This report goes with GENOPT

"SPHERE" - - PROGRAM FOR
MINIMUM WEIGHT DESIGN OF ISOGRID-STIFFENED SPHERICAL SHELLS
UNDER UNIFORM EXTERNAL PRESSURE

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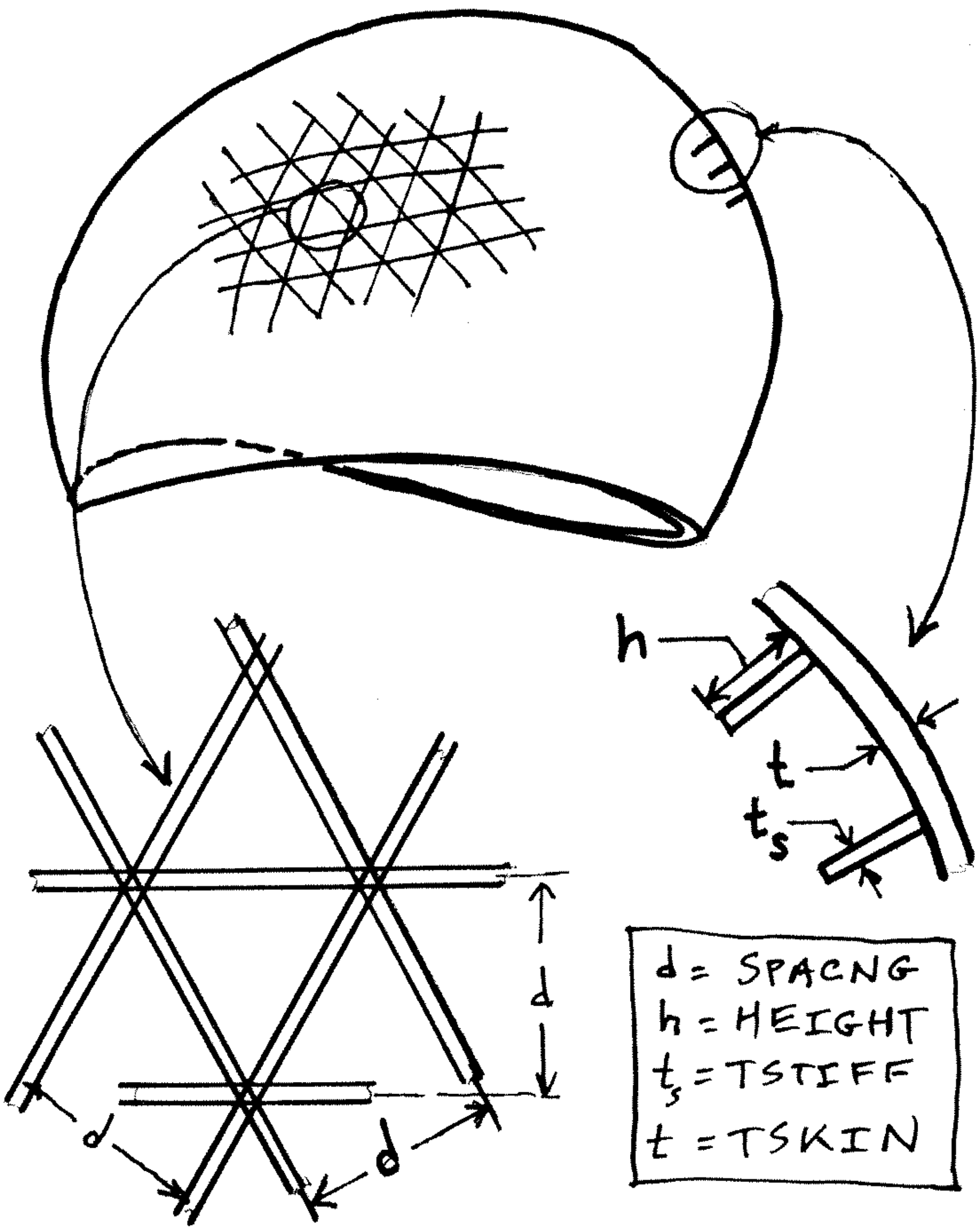
January 15, 1990 Report LMSC-F372046



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ABSTRACT

A system of programs called SPHERE has been developed for optimization of stiffened spherical shells under uniform external pressure. The stiffeners are assumed to be blades and are arranged in an isogrid pattern in order to maintain isotropy of the stiffened wall. In this way formulas and tables applicable to buckling of monocoque isotropic spherical shells can be applied, with proper definition of effective modulus and thickness, to buckling of stiffened spherical shells. Both the skin of the shell and the stiffeners are assumed to be of isotropic material, with different material properties in skin and stiffeners. Only membrane prebuckling states are considered. The theory used follows, for the most part, that given in Ref. 1, with the exception that skin and stiffeners may be of different material. The effect of transverse shear deformation is ignored. The effect of initial imperfections is included. An example is provided.

SUMMARY OF THEORY

The geometry pertaining to the subject of this paper is illustrated in Figs. 1 and 2. Decision variables for the determination of minimum weight design are the dimensions d, h, t, and ts (named SPACNG, HEIGHT, TSKIN, and TSTIFF, respectively, in SPHERE).

The following phenomena (behaviors) constrain the design:

1. general instability of the stiffened shell (Refs. 1,2,3)
2. local buckling between stiffeners (Refs. 1,3,4)
   (a) buckling of shallow spherical cap (Ref. 3)
   (b) buckling of triangular plate (Refs. 1,4)
3. buckling of stiffeners (Refs. 5,6)
4. stress in the skin (Ref. 1)
5. stress in the stiffeners (Ref. 1)

The spherical cap mentioned in Item 2(a) has a radius that lies between r1 and r2 in Fig. 2. The effect of initial imperfections is accounted for by means of "knockdown" factors provided in tabular form by the user of SPHERE. Figures 3 shows the "knockdown" factor KGEN vs normalized imperfection amplitude DELBAR for general buckling of a complete spherical shell, and Figure 4 shows the "knockdown" factor KLOC vs. a geometrical "shallowness" parameter

LAMBDA for local buckling of a spherical cap.

More details on the theory used in SPHERE are given in Appendices C and D.

The optimizer used in SPHERE is called ADS, developed by Vanderplaats (Refs [8], [9]). SPHERE uses the subset of ADS identified as "the method of feasible directions".

"SPHERE" IS PRODUCED VIA "GENOPT"

A system of programs, BEGIN, DECIDE, MAINSETUP, OPTIMIZE, CHANGE, CHOOSEPLOT, DIPLOT, (collectively called "SPHERE") for the minimum-weight design of isogrid-blade-stiffened spherical shells under uniform external pressure, was written with the use of GENOPT (Ref. 7).

In the GENOPT literature [7] two kinds of user are identified:

1. the GENOPT user, that is, the person who uses GENOPT in order to create a system of user-friendly programs for optimizing a class of objects;

2 the "end" user, that is, the person who uses the program system created by the GENOPT user in order to optimize specific members of the class of objects encompassed by the GENOPT-user-created system of programs.

In this case the GENOPT user is the writer and the "end" user is the reader.

The user of GENOPT (the writer in this case) is asked by GENOPT in an interactive mode to provide:

1. Text that describes the problem at hand and its method of solution.

2. names, definitions, and "help" text for input data required for complete characterization of the object being optimized (elastic, isogrid-stiffened spherical shell in this case).

