmetric STAGS shell units is shown in a different color. This model is analogous to the BIGBOSOR4 model displayed in Fig. 2. The elongated shape of the 410 finite elements nearest the pole causes early lack of convergence in nonlinear cases that involve elastic-plastic mat'l. STAGS results in Figs. 6 – 168 are based on this 360-degree model.

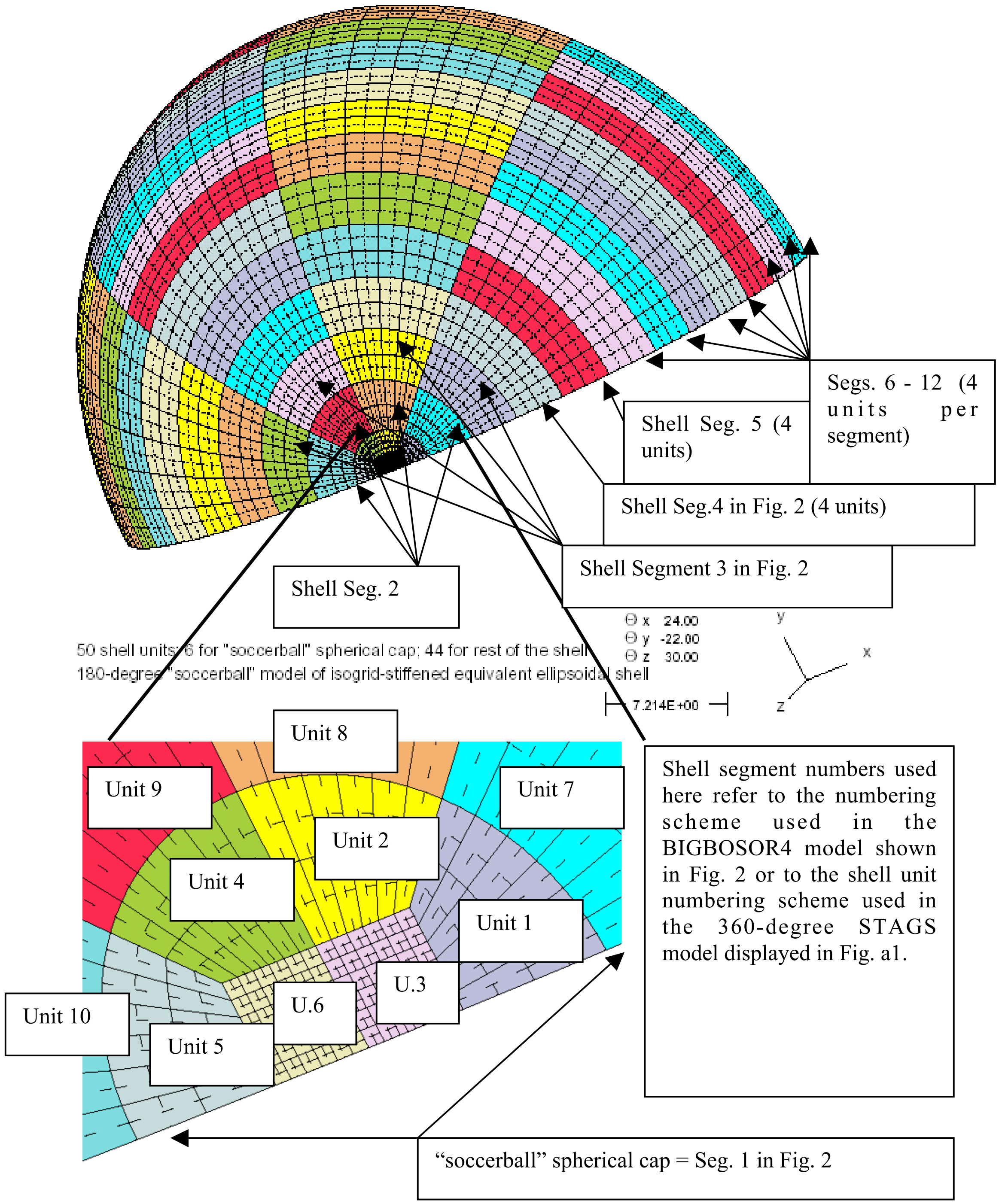

Fig. a2 180-degree STAGS "soccerball" model of the equivalent ellipsoidal shell, showing the numbering of the STAGS shell units within the six-shell-unit "soccerball" spherical cap, which corresponds to Shell Segment No. 1 in Fig. 2. The units just outside the "soccerball" cap are Units 7, 8, 9, and 10, increasing unit numbers counterclockwise (Fig. a3 of [26]). The entire STAGS 180-degree "soccerball" model of the equivalent ellipsoidal shell is then built up of 10 additional ranks of 4 shell units each, each 4-shell-unit rank corresponding to one of the BIGBOSOR4 shell segments depicted in Fig. 2.

Table A1 List of the file, **equivellipse.INP .** Here we have the **complete** input data for the entire "GENTEXT" interactive session corresponding to the GENOPT user's generic case, "**equivellipse**". This file, along with subsequent copying the saved "**fleshed out**" version of SUBROUTINE STRUCT listed in Table a16 of [26] into struct.new (**cp …/genopt/torisph/struct.equivellipse …/genoptcase/struct.new**) followed by re-execution of the GENOPT processor called **GENPROGRAMS,** can be used to re-generate the generic case called "**equivellipse**". Here the GENOPT user's responses to GENOPT prompts are shown in regular type, **not** in bold. Compare with Tables 3 and 15.

```
=====================================================================
       5  $ starting prompt index in the file equivellipse.PRO
       5  $ increment for prompt index
       0  $ Type of prompt: 0="help" paragraph, 1=one-line prompt
 OPTIMUM DESIGN OF ISOGRID-STIFFENED ELLIPSOIDAL HEAD
 y        $ Are there more lines in the "help" paragraph?
 David Bushnell, retired (formerly with Lockheed Martin)
 y        $ Are there more lines in the "help" paragraph?
 ABSTACT: The externally pressurized head is elastic, has
 y        $ Are there more lines in the "help" paragraph?
 internal isogrid stiffening, and is attached to a short,
 y        $ Are there more lines in the "help" paragraph?
 unstiffened cylindrical shell of uniform thickness.
 y        $ Are there more lines in the "help" paragraph?
 The BIGBOSOR4 computer program is used for the structural
 y        $ Are there more lines in the "help" paragraph?
 analysis and GENOPT is used to set up the user-friendly
 y        $ Are there more lines in the "help" paragraph?
 optimization program. Please read the following papers
 y        $ Are there more lines in the "help" paragraph?
 for descriptions of BIGBOSOR4 and GENOPT:
 y        $ Are there more lines in the "help" paragraph?
 [1] Bushnell, D., "Automated optimum design of shells of
 y        $ Are there more lines in the "help" paragraph?
 revolution with application to ring-stiffened cylindrical
 y        $ Are there more lines in the "help" paragraph?
 shells with wavy walls", Proc. AIAA 41st SDM Meeting, AIAA
 y        $ Are there more lines in the "help" paragraph?
 Paper No. AIAA-2000-1663, April 2000. (Also see the Lockheed
 y        $ Are there more lines in the "help" paragraph?
 Martin report, LMMS P525674, November, 1999 for more details).
 y        $ Are there more lines in the "help" paragraph?
 [2] Bushnell, D., "GENOPT - a program that writes user-friendly
 y        $ Are there more lines in the "help" paragraph?
 optimization code", Int. J. Solids Structures, Vol. 26, No. 9/10
 y        $ Are there more lines in the "help" paragraph?
 pp. 1173-1210, 1990
 n        $ Are there more lines in the "help" paragraph?
       1  $ Type of prompt: 0="help" paragraph, 1=one-line prompt

 npoint    $ Name of a variable in the users program (defined below)
       2  $ Role of the variable in the users program
       1  $ type of variable:  1 =integer,  2 =floating point
 n         $ Is the variable  npoint  an array?
 number of x-coordinates
 y         $ Do you want to include a "help" paragraph?
 The ellipse is simulated by a number of shell segments (try 10)
```

```
y         $ Any more lines in the "help" paragraph?
each of which has constant meridional curvature (toroidal).
y         $ Any more lines in the "help" paragraph?
npoint is the number of x-coordinates corresponding to the
y         $ Any more lines in the "help" paragraph?
ends of the toroidal segments that make up the equivalent
y         $ Any more lines in the "help" paragraph?
ellipse. You might try to simulate the ellipse by using 10
y         $ Any more lines in the "help" paragraph?
toroidal segments. Then the value of npoint would be 11
y         $ Any more lines in the "help" paragraph?
npoint includes the apex of the ellipse (x = 0) and the equator
y         $ Any more lines in the "help" paragraph?
of the ellipse (x = a, in which a = semimajor axis length).
n         $ Any more lines in the "help" paragraph?
y         $ Any more variables for role types  1  or  2   ?    $10
      1  $ Type of prompt: 0="help" paragraph, 1=one-line prompt
xinput    $ Name of a variable in the users program (defined below)
      2  $ Role of the variable in the users program
      2  $ type of variable:  1 =integer,  2 =floating point
y         $ Is the variable  xinput  an array?
y         $ Do you want to establish new dimensions for xinput ?
      1  $ Number of dimensions in the array,  xinput
vector element number for xinput
     21  $ Max. allowable number of rows NROWS in the array, xinput
x-coordinates for ends of segments
y         $ Do you want to include a "help" paragraph?
Please make sure to include x = 0 and x = a (equator) when
y         $ Any more lines in the "help" paragraph?
you provide values for xinput.
n         $ Any more lines in the "help" paragraph?
y         $ Any more variables for role types  1  or  2   ?    $20
      1  $ Type of prompt: 0="help" paragraph, 1=one-line prompt
ainput    $ Name of a variable in the users program (defined below)
      2  $ Role of the variable in the users program
      2  $ type of variable:  1 =integer,  2 =floating point
n         $ Is the variable  ainput  an array?
length of semi-major axis
y         $ Do you want to include a "help" paragraph?
ainput is the maximum "x=dimension" of the ellipse.
y         $ Any more lines in the "help" paragraph?
The equation for the ellipse is x^2/a^2 + y^2/b^2 = 1.0
n         $ Any more lines in the "help" paragraph?
y         $ Any more variables for role types  1  or  2   ?    $25
      1  $ Type of prompt: 0="help" paragraph, 1=one-line prompt
binput    $ Name of a variable in the users program (defined below)
      2  $ Role of the variable in the users program
      2  $ type of variable:  1 =integer,  2 =floating point
n         $ Is the variable  binput  an array?
length of semi-minor axis of ellipse
y         $ Do you want to include a "help" paragraph?
binput is the y-dimension of the ellipse, the equation for which
y         $ Any more lines in the "help" paragraph?
is x^2/a^2 + y^2/b^2 = 1.0.
n         $ Any more lines in the "help" paragraph?
y         $ Any more variables for role types  1  or  2   ?    $30
      1  $ Type of prompt: 0="help" paragraph, 1=one-line prompt
nodes     $ Name of a variable in the users program (defined below)
```

```
      2  $ Role of the variable in the users program
      1  $ type of variable:  1 =integer,  2 =floating point
n         $ Is the variable  nodes  an array?
number of nodal points per segment
y         $ Do you want to include a "help" paragraph?
If you have about 10 segments, use a number less than 31.
y         $ Any more lines in the "help" paragraph?
Use an odd number, greater than or equal to 11
n         $ Any more lines in the "help" paragraph?
y         $ Any more variables for role types  1  or  2   ?    $35
      1  $ Type of prompt: 0="help" paragraph, 1=one-line prompt
xlimit    $ Name of a variable in the users program (defined below)
      2  $ Role of the variable in the users program
      2  $ type of variable:  1 =integer,  2 =floating point
n         $ Is the variable  xlimit  an array?
max. x-coordinate for x-coordinate callouts
y         $ Do you want to include a "help" paragraph?
xlimit has two functions:
y         $ Any more lines in the "help" paragraph?
1. a delimiter for the definition of callouts:
y         $ Any more lines in the "help" paragraph?
for x < xlimit callouts are x-coordinates.
y         $ Any more lines in the "help" paragraph?
for x > xlimit callouts are y-coordinates.
y         $ Any more lines in the "help" paragraph?
Set xlimit equal to about a/2, where a = length of the
y         $ Any more lines in the "help" paragraph?
semi-major axis of the ellipse.
y         $ Any more lines in the "help" paragraph?
2. a delimiter for the boundary between Region 1
y         $ Any more lines in the "help" paragraph?
and Region 2, Design margins for maximum stress and
y         $ Any more lines in the "help" paragraph?
minimum buckling load in the shell skin and in the
y         $ Any more lines in the "help" paragraph?
isogrid stiffeners can be computed in two regions,
y         $ Any more lines in the "help" paragraph?
Region 1: 0 < x < xlimit, and
y         $ Any more lines in the "help" paragraph?
Region 2: xlimit < x < semi-major axis.
n         $ Any more lines in the "help" paragraph?
y         $ Any more variables for role types  1  or  2   ?    $40
      1  $ Type of prompt: 0="help" paragraph, 1=one-line prompt
THKSKN    $ Name of a variable in the users program (defined below)
      1  $ Role of the variable in the users program
y         $ Is the variable  THKSKN  an array?
n         $ Do you want to establish new dimensions for THKSKN ?
skin thickness at xinput
y         $ Do you want to include a "help" paragraph?
xinput is the vector of x-coordinate callouts for
y         $ Any more lines in the "help" paragraph?
thickness of the shell skin and height of the
y         $ Any more lines in the "help" paragraph?
isogrid stiffeners.
n         $ Any more lines in the "help" paragraph?
y         $ Any more variables for role types  1  or  2   ?    $50
      1  $ Type of prompt: 0="help" paragraph, 1=one-line prompt
HIGHST    $ Name of a variable in the users program (defined below)
```

```
      1  $ Role of the variable in the users program
y         $ Is the variable  HIGHST  an array?
n         $ Do you want to establish new dimensions for HIGHST ?
height of isogrid members at xinput
y         $ Do you want to include a "help" paragraph?
xinput is the vector of x-coordinate callouts for
y         $ Any more lines in the "help" paragraph?
thickness of the shell skin and height of the
y         $ Any more lines in the "help" paragraph?
isogrid stiffeners.
n         $ Any more lines in the "help" paragraph?
y        $ Any more variables for role types  1  or  2   ?    $45
      1  $ Type of prompt: 0="help" paragraph, 1=one-line prompt
SPACNG   $ Name of a variable in the users program (defined below)
      1  $ Role of the variable in the users program
n        $ Is the variable  SPACNG  an array?
spacing of the isogrid members
y        $ Do you want to include a "help" paragraph?
SPACNG = altitude of the equilateral triangle between adjacent
y        $ Any more lines in the "help" paragraph?
isogrid members, measured to middle surfaces of isogrid members.
y        $ Any more lines in the "help" paragraph?
SPACNG = (length of side of triangle)*sqrt(3)/2.
y        $ Any more lines in the "help" paragraph?
SPACNG is constant over the entire shell.
n        $ Any more lines in the "help" paragraph?
y        $ Any more variables for role types  1  or  2   ?    $50
      1  $ Type of prompt: 0="help" paragraph, 1=one-line prompt
THSTIF   $ Name of a variable in the users program (defined below)
      1  $ Role of the variable in the users program
n        $ Is the variable  THSTIF  an array?
thickness of an isogrid stiffening member
y        $ Do you want to include a "help" paragraph?
THSTIF is constant over the entire shell.
n        $ Any more lines in the "help" paragraph?
y        $ Any more variables for role types  1  or  2   ?    $55
      1  $ Type of prompt: 0="help" paragraph, 1=one-line prompt
THKCYL   $ Name of a variable in the users program (defined below)
      2  $ Role of the variable in the users program
      2  $ type of variable:  1 =integer,  2 =floating point
n        $ Is the variable  THKCYL  an array?
thickness of the cylindrical shell
n        $ Do you want to include a "help" paragraph?
y        $ Any more variables for role types  1  or  2   ?    $60
      1  $ Type of prompt: 0="help" paragraph, 1=one-line prompt
RADCYL   $ Name of a variable in the users program (defined below)
      2  $ Role of the variable in the users program
      2  $ type of variable:  1 =integer,  2 =floating point
n        $ Is the variable  RADCYL  an array?
radius of the cylindrical shell
n        $ Do you want to include a "help" paragraph?
y        $ Any more variables for role types  1  or  2   ?    $80
      1  $ Type of prompt: 0="help" paragraph, 1=one-line prompt
LENCYL   $ Name of a variable in the users program (defined below)
      2  $ Role of the variable in the users program
      2  $ type of variable:  1 =integer,  2 =floating point
n        $ Is the variable  LENCYL  an array?
length of the cylindrical segment
```

```
n        $ Do you want to include a "help" paragraph?
y        $ Any more variables for role types  1  or  2   ?    $85
      1  $ Type of prompt: 0="help" paragraph, 1=one-line prompt
WIMP     $ Name of a variable in the users program (defined below)
      2  $ Role of the variable in the users program
      2  $ type of variable:  1 =integer,  2 =floating point
n        $ Is the variable  WIMP  an array?
amplitude of the axisymmetric imperfection
y        $ Do you want to include a "help" paragraph?
Use a positive value greater than zero.
y        $ Any more lines in the "help" paragraph?
For a perfect shell, use a value of WIMP that is
y        $ Any more lines in the "help" paragraph?
very, very small compared to the skin thickness.
y        $ Any more lines in the "help" paragraph?
The imperfections are in the shapes of the axisymmetric
y        $ Any more lines in the "help" paragraph?
buckling modes obtained from linear theory for the
y        $ Any more lines in the "help" paragraph?
PERFECT shell. The actual imperfections are equal to
y        $ Any more lines in the "help" paragraph?
WIMP*WSHAPE(i), i = 1,NUMB,
y        $ Any more lines in the "help" paragraph?
in which NUMB = number of nodes in a shell segment.
y        $ Any more lines in the "help" paragraph?
In the paper about optimization of ellipsoidal shells
y        $ Any more lines in the "help" paragraph?
the axisymmetric buckling modal imperfections are
y        $ Any more lines in the "help" paragraph?
called "mode 1", "mode 2", "mode 3", "mode 4",
y        $ Any more lines in the "help" paragraph?
corresponding to the number of the linear buckling
y        $ Any more lines in the "help" paragraph?
eigenvalue corresponding to axisymmetric buckling.
y        $ Any more lines in the "help" paragraph?
Optimization can be performed with the use of
y        $ Any more lines in the "help" paragraph?
two modes, "mode 1" and "mode 2" or with the use
y        $ Any more lines in the "help" paragraph?
of four modes, "mode 1", "mode 2", "mode 3", "mode 4".
y        $ Any more lines in the "help" paragraph?
The shell is optimized with the plus and minus
y        $ Any more lines in the "help" paragraph?
version of each axisymmetric buckling modal
y        $ Any more lines in the "help" paragraph?
imperfection present by itself. In other words,
y        $ Any more lines in the "help" paragraph?
the shell is optimized such that it will survive
y        $ Any more lines in the "help" paragraph?
if any ONE of up to eight axisymmetric buckling
y        $ Any more lines in the "help" paragraph?
modal imperfections of amplitude WIMP is present.
y        $ Any more lines in the "help" paragraph?
The plus and minus versions of the axisymmetric
y        $ Any more lines in the "help" paragraph?
buckling modal imperfections are processed as
y        $ Any more lines in the "help" paragraph?
different load sets "applied" to the shell:
```

```
y        $ Any more lines in the "help" paragraph?
Load set 1 has plus  "mode 1" and plus  "mode 2";
y        $ Any more lines in the "help" paragraph?
Load set 2 has minus "mode 1" and minus "mode 2";
y        $ Any more lines in the "help" paragraph?
Load set 3 has plus  "mode 3" and plus  "mode 4";
y        $ Any more lines in the "help" paragraph?
Load set 4 has minus "mode 3" and minus "mode 4.
y        $ Any more lines in the "help" paragraph?
Usually, optimization should be performed with use
y        $ Any more lines in the "help" paragraph?
of only "mode 1" and "mode 2" imperfection shapes.
n        $ Any more lines in the "help" paragraph?
y        $ Any more variables for role types  1  or  2   ?    $90
      1  $ Type of prompt: 0="help" paragraph, 1=one-line prompt
EMATL    $ Name of a variable in the users program (defined below)
      2  $ Role of the variable in the users program
      2  $ type of variable:  1 =integer,  2 =floating point
n        $ Is the variable  EMATL  an array?
elastic modulus
n        $ Do you want to include a "help" paragraph?
y        $ Any more variables for role types  1  or  2   ?    $95
      1  $ Type of prompt: 0="help" paragraph, 1=one-line prompt
NUMATL   $ Name of a variable in the users program (defined below)
      2  $ Role of the variable in the users program
      2  $ type of variable:  1 =integer,  2 =floating point
n        $ Is the variable  NUMATL  an array?
Poisson ratio of material
n        $ Do you want to include a "help" paragraph?
y        $ Any more variables for role types  1  or  2   ?    $100
      1  $ Type of prompt: 0="help" paragraph, 1=one-line prompt
DNMATL   $ Name of a variable in the users program (defined below)
      2  $ Role of the variable in the users program
      2  $ type of variable:  1 =integer,  2 =floating point
n        $ Is the variable  DNMATL  an array?
mass density of material
y        $ Do you want to include a "help" paragraph?
For example, the mass density of aluminum in English units is
y        $ Any more lines in the "help" paragraph?
0.000259
n        $ Any more lines in the "help" paragraph?
y        $ Any more variables for role types  1  or  2   ?    $100
      1  $ Type of prompt: 0="help" paragraph, 1=one-line prompt
IMODE    $ Name of a variable in the users program (defined below)
      2  $ Role of the variable in the users program
      1  $ type of variable:  1 =integer,  2 =floating point
n        $ Is the variable  IMODE  an array?
strategy control for imperfection shapes
y        $ Do you want to include a "help" paragraph?
IMODE governs the strategy used to generate axisymmetric
y        $ Any more lines in the "help" paragraph?
buckling modal imperfection shapes.
y        $ Any more lines in the "help" paragraph?
IMODE = 1 means use Strategy 1 (Do not use this)
y        $ Any more lines in the "help" paragraph?
IMODE = 2 means use Strategy 2 (Use this choice)
y        $ Any more lines in the "help" paragraph?
```

```
y        $ Any more lines in the "help" paragraph?
In Strategy 1 axisymmetric buckling modes are
y        $ Any more lines in the "help" paragraph?
scanned until a mode is found in which the normal
y        $ Any more lines in the "help" paragraph?
modal displacement amplitude at the apex of the shell
y        $ Any more lines in the "help" paragraph?
is at least 0.7. (All buckling modes are normalized so that
y        $ Any more lines in the "help" paragraph?
the maximum buckling modal displacement is 1.0. The
y        $ Any more lines in the "help" paragraph?
buckling modal imperfection is the user-specified amplitude,
y        $ Any more lines in the "help" paragraph?
WIMP, multiplied by the normalized buckling modal displacement
y        $ Any more lines in the "help" paragraph?
distribution WSHAPE along the meridian of the shell.)
y        $ Any more lines in the "help" paragraph?
The remaining n (n = 2 or n = 4) modes are selected without
y        $ Any more lines in the "help" paragraph?
regard to the imperfection amplitude at the apex.
y        $ Any more lines in the "help" paragraph?

y        $ Any more lines in the "help" paragraph?
In Strategy 2 the first n axisymmetric buckling
y        $ Any more lines in the "help" paragraph?
modes (n = 2 or n = 4) are selected regardless of their
y        $ Any more lines in the "help" paragraph?
amplitude at the apex of the shell.
y        $ Any more lines in the "help" paragraph?
It is best to try Strategy 2 first.
n        $ Any more lines in the "help" paragraph?
n        $ Any more variables for role types  1  or  2   ?    $
      1  $ Type of prompt: 0="help" paragraph, 1=one-line prompt
PRESS    $ Name of a variable in the users program (defined below)
      3  $ Role of the variable in the users program
uniform external pressure
n        $ Do you want to include a "help" paragraph?
n        $ Any more variables for role type  3 ?             $
      1  $ Type of prompt: 0="help" paragraph, 1=one-line prompt
CLAPS1   $ Name of a variable in the users program (defined below)
      4  $ Role of the variable in the users program
n        $ Do you want to reset the number of columns in CLAPS ?
collapse pressure with imperfection mode 1
n        $ Do you want to include a "help" paragraph?
      1  $ Type of prompt: 0="help" paragraph, 1=one-line prompt
CLAPS1A  $ Name of a variable in the users program (defined below)
      5  $ Role of the variable in the users program
allowable pressure for axisymmetric collapse
n        $ Do you want to include a "help" paragraph?
      1  $ Type of prompt: 0="help" paragraph, 1=one-line prompt
CLAPS1F  $ Name of a variable in the users program (defined below)
      6  $ Role of the variable in the users program
factor of safety for axisymmetric collapse
n        $ Do you want to include a "help" paragraph?
      2  $ Indicator (1 or 2 or 3) for type of constraint
y        $ Any more variables for role type  4 ?             $130
      1  $ Type of prompt: 0="help" paragraph, 1=one-line prompt
GENBK1   $ Name of a variable in the users program (defined below)
```

```
      4  $ Role of the variable in the users program
n        $ Do you want to reset the number of columns in GENBK ?
general buckling load factor, mode 1
n        $ Do you want to include a "help" paragraph?
      1  $ Type of prompt: 0="help" paragraph, 1=one-line prompt
GENBK1A  $ Name of a variable in the users program (defined below)
      5  $ Role of the variable in the users program
allowable general buckling load factor (use 1.0)
y        $ Do you want to include a "help" paragraph?
GENBK1 is defined as a "buckling load FACTOR",
y        $ Any more lines in the "help" paragraph?
not as a "buckling LOAD". Therefore, you should
y        $ Any more lines in the "help" paragraph?
always use a value of the "allowable general buckling
y        $ Any more lines in the "help" paragraph?
load factor" equal to unity. This point holds for
y        $ Any more lines in the "help" paragraph?
the treatment of all buckling allowables in this
y        $ Any more lines in the "help" paragraph?
application.
n        $ Any more lines in the "help" paragraph?
      1  $ Type of prompt: 0="help" paragraph, 1=one-line prompt
GENBK1F  $ Name of a variable in the users program (defined below)
      6  $ Role of the variable in the users program
factor of safety for general buckling
y        $ Do you want to include a "help" paragraph?
Remember, this program already includes the effect of an
y        $ Any more lines in the "help" paragraph?
axisymmetric buckling modal imperfection. If you use an
y        $ Any more lines in the "help" paragraph?
imperfection amplitude, WIMP, significantly greater
y        $ Any more lines in the "help" paragraph?
than zero you should accordingly use a factor of safety
y        $ Any more lines in the "help" paragraph?
closer to unity than you would for an almost perfect
y        $ Any more lines in the "help" paragraph?
shell.
n        $ Any more lines in the "help" paragraph?
      2  $ Indicator (1 or 2 or 3) for type of constraint
y        $ Any more variables for role type  4 ?            $145
      1  $ Type of prompt: 0="help" paragraph, 1=one-line prompt
SKNBK1   $ Name of a variable in the users program (defined below)
      4  $ Role of the variable in the users program
y         $ Do you want to reset the number of columns in SKNBK1 ?
      2  $ Number of dimensions in the array,  SKNBK1
number of regions for computing behavior
     10  $ Max. allowable number of columns NCOLS in the array, SKNBK1
local skin buckling load factor, mode 1
n         $ Do you want to include a "help" paragraph?
      1  $ Type of prompt: 0="help" paragraph, 1=one-line prompt
SKNBK1A   $ Name of a variable in the users program (defined below)
      5  $ Role of the variable in the users program
allowable buckling load factor
n         $ Do you want to include a "help" paragraph?
      1  $ Type of prompt: 0="help" paragraph, 1=one-line prompt
SKNBK1F   $ Name of a variable in the users program (defined below)
      6  $ Role of the variable in the users program
factor of safety for skin buckling
```

```
n         $ Do you want to include a "help" paragraph?
      2  $ Indicator (1 or 2 or 3) for type of constraint
y         $ Any more variables for role type  4 ?             $165
      1  $ Type of prompt: 0="help" paragraph, 1=one-line prompt
STFBK1   $ Name of a variable in the users program (defined below)
      4  $ Role of the variable in the users program
n        $ Do you want to reset the number of columns in STFBK ?
buckling load factor, isogrid member, mode 1
n        $ Do you want to include a "help" paragraph?
      1  $ Type of prompt: 0="help" paragraph, 1=one-line prompt
STFBK1A  $ Name of a variable in the users program (defined below)
      5  $ Role of the variable in the users program
allowable for isogrid stiffener buckling (Use 1.)
n        $ Do you want to include a "help" paragraph?
      1  $ Type of prompt: 0="help" paragraph, 1=one-line prompt
STFBK1F  $ Name of a variable in the users program (defined below)
      6  $ Role of the variable in the users program
factor of safety for isogrid stiffener buckling
n        $ Do you want to include a "help" paragraph?
      2  $ Indicator (1 or 2 or 3) for type of constraint
y        $ Any more variables for role type  4 ?             $175
      1  $ Type of prompt: 0="help" paragraph, 1=one-line prompt
SKNST1   $ Name of a variable in the users program (defined below)
      4  $ Role of the variable in the users program
n        $ Do you want to reset the number of columns in SKNST ?
maximum stress in the shell skin, mode 1
n        $ Do you want to include a "help" paragraph?
      1  $ Type of prompt: 0="help" paragraph, 1=one-line prompt
SKNST1A  $ Name of a variable in the users program (defined below)
      5  $ Role of the variable in the users program
allowable stress for the shell skin
n        $ Do you want to include a "help" paragraph?
      1  $ Type of prompt: 0="help" paragraph, 1=one-line prompt
SKNST1F  $ Name of a variable in the users program (defined below)
      6  $ Role of the variable in the users program
factor of safety for skin stress
n        $ Do you want to include a "help" paragraph?
      3  $ Indicator (1 or 2 or 3) for type of constraint
y        $ Any more variables for role type  4 ?             $190
      1  $ Type of prompt: 0="help" paragraph, 1=one-line prompt
STFST1   $ Name of a variable in the users program (defined below)
      4  $ Role of the variable in the users program
n        $ Do you want to reset the number of columns in STFST ?
maximum stress in isogrid stiffener, mode 1
n        $ Do you want to include a "help" paragraph?
      1  $ Type of prompt: 0="help" paragraph, 1=one-line prompt
STFST1A  $ Name of a variable in the users program (defined below)
      5  $ Role of the variable in the users program
allowable stress in isogrid stiffeners
n        $ Do you want to include a "help" paragraph?
      1  $ Type of prompt: 0="help" paragraph, 1=one-line prompt
STFST1F  $ Name of a variable in the users program (defined below)
      6  $ Role of the variable in the users program
factor of safety for stress in isogrid member
n        $ Do you want to include a "help" paragraph?
      3  $ Indicator (1 or 2 or 3) for type of constraint
y        $ Any more variables for role type  4 ?             $205
y        $ Any more variables for role type  4 ?             $205
```

```
      1  $ Type of prompt: 0="help" paragraph, 1=one-line prompt
WAPEX1   $ Name of a variable in the users program (defined below)
      4  $ Role of the variable in the users program
y         $ Do you want to reset the number of columns in WAPEX1 ?
      1  $ Number of dimensions in the array,  WAPEX1
normal (axial) displacement at apex, mode 1
n         $ Do you want to include a "help" paragraph?
      1  $ Type of prompt: 0="help" paragraph, 1=one-line prompt
WAPEX1A  $ Name of a variable in the users program (defined below)
      5  $ Role of the variable in the users program
allowable normal (axial) displacement at apex
n        $ Do you want to include a "help" paragraph?
      1  $ Type of prompt: 0="help" paragraph, 1=one-line prompt
WAPEX1F  $ Name of a variable in the users program (defined below)
      6  $ Role of the variable in the users program
factor of safety for WAPEX
n        $ Do you want to include a "help" paragraph?
      3  $ Indicator (1 or 2 or 3) for type of constraint
y        $ Any more variables for role type  4 ?             $
      1  $ Type of prompt: 0="help" paragraph, 1=one-line prompt
CLAPS2   $ Name of a variable in the users program (defined below)
      4  $ Role of the variable in the users program
n        $ Do you want to reset the number of columns in CLAPS ?
collapse pressure with imperfection mode 2
n        $ Do you want to include a "help" paragraph?
      1  $ Type of prompt: 0="help" paragraph, 1=one-line prompt
CLAPS2A  $ Name of a variable in the users program (defined below)
      5  $ Role of the variable in the users program
allowable pressure for axisymmetric collapse
n        $ Do you want to include a "help" paragraph?
      1  $ Type of prompt: 0="help" paragraph, 1=one-line prompt
CLAPS2F  $ Name of a variable in the users program (defined below)
      6  $ Role of the variable in the users program
factor of safety for axisymmetric collapse
n        $ Do you want to include a "help" paragraph?
      2  $ Indicator (1 or 2 or 3) for type of constraint
y        $ Any more variables for role type  4 ?             $130
      1  $ Type of prompt: 0="help" paragraph, 1=one-line prompt
GENBK2   $ Name of a variable in the users program (defined below)
      4  $ Role of the variable in the users program
n        $ Do you want to reset the number of columns in GENBK ?
general buckling load factor, mode 2
n        $ Do you want to include a "help" paragraph?
      1  $ Type of prompt: 0="help" paragraph, 1=one-line prompt
GENBK2A  $ Name of a variable in the users program (defined below)
      5  $ Role of the variable in the users program
allowable general buckling load factor (use 1.0)
n        $ Do you want to include a "help" paragraph?
      1  $ Type of prompt: 0="help" paragraph, 1=one-line prompt
GENBK2F  $ Name of a variable in the users program (defined below)
      6  $ Role of the variable in the users program
factor of safety for general buckling
y        $ Do you want to include a "help" paragraph?
Remember, this program already includes the effect of an
y        $ Any more lines in the "help" paragraph?
axisymmetric buckling modal imperfection. If you use an
y        $ Any more lines in the "help" paragraph?
imperfection amplitude, WIMP, significantly greater
```

```
y        $ Any more lines in the "help" paragraph?
than zero you should accordingly use a factor of safety
y        $ Any more lines in the "help" paragraph?
closer to unity than you would for an almost perfect
y        $ Any more lines in the "help" paragraph?
shell.
n        $ Any more lines in the "help" paragraph?
      2  $ Indicator (1 or 2 or 3) for type of constraint
y        $ Any more variables for role type  4 ?              $145
      1  $ Type of prompt: 0="help" paragraph, 1=one-line prompt
SKNBK2   $ Name of a variable in the users program (defined below)
      4  $ Role of the variable in the users program
y         $ Do you want to reset the number of columns in SKNBK2 ?
      2  $ Number of dimensions in the array,  SKNBK2
number of regions for computing behavior
     10  $ Max. allowable number of columns NCOLS in the array, SKNBK2
local skin buckling load factor, mode 2
n        $ Do you want to include a "help" paragraph?
      1  $ Type of prompt: 0="help" paragraph, 1=one-line prompt
SKNBK2A  $ Name of a variable in the users program (defined below)
      5  $ Role of the variable in the users program
allowable skin buckling load factor (use 1.0)
n        $ Do you want to include a "help" paragraph?
      1  $ Type of prompt: 0="help" paragraph, 1=one-line prompt
SKNBK2F  $ Name of a variable in the users program (defined below)
      6  $ Role of the variable in the users program
factor of safety for local skin buckling
n        $ Do you want to include a "help" paragraph?
      2  $ Indicator (1 or 2 or 3) for type of constraint
y        $ Any more variables for role type  4 ?              $160
      1  $ Type of prompt: 0="help" paragraph, 1=one-line prompt
STFBK2   $ Name of a variable in the users program (defined below)
      4  $ Role of the variable in the users program
n        $ Do you want to reset the number of columns in STFBK ?
buckling load factor for isogrid member, mode 2
n        $ Do you want to include a "help" paragraph?
      1  $ Type of prompt: 0="help" paragraph, 1=one-line prompt
STFBK2A  $ Name of a variable in the users program (defined below)
      5  $ Role of the variable in the users program
allowable for isogrid stiffener buckling (Use 1.)
n        $ Do you want to include a "help" paragraph?
      1  $ Type of prompt: 0="help" paragraph, 1=one-line prompt
STFBK2F  $ Name of a variable in the users program (defined below)
      6  $ Role of the variable in the users program
factor of safety for isogrid stiffener buckling
n        $ Do you want to include a "help" paragraph?
      2  $ Indicator (1 or 2 or 3) for type of constraint
y        $ Any more variables for role type  4 ?              $175
      1  $ Type of prompt: 0="help" paragraph, 1=one-line prompt
SKNST2   $ Name of a variable in the users program (defined below)
      4  $ Role of the variable in the users program
n        $ Do you want to reset the number of columns in SKNST ?
maximum stress in the shell skin, mode 2
n        $ Do you want to include a "help" paragraph?
      1  $ Type of prompt: 0="help" paragraph, 1=one-line prompt
SKNST2A  $ Name of a variable in the users program (defined below)
      5  $ Role of the variable in the users program
allowable stress for the shell skin
```

```
n        $ Do you want to include a "help" paragraph?
      1  $ Type of prompt: 0="help" paragraph, 1=one-line prompt
SKNST2F  $ Name of a variable in the users program (defined below)
      6  $ Role of the variable in the users program
factor of safety for skin stress
n        $ Do you want to include a "help" paragraph?
      3  $ Indicator (1 or 2 or 3) for type of constraint
y        $ Any more variables for role type  4 ?              $190
      1  $ Type of prompt: 0="help" paragraph, 1=one-line prompt
STFST2   $ Name of a variable in the users program (defined below)
      4  $ Role of the variable in the users program
n        $ Do you want to reset the number of columns in STFST ?
maximum stress in isogrid stiffener, mode 2
n        $ Do you want to include a "help" paragraph?
      1  $ Type of prompt: 0="help" paragraph, 1=one-line prompt
STFST2A  $ Name of a variable in the users program (defined below)
      5  $ Role of the variable in the users program
allowable stress in isogrid stiffeners
n        $ Do you want to include a "help" paragraph?
      1  $ Type of prompt: 0="help" paragraph, 1=one-line prompt
STFST2F  $ Name of a variable in the users program (defined below)
      6  $ Role of the variable in the users program
factor of safety for stress in isogrid member
n        $ Do you want to include a "help" paragraph?
      3  $ Indicator (1 or 2 or 3) for type of constraint
y        $ Any more variables for role type  4 ?              $205
      1  $ Type of prompt: 0="help" paragraph, 1=one-line prompt
WAPEX2   $ Name of a variable in the users program (defined below)
      4  $ Role of the variable in the users program
y         $ Do you want to reset the number of columns in WAPEX2 ?
      1  $ Number of dimensions in the array,  WAPEX2
normal (axial) displacement at apex, mode 2
n        $ Do you want to include a "help" paragraph?
      1  $ Type of prompt: 0="help" paragraph, 1=one-line prompt
WAPEX2A  $ Name of a variable in the users program (defined below)
      5  $ Role of the variable in the users program
allowable normal (axial) displacement at apex
n        $ Do you want to include a "help" paragraph?
      1  $ Type of prompt: 0="help" paragraph, 1=one-line prompt
WAPEX2F  $ Name of a variable in the users program (defined below)
      6  $ Role of the variable in the users program
factor of safety for WAPEX
n        $ Do you want to include a "help" paragraph?
      3  $ Indicator (1 or 2 or 3) for type of constraint
n        $ Any more variables for role type  4 ?              $
      1  $ Type of prompt: 0="help" paragraph, 1=one-line prompt
WEIGHT   $ Name of a variable in the users program (defined below)
      7  $ Role of the variable in the users program
weight of the equivalent ellipsoidal head
y        $ Do you want to include a "help" paragraph?
You can get the weight of just the head (no cylindrical shell
y        $ Any more lines in the "help" paragraph?
by setting the density of the cylindrical segment equal to 0.
y        $ Any more lines in the "help" paragraph?
NOTE: This is done in SUBROUTINE BOSDEC for you.
n        $ Any more lines in the "help" paragraph?
======================================================================
```