3. names, definitions, and "help" text for input data that defines the environment (uniform static external pressure in this case).

4. names, definitions, and "help" text for all phenomena that may affect the design (general buckling, local skin buckling, stiffener buckling, skin stress, stiffener stress in this case).

5. names, definitions, and "help" text for an allowable and a factor of safety corresponding to each phenomenon named and defined in 4.

6. the name, definition, and supporting "help" of the objective of the optimization (weight in this case).

7. algorithms for the prediction of all phenomena that may affect the design, written in terms of the data names provided in Items 2 - 5. In this case the five phenomena (called "behaviors") are listed above. The algorithms are listed in SUBROUTINES BEHXi, i=1,5, which appear in APPENDIX D.

8. an algorithm written in terms of the names provided in Items 2 - 6 for calculation of the objective of the optimization (weight in this case). The algorithm is very simple in this case:

   ```
   WEIGHT = RHOSKN*TSKIN + 3.*RHOSTIF*TSTIFF*HEIGHT/SPACNG
   ```

   and occurs in SUBROUTINE OBJECT, which appears in APPENDIX D.

Input data supplied to GENOPT by the GENOPT user (the writer in this case) are listed in APPENDIX A. Directions for the use of GENOPT and information about the files that GENOPT produces are given in APPENDIX B included here, and in the files GENOPTST.ORY and GENOPT.HLP, two of the many files that constitute the GENOPT system [7].

GENOPT produces a number of processors, BEGIN, DECIDE, MAINSETUP, etc. that a designer may use to find minimum weight designs. Definitions of these processors and directions for using the system of programs, written partly by GENOPT and augmented by the "behavior" algorithms mentioned in Items 7 and 8 above, are given in APPENDIX E. The "behavior" algorithms supplied by the GENOPT user are listed in APPENDIX D (SUBROUTINES BEHX1, BEHX2, BEHX3, BEHX4, BEHX5, and OBJECT).

For more information about GENOPT the reader should consult Ref. [7].

DESCRIPTION OF APPENDICES

APPENDIX A - the file SPHERE.INP

During the interactive GENOPT session a file called NAME.INP is produced, in which NAME is a "generic" name supplied by the GENOPT user. (In this case the "generic" name is SPHERE, and this name is chosen here to identify the program system by means of which isogrid-stiffened spherical shells can be optimized.)

The file SPHERE.INP can be used as input to GENOPT, should the GENOPT user wish to modify some of the items and "help" paragraphs via text editing rather than via a lengthy and repetitive GENOPT interactive session.

One of the items the GENOPT user is asked to supply with each input datum name is the "role of the variable in the user's program". There are 7 possible roles. They are listed in APPENDIX B.

APPENDIX B - the file SPHERE.DEF

This file, called SPHERE.DEF in this case, is created by GENOPT. The file SPHERE.DEF gives some general information about GENOPT, a glossary of variables named and defined by the GENOPT user, a list of processors built by GENOPT, a list of files produced by GENOPT, and some directions for the GENOPT user. The file SPHERE.DEF is produced mainly for the benefit of the GENOPT user, but may be useful also to the "end" user (the user of the program system created by GENOPT - called "SPHERE" in this case).

APPENDIX C - the file SPHERE.PRO

The file SPHERE.PRO is produced by GENOPT. Here, the data names, definitions, and "help" paragraphs created by the GENOPT user appear for the benefit of the "end" user. This file represents the prompting data used in the processor called BEGIN, in which the "end" user interactively supplies the following data:

1. starting dimensions (items 10 - 30 in SPHERE.PRO)

2. material properties (items 35 - 60 in SPHERE.PRO)

3. tabular data for "knockdown" factor KLOC for local buckling of a shallow spherical cap as a function of "shallowness" parameter LAMBDA (items 65 - 80)

4. tabular data for "knockdown" factor KGEN for general instability of a monocoque isotropic complete spherical shell as a function of normalized imperfection amplitude DELBAR (items 85 - 95)

5. the assumed amplitude of an imperfection, WGEN (item 100)

6. a factor, EDGSTF, for elastic support of blade stiffener (used in the calculation of stiffener buckling (item 105)

7. characterization of the environment (items 110, 115)

8. for each behavior that may affect the design, identification of the:
   - 8(a) behavior (items 125, 140, 155, 170, 185)
   - 8(b) allowable (items 130, 145, 160, 175, 190)
   - 8(c) factor of safety (items 135, 150, 165, 180, 195)

9. identification of the objective (item 200).

Actually, although the SPHERE.PRO file lists behaviors and identifies the objective, these items have already been defined by the GENOPT user. No input from the "end" user is required; rather the GENOPT-created program system SPHERE calculates these behaviors, uses them along with allowables and factors of safety to create constraint conditions for the optimization process, and supplies them as output. For each behavior the user must supply an allowable and a factor of safety.

APPENDIX D - the file BEHAVIOR.NEW

This file, a skeletal form of which is produced by GENOPT, now includes the algorithms for calculation of the various behaviors identified in the file SPHERE.PRO. In this case the BEHAVIOR.NEW library contains five "behavior" subroutines, as follows:

1. SUBROUTINE BEHX1 - calculates general instability load factor.

2. SUBROUTINE BEHX2 - calculates local buckling load factor.

3. SUBROUTINE BEHX3 - calculates load factor for buckling of a stiffener.

4. SUBROUTINE BEHX4 - calculates stress in the skin.

5. SUBROUTINE BEHX5 - calculates stress in a stiffener.

In each subroutine BEHXi, the portion of code and comments supplied by the GENOPT user occur immediately following the comment "INSERT SUBROUTINE STATEMENTS HERE". The portion preceeding and including the comment "INSERT SUBROUTINE STATEMENTS HERE" is written by GENOPT. The BEHXi subroutines have many comments that describe the theories used to predict the various behaviors that may constrain the design. Therefore, these theories will not be described here.

In addition to the five "behavior" subroutines, the library BEHAVIOR.NEW contains a subroutine USRCON that permits user-written geometrical constraint conditions (not used in this application) and SUBROUTINE OBJECT, in which the value of the objective is calculated.

The subroutines BEHXi, i=1,5 and SUBROUTINE OBJECT are called by SUBROUTINE STRUCT, which is written entirely by GENOPT in this case. SUBROUTINE STRUCT is called by the main program, which is also entirely provided by GENOPT.

APPENDIX E - the HOWTO.RUN file

This file gives directions to the "end" user how to run the program system SPHERE.

APPENDIX F - the SPHERE3.* files

This appendix contains input data for BEGIN, DECIDE, MAINSETUP, CHOOSEPLOT, and DIPLOT for a sample case:

1.	SPHERE3.BEG	(input data for BEGIN	APPENDIX F1)
2.	SPHERE3.DEC	(input data for DECIDE	APPENDIX F2)
3.	SPHERE3.OPT	(input data for MAINSETUP	APPENDIX F3)
4.	SPHERE3.CPL	(input data for CHOOSEPLOT	APPENDIX F4)
5.	SPHERE3.DIP	(input data for DIPLOT	APPENDIX F5)

A SPECIFIC EXAMPLE: "SPHERE3"

This example involves a stiffened spherical shell in which the modulus of the stiffeners is different from that of the skin. The "end" user (the writer in this case) decided to call the specific case SPHERE3.