Table A2 List of the file, **equivellipse.DEF.**
This file is generated automatically by GENOPT
after the GENOPT user completes the "GENTEXT"
interactive session. A copy of this file is
automatically inserted near the beginning of
the skeletal behavior.new file (Table a13 of [26]).

```
======================================================================
C YOU ARE USING WHAT I HAVE CALLED "GENOPT" TO GENERATE AN
C OPTIMIZATION PROGRAM FOR A PARTICULAR CLASS OF PROBLEMS.
C THE NAME YOU HAVE CHOSEN FOR THIS CLASS OF PROBLEMS IS: equivellipse

C "GENOPT" (GENeral OPTimization) was written during 1987-1988
C by Dr. David Bushnell, Dept. 93-30, Bldg. 251, (415)424-3237
C    Lockheed Missiles and Space Co., 3251 Hanover St.,
C    Palo Alto, California, USA  94304

C The optimizer used in GENOPT is called ADS, and was
C written by G. Vanderplaats [3]. It is based on the method
C of feasible directions [4].

C                        ABSTRACT

C "GENOPT" has the following purposes and properties:
C      1. Any relatively simple analysis is "automatically"
C         converted into an optimization of whatever system
C         can be analyzed with fixed properties. Please note
C         that GENOPT is not intended to be used for problems
C         that require elaborate data-base management systems
C         or large numbers of degrees of freedom.

C      2. The optimization problems need not be in fields nor
C         jargon familiar to me, the developer of GENOPT.
C         Although all of the example cases (See the cases
C         in the directories under genopt/case)
C         are in the field of structural analysis, GENOPT is
C         not limited to that field.


C      3. GENOPT is a program that writes other programs. These
C         programs, WHEN AUGMENTED BY USER-SUPPLIED CODING,
C         form a program system that should be user-friendly in
C         the GENOPT-user"s field. In this instance the user
C         of GENOPT must later supply FORTRAN coding that
C         calculates behavior in the problem class called "equivellipse".

C      4. Input data and textual material are elicited from
C         the user of GENOPT in a general enough way so that
C         he or she may employ whatever data, definitions, and
C         "help" paragraphs will make subsequent use of the
C         program system thus generated easy by those less
C         familiar with the class of problems "equivellipse" than
C         the GENOPT user.

C      5. The program system generated by GENOPT has the same
C         general architecture as previous programs written for
C         specific applications by the developer [7 - 16]. That
```

```
C        is, the command set is:

C           BEGIN     (User supplies starting design, loads,
C                      control integers, material properties,
C                      etc. in an interactive-help mode.)

C           DECIDE    (User chooses decision and linked
C                      variables and inequality constraints
C                      that are not based on behavior.)

C           MAINSETUP (User chooses output option, whether
C                      to perform analysis of a fixed design
C                      or to optimize, and number of design
C                      iterations.)

C           OPTIMIZE  (The program system performs, in a batch
C                      mode, the work specified in MAINSETUP.)

C           SUPEROPT  (Program tries to find the GLOBAL optimum
C                      design as described in Ref.[11] listed
C                      below (Many OPTIMIZEs in one run.)

C           CHANGE    (User changes certain parameters)

C           CHOOSEPLOT (User selects which quantities to plot
C                       vs. design iterations.)

C           DIPLOT    (User generates plots)

C           CLEANSPEC (User cleans out unwanted files.)

C     A typical runstream is:
C       GENOPTLOG   (activate command set)
C       BEGIN       (provide starting design, loads, etc.)
C       DECIDE      (choose decision variables and bounds)
C       MAINSETUP   (choose print option and analysis type)
C       OPTIMIZE    (launch batch run for n design iterations)
C       OPTIMIZE    (launch batch run for n design iterations)
C       OPTIMIZE    (launch batch run for n design iterations)
C       OPTIMIZE    (launch batch run for n design iterations)
C       OPTIMIZE    (launch batch run for n design iterations)
C       CHANGE      (change some variables for new starting pt)
C       OPTIMIZE    (launch batch run for n design iterations)
C       OPTIMIZE    (launch batch run for n design iterations)
C       OPTIMIZE    (launch batch run for n design iterations)
C       OPTIMIZE    (launch batch run for n design iterations)
C       OPTIMIZE    (launch batch run for n design iterations)
C       CHOOSEPLOT  (choose which variables to plot)
C       DIPLOT      (plot variables v. iterations)
C       CHOOSEPLOT  (choose additional variables to plot)
C       DIPLOT      (plot more variables v design iterations)
C       CLEANSPEC   (delete extraneous files for specific case)

C  IMPORTANT:  YOU MUST ALWAYS GIVE THE COMMAND "OPTIMIZE"
C              SEVERAL TIMES IN SUCCESSION IN ORDER TO OBTAIN
C              CONVERGENCE! AN EXPLANATION OF WHY YOU MUST DO
C              THIS IS GIVEN ON P 580-582 OF THE PAPER "PANDA2,
C              PROGRAM FOR MINIMUM WEIGHT DESIGN OF STIFFENED,
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```
C               COMPOSITE LOCALLY BUCKLED PANELS", Computers and
C               Structures, Vol. 25, No. 4, pp 469-605 (1987).

C Due to introduction of a "global" optimizer, SUPEROPT,
C described in Ref.[11], you can now use the runstream

C      BEGIN       (provide starting design, loads, etc.)
C      DECIDE      (choose decision variables and bounds)
C      MAINSETUP   (choose print option and analysis type)
C      SUPEROPT    (launch batch run for "global" optimization)
C      CHOOSEPLOT  (choose which variables to plot)
C      DIPLOT      (plot variables v. iterations)

C "Global" is in quotes because SUPEROPT does its best to find
C a true global optimum design. The user is strongly urged to
C execute SUPEROPT/CHOOSEPLOT several times in succession in
C order to determine an optimum that is essentially just as
C good as the theoretical true global optimum. Each execution
C of the series,
C      SUPEROPT
C      CHOOSEPLOT

C does the following:

C 1. SUPEROPT executes many sets of the two processors,
C    OPTIMIZE and AUTOCHANGE (AUTOCHANGE gets a new random
C    "starting" design), in which each set does the following:

C      OPTIMIZE          (perform k design iterations)
C      OPTIMIZE          (perform k design iterations)
C      OPTIMIZE          (perform k design iterations)
C      OPTIMIZE          (perform k design iterations)
C      OPTIMIZE          (perform k design iterations)
C      AUTOCHANGE        (get new starting design randomly)

C    SUPEROPT keeps repeating the above sequence until the
C    total number of design iterations reaches about 270.
C    The number of OPTIMIZEs per AUTOCHANGE is user-provided.

C 2. CHOOSEPLOT allows the user to plot stuff and resets the
C    total number of design iterations from SUPEROPT to zero.
C    After each execution of SUPEROPT the user MUST execute
C    CHOOSEPLOT: before the next execution of SUPEROPT the
C    total number of design iterations MUST be reset to zero.

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```

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C===============================================================
C                TABLE 1      "GENOPT" COMMANDS
C===============================================================
```

```
C     HELPG        (get information on GENOPT.)
C     GENTEXT      (GENOPT user generate a prompt file, program
C                   fragments [see TABLE 5], programs [see
C                   TABLE 4]., and this and other files
C                   [see TABLE 5 and the rest of this file.])
C     GENPROGRAMS  (GENOPT user generate absolute elements:
C                   BEGIN.EXE, DECIDE.EXE, MAINSETUP.EXE,
C                   OPTIMIZE.EXE, CHANGE.EXE, STORE.EXE,
C                   CHOOSEPLOT.EXE, DIPLOT.EXE.)

C     BEGIN        (end user provide starting data.)
C     DECIDE       (end user choose decision variables, bounds,
C                   linked variables,inequality constraints.)
C     MAINSETUP    (end user set up strategy parameters.)
C     OPTIMIZE     (end user perform optimization, batch mode.)
C     SUPEROPT     (Program tries to find the GLOBAL optimum
C                   design as described in Ref.[11] listed
C                   above (Many OPTIMIZEs in one run.)

C     CHANGE       (end user change some parameters.)
C     CHOOSEPLOT   (end user choose which variables to plot v.
C                   design iterations.)
C     DIPLOT       (end user obtain plots.)
C     INSERT       (GENOPT user add parameters to the problem.)
C     CLEANGEN     (GENOPT user cleanup your GENeric files.)
C     CLEANSPEC    (end user cleanup your SPECific case files)

C   Please consult the following sources for more
C   information about GENOPT:
C        1.  GENOPT.STORY  and  HOWTO.RUN  and  GENOPT.NEWS
C        2.  Sample cases: (in the directory, genopt/case)
C        3.  NAME.DEF file, where NAME is the name chosen by
C            the GENOPT-user for a class of problems. (In this
C            case  NAME = equivellipse)
C        4.  GENOPT.HLP file    (type HELPG)
C==============================================================

C==============================================================
C   TABLE 2   GLOSSARY OF VARIABLES USED IN "equivellipse"
C==============================================================
C  ARRAY  NUMBER OF         PROMPT
C     ?    (ROWS,COLS)  ROLE  NUMBER    NAME                      DEFINITION OF
VARIABLE
C                          (equivellipse.PRO)
C==============================================================
C    n   (    0,    0)    2      10   npoint   = number of x-coordinates
C     n   (    0,    0)    2      15   Ixinpu    = vector element number for
xinput in xinput(Ixinpu)
C     y   (   21,    0)    2      20   xinput    = x-coordinates for ends of
segments
C    n   (    0,    0)    2      25   ainput   = length of semi-major axis
C     n   (    0,    0)    2      30   binput    = length of semi-minor axis of
ellipse
C     n   (    0,    0)    2      35   nodes     = number of nodal points per
segment
C     n   (    0,    0)    2      40   xlimit    = max. x-coordinate for x-
coordinate callouts
C    y   (   21,    0)    1      45   THKSKN   = skin thickness at xinput
```

```
C    y   (  21,   0)    1      50   HIGHST   = height of isogrid members at
xinput
C   n   (   0,   0)    1      55   SPACNG   = spacing of the isogrid members
C    n   (   0,   0)    1      60   THSTIF   = thickness of an isogrid
stiffening member
C   n   (   0,   0)    2      65   THKCYL   = thickness of the cylindrical
shell
C    n   (   0,   0)    2      70   RADCYL   = radius of the cylindrical
shell
C    n   (   0,   0)    2      75   LENCYL   = length of the cylindrical
segment
C    n   (   0,   0)    2      80   WIMP     = amplitude of the axisymmetric
imperfection
C   n   (   0,   0)    2      85   EMATL    = elastic modulus
C   n   (   0,   0)    2      90   NUMATL   = Poisson ratio of material
C   n   (   0,   0)    2      95   DNMATL   = mass density of material
C    n   (   0,   0)    2     100   IMODE    = strategy control for
imperfection shapes
C   n   (   0,   0)    2     105   NCASES   = Number of load cases (number
of environments)  in PRESS(NCASES)
C   y   (  20,   0)    3     110   PRESS    = uniform external pressure
C    y   (  20,   0)    4     115   CLAPS1   = collapse pressure with
imperfection mode 1
C    y   (  20,   0)    5     120   CLAPS1A  = allowable pressure for
axisymmetric collapse
C    y   (  20,   0)    6     125   CLAPS1F  = factor of safety for
axisymmetric collapse
C   y   (  20,   0)    4     130   GENBK1   = general buckling load factor,
mode 1
C    y   (  20,   0)    5     135   GENBK1A  = allowable general buckling
load factor (use 1.0)
C   y   (  20,   0)    6     140   GENBK1F  = factor of safety for general
buckling
C    n   (   0,   0)    2     145   JSKNBK1  = number of regions for
computing behavior in SKNBK1(NCASES,JSKNBK1)
C    y   (  20,  10)    4     150   SKNBK1   = local skin buckling load
factor, mode 1
C   y   (  20,  10)    5     155   SKNBK1A  = allowable buckling load factor
C    y   (  20,  10)    6     160   SKNBK1F  = factor of safety for skin
buckling
C   y   (  20,  10)    4     165   STFBK1   = buckling load factor, isogrid
member, mode 1
C    y   (  20,  10)    5     170   STFBK1A  = allowable for isogrid
stiffener buckling (Use 1.)
C   y   (  20,  10)    6     175   STFBK1F  = factor of safety for isogrid
stiffener buckling
C    y   (  20,  10)    4     180   SKNST1   = maximum stress in the shell
skin, mode 1
C   y   (  20,  10)    5     185   SKNST1A  = allowable stress for the shell
skin
C    y   (  20,  10)    6     190   SKNST1F  = factor of safety for skin
stress
C    y   (  20,  10)    4     195   STFST1   = maximum stress in isogrid
stiffener, mode 1
C    y   (  20,  10)    5     200   STFST1A  = allowable stress in isogrid
stiffeners
C   y   (  20,  10)    6     205   STFST1F  = factor of safety for stress in
isogrid member
```

```
C    y   (  20,   0)    4     210   WAPEX1   = normal (axial) displacement at
apex, mode 1
C    y   (  20,   0)    5     215   WAPEX1A  = allowable normal (axial)
displacement at apex
C    y   (  20,   0)    6     220   WAPEX1F  = factor of safety for WAPEX
C    y   (  20,   0)    4     225   CLAPS2   = collapse pressure with
imperfection mode 2
C    y   (  20,   0)    5     230   CLAPS2A  = allowable pressure for
axisymmetric collapse
C    y   (  20,   0)    6     235   CLAPS2F  = factor of safety for
axisymmetric collapse
C    y   (  20,   0)    4     240   GENBK2   = general buckling load factor,
mode 2
C    y   (  20,   0)    5     245   GENBK2A  = allowable general buckling
load factor (use 1.0)
C    y   (  20,   0)    6     250   GENBK2F  = factor of safety for general
buckling
C    n   (   0,   0)    2     255   JSKNBK2  = number of regions for
computing behavior in SKNBK2(NCASES,JSKNBK2)
C    y   (  20,  10)    4     260   SKNBK2   = local skin buckling load
factor, mode 2
C    y   (  20,  10)    5     265   SKNBK2A  = allowable skin buckling load
factor (use 1.0)
C    y   (  20,  10)    6     270   SKNBK2F  = factor of safety for local
skin buckling
C    y   (  20,  10)    4     275   STFBK2   = buckling load factor for
isogrid member, mode 2
C    y   (  20,  10)    5     280   STFBK2A  = allowable for isogrid
stiffener buckling (Use 1.)
C    y   (  20,  10)    6     285   STFBK2F  = factor of safety for isogrid
stiffener buckling
C    y   (  20,  10)    4     290   SKNST2   = maximum stress in the shell
skin, mode 2
C    y   (  20,  10)    5     295   SKNST2A  = allowable stress for the shell
skin
C    y   (  20,  10)    6     300   SKNST2F  = factor of safety for skin
stress
C    y   (  20,  10)    4     305   STFST2   = maximum stress in isogrid
stiffener, mode 2
C    y   (  20,  10)    5     310   STFST2A  = allowable stress in isogrid
stiffeners
C    y   (  20,  10)    6     315   STFST2F  = factor of safety for stress in
isogrid member
C    y   (  20,   0)    4     320   WAPEX2   = normal (axial) displacement at
apex, mode 2
C    y   (  20,   0)    5     325   WAPEX2A  = allowable normal (axial)
displacement at apex
C    y   (  20,   0)    6     330   WAPEX2F  = factor of safety for WAPEX
C    n   (   0,   0)    7     335   WEIGHT   = weight of the equivalent
ellipsoidal head
C
C=============================================================
C       TABLE 3   SEVEN ROLES THAT VARIABLES PLAY
C=============================================================
C    A variable can have one of the following roles:
C
C    1 = a possible decision variable for optimization,
C        typically a dimension of a structure.
```

```
C    2 = a constant parameter (cannot vary as design evolves),
C        typically a control integer or material property,
C        but not a load, allowable, or factor of safety,
C        which are asked for later.
C    3 = a parameter characterizing the environment, such
C        as a load component or a temperature.
C    4 = a quantity that describes the response of the
C        structure, (e.g. stress, buckling load, frequency)
C    5 = an allowable, such as maximum allowable stress,
C        minimum allowable frequency, etc.
C    6 = a factor of safety
C    7 = the quantity that is to be minimized or maximized,
C        called the "objective function" (e.g. weight).
C ===========================================================
```

```
 The purpose of GENTEXT is to generate a file of
 prompting phrases and helps called equivellipse.PRO and five
 FORTRAN source libraries, BEGIN.NEW, STOGET.NEW, STRUCT.NEW,
 BEHAVIOR.NEW, and CHANGE.NEW.  The purposes of these files are
 as follows:

 ==============================================================
 TABLE 4   FILE OF PROMPTING PHRASES AND HELPS AND
           SOURCE CODE LIBRARIES GENERATED BY "GENTEXT"
 ==============================================================
  equivellipse.PRO   = prompt file for input data for the problem
                class that you wish to set up for optimization.
                When BEGIN asks you for the name of the generic
                file, you should respond in this case with equivellipse.

                The Prompt Numbers listed in TABLE 2 correspond
                to the prompts in this file.

  BEGIN.NEW   = source library for FORTRAN program which will
                be used to set up the starting design, material
                properties, and any other data you wish.

  STOGET.NEW  = source library for FORTRAN subroutines which
                are used to transfer labelled common blocks.
                These labelled common blocks are the data base.

  STRUCT.NEW  = source library for FORTRAN subroutines that
                perform the analysis for each iterate in the
                set of optimization iterations.  You may have
                to complete this routine (add dimension state-
                ments, subroutine calls, output statements,
                etc.).  The library, STRUCT.NEW, also contains
                a skeletal routine, SUB. TRANFR, that you can
                complete in order to translate data names from
                from those just established by you (TABLE 2) to
                other names used by the developer of previously
                written code that you may plan to incorporate
                into SUBROUTINE STRUCT and/or SUBROUTINES
                BEHX1, BEHX2, BEHX3,...BEHXn (described next).


  BEHAVIOR.NEW= a library of subroutine skeletons, BEHX1,BEHX2,
                BEHX3,...BEHXn, that, upon completion by you,
```

```
               will calculate behavior for a given design or
               design perturbation.  Skeletal subroutines for
               a user-written constraint condition, USRCON,
               and a skeletal routine for the objective func-
               tion, OBJECT, are also generated and are
               included in the BEHAVIOR.NEW library.

 CHANGE.NEW  = FORTRAN program that permits you to change
               certain program parameters without having to
               go back to BEGIN and run a case from scratch.
=============================================================
```

```
============================================================
  TABLE 5: CONTENTS OF SMALL FILES CREATED BY   "GENTEXT"
============================================================
  FILE NAME                DEFINITION OF FILE CONTENTS
------------------------------------------------------------
equivellipse.PRO     Prompts and help paragraphs for interactive
                         input to the user-developed optimization code.

equivellipse.NEW     Part of BEGIN.NEW that contains calls to
                         SUBROUTINE DATUM and SUBROUTINE GETVAR.
                         This coding sets up the interactive input
                         for the starting design in the user-generated
                         design code.

equivellipse.INP     Image of interactive input for user-developed
                         program, generated to save time in case you make
                         a mistake during input.

equivellipse.COM     Labelled common blocks generated specifically
                         for the user-developed class of problems.

equivellipse.WRI     Part of subroutine for writing labelled common
                         blocks in SUBROUTINE STORCM (in Library STOGET).

equivellipse.REA     Part of subroutine for reading labelled common
                         blocks in SUBROUTINE GETCOM (in Library STOGET).

equivellipse.SET     Part of SUBROUTINE SETUPC in which new values
                         are installed in labelled common blocks from
                         the array VAR(I), which contains the latest
                         values of all candidates for decision variables.

equivellipse.CON     Calls to subroutines, BEHX1, BEHX2, BEHX3,...,
                         which calculate behavior such as stresses
                         modal frequencies, buckling loads, etc.
                         Also, calls to CON, which generate the value
                         of the behavioral constraints corresponding
                         to BEHX1, BEHX2, BEHX3,...
                         Also, generates phrases that identify, in the
                         output of the user-generated program, the
                         exact meaning of each behavioral constraint.

equivellipse.SUB     Skeletal subroutines, BEHX1, BEHX2, ..., and the
                         skeletal objective function, OBJECT.
```

```
equivellipse.DEF     List of user-established variable names,
                         definitions, and roles that these variables play
                         in the user-generated program.  Also, contains
                         list of files created by GENTEXT and the
                         functions of these files.

equivellipse.CHA     Part of SUBROUTINE NEWPAR (called in the CHANGE
                         processor) in which labelled common values are
                         updated.

equivellipse.DAT     Image of interactive input for user-developed
                         program, generated to save time in case you make
                         a mistake during input. This file is used by
                         the INSERT processor.
============================================================


WHAT TO DO NEXT (THIS IS REALLY IMPORTANT!):
Next, if necessary, provide the algorithms called for in the
skeletal subroutines listed in the library BEHAVIOR.NEW. You
may find useful routines, such as a linear interpolator,
in the library UTIL.NEW.

And/Or, if necessary, complete the skeletal routines STRUCT
and TRANFR.  (You may find useful routines in UTIL.NEW).
If you are adding subroutine calls to SUBROUTINE STRUCT or
SUBROUTINE TRANFR, store the subroutines themselves in
the libraries called ADDCODEn.NEW, n = 1,2,3,...5. (Please
list one of the ADDCODEn.NEW libraries for instructions.)

After you have done all this,  give the command GENPROGRAMS.
GENPROGRAMS will generate the absolute elements needed to
optimize whatever you have chosen as your objective (see
OBJECT routine in BEHAVIOR.NEW) in the presence of whatever
behavior or other factors (e.g. clearance) are quantified by
user-written subroutines collected in the libraries
ADDCODEn.NEW  and/or algorithms added to the skeletal
routines in the library BEHAVIOR.NEW .


If an error occurs during GENPROGRAMS, check your FORTRAN
coding. If you have to change something and rerun, make sure
to save the old version under a different file name so that
you can efficiently delete all outdated files with names
*.NEW without losing a lot of good coding! The writer had
fallen more than once into that trap during development of
GENOPT.

If GENPROGRAMS runs without bombing, try test examples within
the class of problems covered by your FORTRAN contributions
to GENOPT before assigning specific design development tasks
to individuals who may be more naive in the field covered by
your FORTRAN contributions to GENOPT than you are!

Please see the cases under genopt/case for examples and more
information.
```

USING GENOPT IN GENERAL AND WITH BIGBOSOR4

```
Please read the file, ..genopt/doc/getting.started.
Please also read the files:
...genopt/case/cylinder/howto.bosdec
...genopt/case/cylinder/howto.struct
...genopt/case/cylinder/howto.behavior
...genopt/case/torisph/howto.stags
...genopt/case/torisph/readme.equivellipse
...genopt/case/wavycyl/readme.wavycyl

The main things you must do are the following:

1. create a file called ..bosdec/sources/bosdec.src, the
purpose of which is to create a BOSOR4 input file, *.ALL .
in which "*" represents the users name for the specific case.
The file, ..genopt/case/torisph/bosdec.equivellipse is a good
example. Make sure to save bosdec.src by copying it into
another file. Example: cp bosdec.src bosdec.equivellipse

2. Flesh out either or both the libraries, struct.new and/or
behavior.new. In the case, ..genopt/case/torisph, only the
library struct.new is fleshed out. The library behavior.new is
not changed from that created automatically by GENOPT. In the
case, genopt/case/cylinder, both struct.new and behavior.new
are changed, struct.new in minor ways and behavior.new in
major ways. Make sure to save struct.new and behavior.new. For
example: cp struct.new   struct.cylinder
         cp behavior.new behavior.cylinder
(You save copies of bosdec.src, struct.new, behavior.new
 because it usually takes quite a bit of effort to modify
 the versions automatically created by GENOPT in order to
 solve your generic class of problems.)
See the following files for examples of modified libraries:

genopt/case/torisph/struct.tori    (behavior.new not modified)
genopt/case/torisph/struct.ellipse (behavior.new not modified)
genopt/case/torisph/struct.equivellipse
                                   (behavior.new not modified)
genopt/case/cylinder/struct.cylinder
genopt/case/cylinder/behavior.cylinder
genopt/case/wavycyl/struct.wavycyl
genopt/case/wavycyl/behavior.wavycyl
genopt/case/plate/behavior.plate  (struct.new is not modified)
genopt/case/plate/behavior.plate  (struct.new is not modified)
genopt/case/sphere/behavior.plate (struct.new is not modified)

3. Execute the GENOPT script called GENPROGRAMS. This script
"makes" the processors for the user-named generic case. The
"makefile" called ..genopt/execute/usermake.linux is used. If
GENPROGRAMS compiles everything successfully, which is not
likely on your first try because you probably did a lot of
FORTRAN coding to create bosdec.src, struct.new, behavior.new,
GENPROGRAMS will end with a list like the following:

Here is a list of all your newly created executables:
-rwxr-xr-x  1 bush bush 71562 Oct  8 15:56 autochange.linux
-rwxr-xr-x  1 bush bush 139553 Oct  8 15:56 begin.linux
```

```
-rwxr-xr-x  1 bush bush 124383 Oct  8 15:56 change.linux
-rwxr-xr-x  1 bush bush 156054 Oct  8 15:56 chooseplot.linux
-rwxr-xr-x  1 bush bush 161231 Oct  8 15:56 decide.linux
-rwxr-xr-x  1 bush bush 104222 Oct  8 15:56 mainsetup.linux
-rwxr-xr-x  1 bush bush 1691559 Oct  8 15:56 optimize.linux
-rwxr-xr-x  1 bush bush 95653 Oct  8 15:56 store.linux
```

Next, type the command BEGIN to input data for a new specific case.

If GENPROGRAMS bombs due to fatal compilation errors, or even if GENPROGRAMS seems to finish successfully, it is best to inspect the file ..genoptcase/usermakelinux.log. If there are compilation errors, revise the appropriate source codes, bosdec.src and/or struct.new and/or behavior.new, and execute GENPROGRAMS again. Keep doing this until everything is okay.

4. Next, think up a good name for your specific case and run BEGIN, DECIDE, MAINSETUP, and OPTIMISE (several times) or SUPEROPT. (See the file ..genopt/doc/getting.started and the directories, genopt/case/cylinder and genopt/case/torisph for examples.) Even though you had a successful "make" via GENPROGRAMS in the previous step, something will doubtless not be satisfactory and you will have to or want to make further changes to one or more of the source files, bosdec.src, struct.new, behavior.new.

THE NEXT STEPS PERTAIN TO THE USE OF GENOPT WITH BIGBOSOR4

5. You must have the BIGBOSOR4 software in the directory, ..bosdec/sources. You need to have the following files there: addbosor4.src, b4util.src, opngen.src, prompter.src, gasp.F, gasp_linux.o, bio_linux.c, bio_linux.o, b4plot.src, as well as the bosdec.src file discussed above.

6. The "make" file, ..genopt/execute/usermake.linux, must include references to the BIGBOSOR4 sofware listed in Step 5. Please see the file ..genopt/execute/usermake.linux, which already exists. (You do not have to do anything about it!)

7. Suppose everything compiles correctly during the GENPROGRAMS execution, but when you try to run a specific case the run bombs. Suppose all of your contributed FORTRAN coding is in ..bosdec/sources/bosdec.src and in
..genoptcase/struct.new (..genoptcase/behavior.new did not need to be modified for your case, as is true for the generic case called "equivellipse" in ..genopt/case/torisph). It is very helpful to insert a "CALL EXIT" statement after one of the analyses performed in struct.new, then to execute GENPROGRAMS again to recompile the temporarily changed struct.new. The reason for doing this is explained in the file ..genopt/case/torisph/struct.equivellipse and also in the file ..genopt/doc/getting.started: you want to be able to make a BIGBOSOR4 run to be certain that:

a. ..bosdec/sources/bosdec.src created a valid BOSOR4 input file, and,
b. the BIGBOSOR4 run did not finish for some reason.

```
************** NOTE ****************** NOTE ******************
MAKE SURE ALWAYS TO SAVE COPIES OF struct.new AND behavior.new
THAT YOU HAVE PUT A LOT OF EFFORT INTO CREATING.
THE struct.new AND behavior.new FILES ARE DESTROYED BY
EXECUTION OF "gentext".
**************************************************************
```
==

NOTE: Tables a3 – a14 in [26]