The starting design, material properties, tables of "knockdown" factors for local and general buckling, imperfection amplitude, loading, allowables, and factors of safety are listed in the input file for the BEGIN processor, SPHERE3.BEG (APPENDIX F1) The eight values of the "knockdown" factor KLOC v. shallowness parameter LAMBDA are indicated in Fig. 4. The 10 values of the "knockdown" factor KGEN v. normalized amplitude of imperfection DELBAR are points on the lowest curve plotted in Fig. 3. A factor of safety of 1.5 on stress in the skin of the spherical shell is used to allow for local bending in the neighborhoods of stiffeners, which is not accounted for in the membrane prebuckling theory used in this work.

Decision variables and lower and upper bounds are selected in the DECIDE processor. The input data for DECIDE are listed in the file SPHERE3.DEC (APPENDIX F2).

Analysis type, amount of output, and maximum number of design iterations per execution are selected in the MAINSETUP processor. The input data for MAINSETUP are listed in the file SPHERE3.OPT (APPENDIX F3).

Table 1 and Figs. 5 - 8 show results during optimization. The runstream used to obtain these results is:

COMMAND	PURPOSE OF THE COMMAND
GENOPTLOG	(activate "SPHERE" command set)
BEGIN	(provide starting design, loads, etc.)
DECIDE	(choose decision variables and bounds)
MAINSETUP	(choose print option and analysis type)
OPTIMIZE	(launch batch run for 5 design iterations)
OPTIMIZE	(launch batch run for 5 design iterations)
OPTIMIZE	(launch batch run for 5 design iterations)
OPTIMIZE	(launch batch run for 5 design iterations)
OPTIMIZE	(launch batch run for 5 design iterations. Convergence to an optimum achieved after one iteration.)
CHOOSEPLOT	(choose which variables to plot vs. all design iterations since start of the case.)
DIPLOT	(plot variables v. iterations on laser printer)
CHOOSEPLOT	(choose additional variables to plot)
DIPLOT	(plot additional variables v design iterations)
CLEANSPEC	(delete extraneous files for specific case)

IMPORTANT NOTE: YOU MUST ALWAYS GIVE THE COMMAND "OPTIMIZE" SEVERAL TIMES IN SUCCESSION IN ORDER TO OBTAIN CONVERGENCE! AN EXPLANATION OF WHY YOU MUST DO

THIS IS GIVEN ON PP 580-582 OF THE PAPER "PANDA2, PROGRAM FOR MINIMUM WEIGHT DESIGN OF STIFFENED, COMPOSITE LOCALLY BUCKLED PANELS", Computers and Structures, Vol. 25, No. 4, pp 469-605 (1987).

Table 1 lists the values of the design margins, design variables, and objective for all design iterations since the start of the case. Corresponding to each command "OPTIMIZE" values accumulate in the file SPHERE3.OPP. The "end" user should inspect the *.OPP file frequently as design iterations accumulate.

Design variables and design margins are selected for plotting in the CHOOSEPLOT processor. The input data for the first CHOOSEPLOT are listed in the file SPHERE3.CPL (APPENDIX F4). Input for the DIPLOT processor, which generates plot files, is listed in the file SPHERE3.DIP (APPENDIX F5).

Output corresponding to the two CHOOSEPLOT/DIPLOT combinations listed in the runstream above is plotted in Figs. 5 - 8. Figures. 5, 6, and 8 correspond to the input to CHOOSEPLOT listed in APPENDIX F4. Figure 7 results from the second set CHOOSEPLOT/DIPLOT. The two design variables, HEIGHT and SPACNG, are plotted separately from the thicknesses, TSKIN and TSTIFF, because the thickness variables, being an order of magnitude smaller than HEIGHT and SPACNG, would not show up well if plotted in the same frame as HEIGHT and SPACNG.

Table 2 lists the SPHERE3.OPM file for one of the sets of five design iterations. The print option is unity. Table 3 lists the SPHERE3.OPM file corresponding to the final design. The print option is 2 and the type of analysis, ITYPE = 2, means "analysis of a fixed design" (as opposed to ITYPE = 1, which means "optimization").

SUMMARY AND CONCLUSIONS

The purpose of this paper has been to describe a new program system called "SPHERE" for the minimum-weight design of elastic spherical shells with isogrid stiffening and loaded by uniform external pressure. The framework and much of the coding of the "SPHERE" system was created by GENOPT [7]. The algorithms (supplied by the GENOPT user) for prediction of the various behaviors which may constrain the design are listed in the five subroutines, BEHXi, i=1,5, that appear as part of APPENDIX D. The use of SPHERE is demonstrated by means of a specific example, input data for which appear in APPENDIX F and output from which appear in Tables 1 - 3 and Figures 5 - 8.

The purpose here is not to identify optimum materials and designs of stiffened spherical shells, but to describe a tool by means of which such designs can be identified.

ACKNOWLEDGMENTS

The author is indeed grateful for the continuing support of

Mr. Bill Sable and Mr. Stan Simson, Structural Analysis and Test in Lockheed Missiles and Space Company's Satellite Systems Division. Ms. Karen Neier of Dept. 97-10 of the Lockheed Palo Alto Research Laboratories wrote the original plot package (based on DISSPLA), which was rather extensively modified for use with GENOPT applications. The author also appreciates the assistance of Mr. Harold Cabiness, whose advice on the implementation of the optimizer ADS into the GENOPT system was crucial for the success of the project.