Table A15 List of the file, **bosdec.equivellipse.**
This is a GENOPT-user-written file that must exist if the GENOPT user's generic class of cases to be optimized makes use of the BIGBOSOR4 software. **See Table a29 of [26] for a list of the file, "howto.bosdec", which gives guidelines on how to write a valid bosdec.src file. SUBROUTINE BOSDEC produces a valid input file for BIGBOSOR4 (or for BOSOR4). This particular version of SUBROUTINE BOSDEC produces a valid BIGBOSOR4 input file called "equivellipse.ALL" corresponding to the GENOPT user's generic case called "equivellipse".**

```
=====================================================================
C=DECK      BOSDEC
C
C  PURPOSE IS TO SET UP BOSOR4 INPUT FILE FOR "equivellipse"
C
C This program was used in some (uncompleted) research I did in
C 2005 to automate the optimization of ellipsoidal tank heads
C with thickness that varies along the meridian. An ellipsoidal head
C is modelled as a number of shell segments each of which has a
C constant meridional radius of curvature. This is done in order to
C avoid element "locking" that can occur in BOSOR4 shell segments
C which have a meridional curvature that varies within a given
C shell segment.
C
C This technology was used to generate a BIGBOSOR4 input file for
C the ellipsoidal head under uniform internal pressure, studied
C in November, 2006.
C
      SUBROUTINE BOSDEC(INDX,ILOADX,INDIC,IMPERF,IFIL14,IFILE,
     1                  npoint,ainput,binput,LENCYL,nodes,WIMP,
     1                  WMODEX,xinput,xlimit,EMATL,NUMATL,DNMATL,
     1                  THKSKN,HIGHST,SPACNG,THSTIF,THKCYL,
     1                  PRESS,PMAX,N0BX,NMINBX,NMAXBX,INCRBX)
C
C234567890123456789012345678901234567890123456789012345678901234567890
12
C
C Meaning of INDX:
C  INDX = 1 means linear buckling of perfect shell (INDIC=1).
C           Purpose is to obtain the axisymmetric buckling modal
C           imperfection shape, which is present in all other analyses.
C
C  INDX = 2 means axisymmetric collapse of imperfect shell (INDIC=0).
C                                       (Behavior no. 1: BEHX1)
C  INDX = 3 means non-axisymmetric nonlinear bifurcation buckling
C           of imperfect shell (INDIC=1).    (Behavior no. 2: BEHX2)
C  INDX = 4 means axisymmetric stress analysis at design load (INDIC=0).
C    This branch yields the following behaviors:
C    a. local buckling load factor of shell skin   (BUCSKN). (BEHX3)
C    b. local buckling load factor of stiffener    (BUCSTF). (BEHX4)
C    c. maximum effective stress in the shell skin (STRMAX). (BEHX5)
C    d. maximum effective stress in stiffener      (STRSTF). (BEHX6)
C    e. normal displacement at shell apex          (ENDUV).  (BEHX7)
C
C definitions of other variables in the argument list...
```

```
c   ILOADX = load case number
c   INDIC  = bigbosor4 analysis type (0 or 1 used here)
c   IMPERF = 0 no imperfection; 1 yes imperfection
c   IFIL14 = file where bigbosor4 input "deck" is stored
c   IFILE  = file were list output is accumulated
c   npoint = number of x-coordinates (including x=0 and x at equator)
c            where a segment end is provided by the user: xinput
c   ainput = semi-major axis of ellipse (ainput = xinput(npoint)
c   binput = semi-minor axis of ellipse, x^2/a^2 + y^2/b^2 = 1.0
c   LENCYL = length of the cylindrical segment, if any
c   nodes  = number of nodal points in each segment
c   WIMP   = amplitude of initial buckling modal imperfection shape,
c            WMODEX
c   WMODEX = axisymmetric buckling modal imperfection shape
c            (obtained from bigbosor4)
c   xinput = x-coordinates corresponding to segment ends
c   xlimit = for x < xlimit use x-coordinate for callouts
c            for x > xlimit use y-coordinate for callouts
c   EMATL  = elastic modulus of isotropic material
c   NUMATL = Poisson ratio of isotropic material
c   DNMATL = mass density of isotropic material
c   THKSKN = skin thickness corresponding to xinput
c   HIGHST = stiffener height corresponding to xinput
c   SPACNG = isogrid spacing
c   THSTIF = isogrid member thickness
c   THKCYL = thickness of cylindrical segment, if any
c   PRESS(ILOADX) = applied pressure for load case ILOADX
c   PMAX = maximum pressure to be applied
c   N0BX = starting circ. wavenumber for buckling analysis
c   NMINBX = minimum circ. wavenumber for buckling analysis
c   NMAXBX = maximum circ. wavenumber for buckling analysis
c   INCRBX = increment in circ. wavenumber for buckling analysis
c
      COMMON/NUMPR2/ILAR,ICAR,IOAR,NFLAT,NCASES,NPRINT
      real LENCYL,NUMATL
      double precision x,y,phi,r,rknuck,a1,a2,b1,b2,x03,y03
      double precision x1,y1,x2,y2,x3,y3,a,b,r1,r2
      dimension x(21),y(21),x1(20),y1(20),x2(20),y2(20),x3(20),y3(20)
      dimension r1(20),r2(20)
      dimension THKSKN(21),HIGHST(21)
      dimension PRESS(*),WMODEX(*),xinput(21),NMESH(20)
C
      REWIND IFIL14
C
      IF (NPRINT.GE.2) WRITE(IFILE,3)
    3 FORMAT(//'  ***************  BOSDEC  ******************'/
     1'  The purpose of BOSDEC is to set up an input file, NAME.ALL,'/
     1'  for equivalent ellipsoidal shell. NAME is your name for'/
     1'  the case. The file NAME.ALL is a BOSOR4 input "deck" used'/
     1'  by SUBROUTINE B4READ.'/
     1'  ***********************************************'/)
C
c This version of SUBROUTINE BOSDEC is for an "equivalent" ellipsoidal head.
c The "equivalent" ellipsoidal head is constructed because BOSOR4 (bigbosor4)
c finite elements tend to "lock up" for shells of revolution in which the
c meridional curvature varies significantly within a single shell segment.
c
c The "equivalent" ellipsoidal head consists of a user-defined number of
```

```
c toroidal segments that match as well as possible the contour of the
c ellipsoidal head. The meridional curvature of each toroidal segment
c is constant in that segment. Therefore, there is no problem of finite
c element "lock up" in a segmented model of this type.
c
c For each toroidal segment, bigbosor4 needs three points for input:
c (x1,y1), (x2,y2), and (x3,y3). (x1,y1) and (x2,y2) lie on the ellipsoidal
c contour and are the (x,y) coordinates at the two ends of the toroidal
c segment. (x3,y3) is the center of meridional curvature of the toroidal
c segment. The trick is to obtain (x3,y3) so that to toroidal segment best
c fits the ellipsoidal contour in that segment.
c
c We use the following procedure to get (x3,y3):
c
c 1. The equation of the ellipse is
c
c     x^2/a^2 + y^2/b^2 = 1.0                                        (1)
c
c 2. The equation for the normal to the ellipse at (x1,y1) is:
c
c     y - y1 = (y1/x1)(a^2/b^2)(x - x1)                              (2)
c
c 3. The equation for the normal to the ellipse at (x2,y2) is:
c
c     y - y2 = (y2/x2)(a^2/b^2)(x - x2)                              (3)
c
c 4. These two straight lines in (x,y) space intersect at (x03,y03),
c    with (x03,y03) are given by:
c    x03 = (b2 - b1)/(a1 - a2);   y03 = (a2*b1 - a1*b2)/(a2 - a1) (4)
c    in which a1, b1 and a2, b2 are:
c
c     a1 = (y1/x1)(a^2/b^2);      b1 = -a1*x1 + y1                   (5)
c     a2 = (y2/x2)(a^2/b^2);      b2 = -a2*x2 + y2                   (6)
c
c 5. For an ellipse the distance from the point (x03,y03) to (x1,y1) is
c    different than the distance from the point (x03,y03) to (x2,y2)
c    because the meridional curvature varies along the contour of the
c    ellipse. We wish to find a new point (x3,y3) in the neighborhood
c    of (x03,y03) for which the distance from (x3,y3) to (x1,y1) equals
c    the distance from (x3,y3) to (x2,y2). For such a point the
c    "equivalent" segment will be a toroidal segment in which the
c    meridional curvature is constant along the segment arc.
c
c 6. The square of the distances from (x03,y03) to (x1,y1) and to (x2,y2)
c    are:
c
c     d1sq = (x1 - x03)**2 + (y1 - y03)**2                           (7)
c     d2sq = (x2 - x03)**2 + (y2 - y03)**2                           (8)
c
c    and the difference of these is:
c
c     delsq = d1sq - d2sq                                            (9)
c
c 7. We determine the location of the center of meridional curvature of
c    the "equivalent" torioidal segment by allocating half of delsq to
c    each (distance)**2, d1sq and d2sq. We then have two (distance)^2
c    that are equal:
c
```

```
c     (x1 - x03)**2 + (y1 - y03)**2 - delsq/2                     (10)
c     (x2 - x03)**2 + (y2 - y03)**2 + delsq/2                     (11)
c
c 8. Suppose we let
c
c     x3 = x03 + dx  ;             y3 = y03 + dy                  (12)
c
c    Then we have two nonlinear equations for the unknowns (dx,dy):
c
c    [x1 - (x03+dx)]**2 + [y1 - (y03+dy)]**2 =
c                         (x1 - x03)**2 +(y1 - y03)**2 -delsq/2  (13)
c
c    [x2 - (x03+dx)]**2 + [y2 - (y03+dy)]**2 =
c                         (x2 - x03)**2 +(y2 - y03)**2 +delsq/2  (14)
c
c    These two equations say that the square of the distance from
c    (x3,y3) to (x1,y1) Eq.(13) is equal to that from (x3,y3) to (x2,y2)
c    Eq.(14).
c
c 9. We use Newton's method to solve the two simultaneous nonlinear
c    equations for (dx,dy):
c
c    For the ith Newton iteration, let
c
c     dx(i) = dx(i-1) + u                                         (15)
c     dy(i) = dy(i-1) + v                                         (16)
c
c    Then we develop two linear equations for u and v for the ith
c    Newton iteration:
c
c     u*2.*(x03-x1+dx(i-1)) +v*2.*(y03-y1 +dy(i-1)) = f1pp       (17)
c     u*2.*(x03-x2+dx(i-1)) +v*2.*(y03-y2 +dy(i-1)) = f2pp       (18)
c
c    in which the right-hand sides, f1pp and f2pp, are rather long
c    expressions given in SUBROUTINE x3y3, where the Newton iterations
c    occur.
c
c Now find (x3,y3)...
c
c Get end points (x1,y1), (x2,y2), and center of curvature (x3,y3)
c of each shell segment in the model...
c
c first, given x, get y...
c the y are obtained from the equation for an ellipse: x^2/a^2 + y^2/b^2 = 1
c
      a = ainput
      b = binput
      do 10 i = 1,npoint
         x(i) = xinput(i)
         y(i) = -b*dsqrt(1.-x(i)**2/a**2)
   10 continue
c
c the endpoints of the first segment (bottom of "ellipse") are
c
      r = a**2/b
      x1(1) = 0.
      y1(1) = -b
      x2(1) = x(2)
```

```
      phi = dasin(x(2)/r)
      y2(1) = r*(1 - dcos(phi)) - b
      x3(1) = 0.
      y3(1) = r - b
c
c the endpoints of the last segment (nearest the equator) are
c
      nseg = npoint - 1
      rknuck = b**2/a
      x1(nseg) = x(npoint-1)
      phi = dacos((x(npoint-1) - a + rknuck)/rknuck)
      y1(nseg) = -rknuck*dsin(phi)
      x2(nseg) = a
      y2(nseg) = 0.
      x3(nseg) = a -rknuck
      y3(nseg) = 0.
c
c next, establish the endpoints and centers of curvature of
c shell segments 2 - (nseg-1)
c
C23456789012345678901234567890123456789012345678901234567890123456789012
      if (NPRINT.GE.2) write(ifile,'(/,A,A,I3,A,/,A,A)')
     1'  End points (x1,y1), (x2,y2) and center of curvature, (x3,y3)',
     1'  for',nseg,' toroidal segments',
     1' Seg.    x1          y1          x2          y2           x3',
     1'         y3          r1          r2'
      iseg = 1
c
      r1(iseg) = dsqrt((x1(iseg) - x3(iseg))**2
     1                +(y1(iseg) - y3(iseg))**2)
      r2(iseg) = dsqrt((x2(iseg) - x3(iseg))**2
     1                +(y2(iseg) - y3(iseg))**2)
c
      if (NPRINT.GE.2) write(ifile,'(I3,1P,8E12.4)')
     1 iseg,x1(iseg),y1(iseg),x2(iseg),y2(iseg),x3(iseg),y3(iseg),
     1      r1(iseg),r2(iseg)
      do 1000 iseg = 2,nseg
         iseg1 = iseg - 1
         x1(iseg) = x2(iseg1)
         y1(iseg) = y2(iseg1)
         ipoint = iseg + 1
         x2(iseg) = x(ipoint)
         y2(iseg) = y(ipoint)
c  find point, (x03,y03), where the normals to the ellipse at
c  (x1,y1) and (x2,y2) intersect.
         a1 = y1(iseg)*a**2/(x1(iseg)*b**2)
         a2 = y2(iseg)*a**2/(x2(iseg)*b**2)
         b1 = -a1*x1(iseg) + y1(iseg)
         b2 = -a2*x2(iseg) + y2(iseg)
         x03 = (b2 - b1)/(a1 - a2)
         y03 = (a2*b1 - a1*b2)/(a2 - a1)
c
c  we wish to replace the ellipse with an "equivalent" ellipse.
c  the "equivalent" ellipse consists of a number of torispherical
c  segments with end  points (x1,y1) and (x2,y2) and center of
c  curvature (x3,y3). The purpose of subroutine x3y3 is to
c  determine (x3,y3) given (x1,y1), (x2,y2), and (x03,y03).
c
```

```
         call x3y3(ifile,iseg,x1(iseg),y1(iseg),x2(iseg),y2(iseg),
     1             x03,y03, x3(iseg),y3(iseg))
c
         r1(iseg) = dsqrt((x1(iseg) - x3(iseg))**2
     1                  +(y1(iseg) - y3(iseg))**2)
         r2(iseg) = dsqrt((x2(iseg) - x3(iseg))**2
     1                  +(y2(iseg) - y3(iseg))**2)
c
         if (NPRINT.GE.2) write(ifile,'(I3,1P,8E12.4)')
     1    iseg,x1(iseg),y1(iseg),x2(iseg),y2(iseg),x3(iseg),y3(iseg),
     1         r1(iseg),r2(iseg)
c
 1000 continue
C234567890123456789012345678901234567890123456789012345678901234567890 12
c
      IF (INDIC.EQ.0.AND.INDX.EQ.4) WRITE(IFIL14,'(A)')
     1' Nonlinear axisymmetric stress analysis (INDIC=0)'
      IF (INDIC.EQ.0.AND.INDX.EQ.2) WRITE(IFIL14,'(A)')
     1' Nonlinear axisymmetric collapse analysis (INDIC=0)'
      IF (INDIC.EQ.1) WRITE(IFIL14,'(A)')
     1' Bifurcation buckling analysis (INDIC=1)'
C BEG MAR 2008
      IF (INDIC.EQ.-2) WRITE(IFIL14,'(A)')
     1' Bifurcation buckling analysis (INDIC=-2)'
C END MAR 2008
      IF (INDIC.EQ.2) WRITE(IFIL14,'(A)')
     1' Modal vibration of prestressed shell'
      WRITE(IFIL14,'(I3,A)') INDIC, '            $ INDIC'
      WRITE(IFIL14,'(A)')'  1            $ NPRT'
      ISTRES = 0
      IF (INDIC.EQ.0) ISTRES = 1
      WRITE(IFIL14,'(I3,A)') ISTRES, '            $ ISTRES'
      IF (LENCYL.GT.0.001)
     1 WRITE(IFIL14,'(I4,A)') nseg+1,'           $ nseg'
      IF (LENCYL.LE.0.001)
     1 WRITE(IFIL14,'(I4,A)') nseg,'           $ nseg'
C
C Begin loop over Segment data
C
C234567890123456789012345678901234567890123456789012345678901234567890 12
      IALL = 0
      Do 2000 iseg = 1,nseg
         NMESH(iseg) = nodes
         WRITE(IFIL14,'(I4,A)') NMESH(iseg),'           $ NMESH'
         WRITE(IFIL14,'(A)')'  3            $ NTYPEH'
         WRITE(IFIL14,'(A)')'  2            $ NSHAPE'
         WRITE(IFIL14,'(1P,E14.6,A)') x1(iseg), ' $ R1'
         WRITE(IFIL14,'(1P,E14.6,A)') y1(iseg), ' $ Z1'
         WRITE(IFIL14,'(1P,E14.6,A)') x2(iseg), ' $ R2'
         WRITE(IFIL14,'(1P,E14.6,A)') y2(iseg), ' $ Z2'
         WRITE(IFIL14,'(1P,E14.6,A)') x3(iseg), ' $ RC'
         WRITE(IFIL14,'(1P,E14.6,A)') y3(iseg), ' $ ZC'
         WRITE(IFIL14,'(A)')' -1.           $ SROT'
         WRITE(IFIL14,'(I4,A)') IMPERF,'            $ IMP'
         IF (IMPERF.EQ.1) THEN
            WRITE(IFIL14,'(A)')'  4            $ ITYPE'
            WRITE(IFIL14,'(1P,E14.6,A)') WIMP, ' $ WIMP'
            WRITE(IFIL14,'(A)')'  1            $ ISTART'
```

```
         NUMB = NMESH(iseg) + 2
         WRITE(IFIL14,'(I4,A)') NUMB,'            $ NUMB'
         DO 5 I = 1,NUMB
         J = I + IALL
         WRITE(IFIL14,'(1P,E14.6,A)') WMODEX(J), ' $ WSHAPE'
 5       CONTINUE
         WRITE(IFIL14,'(A)')'  N            $ any more modes?'
      ENDIF
      WRITE(IFIL14,'(A)')'  3            $ NTYPEZ'
      WRITE(IFIL14,'(A)')'  0.           $ ZVAL'
      WRITE(IFIL14,'(A)')'  Y            $ print r(s)...?'
      WRITE(IFIL14,'(A)')'  0            $ NRINGS'
      WRITE(IFIL14,'(A)')'  0            $ K'
      WRITE(IFIL14,'(A)')'  0            $ LINTYP'
      WRITE(IFIL14,'(A)')'  1            $ IDISAB'
      WRITE(IFIL14,'(A)')'  1            $ NLTYPE'
      WRITE(IFIL14,'(A)')'  2            $ NPSTAT'
      WRITE(IFIL14,'(A)')'  0            $ NLOAD(1)'
      WRITE(IFIL14,'(A)')'  0            $ NLOAD(2)'
      WRITE(IFIL14,'(A)')'  1            $ NLOAD(3)'
      WRITE(IFIL14,'(A)')' -1.           $ PN(1)'
      WRITE(IFIL14,'(A)')' -1.           $ PN(2)'
      IF (x1(iseg).le.xlimit) then
         ntype = 3
         call1 = x1(iseg)
         call2 = x2(iseg)
      else
         ntype = 2
         call1 = y1(iseg)
         call2 = y2(iseg)
      endif
      WRITE(IFIL14,'(I4,A)') ntype,'           $ ntype'
      WRITE(IFIL14,'(1P,E14.6,A)')  call1,  ' $ callout1'
      WRITE(IFIL14,'(1P,E14.6,A)')  call2,  ' $ callout2'
      WRITE(IFIL14,'(A)')' 10            $ NWALL'
      WRITE(IFIL14,'(A)')'  2            $ NWALL2'
      WRITE(IFIL14,'(1P,E14.6,A)') EMATL,   ' $ E'
      WRITE(IFIL14,'(1P,E14.6,A)') NUMATL,  ' $ U'
      WRITE(IFIL14,'(1P,E14.6,A)') DNMATL,  ' $ SM'
      WRITE(IFIL14,'(A)')'  0.           $ ALPHA'
      WRITE(IFIL14,'(A)')'  1            $ NRS'
      WRITE(IFIL14,'(A)')' -1            $ NSUR'
      WRITE(IFIL14,'(A)')'  1            $ NTYPET'
      IRADTH = 2
      WRITE(IFIL14,'(I4,A)') IRADTH,'           $ NTVALU'
      WRITE(IFIL14,'(I4,A)') ntype,'           $ ntype'
      WRITE(IFIL14,'(1P,E14.6,A)') call1,' $ callout1'
      WRITE(IFIL14,'(1P,E14.6,A)') call2,' $ callout2'
      ipoint = iseg + 1
      WRITE(IFIL14,'(1P,E14.6,A)') THKSKN(iseg),' $ THKSKN(iseg)'
      WRITE(IFIL14,'(1P,E14.6,A)') THKSKN(ipoint),' $ THKSKN(ipoint)'
C234567890123456789012345678901234567890123456789012345678901234567890123456789012
      WRITE(IFIL14,'(A)')'  Y            $ print refsurf...?'
      WRITE(IFIL14,'(A)')'  Y   $ are there stringers or isogrid...?'
      WRITE(IFIL14,'(A)')'  0            $ K1 (0 means internal)'
      WRITE(IFIL14,'(1P,E14.6,A)') EMATL,   ' $ E'
      WRITE(IFIL14,'(1P,E14.6,A)') NUMATL,  ' $ U'
      WRITE(IFIL14,'(1P,E14.6,A)') DNMATL,  ' $ SM'
```

```
         WRITE(IFIL14,'(1P,E14.6,A)') SPACNG,  ' $ isogrid spacing'
         WRITE(IFIL14,'(A)')'  N            $ constant cross section?'
         WRITE(IFIL14,'(I4,A)') IRADTH,'          $ number of callouts'
         WRITE(IFIL14,'(I4,A)') ntype,'           $ ntype'
         WRITE(IFIL14,'(1P,E14.6,A)') call1,' $ callout1'
         WRITE(IFIL14,'(1P,E14.6,A)') call2,' $ callout2'
         WRITE(IFIL14,'(1P,E14.6,A)') THSTIF,' $ THSTIF'
         WRITE(IFIL14,'(1P,E14.6,A)') THSTIF,' $ THSTIF'
         WRITE(IFIL14,'(1P,E14.6,A)') HIGHST(iseg),' $ HIGHST(iseg)'
         WRITE(IFIL14,'(1P,E14.6,A)') HIGHST(ipoint),' $ HIGHST(ipoint)'
         WRITE(IFIL14,'(A)')'  N            $ are there smeared rings?'
         WRITE(IFIL14,'(A)')'  N            $ print Cij?'
         WRITE(IFIL14,'(A)')'  N            $ print loads?'
C
C end of Segment iseg input data
         IALL = IALL + NMESH(iseg) + 2
 2000 continue
C
C Begin  Segment nseg+1 data       (cylindrical segment)
C
C234567890123456789012345678901234567890123456789012345678901234567890123456789012
      IF (LENCYL.GT.0.001) THEN
      NMESH(nseg+1) = 51
      WRITE(IFIL14,'(I4,A)') NMESH(nseg+1),'         $ NMESH seg.nseg+1'
      WRITE(IFIL14,'(A)')'  1            $ NTYPEH'
      WRITE(IFIL14,'(A)')'  4            $ NHVALU'
      WRITE(IFIL14,'(A)')'  1            $ IHVALU'
      WRITE(IFIL14,'(A)')' 25            $ IHVALU'
      WRITE(IFIL14,'(A)')' 26            $ IHVALU'
      WRITE(IFIL14,'(A)')' 50            $ IHVALU'
      WRITE(IFIL14,'(A)')' 0.2           $ HVALU'
      WRITE(IFIL14,'(A)')' 0.2           $ HVALU'
      WRITE(IFIL14,'(A)')' 1.0           $ HVALU'
      WRITE(IFIL14,'(A)')' 1.0           $ HVALU'
      WRITE(IFIL14,'(A)')'  1            $ NSHAPE'
      WRITE(IFIL14,'(1P,E14.6,A)') x2(nseg), ' $ R1'
      WRITE(IFIL14,'(1P,E14.6,A)') y2(nseg), ' $ Z1'
      WRITE(IFIL14,'(1P,E14.6,A)') x2(nseg), ' $ R2'
      WRITE(IFIL14,'(1P,E14.6,A)') y2(nseg)+LENCYL, ' $ Z2'
      WRITE(IFIL14,'(I4,A)') IMPERF,'           $ IMP'
      IF (IMPERF.EQ.1) THEN
         WRITE(IFIL14,'(A)')'  4            $ ITYPE'
         WRITE(IFIL14,'(1P,E14.6,A)') WIMP, ' $ WIMP'
         WRITE(IFIL14,'(A)')'  1            $ ISTART'
         NUMB = NMESH(nseg+1) + 2
         WRITE(IFIL14,'(I4,A)') NUMB,'           $ NUMB'
         DO 70 I = 1,NUMB
         J = I + IALL
         WRITE(IFIL14,'(1P,E14.6,A)') WMODEX(J), ' $ WSHAPE'
   70    CONTINUE
         WRITE(IFIL14,'(A)')'  N            $ any more modes?'
      ENDIF
      WRITE(IFIL14,'(A)')'  3            $ NTYPEZ'
      WRITE(IFIL14,'(A)')'  0.           $ ZVAL'
      WRITE(IFIL14,'(A)')'  N            $ print r(s)...?'
      WRITE(IFIL14,'(A)')'  0            $ NRINGS'
      WRITE(IFIL14,'(A)')'  0            $ K'
      WRITE(IFIL14,'(A)')'  0            $ LINTYP'
```

```
      WRITE(IFIL14,'(A)')'  1            $ IDISAB'
      WRITE(IFIL14,'(A)')'  1            $ NLTYPE'
      WRITE(IFIL14,'(A)')'  2            $ NPSTAT'
      WRITE(IFIL14,'(A)')'  0            $ NLOAD(1)'
      WRITE(IFIL14,'(A)')'  0            $ NLOAD(2)'
      WRITE(IFIL14,'(A)')'  1            $ NLOAD(3)'
      WRITE(IFIL14,'(A)')'  1.           $ PN(1)'
      WRITE(IFIL14,'(A)')'  1.           $ PN(2)'
      WRITE(IFIL14,'(A)')'  2            $ NTYPE'
      WRITE(IFIL14,'(1P,E14.6,A)')  y2(nseg),  ' $ Z1'
      WRITE(IFIL14,'(1P,E14.6,A)')  y2(nseg)+LENCYL,  ' $ Z2'
      WRITE(IFIL14,'(A)')'  2            $ NWALL'
      WRITE(IFIL14,'(1P,E14.6,A)') EMATL,   ' $ E'
      WRITE(IFIL14,'(1P,E14.6,A)') NUMATL,  ' $ U'
      WRITE(IFIL14,'(A)')'  0.           $ SM'
      WRITE(IFIL14,'(A)')'  0.           $ ALPHA'
      WRITE(IFIL14,'(A)')'  0            $ NRS'
      WRITE(IFIL14,'(A)')' -1            $ NSUR'
      WRITE(IFIL14,'(A)')'  3            $ NTYPET'
      WRITE(IFIL14,'(1P,E14.6,A)') THKCYL,   ' $ TVAL'
      WRITE(IFIL14,'(A)')'  N            $ print ref. surf?'
      WRITE(IFIL14,'(A)')'  N            $ print Cij?'
      WRITE(IFIL14,'(A)')'  N            $ print loads?'
      ENDIF
C23456789012345678901234567890123456789012345678901234567890123456789012
C     End of (LENCYL.GT.0.001)
C
C End of input for Segment nseg+1 (cylindrical segment)
C
C Start GLOBAL data..
C
      WRITE(IFIL14,'(A)')'  1            $ NLAST'
      WRITE(IFIL14,'(A)')'  N            $ expanded plots?'
C
C Following for linear buckling of perfect shell...
      IF (INDX.EQ.1) THEN
         WRITE(IFIL14,'(A)')'  0            $ N0B'
         WRITE(IFIL14,'(A)')'  0            $ NMINB'
         WRITE(IFIL14,'(A)')'  0            $ NMAXB'
         WRITE(IFIL14,'(A)')'  1            $ INCRB'
         WRITE(IFIL14,'(A)')' 10            $ NVEC'
         WRITE(IFIL14,'(A)')'  0.           $ P'
         WRITE(IFIL14,'(1P,E14.6,A)') PRESS(ILOADX)/1000.0,  ' $ DP'
         WRITE(IFIL14,'(A)')'  0.           $ TEMP'
         WRITE(IFIL14,'(A)')'  0.           $ DTEMP'
         WRITE(IFIL14,'(A)')'  0.           $ OMEGA'
         WRITE(IFIL14,'(A)')'  0.           $ DOMEGA'
      ENDIF
C
C23456789012345678901234567890123456789012345678901234567890123456789012
C Following is for nonlinear axisymmetric collapse...
      IF (INDX.EQ.2) THEN
         WRITE(IFIL14,'(1P,E14.6,A)') PMAX/10.0,  ' $ P'
         WRITE(IFIL14,'(1P,E14.6,A)') PMAX/10.0,  ' $ DP'
         WRITE(IFIL14,'(A)')'  0.           $ TEMP'
         WRITE(IFIL14,'(A)')'  0.           $ DTEMP'
         WRITE(IFIL14,'(A)')'  20           $ NSTEPS'
         WRITE(IFIL14,'(A)')'  0.           $ OMEGA'
```

```
         WRITE(IFIL14,'(A)')'  0.           $ DOMEGA'
      ENDIF
C
C Following is for nonlinear non-axisymmetric bifurcation buckling
C of imperfect shell...
      IF (INDX.EQ.3) THEN
         WRITE(IFIL14,'(I4,A)') N0BX,  '             $ N0B'
         WRITE(IFIL14,'(I4,A)') NMINBX,'             $ NMINB'
         WRITE(IFIL14,'(I4,A)') NMAXBX,'             $ NMAXB'
         WRITE(IFIL14,'(I4,A)') INCRBX,'             $ INCRB'
         WRITE(IFIL14,'(A)')'  1            $ NVEC'
         WRITE(IFIL14,'(1P,E14.6,A)') PMAX       ,  ' $ P'
C BEG MAR 2008
         IF (INDIC.NE.-2)
     1   WRITE(IFIL14,'(1P,E14.6,A)') PMAX/1000.0,  ' $ DP'
         IF (INDIC.EQ.-2)
     1   WRITE(IFIL14,'(1P,E14.6,A)') PMAX/100.0,   ' $ DP'
C END MAR 2000
         WRITE(IFIL14,'(A)')'  0.           $ TEMP'
         WRITE(IFIL14,'(A)')'  0.           $ DTEMP'
C BEG MAR 2008
         IF (INDIC.EQ.-2)
     1   WRITE(IFIL14,'(A)')'  50           $ Number of steps'
C END MAR 2008
         WRITE(IFIL14,'(A)')'  0.           $ OMEGA'
         WRITE(IFIL14,'(A)')'  0.           $ DOMEGA'
      ENDIF
C
C Following is for nonlinear axisymmetric stress analysis...
      IF (INDX.EQ.4) THEN
         WRITE(IFIL14,'(1P,E14.6,A)') PMAX/10.0,  ' $ P'
         WRITE(IFIL14,'(1P,E14.6,A)') PMAX/10.0,  ' $ DP'
         WRITE(IFIL14,'(A)')'  0.           $ TEMP'
         WRITE(IFIL14,'(A)')'  0.           $ DTEMP'
         WRITE(IFIL14,'(A)')' 10            $ NSTEPS'
         WRITE(IFIL14,'(A)')'  0.           $ OMEGA'
         WRITE(IFIL14,'(A)')'  0.           $ DOMEGA'
      ENDIF
C
C Start CONSTRAINTS...
C
      IF (LENCYL.GT.0.001)
     1 WRITE(IFIL14,'(I4,A)') nseg+1,'           $ nseg'
      IF (LENCYL.LE.0.001)
     1 WRITE(IFIL14,'(I4,A)') nseg,'           $ nseg'
C
       Do 3000 iseg = 1,nseg
C
         if (iseg.eq.1) then
C Segment 1 constraint pole condition...
            WRITE(IFIL14,'(A)')'  1            $ number of poles'
            WRITE(IFIL14,'(A)')'  1            $ nodal point at pole'
            WRITE(IFIL14,'(A)')'  0      $ grounded how many stations?'
            WRITE(IFIL14,'(A)')'  N            $ joined to lower segs?'
         endif
C23456789012345678901234567890123456789012345678901234567890123456789012
         if (iseg.eq.nseg) then
C Segment nseg constraint conditions...
```

```
            WRITE(IFIL14,'(A)')'  0            $ number of poles'
            IF (LENCYL.GT.0.001)
     1      WRITE(IFIL14,'(A)')'  0       $ grounded how many stations?'
            IF (LENCYL.LE.0.001) THEN
               WRITE(IFIL14,'(A)')'  1    $ grounded how many stations?'
               WRITE(IFIL14,'(I4,A)') NMESH(nseg),'     $ INODE = node'
               WRITE(IFIL14,'(A)')'  1            $ IUSTAR constrained'
               WRITE(IFIL14,'(A)')'  1            $ IVSTAR constrained'
               WRITE(IFIL14,'(A)')'  0            $ IWSTAR constrained'
               WRITE(IFIL14,'(A)')'  1            $ ICHI   constrained'
               WRITE(IFIL14,'(A)')'  0.        $ D1=radial eccentricity'
               WRITE(IFIL14,'(A)')'  0.        $ D2=axial  eccentricity'
               WRITE(IFIL14,'(A)')'  N       $ bc same prebuck & buck.?'
               WRITE(IFIL14,'(A)')'  1            $ IUSTARB constrained'
               WRITE(IFIL14,'(A)')'  1            $ IVSTARB constrained'
               WRITE(IFIL14,'(A)')'  0            $ IWSTARB constrained'
               WRITE(IFIL14,'(A)')'  1            $ ICHIB   constrained'
            ENDIF
C           End of (LENCYL.LE.0.001) condition
         endif
C23456789012345678901234567890123456789012345678901234567890123456789012
         if (iseg.gt.1) then
            if (iseg.lt.nseg) then
               WRITE(IFIL14,'(A)')'  0            $ number of poles'
               WRITE(IFIL14,'(A)')'  0    $ grounded how many stations?'
            endif
            WRITE(IFIL14,'(A)')'  Y            $ joined to lower segs?'
            WRITE(IFIL14,'(A)')'  1      $ at how many stations joined?'
            WRITE(IFIL14,'(A)')'  1      $ INODE= node of current seg.'
            WRITE(IFIL14,'(I4,A)') iseg-1,'     $ JSEG=previous segment'
            WRITE(IFIL14,'(I4,A)') NMESH(iseg-1),'    $ JNODE prev.seg.'
            WRITE(IFIL14,'(A)')'  1            $ IUSTAR constrained'
            WRITE(IFIL14,'(A)')'  1            $ IVSTAR constrained'
            WRITE(IFIL14,'(A)')'  1            $ IWSTAR constrained'
            WRITE(IFIL14,'(A)')'  1            $ ICHI   constrained'
            WRITE(IFIL14,'(A)')'  0.           $ D1=radial eccentricity'
            WRITE(IFIL14,'(A)')'  0.           $ D2=axial  eccentricity'
            WRITE(IFIL14,'(A)')'  Y      $ bc same for prebuck & buck.?'
         endif
c
 3000 continue
c
C23456789012345678901234567890123456789012345678901234567890123456789012
C
      IF (LENCYL.GT.0.001) THEN
C Segment nseg+1 constraint conditions...
      WRITE(IFIL14,'(A)')'  0            $ number of poles'
      WRITE(IFIL14,'(A)')'  2          $ grounded at how many stations?'
      WRITE(IFIL14,'(A)')'  1            $ INODE= node of current seg.'
      WRITE(IFIL14,'(A)')'  1            $ IUSTAR constrained'
      WRITE(IFIL14,'(A)')'  0            $ IVSTAR constrained'
      WRITE(IFIL14,'(A)')'  0            $ IWSTAR constrained'
      WRITE(IFIL14,'(A)')'  0            $ ICHI   constrained'
      WRITE(IFIL14,'(A)')'  0.           $ D1=radial eccentricity'
      WRITE(IFIL14,'(A)')'  0.           $ D2=axial  eccentricity'
      WRITE(IFIL14,'(A)')'  N            $ bc same for prebuck & buck.?'
      WRITE(IFIL14,'(A)')'  0            $ IUSTARB constrained'
      WRITE(IFIL14,'(A)')'  0            $ IVSTARB constrained'
```

```
      WRITE(IFIL14,'(A)')'  0              $ IWSTARB constrained'
      WRITE(IFIL14,'(A)')'  0              $ ICHIB   constrained'
      WRITE(IFIL14,'(I4,A)') NMESH(nseg+1),'    $ INODE= node of constr'
      WRITE(IFIL14,'(A)')'  1              $ IUSTAR constrained'
      WRITE(IFIL14,'(A)')'  1              $ IVSTAR constrained'
      WRITE(IFIL14,'(A)')'  0              $ IWSTAR constrained'
      WRITE(IFIL14,'(A)')'  1              $ ICHI   constrained'
      WRITE(IFIL14,'(A)')'  0.             $ D1=radial eccentricity'
      WRITE(IFIL14,'(A)')'  0.             $ D2=axial  eccentricity'
      WRITE(IFIL14,'(A)')'  N              $ bc same for prebuck & buck.?'
      WRITE(IFIL14,'(A)')'  1              $ IUSTARB constrained'
      WRITE(IFIL14,'(A)')'  1              $ IVSTARB constrained'
      WRITE(IFIL14,'(A)')'  1              $ IWSTARB constrained'
      WRITE(IFIL14,'(A)')'  1              $ ICHIB   constrained'
      WRITE(IFIL14,'(A)')'  Y              $ joined to lower segs?'
      WRITE(IFIL14,'(A)')'  1              $ at how many stations joined?'
      WRITE(IFIL14,'(A)')'  1              $ INODE= node of current seg.'
      WRITE(IFIL14,'(A)')'  2              $ JSEG = previous segment'
      WRITE(IFIL14,'(I4,A)') NMESH(nseg),'      $ JNODE=node prev. seg.'
      WRITE(IFIL14,'(A)')'  1              $ IUSTAR constrained'
      WRITE(IFIL14,'(A)')'  1              $ IVSTAR constrained'
      WRITE(IFIL14,'(A)')'  1              $ IWSTAR constrained'
      WRITE(IFIL14,'(A)')'  1              $ ICHI   constrained'
      WRITE(IFIL14,'(A)')'  0.             $ D1=radial eccentricity'
      WRITE(IFIL14,'(A)')'  0.             $ D2=axial  eccentricity'
      WRITE(IFIL14,'(A)')'  Y              $ bc same for prebuck & buck.?'
      ENDIF
C     End of (LENCYL.GT.0.001) condition
C
      WRITE(IFIL14,'(A)')'  N              $ rigid body possible?'
C23456789012345678901234567890123456789012345678901234567890123456789012
      IF (INDX.EQ.4) THEN
         do 3010 iseg = 1,nseg
         WRITE(IFIL14,'(A)')'  Y             $ output for seg. i?'
 3010    continue
         IF (LENCYL.GT.0.001)
     1   WRITE(IFIL14,'(A)')'  N             $ output for seg. nseg+1?'
         WRITE(IFIL14,'(A)')'  Y             $ output for rings?'
      ELSE
         do 3020 iseg = 1,nseg
         WRITE(IFIL14,'(A)')'  Y             $ output for seg. i?'
 3020    continue
         IF (LENCYL.GT.0.001)
     1   WRITE(IFIL14,'(A)')'  Y             $ output for seg. nseg+1?'
         WRITE(IFIL14,'(A)')'  Y             $ output for rings?'
      ENDIF
C
      RETURN
      END
c
c
c
C=DECK      x3y3
      SUBROUTINE x3y3(ifile,iseg,x1,y1,x2,y2,x03,y03,x3,y3)
c  input:
c  (x1,y1), (x2,y2) = end points that lie on the original ellipse
c  (x03,y03) = point where normals to the ellipse at (x1,y1) and
c              (x2,y2) intersect
```

```
c  output:
c  (x3,y3) center of curvature of the "equivalent" toroidal segment.
c
c  (x3,y3) are determined by Newton's method from two nonlinear
c  equations in dx,dy, in which dx,dy are the distances between
c  x03,y03 and x3,y3.
c
      double precision x1,y1,x2,y2,x3,y3,x03,y03
      double precision d1sq,d2sq,delsq,a1,a2,b1,b2
      double precision f1,f1p,f1pp, f2,f2p,f2pp
      double precision dx,dy,u,v
c
c  For a toroidal segment, the two distances from (x3,y3) to the two
c  segment end points (x1,y1) and (x2,y2) must be equal. In other
c  words the meridional radius of curvature of the torioidal segment
c  must be constant in that segment.
c
c  However, in the ellipse these two distances are different. The
c  square of the difference is given by delta**2 (delsq):
c
      d1sq = (x1 - x03)**2 + (y1 - y03)**2
      d2sq = (x2 - x03)**2 + (y2 - y03)**2
      delsq = d1sq - d2sq
c
c  Here we determine the location of the center of meridional
c  curvature of the "equivalent" torioidal segment by allocating
c  half of delsq to each (distance)**2, d1sq and d2sq. We have two
c  (distances)**2 that are equal:
c
c   (x1 - x03)**2 + (y1 - y03)**2 - delsq/2
c   (x2 - x03)**2 + (y2 - y03)**2 + delsq/2
c
c  We must solve the following two nonlinear equations for (dx,dy):
c
c  [x1 - (x03+dx)]**2 + [y1 - (y03+dy)]**2 =
c                       (x1 - x03)**2 +(y1 - y03)**2 -delsq/2   (1)
c
c  [x2 - (x03+dx)]**2 + [y2 - (y03+dy)]**2 =
c                       (x2 - x03)**2 +(y2 - y03)**2 +delsq/2   (2)
c
c  We use Newton's method:
c
c  For the ith Newton iteration, let
c
c  dx(i) = dx(i-1) + u
c  dy(i) = dy(i-1) + v
c
c  Then we develop two linear equations for u and v for the ith iteration:
c
c  u*(x03-x1+dx(i-1)) +v*(y03-y1 +dy(i-1)) = f1pp
c  u*(x03-x2+dx(i-1)) +v*(y03-y2 +dy(i-1)) = f2pp
c
c  solve them, add u and v to dx(i-1) and dy(i-1), respectively, and
c  iterate. We keep iterating until convergence is achieved.
c
      iter = 0
      dx = 0.
      dy = 0.
```

```
c
   10 continue
      iter = iter + 1
c
      a1 = 2.*(x03 - x1 + dx)
      a2 = 2.*(x03 - x2 + dx)
      b1 = 2.*(y03 - y1 + dy)
      b2 = 2.*(y03 - y2 + dy)
c
      f1 = (x1 - x03)**2 + (y1 - y03)**2 - delsq/2.
      f2 = (x2 - x03)**2 + (y2 - y03)**2 + delsq/2.
      f1p = f1 - x1**2 + 2.*x1*x03 - x03**2
     1          -y1**2 + 2.*y1*y03 - y03**2
      f2p = f2 - x2**2 + 2.*x2*x03 - x03**2
     1          -y2**2 + 2.*y2*y03 - y03**2
      f1pp = f1p - dx*2.*(x03-x1) -dy*2.*(y03-y1) -dx**2 -dy**2
      f2pp = f2p - dx*2.*(x03-x2) -dy*2.*(y03-y2) -dx**2 -dy**2
c
      u = (b2*f1pp - b1*f2pp)/(b2*a1 - b1*a2)
      v = (a2*f1pp - a1*f2pp)/(a2*b1 - a1*b2)
      dx = dx + u
      dy = dy + v
c
C234567890123456789012345678901234567890123456789012345678901234567890123456789012
c     if (iter.eq.1) write(ifile,'(/,A,i3,/,A,A)')
c    1' ******** Results from Newton iterations for segment no.',iseg,
c    1' iter     x03       dx       y03         dy         u',
c    1'         v'
c     write(ifile,'(i3,1p,6e12.4)')
c    1 iter, x03, dx, y03, dy, u, v
c
      if (iter.gt.100) then
         write(ifile,'(A)')' No convergence.'
         call exit
      endif
c
      if (iter.lt.3) go to 10
      if (abs(u).gt.0.001*abs(dx)) go to 10
      if (abs(v).gt.0.001*abs(dy)) go to 10
c
c  Convergence has been achieved
c
      x3 = x03 + dx
      y3 = y03 + dy
c
      return
      end
======================================================================
```

NOTE: Tables a16 – a18 in [26].

Table A19 List of the file, **eqellipse.stiffened.opm4**.
This file contains a complete list of the output file, **eqellipse.OPM**, corresponding to the **optimized imperfect isogrid-stiffened equivalent ellipsoidal shell** for the specific case called "**eqellipse**". (See Section 8.1).

```
==============================================================
    n       $ Do you want a tutorial session and tutorial output?
      0     $ Choose an analysis you DON'T want (1, 2,..), IBEHAV
      0     $ Choose an analysis you DON'T want (1, 2,..), IBEHAV
      1     $ NPRINT= output index (0=GOOD, 1=ok, 2=debug, 3=too much)
      2     $ Choose type of analysis (1=opt., 2=fixed, 3=sensit.) ITYPE
      5     $ How many design iterations in this run (3 to 25)?
    n       $ Take "shortcuts" for perturbed designs (Y or N)?
      2     $ Choose 1 or 2 or 3 or 4 or 5 for IDESIGN
      1     $ Choose 1 or 2 or 3 or 4 or 5 for move limits, IMOVE
    y       $ Do you want default (RATIO=10) for initial move limit jump?
    y       $ Do you want the default perturbation (dx/x = 0.05)?
    y       $ Do you want to have dx/x modified by GENOPT?
    n       $ Do you want to reset total iterations to zero (Type H)?

 ************ END OF THE  eqellipse.OPT  FILE ***********
 ************ MARCH, 2008 VERSION OF GENOPT ****************
 ******** BEGINNING OF THE  eqellipse.OPM  FILE *********


 *********************** MAIN PROCESSOR **********************
 The purpose of the mainprocessor, OPTIMIZE, is to perform,
 in a batch mode, the work specified by MAINSETUP for the case
 called eqellipse.  Results are stored in the file  eqellipse.OPM.
 Please inspect eqellipse.OPM before doing more design iterations.
 ************************************************************




 STRUCTURAL ANALYSIS FOR DESIGN ITERATION NO.   0:
0
  STRUCTURAL ANALYSIS WITH UNPERTURBED DECISION VARIABLES
 VAR. DEC. ESCAPE LINK. LINKED  LINKING   LOWER    CURRENT    UPPER      DEFINITION
  NO. VAR.  VAR.  VAR.    TO   CONSTANT   BOUND     VALUE     BOUND
   1   Y     N     N      0    0.00E+00  1.00E-01 1.2453E-01  1.00E+00  skin thickness at xinput:
THKSKN(1 )
   2   Y     N     N      0    0.00E+00  1.00E-01 1.6641E-01  1.00E+00  skin thickness at xinput:
THKSKN(2 )
   3   Y     N     N      0    0.00E+00  1.00E-01 1.4460E-01  1.00E+00  skin thickness at xinput:
```

THKSKN(3)
4 Y N N 0 0.00E+00 1.00E-01 1.6082E-01 1.00E+00 skin thickness at xinput: THKSKN(4)
5 Y N N 0 0.00E+00 1.00E-01 1.0412E-01 1.00E+00 skin thickness at xinput: THKSKN(5)
6 Y N N 0 0.00E+00 1.00E-01 1.0000E-01 1.00E+00 skin thickness at xinput: THKSKN(6)
7 Y N N 0 0.00E+00 1.00E-01 1.0162E-01 1.00E+00 skin thickness at xinput: THKSKN(7)
8 Y N N 0 0.00E+00 1.00E-01 1.3795E-01 1.00E+00 skin thickness at xinput: THKSKN(8)
9 Y N N 0 0.00E+00 1.00E-01 1.0201E-01 1.00E+00 skin thickness at xinput: THKSKN(9)
10 Y N N 0 0.00E+00 1.00E-01 1.0411E-01 1.00E+00 skin thickness at xinput: THKSKN(10)
11 Y N N 0 0.00E+00 1.00E-01 1.9869E-01 1.00E+00 skin thickness at xinput: THKSKN(11)
12 Y N N 0 0.00E+00 1.00E-01 1.0000E-01 1.00E+00 skin thickness at xinput: THKSKN(12)
13 Y N N 0 0.00E+00 1.00E-01 1.9779E-01 1.00E+00 skin thickness at xinput: THKSKN(13)
14 Y N N 0 0.00E+00 5.00E-01 6.6766E-01 3.00E+00 height of isogrid members at xinput: HIGHST(1)
15 Y N N 0 0.00E+00 5.00E-01 6.0783E-01 3.00E+00 height of isogrid members at xinput: HIGHST(2)
16 Y N N 0 0.00E+00 5.00E-01 9.7928E-01 3.00E+00 height of isogrid members at xinput: HIGHST(3)
17 Y N N 0 0.00E+00 2.00E-01 1.2562E+00 3.00E+00 height of isogrid members at xinput: HIGHST(4)
18 Y N N 0 0.00E+00 2.00E-01 1.1540E+00 3.00E+00 height of isogrid members at xinput: HIGHST(5)
19 Y N N 0 0.00E+00 2.00E-01 8.0422E-01 3.00E+00 height of isogrid members at xinput: HIGHST(6)
20 Y N N 0 0.00E+00 2.00E-01 1.2686E+00 3.00E+00 height of isogrid members at xinput: HIGHST(7)
21 Y N N 0 0.00E+00 2.00E-01 8.8339E-01 3.00E+00 height of isogrid members at xinput: HIGHST(8)
22 Y N N 0 0.00E+00 2.00E-01 7.0560E-01 3.00E+00 height of isogrid members at xinput: HIGHST(9)
23 Y N N 0 0.00E+00 2.00E-01 5.8445E-01 3.00E+00 height of isogrid members at xinput: HIGHST(10)
24 Y N N 0 0.00E+00 2.00E-01 5.1581E-01 3.00E+00 height of isogrid members at xinput: HIGHST(11)
25 Y N N 0 0.00E+00 2.00E-01 3.4417E-01 3.00E+00 height of isogrid members at xinput: HIGHST(12)
26 Y N N 0 0.00E+00 2.00E-01 4.6660E-01 3.00E+00 height of isogrid members at xinput: HIGHST(13)
27 Y N N 0 0.00E+00 1.00E+00 2.9154E+00 3.00E+00 spacing of the isogrid

members: SPACNG
28 Y N N 0 0.00E+00 5.00E-02 9.0531E-02 1.00E+00 thickness of an isogrid stiffening member: THSTIF
BEHAVIOR FOR 1 ENVIRONMENT (LOAD SET)

CONSTRAINT BEHAVIOR DEFINITION
NUMBER VALUE

BEHAVIOR FOR LOAD SET NUMBER, ILOADX= 1

****
Start of all analyses:
Design iteration 1, Load Set 1, IMODX= 0, Dec.var.no.,IDV= 0
****
SUBROUTINE STRUCT computes seven "behaviors" (stress, collapse, bifurcation buckling, etc.). The seven behaviors are:
1. linear axisymmetric buckling of the perfect ellipsoid in order to obtain 2 or 4 axisymmetric buckling modes (NCASES = 2 or 4) which are to be used as initial imperfection shapes in the following analyses 2 - 7, listed next.
2. nonlinear axisymmetric stress with mode 1 imperfection
3. nonlinear axisymmetric stress with mode 2 imperfection
4. axisymmetric collapse with mode 1 imperfection
5. axisymmetric collapse with mode 2 imperfection
6. nonlinear bifurcation buckling with mode 1 imperfection
7. nonlinear bifurcation buckling with mode 2 imperfection.

Brief description of each of the seven analyses corresponding to the seven "behaviors" just listed:

1. Ten axisymmetric buckling modes are computed from linear analysis. Only two modes are used for imperfection shapes:
   A. The mode corresponding to the lowest buckling load, and
   B. one other mode, usually the 2nd mode.

   For each of mode 1 and mode 2, the actual imperfection is the normalized buckling modal w-deflection times an amplitude factor supplied by the user by means of "BEGIN".

   In MAINSETUP (*.OPT file) the user can choose whether or not the linear axisymmetric buckling modes, (that is, the imperfection shapes) are to be recomputed for each of the PERTURBED designs. If the user answers the prompt,
   Take "shortcuts" for perturbed designs (Y or N)?
   with "N" (NO), then the axisymmetric buckling modal imperfection shapes will be recomputed for each PERTURBED design. (This is the preferred choice, even though it

leads to some high constraint gradients). If the user
answers "Y" (YES), then the imperfection shapes will NOT
be recomputed for the PERTURBED designs. The constraint
gradients will be lower, but GENOPT will usually have a
harder time finding the "global" optimum design.

2. Nonlinear axisymmetric stress analysis with "mode 1" Wimp:
This analysis is performed for both +(mode 1) and -(mode 1)
For each of these "sub-analyses" the following is done:
a. The nonlinear equilibrium path is traced over the range
P(design)/10. < P < P(design) in 10 steps of dP, where
P(design) = design pressure and dP = P(design)/10.
b. If the shell collapses nonlinearly (convergence failure)
for P < P(design), then step 2a is redone with the range
P(collapse)/10. < P < P(collapse); dP=P(collapse)/10.
c. At the maximum load (either P(collapse) or P(design),
whichever is smaller) the following quantities are
computed:

```
Region 1 local skin buckling load factor,       BUCMIN
Region 1 isogrid member buckling load factor,   BUCMNS
Region 1 skin maximum effective stress,         SKNMAX
Region 1 isogrid member max. effective stress,  STFMXS
Region 2 local skin buckling load factor,       BUCMIN
Region 2 isogrid member buckling load factor,   BUCMNS
Region 2 skin maximum effective stress,         SKNMAX
Region 2 isogrid member max. effective stress,  STFMXS
Normal displacement of the shell at its apex,   ENDUV
```

The quantities, BUCMIN, BUCMNS, etc. may constrain the
evolution of the optimum design.

Region 1 represents the ellipsoidal cap region, and
Region 2 represents the rest of the ellipsoidal shell.
Note that typical margins contain the following strings:

(SKNBK1(1,1)/SKNBK1A(1,1))/SKNBK1F(1,1)-1
(SKNBK1(1,2)/SKNBK1A(1,2))/SKNBK1F(1,2)-1

with two-dimensional arrays, SKNBK1, SKNBK1A, SKNBK1F,
in this example signifying "skin buckling for mode 1".
The analogous margins,

(SKNBK2(1,1)/SKNBK2A(1,1))/SKNBK2F(1,1)-1
(SKNBK2(1,2)/SKNBK2A(1,2))/SKNBK2F(1,2)-1

with two-dimensional arrays, SKNBK2, SKNBK2A, SKNBK2F,
in this example signify "skin buckling for mode 2".
The "i" in the arrays *(i,j) is the load set number.
The "j" is the region number, called "Region 1" for
Region no. 1 and "Region 2" for region no. 2 above.
Region no. 1: the radial coordinate, x, 0 < x < xlimit.
Region no. 2: the radial coordinate, x,xlimit < x < xmax
where xmax is the value of the x-coord. at the equator,

and xlimit is a user-provided input datum, usually
equal to about half the semimajor axis (xlimit=a/2).
This scheme of computing minimum buckling load factors
and maximum stresses in two regions of the ellipsoidal
head and having margins for each smooths the values of
the margins from design iteration to iteration, making
it easier to find a "global" optimum design.

The quantities, BUCMIN, BUCMNS, SKNMAX, STFMXS, are
computed in SUBROUTINE PLOCAL in the BIGBOSOR4 code,
..bosdec/sources/addbosor4.src, as follows:

COMPUTATION OF BUCMIN: In the following code fragment
the critical buckling resultant is NSCRIT; BUCLOD(I) =
buckling load factor at nodal point I in Segment No. IS;
BUCMIN(IS) = minimum buckling load factor in Segment IS.

```
FCOEF = 0.5
NSCRIT = FCOEF*PI**2*CSKIN(4,4,I)/SIDE**2           (1)
NSMAX  = MIN(N1SKIN,N2SKIN)                         (2)
BUCLOD(I) = NSCRIT/ABS(NSMAX)                        (3)
BUCMIN(IS) = MIN(BUCMIN(IS),BUCLOD(I))              (4)
```

in which the variables used in Eqs.(1-4) are as follows:

```
CSKIN(i,j,I) = 6 x 6 matrix of shell wall stiffnesses at
            nodal point I
SIDE = length of a side of the equilateral triangle
      formed by the isogrid configuration
N1SKIN, N2SKIN are the meridional and hoop resultants
            in the shell skin, given by:
N1SKIN = CSKIN(1,1,I)*EPS1 + CSKIN(1,2,I)*EPS2
       +CSKIN(1,4,I)*K1    + CSKIN(1,5,I)*K2
N2SKIN = CSKIN(1,2,I)*EPS1 + CSKIN(2,2,I)*EPS2
       +CSKIN(2,4,I)*K1    + CSKIN(2,5,I)*K2

EPS1, K1 = meridional reference surface membrane
         strain and curvature change at nodal point I
EPS2, K2 = circumferential reference surface membrane
         strain and curvature change at nodal point I
```

The buckling load, NSCRIT, is for a flat equilateral
triangular piece of skin. The formula for NSCRIT is from
NACA TN-3781, July 1957 by Gerard & Becker: "Handbook of
Structural Stability, Part I - Buckling of Flat Plates".
The formula is for buckling of an equilateral flat plate
with N1SKIN = N2SKIN (compression). The result here is
approximate because in general N1SKIN is not equal to
N2SKIN, and in general the skin is not isotropic.
The prediction of the shell skin buckling load factor

should be conservative because:
a. The compressive stress resultant used in the formula
   for buckling load factor is NSMAX=MIN(N1SKIN,N2SKIN).
b. The triangular piece of skin is assumed to be flat
   when in fact it is curved.
c. The triangular piece of skin is assumed to be simply
   supported when in fact it is supported by isogrid
   stiffeners along all three edges.

COMPUTATION OF BUCMNS AND STFMXS: In the code fragment in PLOCAL that computes stiffener buckling and stress, BUCMNS(IS) and STFMXS(IS), useful definitions are:

NUSTIF = Poisson ratio for stringer/isogrid member
SIGCR = buckling stress for stringer/isogrid member
STRTIP = stress at the tip of stringer/isogrid member
STRROT = stress at the root of the stringer/isogrid
BUCSTR(I) = buckling load factor for stringer/isogrid
          at nodal point I
BUCMNS(IS)= minimum buckling load factor for stiffener
          in shell segment IS
STRSTR(I) = maximum stress in stringer/isogrid at nodal
          point I
STFMXS(IS)= maximum stress in stringer/isogrid in shell
          segment IS

The critical buckling load of stiffener is derived from formulas from ROARK: FORMULAS FOR STRESS AND STRAIN, 3rd Edition, McGraw-Hill, 1954, Table XVI, p. 312, Formulas 4 (s.s.,free) and 5 (clamped,free). Roark has
SIGCR = k*[ESTIFF/(1-NUSTIF**2)]*(TSTIFF/HEIGHT)**2
in which k is a coefficient that depends on the aspect ratio of the plate (stiffener). For long, uniformly axially compressed plates:
a. k = 0.375 if the plate is simply-supported-free
b. k = 1.1   if the plate is clamped-free
Later edition of "ROARK":
Seventh Edition by Warren C. Young and Richard G. Budynas, McGraw-Hill 2002, Chapter 15, Table 15.2, Formulas 1.d and 1.e, on p. 730

More definitions...

IRECT(1,IS) = 1 if stringer/isogrid member has a
              rectangular cross section
            = 0 if stringer/isogrid member does not have
              a rectangular cross section
INTEXT(1,IS)= 0 for stringer/isogrid attached to the
              leftmost shell skin surface
              (e.g. internal smeared stringer/isogrid)

INTEXT(1,IS)= 1 for stringer/isogrid attached to the
rightmost shell skin surface

Z(I) = distance from the shell skin leftmost surface to the reference surface at nodal point I. (The reference surface is where the membrane strain and curvature changes (EPS1,K1,EPS2,K2) are measured].

T(I) = thickness of shell skin at nodal point I of shell segment IS

ZTIP = distance from shell reference surface to the tip of stringer/isogrid

STRTIP = stress at the tip of a smeared stringer/isogrid member.

STFPRP(j,1,I) = properties of smeared stringer/isogrd at nodal point I, defined as follows:

STFPRP(1,1,I) = stiffener thickness, TSTIFF
STFPRP(2,1,I) = stiffener height from nearest shell skin surface
STFPRP(3,1,I) = stiffener spacing: SIDE*SQRT(3.)/2.
STFPRP(4,1,I) = stiffener elastic modulus
STFPRP(j,2,I), j = 1,2,3,4 = same as above, for smeared rings.

SUBROUTINE PLOCAL has the following code for computing buckling and stress in the stiffener/isogrid member:

```
IF (INTEXT(1,IS).EQ.0) ZTIP = -(STFPRP(2,1,I) + Z(I))
IF (INTEXT(1,IS).EQ.1) ZTIP = STFPRP(2,1,I) + T(I) -Z(I)
STRTIP = STFPRP(4,1,I)*(EPS1 - ZTIP*K1)
EDGSTF = 0.5
NUSTIF = 0.3
SIGCR =(0.375+0.7*EDGSTF)*(STFPRP(4,1,I)/(1.-NUSTIF**2))
                *(STFPRP(1,1,I)/STFPRP(2,1,I))**2
IF (STRTIP.LT.0.0) THEN
  BUCSTR(I) = SIGCR/ABS(STRTIP)
  BUCMNS(IS) = MIN(BUCMNS(IS),BUCSTR(I))
ENDIF
IF (INTEXT(1,IS).EQ.0) ZROOT = -Z(I)
IF (INTEXT(1,IS).EQ.1) ZROOT =  T(I) - Z(I)
STRROT = STFPRP(4,1,I)*(EPS1 - ZROOT*K1)
STRSTR(I) = MAX(ABS(STRTIP),ABS(STRROT))
STFMXS(IS) = MAX(STFMXS(IS),STRSTR(I))
```

The stiffener buckling load factor and maximum stress used here should be conservative compared to what happens in the case of an actual isogrid member because:

a. The compressive stress STRTIP at the tip of the stiffener is used, which in the worst case would be the maximum compressive stress over the height of the stiffener, whereas the ROARK formula for buckling is for a uniformly compressed flat plate.

b. For typical optimum designs the aspect ratio of the plate is about 2.0, for which ROARK gives a buckling coefficient, k = 0.574 for a plate simply supported along one edge and free along the opposite edge.

c. Where the isogrid members intersect the actual b.c. should probably be clamped, whereas the formula is for simple support along plate edges "b".

d. The formula for maximum stress at the stiffener tip,
STRTIP = STFPRP(4,1,I)*(EPS1 - ZTIP*K1)
is based on the assumption that the isogrid member is oriented meridionally. This is the worst possible orientation from the point of view of maximum stress for a stiffener attached to an axisymmetrically deformed shell.

COMPUTATION OF SKNMAX: The maximum effective stress in the skin of the shell segment IS is computed by BIGBOSOR4 as it always has been. No new coding was added to BIGBOSOR4 in order to generate SKNMAX(IS).

COMPUTATION OF ENDUV: The normal displacement w at the apex of the ellipsoidal head is computed by BIGBOSOR4 as it always has been. No new coding has been added. NOTE: prebuckling axial displacement at the first nodal point in the cylindrical segment (Segment NSEG) is set to zero in the prebuckling phase of the analysis only. This is done so that ENDUV is for the ellipsoidal head by itself (does not include any axial deformation of the cylindrical segment to which the ellipsoidal head is attached).

d. Steps 2a, 2b, 2c are repeated for the negative of mode 1 that is, for -(mode 1).

e. Both +(mode 1) and -(mode 1) behavior are investigated for both the UNPERTURBED (current) and PERTURBED designs

f. Based on the results from the +(mode 1) and -(mode 1) nonlinear analyses, SUBROUTINE STRUCT may choose which condition is worst for determination of the items listed under 2c (BUCMIN, BUCMNS, etc) and which condition is worst for determination of the collapse pressure, which later becomes one of the margins. These choices hold for the nonlinear stress and collapse analyses of the PERTURBED designs (IMODX = 1).

g. It is generally best to use multiple load sets in order to compute margins with +(modal imperfection shapes) and -(modal imperfection shapes) separately instead of using SUBROUTINE STRUCT to choose the worst of (+) and (-) imperfection shapes in a single load set, as described in f. Experience has demonstrated that processing (+) and (-) imperfection shapes in separate load sets leads to smoother plots of margins vs design iterations and also to smaller minimum weights.

3. Nonlinear axisymmetric stress analysis with "mode 2" Wimp: This analysis is performed for both +(mode 2) and -(mode 2) in exactly the same manner as just described for mode 1.

4. Axisymmetric collapse with + or - mode 1 imperfection. Which of the +(mode 1) or -(mode 1) imperfections is used has already been determined as described in Steps 2a-f. The nonlinear equilibrium path is traced over the range PMAX/10. < P < 2.*PMAX in 20 steps of dP, where PMAX=either P(design) or P(collapse), whichever is smaller and dP = PMAX/10.

5. Axisymmetric collapse with + or - mode 2 imperfection. Which of the +(mode 2) or -(mode 2) imperfections is used has already been determined as described in Step 3.