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LIST OF FIGURES

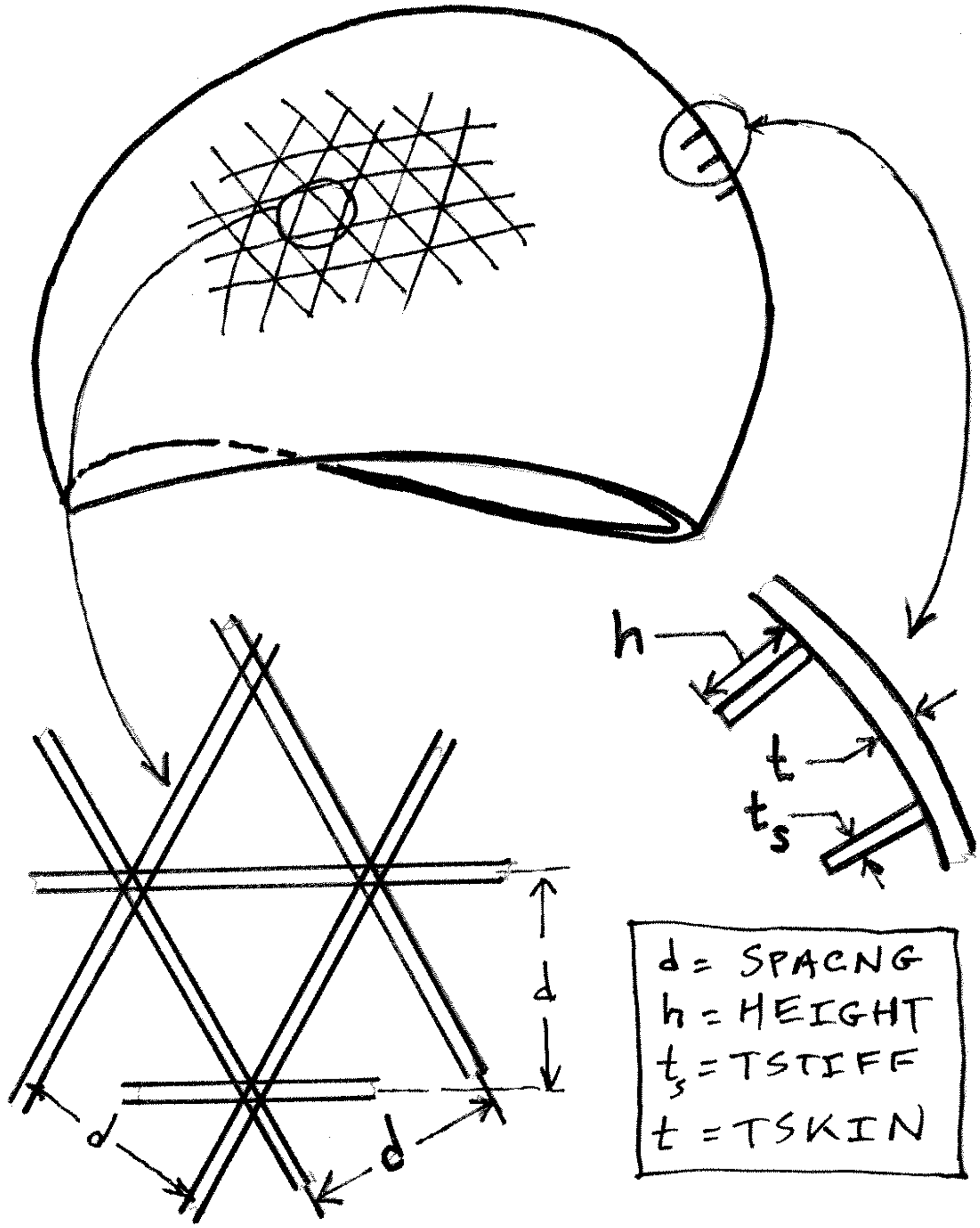

Fig. 1. Spherical shell with blade stiffeners in an isogrid pattern. For calculation of general instability the stiffeners can be smeared out to form a layer of the shell wall with modulus, E(effective) = ESTIFF*TSTIFF/SPACNG and Poisson's ratio, nu(effective)= 1/3 (Ref.[1]). The resulting two-layered shell wall can be replaced by a monocoque, homogenous, isotropic wall with effective modulus and effective thickness calculated as in SUBROUTINE BEHX1 (APPENDIX D).

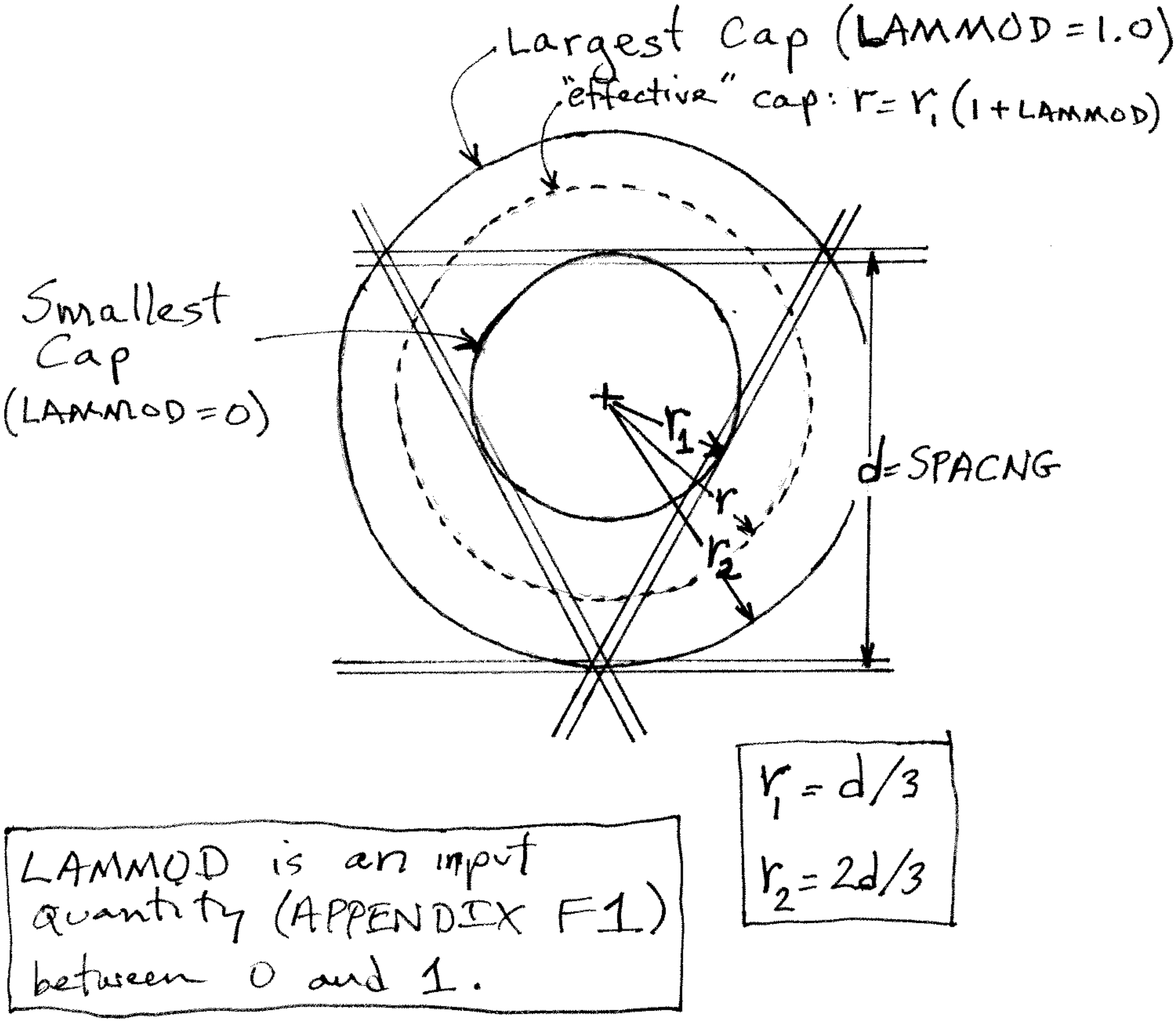

Fig. 2. Radius r of base plane of "effective" shallow spherical cap used in local buckling load calculation. This calculation is performed in SUBROUTINE BEHX2 (APPENDIX D).