6. Nonlinear bifurcation buckling with mode 1 imperfection: For the UNPERTURBED (current) design (IMODX=0), nonlinear bifurcation buckling is investigated over a range of circumferential wave numbers from 0 to 10 with the load set equal to PMAX if PMAX = P(design) or 0.9*PMAX if PMAX = P(collapse). This is done for BOTH +(mode 1) and for -(mode 1) imperfections. SUBROUTINE STRUCT decides which of the conditions, +(mode 1) or -(mode 1), is the worst. This choice holds for the mode 1 bifurcation buckling analyses of the PERTURBED (IMODX=1) designs.

7. Nonlinear bifurcation buckling with mode 2 imperfection: This is done in exactly the same way as for the mode 1 imperfection; see Step 6.

A NOTE ABOUT DESIGN Margins...
The margins for an optimized isogrid-stiffened ellipsoidal shell with shell skin thickness and isogrid height varying along the meridian (callout points at the pole, at the junctions between each toroidal segment of the equivalent ellipsoid, and at the equator of the equivalent ellipsoid: (case name =eqellipse) are as follows:

For mode 1 buckling modal imperfection shape:
Margins CORRESPONDING TO CURRENT DESIGN (FS= FACTOR OF SAFETY)

```
MAR. CURRENT
NO.   VALUE           DEFINITION
 1  2.303E-01 (CLAPS1(1)/CLAPS1A(1))/CLAPS1F(1)-1;FS=1.0
 2  9.988E-01 (GENBK1(1)/GENBK1A(1))/GENBK1F(1)-1;FS=1.0
 3  3.853E-02 (SKNBK1(1,1)/SKNBK1A(1,1))/SKNBK1F(1,1)-1;FS=1.0
 4 -1.235E-02 (SKNBK1(1,2)/SKNBK1A(1,2))/SKNBK1F(1,2)-1;FS=1.0
 5  6.174E-01 (STFBK1(1,1)/STFBK1A(1,1))/STFBK1F(1,1)-1;FS=1.0
 6  1.564E-01 (STFBK1(1,2)/STFBK1A(1,2))/STFBK1F(1,2)-1;FS=1.0
 7  6.878E-02 (SKNST1A(1,1)/SKNST1(1,1))/SKNST1F(1,1)-1;FS=1.0
 8  1.294E-02 (SKNST1A(1,2)/SKNST1(1,2))/SKNST1F(1,2)-1;FS=1.0
 9 -3.474E-02 (STFST1A(1,1)/STFST1(1,1))/STFST1F(1,1)-1;FS=1.0
10  2.015E-02 (STFST1A(1,2)/STFST1(1,2))/STFST1F(1,2)-1;FS=1.0
11  3.439E-01 (WAPEX1A(1)/WAPEX1(1))/WAPEX1F(1)-1;FS=1.0
```

For mode 2 buckling modal imperfection shape:
Margins CORRESPONDING TO CURRENT DESIGN (FS= FACTOR OF SAFETY)

```
MAR. CURRENT
NO.   VALUE           DEFINITION
12  8.393E-02 (CLAPS2(1)/CLAPS2A(1))/CLAPS2F(1)-1;FS=1.0
13  8.220E-01 (GENBK2(1)/GENBK2A(1))/GENBK2F(1)-1;FS=1.0
14  6.012E-02 (SKNBK2(1,1)/SKNBK2A(1,1))/SKNBK2F(1,1)-1;FS=1.0
15 -2.458E-02 (SKNBK2(1,2)/SKNBK2A(1,2))/SKNBK2F(1,2)-1;FS=1.0
16  2.769E+00 (STFBK2(1,1)/STFBK2A(1,1))/STFBK2F(1,1)-1;FS=1.0
17  4.838E-02 (STFBK2(1,2)/STFBK2A(1,2))/STFBK2F(1,2)-1;FS=1.0
18  9.176E-02 (SKNST2A(1,1)/SKNST2(1,1))/SKNST2F(1,1)-1;FS=1.0
19  1.170E-02 (SKNST2A(1,2)/SKNST2(1,2))/SKNST2F(1,2)-1;FS=1.0
20  1.049E-01 (STFST2A(1,1)/STFST2(1,1))/STFST2F(1,1)-1;FS=1.0
21 -1.931E-02 (STFST2A(1,2)/STFST2(1,2))/STFST2F(1,2)-1;FS=1.0
22  1.185E+00 (WAPEX2A(1)/WAPEX2(1))/WAPEX2F(1)-1;FS=1.0
```

In these margins the "A" endings in names such as "CLAPS1A" denote "allowable". The "F" endings in names such as "CLAPS1F" denote "factor of safety". The margins are equal to the corresponding behavioral constraints minus 1.0. The chart below lists names that characterize the margin depending on its value, as follows:

Designation	The most negative margin must be greater than:	The most negative margin must be less than or equal to:
"FEASIBLE"	-0.01	------
"ALMOST FEASIBLE"	-0.05	-0.01
"MILDLY UNFEASIBLE"	-0.10	-0.05
"MORE UNFEASIBLE"	-0.15	-0.10
"MOSTLY UNFEASIBLE"	-0.20	-0.15

```
"NOT FEASIBLE"        ------            -0.20




============ Analysis No. 1 for Load Set No. 1 ============
**** Start linear axisymmetric bifurcation buckling of perfect shell. IMODX= 0
**** The purpose is to get two axisymmetric buckling modal
**** imperfection shapes: mode 1 and mode 2.
BIGBOSOR4 input file for linear buckling,perfect shell=
eqellipse.ALL1
Input file for SUBROUTINE WALL for STAGS models=
eqellipse.STAGS


*** In STRUCT: IMODX, IDV=       0       0
****** WEIGHT=  8.6101E+01
Linear buckling eigenvalues from BIGBOSOR4, EGV(i)=
 2.8386E+03  3.5262E+03  4.1902E+03  4.3751E+03  5.8141E+03
 6.9852E+03  9.0675E+03  1.0883E+04  1.2440E+04  1.3618E+04
Linear axisymmetric buckling pressure of perfect shell=  1.3057E+03
Buckling modal normal displacement w at apex of shell,=  1.0000E+00


********* Buckling modal imperfection shape: mode 1 **********

Buckling mode 1 imperfection in Segment no.  1 WSAVEX=
 1.0000E+00  9.9981E-01  9.9742E-01  9.9006E-01  9.7787E-01
 9.6118E-01  9.4028E-01  9.1554E-01  8.8741E-01  8.5638E-01
 8.2339E-01  7.9756E-01  7.8772E-01

Buckling mode 1 imperfection in Segment no.  2 WSAVEX=
 7.8772E-01  7.7557E-01  7.4245E-01  6.9745E-01  6.5174E-01
 6.0638E-01  5.6171E-01  5.1794E-01  4.7520E-01  4.3356E-01
 3.9354E-01  3.6436E-01  3.5362E-01

Buckling mode 1 imperfection in Segment no.  3 WSAVEX=
 3.5363E-01  3.4297E-01  3.1481E-01  2.7802E-01  2.4185E-01
 2.0674E-01  1.7269E-01  1.3964E-01  1.0758E-01  7.6473E-02
 4.6659E-02  2.4964E-02  1.6991E-02

Buckling mode 1 imperfection in Segment no.  4 WSAVEX=
 1.7006E-02  9.0904E-03 -1.1800E-02 -3.9009E-02 -6.5639E-02
-9.1297E-02 -1.1594E-01 -1.3950E-01 -1.6192E-01 -1.8314E-01
-2.0283E-01 -2.1667E-01 -2.2164E-01

Buckling mode 1 imperfection in Segment no.  5 WSAVEX=
-2.2163E-01 -2.2649E-01 -2.3897E-01 -2.5429E-01 -2.6800E-01
```

-2.7970E-01 -2.8918E-01 -2.9619E-01 -3.0050E-01 -3.0186E-01
-3.0005E-01 -2.9653E-01 -2.9471E-01

Buckling mode 1 imperfection in Segment no. 6 WSAVEX=
-2.9472E-01 -2.9263E-01 -2.8574E-01 -2.7408E-01 -2.5995E-01
-2.4399E-01 -2.2661E-01 -2.0814E-01 -1.8886E-01 -1.6898E-01
-1.4894E-01 -1.3379E-01 -1.2811E-01

Buckling mode 1 imperfection in Segment no. 7 WSAVEX=
-1.2810E-01 -1.2388E-01 -1.1251E-01 -9.7237E-02 -8.1734E-02
-6.6229E-02 -5.0763E-02 -3.5378E-02 -2.0125E-02 -5.0600E-03
 9.5711E-03 2.0297E-02 2.4246E-02

Buckling mode 1 imperfection in Segment no. 8 WSAVEX=
 2.4234E-02 2.7684E-02 3.6810E-02 4.8716E-02 6.0355E-02
 7.1518E-02 8.2140E-02 9.2155E-02 1.0149E-01 1.1007E-01
 1.1773E-01 1.2287E-01 1.2466E-01

Buckling mode 1 imperfection in Segment no. 9 WSAVEX=
 1.2463E-01 1.2636E-01 1.3060E-01 1.3536E-01 1.3907E-01
 1.4162E-01 1.4297E-01 1.4310E-01 1.4200E-01 1.3965E-01
 1.3612E-01 1.3271E-01 1.3127E-01

Buckling mode 1 imperfection in Segment no. 10 WSAVEX=
 1.3128E-01 1.2975E-01 1.2521E-01 1.1822E-01 1.1019E-01
 1.0133E-01 9.1772E-02 8.1639E-02 7.1051E-02 6.0121E-02
 4.9095E-02 4.0764E-02 3.7644E-02

Buckling mode 1 imperfection in Segment no. 11 WSAVEX=
 3.7623E-02 3.4771E-02 2.7114E-02 1.6868E-02 6.5622E-03
-3.5953E-03 -1.3511E-02 -2.3075E-02 -3.2155E-02 -4.0594E-02
-4.8117E-02 -5.3089E-02 -5.4781E-02

Buckling mode 1 imperfection in Segment no. 12 WSAVEX=
-5.4840E-02 -5.6283E-02 -5.9771E-02 -6.3694E-02 -6.6898E-02
-6.9442E-02 -7.1423E-02 -7.2922E-02 -7.4009E-02 -7.4739E-02
-7.5151E-02 -7.5278E-02 -7.5289E-02

********* Buckling modal imperfection shape: mode 2 **********

Buckling mode 2 imperfection in Segment no. 1 WMODX2=
 1.0000E+00 9.9958E-01 9.9428E-01 9.7792E-01 9.5090E-01
 9.1403E-01 8.6820E-01 8.1455E-01 7.5438E-01 6.8920E-01
 6.2149E-01 5.6973E-01 5.5035E-01

Buckling mode 2 imperfection in Segment no. 2 WMODX2=
 5.5035E-01 5.2667E-01 4.6355E-01 3.8164E-01 3.0332E-01

 2.3077E-01 1.6462E-01 1.0511E-01 5.2240E-02 5.7982E-03
-3.4057E-02 -6.0147E-02 -6.9124E-02

Buckling mode 2 imperfection in Segment no. 3 WMODX2=
-6.9118E-02 -7.7696E-02 -9.8737E-02 -1.2272E-01 -1.4245E-01
-1.5796E-01 -1.6961E-01 -1.7777E-01 -1.8277E-01 -1.8493E-01
-1.8458E-01 -1.8286E-01 -1.8193E-01

Buckling mode 2 imperfection in Segment no. 4 WMODX2=
-1.8193E-01 -1.8085E-01 -1.7721E-01 -1.7069E-01 -1.6223E-01
-1.5199E-01 -1.4005E-01 -1.2652E-01 -1.1154E-01 -9.5226E-02
-7.7973E-02 -6.4445E-02 -5.9281E-02

Buckling mode 2 imperfection in Segment no. 5 WMODX2=
-5.9282E-02 -5.4056E-02 -3.9764E-02 -2.0126E-02 1.4207E-04
 2.0524E-02 4.0701E-02 6.0302E-02 7.8897E-02 9.5998E-02
 1.1089E-01 1.2038E-01 1.2348E-01

Buckling mode 2 imperfection in Segment no. 6 WMODX2=
 1.2348E-01 1.2635E-01 1.3282E-01 1.3893E-01 1.4237E-01
 1.4336E-01 1.4218E-01 1.3912E-01 1.3443E-01 1.2832E-01
 1.2111E-01 1.1506E-01 1.1268E-01

Buckling mode 2 imperfection in Segment no. 7 WMODX2=
 1.1267E-01 1.1086E-01 1.0581E-01 9.8630E-02 9.0867E-02
 8.2604E-02 7.3835E-02 6.4561E-02 5.4783E-02 4.4509E-02
 3.3891E-02 2.5666E-02 2.2536E-02

Buckling mode 2 imperfection in Segment no. 8 WMODX2=
 2.2543E-02 1.9766E-02 1.2200E-02 1.8232E-03 -8.9317E-03
-1.9883E-02 -3.0970E-02 -4.2121E-02 -5.3252E-02 -6.4270E-02
-7.4932E-02 -8.2683E-02 -8.5513E-02

Buckling mode 2 imperfection in Segment no. 9 WMODX2=
-8.5494E-02 -8.8304E-02 -9.5635E-02 -1.0491E-01 -1.1353E-01
-1.2125E-01 -1.2793E-01 -1.3343E-01 -1.3761E-01 -1.4036E-01
-1.4156E-01 -1.4142E-01 -1.4113E-01

Buckling mode 2 imperfection in Segment no. 10 WMODX2=
-1.4114E-01 -1.4072E-01 -1.3892E-01 -1.3509E-01 -1.2960E-01
-1.2261E-01 -1.1422E-01 -1.0457E-01 -9.3798E-02 -8.2058E-02
-6.9658E-02 -5.9961E-02 -5.6262E-02

Buckling mode 2 imperfection in Segment no. 11 WMODX2=
-5.6234E-02 -5.2818E-02 -4.3503E-02 -3.0703E-02 -1.7424E-02
-3.9152E-03 9.7028E-03 2.3275E-02 3.6602E-02 4.9426E-02
 6.1282E-02 6.9387E-02 7.2202E-02

```
Buckling mode 2 imperfection in Segment no. 12 WMODX2=
 7.2286E-02  7.4711E-02  8.0690E-02  8.7606E-02  9.3420E-02
 9.8150E-02  1.0191E-01  1.0480E-01  1.0692E-01  1.0835E-01
 1.0916E-01  1.0941E-01  1.0943E-01



=========== Analysis No. 2 for Load Set No. 1 ===========
*** Start nonlinear axisymmetric stress,+(mode 1) imperfection      IMODX= 0
BIGBOSOR4 input file for nonlinear stress,+(mode 1) imperfect=
eqellipse.ALL2P


*** Output from mode 1 INDIC=0, stress analysis; IMODX= 0 ***
Pressure multiplier, P, for all load steps=
 4.6000E+01  9.2000E+01  1.3800E+02  1.8400E+02  2.3000E+02
 2.7600E+02  3.2200E+02  3.6800E+02  4.1400E+02  4.6000E+02
End displacement, ENDUVS, for all load steps=
 2.8039E-02  5.6250E-02  8.4628E-02  1.1317E-01  1.4188E-01
 1.7076E-01  1.9982E-01  2.2909E-01  2.5860E-01  2.8842E-01

Local skin and smeared stiffener buckling and stress, Seg.   1
Skin buckling load factor,                    BUCMIN=  9.4633E+00 at nodal point  2
Smeared stringer/isogrid buckling load factor, BUCMNS=  2.9187E+00 at nodal point  1
Smeared ring buckling load factor,            BUCMNR=  1.0000E+17 at nodal point 13
Smeared stringer/isogrid maximum eff. stress,  STFMXS=  8.6190E+04 at nodal point  8
Smeared ring maximum effective stress,        STFMXR=  0.0000E+00 at nodal point  0
Shell skin maximum effective stress,          SKNMAX=  4.7007E+04 at nodal point 13

Local skin and smeared stiffener buckling and stress, Seg.   2
Skin buckling load factor,                    BUCMIN=  8.6543E+00 at nodal point 13
Smeared stringer/isogrid buckling load factor, BUCMNS=  3.3413E+00 at nodal point  1
Smeared ring buckling load factor,            BUCMNR=  1.0000E+17 at nodal point 13
Smeared stringer/isogrid maximum eff. stress,  STFMXS=  8.4631E+04 at nodal point  1
Smeared ring maximum effective stress,        STFMXR=  0.0000E+00 at nodal point  0
Shell skin maximum effective stress,          SKNMAX=  5.6745E+04 at nodal point 13

Local skin and smeared stiffener buckling and stress, Seg.   3
Skin buckling load factor,                    BUCMIN=  8.6478E+00 at nodal point  1
Smeared stringer/isogrid buckling load factor, BUCMNS=  1.0000E+17 at nodal point 13
Smeared ring buckling load factor,            BUCMNR=  1.0000E+17 at nodal point 13
Smeared stringer/isogrid maximum eff. stress,  STFMXS=  3.4130E+04 at nodal point  1
Smeared ring maximum effective stress,        STFMXR=  0.0000E+00 at nodal point  0
Shell skin maximum effective stress,          SKNMAX=  6.1198E+04 at nodal point 13

Local skin and smeared stiffener buckling and stress, Seg.   4
Skin buckling load factor,                    BUCMIN=  3.0235E+00 at nodal point 13
```

Smeared stringer/isogrid buckling load factor, BUCMNS= 1.0000E+17 at nodal point 13
Smeared ring buckling load factor,   BUCMNR= 1.0000E+17 at nodal point 13
Smeared stringer/isogrid maximum eff. stress, STFMXS= 6.5071E+04 at nodal point 13
Smeared ring maximum effective stress,   STFMXR= 0.0000E+00 at nodal point 0
Shell skin maximum effective stress,   SKNMAX= 8.7084E+04 at nodal point 13

Local skin and smeared stiffener buckling and stress, Seg.   5
Skin buckling load factor,   BUCMIN= 2.6863E+00 at nodal point 12
Smeared stringer/isogrid buckling load factor, BUCMNS= 1.0000E+17 at nodal point 13
Smeared ring buckling load factor,   BUCMNR= 1.0000E+17 at nodal point 13
Smeared stringer/isogrid maximum eff. stress, STFMXS= 6.9978E+04 at nodal point 13
Smeared ring maximum effective stress,   STFMXR= 0.0000E+00 at nodal point 0
Shell skin maximum effective stress,   SKNMAX= 8.9086E+04 at nodal point 8

Local skin and smeared stiffener buckling and stress, Seg.   6
Skin buckling load factor,   BUCMIN= 2.6893E+00 at nodal point 1
Smeared stringer/isogrid buckling load factor, BUCMNS= 1.9258E+01 at nodal point 13
Smeared ring buckling load factor,   BUCMNR= 1.0000E+17 at nodal point 13
Smeared stringer/isogrid maximum eff. stress, STFMXS= 7.0013E+04 at nodal point 1
Smeared ring maximum effective stress,   STFMXR= 0.0000E+00 at nodal point 0
Shell skin maximum effective stress,   SKNMAX= 8.7480E+04 at nodal point 1

Local skin and smeared stiffener buckling and stress, Seg.   7
Skin buckling load factor,   BUCMIN= 3.1890E+00 at nodal point 1
Smeared stringer/isogrid buckling load factor, BUCMNS= 1.6103E+00 at nodal point 13
Smeared ring buckling load factor,   BUCMNR= 1.0000E+17 at nodal point 13
Smeared stringer/isogrid maximum eff. stress, STFMXS= 8.3139E+04 at nodal point 13
Smeared ring maximum effective stress,   STFMXR= 0.0000E+00 at nodal point 0
Shell skin maximum effective stress,   SKNMAX= 7.2323E+04 at nodal point 1

Local skin and smeared stiffener buckling and stress, Seg.   8
Skin buckling load factor,   BUCMIN= 4.2428E+00 at nodal point 13
Smeared stringer/isogrid buckling load factor, BUCMNS= 1.5813E+00 at nodal point 2
Smeared ring buckling load factor,   BUCMNR= 1.0000E+17 at nodal point 13
Smeared stringer/isogrid maximum eff. stress, STFMXS= 1.1415E+05 at nodal point 13
Smeared ring maximum effective stress,   STFMXR= 0.0000E+00 at nodal point 0
Shell skin maximum effective stress,   SKNMAX= 7.9991E+04 at nodal point 13

Local skin and smeared stiffener buckling and stress, Seg.   9
Skin buckling load factor,   BUCMIN= 4.2470E+00 at nodal point 1
Smeared stringer/isogrid buckling load factor, BUCMNS= 1.8018E+00 at nodal point 2
Smeared ring buckling load factor,   BUCMNR= 1.0000E+17 at nodal point 13
Smeared stringer/isogrid maximum eff. stress, STFMXS= 1.2476E+05 at nodal point 7
Smeared ring maximum effective stress,   STFMXR= 0.0000E+00 at nodal point 0
Shell skin maximum effective stress,   SKNMAX= 9.2786E+04 at nodal point 13

Local skin and smeared stiffener buckling and stress, Seg. 10
Skin buckling load factor,   BUCMIN= 4.8516E+00 at nodal point 1

```
Smeared stringer/isogrid buckling load factor, BUCMNS=  2.5233E+00 at nodal point  2
Smeared ring buckling load factor,            BUCMNR=  1.0000E+17 at nodal point 13
Smeared stringer/isogrid maximum eff. stress,  STFMXS=  1.2200E+05 at nodal point  2
Smeared ring maximum effective stress,        STFMXR=  0.0000E+00 at nodal point  0
Shell skin maximum effective stress,          SKNMAX=  9.2778E+04 at nodal point  1

Local skin and smeared stiffener buckling and stress, Seg.  11
Skin buckling load factor,                    BUCMIN=  4.5458E+00 at nodal point 13
Smeared stringer/isogrid buckling load factor, BUCMNS=  3.7129E+00 at nodal point  1
Smeared ring buckling load factor,            BUCMNR=  1.0000E+17 at nodal point 13
Smeared stringer/isogrid maximum eff. stress,  STFMXS=  1.0622E+05 at nodal point  2
Smeared ring maximum effective stress,        STFMXR=  0.0000E+00 at nodal point  0
Shell skin maximum effective stress,          SKNMAX=  1.0543E+05 at nodal point 13

Local skin and smeared stiffener buckling and stress, Seg.  12
Skin buckling load factor,                    BUCMIN=  4.5472E+00 at nodal point  1
Smeared stringer/isogrid buckling load factor, BUCMNS=  5.5937E+00 at nodal point 13
Smeared ring buckling load factor,            BUCMNR=  1.0000E+17 at nodal point 13
Smeared stringer/isogrid maximum eff. stress,  STFMXS=  8.5788E+04 at nodal point 13
Smeared ring maximum effective stress,        STFMXR=  0.0000E+00 at nodal point  0
Shell skin maximum effective stress,          SKNMAX=  1.0541E+05 at nodal point  1

                                        PERTURBED  UNPERTURBED
Region 1 skin buckling load factor,        bskin1=  2.6863E+00  2.6863E+00
Region 1 stiffener buckling load factor,   bstif1=  2.9187E+00  2.9187E+00
Region 1 skin maximum effective stress,    sknmx1=  8.9086E+04  8.9086E+04
Region 1 stiffener max. effective stress,  stfmx1=  8.6190E+04  8.6190E+04
Region 2 skin buckling load factor,        bskin2=  2.6893E+00  2.6893E+00
Region 2 stiffener buckling load factor,   bstif2=  1.5813E+00  1.5813E+00
Region 2 skin maximum effective stress,    sknmx2=  1.0543E+05  1.0543E+05
Region 2 stiffener max. effective stress,  stfmx2=  1.2476E+05  1.2476E+05
Normal displacement of shell at apex,       ENDUV=  2.8842E-01  2.8842E-01

The following quantities are used to generate behavioral constraint conditions and margins:
                                        PERTURBED  UNPERTURBED
Region 1 skin buckling load factor,        bskin1=  2.6863E+00  2.6863E+00
Region 1 stiffener buckling load factor,   bstif1=  2.9187E+00  2.9187E+00
Region 1 skin maximum effective stress,    sknmx1=  8.9086E+04  8.9086E+04
Region 1 stiffener max. effective stress,  stfmx1=  8.6190E+04  8.6190E+04
Region 2 skin buckling load factor,        bskin2=  2.6893E+00  2.6893E+00
Region 2 stiffener buckling load factor,   bstif2=  1.5813E+00  1.5813E+00
Region 2 skin maximum effective stress,    sknmx2=  1.0543E+05  1.0543E+05
Region 2 stiffener max. effective stress,  stfmx2=  1.2476E+05  1.2476E+05
Normal displacement of shell at apex,       ENDUV=  2.8842E-01  2.8842E-01
```

```
 ============ Analysis No. 3 for Load Set No. 1 ============
 *** Start nonlinear axisymmetric stress,+(mode 2) imperfection      IMODX= 0
 BIGBOSOR4 input file for nonlinear stress,+(mode 2) imperfect=
eqellipse.ALL4P


 *** Output from mode 2 INDIC=0, stress analysis; IMODX= 0 ***
 Pressure multiplier, P, for all load steps=
  4.6000E+01  9.2000E+01  1.3800E+02  1.8400E+02  2.3000E+02
  2.7600E+02  3.2200E+02  3.6800E+02  4.1400E+02  4.6000E+02
 End displacement, ENDUVS, for all load steps=
  2.9910E-02  6.0185E-02  9.0836E-02  1.2188E-01  1.5332E-01
  1.8520E-01  2.1751E-01  2.5030E-01  2.8360E-01  3.1743E-01

 Local skin and smeared stiffener buckling and stress, Seg.   1
 Skin buckling load factor,                    BUCMIN=  1.0223E+01 at nodal point  2
 Smeared stringer/isogrid buckling load factor, BUCMNS=  1.9224E+00 at nodal point  1
 Smeared ring buckling load factor,            BUCMNR=  1.0000E+17 at nodal point 13
 Smeared stringer/isogrid maximum eff. stress,  STFMXS=  1.2255E+05 at nodal point  3
 Smeared ring maximum effective stress,        STFMXR=  0.0000E+00 at nodal point  0
 Shell skin maximum effective stress,          SKNMAX=  5.3373E+04 at nodal point 13

 Local skin and smeared stiffener buckling and stress, Seg.   2
 Skin buckling load factor,                    BUCMIN=  7.3064E+00 at nodal point 13
 Smeared stringer/isogrid buckling load factor, BUCMNS=  4.1002E+00 at nodal point  1
 Smeared ring buckling load factor,            BUCMNR=  1.0000E+17 at nodal point 13
 Smeared stringer/isogrid maximum eff. stress,  STFMXS=  6.8967E+04 at nodal point  1
 Smeared ring maximum effective stress,        STFMXR=  0.0000E+00 at nodal point  0
 Shell skin maximum effective stress,          SKNMAX=  7.0925E+04 at nodal point 13

 Local skin and smeared stiffener buckling and stress, Seg.   3
 Skin buckling load factor,                    BUCMIN=  7.3011E+00 at nodal point  1
 Smeared stringer/isogrid buckling load factor, BUCMNS=  1.0000E+17 at nodal point 13
 Smeared ring buckling load factor,            BUCMNR=  1.0000E+17 at nodal point 13
 Smeared stringer/isogrid maximum eff. stress,  STFMXS=  4.3008E+04 at nodal point  1
 Smeared ring maximum effective stress,        STFMXR=  0.0000E+00 at nodal point  0
 Shell skin maximum effective stress,          SKNMAX=  7.1210E+04 at nodal point  4

 Local skin and smeared stiffener buckling and stress, Seg.   4
 Skin buckling load factor,                    BUCMIN=  2.9943E+00 at nodal point 13
 Smeared stringer/isogrid buckling load factor, BUCMNS=  1.0000E+17 at nodal point 13
 Smeared ring buckling load factor,            BUCMNR=  1.0000E+17 at nodal point 13
 Smeared stringer/isogrid maximum eff. stress,  STFMXS=  6.9629E+04 at nodal point 13
 Smeared ring maximum effective stress,        STFMXR=  0.0000E+00 at nodal point  0
 Shell skin maximum effective stress,          SKNMAX=  8.3938E+04 at nodal point 13

 Local skin and smeared stiffener buckling and stress, Seg.   5
 Skin buckling load factor,                    BUCMIN=  2.9925E+00 at nodal point  1
```

Smeared stringer/isogrid buckling load factor, BUCMNS= 1.8143E+00 at nodal point 13
Smeared ring buckling load factor,   BUCMNR= 1.0000E+17 at nodal point 13
Smeared stringer/isogrid maximum eff. stress, STFMXS= 8.9031E+04 at nodal point 13
Smeared ring maximum effective stress,   STFMXR= 0.0000E+00 at nodal point 0
Shell skin maximum effective stress,   SKNMAX= 8.3974E+04 at nodal point 1

Local skin and smeared stiffener buckling and stress, Seg.   6
Skin buckling load factor,   BUCMIN= 3.1488E+00 at nodal point 1
Smeared stringer/isogrid buckling load factor, BUCMNS= 1.7834E+00 at nodal point 2
Smeared ring buckling load factor,   BUCMNR= 1.0000E+17 at nodal point 13
Smeared stringer/isogrid maximum eff. stress, STFMXS= 8.9544E+04 at nodal point 1
Smeared ring maximum effective stress,   STFMXR= 0.0000E+00 at nodal point 0
Shell skin maximum effective stress,   SKNMAX= 6.9545E+04 at nodal point 1

Local skin and smeared stiffener buckling and stress, Seg.   7
Skin buckling load factor,   BUCMIN= 3.4621E+00 at nodal point 1
Smeared stringer/isogrid buckling load factor, BUCMNS= 1.7368E+00 at nodal point 13
Smeared ring buckling load factor,   BUCMNR= 1.0000E+17 at nodal point 13
Smeared stringer/isogrid maximum eff. stress, STFMXS= 7.7081E+04 at nodal point 13
Smeared ring maximum effective stress,   STFMXR= 0.0000E+00 at nodal point 0
Shell skin maximum effective stress,   SKNMAX= 6.6328E+04 at nodal point 1

Local skin and smeared stiffener buckling and stress, Seg.   8
Skin buckling load factor,   BUCMIN= 3.9860E+00 at nodal point 13
Smeared stringer/isogrid buckling load factor, BUCMNS= 1.7200E+00 at nodal point 2
Smeared ring buckling load factor,   BUCMNR= 1.0000E+17 at nodal point 13
Smeared stringer/isogrid maximum eff. stress, STFMXS= 7.8703E+04 at nodal point 2
Smeared ring maximum effective stress,   STFMXR= 0.0000E+00 at nodal point 0
Shell skin maximum effective stress,   SKNMAX= 7.0892E+04 at nodal point 13

Local skin and smeared stiffener buckling and stress, Seg.   9
Skin buckling load factor,   BUCMIN= 3.9885E+00 at nodal point 1
Smeared stringer/isogrid buckling load factor, BUCMNS= 3.3026E+00 at nodal point 2
Smeared ring buckling load factor,   BUCMNR= 1.0000E+17 at nodal point 13
Smeared stringer/isogrid maximum eff. stress, STFMXS= 6.7528E+04 at nodal point 13
Smeared ring maximum effective stress,   STFMXR= 0.0000E+00 at nodal point 0
Shell skin maximum effective stress,   SKNMAX= 8.3523E+04 at nodal point 13

Local skin and smeared stiffener buckling and stress, Seg. 10
Skin buckling load factor,   BUCMIN= 4.3321E+00 at nodal point 1
Smeared stringer/isogrid buckling load factor, BUCMNS= 4.2840E+00 at nodal point 13
Smeared ring buckling load factor,   BUCMNR= 1.0000E+17 at nodal point 13
Smeared stringer/isogrid maximum eff. stress, STFMXS= 9.1661E+04 at nodal point 13
Smeared ring maximum effective stress,   STFMXR= 0.0000E+00 at nodal point 0
Shell skin maximum effective stress,   SKNMAX= 8.6618E+04 at nodal point 13

Local skin and smeared stiffener buckling and stress, Seg. 11
Skin buckling load factor,   BUCMIN= 4.8141E+00 at nodal point 13

Smeared stringer/isogrid buckling load factor, BUCMNS= 4.2701E+00 at nodal point 1
Smeared ring buckling load factor, BUCMNR= 1.0000E+17 at nodal point 13
Smeared stringer/isogrid maximum eff. stress, STFMXS= 1.1479E+05 at nodal point 13
Smeared ring maximum effective stress, STFMXR= 0.0000E+00 at nodal point 0
Shell skin maximum effective stress, SKNMAX= 1.1436E+05 at nodal point 13

Local skin and smeared stiffener buckling and stress, Seg. 12
Skin buckling load factor, BUCMIN= 4.8171E+00 at nodal point 1
Smeared stringer/isogrid buckling load factor, BUCMNS= 4.3387E+00 at nodal point 13
Smeared ring buckling load factor, BUCMNR= 1.0000E+17 at nodal point 13
Smeared stringer/isogrid maximum eff. stress, STFMXS= 1.2331E+05 at nodal point 4
Smeared ring maximum effective stress, STFMXR= 0.0000E+00 at nodal point 0
Shell skin maximum effective stress, SKNMAX= 1.1438E+05 at nodal point 1

		PERTURBED	UNPERTURBED
Region 1 skin buckling load factor,	bskin1=	2.9925E+00	2.9925E+00
Region 1 stiffener buckling load factor,	bstif1=	1.8143E+00	1.8143E+00
Region 1 skin maximum effective stress,	sknmx1=	8.3974E+04	8.3974E+04
Region 1 stiffener max. effective stress,	stfmx1=	1.2255E+05	1.2255E+05
Region 2 skin buckling load factor,	bskin2=	3.1488E+00	3.1488E+00
Region 2 stiffener buckling load factor,	bstif2=	1.7200E+00	1.7200E+00
Region 2 skin maximum effective stress,	sknmx2=	1.1438E+05	1.1438E+05
Region 2 stiffener max. effective stress,	stfmx2=	1.2331E+05	1.2331E+05
Normal displacement of shell at apex,	ENDUV=	3.1743E-01	3.1743E-01

The following quantities are used to generate behavioral constraint conditions and margins:

		PERTURBED	UNPERTURBED
Region 1 skin buckling load factor,	bskin1=	2.9925E+00	2.9925E+00
Region 1 stiffener buckling load factor,	bstif1=	1.8143E+00	1.8143E+00
Region 1 skin maximum effective stress,	sknmx1=	8.3974E+04	8.3974E+04
Region 1 stiffener max. effective stress,	stfmx1=	1.2255E+05	1.2255E+05
Region 2 skin buckling load factor,	bskin2=	3.1488E+00	3.1488E+00
Region 2 stiffener buckling load factor,	bstif2=	1.7200E+00	1.7200E+00
Region 2 skin maximum effective stress,	sknmx2=	1.1438E+05	1.1438E+05
Region 2 stiffener max. effective stress,	stfmx2=	1.2331E+05	1.2331E+05
Normal displacement of shell at apex,	ENDUV=	3.1743E-01	3.1743E-01

============ Analysis No. 4 for Load Set No. 1 ============
** Start nonlinear axisymmetric collpse,+(mode 1) imperfection IMODX= 0
BIGBOSOR4 input file, axisymmetric collpse, +mode 1 imperfect=
eqellipse.ALL6P

*** Output from +(mode 1) INDIC=0, collapse analysis; IMODX= 0 *********
Pressure multiplier, P, for all load steps=

```
 4.6000E+01  9.2000E+01  1.3800E+02  1.8400E+02  2.3000E+02
 2.7600E+02  3.2200E+02  3.6800E+02  4.1400E+02  4.6000E+02
 5.0600E+02  5.5200E+02  5.9800E+02  6.4400E+02  6.9000E+02
 7.3600E+02  7.8200E+02  8.2800E+02  8.3260E+02  8.3720E+02
 8.4180E+02  8.4640E+02  8.5100E+02  8.5560E+02  8.6020E+02
 8.6480E+02  8.6940E+02  8.7400E+02  8.7860E+02  8.8320E+02
 8.8780E+02  8.8826E+02  8.8872E+02  8.8918E+02  8.8964E+02
 8.9010E+02  8.9056E+02  8.9102E+02  8.9148E+02
End displacement, ENDUVS, for all load steps=
 2.8039E-02  5.6250E-02  8.4628E-02  1.1317E-01  1.4188E-01
 1.7076E-01  1.9982E-01  2.2909E-01  2.5860E-01  2.8842E-01
 3.1864E-01  3.4943E-01  3.8102E-01  4.1382E-01  4.4851E-01
 4.8631E-01  5.2972E-01  5.8489E-01  5.9161E-01  5.9865E-01
 6.0608E-01  6.1395E-01  6.2233E-01  6.3134E-01  6.4110E-01
 6.5179E-01  6.6368E-01  6.7715E-01  6.9288E-01  7.1211E-01
 7.3788E-01  7.4110E-01  7.4449E-01  7.4809E-01  7.5193E-01
 7.5606E-01  7.6055E-01  7.6550E-01  7.7105E-01

                                             PERTURBED  UNPERTURBED
 Collapse pressure with +(mode 1): PSTEP(ISTEP)=  8.9148E+02  8.9148E+02

 The following quantity is used to generate the behavioral constraint condition and margin:
                                             PERTURBED  UNPERTURBED
 Collapse pressure with mode 1: CLAPS1(ILOADX)=  8.9148E+02  8.9148E+02




 ============ Analysis No. 5 for Load Set No. 1 ============
 ** Start nonlinear axisymmetric collpse,+(mode 2) imperfection      IMODX= 0
 BIGBOSOR4 input file, axisymmetric collpse, +mode 2 imperfect=
eqellipse.ALL7P


 *** Output from +(mode 2) INDIC=0, collapse analysis; IMODX= 0 *********
 Pressure multiplier, P, for all load steps=
 4.6000E+01  9.2000E+01  1.3800E+02  1.8400E+02  2.3000E+02
 2.7600E+02  3.2200E+02  3.6800E+02  4.1400E+02  4.6000E+02
 5.0600E+02  5.5200E+02  5.9800E+02  6.4400E+02  6.9000E+02
 7.3600E+02  7.8200E+02  8.2800E+02  8.7400E+02  9.2000E+02
 End displacement, ENDUVS, for all load steps=
 2.9910E-02  6.0185E-02  9.0836E-02  1.2188E-01  1.5332E-01
 1.8520E-01  2.1751E-01  2.5030E-01  2.8360E-01  3.1743E-01
 3.5186E-01  3.8692E-01  4.2270E-01  4.5927E-01  4.9675E-01
 5.3526E-01  5.7499E-01  6.1616E-01  6.5905E-01  7.0406E-01

                                             PERTURBED  UNPERTURBED
 Collapse pressure with +(mode 2): PSTEP(ISTEP)=  9.2000E+02  9.2000E+02
```

The following quantity is used to generate the behavioral constraint condition and margin:
PERTURBED UNPERTURBED
Collapse pressure with mode 2: CLAPS2(ILOADX)= 9.2000E+02 9.2000E+02

============ Analysis No. 6 for Load Set No. 1 ============
** Start nonlinear bifurcation buckling,+(mode 1) imperfection IMODX= 0
BIGBOSOR4 input file, bifurcation buckling, +(mode 1) imperf.=
eqellipse.ALL8P

******* Nonlinear overall bifurcation buckling results ******
Overall buckling, +(mode 1) imperfection shape; Applied pressure, PMAX = 4.6000E+02
*** Output from +(mode 1) INDIC=1, buckling analysis; IMODX= 0 *********

**** CRITICAL EIGENVALUE AND WAVENUMBER ****
EIGCRT= 1.5888E+03; NO. OF CIRC. WAVES, NWVCRT= 2
****

***** EIGENVALUES AND MODE SHAPES *****
EIGENVALUE(CIRC. WAVES)
===
1.8046E+03(0)
1.8932E+03(1)
1.5888E+03(2)
1.8533E+03(3)
2.5006E+03(4)
3.3465E+03(5)
4.3555E+03(6)
5.5194E+03(7)
6.8261E+03(8)
8.2624E+03(9)
9.8146E+03(10)
1.1469E+04(11)
1.3219E+04(12)
1.5061E+04(13)
1.6996E+04(14)
1.9024E+04(15)
2.1145E+04(16)
2.3359E+04(17)
2.5666E+04(18)
2.8066E+04(19)
3.0559E+04(20)
3.3145E+04(21)
3.5823E+04(22)

```
  3.8591E+04(  23)
  4.1449E+04(  24)
  4.4394E+04(  25)
  4.7426E+04(  26)
  5.0540E+04(  27)
  5.3732E+04(  28)
  5.6995E+04(  29)
  6.0318E+04(  30)
========================================

**** CRITICAL NEGATIVE EIGENVALUE AND WAVENUMBER ****
EIGCRN=  0.0000E+00; NO. OF CIRC. WAVES, NWVCRN=*****
****************************************************

***** NEGATIVE EIGENVALUES AND MODE SHAPES *****
 EIGENVALUE(CIRC. WAVES)
========================================
  0.0000E+00(****)
  0.0000E+00(****)
  0.0000E+00(****)
  0.0000E+00(****)
  0.0000E+00(****)
  0.0000E+00(****)
  0.0000E+00(****)
  0.0000E+00(****)
  0.0000E+00(****)
  0.0000E+00(****)
  0.0000E+00(****)
  0.0000E+00(****)
  0.0000E+00(****)
  0.0000E+00(****)
  0.0000E+00(****)
  0.0000E+00(****)
  0.0000E+00(****)
  0.0000E+00(****)
  0.0000E+00(****)
  0.0000E+00(****)
  0.0000E+00(****)
  0.0000E+00(****)
  0.0000E+00(****)
  0.0000E+00(****)
  0.0000E+00(****)
  0.0000E+00(****)
  0.0000E+00(****)
  0.0000E+00(****)
  0.0000E+00(****)
  0.0000E+00(****)
```

```
========================================

Nonlinear bifurcation buckling pressure, BUCPRSP(circ.waves)=  1.1908E+03( 2)
General bifurcation buckling load factor, GENBK1(ILOADX)=  2.5888E+00



                              PERTURBED  UNPERTURBED
Nonlin. bifurcation buckling, +(mode 1):BUCPRSP=  1.1908E+03  1.1908E+03

IMODX=0: M1MULTB,NWAV1,PMAXBUC1=    1    2  4.6000E+02

The following quantity is used to generate the behavioral constraint condition and margin:
                              PERTURBED  UNPERTURBED
Nonlin. bifurcation buckling, +(mode 1):BUCPRS =  1.1908E+03  1.1908E+03




============ Analysis No. 7 for Load Set No. 1 ============
** Start nonlinear bifurcation buckling,+(mode 2) imperfection      IMODX= 0
BIGBOSOR4 input file, bifurcation buckling, +(mode 2) imperf.=
eqellipse.ALL9P


***** Nonlinear overall bifurcation buckling results *****
Overall buckling, +(mode 2) imperfection shape; Applied pressure, PMAX =  4.6000E+02
** Output from +(mode 2) INDIC=1, buckling analysis;IMODX= 0 *********

**** CRITICAL EIGENVALUE AND WAVENUMBER ****
EIGCRT=  1.6818E+03; NO. OF CIRC. WAVES, NWVCRT=    2
**************************************************

***** EIGENVALUES AND MODE SHAPES *****
 EIGENVALUE(CIRC. WAVES)
========================================
   1.7508E+03(   0)
   1.9480E+03(   1)
   1.6818E+03(   2)
   2.3983E+03(   3)
   3.4325E+03(   4)
   4.6169E+03(   5)
   5.8975E+03(   6)
   7.1725E+03(   7)
   8.3814E+03(   8)
   9.6440E+03(   9)
   1.1059E+04(  10)
   1.2661E+04(  11)
```

```
  1.4455E+04(  12)
  1.6421E+04(  13)
  1.8531E+04(  14)
  2.0757E+04(  15)
  2.3086E+04(  16)
  2.5523E+04(  17)
  2.8088E+04(  18)
  3.0802E+04(  19)
  3.3684E+04(  20)
  3.6745E+04(  21)
  3.9991E+04(  22)
  4.3425E+04(  23)
  4.7044E+04(  24)
  5.0840E+04(  25)
  5.4802E+04(  26)
  5.8910E+04(  27)
  6.3134E+04(  28)
  6.7419E+04(  29)
  7.1609E+04(  30)
=========================================

**** CRITICAL NEGATIVE EIGENVALUE AND WAVENUMBER ****
EIGCRN=  0.0000E+00; NO. OF CIRC. WAVES, NWVCRN=*****
****************************************************

***** NEGATIVE EIGENVALUES AND MODE SHAPES *****
 EIGENVALUE(CIRC. WAVES)
=========================================
  0.0000E+00(****)
  0.0000E+00(****)
  0.0000E+00(****)
  0.0000E+00(****)
  0.0000E+00(****)
  0.0000E+00(****)
  0.0000E+00(****)
  0.0000E+00(****)
  0.0000E+00(****)
  0.0000E+00(****)
  0.0000E+00(****)
  0.0000E+00(****)
  0.0000E+00(****)
  0.0000E+00(****)
  0.0000E+00(****)
  0.0000E+00(****)
  0.0000E+00(****)
  0.0000E+00(****)
  0.0000E+00(****)
  0.0000E+00(****)
```

```
  0.0000E+00(****)
  0.0000E+00(****)
  0.0000E+00(****)
  0.0000E+00(****)
  0.0000E+00(****)
  0.0000E+00(****)
  0.0000E+00(****)
  0.0000E+00(****)
  0.0000E+00(****)
  0.0000E+00(****)
  0.0000E+00(****)
========================================

Nonlinear bifurcation buckling pressure, BUCPRSP(circ.waves)=  1.2336E+03( 2)
General bifurcation buckling load factor, GENBK2(ILOADX)=  2.6818E+00



                                          PERTURBED  UNPERTURBED
Nonlin. bifurcation buckling, +(mode 2):BUCPRSP=  1.2336E+03  1.2336E+03

IMODX=0: M2MULTB,NWAV2,PMAXBUC2=    1    2  4.6000E+02

The following quantity is used to generate the behavioral constraint condition and margin:
                                          PERTURBED  UNPERTURBED
Nonlin. bifurcation buckling, +(mode 2):BUCPRS =  1.2336E+03  1.2336E+03


********* End of all analysis. IMODX= 0 **************


  1      891.4798     collapse pressure with imperfection mode 1: CLAPS1(1 )
  2      2.588776     general buckling load factor, mode 1: GENBK1(1 )

 BEHAVIOR OVER J =  number of regions for computing behavior
  3      2.686344     buckling load of skin: SKNBK1(1 ,1 )
  4      2.689327     buckling load of skin: SKNBK1(1 ,2 )

 BEHAVIOR OVER J =  number of regions for computing behavior
  5      2.918745     buckling load factor, isogrid member, mode 1: STFBK1(1 ,1 )
  6      1.581270     buckling load factor, isogrid member, mode 1: STFBK1(1 ,2 )

 BEHAVIOR OVER J =  number of regions for computing behavior
  7      89086.03     maximum stress in the shell skin, mode 1: SKNST1(1 ,1 )
  8      105429.2     maximum stress in the shell skin, mode 1: SKNST1(1 ,2 )

 BEHAVIOR OVER J =  number of regions for computing behavior
  9      86189.76     maximum stress in isogrid stiffener, mode 1: STFST1(1 ,1 )
```