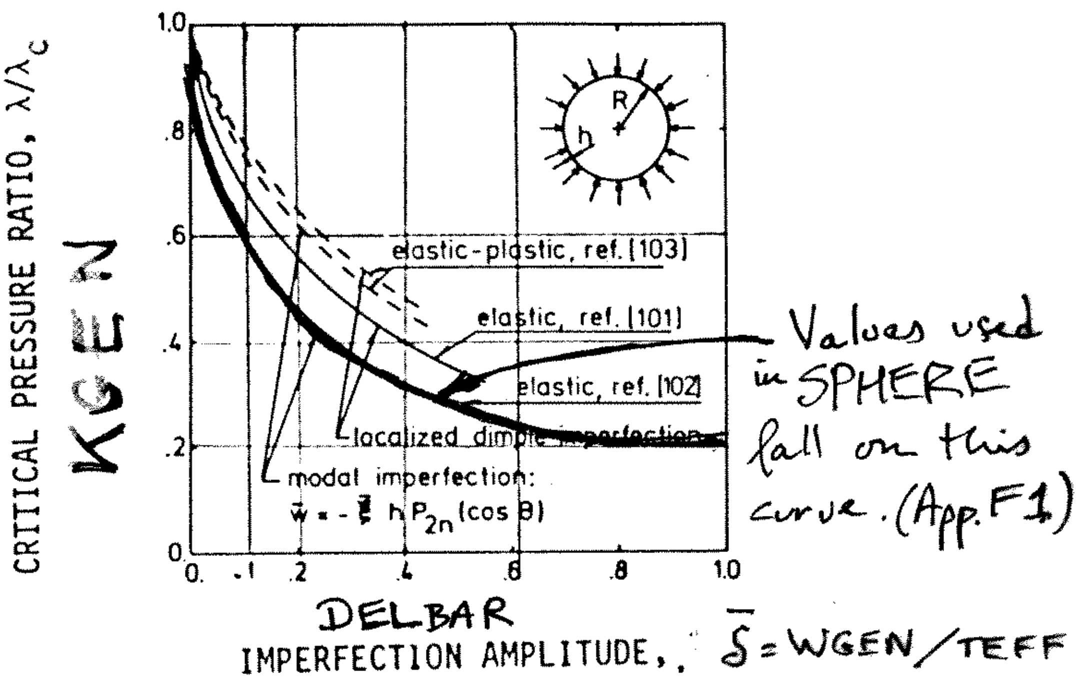

Fig. 3. "Knockdown" factor KGEN vs normalized imperfection amplitude DELBAR for general buckling of a complete spherical shell. The figure is taken from p. 340 of Ref. [7] (Fig. 296 in Ref. [7]). Tabular values of KGEN v DELBAR fall on the lowest curve in the figure. These tabular values appear as input data in the SPHERE3.BEG file (APPENDIX F1).

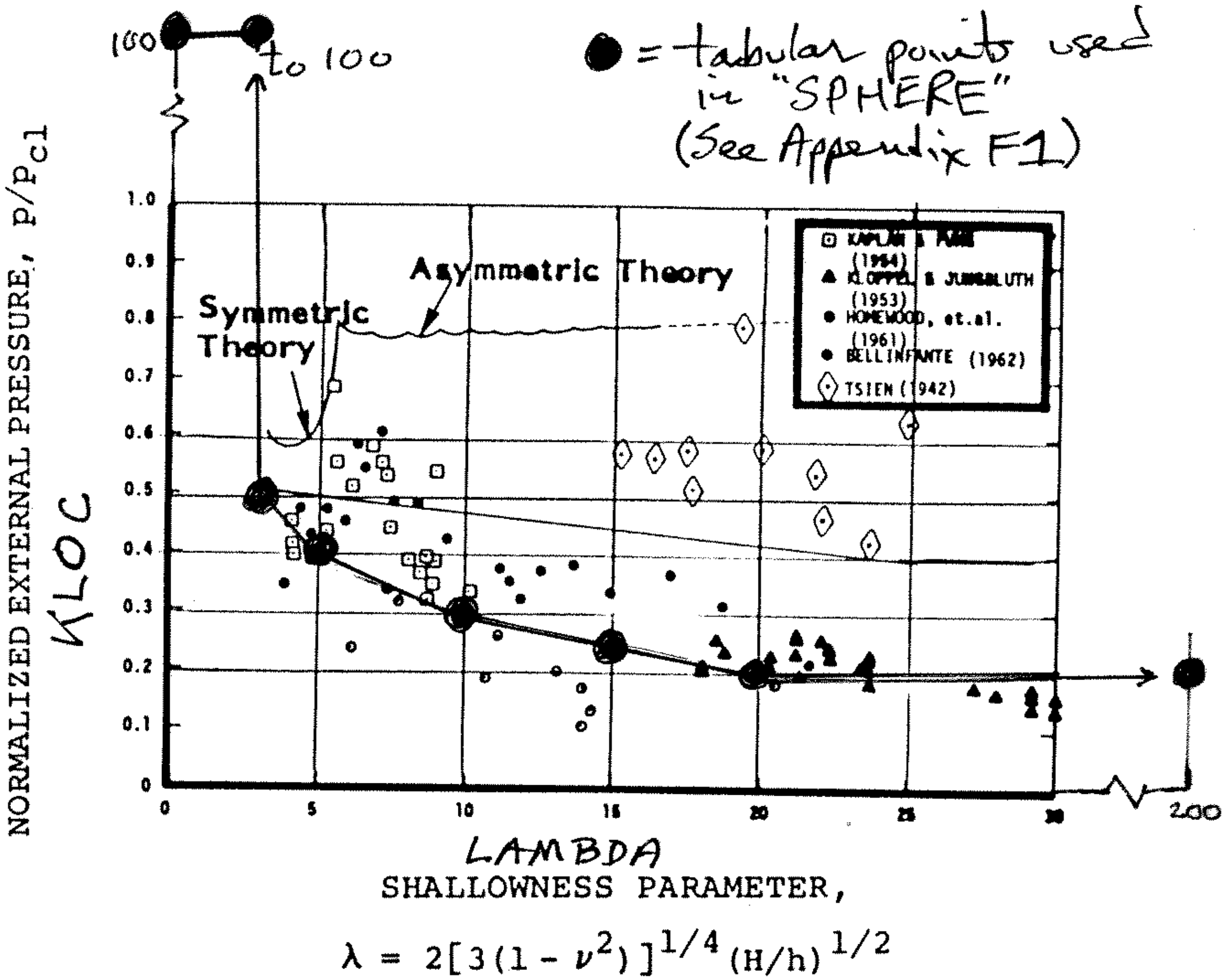

Fig. 4. "Knockdown" factor KLOC vs spherical cap shallowness parameter LAMBDA for local buckling of the portion of the spherical shell between stiffeners (See Fig. 2). The figure if taken from p. 29 of Ref. [7] (Fig. 30 in Ref. [7]). Tabular values of KLOC v LAMBDA fall as indicated. These tabular values appear as input data in the SPHERE3.BEG file (APPENDIX F1).

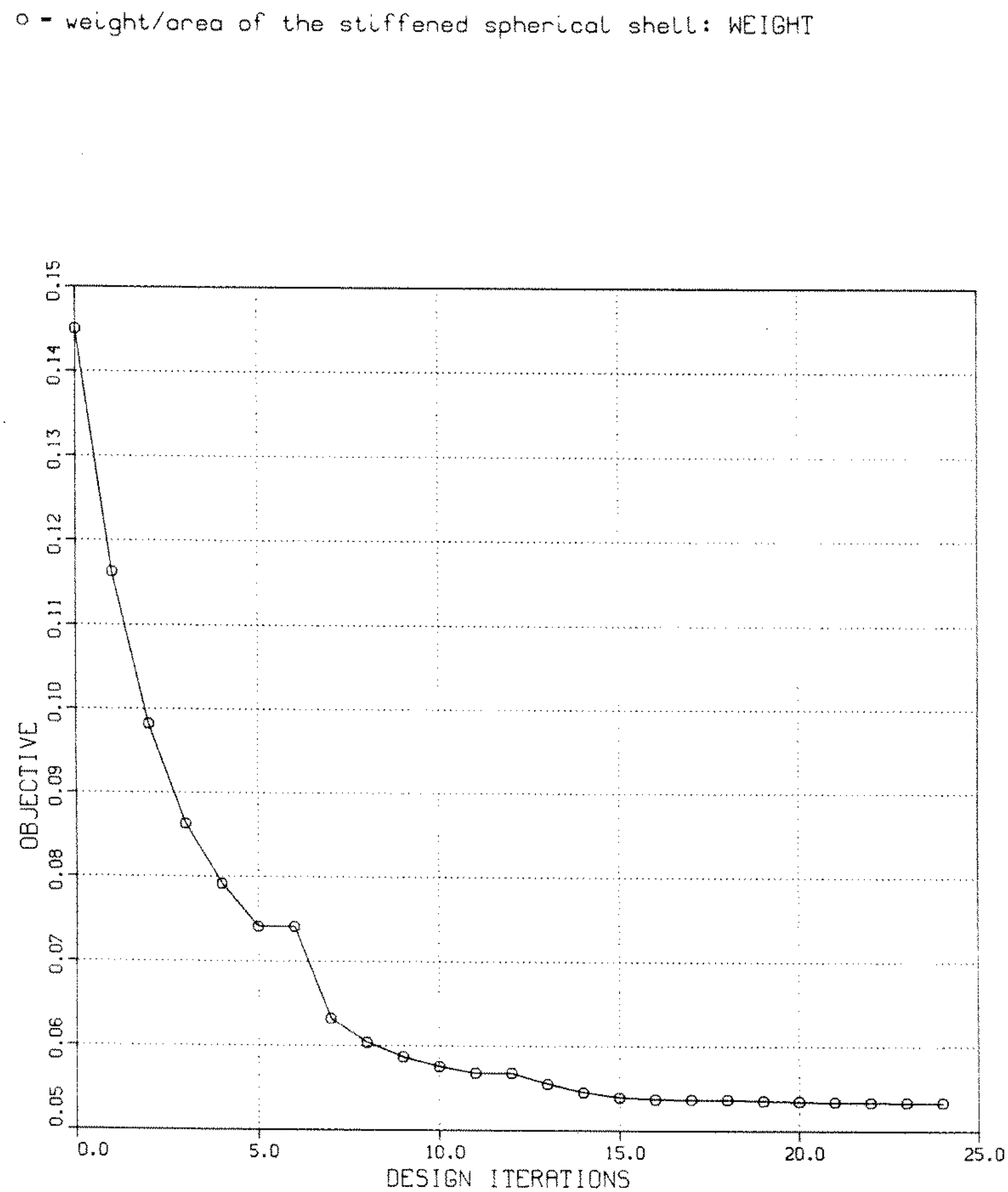

fig. 5. Plot generated by CHOOSEPLOT/DIPLOT for the sample case SPHERE3. The values plotted are listed in Table 1.

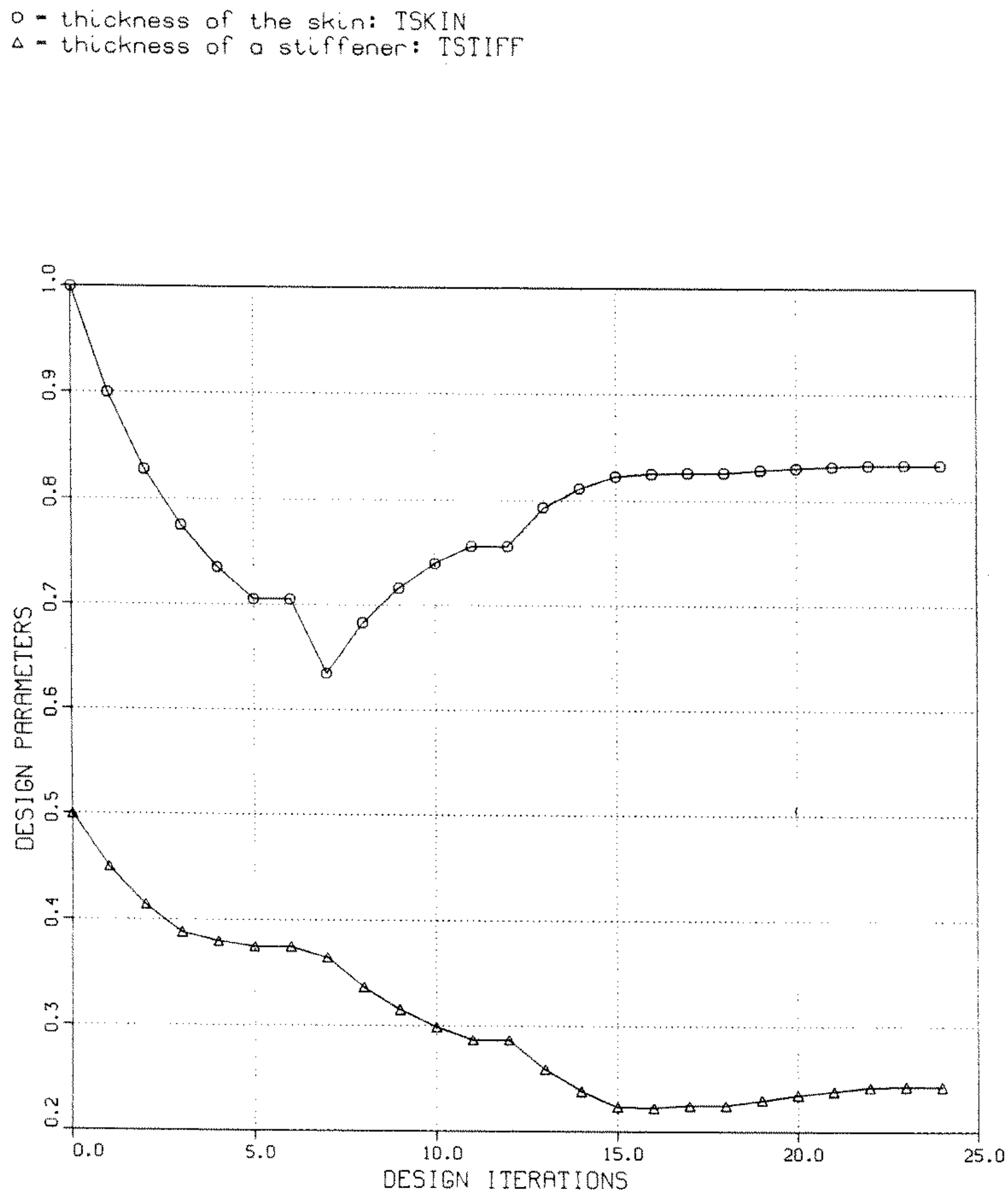

Fig.6. Plot generated by CHOOSEPLOT/DIPLOT for the sample case SPHERE3. The values plotted are listed in Table 1.