10 124760.8 maximum stress in isogrid stiffener, mode 1: STFST1(1 ,2)
11 0.2884182 normal (axial) displacement at apex, mode 1: WAPEX1(1)
12 920.0000 collapse pressure with imperfection mode 2: CLAPS2(1)
13 2.681802 general buckling load factor, mode 2: GENBK2(1)

BEHAVIOR OVER J = number of regions for computing behavior
14 2.992498 local skin buckling load factor, mode 2: SKNBK2(1 ,1)
15 3.148841 local skin buckling load factor, mode 2: SKNBK2(1 ,2)

BEHAVIOR OVER J = number of regions for computing behavior
16 1.814337 buckling load factor for isogrid member: STFBK2(1 ,1)
17 1.720039 buckling load factor for isogrid member: STFBK2(1 ,2)

BEHAVIOR OVER J = number of regions for computing behavior
18 83974.45 maximum stress in the shell skin, mode 2: SKNST2(1 ,1)
19 114376.4 maximum stress in the shell skin, mode 2: SKNST2(1 ,2)

BEHAVIOR OVER J = number of regions for computing behavior
20 122546.8 maximum stress in isogrid stiffener, mode 2: STFST2(1 ,1)
21 123313.6 maximum stress in isogrid stiffener, mode 2: STFST2(1 ,2)
22 0.3174349 normal (axial) displacement at apex, mode 2: WAPEX2(1)

***** RESULTS FOR LOAD SET NO. 1 ******
PARAMETERS WHICH DESCRIBE BEHAVIOR (e.g. stress, buckling load)

BEH. NO.	CURRENT VALUE	DEFINITION
1	8.915E+02	collapse pressure with imperfection mode 1: CLAPS1(1)
2	2.589E+00	general buckling load factor, mode 1: GENBK1(1)
3	2.686E+00	buckling load of skin: SKNBK1(1 ,1)
4	2.689E+00	buckling load of skin: SKNBK1(1 ,2)
5	2.919E+00	buckling load factor, isogrid member, mode 1: STFBK1(1 ,1)
6	1.581E+00	buckling load factor, isogrid member, mode 1: STFBK1(1 ,2)
7	8.909E+04	maximum stress in the shell skin, mode 1: SKNST1(1 ,1)
8	1.054E+05	maximum stress in the shell skin, mode 1: SKNST1(1 ,2)
9	8.619E+04	maximum stress in isogrid stiffener, mode 1: STFST1(1 ,1)
10	1.248E+05	maximum stress in isogrid stiffener, mode 1: STFST1(1 ,2)
11	2.884E-01	normal (axial) displacement at apex, mode 1: WAPEX1(1)
12	9.200E+02	collapse pressure with imperfection mode 2: CLAPS2(1)
13	2.682E+00	general buckling load factor, mode 2: GENBK2(1)
14	2.992E+00	local skin buckling load factor, mode 2: SKNBK2(1 ,1)
15	3.149E+00	local skin buckling load factor, mode 2: SKNBK2(1 ,2)
16	1.814E+00	buckling load factor for isogrid member: STFBK2(1 ,1)
17	1.720E+00	buckling load factor for isogrid member: STFBK2(1 ,2)
18	8.397E+04	maximum stress in the shell skin, mode 2: SKNST2(1 ,1)
19	1.144E+05	maximum stress in the shell skin, mode 2: SKNST2(1 ,2)
20	1.225E+05	maximum stress in isogrid stiffener, mode 2: STFST2(1 ,1)
21	1.233E+05	maximum stress in isogrid stiffener, mode 2: STFST2(1 ,2)

```
22    3.174E-01    normal (axial) displacement at apex, mode 2: WAPEX2(1 )

******* NOTE ******* NOTE ******* NOTE ****** NOTE ******
The phrase, "NOT APPLY", for MARGIN VALUE means that that
particular margin value is exactly zero.
*** END NOTE *** END NOTE *** END NOTE *** END NOTE *****


***** RESULTS FOR LOAD SET NO.  1  ******
MARGINS CORRESPONDING TO CURRENT DESIGN (F.S.= FACTOR OF SAFETY)

MARGIN CURRENT
NO.    VALUE          DEFINITION
 1    6.209E-01  (CLAPS1(1 )/CLAPS1A(1 )) / CLAPS1F(1 )-1; F.S.=  1.00
 2    1.589E+00  (GENBK1(1 )/GENBK1A(1 )) / GENBK1F(1 )-1; F.S.=  1.00
 3    1.686E+00  (SKNBK1(1 ,1 )/SKNBK1A(1 ,1 )) / SKNBK1F(1 ,1 )-1; F.S.=  1.00
 4    1.689E+00  (SKNBK1(1 ,2 )/SKNBK1A(1 ,2 )) / SKNBK1F(1 ,2 )-1; F.S.=  1.00
 5    1.919E+00  (STFBK1(1 ,1 )/STFBK1A(1 ,1 )) / STFBK1F(1 ,1 )-1; F.S.=  1.00
 6    5.813E-01  (STFBK1(1 ,2 )/STFBK1A(1 ,2 )) / STFBK1F(1 ,2 )-1; F.S.=  1.00
 7    3.470E-01  (SKNST1A(1 ,1 )/SKNST1(1 ,1 )) / SKNST1F(1 ,1 )-1; F.S.=  1.00
 8    1.382E-01  (SKNST1A(1 ,2 )/SKNST1(1 ,2 )) / SKNST1F(1 ,2 )-1; F.S.=  1.00
 9    3.923E-01  (STFST1A(1 ,1 )/STFST1(1 ,1 )) / STFST1F(1 ,1 )-1; F.S.=  1.00
10   -3.816E-02  (STFST1A(1 ,2 )/STFST1(1 ,2 )) / STFST1F(1 ,2 )-1; F.S.=  1.00
11    1.427E+00  (WAPEX1A(1 )/WAPEX1(1 )) / WAPEX1F(1 )-1; F.S.=  1.00
12    6.727E-01  (CLAPS2(1 )/CLAPS2A(1 )) / CLAPS2F(1 )-1; F.S.=  1.00
13    1.682E+00  (GENBK2(1 )/GENBK2A(1 )) / GENBK2F(1 )-1; F.S.=  1.00
14    1.992E+00  (SKNBK2(1 ,1 )/SKNBK2A(1 ,1 )) / SKNBK2F(1 ,1 )-1; F.S.=  1.00
15    2.149E+00  (SKNBK2(1 ,2 )/SKNBK2A(1 ,2 )) / SKNBK2F(1 ,2 )-1; F.S.=  1.00
16    8.143E-01  (STFBK2(1 ,1 )/STFBK2A(1 ,1 )) / STFBK2F(1 ,1 )-1; F.S.=  1.00
17    7.200E-01  (STFBK2(1 ,2 )/STFBK2A(1 ,2 )) / STFBK2F(1 ,2 )-1; F.S.=  1.00
18    4.290E-01  (SKNST2A(1 ,1 )/SKNST2(1 ,1 )) / SKNST2F(1 ,1 )-1; F.S.=  1.00
19    4.917E-02  (SKNST2A(1 ,2 )/SKNST2(1 ,2 )) / SKNST2F(1 ,2 )-1; F.S.=  1.00
20   -2.078E-02  (STFST2A(1 ,1 )/STFST2(1 ,1 )) / STFST2F(1 ,1 )-1; F.S.=  1.00
21   -2.687E-02  (STFST2A(1 ,2 )/STFST2(1 ,2 )) / STFST2F(1 ,2 )-1; F.S.=  1.00
22    1.205E+00  (WAPEX2A(1 )/WAPEX2(1 )) / WAPEX2F(1 )-1; F.S.=  1.00
0
 STRUCTURAL ANALYSIS WITH UNPERTURBED DECISION VARIABLES
VAR. DEC. ESCAPE LINK. LINKED  LINKING   LOWER    CURRENT    UPPER      DEFINITION
 NO. VAR.  VAR.  VAR.   TO   CONSTANT   BOUND     VALUE     BOUND
  1  Y    N    N    0   0.00E+00  1.00E-01 1.2453E-01  1.00E+00  skin thickness at xinput:
THKSKN(1 )
  2  Y    N    N    0   0.00E+00  1.00E-01 1.6641E-01  1.00E+00  skin thickness at xinput:
THKSKN(2 )
  3  Y    N    N    0   0.00E+00  1.00E-01 1.4460E-01  1.00E+00  skin thickness at xinput:
THKSKN(3 )
  4  Y    N    N    0   0.00E+00  1.00E-01 1.6082E-01  1.00E+00  skin thickness at xinput:
THKSKN(4 )
  5  Y    N    N    0   0.00E+00  1.00E-01 1.0412E-01  1.00E+00  skin thickness at xinput:
```

THKSKN(5)
6 Y N N 0 0.00E+00 1.00E-01 1.0000E-01 1.00E+00 skin thickness at xinput: THKSKN(6)
7 Y N N 0 0.00E+00 1.00E-01 1.0162E-01 1.00E+00 skin thickness at xinput: THKSKN(7)
8 Y N N 0 0.00E+00 1.00E-01 1.3795E-01 1.00E+00 skin thickness at xinput: THKSKN(8)
9 Y N N 0 0.00E+00 1.00E-01 1.0201E-01 1.00E+00 skin thickness at xinput: THKSKN(9)
10 Y N N 0 0.00E+00 1.00E-01 1.0411E-01 1.00E+00 skin thickness at xinput: THKSKN(10)
11 Y N N 0 0.00E+00 1.00E-01 1.9869E-01 1.00E+00 skin thickness at xinput: THKSKN(11)
12 Y N N 0 0.00E+00 1.00E-01 1.0000E-01 1.00E+00 skin thickness at xinput: THKSKN(12)
13 Y N N 0 0.00E+00 1.00E-01 1.9779E-01 1.00E+00 skin thickness at xinput: THKSKN(13)
14 Y N N 0 0.00E+00 5.00E-01 6.6766E-01 3.00E+00 height of isogrid members at xinput: HIGHST(1)
15 Y N N 0 0.00E+00 5.00E-01 6.0783E-01 3.00E+00 height of isogrid members at xinput: HIGHST(2)
16 Y N N 0 0.00E+00 5.00E-01 9.7928E-01 3.00E+00 height of isogrid members at xinput: HIGHST(3)
17 Y N N 0 0.00E+00 2.00E-01 1.2562E+00 3.00E+00 height of isogrid members at xinput: HIGHST(4)
18 Y N N 0 0.00E+00 2.00E-01 1.1540E+00 3.00E+00 height of isogrid members at xinput: HIGHST(5)
19 Y N N 0 0.00E+00 2.00E-01 8.0422E-01 3.00E+00 height of isogrid members at xinput: HIGHST(6)
20 Y N N 0 0.00E+00 2.00E-01 1.2686E+00 3.00E+00 height of isogrid members at xinput: HIGHST(7)
21 Y N N 0 0.00E+00 2.00E-01 8.8339E-01 3.00E+00 height of isogrid members at xinput: HIGHST(8)
22 Y N N 0 0.00E+00 2.00E-01 7.0560E-01 3.00E+00 height of isogrid members at xinput: HIGHST(9)
23 Y N N 0 0.00E+00 2.00E-01 5.8445E-01 3.00E+00 height of isogrid members at xinput: HIGHST(10)
24 Y N N 0 0.00E+00 2.00E-01 5.1581E-01 3.00E+00 height of isogrid members at xinput: HIGHST(11)
25 Y N N 0 0.00E+00 2.00E-01 3.4417E-01 3.00E+00 height of isogrid members at xinput: HIGHST(12)
26 Y N N 0 0.00E+00 2.00E-01 4.6660E-01 3.00E+00 height of isogrid members at xinput: HIGHST(13)
27 Y N N 0 0.00E+00 1.00E+00 2.9154E+00 3.00E+00 spacing of the isogrid members: SPACNG
28 Y N N 0 0.00E+00 5.00E-02 9.0531E-02 1.00E+00 thickness of an isogrid stiffening member: THSTIF
BEHAVIOR FOR 2 ENVIRONMENT (LOAD SET)

CONSTRAINT BEHAVIOR DEFINITION
NUMBER VALUE

BEHAVIOR FOR LOAD SET NUMBER, ILOADX= 2

****
Start of all analyses:
Design iteration 1, Load Set 2, IMODX= 0, Dec.var.no.,IDV= 0
****
SUBROUTINE STRUCT computes seven "behaviors" (stress, collapse, bifurcation buckling, etc.). The seven behaviors are:

1. linear axisymmetric buckling of the perfect ellipsoid in order to obtain 2 or 4 axisymmetric buckling modes (NCASES = 2 or 4) which are to be used as initial imperfection shapes in the following analyses 2 - 7, listed next.
2. nonlinear axisymmetric stress with mode 1 imperfection
3. nonlinear axisymmetric stress with mode 2 imperfection
4. axisymmetric collapse with mode 1 imperfection
5. axisymmetric collapse with mode 2 imperfection
6. nonlinear bifurcation buckling with mode 1 imperfection
7. nonlinear bifurcation buckling with mode 2 imperfection.

Brief description of each of the seven analyses corresponding to the seven "behaviors" just listed:

1. Ten axisymmetric buckling modes are computed from linear analysis. Only two modes are used for imperfection shapes:
   A. The mode corresponding to the lowest buckling load, and
   B. one other mode, usually the 2nd mode.

   For each of mode 1 and mode 2, the actual imperfection is the normalized buckling modal w-deflection times an amplitude factor supplied by the user by means of "BEGIN".

============ Analysis No. 1 for Load Set No. 2 ============
**** Start linear axisymmetric bifurcation buckling of perfect shell. IMODX= 0
**** The purpose is to get two axisymmetric buckling modal
**** imperfection shapes: mode 1 and mode 2.
BIGBOSOR4 input file for linear buckling,perfect shell=
eqellipse.ALL1

*** In STRUCT: IMODX, IDV= 0 0

****** WEIGHT= 8.6101E+01
Linear buckling eigenvalues from BIGBOSOR4, EGV(i)=
 2.8386E+03 3.5262E+03 4.1902E+03 4.3751E+03 5.8141E+03
 6.9852E+03 9.0675E+03 1.0883E+04 1.2440E+04 1.3618E+04
Linear axisymmetric buckling pressure of perfect shell= 1.3057E+03
Buckling modal normal displacement w at apex of shell,= 1.0000E+00

********* Buckling modal imperfection shape: mode 1 **********

Buckling mode 1 imperfection in Segment no. 1 WSAVEX=
 1.0000E+00 9.9981E-01 9.9742E-01 9.9006E-01 9.7787E-01
 9.6118E-01 9.4028E-01 9.1554E-01 8.8741E-01 8.5638E-01
 8.2339E-01 7.9756E-01 7.8772E-01

Buckling mode 1 imperfection in Segment no. 2 WSAVEX=
 7.8772E-01 7.7557E-01 7.4245E-01 6.9745E-01 6.5174E-01
 6.0638E-01 5.6171E-01 5.1794E-01 4.7520E-01 4.3356E-01
 3.9354E-01 3.6436E-01 3.5362E-01

Buckling mode 1 imperfection in Segment no. 3 WSAVEX=
 3.5363E-01 3.4297E-01 3.1481E-01 2.7802E-01 2.4185E-01
 2.0674E-01 1.7269E-01 1.3964E-01 1.0758E-01 7.6473E-02
 4.6659E-02 2.4964E-02 1.6991E-02

Buckling mode 1 imperfection in Segment no. 4 WSAVEX=
 1.7006E-02 9.0904E-03 -1.1800E-02 -3.9009E-02 -6.5639E-02
-9.1297E-02 -1.1594E-01 -1.3950E-01 -1.6192E-01 -1.8314E-01
-2.0283E-01 -2.1667E-01 -2.2164E-01

Buckling mode 1 imperfection in Segment no. 5 WSAVEX=
-2.2163E-01 -2.2649E-01 -2.3897E-01 -2.5429E-01 -2.6800E-01
-2.7970E-01 -2.8918E-01 -2.9619E-01 -3.0050E-01 -3.0186E-01
-3.0005E-01 -2.9653E-01 -2.9471E-01

Buckling mode 1 imperfection in Segment no. 6 WSAVEX=
-2.9472E-01 -2.9263E-01 -2.8574E-01 -2.7408E-01 -2.5995E-01
-2.4399E-01 -2.2661E-01 -2.0814E-01 -1.8886E-01 -1.6898E-01
-1.4894E-01 -1.3379E-01 -1.2811E-01

Buckling mode 1 imperfection in Segment no. 7 WSAVEX=
-1.2810E-01 -1.2388E-01 -1.1251E-01 -9.7237E-02 -8.1734E-02
-6.6229E-02 -5.0763E-02 -3.5378E-02 -2.0125E-02 -5.0600E-03
 9.5711E-03 2.0297E-02 2.4246E-02

Buckling mode 1 imperfection in Segment no. 8 WSAVEX=
 2.4234E-02 2.7684E-02 3.6810E-02 4.8716E-02 6.0355E-02
 7.1518E-02 8.2140E-02 9.2155E-02 1.0149E-01 1.1007E-01

1.1773E-01 1.2287E-01 1.2466E-01

Buckling mode 1 imperfection in Segment no. 9 WSAVEX=
 1.2463E-01 1.2636E-01 1.3060E-01 1.3536E-01 1.3907E-01
 1.4162E-01 1.4297E-01 1.4310E-01 1.4200E-01 1.3965E-01
 1.3612E-01 1.3271E-01 1.3127E-01

Buckling mode 1 imperfection in Segment no. 10 WSAVEX=
 1.3128E-01 1.2975E-01 1.2521E-01 1.1822E-01 1.1019E-01
 1.0133E-01 9.1772E-02 8.1639E-02 7.1051E-02 6.0121E-02
 4.9095E-02 4.0764E-02 3.7644E-02

Buckling mode 1 imperfection in Segment no. 11 WSAVEX=
 3.7623E-02 3.4771E-02 2.7114E-02 1.6868E-02 6.5622E-03
-3.5953E-03 -1.3511E-02 -2.3075E-02 -3.2155E-02 -4.0594E-02
-4.8118E-02 -5.3089E-02 -5.4781E-02

Buckling mode 1 imperfection in Segment no. 12 WSAVEX=
-5.4840E-02 -5.6283E-02 -5.9771E-02 -6.3694E-02 -6.6898E-02
-6.9442E-02 -7.1423E-02 -7.2922E-02 -7.4010E-02 -7.4739E-02
-7.5151E-02 -7.5278E-02 -7.5289E-02

********* Buckling modal imperfection shape: mode 2 **********

Buckling mode 2 imperfection in Segment no. 1 WMODX2=
 1.0000E+00 9.9958E-01 9.9428E-01 9.7792E-01 9.5090E-01
 9.1403E-01 8.6820E-01 8.1455E-01 7.5438E-01 6.8920E-01
 6.2149E-01 5.6973E-01 5.5035E-01

Buckling mode 2 imperfection in Segment no. 2 WMODX2=
 5.5035E-01 5.2667E-01 4.6355E-01 3.8164E-01 3.0332E-01
 2.3077E-01 1.6462E-01 1.0511E-01 5.2240E-02 5.7982E-03
-3.4057E-02 -6.0147E-02 -6.9124E-02

Buckling mode 2 imperfection in Segment no. 3 WMODX2=
-6.9118E-02 -7.7696E-02 -9.8737E-02 -1.2272E-01 -1.4245E-01
-1.5796E-01 -1.6961E-01 -1.7777E-01 -1.8277E-01 -1.8493E-01
-1.8458E-01 -1.8286E-01 -1.8193E-01

Buckling mode 2 imperfection in Segment no. 4 WMODX2=
-1.8193E-01 -1.8085E-01 -1.7721E-01 -1.7069E-01 -1.6223E-01
-1.5199E-01 -1.4005E-01 -1.2652E-01 -1.1154E-01 -9.5225E-02
-7.7973E-02 -6.4445E-02 -5.9281E-02

Buckling mode 2 imperfection in Segment no. 5 WMODX2=
-5.9282E-02 -5.4056E-02 -3.9764E-02 -2.0126E-02 1.4208E-04
 2.0524E-02 4.0701E-02 6.0302E-02 7.8897E-02 9.5998E-02

1.1089E-01 1.2038E-01 1.2348E-01

Buckling mode 2 imperfection in Segment no. 6 WMODX2=
1.2348E-01 1.2635E-01 1.3282E-01 1.3893E-01 1.4237E-01
1.4336E-01 1.4218E-01 1.3912E-01 1.3443E-01 1.2832E-01
1.2111E-01 1.1506E-01 1.1268E-01

Buckling mode 2 imperfection in Segment no. 7 WMODX2=
1.1267E-01 1.1086E-01 1.0581E-01 9.8630E-02 9.0867E-02
8.2604E-02 7.3835E-02 6.4561E-02 5.4783E-02 4.4509E-02
3.3891E-02 2.5666E-02 2.2536E-02

Buckling mode 2 imperfection in Segment no. 8 WMODX2=
2.2543E-02 1.9766E-02 1.2200E-02 1.8232E-03 -8.9317E-03
-1.9883E-02 -3.0970E-02 -4.2121E-02 -5.3252E-02 -6.4270E-02
-7.4932E-02 -8.2683E-02 -8.5513E-02

Buckling mode 2 imperfection in Segment no. 9 WMODX2=
-8.5494E-02 -8.8304E-02 -9.5635E-02 -1.0491E-01 -1.1353E-01
-1.2125E-01 -1.2793E-01 -1.3343E-01 -1.3761E-01 -1.4036E-01
-1.4156E-01 -1.4142E-01 -1.4113E-01

Buckling mode 2 imperfection in Segment no. 10 WMODX2=
-1.4114E-01 -1.4072E-01 -1.3892E-01 -1.3509E-01 -1.2960E-01
-1.2261E-01 -1.1422E-01 -1.0457E-01 -9.3798E-02 -8.2058E-02
-6.9658E-02 -5.9961E-02 -5.6262E-02

Buckling mode 2 imperfection in Segment no. 11 WMODX2=
-5.6234E-02 -5.2818E-02 -4.3503E-02 -3.0703E-02 -1.7424E-02
-3.9152E-03 9.7028E-03 2.3275E-02 3.6602E-02 4.9426E-02
6.1282E-02 6.9387E-02 7.2202E-02

Buckling mode 2 imperfection in Segment no. 12 WMODX2=
7.2286E-02 7.4711E-02 8.0690E-02 8.7606E-02 9.3420E-02
9.8150E-02 1.0191E-01 1.0480E-01 1.0692E-01 1.0835E-01
1.0916E-01 1.0941E-01 1.0943E-01

============ Analysis No. 2 for Load Set No. 2 ============
*** Start nonlinear axisymmetric stress,-(mode 1) imperfection IMODX= 0
BIGBOSOR4 input file for nonlinear stress,-(mode 1) imperfect=
eqellipse.ALL2N

*** Output from mode 1 INDIC=0, stress analysis; IMODX= 0 ***
Pressure multiplier, P, for all load steps=

4.6000E+01 9.2000E+01 1.3800E+02 1.8400E+02 2.3000E+02
2.7600E+02 3.2200E+02 3.6800E+02 4.1400E+02 4.6000E+02
End displacement, ENDUVS, for all load steps=
4.2352E-02 8.6127E-02 1.3151E-01 1.7876E-01 2.2820E-01
2.8028E-01 3.3567E-01 3.9542E-01 4.6127E-01 5.3669E-01

Local skin and smeared stiffener buckling and stress, Seg. 1
Skin buckling load factor, BUCMIN= 3.9282E+00 at nodal point 2
Smeared stringer/isogrid buckling load factor, BUCMNS= 5.4718E+00 at nodal point 13
Smeared ring buckling load factor, BUCMNR= 1.0000E+17 at nodal point 13
Smeared stringer/isogrid maximum eff. stress, STFMXS= 1.0224E+05 at nodal point 2
Smeared ring maximum effective stress, STFMXR= 0.0000E+00 at nodal point 0
Shell skin maximum effective stress, SKNMAX= 1.2052E+05 at nodal point 3

Local skin and smeared stiffener buckling and stress, Seg. 2
Skin buckling load factor, BUCMIN= 6.9070E+00 at nodal point 13
Smeared stringer/isogrid buckling load factor, BUCMNS= 1.5913E+00 at nodal point 12
Smeared ring buckling load factor, BUCMNR= 1.0000E+17 at nodal point 13
Smeared stringer/isogrid maximum eff. stress, STFMXS= 7.7984E+04 at nodal point 7
Smeared ring maximum effective stress, STFMXR= 0.0000E+00 at nodal point 0
Shell skin maximum effective stress, SKNMAX= 8.9581E+04 at nodal point 1

Local skin and smeared stiffener buckling and stress, Seg. 3
Skin buckling load factor, BUCMIN= 6.8926E+00 at nodal point 1
Smeared stringer/isogrid buckling load factor, BUCMNS= 1.1519E+00 at nodal point 13
Smeared ring buckling load factor, BUCMNR= 1.0000E+17 at nodal point 13
Smeared stringer/isogrid maximum eff. stress, STFMXS= 6.9503E+04 at nodal point 4
Smeared ring maximum effective stress, STFMXR= 0.0000E+00 at nodal point 0
Shell skin maximum effective stress, SKNMAX= 7.4727E+04 at nodal point 1

Local skin and smeared stiffener buckling and stress, Seg. 4
Skin buckling load factor, BUCMIN= 3.1695E+00 at nodal point 13
Smeared stringer/isogrid buckling load factor, BUCMNS= 1.1477E+00 at nodal point 1
Smeared ring buckling load factor, BUCMNR= 1.0000E+17 at nodal point 13
Smeared stringer/isogrid maximum eff. stress, STFMXS= 7.1231E+04 at nodal point 13
Smeared ring maximum effective stress, STFMXR= 0.0000E+00 at nodal point 0
Shell skin maximum effective stress, SKNMAX= 7.5136E+04 at nodal point 13

Local skin and smeared stiffener buckling and stress, Seg. 5
Skin buckling load factor, BUCMIN= 3.1685E+00 at nodal point 1
Smeared stringer/isogrid buckling load factor, BUCMNS= 1.3509E+00 at nodal point 10
Smeared ring buckling load factor, BUCMNR= 1.0000E+17 at nodal point 13
Smeared stringer/isogrid maximum eff. stress, STFMXS= 1.1764E+05 at nodal point 13
Smeared ring maximum effective stress, STFMXR= 0.0000E+00 at nodal point 0
Shell skin maximum effective stress, SKNMAX= 7.5150E+04 at nodal point 1

Local skin and smeared stiffener buckling and stress, Seg. 6
Skin buckling load factor, BUCMIN= 3.2980E+00 at nodal point 4

Smeared stringer/isogrid buckling load factor, BUCMNS= 1.3683E+00 at nodal point 2
Smeared ring buckling load factor, BUCMNR= 1.0000E+17 at nodal point 13
Smeared stringer/isogrid maximum eff. stress, STFMXS= 1.1803E+05 at nodal point 1
Smeared ring maximum effective stress, STFMXR= 0.0000E+00 at nodal point 0
Shell skin maximum effective stress, SKNMAX= 6.7917E+04 at nodal point 12

Local skin and smeared stiffener buckling and stress, Seg. 7
Skin buckling load factor, BUCMIN= 3.4293E+00 at nodal point 1
Smeared stringer/isogrid buckling load factor, BUCMNS= 2.6155E+00 at nodal point 13
Smeared ring buckling load factor, BUCMNR= 1.0000E+17 at nodal point 13
Smeared stringer/isogrid maximum eff. stress, STFMXS= 6.5714E+04 at nodal point 1
Smeared ring maximum effective stress, STFMXR= 0.0000E+00 at nodal point 0
Shell skin maximum effective stress, SKNMAX= 6.7636E+04 at nodal point 1

Local skin and smeared stiffener buckling and stress, Seg. 8
Skin buckling load factor, BUCMIN= 3.8518E+00 at nodal point 13
Smeared stringer/isogrid buckling load factor, BUCMNS= 2.5826E+00 at nodal point 2
Smeared ring buckling load factor, BUCMNR= 1.0000E+17 at nodal point 13
Smeared stringer/isogrid maximum eff. stress, STFMXS= 6.6295E+04 at nodal point 13
Smeared ring maximum effective stress, STFMXR= 0.0000E+00 at nodal point 0
Shell skin maximum effective stress, SKNMAX= 7.1914E+04 at nodal point 13

Local skin and smeared stiffener buckling and stress, Seg. 9
Skin buckling load factor, BUCMIN= 3.8540E+00 at nodal point 1
Smeared stringer/isogrid buckling load factor, BUCMNS= 5.4581E+00 at nodal point 2
Smeared ring buckling load factor, BUCMNR= 1.0000E+17 at nodal point 13
Smeared stringer/isogrid maximum eff. stress, STFMXS= 6.6772E+04 at nodal point 13
Smeared ring maximum effective stress, STFMXR= 0.0000E+00 at nodal point 0
Shell skin maximum effective stress, SKNMAX= 8.1601E+04 at nodal point 13

Local skin and smeared stiffener buckling and stress, Seg. 10
Skin buckling load factor, BUCMIN= 4.3444E+00 at nodal point 1
Smeared stringer/isogrid buckling load factor, BUCMNS= 3.9164E+00 at nodal point 13
Smeared ring buckling load factor, BUCMNR= 1.0000E+17 at nodal point 13
Smeared stringer/isogrid maximum eff. stress, STFMXS= 1.0026E+05 at nodal point 13
Smeared ring maximum effective stress, STFMXR= 0.0000E+00 at nodal point 0
Shell skin maximum effective stress, SKNMAX= 8.6954E+04 at nodal point 13

Local skin and smeared stiffener buckling and stress, Seg. 11
Skin buckling load factor, BUCMIN= 4.8340E+00 at nodal point 13
Smeared stringer/isogrid buckling load factor, BUCMNS= 3.9044E+00 at nodal point 1
Smeared ring buckling load factor, BUCMNR= 1.0000E+17 at nodal point 13
Smeared stringer/isogrid maximum eff. stress, STFMXS= 1.1834E+05 at nodal point 11
Smeared ring maximum effective stress, STFMXR= 0.0000E+00 at nodal point 0
Shell skin maximum effective stress, SKNMAX= 1.1430E+05 at nodal point 13

Local skin and smeared stiffener buckling and stress, Seg. 12
Skin buckling load factor, BUCMIN= 4.8370E+00 at nodal point 1

Smeared stringer/isogrid buckling load factor, BUCMNS= 4.4899E+00 at nodal point 13
Smeared ring buckling load factor, BUCMNR= 1.0000E+17 at nodal point 13
Smeared stringer/isogrid maximum eff. stress, STFMXS= 1.2154E+05 at nodal point 4
Smeared ring maximum effective stress, STFMXR= 0.0000E+00 at nodal point 0
Shell skin maximum effective stress, SKNMAX= 1.1431E+05 at nodal point 1

PERTURBED UNPERTURBED
Region 1 skin buckling load factor, bskin1= 3.1685E+00 3.1685E+00
Region 1 stiffener buckling load factor, bstif1= 1.1477E+00 1.1477E+00
Region 1 skin maximum effective stress, sknmx1= 1.2052E+05 1.2052E+05
Region 1 stiffener max. effective stress, stfmx1= 1.1764E+05 1.1764E+05
Region 2 skin buckling load factor, bskin2= 3.2980E+00 3.2980E+00
Region 2 stiffener buckling load factor, bstif2= 1.3683E+00 1.3683E+00
Region 2 skin maximum effective stress, sknmx2= 1.1431E+05 1.1431E+05
Region 2 stiffener max. effective stress, stfmx2= 1.2154E+05 1.2154E+05
Normal displacement of shell at apex, ENDUV= 5.3669E-01 5.3669E-01

The following quantities are used to generate behavioral constraint conditions and margins:
PERTURBED UNPERTURBED
Region 1 skin buckling load factor, bskin1= 3.1685E+00 3.1685E+00
Region 1 stiffener buckling load factor, bstif1= 1.1477E+00 1.1477E+00
Region 1 skin maximum effective stress, sknmx1= 1.2052E+05 1.2052E+05
Region 1 stiffener max. effective stress, stfmx1= 1.1764E+05 1.1764E+05
Region 2 skin buckling load factor, bskin2= 3.2980E+00 3.2980E+00
Region 2 stiffener buckling load factor, bstif2= 1.3683E+00 1.3683E+00
Region 2 skin maximum effective stress, sknmx2= 1.1431E+05 1.1431E+05
Region 2 stiffener max. effective stress, stfmx2= 1.2154E+05 1.2154E+05
Normal displacement of shell at apex, ENDUV= 5.3669E-01 5.3669E-01

============ Analysis No. 3 for Load Set No. 2 ============
*** Start nonlinear axisymmetric stress,-(mode 2) imperfection IMODX= 0
BIGBOSOR4 input file for nonlinear stress,-(mode 2) imperfect=
eqellipse.ALL4N

*** Output from mode 2 INDIC=0, stress analysis; IMODX= 0 ***
Pressure multiplier, P, for all load steps=
4.6000E+01 9.2000E+01 1.3800E+02 1.8400E+02 2.3000E+02
2.7600E+02 3.2200E+02 3.6800E+02 4.1400E+02 4.6000E+02
End displacement, ENDUVS, for all load steps=
3.9924E-02 8.0747E-02 1.2251E-01 1.6526E-01 2.0903E-01
2.5386E-01 2.9978E-01 3.4678E-01 3.9484E-01 4.4386E-01

Local skin and smeared stiffener buckling and stress, Seg. 1
Skin buckling load factor, BUCMIN= 4.8647E+00 at nodal point 2

Smeared stringer/isogrid buckling load factor, BUCMNS= 3.6423E+00 at nodal point 13
Smeared ring buckling load factor, BUCMNR= 1.0000E+17 at nodal point 13
Smeared stringer/isogrid maximum eff. stress, STFMXS= 1.2200E+05 at nodal point 2
Smeared ring maximum effective stress, STFMXR= 0.0000E+00 at nodal point 0
Shell skin maximum effective stress, SKNMAX= 1.0383E+05 at nodal point 3

Local skin and smeared stiffener buckling and stress, Seg. 2
Skin buckling load factor, BUCMIN= 8.8085E+00 at nodal point 13
Smeared stringer/isogrid buckling load factor, BUCMNS= 1.1020E+00 at nodal point 12
Smeared ring buckling load factor, BUCMNR= 1.0000E+17 at nodal point 13
Smeared stringer/isogrid maximum eff. stress, STFMXS= 1.2191E+05 at nodal point 7
Smeared ring maximum effective stress, STFMXR= 0.0000E+00 at nodal point 0
Shell skin maximum effective stress, SKNMAX= 7.4042E+04 at nodal point 1

Local skin and smeared stiffener buckling and stress, Seg. 3
Skin buckling load factor, BUCMIN= 8.8027E+00 at nodal point 1
Smeared stringer/isogrid buckling load factor, BUCMNS= 1.0785E+00 at nodal point 5
Smeared ring buckling load factor, BUCMNR= 1.0000E+17 at nodal point 13
Smeared stringer/isogrid maximum eff. stress, STFMXS= 9.7738E+04 at nodal point 1
Smeared ring maximum effective stress, STFMXR= 0.0000E+00 at nodal point 0
Shell skin maximum effective stress, SKNMAX= 6.0171E+04 at nodal point 1

Local skin and smeared stiffener buckling and stress, Seg. 4
Skin buckling load factor, BUCMIN= 3.1954E+00 at nodal point 13
Smeared stringer/isogrid buckling load factor, BUCMNS= 1.3035E+00 at nodal point 1
Smeared ring buckling load factor, BUCMNR= 1.0000E+17 at nodal point 13
Smeared stringer/isogrid maximum eff. stress, STFMXS= 6.5633E+04 at nodal point 13
Smeared ring maximum effective stress, STFMXR= 0.0000E+00 at nodal point 0
Shell skin maximum effective stress, SKNMAX= 7.8055E+04 at nodal point 13

Local skin and smeared stiffener buckling and stress, Seg. 5
Skin buckling load factor, BUCMIN= 2.7898E+00 at nodal point 12
Smeared stringer/isogrid buckling load factor, BUCMNS= 9.1698E+00 at nodal point 2
Smeared ring buckling load factor, BUCMNR= 1.0000E+17 at nodal point 13
Smeared stringer/isogrid maximum eff. stress, STFMXS= 6.9813E+04 at nodal point 12
Smeared ring maximum effective stress, STFMXR= 0.0000E+00 at nodal point 0
Shell skin maximum effective stress, SKNMAX= 8.2542E+04 at nodal point 12

Local skin and smeared stiffener buckling and stress, Seg. 6
Skin buckling load factor, BUCMIN= 2.7915E+00 at nodal point 1
Smeared stringer/isogrid buckling load factor, BUCMNS= 3.1585E+01 at nodal point 2
Smeared ring buckling load factor, BUCMNR= 1.0000E+17 at nodal point 13
Smeared stringer/isogrid maximum eff. stress, STFMXS= 6.9824E+04 at nodal point 1
Smeared ring maximum effective stress, STFMXR= 0.0000E+00 at nodal point 0
Shell skin maximum effective stress, SKNMAX= 8.2144E+04 at nodal point 1

Local skin and smeared stiffener buckling and stress, Seg. 7
Skin buckling load factor, BUCMIN= 3.1702E+00 at nodal point 1

```
Smeared stringer/isogrid buckling load factor, BUCMNS=  2.3329E+00 at nodal point 13
Smeared ring buckling load factor,            BUCMNR=  1.0000E+17 at nodal point 13
Smeared stringer/isogrid maximum eff. stress,  STFMXS=  6.8607E+04 at nodal point  1
Smeared ring maximum effective stress,        STFMXR=  0.0000E+00 at nodal point  0
Shell skin maximum effective stress,          SKNMAX=  7.3148E+04 at nodal point  1

Local skin and smeared stiffener buckling and stress, Seg.   8
Skin buckling load factor,                    BUCMIN=  4.0972E+00 at nodal point 13
Smeared stringer/isogrid buckling load factor, BUCMNS=  2.2758E+00 at nodal point  2
Smeared ring buckling load factor,            BUCMNR=  1.0000E+17 at nodal point 13
Smeared stringer/isogrid maximum eff. stress,  STFMXS=  8.9435E+04 at nodal point 13
Smeared ring maximum effective stress,        STFMXR=  0.0000E+00 at nodal point  0
Shell skin maximum effective stress,          SKNMAX=  7.6971E+04 at nodal point 13

Local skin and smeared stiffener buckling and stress, Seg.   9
Skin buckling load factor,                    BUCMIN=  4.1011E+00 at nodal point  1
Smeared stringer/isogrid buckling load factor, BUCMNS=  2.2320E+00 at nodal point  5
Smeared ring buckling load factor,            BUCMNR=  1.0000E+17 at nodal point 13
Smeared stringer/isogrid maximum eff. stress,  STFMXS=  1.1783E+05 at nodal point 13
Smeared ring maximum effective stress,        STFMXR=  0.0000E+00 at nodal point  0
Shell skin maximum effective stress,          SKNMAX=  9.0706E+04 at nodal point 13

Local skin and smeared stiffener buckling and stress, Seg.  10
Skin buckling load factor,                    BUCMIN=  4.8739E+00 at nodal point  1
Smeared stringer/isogrid buckling load factor, BUCMNS=  2.5118E+00 at nodal point  2
Smeared ring buckling load factor,            BUCMNR=  1.0000E+17 at nodal point 13
Smeared stringer/isogrid maximum eff. stress,  STFMXS=  1.2481E+05 at nodal point  5
Smeared ring maximum effective stress,        STFMXR=  0.0000E+00 at nodal point  0
Shell skin maximum effective stress,          SKNMAX=  9.1319E+04 at nodal point 13

Local skin and smeared stiffener buckling and stress, Seg.  11
Skin buckling load factor,                    BUCMIN=  4.5637E+00 at nodal point 13
Smeared stringer/isogrid buckling load factor, BUCMNS=  3.4244E+00 at nodal point  1
Smeared ring buckling load factor,            BUCMNR=  1.0000E+17 at nodal point 13
Smeared stringer/isogrid maximum eff. stress,  STFMXS=  1.1537E+05 at nodal point  2
Smeared ring maximum effective stress,        STFMXR=  0.0000E+00 at nodal point  0
Shell skin maximum effective stress,          SKNMAX=  1.0505E+05 at nodal point 13

Local skin and smeared stiffener buckling and stress, Seg.  12
Skin buckling load factor,                    BUCMIN=  4.5650E+00 at nodal point  1
Smeared stringer/isogrid buckling load factor, BUCMNS=  5.8590E+00 at nodal point 13
Smeared ring buckling load factor,            BUCMNR=  1.0000E+17 at nodal point 13
Smeared stringer/isogrid maximum eff. stress,  STFMXS=  8.1902E+04 at nodal point 13
Smeared ring maximum effective stress,        STFMXR=  0.0000E+00 at nodal point  0
Shell skin maximum effective stress,          SKNMAX=  1.0503E+05 at nodal point  1

                                            PERTURBED  UNPERTURBED
Region 1 skin buckling load factor,        bskin1=  2.7898E+00  2.7898E+00
```

Region 1 stiffener buckling load factor,   bstif1= 1.0785E+00 1.0785E+00
Region 1 skin maximum effective stress,   sknmx1= 1.0383E+05 1.0383E+05
Region 1 stiffener max. effective stress, stfmx1= 1.2200E+05 1.2200E+05
Region 2 skin buckling load factor,   bskin2= 2.7915E+00 2.7915E+00
Region 2 stiffener buckling load factor,   bstif2= 2.2320E+00 2.2320E+00
Region 2 skin maximum effective stress,   sknmx2= 1.0505E+05 1.0505E+05
Region 2 stiffener max. effective stress, stfmx2= 1.2481E+05 1.2481E+05
Normal displacement of shell at apex,   ENDUV= 4.4386E-01 4.4386E-01

The following quantities are used to generate behavioral constraint conditions and margins:
PERTURBED UNPERTURBED
Region 1 skin buckling load factor,   bskin1= 2.7898E+00 2.7898E+00
Region 1 stiffener buckling load factor,   bstif1= 1.0785E+00 1.0785E+00
Region 1 skin maximum effective stress,   sknmx1= 1.0383E+05 1.0383E+05
Region 1 stiffener max. effective stress, stfmx1= 1.2200E+05 1.2200E+05
Region 2 skin buckling load factor,   bskin2= 2.7915E+00 2.7915E+00
Region 2 stiffener buckling load factor,   bstif2= 2.2320E+00 2.2320E+00
Region 2 skin maximum effective stress,   sknmx2= 1.0505E+05 1.0505E+05
Region 2 stiffener max. effective stress, stfmx2= 1.2481E+05 1.2481E+05
Normal displacement of shell at apex,   ENDUV= 4.4386E-01 4.4386E-01

============ Analysis No. 4 for Load Set No. 2 ============
** Start nonlinear axisymmetric collpse,-(mode 1) imperfection   IMODX= 0
BIGBOSOR4 input file, axisymmetric collpse, -mode 1 imperfect=
eqellipse.ALL6N

*** Output from -(mode 1) INDIC=0, collapse analysis; IMODX= 0 *********
Pressure multiplier, P, for all load steps=
4.6000E+01 9.2000E+01 1.3800E+02 1.8400E+02 2.3000E+02
2.7600E+02 3.2200E+02 3.6800E+02 4.1400E+02 4.6000E+02
5.0600E+02 5.1060E+02 5.1520E+02 5.1980E+02 5.2440E+02
5.2900E+02 5.3360E+02 5.3820E+02 5.4280E+02 5.4740E+02
5.5200E+02 5.5660E+02 5.5706E+02 5.5752E+02 5.5798E+02
5.5844E+02 5.5890E+02 5.5936E+02 5.5982E+02 5.6028E+02
5.6074E+02 5.6120E+02 5.6166E+02 5.6212E+02 5.6258E+02
5.6304E+02 5.6350E+02
End displacement, ENDUVS, for all load steps=
4.2352E-02 8.6127E-02 1.3151E-01 1.7876E-01 2.2820E-01
2.8028E-01 3.3567E-01 3.9542E-01 4.6127E-01 5.3669E-01
6.3021E-01 6.4133E-01 6.5295E-01 6.6514E-01 6.7800E-01
6.9166E-01 7.0629E-01 7.2213E-01 7.3953E-01 7.5904E-01
7.8164E-01 8.0929E-01 8.1248E-01 8.1578E-01 8.1919E-01
8.2273E-01 8.2640E-01 8.3024E-01 8.3425E-01 8.3847E-01
8.4292E-01 8.4765E-01 8.5271E-01 8.5818E-01 8.6415E-01

8.7080E-01 8.7839E-01

PERTURBED UNPERTURBED
Collapse pressure with -(mode 1): PSTEP(ISTEP)= 5.6350E+02 5.6350E+02

The following quantity is used to generate the behavioral constraint condition and margin:
PERTURBED UNPERTURBED
Collapse pressure with mode 1: CLAPS1(ILOADX)= 5.6350E+02 5.6350E+02

============ Analysis No. 5 for Load Set No. 2 ============
** Start nonlinear axisymmetric collpse,-(mode 2) imperfection   IMODX= 0
BIGBOSOR4 input file, axisymmetric collpse, -mode 2 imperfect=
eqellipse.ALL7N

*** Output from -(mode 2) INDIC=0, collapse analysis; IMODX= 0 *********
Pressure multiplier, P, for all load steps=
4.6000E+01 9.2000E+01 1.3800E+02 1.8400E+02 2.3000E+02
2.7600E+02 3.2200E+02 3.6800E+02 4.1400E+02 4.6000E+02
5.0600E+02 5.5200E+02 5.9800E+02 6.4400E+02 6.9000E+02
7.3600E+02 7.8200E+02 8.2800E+02 8.7400E+02 9.2000E+02
End displacement, ENDUVS, for all load steps=
3.9924E-02 8.0747E-02 1.2251E-01 1.6526E-01 2.0903E-01
2.5386E-01 2.9978E-01 3.4678E-01 3.9484E-01 4.4386E-01
4.9362E-01 5.4374E-01 5.9347E-01 6.4151E-01 6.8569E-01
7.2269E-01 7.4854E-01 7.6085E-01 7.6284E-01 7.7324E-01

PERTURBED UNPERTURBED
Collapse pressure with -(mode 2): PSTEP(ISTEP)= 9.2000E+02 9.2000E+02

The following quantity is used to generate the behavioral constraint condition and margin:
PERTURBED UNPERTURBED
Collapse pressure with mode 2: CLAPS2(ILOADX)= 9.2000E+02 9.2000E+02

============ Analysis No. 6 for Load Set No. 2 ============
** Start nonlinear bifurcation buckling,-(mode 1) imperfection   IMODX= 0

** Start nonlinear bifurcation buckling,-(mode 1) imperfection   IMODX= 0
BIGBOSOR4 input file, bifurcation buckling, -(mode 1) imperf.=

eqellipse.ALL8N

```
 ******* Nonlinear overall bifurcation buckling results ******
 Overall buckling, -(mode 1) imperfection shape; Applied pressure, PMAX =  4.6000E+02
 *** Output from -(mode 1) INDIC=1, buckling analysis; IMODX= 0 *********

 **** CRITICAL EIGENVALUE AND WAVENUMBER ****
 EIGCRT=  5.8605E+02; NO. OF CIRC. WAVES, NWVCRT=    0
 ****************************************************

 ***** EIGENVALUES AND MODE SHAPES *****
  EIGENVALUE(CIRC. WAVES)
 ========================================
    5.8605E+02(   0)
    9.8961E+02(   1)
    2.2177E+03(   2)
    3.2704E+03(   3)
    4.3261E+03(   4)
    5.3222E+03(   5)
    6.3729E+03(   6)
    7.3273E+03(   7)
    8.3619E+03(   8)
    9.5505E+03(   9)
    1.0931E+04(  10)
    1.2521E+04(  11)
    1.4315E+04(  12)
    1.6287E+04(  13)
    1.8404E+04(  14)
    2.0646E+04(  15)
    2.3000E+04(  16)
    2.5468E+04(  17)
    2.8062E+04(  18)
    3.0802E+04(  19)
    3.3708E+04(  20)
    3.6794E+04(  21)
    4.0068E+04(  22)
    4.3530E+04(  23)
    4.7176E+04(  24)
    5.0999E+04(  25)
    5.4987E+04(  26)
    5.9122E+04(  27)
    6.1089E+04(  28)
    6.1065E+04(  29)
    6.1043E+04(  30)
 ========================================

 **** CRITICAL NEGATIVE EIGENVALUE AND WAVENUMBER ****
```

```
EIGCRN= -7.6012E+03; NO. OF CIRC. WAVES, NWVCRN=   27
**************************************************

***** NEGATIVE EIGENVALUES AND MODE SHAPES *****
 EIGENVALUE(CIRC. WAVES)
==========================================
   0.0000E+00(****)
   0.0000E+00(****)
   0.0000E+00(****)
   0.0000E+00(****)
   0.0000E+00(****)
   0.0000E+00(****)
   0.0000E+00(****)
   0.0000E+00(****)
   0.0000E+00(****)
   0.0000E+00(****)
   0.0000E+00(****)
   0.0000E+00(****)
   0.0000E+00(****)
   0.0000E+00(****)
   0.0000E+00(****)
   0.0000E+00(****)
   0.0000E+00(****)
   0.0000E+00(****)
   0.0000E+00(****)
   0.0000E+00(****)
   0.0000E+00(****)
   0.0000E+00(****)
   0.0000E+00(****)
   0.0000E+00(****)
   0.0000E+00(****)
   0.0000E+00(****)
   0.0000E+00(****)
  -7.6012E+03(  27)
   0.0000E+00(****)
   0.0000E+00(****)
  -7.4524E+03(  30)
==========================================

Nonlinear bifurcation buckling pressure, BUCPRSM(circ.waves)=  7.2958E+02( 0)
General bifurcation buckling load factor, GENBK1(ILOADX)=  1.5860E+00



                                        PERTURBED  UNPERTURBED
 Nonlin. bifurcation buckling, -(mode 1):BUCPRSM=  7.2958E+02  7.2958E+02
SHELL COLLAPSES AXISYMMETRICALLY AT P=  565.5
```

```
**************** INDIC=-2 analysis yields ***************
SHELL COLLAPSES AXISYMMETRICALLY BEFORE NONLINEAR BIFURCA-
TION BUCKLING WITH N =  0 CIRCUMFERENTIAL  WAVES.
*******************************************************
IMODX=0: M1MULTB,NWAV1,PMAXBUC1=    -1     0  4.6000E+02

The following quantity is used to generate the behavioral constraint condition and margin:
                                        PERTURBED  UNPERTURBED
Nonlin. bifurcation buckling, -(mode 1):BUCPRS =  7.2958E+02  7.2958E+02




============ Analysis No. 7 for Load Set No. 2 ============
** Start nonlinear bifurcation buckling,-(mode 2) imperfection      IMODX= 0




** Start nonlinear bifurcation buckling,-(mode 2) imperfection      IMODX= 0
BIGBOSOR4 input file, bifurcation buckling, -(mode 2) imperf.=
eqellipse.ALL9N


******* Nonlinear overall bifurcation buckling results ******
Overall buckling, -(mode 2) imperfection shape; Applied pressure, PMAX =  4.6000E+02
*** Output from -(mode 2) INDIC=1, buckling analysis; IMODX= 0 *********

**** CRITICAL EIGENVALUE AND WAVENUMBER ****
EIGCRT=  1.1512E+03; NO. OF CIRC. WAVES, NWVCRT=    0
***************************************************

***** EIGENVALUES AND MODE SHAPES *****
 EIGENVALUE(CIRC. WAVES)
==========================================
   1.1512E+03(   0)
   1.6440E+03(   1)
   2.1359E+03(   2)
   2.4449E+03(   3)
   3.0720E+03(   4)
   3.9280E+03(   5)
   4.9929E+03(   6)
   6.2580E+03(   7)
   7.7005E+03(   8)
   9.3050E+03(   9)
   1.1059E+04(  10)
   1.2835E+04(  11)
   1.4485E+04(  12)
```

```
  1.6241E+04(  13)
  1.8106E+04(  14)
  2.0071E+04(  15)
  2.2135E+04(  16)
  2.4306E+04(  17)
  2.6597E+04(  18)
  2.9022E+04(  19)
  3.1592E+04(  20)
  3.4320E+04(  21)
  3.7214E+04(  22)
  4.0280E+04(  23)
  4.3521E+04(  24)
  4.6937E+04(  25)
  5.0522E+04(  26)
  5.4268E+04(  27)
  5.8162E+04(  28)
  6.2186E+04(  29)
  6.6320E+04(  30)
========================================

**** CRITICAL NEGATIVE EIGENVALUE AND WAVENUMBER ****
EIGCRN=  0.0000E+00; NO. OF CIRC. WAVES, NWVCRN=*****
****************************************************

***** NEGATIVE EIGENVALUES AND MODE SHAPES *****
 EIGENVALUE(CIRC. WAVES)
========================================
  0.0000E+00(****)
  0.0000E+00(****)
  0.0000E+00(****)
  0.0000E+00(****)
  0.0000E+00(****)
  0.0000E+00(****)
  0.0000E+00(****)
  0.0000E+00(****)
  0.0000E+00(****)
  0.0000E+00(****)
  0.0000E+00(****)
  0.0000E+00(****)
  0.0000E+00(****)
  0.0000E+00(****)
  0.0000E+00(****)
  0.0000E+00(****)
  0.0000E+00(****)
  0.0000E+00(****)
  0.0000E+00(****)
  0.0000E+00(****)
  0.0000E+00(****)
  0.0000E+00(****)
```

```
  0.0000E+00(****)
  0.0000E+00(****)
  0.0000E+00(****)
  0.0000E+00(****)
  0.0000E+00(****)
  0.0000E+00(****)
  0.0000E+00(****)
  0.0000E+00(****)
  0.0000E+00(****)
  0.0000E+00(****)
========================================

Nonlinear bifurcation buckling pressure, BUCPRSM(circ.waves)=  9.8954E+02( 0)
General bifurcation buckling load factor, GENBK2(ILOADX)=  2.1512E+00



                                         PERTURBED  UNPERTURBED
Nonlin. bifurcation buckling, -(mode 2):BUCPRSM=  9.8954E+02  9.8954E+02

IMODX=0: M2MULTB,NWAV2,PMAXBUC2=   -1    0  4.6000E+02

The following quantity is used to generate the behavioral constraint condition and margin:
                                         PERTURBED  UNPERTURBED
Nonlin. bifurcation buckling, -(mode 2):BUCPRS =  9.8954E+02  9.8954E+02


********* End of all analysis. IMODX= 0 **************


   1       563.5001      collapse pressure with imperfection mode 1: CLAPS1(2 )
   2       1.586049      general buckling load factor, mode 1: GENBK1(2 )

 BEHAVIOR OVER J =  number of regions for computing behavior
   3       3.168470      buckling load of skin: SKNBK1(2 ,1 )
   4       3.298037      buckling load of skin: SKNBK1(2 ,2 )

 BEHAVIOR OVER J =  number of regions for computing behavior
   5       1.147719      buckling load factor, isogrid member, mode 1: STFBK1(2 ,1 )
   6       1.368290      buckling load factor, isogrid member, mode 1: STFBK1(2 ,2 )

 BEHAVIOR OVER J =  number of regions for computing behavior
   7       120521.2      maximum stress in the shell skin, mode 1: SKNST1(2 ,1 )
   8       114308.5      maximum stress in the shell skin, mode 1: SKNST1(2 ,2 )

 BEHAVIOR OVER J =  number of regions for computing behavior
   9       117640.9      maximum stress in isogrid stiffener, mode 1: STFST1(2 ,1 )
  10       121541.5      maximum stress in isogrid stiffener, mode 1: STFST1(2 ,2 )
```

11 0.5366920 normal (axial) displacement at apex, mode 1: WAPEX1(2)
12 920.0000 collapse pressure with imperfection mode 2: CLAPS2(2)
13 2.151174 general buckling load factor, mode 2: GENBK2(2)

BEHAVIOR OVER J = number of regions for computing behavior
14 2.789820 local skin buckling load factor, mode 2: SKNBK2(2 ,1)
15 2.791454 local skin buckling load factor, mode 2: SKNBK2(2 ,2)

BEHAVIOR OVER J = number of regions for computing behavior
16 1.078544 buckling load factor for isogrid member: STFBK2(2 ,1)
17 2.231953 buckling load factor for isogrid member: STFBK2(2 ,2)

BEHAVIOR OVER J = number of regions for computing behavior
18 103826.2 maximum stress in the shell skin, mode 2: SKNST2(2 ,1)
19 105047.7 maximum stress in the shell skin, mode 2: SKNST2(2 ,2)

BEHAVIOR OVER J = number of regions for computing behavior
20 121999.7 maximum stress in isogrid stiffener, mode 2: STFST2(2 ,1)
21 124812.6 maximum stress in isogrid stiffener, mode 2: STFST2(2 ,2)
22 0.4438556 normal (axial) displacement at apex, mode 2: WAPEX2(2)

***** RESULTS FOR LOAD SET NO. 2 ******
PARAMETERS WHICH DESCRIBE BEHAVIOR (e.g. stress, buckling load)

BEH. NO.	CURRENT VALUE	DEFINITION
1	5.635E+02	collapse pressure with imperfection mode 1: CLAPS1(2)
2	1.586E+00	general buckling load factor, mode 1: GENBK1(2)
3	3.168E+00	buckling load of skin: SKNBK1(2 ,1)
4	3.298E+00	buckling load of skin: SKNBK1(2 ,2)
5	1.148E+00	buckling load factor, isogrid member, mode 1: STFBK1(2 ,1)
6	1.368E+00	buckling load factor, isogrid member, mode 1: STFBK1(2 ,2)
7	1.205E+05	maximum stress in the shell skin, mode 1: SKNST1(2 ,1)
8	1.143E+05	maximum stress in the shell skin, mode 1: SKNST1(2 ,2)
9	1.176E+05	maximum stress in isogrid stiffener, mode 1: STFST1(2 ,1)
10	1.215E+05	maximum stress in isogrid stiffener, mode 1: STFST1(2 ,2)
11	5.367E-01	normal (axial) displacement at apex, mode 1: WAPEX1(2)
12	9.200E+02	collapse pressure with imperfection mode 2: CLAPS2(2)
13	2.151E+00	general buckling load factor, mode 2: GENBK2(2)
14	2.790E+00	local skin buckling load factor, mode 2: SKNBK2(2 ,1)
15	2.791E+00	local skin buckling load factor, mode 2: SKNBK2(2 ,2)
16	1.079E+00	buckling load factor for isogrid member: STFBK2(2 ,1)
17	2.232E+00	buckling load factor for isogrid member: STFBK2(2 ,2)
18	1.038E+05	maximum stress in the shell skin, mode 2: SKNST2(2 ,1)
19	1.050E+05	maximum stress in the shell skin, mode 2: SKNST2(2 ,2)
20	1.220E+05	maximum stress in isogrid stiffener, mode 2: STFST2(2 ,1)
21	1.248E+05	maximum stress in isogrid stiffener, mode 2: STFST2(2 ,2)
22	4.439E-01	normal (axial) displacement at apex, mode 2: WAPEX2(2)

******* NOTE ******* NOTE ******* NOTE ****** NOTE ******
The phrase, "NOT APPLY", for MARGIN VALUE means that that particular margin value is exactly zero.
*** END NOTE *** END NOTE *** END NOTE *** END NOTE *****

***** RESULTS FOR LOAD SET NO. 2 ******
MARGINS CORRESPONDING TO CURRENT DESIGN (F.S.= FACTOR OF SAFETY)

```
MARGIN CURRENT
NO.    VALUE          DEFINITION
 1   2.455E-02  (CLAPS1(2 )/CLAPS1A(2 )) / CLAPS1F(2 )-1; F.S.=  1.00
 2   5.860E-01  (GENBK1(2 )/GENBK1A(2 )) / GENBK1F(2 )-1; F.S.=  1.00
 3   2.168E+00  (SKNBK1(2 ,1 )/SKNBK1A(2 ,1 )) / SKNBK1F(2 ,1 )-1; F.S.=  1.00
 4   2.298E+00  (SKNBK1(2 ,2 )/SKNBK1A(2 ,2 )) / SKNBK1F(2 ,2 )-1; F.S.=  1.00
 5   1.477E-01  (STFBK1(2 ,1 )/STFBK1A(2 ,1 )) / STFBK1F(2 ,1 )-1; F.S.=  1.00
 6   3.683E-01  (STFBK1(2 ,2 )/STFBK1A(2 ,2 )) / STFBK1F(2 ,2 )-1; F.S.=  1.00
 7  -4.325E-03  (SKNST1A(2 ,1 )/SKNST1(2 ,1 )) / SKNST1F(2 ,1 )-1; F.S.=  1.00
 8   4.979E-02  (SKNST1A(2 ,2 )/SKNST1(2 ,2 )) / SKNST1F(2 ,2 )-1; F.S.=  1.00
 9   2.005E-02  (STFST1A(2 ,1 )/STFST1(2 ,1 )) / STFST1F(2 ,1 )-1; F.S.=  1.00
10  -1.268E-02  (STFST1A(2 ,2 )/STFST1(2 ,2 )) / STFST1F(2 ,2 )-1; F.S.=  1.00
11   3.043E-01  (WAPEX1A(2 )/WAPEX1(2 )) / WAPEX1F(2 )-1; F.S.=  1.00
12   6.727E-01  (CLAPS2(2 )/CLAPS2A(2 )) / CLAPS2F(2 )-1; F.S.=  1.00
13   1.151E+00  (GENBK2(2 )/GENBK2A(2 )) / GENBK2F(2 )-1; F.S.=  1.00
14   1.790E+00  (SKNBK2(2 ,1 )/SKNBK2A(2 ,1 )) / SKNBK2F(2 ,1 )-1; F.S.=  1.00
15   1.791E+00  (SKNBK2(2 ,2 )/SKNBK2A(2 ,2 )) / SKNBK2F(2 ,2 )-1; F.S.=  1.00
16   7.854E-02  (STFBK2(2 ,1 )/STFBK2A(2 ,1 )) / STFBK2F(2 ,1 )-1; F.S.=  1.00
17   1.232E+00  (STFBK2(2 ,2 )/STFBK2A(2 ,2 )) / STFBK2F(2 ,2 )-1; F.S.=  1.00
18   1.558E-01  (SKNST2A(2 ,1 )/SKNST2(2 ,1 )) / SKNST2F(2 ,1 )-1; F.S.=  1.00
19   1.423E-01  (SKNST2A(2 ,2 )/SKNST2(2 ,2 )) / SKNST2F(2 ,2 )-1; F.S.=  1.00
20  -1.639E-02  (STFST2A(2 ,1 )/STFST2(2 ,1 )) / STFST2F(2 ,1 )-1; F.S.=  1.00
21  -3.856E-02  (STFST2A(2 ,2 )/STFST2(2 ,2 )) / STFST2F(2 ,2 )-1; F.S.=  1.00
22   5.771E-01  (WAPEX2A(2 )/WAPEX2(2 )) / WAPEX2F(2 )-1; F.S.=  1.00

****************************************************
******************** DESIGN OBJECTIVE *******************
*************                    ***********
  CURRENT VALUE OF THE OBJECTIVE FUNCTION:

VAR.  CURRENT
NO.    VALUE          DEFINITION
 1   8.610E+01  weight of the equivalent ellipsoidal head: WEIGHT

*************                  ************
******************** DESIGN OBJECTIVE *******************
****************************************************
***********  ALL 2 LOAD CASES PROCESSED ***********
```

****

PARAMETERS WHICH ARE ALWAYS FIXED. NONE CAN BE DECISION VARIAB.

VAR. NO.	CURRENT VALUE	DEFINITION
1	0.000E+00	x-coordinates for ends of segments: xinput(1)
2	2.555E+00	x-coordinates for ends of segments: xinput(2)
3	5.666E+00	x-coordinates for ends of segments: xinput(3)
4	8.754E+00	x-coordinates for ends of segments: xinput(4)
5	1.180E+01	x-coordinates for ends of segments: xinput(5)
6	1.477E+01	x-coordinates for ends of segments: xinput(6)
7	1.763E+01	x-coordinates for ends of segments: xinput(7)
8	1.964E+01	x-coordinates for ends of segments: xinput(8)
9	2.126E+01	x-coordinates for ends of segments: xinput(9)
10	2.270E+01	x-coordinates for ends of segments: xinput(10)
11	2.387E+01	x-coordinates for ends of segments: xinput(11)
12	2.454E+01	x-coordinates for ends of segments: xinput(12)
13	2.475E+01	x-coordinates for ends of segments: xinput(13)
14	2.475E+01	length of semi-major axis: ainput
15	1.238E+01	length of semi-minor axis of ellipse: binput
16	1.763E+01	max. x-coordinate for x-coordinate callouts: xlimit
17	2.000E-01	thickness of the cylindrical shell: THKCYL
18	2.475E+01	radius of the cylindrical shell: RADCYL
19	0.000E+00	length of the cylindrical segment: LENCYL
20	2.000E-01	amplitude of the axisymmetric imperfection: WIMP
21	1.600E+07	elastic modulus: EMATL
22	2.500E-01	Poisson ratio of material: NUMATL
23	4.155E-04	mass density of material: DNMATL

PARAMETERS WHICH ARE ENVIRONMENTAL FACTORS (e.g. loads, temps.)

VAR. NO.	CURRENT VALUE	DEFINITION
1	4.600E+02	uniform external pressure: PRESS(1)
2	4.600E+02	uniform external pressure: PRESS(2)

PARAMETERS WHICH ARE CLASSIFIED AS ALLOWABLES (e.g. max. stress)

VAR. NO.	CURRENT VALUE	DEFINITION
1	5.500E+02	allowable pressure for axisymmetric collapse: CLAPS1A(1)
2	5.500E+02	allowable pressure for axisymmetric collapse: CLAPS1A(2)
3	1.000E+00	allowable general buckling load factor (use 1.0): GENBK1A(1)
4	1.000E+00	allowable general buckling load factor (use 1.0): GENBK1A(2)
5	1.000E+00	allowable buckling load factor: SKNBK1A(1 ,1)
6	1.000E+00	allowable buckling load factor: SKNBK1A(2 ,1)
7	1.000E+00	allowable buckling load factor: SKNBK1A(1 ,2)
8	1.000E+00	allowable buckling load factor: SKNBK1A(2 ,2)

9 1.000E+00 allowable for isogrid stiffener buckling (Use 1.): STFBK1A(1 ,1)
10 1.000E+00 allowable for isogrid stiffener buckling (Use 1.): STFBK1A(2 ,1)
11 1.000E+00 allowable for isogrid stiffener buckling (Use 1.): STFBK1A(1 ,2)
12 1.000E+00 allowable for isogrid stiffener buckling (Use 1.): STFBK1A(2 ,2)
13 1.200E+05 allowable stress for the shell skin: SKNST1A(1 ,1)
14 1.200E+05 allowable stress for the shell skin: SKNST1A(2 ,1)
15 1.200E+05 allowable stress for the shell skin: SKNST1A(1 ,2)
16 1.200E+05 allowable stress for the shell skin: SKNST1A(2 ,2)
17 1.200E+05 allowable stress in isogrid stiffeners: STFST1A(1 ,1)
18 1.200E+05 allowable stress in isogrid stiffeners: STFST1A(2 ,1)
19 1.200E+05 allowable stress in isogrid stiffeners: STFST1A(1 ,2)
20 1.200E+05 allowable stress in isogrid stiffeners: STFST1A(2 ,2)
21 7.000E-01 allowable normal (axial) displacement at apex: WAPEX1A(1)
22 7.000E-01 allowable normal (axial) displacement at apex: WAPEX1A(2)
23 5.500E+02 allowable pressure for axisymmetric collapse: CLAPS2A(1)
24 5.500E+02 allowable pressure for axisymmetric collapse: CLAPS2A(2)
25 1.000E+00 allowable general buckling load factor (use 1.0): GENBK2A(1)
26 1.000E+00 allowable general buckling load factor (use 1.0): GENBK2A(2)
27 1.000E+00 allowable skin buckling load factor (use 1.0): SKNBK2A(1 ,1)
28 1.000E+00 allowable skin buckling load factor (use 1.0): SKNBK2A(2 ,1)
29 1.000E+00 allowable skin buckling load factor (use 1.0): SKNBK2A(1 ,2)
30 1.000E+00 allowable skin buckling load factor (use 1.0): SKNBK2A(2 ,2)
31 1.000E+00 allowable for isogrid stiffener buckling (Use 1.): STFBK2A(1 ,1)
32 1.000E+00 allowable for isogrid stiffener buckling (Use 1.): STFBK2A(2 ,1)
33 1.000E+00 allowable for isogrid stiffener buckling (Use 1.): STFBK2A(1 ,2)
34 1.000E+00 allowable for isogrid stiffener buckling (Use 1.): STFBK2A(2 ,2)
35 1.200E+05 allowable stress for the shell skin: SKNST2A(1 ,1)
36 1.200E+05 allowable stress for the shell skin: SKNST2A(2 ,1)
37 1.200E+05 allowable stress for the shell skin: SKNST2A(1 ,2)
38 1.200E+05 allowable stress for the shell skin: SKNST2A(2 ,2)
39 1.200E+05 allowable stress in isogrid stiffeners: STFST2A(1 ,1)
40 1.200E+05 allowable stress in isogrid stiffeners: STFST2A(2 ,1)
41 1.200E+05 allowable stress in isogrid stiffeners: STFST2A(1 ,2)
42 1.200E+05 allowable stress in isogrid stiffeners: STFST2A(2 ,2)
43 7.000E-01 allowable normal (axial) displacement at apex: WAPEX2A(1)
44 7.000E-01 allowable normal (axial) displacement at apex: WAPEX2A(2)
PARAMETERS WHICH ARE FACTORS OF SAFETY

VAR. CURRENT
NO. VALUE DEFINITION
1 1.000E+00 factor of safety for axisymmetric collapse: CLAPS1F(1)
2 1.000E+00 factor of safety for axisymmetric collapse: CLAPS1F(2)
3 1.000E+00 factor of safety for general buckling: GENBK1F(1)
4 1.000E+00 factor of safety for general buckling: GENBK1F(2)
5 1.000E+00 factor of safety for skin buckling: SKNBK1F(1 ,1)
6 1.000E+00 factor of safety for skin buckling: SKNBK1F(2 ,1)
7 1.000E+00 factor of safety for skin buckling: SKNBK1F(1 ,2)
8 1.000E+00 factor of safety for skin buckling: SKNBK1F(2 ,2)

9 1.000E+00 factor of safety for isogrid stiffener buckling: STFBK1F(1 ,1)
10 1.000E+00 factor of safety for isogrid stiffener buckling: STFBK1F(2 ,1)
11 1.000E+00 factor of safety for isogrid stiffener buckling: STFBK1F(1 ,2)
12 1.000E+00 factor of safety for isogrid stiffener buckling: STFBK1F(2 ,2)
13 1.000E+00 factor of safety for skin stress: SKNST1F(1 ,1)
14 1.000E+00 factor of safety for skin stress: SKNST1F(2 ,1)
15 1.000E+00 factor of safety for skin stress: SKNST1F(1 ,2)
16 1.000E+00 factor of safety for skin stress: SKNST1F(2 ,2)
17 1.000E+00 factor of safety for stress in isogrid member: STFST1F(1 ,1)
18 1.000E+00 factor of safety for stress in isogrid member: STFST1F(2 ,1)
19 1.000E+00 factor of safety for stress in isogrid member: STFST1F(1 ,2)
20 1.000E+00 factor of safety for stress in isogrid member: STFST1F(2 ,2)
21 1.000E+00 factor of safety for WAPEX: WAPEX1F(1)
22 1.000E+00 factor of safety for WAPEX: WAPEX1F(2)
23 1.000E+00 factor of safety for axisymmetric collapse: CLAPS2F(1)
24 1.000E+00 factor of safety for axisymmetric collapse: CLAPS2F(2)
25 1.000E+00 factor of safety for general buckling: GENBK2F(1)
26 1.000E+00 factor of safety for general buckling: GENBK2F(2)
27 1.000E+00 factor of safety for local skin buckling: SKNBK2F(1 ,1)
28 1.000E+00 factor of safety for local skin buckling: SKNBK2F(2 ,1)
29 1.000E+00 factor of safety for local skin buckling: SKNBK2F(1 ,2)
30 1.000E+00 factor of safety for local skin buckling: SKNBK2F(2 ,2)
31 1.000E+00 factor of safety for isogrid stiffener buckling: STFBK2F(1 ,1)
32 1.000E+00 factor of safety for isogrid stiffener buckling: STFBK2F(2 ,1)
33 1.000E+00 factor of safety for isogrid stiffener buckling: STFBK2F(1 ,2)
34 1.000E+00 factor of safety for isogrid stiffener buckling: STFBK2F(2 ,2)
35 1.000E+00 factor of safety for skin stress: SKNST2F(1 ,1)
36 1.000E+00 factor of safety for skin stress: SKNST2F(2 ,1)
37 1.000E+00 factor of safety for skin stress: SKNST2F(1 ,2)
38 1.000E+00 factor of safety for skin stress: SKNST2F(2 ,2)
39 1.000E+00 factor of safety for stress in isogrid member: STFST2F(1 ,1)
40 1.000E+00 factor of safety for stress in isogrid member: STFST2F(2 ,1)
41 1.000E+00 factor of safety for stress in isogrid member: STFST2F(1 ,2)
42 1.000E+00 factor of safety for stress in isogrid member: STFST2F(2 ,2)
43 1.000E+00 factor of safety for WAPEX: WAPEX2F(1)
44 1.000E+00 factor of safety for WAPEX: WAPEX2F(2)

0 INEQUALITY CONSTRAINTS WHICH MUST BE SATISFIED

DESCRIPTION OF FILES USED AND GENERATED IN THIS RUN:

eqellipse.NAM = This file contains only the name of the case.
eqellipse.OPM = Output data. Please list this file and inspect
carefully before proceeding.
eqellipse.OPP = Output file containing evolution of design and
margins since the beginning of optimization cycles.

```
eqellipse.CBL = Labelled common blocks for analysis.
        (This is an unformatted sequential file.)
eqellipse.OPT = This file contains the input data for MAINSETUP
         as well as OPTIMIZE. The batch command OPTIMIZE
         can be given over and over again without having
         to return to MAINSETUP because eqellipse.OPT exists.
URPROMPT.DAT= Prompt file for interactive input.

For further information about files used and generated
during operation of GENOPT, give the command HELPG FILES.

Menu of commands: CHOOSEPLOT, OPTIMIZE, MAINSETUP, CHANGE,
              DECIDE, SUPEROPT

IN ORDER TO AVOID FALSE CONVERGENCE OF THE DESIGN, BE SURE TO
RUN  "OPTIMIZE"  MANY TIMES DURING AN OPTIMIZATION AND/OR USE
THE "GLOBAL" OPTIMIZING SCRIPT, "SUPEROPT".
********************* END OF eqellipse.OPM FILE *****************
=================================================================
```

NOTE: Tables a20 – a22 in [26].

```
Table A23 List of the file, eqellipse.stiffened.opm4.STAGS .
This file, called "eqellipse.STAGS" for the specific case,
"eqellipse", must be called WALLTHICK.STAGS in the directory
from which the STAGS program is executed. The WALLTHICK.STAGS
file must exist at the time that SUBROUTINE WALL is executed.
(See Tables a21, a22, a35, a36 of [26]). The file, "eqellipse.STAGS"
is generated automatically in SUBROUTINE STRUCT whenever the
GENOPT processor, OPTIMIZE, is executed in the "ITYPE = 2"
mode, that is, for the analysis of a "fixed" design.
=====================================================================

     Number of shell segments (units)=  12

        Isogrid  spacing,modulus,nu,density=    2.915400E+00    1.600000E+07
2.500000E-01  1.605492E-01

               Nodal points in Segment  1 =  13

                 Angle (X-coordinate)=
  0.000000E+00  8.156468E-02  2.993615E-01  5.914913E-01  8.873521E-01
  1.183329E+00  1.479094E+00  1.774868E+00  2.070654E+00  2.366536E+00
  2.658591E+00  2.876780E+00  2.958103E+00

 Meridional arc length (X-coordinate)=
  0.000000E+00  7.027998E-02  2.587581E-01  5.111271E-01  7.666907E-01
  1.022254E+00  1.277818E+00  1.533381E+00  1.788945E+00  2.044508E+00
  2.296877E+00  2.485355E+00  2.555635E+00

                 Shell skin thickness=
  1.245300E-01  1.256817E-01  1.287704E-01  1.329060E-01  1.370940E-01
  1.412820E-01  1.454700E-01  1.496580E-01  1.538460E-01  1.580340E-01
  1.621697E-01  1.652583E-01  1.664100E-01

        Stringer (or isogrid)  height=
  6.676600E-01  6.660147E-01  6.616022E-01  6.556940E-01  6.497110E-01
  6.437280E-01  6.377450E-01  6.317620E-01  6.257790E-01  6.197960E-01
  6.138878E-01  6.094753E-01  6.078300E-01

     Stringer (or isogrid)  thickness=
  9.053100E-02  9.053100E-02  9.053100E-02  9.053100E-02  9.053100E-02
  9.053100E-02  9.053100E-02  9.053100E-02  9.053100E-02  9.053100E-02
  9.053100E-02  9.053100E-02  9.053100E-02

               Nodal points in Segment  2 =  13

                 Angle (X-coordinate)=
  2.957441E+00  3.060174E+00  3.335835E+00  3.704859E+00  4.078567E+00
  4.452235E+00  4.825966E+00  5.199648E+00  5.573376E+00  5.947057E+00
  6.316089E+00  6.591689E+00  6.694480E+00

 Meridional arc length (X-coordinate)=
  2.555635E+00  2.641534E+00  2.871897E+00  3.180351E+00  3.492708E+00
  3.805066E+00  4.117423E+00  4.429781E+00  4.742138E+00  5.054496E+00
  5.362949E+00  5.593312E+00  5.679211E+00
```

```
                  Shell skin thickness=
 1.664100E-01  1.658102E-01  1.642017E-01  1.620480E-01  1.598670E-01
 1.576860E-01  1.555050E-01  1.533240E-01  1.511430E-01  1.489620E-01
 1.468083E-01  1.451998E-01  1.446000E-01

         Stringer (or isogrid)  height=
 6.078300E-01  6.180449E-01  6.454393E-01  6.821200E-01  7.192650E-01
 7.564100E-01  7.935550E-01  8.307000E-01  8.678450E-01  9.049900E-01
 9.416707E-01  9.690651E-01  9.792800E-01

      Stringer (or isogrid)  thickness=
 9.053100E-02  9.053100E-02  9.053100E-02  9.053100E-02  9.053100E-02
 9.053100E-02  9.053100E-02  9.053100E-02  9.053100E-02  9.053100E-02
 9.053100E-02  9.053100E-02  9.053100E-02

                Nodal points in Segment  3 =  13

                  Angle (X-coordinate)=
 6.677820E+00  6.787783E+00  7.082718E+00  7.477612E+00  7.877512E+00
 8.277422E+00  8.677313E+00  9.077207E+00  9.477120E+00  9.877010E+00
 1.027192E+01  1.056684E+01  1.067682E+01

Meridional arc length (X-coordinate)=
 5.679211E+00  5.765109E+00  5.995471E+00  6.303923E+00  6.616279E+00
 6.928634E+00  7.240990E+00  7.553346E+00  7.865702E+00  8.178058E+00
 8.486509E+00  8.716871E+00  8.802770E+00

                  Shell skin thickness=
 1.446000E-01  1.450461E-01  1.462423E-01  1.478440E-01  1.494660E-01
 1.510880E-01  1.527100E-01  1.543320E-01  1.559540E-01  1.575760E-01
 1.591777E-01  1.603739E-01  1.608200E-01

         Stringer (or isogrid)  height=
 9.792800E-01  9.868953E-01  1.007318E+00  1.034664E+00  1.062356E+00
 1.090048E+00  1.117740E+00  1.145432E+00  1.173124E+00  1.200816E+00
 1.228162E+00  1.248585E+00  1.256200E+00

      Stringer (or isogrid)  thickness=
 9.053100E-02  9.053100E-02  9.053100E-02  9.053100E-02  9.053100E-02
 9.053100E-02  9.053100E-02  9.053100E-02  9.053100E-02  9.053100E-02
 9.053100E-02  9.053100E-02  9.053100E-02

                Nodal points in Segment  4 =  13

                  Angle (X-coordinate)=
 1.065673E+01  1.077948E+01  1.110865E+01  1.154942E+01  1.199575E+01
 1.244210E+01  1.288845E+01  1.333478E+01  1.378113E+01  1.422747E+01
 1.466823E+01  1.499742E+01  1.512016E+01

Meridional arc length (X-coordinate)=
 8.802770E+00  8.888667E+00  9.119027E+00  9.427476E+00  9.739830E+00
 1.005218E+01  1.036454E+01  1.067689E+01  1.098924E+01  1.130160E+01
 1.161005E+01  1.184041E+01  1.192630E+01

                  Shell skin thickness=
 1.608200E-01  1.592607E-01  1.550791E-01  1.494800E-01  1.438100E-01
 1.381400E-01  1.324700E-01  1.268000E-01  1.211300E-01  1.154600E-01
```

```
 1.098609E-01  1.056792E-01  1.041200E-01

       Stringer (or isogrid)  height=
 1.256200E+00  1.253389E+00  1.245852E+00  1.235760E+00  1.225540E+00
 1.215320E+00  1.205100E+00  1.194880E+00  1.184660E+00  1.174440E+00
 1.164348E+00  1.156811E+00  1.154000E+00

    Stringer (or isogrid)  thickness=
 9.053100E-02  9.053100E-02  9.053100E-02  9.053100E-02  9.053100E-02
 9.053100E-02  9.053100E-02  9.053100E-02  9.053100E-02  9.053100E-02
 9.053100E-02  9.053100E-02  9.053100E-02

              Nodal points in Segment  5 =  13

                Angle (X-coordinate)=
 1.508829E+01  1.523219E+01  1.561814E+01  1.613492E+01  1.665823E+01
 1.718155E+01  1.770487E+01  1.822818E+01  1.875149E+01  1.927481E+01
 1.979159E+01  2.017753E+01  2.032144E+01

Meridional arc length (X-coordinate)=
 1.192630E+01  1.201220E+01  1.224257E+01  1.255102E+01  1.286338E+01
 1.317574E+01  1.348810E+01  1.380046E+01  1.411282E+01  1.442518E+01
 1.473364E+01  1.496400E+01  1.504990E+01

                Shell skin thickness=
 1.041200E-01  1.040067E-01  1.037029E-01  1.032960E-01  1.028840E-01
 1.024720E-01  1.020600E-01  1.016480E-01  1.012360E-01  1.008240E-01
 1.004172E-01  1.001133E-01  1.000000E-01

       Stringer (or isogrid)  height=
 1.154000E+00  1.144381E+00  1.118585E+00  1.084044E+00  1.049066E+00
 1.014088E+00  9.791100E-01  9.441320E-01  9.091539E-01  8.741760E-01
 8.396352E-01  8.138389E-01  8.042200E-01

    Stringer (or isogrid)  thickness=
 9.053100E-02  9.053100E-02  9.053100E-02  9.053100E-02  9.053100E-02
 9.053100E-02  9.053100E-02  9.053100E-02  9.053100E-02  9.053100E-02
 9.053100E-02  9.053100E-02  9.053100E-02

              Nodal points in Segment  6 =  13

                Angle (X-coordinate)=
 2.026536E+01  2.044455E+01  2.092512E+01  2.156858E+01  2.222019E+01
 2.287180E+01  2.352341E+01  2.417502E+01  2.482663E+01  2.547823E+01
 2.612170E+01  2.660226E+01  2.678145E+01

Meridional arc length (X-coordinate)=
 1.504990E+01  1.513580E+01  1.536616E+01  1.567462E+01  1.598697E+01
 1.629933E+01  1.661169E+01  1.692405E+01  1.723640E+01  1.754876E+01
 1.785721E+01  1.808758E+01  1.817347E+01

                Shell skin thickness=
 1.000000E-01  1.000445E-01  1.001640E-01  1.003240E-01  1.004860E-01
 1.006480E-01  1.008100E-01  1.009720E-01  1.011340E-01  1.012960E-01
 1.014560E-01  1.015754E-01  1.016200E-01

       Stringer (or isogrid)  height=
 8.042200E-01  8.169905E-01  8.512385E-01  8.970960E-01  9.435340E-01
```

```
 9.899721E-01  1.036410E+00  1.082848E+00  1.129286E+00  1.175724E+00
 1.221582E+00  1.255830E+00  1.268600E+00

    Stringer (or isogrid)  thickness=
 9.053100E-02  9.053100E-02  9.053100E-02  9.053100E-02  9.053100E-02
 9.053100E-02  9.053100E-02  9.053100E-02  9.053100E-02  9.053100E-02
 9.053100E-02  9.053100E-02  9.053100E-02

              Nodal points in Segment  7 =  13

                Angle (X-coordinate)=
 2.679548E+01  2.696524E+01  2.742050E+01  2.803009E+01  2.864739E+01
 2.926470E+01  2.988201E+01  3.049931E+01  3.111662E+01  3.173392E+01
 3.234351E+01  3.279877E+01  3.296853E+01

Meridional arc length (X-coordinate)=
 1.817347E+01  1.823699E+01  1.840732E+01  1.863539E+01  1.886634E+01
 1.909730E+01  1.932825E+01  1.955921E+01  1.979016E+01  2.002112E+01
 2.024919E+01  2.041952E+01  2.048303E+01

                Shell skin thickness=
 1.016200E-01  1.026191E-01  1.052984E-01  1.088860E-01  1.125190E-01
 1.161520E-01  1.197850E-01  1.234180E-01  1.270510E-01  1.306840E-01
 1.342716E-01  1.369509E-01  1.379500E-01

       Stringer (or isogrid)  height=
 1.268600E+00  1.258007E+00  1.229597E+00  1.191558E+00  1.153037E+00
 1.114516E+00  1.075995E+00  1.037474E+00  9.989530E-01  9.604321E-01
 9.223925E-01  8.939837E-01  8.833901E-01

    Stringer (or isogrid)  thickness=
 9.053100E-02  9.053100E-02  9.053100E-02  9.053100E-02  9.053100E-02
 9.053100E-02  9.053100E-02  9.053100E-02  9.053100E-02  9.053100E-02
 9.053100E-02  9.053100E-02  9.053100E-02

              Nodal points in Segment  8 =  13

                Angle (X-coordinate)=
 3.294721E+01  3.313707E+01  3.364623E+01  3.432798E+01  3.501837E+01
 3.570876E+01  3.639914E+01  3.708953E+01  3.777991E+01  3.847030E+01
 3.915207E+01  3.966122E+01  3.985107E+01

Meridional arc length (X-coordinate)=
 2.048303E+01  2.053856E+01  2.068748E+01  2.088689E+01  2.108882E+01
 2.129074E+01  2.149267E+01  2.169460E+01  2.189653E+01  2.209846E+01
 2.229786E+01  2.244678E+01  2.250231E+01

                Shell skin thickness=
 1.379500E-01  1.369617E-01  1.343111E-01  1.307620E-01  1.271680E-01
 1.235740E-01  1.199800E-01  1.163860E-01  1.127920E-01  1.091980E-01
 1.056489E-01  1.029984E-01  1.020100E-01

       Stringer (or isogrid)  height=
 8.833901E-01  8.785008E-01  8.653888E-01  8.478320E-01  8.300531E-01
 8.122740E-01  7.944950E-01  7.767161E-01  7.589370E-01  7.411581E-01
 7.236013E-01  7.104893E-01  7.056000E-01

    Stringer (or isogrid)  thickness=
```

```
 9.053100E-02  9.053100E-02  9.053100E-02  9.053100E-02  9.053100E-02
 9.053100E-02  9.053100E-02  9.053100E-02  9.053100E-02  9.053100E-02
 9.053100E-02  9.053100E-02  9.053100E-02

             Nodal points in Segment  9 =  13

               Angle (X-coordinate)=
 3.977901E+01  4.002785E+01  4.069519E+01  4.158876E+01  4.249363E+01
 4.339851E+01  4.430339E+01  4.520827E+01  4.611314E+01  4.701801E+01
 4.791158E+01  4.857893E+01  4.882777E+01

Meridional arc length (X-coordinate)=
 2.250231E+01  2.255784E+01  2.270677E+01  2.290617E+01  2.310810E+01
 2.331003E+01  2.351196E+01  2.371389E+01  2.391582E+01  2.411775E+01
 2.431715E+01  2.446608E+01  2.452161E+01

               Shell skin thickness=
 1.020100E-01  1.020677E-01  1.022226E-01  1.024300E-01  1.026400E-01
 1.028500E-01  1.030600E-01  1.032700E-01  1.034800E-01  1.036900E-01
 1.038974E-01  1.040523E-01  1.041100E-01

       Stringer (or isogrid)  height=
 7.056000E-01  7.022684E-01  6.933335E-01  6.813701E-01  6.692550E-01
 6.571400E-01  6.450250E-01  6.329100E-01  6.207951E-01  6.086801E-01
 5.967165E-01  5.877816E-01  5.844500E-01

    Stringer (or isogrid)  thickness=
 9.053100E-02  9.053100E-02  9.053100E-02  9.053100E-02  9.053100E-02
 9.053100E-02  9.053100E-02  9.053100E-02  9.053100E-02  9.053100E-02
 9.053100E-02  9.053100E-02  9.053100E-02

             Nodal points in Segment 10 =  13

               Angle (X-coordinate)=
 4.874254E+01  4.907703E+01  4.997408E+01  5.117522E+01  5.239155E+01
 5.360789E+01  5.482423E+01  5.604056E+01  5.725691E+01  5.847325E+01
 5.967438E+01  6.057143E+01  6.090592E+01

Meridional arc length (X-coordinate)=
 2.452161E+01  2.457714E+01  2.472606E+01  2.492546E+01  2.512739E+01
 2.532931E+01  2.553124E+01  2.573317E+01  2.593509E+01  2.613702E+01
 2.633642E+01  2.648534E+01  2.654087E+01

               Shell skin thickness=
 1.041100E-01  1.067110E-01  1.136862E-01  1.230260E-01  1.324840E-01
 1.419420E-01  1.514000E-01  1.608580E-01  1.703160E-01  1.797740E-01
 1.891138E-01  1.960891E-01  1.986900E-01

       Stringer (or isogrid)  height=
 5.844500E-01  5.825624E-01  5.775002E-01  5.707220E-01  5.638580E-01
 5.569940E-01  5.501300E-01  5.432660E-01  5.364020E-01  5.295380E-01
 5.227598E-01  5.176976E-01  5.158100E-01

    Stringer (or isogrid)  thickness=
 9.053100E-02  9.053100E-02  9.053100E-02  9.053100E-02  9.053100E-02
 9.053100E-02  9.053100E-02  9.053100E-02  9.053100E-02  9.053100E-02
 9.053100E-02  9.053100E-02  9.053100E-02
```

```
               Nodal points in Segment 11 =  13

                Angle (X-coordinate)=
  6.095361E+01  6.134404E+01  6.239109E+01  6.379308E+01  6.521282E+01
  6.663256E+01  6.805230E+01  6.947204E+01  7.089178E+01  7.231151E+01
  7.371350E+01  7.476056E+01  7.515099E+01

 Meridional arc length (X-coordinate)=
  2.654087E+01  2.659085E+01  2.672488E+01  2.690434E+01  2.708607E+01
  2.726781E+01  2.744954E+01  2.763127E+01  2.781301E+01  2.799474E+01
  2.817420E+01  2.830823E+01  2.835821E+01

                Shell skin thickness=
  1.986900E-01  1.959760E-01  1.886976E-01  1.789520E-01  1.690830E-01
  1.592140E-01  1.493450E-01  1.394761E-01  1.296070E-01  1.197381E-01
  1.099924E-01  1.027141E-01  1.000000E-01

       Stringer (or isogrid)  height=
  5.158100E-01  5.110899E-01  4.984314E-01  4.814821E-01  4.643180E-01
  4.471541E-01  4.299900E-01  4.128261E-01  3.956620E-01  3.784981E-01
  3.615486E-01  3.488902E-01  3.441700E-01

    Stringer (or isogrid)  thickness=
  9.053100E-02  9.053100E-02  9.053100E-02  9.053100E-02  9.053100E-02
  9.053100E-02  9.053100E-02  9.053100E-02  9.053100E-02  9.053100E-02
  9.053100E-02  9.053100E-02  9.053100E-02

               Nodal points in Segment 12 =  13

                Angle (X-coordinate)=
  7.531520E+01  7.571658E+01  7.679298E+01  7.823426E+01  7.969379E+01
  8.115332E+01  8.261285E+01  8.407239E+01  8.553191E+01  8.699145E+01
  8.843273E+01  8.950913E+01  8.991051E+01

 Meridional arc length (X-coordinate)=
  2.835821E+01  2.840263E+01  2.852177E+01  2.868129E+01  2.884283E+01
  2.900438E+01  2.916592E+01  2.932747E+01  2.948901E+01  2.965055E+01
  2.981007E+01  2.992921E+01  2.997364E+01

                Shell skin thickness=
  1.000000E-01  1.026892E-01  1.099013E-01  1.195580E-01  1.293370E-01
  1.391161E-01  1.488951E-01  1.586740E-01  1.684530E-01  1.782320E-01
  1.878887E-01  1.951008E-01  1.977900E-01

       Stringer (or isogrid)  height=
  3.441700E-01  3.475368E-01  3.565661E-01  3.686560E-01  3.808990E-01
  3.931421E-01  4.053851E-01  4.176280E-01  4.298711E-01  4.421140E-01
  4.542039E-01  4.632332E-01  4.666000E-01

    Stringer (or isogrid)  thickness=
  9.053100E-02  9.053100E-02  9.053100E-02  9.053100E-02  9.053100E-02
  9.053100E-02  9.053100E-02  9.053100E-02  9.053100E-02  9.053100E-02
  9.053100E-02  9.053100E-02  9.053100E-02
======================================================================
```