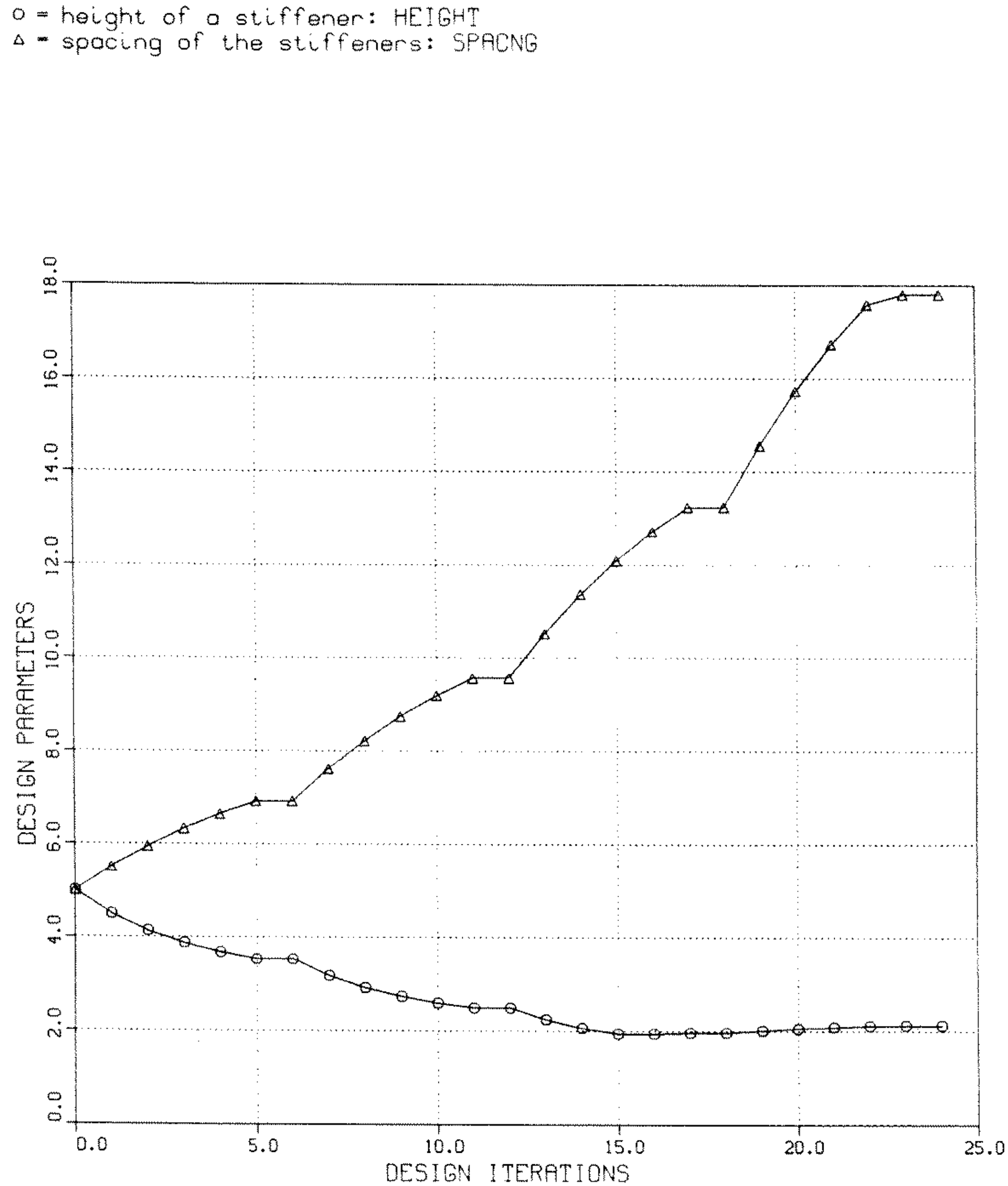

Fig. 7. Plot generated by CHOOSEPLOT/DIPLOT for the sample case SPHERE3. The values plotted are listed in Table 1.

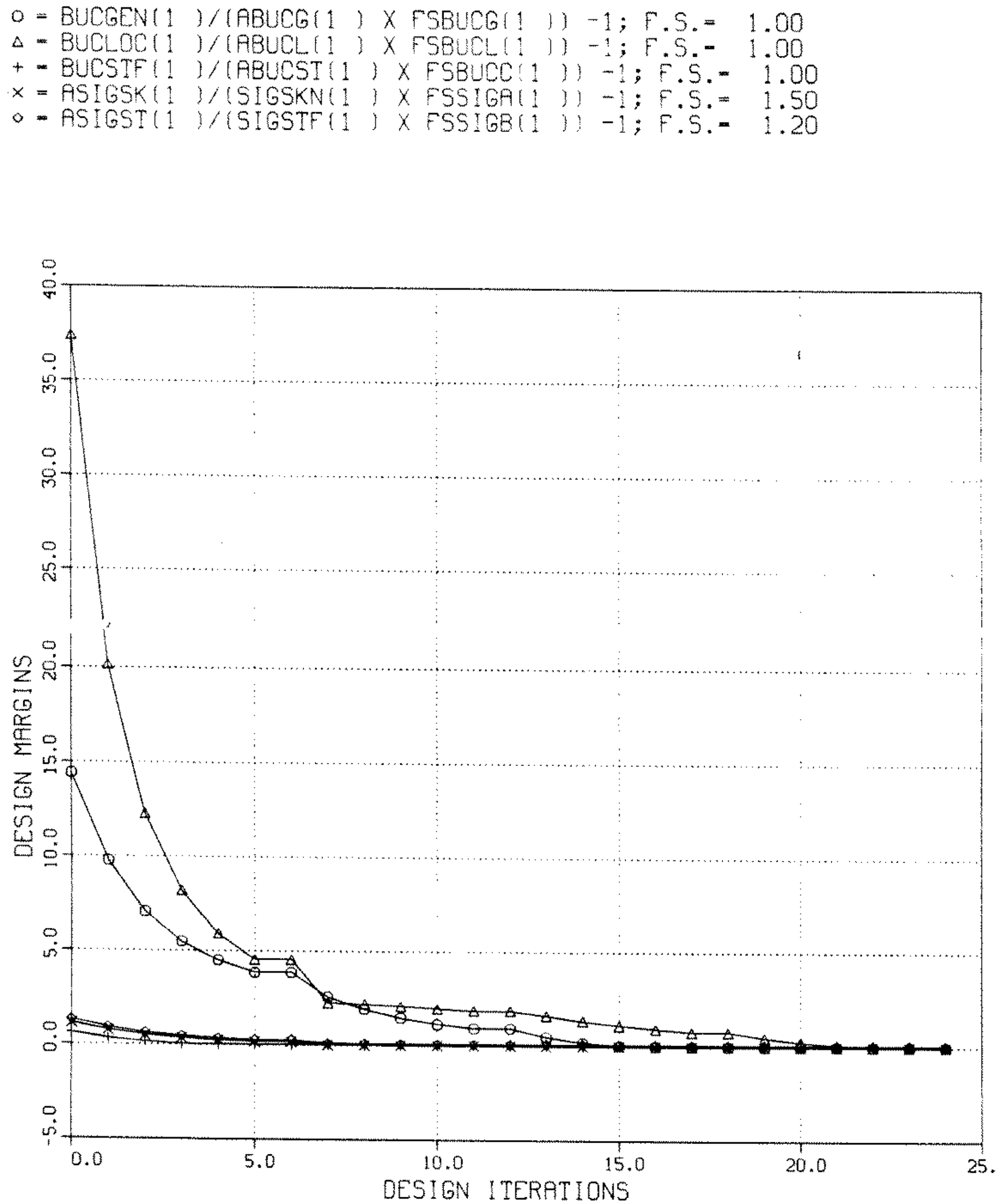

fig 8. Plot generated by CHOOSEPLOT/DIPLOT for the sample case SPHERE3. The values plotted are listed in Table 1.