NOTE: Tables a24 – a35 in [26].

Table a36 List of the file, **usrfab.soccerball.plastic.src.** This is the "fleshed out" version of **SUBROUTINE USRFAB** valid for the elastic-plastic 180-degree "soccerball" model displayed in Fig. a2. The difference between usrfab.soccerball.plastic.src and usrfab.plastic.src is analogous to the difference between wall.soccerball.plastic.src and wall.plastic.src.(See Table a33[26]).
SUBROUTINE USRFAB is always used in connection with a "GCP" model, that is, when NGCP = 1 in the STAGS input file, *.inp .
NOTE: From the experience gained in generating the results for the generic case, equivellipse, (see especially Fig. 175 of [26] and the discussion associated with Fig. 175 of [26]), the writer urges future STAGS users to use USRFAB rather than WALL.

```
=================================================================
c=deck    usrfab
c=purpose Template for user-written subroutine USRFAB
c=author  F.A. Brogan (with W.A. Loden revisions)
c=version May, 2002
c
c=This particular version is for an isogrid-stiffened
c=torispherical head optimized by GENOPT.
c=The isogrid stiffeners are internal and smeared.
c=The shell skin is layer 2; the internal isogrid is layer1.
c=The skin thickness and isogrid height vary in the meridional
c=direction only. (Meridional direction=XYs(1) coordinate.)

#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)
*     ilin      = 0 -- Non-inear 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
      Integer    icap
      Integer    junit
      Integer    icirc
```

```
#include "mater1.h"
#include "mater2.h"
#include "mater3.h"
#include "mater4.h"
Cinclude "mater5.m"
Cinclude "mater6.m"
Cinclude "mater7.m"
#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      40    Abaqus umat material
*       9      10    Membrane wrinkling material
*      10      19    Nonlinear elastic orthotropic material
C
      Real SPACNG,EMATL,DNMATL,PHDIFF,XDIFF,RATIO,TDIFF,HDIFF,TATX,HATX
      Real THSKIN,THKSTF,HEIGHT,PHORIG,SARCLT
      Integer I5,NSEG,ISEG,JSEG,I5I,I,IMORE,IMORE1
      COMMON/ISEGX1/PHORIG(100,30),SARCLT(100,30)
      COMMON/ISEGX2/THSKIN(100,30),THKSTF(100,30),HEIGHT(100,30)
      COMMON/ISEGX3/I5(30)
      COMMON/ISEGX4/SPACNG,EMATL,NUMATL,DNMATL
      REAL NUMATL
      CHARACTER*38 WORD1,WORD2,WORD3,WORD4,WORD5,WORD6,WORD7,WORD8
      CHARACTER*2 WORD3B
C23456789012345678901234567890123456789012345678901234567890123456789012
C
      character       filnam*33
      integer         iw,       ios,      itime
      data            iw    / 61 /
      data            itime / -1 /

c-----------------------------------------------------------------------
c     1st time enter, open the wall thickness file (iw)
c     read the data therein
c     and fill common blocks ISEGX1, ISEGX2, ISEGX3
c-----------------------------------------------------------------------
      if ( itime .lt. 0 ) then

        filnam  =  'WALLTHICK.STAGS'
```

```
        open ( unit=iw, name=filnam, access='SEQUENTIAL',
     $         form='FORMATTED', iostat=ios)

        if (ios .ne. 0) then
          write(not,3000) iw, filnam, ios
 3000     format (/,'*****ERROR in routine WALL(---) *****',
     $            /,'tried to open file:  iw = ',I4,'   name = ',A,
     $            /,'error return (iostat) = ',I12,/)
          call exit
        endif
c-----------------------------------------------------------------------
C  Retrieve angle, PHORIG and arc length SARCLT (X-coordinates),
C  shell skin thickness THSKIN, stringer thickness, THKSTF, and
C  stringer height, HEIGHT
C
        WORD1 = '     Number of shell segments (units)='
        WORD2 = '   Isogrid spacing,modulus,nu,density='
        WORD3 = '               Nodal points in Segment'
        WORD3B= '= '
        WORD4 = '                 Angle (X-coordinate)='
        WORD5 = ' Meridional arc length (X-coordinate)='
        WORD6 = '                 Shell skin thickness='
        WORD7 = '        Stringer (or isogrid)  height='
        WORD8 = '     Stringer (or isogrid)  thickness='
        READ(iw,'(/,A38,I4)') WORD1,NSEG
        READ(iw,'(/,A38,1P,4E14.6)')
     1   WORD2,SPACNG,EMATL,NUMATL,DNMATL
        DO 3 ISEG = 1,NSEG
           READ(iw,'(/,A38,I3,A2,I4)') WORD3,JSEG,WORD3B,I5I
           I5(ISEG) = I5I
           READ(iw,'(/,A38,/(1P5E14.6))') WORD4,(PHORIG(I,ISEG),I=1,I5I)
           READ(iw,'(/,A38,/(1P5E14.6))') WORD5,(SARCLT(I,ISEG),I=1,I5I)
           READ(iw,'(/,A38,/(1P5E14.6))') WORD6,(THSKIN(I,ISEG),I=1,I5I)
           READ(iw,'(/,A38,/(1P5E14.6))') WORD7,(HEIGHT(I,ISEG),I=1,I5I)
           READ(iw,'(/,A38,/(1P5E14.6))') WORD8,(THKSTF(I,ISEG),I=1,I5I)
    3   CONTINUE
C23456789012345678901234567890123456789012345678901234567890123456789012
C
c  Test SUBROUTINE WALL (remove the following statements later)
        rewind iw
        WRITE(not,'(/,A38,I4)')
     1  '     Number of shell segments (units)=',NSEG
        WRITE(not,'(/,A38,1P,4E14.6)')
     1  '   Isogrid spacing,modulus,nu,density=',
     1      SPACNG,EMATL,NUMATL,DNMATL
        DO 20 ISEG = 1,NSEG
           I5I = I5(ISEG)
           WRITE(not,'(/,A38,I3,A2,I4)')
     1'               Nodal points in Segment',ISEG,' =',I5I
           WRITE(not,'(/,A38,/(1P5E14.6))')
     1'                 Angle (X-coordinate)=', (PHORIG(I,ISEG),I=1,I5I)
           WRITE(not,'(/,A38,/(1P5E14.6))')
     1' Meridional arc length (X-coordinate)=', (SARCLT(I,ISEG),I=1,I5I)
           WRITE(not,'(/,A38,/(1P5E14.6))')
     1'                 Shell skin thickness=', (THSKIN(I,ISEG),I=1,I5I)
           WRITE(not,'(/,A38,/(1P5E14.6))')
```

```
     1'        Stringer (or isogrid)  height=', (HEIGHT(I,ISEG),I=1,I5I)
           WRITE(not,'(/,A38,/(1P5E14.6))')
     1'     Stringer (or isogrid)  thickness=', (THKSTF(I,ISEG),I=1,I5I)
   20   CONTINUE
C234567890123456789012345678901234567890123456789012345678901234567890 12
c
        CLOSE(UNIT=iw)
C
        itime  =  0

      endif
C
c  Find thickness, stiffener height at shell coordinate, X:
c  thickness at X = TATX;  stiffener height at X = HATX
c
c BEG NOV 2008
c  soccerball shell unit number is not the same as the
c  equivalent ellipsoidal shell unit number...
      icirc = 180
      icap = 1
      if (icirc.eq.180) icap = 2
      if (icirc.eq.360) icap = 4
      if (iunit.le.(icap*3)) then
c      We are in the soccerball cap region (Shell Unit 1
c      in the 360-degree "polar coordinate" STAGS model).
c      TATX and HATX must be uniform within the soccerball
c      cap region for this "soccerball" version of usrfab
c      to be valid:
         TATX = THSKIN(1,1)
         HATX = HEIGHT(1,1)
         go to 30
      endif
c
      junit = (iunit - icap*3 + 2*icap-1)/(2*icap) + 1
      I5I = I5(junit)
      DO 10 I = 2,I5I
         IF (XYs(1).LT.PHORIG(I,junit)) THEN
            IMORE = I
            GO TO 11
         ENDIF
   10 CONTINUE
   11 CONTINUE
      IMORE1 = IMORE - 1
      PHDIFF = PHORIG(IMORE,junit) - PHORIG(IMORE1,junit)
      XDIFF  = XYs(1) - PHORIG(IMORE1,junit)
      RATIO  = XDIFF/PHDIFF
      TDIFF  = THSKIN(IMORE,junit) - THSKIN(IMORE1,junit)
      HDIFF  = HEIGHT(IMORE,junit) - HEIGHT(IMORE1,junit)
      TATX   = THSKIN(IMORE1,junit) + RATIO*TDIFF
      HATX   = HEIGHT(IMORE1,junit) + RATIO*HDIFF
c
   30 CONTINUE
C END NOV 2008
c
      ecz = (TATX + HATX)/2. - HATX
      laymat(1) = 2
      laymat(2) = 1
```

```
      layint(1) = 3
      if (HATX.GT.0.1*TATX) layint(1) = 5
      layint(2) = 5
      laythk(2)   = TATX
      laythk(1)   = HATX
      layang(1) = 0.
      layang(2) = 0.
      zeta = 0.
      ilin = 0
      iplas = 1
c
      return
c
c     debug = .false.
c     if (NTITLE('X_UsrFab')) debug = .true.
c     write (not,1000)
c1000  format (//'ERROR: Subroutine USRFAB has not been provided.' )
c     STOP
c
      end
=================================================================
```

Table a37 STAGS "soccerball" model of equivalent ellipsoidal shell.
This list is of the file: **soccerball.localpress.usrfab.410.inp, which pertains to one of the cases in which a residual dent is generated by a concentrated load produced by inward-directed pressure applied to a single finite element at Row 1, Column 1 of Shell unit 15.**
Figure a2 is a plot of the STAGS model corresponding to this file (except in Fig. a2 the 480 finite element is used, not the 410 element).
The concentrated load is in the form of inward normal pressure applied uniformly over a **single finite element:** the finite element at (LI,LJ) = (Row 1,Column 1) in Shell unit no. 15.
This input file, when combined with the proper eqellipse.bin file, produces deformation such as that displayed in Fig. 170 of [26] (except that Fig. 170 of [26] is a “refined” model and has 480 finite elements).

```
========================================================================
soccerball model of isogrid-stiffened equivalent ellipsoidal shell
  0  0  0  0  0  0  0   $B-1 IGRAV,ICHECK,ILIST,INCBC,NRUNIT,NROTS,KDEV
  50  0  0  85  0,  $B-2 NUNITS,NUNITE,NSTFS,NINTS,NPATS,
  0  0  0  0  0  0  $B-2 NCONST,NIMPFS,INERT,NINSR,NPATX,NSTIFS
  2  0  1  0  0  1  $B-3 NTAM,NTAB,NTAW,NTAP,NTAMT,NGCP
$ F-1 records...
  5 13,             $F-1 NROWS(1),NCOLS(1)
  5 13,             $F-1 NROWS(1),NCOLS(1)
 13 13,             $F-1 NROWS(1),NCOLS(1)
  5 13,             $F-1 NROWS(1),NCOLS(1)
  5 13,             $F-1 NROWS(1),NCOLS(1)
 13 13,             $F-1 NROWS(1),NCOLS(1)
  5 13,             $F-1 NROWS(1),NCOLS(1)
  5 13,             $F-1 NROWS(1),NCOLS(1)
  5 13,             $F-1 NROWS(1),NCOLS(1)
  5 13,             $F-1 NROWS(1),NCOLS(1)
  5 13,             $F-1 NROWS(1),NCOLS(1)
  5 13,             $F-1 NROWS(1),NCOLS(1)
  5 13,             $F-1 NROWS(1),NCOLS(1)
  5 13,             $F-1 NROWS(1),NCOLS(1)
  5 13,             $F-1 NROWS(1),NCOLS(1)
  5 13,             $F-1 NROWS(1),NCOLS(1)
  5 13,             $F-1 NROWS(1),NCOLS(1)
  5 13,             $F-1 NROWS(1),NCOLS(1)
  5 13,             $F-1 NROWS(1),NCOLS(1)
  5 13,             $F-1 NROWS(1),NCOLS(1)
  5 13,             $F-1 NROWS(1),NCOLS(1)
  5 13,             $F-1 NROWS(1),NCOLS(1)
  5 13,             $F-1 NROWS(1),NCOLS(1)
  5 13,             $F-1 NROWS(1),NCOLS(1)
  5 13,             $F-1 NROWS(1),NCOLS(1)
  5 13,             $F-1 NROWS(1),NCOLS(1)
  5 13,             $F-1 NROWS(1),NCOLS(1)
  5 13,             $F-1 NROWS(1),NCOLS(1)
  5 13,             $F-1 NROWS(1),NCOLS(1)
  5 13,             $F-1 NROWS(1),NCOLS(1)
  5 13,             $F-1 NROWS(1),NCOLS(1)
  5 13,             $F-1 NROWS(1),NCOLS(1)
  5 13,             $F-1 NROWS(1),NCOLS(1)
```

```
  5 13,             $F-1 NROWS(1),NCOLS(1)
  5 13,             $F-1 NROWS(1),NCOLS(1)
  5 13,             $F-1 NROWS(1),NCOLS(1)
  5 13,             $F-1 NROWS(1),NCOLS(1)
  5 13,             $F-1 NROWS(1),NCOLS(1)
  5 13,             $F-1 NROWS(1),NCOLS(1)
  5 13,             $F-1 NROWS(1),NCOLS(1)
  5 13,             $F-1 NROWS(1),NCOLS(1)
  5 13,             $F-1 NROWS(1),NCOLS(1)
  5 13,             $F-1 NROWS(1),NCOLS(1)
  5 13,             $F-1 NROWS(1),NCOLS(1)
  5 13,             $F-1 NROWS(1),NCOLS(1)
  5 13,             $F-1 NROWS(1),NCOLS(1)
  5 13,             $F-1 NROWS(1),NCOLS(1)
  5 13,             $F-1 NROWS(1),NCOLS(1)
  5 13,             $F-1 NROWS(1),NCOLS(1)
  5 13              $F-1 NROWS(1),NCOLS(1)
$ G-1 records...
$ soccerball cap junctions...
  1  2  2  4        $G-1 MUNIT,MBOUND,NUNIT,NBOUND
  1  1  3  3        $G-1 MUNIT,MBOUND,NUNIT,NBOUND
  2  1  3 -2        $G-1 MUNIT,MBOUND,NUNIT,NBOUND
  2  2  4  4        $G-1 MUNIT,MBOUND,NUNIT,NBOUND
  3  1  6  4        $G-1 MUNIT,MBOUND,NUNIT,NBOUND
  4  1  6  3        $G-1 MUNIT,MBOUND,NUNIT,NBOUND
  4  2  5  4        $G-1 MUNIT,MBOUND,NUNIT,NBOUND
  5  1  6 -2        $G-1 MUNIT,MBOUND,NUNIT,NBOUND
$ junction at xinput(2)...
  1  3  7  1        $G-1 MUNIT,MBOUND,NUNIT,NBOUND
  2  3  8  1        $G-1 MUNIT,MBOUND,NUNIT,NBOUND
  4  3  9  1        $G-1 MUNIT,MBOUND,NUNIT,NBOUND
  5  3 10  1        $G-1 MUNIT,MBOUND,NUNIT,NBOUND
  7  2  8  4        $G-1 MUNIT,MBOUND,NUNIT,NBOUND
  8  2  9  4        $G-1 MUNIT,MBOUND,NUNIT,NBOUND
  9  2 10  4        $G-1 MUNIT,MBOUND,NUNIT,NBOUND
$ junction at xinput(3)...
  7  3 11  1        $G-1 MUNIT,MBOUND,NUNIT,NBOUND
  8  3 12  1        $G-1 MUNIT,MBOUND,NUNIT,NBOUND
  9  3 13  1        $G-1 MUNIT,MBOUND,NUNIT,NBOUND
 10  3 14  1        $G-1 MUNIT,MBOUND,NUNIT,NBOUND
 11  2 12  4        $G-1 MUNIT,MBOUND,NUNIT,NBOUND
 12  2 13  4        $G-1 MUNIT,MBOUND,NUNIT,NBOUND
 13  2 14  4        $G-1 MUNIT,MBOUND,NUNIT,NBOUND
$ junction at xinput(4)...
 11  3 15  1        $G-1 MUNIT,MBOUND,NUNIT,NBOUND
 12  3 16  1        $G-1 MUNIT,MBOUND,NUNIT,NBOUND
 13  3 17  1        $G-1 MUNIT,MBOUND,NUNIT,NBOUND
 14  3 18  1        $G-1 MUNIT,MBOUND,NUNIT,NBOUND
 15  2 16  4        $G-1 MUNIT,MBOUND,NUNIT,NBOUND
 16  2 17  4        $G-1 MUNIT,MBOUND,NUNIT,NBOUND
 17  2 18  4        $G-1 MUNIT,MBOUND,NUNIT,NBOUND
$ junction at xinput(5)...
 15  3 19  1        $G-1 MUNIT,MBOUND,NUNIT,NBOUND
 16  3 20  1        $G-1 MUNIT,MBOUND,NUNIT,NBOUND
 17  3 21  1        $G-1 MUNIT,MBOUND,NUNIT,NBOUND
 18  3 22  1        $G-1 MUNIT,MBOUND,NUNIT,NBOUND
 19  2 20  4        $G-1 MUNIT,MBOUND,NUNIT,NBOUND
```

```
 20  2 21  4         $G-1 MUNIT,MBOUND,NUNIT,NBOUND
 21  2 22  4         $G-1 MUNIT,MBOUND,NUNIT,NBOUND
$ junction at xinput(6)...
 19  3 23  1         $G-1 MUNIT,MBOUND,NUNIT,NBOUND
 20  3 24  1         $G-1 MUNIT,MBOUND,NUNIT,NBOUND
 21  3 25  1         $G-1 MUNIT,MBOUND,NUNIT,NBOUND
 22  3 26  1         $G-1 MUNIT,MBOUND,NUNIT,NBOUND
 23  2 24  4         $G-1 MUNIT,MBOUND,NUNIT,NBOUND
 24  2 25  4         $G-1 MUNIT,MBOUND,NUNIT,NBOUND
 25  2 26  4         $G-1 MUNIT,MBOUND,NUNIT,NBOUND
$ junction at xinput(7)...
 23  3 27  1         $G-1 MUNIT,MBOUND,NUNIT,NBOUND
 24  3 28  1         $G-1 MUNIT,MBOUND,NUNIT,NBOUND
 25  3 29  1         $G-1 MUNIT,MBOUND,NUNIT,NBOUND
 26  3 30  1         $G-1 MUNIT,MBOUND,NUNIT,NBOUND
 27  2 28  4         $G-1 MUNIT,MBOUND,NUNIT,NBOUND
 28  2 29  4         $G-1 MUNIT,MBOUND,NUNIT,NBOUND
 29  2 30  4         $G-1 MUNIT,MBOUND,NUNIT,NBOUND
$ junction at xinput(8)...
 27  3 31  1         $G-1 MUNIT,MBOUND,NUNIT,NBOUND
 28  3 32  1         $G-1 MUNIT,MBOUND,NUNIT,NBOUND
 29  3 33  1         $G-1 MUNIT,MBOUND,NUNIT,NBOUND
 30  3 34  1         $G-1 MUNIT,MBOUND,NUNIT,NBOUND
 31  2 32  4         $G-1 MUNIT,MBOUND,NUNIT,NBOUND
 32  2 33  4         $G-1 MUNIT,MBOUND,NUNIT,NBOUND
 33  2 34  4         $G-1 MUNIT,MBOUND,NUNIT,NBOUND
$ junction at xinput(9)...
 31  3 35  1         $G-1 MUNIT,MBOUND,NUNIT,NBOUND
 32  3 36  1         $G-1 MUNIT,MBOUND,NUNIT,NBOUND
 33  3 37  1         $G-1 MUNIT,MBOUND,NUNIT,NBOUND
 34  3 38  1         $G-1 MUNIT,MBOUND,NUNIT,NBOUND
 35  2 36  4         $G-1 MUNIT,MBOUND,NUNIT,NBOUND
 36  2 37  4         $G-1 MUNIT,MBOUND,NUNIT,NBOUND
 37  2 38  4         $G-1 MUNIT,MBOUND,NUNIT,NBOUND
$ junction at xinput(10)...
 35  3 39  1         $G-1 MUNIT,MBOUND,NUNIT,NBOUND
 36  3 40  1         $G-1 MUNIT,MBOUND,NUNIT,NBOUND
 37  3 41  1         $G-1 MUNIT,MBOUND,NUNIT,NBOUND
 38  3 42  1         $G-1 MUNIT,MBOUND,NUNIT,NBOUND
 39  2 40  4         $G-1 MUNIT,MBOUND,NUNIT,NBOUND
 40  2 41  4         $G-1 MUNIT,MBOUND,NUNIT,NBOUND
 41  2 42  4         $G-1 MUNIT,MBOUND,NUNIT,NBOUND
$ junction at xinput(11)...
 39  3 43  1         $G-1 MUNIT,MBOUND,NUNIT,NBOUND
 40  3 44  1         $G-1 MUNIT,MBOUND,NUNIT,NBOUND
 41  3 45  1         $G-1 MUNIT,MBOUND,NUNIT,NBOUND
 42  3 46  1         $G-1 MUNIT,MBOUND,NUNIT,NBOUND
 43  2 44  4         $G-1 MUNIT,MBOUND,NUNIT,NBOUND
 44  2 45  4         $G-1 MUNIT,MBOUND,NUNIT,NBOUND
 45  2 46  4         $G-1 MUNIT,MBOUND,NUNIT,NBOUND
$ junction at xinput(12)...
 43  3 47  1         $G-1 MUNIT,MBOUND,NUNIT,NBOUND
 44  3 48  1         $G-1 MUNIT,MBOUND,NUNIT,NBOUND
 45  3 49  1         $G-1 MUNIT,MBOUND,NUNIT,NBOUND
 46  3 50  1         $G-1 MUNIT,MBOUND,NUNIT,NBOUND
 47  2 48  4         $G-1 MUNIT,MBOUND,NUNIT,NBOUND
 48  2 49  4         $G-1 MUNIT,MBOUND,NUNIT,NBOUND
```

```
 49  2 50  4         $G-1 MUNIT,MBOUND,NUNIT,NBOUND
$ Materials...
  1  7  1  1  0  0  $I-1 ITAM,NESP,IPLST,ITANST,ICREEP,IPLANE
 16.E+06  0.25  0.0  0.16  0.0  16.E+06  0. $I-2 E1,U12,G,RHO,A1,E2,A2
  .0075 120000.,     $I-3 E(i), S(i)
  .0088 138000.,     $I-3 E(i), S(i)
  .0102 148000.,     $I-3 E(i), S(i)
  .0122 156000.,     $I-3 E(i), S(i)
  .0156 164000.,     $I-3 E(i), S(i)
  .0200 165000.,     $I-3 E(i), S(i)
  .0400 166000.      $I-3 E(i), S(i)
  2  7  1  1  0  0  $I-1 ITAM,NESP,IPLST,ITANST,ICREEP,IPLANE
 496894.4 .333 0. .004969 496894.4 0. $I-2 E1,U12,G,RHO,A1,E2,A2
  .0075 3726.710,     $I-3 E(i), S(i)
  .0088 4285.710,     $I-3 E(i), S(i)
  .0102 4596.270,     $I-3 E(i), S(i)
  .0122 4844.720,     $I-3 E(i), S(i)
  .0156 5093.170,     $I-3 E(i), S(i)
  .0200 5124.220,     $I-3 E(i), S(i)
  .0400 5155.280      $I-3 E(i), S(i)
C
C New section added for GCP records
C
C GCP Material in one or more of shell unit walls
PLASTIC_WB_MATERIAL   1 1 1 2 0  $ I-5a matid,ngroups,nstates.onetwo
 16.E+06 0.25 0.16 0.0 7 0.      $ I-9a E,GNU,RHO,ALPHA,NSUBS,T
 .0075 120000. .0088 138000.,    $ I-9b strain, stress material 1
 .0102 148000. .0122 156000.,    $ I-9b strain, stress material 1
 .0156 164000. .0200 165000.,    $ I-9b strain, stress material 1
 .0400 166000.                   $ I-9b strain, stress material 1
C
PLASTIC_WB_MATERIAL   2 1 1 2 0  $ I-5a matid,ngroups,nstates.onetwo
 496894.4 0.333 0.004969 0. 7 0. $ I-9a E,GNU,RHO,ALPHA,NSUBS,T
 .0075 3726.71 .0088 4285.71,    $ I-9b strain, stress material 2
 .0102 4596.27 .0122 4844.72,    $ I-9b strain, stress material 2
 .0156 5093.17 .0200 5124.22,    $ I-9b strain, stress material 2
 .0400 5155.28                   $ I-9b strain, stress material 2
C
C shell unit wall props
SHELL_FABRICATION -1 2 1 0 0 $ I-5a fabid,nlayer,ipts,ishr,isym
 2  1  $ I-21a  MATID(j), j = 1,nlayer
 1  5  $ I=21b INTSHL(j), j = 1,nlayer
 1.0E-06 0.4  $ I-21c THKSHL(j), j=1,nlayer
 0.0   0.0    $ I-21d ANGSHL(j), j=1,nlayer
C
END     $ I-5a cease (end of GCP input data, all matl,all walls)
C
C wall properties for the six segments of the soccerball apex...
  1  1  2  5  0      $K-1 ITAW,KWALL,NLAY,NLIP,NSMRS
  2  .000001  0.  0 $K-2 MATL,TL,XETL,LSOL
  1  .4  0.  0 $K-2 MATL,TL,XETL,LSOL
C
$ Soccerball apex follows (2 x three shell units)...
$ First 90-degree (0 - 90 deg) group of 3 units...
$ Unit 1: Right pie segment
  1  0  0  0  0  0  $M-1 ISHELL,IGLOBE,NROWS,NCOLS,NLAYS,NFABS
  0. 2.958103  0. 45. 49.5  0. 90.
```

```
 -1  0  0. 0.  0  1  0 $M-5 IWALL,IWIMP,ZETA,ECZ,ILIN,IPLAS,IRAMP
  410               $N-1 KELT
  6  6  6  4  0     $P-1 IBLN(i), i=1,4, IBOND
  1  0  0  0  0  0  0 $Q-1 NSYS,NICS,NAMS,NUSS,NHINGE,etc.
  1  1  0           $Q-2 ISYS,NN,IFLG
 -460.  5  3  0  0  0 $Q-3 P,LT,LD,LI,LJ,LAX
  0  0  0  0  0     $R-1 IPRD,IPRR,IPRE,IPRS,IPRP
$ Unit 2: Left pie segment
  1  0  0  0  0  0  $M-1 ISHELL,IGLOBE,NROWS,NCOLS,NLAYS,NFABS
  0. 2.958103  45. 90. 49.5  0. 90.
 -1  0  0. 0.  0  1  0 $M-5 IWALL,IWIMP,ZETA,ECZ,ILIN,IPLAS,IRAMP
  410               $N-1 KELT
  6  6  6  6  0     $P-1 IBLN(i), i=1,4, IBOND
  1  0  0  0  0  0  0 $Q-1 NSYS,NICS,NAMS,NUSS,NHINGE,etc.
  1  1  0           $Q-2 ISYS,NN,IFLG
 -460.  5  3  0  0  0 $Q-3 P,LT,LD,LI,LJ,LAX
  0  0  0  0  0     $R-1 IPRD,IPRR,IPRE,IPRS,IPRP
$ Unit 3: inner square
  1  0  0  0  0  0  $M-1 ISHELL,IGLOBE,NROWS,NCOLS,NLAYS,NFABS
  0. 2.958103  0. 90. 49.5  0. 90.
 -1  0  0. 0.  0  1  0 $M-5 IWALL,IWIMP,ZETA,ECZ,ILIN,IPLAS,IRAMP
  410               $N-1 KELT
  6  6  6  4  0     $P-1 IBLN(i), i=1,4, IBOND
  1  0  0  0  0  0  0 $Q-1 NSYS,NICS,NAMS,NUSS,NHINGE,etc.
  1  1  0           $Q-2 ISYS,NN,IFLG
 -460.  5  3  0  0  0 $Q-3 P,LT,LD,LI,LJ,LAX
  0  0  0  0  0     $R-1 IPRD,IPRR,IPRE,IPRS,IPRP
$ Second 90-degree (90 - 180 deg) group of 3 units...
$ Unit 1: Right pie segment  (Shell unit 4)
  1  1  0  0  0  0  $M-1 ISHELL,IGLOBE,NROWS,NCOLS,NLAYS,NFABS
  0. 2.958103   0. 45. 49.5   0. 90.
 -1  0  0. 0.  0  1  0 $M-5 IWALL,IWIMP,ZETA,ECZ,ILIN,IPLAS,IRAMP
  410               $N-1 KELT
  6  6  6  6  0     $P-1 IBLN(i), i=1,4, IBOND
  1  0  0  0  0  0  0 $Q-1 NSYS,NICS,NAMS,NUSS,NHINGE,etc.
  1  1  0           $Q-2 ISYS,NN,IFLG
 -460.  5  3  0  0  0 $Q-3 P,LT,LD,LI,LJ,LAX
  0  0  0  0  0     $R-1 IPRD,IPRR,IPRE,IPRS,IPRP
$ Unit 2: Left pie segment  (Shell unit 5)
  1  1  0  0  0  0  $M-1 ISHELL,IGLOBE,NROWS,NCOLS,NLAYS,NFABS
  0. 2.958103  45. 90. 49.5  0. 90.
 -1  0  0. 0.  0  1  0 $M-5 IWALL,IWIMP,ZETA,ECZ,ILIN,IPLAS,IRAMP
  410               $N-1 KELT
  6  4  6  6  0     $P-1 IBLN(i), i=1,4, IBOND
  1  0  0  0  0  0  0 $Q-1 NSYS,NICS,NAMS,NUSS,NHINGE,etc.
  1  1  0           $Q-2 ISYS,NN,IFLG
 -460.  5  3  0  0  0 $Q-3 P,LT,LD,LI,LJ,LAX
  0  0  0  0  0     $R-1 IPRD,IPRR,IPRE,IPRS,IPRP
$ Unit 3: inner square      (Shell unit 6)
  1  1  0  0  0  0  $M-1 ISHELL,IGLOBE,NROWS,NCOLS,NLAYS,NFABS
  0. 2.958103  0. 90. 49.5  0. 90.
 -1  0  0. 0.  0  1  0 $M-5 IWALL,IWIMP,ZETA,ECZ,ILIN,IPLAS,IRAMP
  410               $N-1 KELT
  4  6  6  6  0     $P-1 IBLN(i), i=1,4, IBOND
  1  0  0  0  0  0  0 $Q-1 NSYS,NICS,NAMS,NUSS,NHINGE,etc.
  1  1  0           $Q-2 ISYS,NN,IFLG
 -460.  5  3  0  0  0 $Q-3 P,LT,LD,LI,LJ,LAX
```

```
  0  0  0  0  0     $R-1 IPRD,IPRR,IPRE,IPRS,IPRP
$ The remainder of the shell follows (2 x 22 shell units)...
C original unit 2 = toroidal, now unit 7  (0 - 45 degrees)
  8  1  0  0  0  0  $M-1 ISHELL,IGLOBE,NROWS,NCOLS,NLAYS,NFABS
  2.957441 6.69448 0. 45. .08364234 47.890324 $M-2 PH1,PH2,THET1,
                                            $    THET2,Ra,Rb
 -1  0  0. 0. 0  1  0 $M-5 IWALL,IWIMP,ZETA,ECZ,ILIN,IPLAS,IRAMP
  410               $N-1 KELT
  6  6  6  4  0     $P-1 IBLN(i), i=1,4, IBOND
  1  0  0  0  0  0  0 $Q-1 NSYS,NICS,NAMS,NUSS,NHINGE,etc.
  1  1  0           $Q-2 ISYS,NN,IFLG
 -460.  5  3  0  0  0 $Q-3 P,LT,LD,LI,LJ,LAX
  0  0  0  0  0     $R-1 IPRD,IPRR,IPRE,IPRS,IPRP
C original unit 2 = toroidal now unit 8  (45 - 90 degrees)
  8  1  0  0  0  0  $M-1 ISHELL,IGLOBE,NROWS,NCOLS,NLAYS,NFABS
  2.957441 6.69448 45. 90. .08364234 47.890324 $M-2 PH1,PH2,THET1,
                                             $    THET2,Ra,Rb
 -1  0  0. 0. 0  1  0 $M-5 IWALL,IWIMP,ZETA,ECZ,ILIN,IPLAS,IRAMP
  410               $N-1 KELT
  6  6  6  6  0     $P-1 IBLN(i), i=1,4, IBOND
  1  0  0  0  0  0  0 $Q-1 NSYS,NICS,NAMS,NUSS,NHINGE,etc.
  1  1  0           $Q-2 ISYS,NN,IFLG
 -460.  5  3  0  0  0 $Q-3 P,LT,LD,LI,LJ,LAX
  0  0  0  0  0     $R-1 IPRD,IPRR,IPRE,IPRS,IPRP
C original unit 2 = toroidal, now unit 9  (90 - 135 degrees)
  8  1  0  0  0  0  $M-1 ISHELL,IGLOBE,NROWS,NCOLS,NLAYS,NFABS
  2.957441 6.69448 90. 135. .08364234 47.890324 $M-2 PH1,PH2,THET1,
                                              $    THET2,Ra,Rb
 -1  0  0. 0. 0  1  0 $M-5 IWALL,IWIMP,ZETA,ECZ,ILIN,IPLAS,IRAMP
  410               $N-1 KELT
  6  6  6  6  0     $P-1 IBLN(i), i=1,4, IBOND
  1  0  0  0  0  0  0 $Q-1 NSYS,NICS,NAMS,NUSS,NHINGE,etc.
  1  1  0           $Q-2 ISYS,NN,IFLG
 -460.  5  3  0  0  0 $Q-3 P,LT,LD,LI,LJ,LAX
  0  0  0  0  0     $R-1 IPRD,IPRR,IPRE,IPRS,IPRP
C original unit 2 = toroidal now unit 10  (135 - 180 degrees)
  8  1  0  0  0  0  $M-1 ISHELL,IGLOBE,NROWS,NCOLS,NLAYS,NFABS
  2.957441 6.69448  135. 180. .08364234 47.890324 $M-2 PH1,PH2,THET1,
                                                $    THET2,Ra,Rb
 -1  0  0. 0. 0  1  0 $M-5 IWALL,IWIMP,ZETA,ECZ,ILIN,IPLAS,IRAMP
  410               $N-1 KELT
  6  4  6  6  0     $P-1 IBLN(i), i=1,4, IBOND
  1  0  0  0  0  0  0 $Q-1 NSYS,NICS,NAMS,NUSS,NHINGE,etc.
  1  1  0           $Q-2 ISYS,NN,IFLG
 -460.  5  3  0  0  0 $Q-3 P,LT,LD,LI,LJ,LAX
  0  0  0  0  0     $R-1 IPRD,IPRR,IPRE,IPRS,IPRP
C original unit 3 = toroidal now unit 11
  8  1  0  0  0  0  $M-1 ISHELL,IGLOBE,NROWS,NCOLS,NLAYS,NFABS
  6.67782 10.67682 0. 45. .4623073 44.752884 $M-2 PH1,PH2,THET1,
                                          $    THET2,Ra,Rb
 -1  0  0. 0. 0  1  0 $M-5 IWALL,IWIMP,ZETA,ECZ,ILIN,IPLAS,IRAMP
  410               $N-1 KELT
  6  6  6  4  0     $P-1 IBLN(i), i=1,4, IBOND
  1  0  0  0  0  0  0 $Q-1 NSYS,NICS,NAMS,NUSS,NHINGE,etc.
  1  1  0           $Q-2 ISYS,NN,IFLG
 -460.  5  3  0  0  0 $Q-3 P,LT,LD,LI,LJ,LAX
  0  0  0  0  0     $R-1 IPRD,IPRR,IPRE,IPRS,IPRP
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C original unit 3 = toroidal now unit 12
  8  1  0  0  0  0  $M-1 ISHELL,IGLOBE,NROWS,NCOLS,NLAYS,NFABS
  6.67782 10.67682 45. 90. .4623073 44.752884 $M-2 PH1,PH2,THET1,
                                              $    THET2,Ra,Rb
 -1  0  0. 0. 0  1  0 $M-5 IWALL,IWIMP,ZETA,ECZ,ILIN,IPLAS,IRAMP
  410               $N-1 KELT
  6  6  6  6  0     $P-1 IBLN(i), i=1,4, IBOND
  1  0  0  0  0  0  0 $Q-1 NSYS,NICS,NAMS,NUSS,NHINGE,etc.
  1  1  0           $Q-2 ISYS,NN,IFLG
 -460.  5  3  0  0  0 $Q-3 P,LT,LD,LI,LJ,LAX
  0  0  0  0  0     $R-1 IPRD,IPRR,IPRE,IPRS,IPRP
C original unit 3 = toroidal now unit 13
  8  1  0  0  0  0  $M-1 ISHELL,IGLOBE,NROWS,NCOLS,NLAYS,NFABS
  6.67782 10.67682 90. 135. .4623073 44.752884 $M-2 PH1,PH2,THET1,
                                               $    THET2,Ra,Rb
 -1  0  0. 0. 0  1  0 $M-5 IWALL,IWIMP,ZETA,ECZ,ILIN,IPLAS,IRAMP
  410               $N-1 KELT
  6  6  6  6  0     $P-1 IBLN(i), i=1,4, IBOND
  1  0  0  0  0  0  0 $Q-1 NSYS,NICS,NAMS,NUSS,NHINGE,etc.
  1  1  0           $Q-2 ISYS,NN,IFLG
 -460.  5  3  0  0  0 $Q-3 P,LT,LD,LI,LJ,LAX
  0  0  0  0  0     $R-1 IPRD,IPRR,IPRE,IPRS,IPRP
C original unit 3 = toroidal now unit 14
  8  1  0  0  0  0  $M-1 ISHELL,IGLOBE,NROWS,NCOLS,NLAYS,NFABS
  6.67782 10.67682  135. 180. .4623073 44.752884 $M-2 PH1,PH2,THET1,
                                                 $    THET2,Ra,Rb
 -1  0  0. 0. 0  1  0 $M-5 IWALL,IWIMP,ZETA,ECZ,ILIN,IPLAS,IRAMP
  410               $N-1 KELT
  6  4  6  6  0     $P-1 IBLN(i), i=1,4, IBOND
  1  0  0  0  0  0  0 $Q-1 NSYS,NICS,NAMS,NUSS,NHINGE,etc.
  1  1  0           $Q-2 ISYS,NN,IFLG
 -460.  5  3  0  0  0 $Q-3 P,LT,LD,LI,LJ,LAX
  0  0  0  0  0     $R-1 IPRD,IPRR,IPRE,IPRS,IPRP
C original unit 4 = toroidal now unit 15
  8  1  0  0  0  0  $M-1 ISHELL,IGLOBE,NROWS,NCOLS,NLAYS,NFABS
  10.65673 15.12016 0. 45. 1.338907 40.095947 $M-2 PH1,PH2,THET1,
                                              $    THET2,Ra,Rb
 -1  0  0. 0. 0  1  0 $M-5 IWALL,IWIMP,ZETA,ECZ,ILIN,IPLAS,IRAMP
  410               $N-1 KELT
  6  6  6  4  0     $P-1 IBLN(i), i=1,4, IBOND
  2  0  0  0  0  0  0 $Q-1 NSYS,NICS,NAMS,NUSS,NHINGE,etc.
  1  1  0           $Q-2 ISYS,NN,IFLG
 -460.  5  3  0  0  0 $Q-3 P,LT,LD,LI,LJ,LAX
  2  1  0           $Q-2 ISYS,NN,IFLG
 -1.  5  3  1  1  0 $Q-3 P,LT,LD,LI,LJ,LAX
  0  0  0  0  0     $R-1 IPRD,IPRR,IPRE,IPRS,IPRP
C original unit 4 = toroidal now unit 16
  8  1  0  0  0  0  $M-1 ISHELL,IGLOBE,NROWS,NCOLS,NLAYS,NFABS
  10.65673 15.12016 45. 90. 1.338907 40.095947 $M-2 PH1,PH2,THET1,
                                               $    THET2,Ra,Rb
 -1  0  0. 0. 0  1  0 $M-5 IWALL,IWIMP,ZETA,ECZ,ILIN,IPLAS,IRAMP
  410               $N-1 KELT
  6  6  6  6  0     $P-1 IBLN(i), i=1,4, IBOND
  1  0  0  0  0  0  0 $Q-1 NSYS,NICS,NAMS,NUSS,NHINGE,etc.
  1  1  0           $Q-2 ISYS,NN,IFLG
 -460.  5  3  0  0  0 $Q-3 P,LT,LD,LI,LJ,LAX
  0  0  0  0  0     $R-1 IPRD,IPRR,IPRE,IPRS,IPRP
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C original unit 4 = toroidal now unit 17
  8  1  0  0  0  0  $M-1 ISHELL,IGLOBE,NROWS,NCOLS,NLAYS,NFABS
  10.65673 15.12016 90. 135. 1.338907 40.095947 $M-2 PH1,PH2,THET1,
                                                $    THET2,Ra,Rb
 -1  0  0. 0. 0  1  0 $M-5 IWALL,IWIMP,ZETA,ECZ,ILIN,IPLAS,IRAMP
  410               $N-1 KELT
  6  6  6  6  0     $P-1 IBLN(i), i=1,4, IBOND
  1  0  0  0  0  0  0 $Q-1 NSYS,NICS,NAMS,NUSS,NHINGE,etc.
  1  1  0           $Q-2 ISYS,NN,IFLG
 -460.  5  3  0  0  0 $Q-3 P,LT,LD,LI,LJ,LAX
  0  0  0  0  0     $R-1 IPRD,IPRR,IPRE,IPRS,IPRP
C original unit 4 = toroidal now unit 18
  8  1  0  0  0  0  $M-1 ISHELL,IGLOBE,NROWS,NCOLS,NLAYS,NFABS
  10.65673 15.12016  135. 180. 1.338907 40.095947 $M-2 PH1,PH2,THET1,
                                                  $    THET2,Ra,Rb
 -1  0  0. 0. 0  1  0 $M-5 IWALL,IWIMP,ZETA,ECZ,ILIN,IPLAS,IRAMP
  410               $N-1 KELT
  6  4  6  6  0     $P-1 IBLN(i), i=1,4, IBOND
  1  0  0  0  0  0  0 $Q-1 NSYS,NICS,NAMS,NUSS,NHINGE,etc.
  1  1  0           $Q-2 ISYS,NN,IFLG
 -460.  5  3  0  0  0 $Q-3 P,LT,LD,LI,LJ,LAX
  0  0  0  0  0     $R-1 IPRD,IPRR,IPRE,IPRS,IPRP
C original unit 5 = toroidal now unit 19
  8  1  0  0  0  0  $M-1 ISHELL,IGLOBE,NROWS,NCOLS,NLAYS,NFABS
  15.08829 20.32144 0. 45. 2.895449 34.199043 $M-2 PH1,PH2,THET1,
                                              $    THET2,Ra,Rb
 -1  0  0. 0. 0  1  0 $M-5 IWALL,IWIMP,ZETA,ECZ,ILIN,IPLAS,IRAMP
  410               $N-1 KELT
  6  6  6  4  0     $P-1 IBLN(i), i=1,4, IBOND
  1  0  0  0  0  0  0 $Q-1 NSYS,NICS,NAMS,NUSS,NHINGE,etc.
  1  1  0           $Q-2 ISYS,NN,IFLG
 -460.  5  3  0  0  0 $Q-3 P,LT,LD,LI,LJ,LAX
  0  0  0  0  0     $R-1 IPRD,IPRR,IPRE,IPRS,IPRP
C original unit 5 = toroidal now unit 20
  8  1  0  0  0  0  $M-1 ISHELL,IGLOBE,NROWS,NCOLS,NLAYS,NFABS
  15.08829 20.32144 45. 90. 2.895449 34.199043 $M-2 PH1,PH2,THET1,
                                               $    THET2,Ra,Rb
 -1  0  0. 0. 0  1  0 $M-5 IWALL,IWIMP,ZETA,ECZ,ILIN,IPLAS,IRAMP
  410               $N-1 KELT
  6  6  6  6  0     $P-1 IBLN(i), i=1,4, IBOND
  1  0  0  0  0  0  0 $Q-1 NSYS,NICS,NAMS,NUSS,NHINGE,etc.
  1  1  0           $Q-2 ISYS,NN,IFLG
 -460.  5  3  0  0  0 $Q-3 P,LT,LD,LI,LJ,LAX
  0  0  0  0  0     $R-1 IPRD,IPRR,IPRE,IPRS,IPRP
C original unit 5 = toroidal now unit 21
  8  1  0  0  0  0  $M-1 ISHELL,IGLOBE,NROWS,NCOLS,NLAYS,NFABS
  15.08829 20.32144 90. 135. 2.895449 34.199043 $M-2 PH1,PH2,THET1,
                                                $    THET2,Ra,Rb
 -1  0  0. 0. 0  1  0 $M-5 IWALL,IWIMP,ZETA,ECZ,ILIN,IPLAS,IRAMP
  410               $N-1 KELT
  6  6  6  6  0     $P-1 IBLN(i), i=1,4, IBOND
  1  0  0  0  0  0  0 $Q-1 NSYS,NICS,NAMS,NUSS,NHINGE,etc.
  1  1  0           $Q-2 ISYS,NN,IFLG
 -460.  5  3  0  0  0 $Q-3 P,LT,LD,LI,LJ,LAX
  0  0  0  0  0     $R-1 IPRD,IPRR,IPRE,IPRS,IPRP
C original unit 5 = toroidal now unit 22
  8  1  0  0  0  0  $M-1 ISHELL,IGLOBE,NROWS,NCOLS,NLAYS,NFABS
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  15.08829 20.32144  135. 180. 2.895449 34.199043 $M-2 PH1,PH2,THET1,
                                                  $    THET2,Ra,Rb
 -1  0  0. 0. 0  1  0 $M-5 IWALL,IWIMP,ZETA,ECZ,ILIN,IPLAS,IRAMP
  410                $N-1 KELT
  6  4  6  6  0      $P-1 IBLN(i), i=1,4, IBOND
  1  0  0  0  0  0  0 $Q-1 NSYS,NICS,NAMS,NUSS,NHINGE,etc.
  1  1  0            $Q-2 ISYS,NN,IFLG
 -460.  5  3  0  0  0 $Q-3 P,LT,LD,LI,LJ,LAX
  0  0  0  0  0      $R-1 IPRD,IPRR,IPRE,IPRS,IPRP
C original unit 6 = toroidal now unit 23
  8  1  0  0  0  0   $M-1 ISHELL,IGLOBE,NROWS,NCOLS,NLAYS,NFABS
  20.26536 26.78145 0. 45. 5.259145 27.465466 $M-2 PH1,PH2,THET1,
                                              $    THET2,Ra,Rb
 -1  0  0. 0. 0  1  0 $M-5 IWALL,IWIMP,ZETA,ECZ,ILIN,IPLAS,IRAMP
  410                $N-1 KELT
  6  6  6  4  0      $P-1 IBLN(i), i=1,4, IBOND
  1  0  0  0  0  0  0 $Q-1 NSYS,NICS,NAMS,NUSS,NHINGE,etc.
  1  1  0            $Q-2 ISYS,NN,IFLG
 -460.  5  3  0  0  0 $Q-3 P,LT,LD,LI,LJ,LAX
  0  0  0  0  0      $R-1 IPRD,IPRR,IPRE,IPRS,IPRP
C original unit 6 = toroidal now unit 24
  8  1  0  0  0  0   $M-1 ISHELL,IGLOBE,NROWS,NCOLS,NLAYS,NFABS
  20.26536 26.78145 45. 90. 5.259145 27.465466 $M-2 PH1,PH2,THET1,
                                               $    THET2,Ra,Rb
 -1  0  0. 0. 0  1  0 $M-5 IWALL,IWIMP,ZETA,ECZ,ILIN,IPLAS,IRAMP
  410                $N-1 KELT
  6  6  6  6  0      $P-1 IBLN(i), i=1,4, IBOND
  1  0  0  0  0  0  0 $Q-1 NSYS,NICS,NAMS,NUSS,NHINGE,etc.
  1  1  0            $Q-2 ISYS,NN,IFLG
 -460.  5  3  0  0  0 $Q-3 P,LT,LD,LI,LJ,LAX
  0  0  0  0  0      $R-1 IPRD,IPRR,IPRE,IPRS,IPRP
C original unit 6 = toroidal now unit 25
  8  1  0  0  0  0   $M-1 ISHELL,IGLOBE,NROWS,NCOLS,NLAYS,NFABS
  20.26536 26.78145 90. 135. 5.259145 27.465466 $M-2 PH1,PH2,THET1,
                                                $    THET2,Ra,Rb
 -1  0  0. 0. 0  1  0 $M-5 IWALL,IWIMP,ZETA,ECZ,ILIN,IPLAS,IRAMP
  410                $N-1 KELT
  6  6  6  6  0      $P-1 IBLN(i), i=1,4, IBOND
  1  0  0  0  0  0  0 $Q-1 NSYS,NICS,NAMS,NUSS,NHINGE,etc.
  1  1  0            $Q-2 ISYS,NN,IFLG
 -460.  5  3  0  0  0 $Q-3 P,LT,LD,LI,LJ,LAX
  0  0  0  0  0      $R-1 IPRD,IPRR,IPRE,IPRS,IPRP
C original unit 6 = toroidal now unit 26
  8  1  0  0  0  0   $M-1 ISHELL,IGLOBE,NROWS,NCOLS,NLAYS,NFABS
  20.26536 26.78145  135. 180. 5.259145 27.465466 $M-2 PH1,PH2,THET1,
                                                  $    THET2,Ra,Rb
 -1  0  0. 0. 0  1  0 $M-5 IWALL,IWIMP,ZETA,ECZ,ILIN,IPLAS,IRAMP
  410                $N-1 KELT
  6  4  6  6  0      $P-1 IBLN(i), i=1,4, IBOND
  1  0  0  0  0  0  0 $Q-1 NSYS,NICS,NAMS,NUSS,NHINGE,etc.
  1  1  0            $Q-2 ISYS,NN,IFLG
 -460.  5  3  0  0  0 $Q-3 P,LT,LD,LI,LJ,LAX
  0  0  0  0  0      $R-1 IPRD,IPRR,IPRE,IPRS,IPRP
C original unit 7 = toroidal now unit 27
  8  1  0  0  0  0   $M-1 ISHELL,IGLOBE,NROWS,NCOLS,NLAYS,NFABS
  26.79548 32.96853 0. 45. 7.971097 21.436380 $M-2 PH1,PH2,THET1,
                                              $    THET2,Ra,Rb
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 -1  0  0. 0.  0  1  0 $M-5 IWALL,IWIMP,ZETA,ECZ,ILIN,IPLAS,IRAMP
  410                  $N-1 KELT
  6  6  6  4  0        $P-1 IBLN(i), i=1,4, IBOND
  1  0  0  0  0  0  0 $Q-1 NSYS,NICS,NAMS,NUSS,NHINGE,etc.
  1  1  0              $Q-2 ISYS,NN,IFLG
 -460.  5  3  0  0  0 $Q-3 P,LT,LD,LI,LJ,LAX
  0  0  0  0  0        $R-1 IPRD,IPRR,IPRE,IPRS,IPRP
C original unit 7 = toroidal now unit 28
  8  1  0  0  0  0  $M-1 ISHELL,IGLOBE,NROWS,NCOLS,NLAYS,NFABS
  26.79548 32.96853 45. 90. 7.971097 21.436380 $M-2 PH1,PH2,THET1,
                                               $    THET2,Ra,Rb
 -1  0  0. 0.  0  1  0 $M-5 IWALL,IWIMP,ZETA,ECZ,ILIN,IPLAS,IRAMP
  410                  $N-1 KELT
  6  6  6  6  0        $P-1 IBLN(i), i=1,4, IBOND
  1  0  0  0  0  0  0 $Q-1 NSYS,NICS,NAMS,NUSS,NHINGE,etc.
  1  1  0              $Q-2 ISYS,NN,IFLG
 -460.  5  3  0  0  0 $Q-3 P,LT,LD,LI,LJ,LAX
  0  0  0  0  0        $R-1 IPRD,IPRR,IPRE,IPRS,IPRP
C original unit 7 = toroidal now unit 29
  8  1  0  0  0  0  $M-1 ISHELL,IGLOBE,NROWS,NCOLS,NLAYS,NFABS
  26.79548 32.96853 90. 135. 7.971097 21.436380 $M-2 PH1,PH2,THET1,
                                                $    THET2,Ra,Rb
 -1  0  0. 0.  0  1  0 $M-5 IWALL,IWIMP,ZETA,ECZ,ILIN,IPLAS,IRAMP
  410                  $N-1 KELT
  6  6  6  6  0        $P-1 IBLN(i), i=1,4, IBOND
  1  0  0  0  0  0  0 $Q-1 NSYS,NICS,NAMS,NUSS,NHINGE,etc.
  1  1  0              $Q-2 ISYS,NN,IFLG
 -460.  5  3  0  0  0 $Q-3 P,LT,LD,LI,LJ,LAX
  0  0  0  0  0        $R-1 IPRD,IPRR,IPRE,IPRS,IPRP
C original unit 7 = toroidal now unit 30
  8  1  0  0  0  0  $M-1 ISHELL,IGLOBE,NROWS,NCOLS,NLAYS,NFABS
  26.79548 32.96853  135. 180. 7.971097 21.436380 $M-2 PH1,PH2,THET1,
                                                  $    THET2,Ra,Rb
 -1  0  0. 0.  0  1  0 $M-5 IWALL,IWIMP,ZETA,ECZ,ILIN,IPLAS,IRAMP
  410                  $N-1 KELT
  6  4  6  6  0        $P-1 IBLN(i), i=1,4, IBOND
  1  0  0  0  0  0  0 $Q-1 NSYS,NICS,NAMS,NUSS,NHINGE,etc.
  1  1  0              $Q-2 ISYS,NN,IFLG
 -460.  5  3  0  0  0 $Q-3 P,LT,LD,LI,LJ,LAX
  0  0  0  0  0        $R-1 IPRD,IPRR,IPRE,IPRS,IPRP
C original unit 8 = toroidal now unit 31
  8  1  0  0  0  0  $M-1 ISHELL,IGLOBE,NROWS,NCOLS,NLAYS,NFABS
  32.94721 39.85107 0. 45. 10.52211 16.758169 $M-2 PH1,PH2,THET1,
                                              $    THET2,Ra,Rb
 -1  0  0. 0.  0  1  0 $M-5 IWALL,IWIMP,ZETA,ECZ,ILIN,IPLAS,IRAMP
  410                  $N-1 KELT
  6  6  6  4  0        $P-1 IBLN(i), i=1,4, IBOND
  1  0  0  0  0  0  0 $Q-1 NSYS,NICS,NAMS,NUSS,NHINGE,etc.
  1  1  0              $Q-2 ISYS,NN,IFLG
 -460.  5  3  0  0  0 $Q-3 P,LT,LD,LI,LJ,LAX
  0  0  0  0  0        $R-1 IPRD,IPRR,IPRE,IPRS,IPRP
C original unit 8 = toroidal now unit 32
  8  1  0  0  0  0  $M-1 ISHELL,IGLOBE,NROWS,NCOLS,NLAYS,NFABS
  32.94721 39.85107 45. 90. 10.52211 16.758169 $M-2 PH1,PH2,THET1,T
                                               $    THET2,Ra,Rb
 -1  0  0. 0.  0  1  0 $M-5 IWALL,IWIMP,ZETA,ECZ,ILIN,IPLAS,IRAMP
  410                  $N-1 KELT
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  6  6  6  6  0      $P-1 IBLN(i), i=1,4, IBOND
  1  0  0  0  0  0  0 $Q-1 NSYS,NICS,NAMS,NUSS,NHINGE,etc.
  1  1  0            $Q-2 ISYS,NN,IFLG
 -460.  5  3  0  0  0 $Q-3 P,LT,LD,LI,LJ,LAX
  0  0  0  0  0      $R-1 IPRD,IPRR,IPRE,IPRS,IPRP
C original unit 8 = toroidal now unit 33
  8  1  0  0  0  0  $M-1 ISHELL,IGLOBE,NROWS,NCOLS,NLAYS,NFABS
  32.94721 39.85107 90. 135. 10.52211 16.758169 $M-2 PH1,PH2,THET1,
                                                $    THET2,Ra,Rb
 -1  0  0. 0. 0  1  0 $M-5 IWALL,IWIMP,ZETA,ECZ,ILIN,IPLAS,IRAMP
  410                $N-1 KELT
  6  6  6  6  0      $P-1 IBLN(i), i=1,4, IBOND
  1  0  0  0  0  0  0 $Q-1 NSYS,NICS,NAMS,NUSS,NHINGE,etc.
  1  1  0            $Q-2 ISYS,NN,IFLG
 -460.  5  3  0  0  0 $Q-3 P,LT,LD,LI,LJ,LAX
  0  0  0  0  0      $R-1 IPRD,IPRR,IPRE,IPRS,IPRP
C original unit 8 = toroidal now unit 34
  8  1  0  0  0  0  $M-1 ISHELL,IGLOBE,NROWS,NCOLS,NLAYS,NFABS
  32.94721 39.85107  135. 180. 10.52211 16.758169 $M-2 PH1,PH2,THET1,
                                                  $    THET2,Ra,Rb
 -1  0  0. 0. 0  1  0 $M-5 IWALL,IWIMP,ZETA,ECZ,ILIN,IPLAS,IRAMP
  410                $N-1 KELT
  6  4  6  6  0      $P-1 IBLN(i), i=1,4, IBOND
  1  0  0  0  0  0  0 $Q-1 NSYS,NICS,NAMS,NUSS,NHINGE,etc.
  1  1  0            $Q-2 ISYS,NN,IFLG
 -460.  5  3  0  0  0 $Q-3 P,LT,LD,LI,LJ,LAX
  0  0  0  0  0      $R-1 IPRD,IPRR,IPRE,IPRS,IPRP
C original unit 9 = toroidal now unit 35
  8  1  0  0  0  0  $M-1 ISHELL,IGLOBE,NROWS,NCOLS,NLAYS,NFABS
  39.77901 48.82777 0. 45. 13.07984 12.785950 $M-2 PH1,PH2,THET1,
                                              $    THET2,Ra,Rb
 -1  0  0. 0. 0  1  0 $M-5 IWALL,IWIMP,ZETA,ECZ,ILIN,IPLAS,IRAMP
  410                $N-1 KELT
  6  6  6  4  0      $P-1 IBLN(i), i=1,4, IBOND
  1  0  0  0  0  0  0 $Q-1 NSYS,NICS,NAMS,NUSS,NHINGE,etc.
  1  1  0            $Q-2 ISYS,NN,IFLG
 -460.  5  3  0  0  0 $Q-3 P,LT,LD,LI,LJ,LAX
  0  0  0  0  0      $R-1 IPRD,IPRR,IPRE,IPRS,IPRP
C original unit 9 = toroidal now unit 36
  8  1  0  0  0  0  $M-1 ISHELL,IGLOBE,NROWS,NCOLS,NLAYS,NFABS
  39.77901 48.82777 45. 90. 13.07984 12.785950 $M-2 PH1,PH2,THET1,
                                               $    THET2,Ra,Rb
 -1  0  0. 0. 0  1  0 $M-5 IWALL,IWIMP,ZETA,ECZ,ILIN,IPLAS,IRAMP
  410                $N-1 KELT
  6  6  6  6  0      $P-1 IBLN(i), i=1,4, IBOND
  1  0  0  0  0  0  0 $Q-1 NSYS,NICS,NAMS,NUSS,NHINGE,etc.
  1  1  0            $Q-2 ISYS,NN,IFLG
 -460.  5  3  0  0  0 $Q-3 P,LT,LD,LI,LJ,LAX
  0  0  0  0  0      $R-1 IPRD,IPRR,IPRE,IPRS,IPRP
C original unit 9 = toroidal now unit 37
  8  1  0  0  0  0  $M-1 ISHELL,IGLOBE,NROWS,NCOLS,NLAYS,NFABS
  39.77901 48.82777 90. 135. 13.07984 12.785950 $M-2 PH1,PH2,THET1,
                                                $    THET2,Ra,Rb
 -1  0  0. 0. 0  1  0 $M-5 IWALL,IWIMP,ZETA,ECZ,ILIN,IPLAS,IRAMP
  410                $N-1 KELT
  6  6  6  6  0      $P-1 IBLN(i), i=1,4, IBOND
  1  0  0  0  0  0  0 $Q-1 NSYS,NICS,NAMS,NUSS,NHINGE,etc.
```

```
  1  1  0            $Q-2 ISYS,NN,IFLG
 -460.  5  3  0  0  0 $Q-3 P,LT,LD,LI,LJ,LAX
  0  0  0  0  0      $R-1 IPRD,IPRR,IPRE,IPRS,IPRP
C original unit 9 = toroidal now unit 38
  8  1  0  0  0  0  $M-1 ISHELL,IGLOBE,NROWS,NCOLS,NLAYS,NFABS
  39.77901 48.82777  135. 180. 13.07984 12.785950 $M-2 PH1,PH2,THET1,
                                                  $    THET2,Ra,Rb
 -1  0  0. 0.  0  1  0 $M-5 IWALL,IWIMP,ZETA,ECZ,ILIN,IPLAS,IRAMP
  410                $N-1 KELT
  6  4  6  6  0      $P-1 IBLN(i), i=1,4, IBOND
  1  0  0  0  0  0  0 $Q-1 NSYS,NICS,NAMS,NUSS,NHINGE,etc.
  1  1  0            $Q-2 ISYS,NN,IFLG
 -460.  5  3  0  0  0 $Q-3 P,LT,LD,LI,LJ,LAX
  0  0  0  0  0      $R-1 IPRD,IPRR,IPRE,IPRS,IPRP
C original unit 10 = toroidal now unit 39
  8  1  0  0  0  0  $M-1 ISHELL,IGLOBE,NROWS,NCOLS,NLAYS,NFABS
  48.74254 60.90592 0. 45. 15.55374 9.5117826 $M-2 PH1,PH2,THET1,
                                              $    THET2,Ra,Rb
 -1  0  0. 0.  0  1  0 $M-5 IWALL,IWIMP,ZETA,ECZ,ILIN,IPLAS,IRAMP
  410                $N-1 KELT
  6  6  6  4  0      $P-1 IBLN(i), i=1,4, IBOND
  1  0  0  0  0  0  0 $Q-1 NSYS,NICS,NAMS,NUSS,NHINGE,etc.
  1  1  0            $Q-2 ISYS,NN,IFLG
 -460.  5  3  0  0  0 $Q-3 P,LT,LD,LI,LJ,LAX
  0  0  0  0  0      $R-1 IPRD,IPRR,IPRE,IPRS,IPRP
C original unit 10 = toroidal now unit 40
  8  1  0  0  0  0  $M-1 ISHELL,IGLOBE,NROWS,NCOLS,NLAYS,NFABS
  48.74254 60.90592 45. 90. 15.55374 9.5117826 $M-2 PH1,PH2,THET1,
                                               $    THET2,Ra,Rb
 -1  0  0. 0.  0  1  0 $M-5 IWALL,IWIMP,ZETA,ECZ,ILIN,IPLAS,IRAMP
  410                $N-1 KELT
  6  6  6  6  0      $P-1 IBLN(i), i=1,4, IBOND
  1  0  0  0  0  0  0 $Q-1 NSYS,NICS,NAMS,NUSS,NHINGE,etc.
  1  1  0            $Q-2 ISYS,NN,IFLG
 -460.  5  3  0  0  0 $Q-3 P,LT,LD,LI,LJ,LAX
  0  0  0  0  0      $R-1 IPRD,IPRR,IPRE,IPRS,IPRP
C original unit 10 = toroidal now unit 41
  8  1  0  0  0  0  $M-1 ISHELL,IGLOBE,NROWS,NCOLS,NLAYS,NFABS
  48.74254 60.90592 90. 135. 15.55374 9.5117826 $M-2 PH1,PH2,THET1,
                                                $    THET2,Ra,Rb
 -1  0  0. 0.  0  1  0 $M-5 IWALL,IWIMP,ZETA,ECZ,ILIN,IPLAS,IRAMP
  410                $N-1 KELT
  6  6  6  6  0      $P-1 IBLN(i), i=1,4, IBOND
  1  0  0  0  0  0  0 $Q-1 NSYS,NICS,NAMS,NUSS,NHINGE,etc.
  1  1  0            $Q-2 ISYS,NN,IFLG
 -460.  5  3  0  0  0 $Q-3 P,LT,LD,LI,LJ,LAX
  0  0  0  0  0      $R-1 IPRD,IPRR,IPRE,IPRS,IPRP
C original unit 10 = toroidal now unit 42
  8  1  0  0  0  0  $M-1 ISHELL,IGLOBE,NROWS,NCOLS,NLAYS,NFABS
  48.74254 60.90592  135. 180. 15.55374 9.5117826 $M-2 PH1,PH2,THET1,
                                                  $    THET2,Ra,Rb
 -1  0  0. 0.  0  1  0 $M-5 IWALL,IWIMP,ZETA,ECZ,ILIN,IPLAS,IRAMP
  410                $N-1 KELT
  6  4  6  6  0      $P-1 IBLN(i), i=1,4, IBOND
  1  0  0  0  0  0  0 $Q-1 NSYS,NICS,NAMS,NUSS,NHINGE,etc.
  1  1  0            $Q-2 ISYS,NN,IFLG
 -460.  5  3  0  0  0 $Q-3 P,LT,LD,LI,LJ,LAX
```

```
  0  0  0  0  0      $R-1 IPRD,IPRR,IPRE,IPRS,IPRP
C original unit 11 = toroidal now unit 43
  8  1  0  0  0  0  $M-1 ISHELL,IGLOBE,NROWS,NCOLS,NLAYS,NFABS
  60.95361 75.15099 0. 45. 17.45365 7.3341379 $M-2 PH1,PH2,THET1,
                                             $    THET2,Ra,Rb
 -1  0  0. 0. 0  1  0 $M-5 IWALL,IWIMP,ZETA,ECZ,ILIN,IPLAS,IRAMP
  410                $N-1 KELT
  6  6  6  4  0      $P-1 IBLN(i), i=1,4, IBOND
  1  0  0  0  0  0  0 $Q-1 NSYS,NICS,NAMS,NUSS,NHINGE,etc.
  1  1  0            $Q-2 ISYS,NN,IFLG
 -460.  5  3  0  0  0 $Q-3 P,LT,LD,LI,LJ,LAX
  0  0  0  0  0      $R-1 IPRD,IPRR,IPRE,IPRS,IPRP
C original unit 11 = toroidal now unit 44
  8  1  0  0  0  0  $M-1 ISHELL,IGLOBE,NROWS,NCOLS,NLAYS,NFABS
  60.95361 75.15099 45. 90. 17.45365 7.3341379 $M-2 PH1,PH2,THET1,
                                              $    THET2,Ra,Rb
 -1  0  0. 0. 0  1  0 $M-5 IWALL,IWIMP,ZETA,ECZ,ILIN,IPLAS,IRAMP
  410                $N-1 KELT
  6  6  6  6  0      $P-1 IBLN(i), i=1,4, IBOND
  1  0  0  0  0  0  0 $Q-1 NSYS,NICS,NAMS,NUSS,NHINGE,etc.
  1  1  0            $Q-2 ISYS,NN,IFLG
 -460.  5  3  0  0  0 $Q-3 P,LT,LD,LI,LJ,LAX
  0  0  0  0  0      $R-1 IPRD,IPRR,IPRE,IPRS,IPRP
C original unit 11 = toroidal now unit 45
  8  1  0  0  0  0  $M-1 ISHELL,IGLOBE,NROWS,NCOLS,NLAYS,NFABS
  60.95361 75.15099 0. 45. 17.45365 7.3341379 $M-2 PH1,PH2,THET1,
                                             $    THET2,Ra,Rb
 -1  0  0. 0. 0  1  0 $M-5 IWALL,IWIMP,ZETA,ECZ,ILIN,IPLAS,IRAMP
  410                $N-1 KELT
  6  6  6  6  0      $P-1 IBLN(i), i=1,4, IBOND
  1  0  0  0  0  0  0 $Q-1 NSYS,NICS,NAMS,NUSS,NHINGE,etc.
  1  1  0            $Q-2 ISYS,NN,IFLG
 -460.  5  3  0  0  0 $Q-3 P,LT,LD,LI,LJ,LAX
  0  0  0  0  0      $R-1 IPRD,IPRR,IPRE,IPRS,IPRP
C original unit 11 = toroidal now unit 46
  8  1  0  0  0  0  $M-1 ISHELL,IGLOBE,NROWS,NCOLS,NLAYS,NFABS
  60.95361 75.15099 45. 90. 17.45365 7.3341379 $M-2 PH1,PH2,THET1,
                                              $    THET2,Ra,Rb
 -1  0  0. 0. 0  1  0 $M-5 IWALL,IWIMP,ZETA,ECZ,ILIN,IPLAS,IRAMP
  410                $N-1 KELT
  6  4  6  6  0      $P-1 IBLN(i), i=1,4, IBOND
  1  0  0  0  0  0  0 $Q-1 NSYS,NICS,NAMS,NUSS,NHINGE,etc.
  1  1  0            $Q-2 ISYS,NN,IFLG
 -460.  5  3  0  0  0 $Q-3 P,LT,LD,LI,LJ,LAX
  0  0  0  0  0      $R-1 IPRD,IPRR,IPRE,IPRS,IPRP
C original unit 12 = toroidal now unit 47
  8  1  0  0  0  0  $M-1 ISHELL,IGLOBE,NROWS,NCOLS,NLAYS,NFABS
  75.3152 89.91051 0. 45. 18.40842 6.3415871 $M-2 PH1,PH2,THET1,
                                            $    THET2,Ra,Rb
 -1  0  0. 0. 0  1  0 $M-5 IWALL,IWIMP,ZETA,ECZ,ILIN,IPLAS,IRAMP
  410                $N-1 KELT
  6  6  0  4  0      $P-1 IBLN(i), i=1,4, IBOND
 001  000            $P-2 ITRA, IROT (conditions at pole)
  1  0  0  0  0  0  0 $Q-1 NSYS,NICS,NAMS,NUSS,NHINGE,etc.
  1  1  0            $Q-2 ISYS,NN,IFLG
 -460.  5  3  0  0  0 $Q-3 P,LT,LD,LI,LJ,LAX
  0  0  0  0  0      $R-1 IPRD,IPRR,IPRE,IPRS,IPRP
```

```
C original unit 12 = toroidal now unit 48
  8  1  0  0  0  0  $M-1 ISHELL,IGLOBE,NROWS,NCOLS,NLAYS,NFABS
  75.3152 89.91051 45. 90. 18.40842 6.3415871 $M-2 PH1,PH2,THET1,
                                              $    THET2,Ra,Rb
 -1  0  0. 0. 0  1  0 $M-5 IWALL,IWIMP,ZETA,ECZ,ILIN,IPLAS,IRAMP
  410               $N-1 KELT
  6  6  0  6  0     $P-1 IBLN(i), i=1,4, IBOND
 001  000           $P-2 ITRA, IROT (conditions at pole)
  1  0  0  0  0  0  0 $Q-1 NSYS,NICS,NAMS,NUSS,NHINGE,etc.
  1  1  0           $Q-2 ISYS,NN,IFLG
 -460.  5  3  0  0  0 $Q-3 P,LT,LD,LI,LJ,LAX
  0  0  0  0  0     $R-1 IPRD,IPRR,IPRE,IPRS,IPRP
C original unit 12 = toroidal now unit 49
  8  1  0  0  0  0  $M-1 ISHELL,IGLOBE,NROWS,NCOLS,NLAYS,NFABS
  75.3152 89.91051 90. 135. 18.40842 6.3415871 $M-2 PH1,PH2,THET1,
                                               $    THET2,Ra,Rb
 -1  0  0. 0. 0  1  0 $M-5 IWALL,IWIMP,ZETA,ECZ,ILIN,IPLAS,IRAMP
  410               $N-1 KELT
  6  6  0  6  0     $P-1 IBLN(i), i=1,4, IBOND
 001  000           $P-2 ITRA, IROT (conditions at pole)
  1  0  0  0  0  0  0 $Q-1 NSYS,NICS,NAMS,NUSS,NHINGE,etc.
  1  1  0           $Q-2 ISYS,NN,IFLG
 -460.  5  3  0  0  0 $Q-3 P,LT,LD,LI,LJ,LAX
  0  0  0  0  0     $R-1 IPRD,IPRR,IPRE,IPRS,IPRP
C original unit 12 = toroidal now unit 50
  8  1  0  0  0  0  $M-1 ISHELL,IGLOBE,NROWS,NCOLS,NLAYS,NFABS
  75.3152 89.91051  135. 180. 18.40842 6.3415871 $M-2 PH1,PH2,THET1,
                                                 $    THET2,Ra,Rb
 -1  0  0. 0. 0  1  0 $M-5 IWALL,IWIMP,ZETA,ECZ,ILIN,IPLAS,IRAMP
  410               $N-1 KELT
  6  4  0  6  0     $P-1 IBLN(i), i=1,4, IBOND
 001  000           $P-2 ITRA, IROT (conditions at pole)
  1  0  0  0  0  0  0 $Q-1 NSYS,NICS,NAMS,NUSS,NHINGE,etc.
  1  1  0           $Q-2 ISYS,NN,IFLG
 -460.  5  3  0  0  0 $Q-3 P,LT,LD,LI,LJ,LAX
  0  0  0  0  0     $R-1 IPRD,IPRR,IPRE,IPRS,IPRP
===================================================================
```

NOTE: Table a38 is in [26].

Table a39 **SUBROUTINE LAME, written by Charles Rankin.**
This user-written STAGS subroutine is for shell types that are not included in the STAGS "standard shell surfaces" list. **On the M-1 record if ISHELL = 1 (shell type no. 1) the shell surface is defined by SUBROUTINE LAME.** This particular version of SUBROUTINE LAME generates the "soccerball" spherical cap. See the first six shell units listed in Table a37 for a list of input data for a 180-degree "soccerball" spherical cap. This spherical cap has the same shape as Shell unit no. 1 of the 360-degree "eqellipse" model, but the finite element mesh differs. The singularity at the pole of the spherical cap in the 360-degree "eqellipse" model, in which polar coordinates are used, is avoided by the "soccerball" finite element grid. **As of this writing the thickness of the 180-degree "soccerball" spherical cap (Shell units 1 - 6) MUST BE UNIFORM.** See Figs. a2 and a3 for the finite element "soccerball" configuration. See Fig. a1 for the 360-degree polar coordinate configuration.

```
=====================================================================
#include "keydefs.h"
      subroutine LAME ( IUNIT, PROP, XYs, ISLAM )

*     ----------------------------------------------------------------
*     Given shell unit IUNIT & surface coordinates (Xs,Ys),  compute
*     branch coordinates (F,G,H) of the point.
*     GENERATES SOCCER BALL MESH using 3 Units
*
*     Compute the  First Fundamental Form,  or the derivative of the
*     position vector (F,G,H), as a function of Xs (Fx,Gx,Hx)  or of
*     Ys (Fy,Gy,Hy). Setting ISLAM = 1 aligns the local x axis along
*     the vector (Fx,Gx,Hx).   The z axis is always perpendicular to
*     both base vectors (Fx,Gx,Hx) and (Fy,Gy,Hy)
*
*     The PROP vector contains the following parameters, here:
*
*     PROP(1) = Radial coordinate (minimum) MUST BE ZERO!!
*     PROP(2) = Radial coordinate (maximum) 0<PROP(2)<=90. (degrees)
*               This coordinate applies to all THREE units: maximum
*               for the assemblage.
*     PROP(3) = Hoop coordinate (minimum--degrees)
*     PROP(4) = Hoop coordinate (maximum--degrees)
*               Note: Either Prop(3) = Prop(6) OR
*                            Prop(4) = Prop(7) -- BUT NOT BOTH
*                     Either Prop(3) = (Prop(6)+Prop(7))/2 or
*                            Prop(4) = (Prop(6)+Prop(7))/2
*     PROP(5) = Radius
*     PROP(6) = Hoop coordinate for COMBINED 3 Units,
*               (minimum--degrees)
*     PROP(7) = Hoop coordinate for COMBINED 3 Units,
*               (maximum--degrees)
*
*
*     ----------------------------------------------------------------
```

```
      _implicit_none_
#include "pie.h"

      Integer IUNIT
      Real    PROP(*)
      Real    XYs(2)
      Integer ISLAM
      _float_ xx,dx,yy,dy
      _float_ a,b,d1,xp,yp,zp
      _float_ z0p

      _float_ sn,cs,ar
      _float_ xpx,ypx,xpp,ypp,zx,zy,zpx,zpp
      _float_ rm,rh,tn
      _float_ one,two,four,ninety,ft5
      _float_ xus(4),yus(4),shp(4)
      _float_ csdy, sndy, shp1,shp2,shp3,shp4

      shp1(xx,yy)=(1.-xx)*(1.-yy)
      shp2(xx,yy)=(1.-xx)*yy
      shp3(xx,yy)=xx*yy
      shp4(xx,yy)=xx*(1.-yy)

#include "lamex.h"

      a=Prop(5)     !  RADIUS
      b=a*sin(dtr*Prop(2))  ! Radius of opening at base

      z0p= a**2-b**2  !  Maximum "Z" offset
      ar=b*.4    !  Ratio of soccerball "square" to total meridional span
      ft5=(Prop(7)-Prop(6))*.5  ! Half the included angle

*     Rescale X coordinate to lie between 0 and 1:

      dx=prop(2)
      xx=xys(1)/dx

*     Rescale Y coordinate to lie between 0 and 1:

      dy=Prop(4)-Prop(3)

      sndy=sin(dtr*(Prop(7)-Prop(6)))
      csdy=cos(dtr*(Prop(7)-Prop(6)))
      yy=(XYs(2)-Prop(3))/dy

*     Compute Global Coordinates

      cs = cos(dtr*xys(2))
      sn = sin(dtr*xys(2))
      islam=2
      if (Prop(3).eq.Prop(6) .and. Prop(4).eq.Prop(7)) then

*     Define 4 local points:

         xus(1)=0.
         yus(1)=0.
```

```
          xus(2)=ar*csdy
          yus(2)=ar*sndy
          xus(3)=ar*(1.+csdy)
          yus(3)=ar*sndy
          xus(4)=ar
          yus(4)=0.

          xp=shp1(xx,yy)*xus(1)+shp2(xx,yy)*xus(2) +
     &         shp3(xx,yy)*xus(3)+shp4(xx,yy)*xus(4)
          yp=shp1(xx,yy)*yus(1)+shp2(xx,yy)*yus(2) +
     &         shp3(xx,yy)*yus(3)+shp4(xx,yy)*yus(4)
          xpx =
     &      (1.-yy)*(xus(4)-xus(1)) + yy*(xus(3)-xus(2))
          ypx =
     &      (1.-yy)*(yus(4)-yus(1)) + yy*(yus(3)-yus(2))
          xpp =
     &      (1.-xx)*(xus(2)-xus(1)) + xx*(xus(3)-xus(4))
          ypp =
     &      (1.-xx)*(yus(2)-yus(1)) + xx*(yus(3)-yus(4))
          if(xx.le.1.e-5) then
             islam=2
          else
             islam=1
          endif


       else if (Prop(3).lt.ft5 ) then

          xus(1)=ar
          yus(1)=0
          xus(2)=ar*(1.+csdy)
          yus(2)=ar*sndy
          xus(3)=(1.-yy)*xus(1)+yy*xus(2)
          yus(3)=(1.-yy)*yus(1)+yy*yus(2)
          xp = b*xx*cs + (1.-xx)*xus(3)
          yp = b*xx*sn + (1.-xx)*yus(3)


*debug       write (6,*) 'xp,yp,zp = ',xp,yp,zp

*      Compute derivatives (for First Fundamental Form)
*      ================================================

          xpx = b*cs-xus(3)
          ypx = b*sn-yus(3)
          xpp = -b*sn*xys(1)*dtr
     &         +(1.-xx)*(xus(2)-xus(1))/dy
          ypp = b*xys(1)*cs*dtr
     &         +(1.-xx)*(yus(2)-yus(1))/dy
          islam=1


       elseif (Prop(4).gt.ft5) then


          xus(1)=ar*(1.+csdy)
          yus(1)=ar*sndy
```

```
          xus(2)=ar*csdy
          yus(2)=ar*sndy
          xus(3)=(1.-yy)*xus(1)+yy*xus(2)
          yus(3)=(1.-yy)*yus(1)+yy*yus(2)
          xp = b*xx*cs + (1.-xx)*xus(3)
          yp = b*xx*sn + (1.-xx)*yus(3)

*debug      write (6,*) 'xp,yp,zp = ',xp,yp,zp

*     Compute derivatives (for First Fundamental Form)
*     ===============================================

          xpx = b*cs-xus(3)
          ypx = b*sn-yus(3)
          xpp = -b*sn*xx*dtr
     &         +(1.-xx)*(xus(2)-xus(1))/dy
          ypp = b*xx*cs*dtr
     &         +(1.-xx)*(yus(2)-yus(1))/dy
          islam=1
      endif


      zp = -z0p+sqrt(abs(a**2-xp**2-yp**2))


*     Set STAGS System Coordinates
*     ++++++++++++++++++++++++++++

      ff = xp
      gg = yp
      hh = zp


      d1 = zp+z0p
      zx  = -xp/d1
      zy  = -yp/d1

      zpx = zx*xpx+zy*ypx
      zpp = zx*xpp+zy*ypp

*     Set STAGS system variables with derivative information
*     ======================================================

      fx = xpx
      gx = ypx
      hx = zpx

      fy = xpp
      gy = ypp
      hy = zpp

      return

      end
====================================================================
```