TABLE 1: VALUES OF DESIGN MARGINS, DESIGN VARIABLES, AND OBJECTIVE FOR ALL DESIGN ITERATIONS SINCE THE BEGINNING OF THE CASE
(NOTE: The format of the output has been modified in order to:
1. emphasize that there were five "OPTIMIZE" runs and that the results listed here are for all five runs;
2. decrease the width of the output for printing purposes.)

```
***************** THIS IS THE  SPHERE3.OPP FILE *****************
*********************** STORE PROCESSOR *********************
The purpose of STORE is to add the latest results for
margins, design variables, and objective to those for previous
iterations for the specific case called SPHERE3.  Later, when
the final design has been obtained, the entire history of the
design evolution for the specific case SPHERE3 can be plotted.
*********************************************************

*********** MARGINS FOR  25 ITERATIONS **********
BUCGEN(1 )/(ABUCG(1 ) X FSBUCG(1 )) -1; F.S.=  1.00 =
RUN 1: 1.4398E+01  9.7629E+00  7.0762E+00  5.4653E+00  4.5069E+00  3.8505E+00
RUN 2: 3.8505E+00  2.5314E+00  1.8943E+00  1.4473E+00  1.1285E+00  9.2156E-01
RUN 3: 9.2156E-01  4.8342E-01  1.9381E-01  2.7182E-02  7.5448E-04 -1.4007E-05
RUN 4:-1.4007E-05 -8.1843E-04  1.8942E-04 -7.9387E-04 -3.9142E-04 -7.2390E-04
RUN 5:-7.2390E-04

BUCLOC(1 )/(ABUCL(1 ) X FSBUCL(1 )) -1; F.S.=  1.00 =
RUN 1: 3.7398E+01  2.0184E+01  1.2275E+01  8.1804E+00  5.9271E+00  4.5417E+00
RUN 2: 4.5417E+00  2.2157E+00  2.1677E+00  2.0626E+00  1.9534E+00  1.8444E+00
RUN 3: 1.8444E+00  1.5959E+00  1.3245E+00  1.1093E+00  9.1872E-01  7.7523E-01
RUN 4: 7.7523E-01  4.7672E-01  2.7195E-01  1.2775E-01  2.3164E-02 -1.5017E-03
RUN 5:-1.5017E-03

BUCSTF(1 )/(ABUCST(1 ) X FSBUCC(1 )) -1; F.S.=  1.00 =
RUN 1: 6.0927E-01  3.2626E-01  1.4528E-01  2.3497E-02  9.1865E-03  6.7306E-03
RUN 2: 6.7306E-03  1.9634E-02  1.8403E-02  1.5325E-02  1.4209E-02  1.2002E-02
RUN 3: 1.2002E-02  2.2377E-02  1.9671E-02  1.2271E-02  2.7847E-04 -1.9021E-03
RUN 4:-1.9021E-03 -6.4850E-03 -3.9523E-03 -6.9843E-03 -2.6385E-03 -3.2649E-03
RUN 5:-3.2649E-03

ASIGSK(1 )/(SIGSKN(1 ) X FSSIGA(1 )) -1; F.S.=  1.50 =
RUN 1: 1.1092E+00  7.3825E-01  5.0104E-01  3.4143E-01  2.4245E-01  1.7102E-01
RUN 2: 1.7102E-01  1.5088E-02  6.5597E-03  2.8392E-03  1.7684E-03  1.0307E-03
RUN 3: 1.0307E-03  4.7243E-03  2.2647E-03  9.6583E-04  1.2124E-04  2.4676E-05
RUN 4: 2.4676E-05  5.3406E-05  8.9049E-05  3.8266E-05 -1.2457E-05 -4.1485E-05
RUN 5:-4.1485E-05

ASIGST(1 )/(SIGSTF(1 ) X FSSIGB(1 )) -1; F.S.=  1.20 =
RUN 1: 1.2876E+00  8.8533E-01  6.2805E-01  4.5494E-01  3.4758E-01  2.7011E-01
RUN 2: 2.7011E-01  1.0098E-01  9.1730E-02  8.7695E-02  8.6533E-02  8.5733E-02
RUN 3: 8.5733E-02  8.9739E-02  8.7072E-02  8.5663E-02  8.4747E-02  8.4642E-02
RUN 4: 8.4642E-02  8.4673E-02  8.4712E-02  8.4657E-02  8.4602E-02  8.4570E-02
RUN 5: 8.4570E-02

****** DESIGN VARIABLES FOR  25 ITERATIONS ******

thickness of the skin: TSKIN =
RUN 1: 1.0000E+00  9.0000E-01  8.2800E-01  7.7501E-01  7.3533E-01  7.0521E-01
RUN 2: 7.0521E-01  6.3469E-01  6.8320E-01  7.1608E-01  7.3960E-01  7.5584E-01
RUN 3: 7.5584E-01  7.9281E-01  8.1124E-01  8.2277E-01  8.2524E-01  8.2633E-01
RUN 4: 8.2633E-01  8.2902E-01  8.3093E-01  8.3251E-01  8.3359E-01  8.3388E-01
```

```
RUN 5: 8.3388E-01

thickness of a stiffener: TSTIFF =
RUN 1: 5.0000E-01  4.5000E-01  4.1400E-01  3.8750E-01  3.7935E-01  3.7429E-01
RUN 2: 3.7429E-01  3.6412E-01  3.3620E-01  3.1502E-01  2.9889E-01  2.8665E-01
RUN 3: 2.8665E-01  2.5882E-01  2.3812E-01  2.2346E-01  2.2248E-01  2.2458E-01
RUN 4: 2.2458E-01  2.2978E-01  2.3481E-01  2.3830E-01  2.4191E-01  2.4262E-01
RUN 5: 2.4262E-01

height of a stiffener: HEIGHT =
RUN 1: 5.0000E+00  4.5000E+00  4.1400E+00  3.8750E+00  3.6766E+00  3.5260E+00
RUN 2: 3.5260E+00  3.1734E+00  2.9196E+00  2.7347E+00  2.5947E+00  2.4902E+00
RUN 3: 2.4902E+00  2.2412E+00  2.0621E+00  1.9410E+00  1.9432E+00  1.9636E+00
RUN 4: 1.9636E+00  2.0137E+00  2.0552E+00  2.0889E+00  2.1158E+00  2.1227E+00
RUN 5: 2.1227E+00

spacing of the stiffeners: SPACNG =
RUN 1: 5.0000E+00  5.5000E+00  5.9400E+00  6.3202E+00  6.6438E+00  6.9159E+00
RUN 2: 6.9159E+00  7.6075E+00  8.2161E+00  8.7419E+00  9.1895E+00  9.5659E+00
RUN 3: 9.5659E+00  1.0522E+01  1.1364E+01  1.2092E+01  1.2711E+01  1.3231E+01
RUN 4: 1.3231E+01  1.4554E+01  1.5719E+01  1.6725E+01  1.7581E+01  1.7803E+01
RUN 5: 1.7803E+01


********** OBJECTIVE FOR  25 ITERATIONS *********

weight/area of the stiffened spherical shell: WEIGHT =
RUN 1: 1.4500E-01  1.1626E-01  9.8231E-02  8.6291E-02  7.9177E-02  7.4106E-02
RUN 2: 7.4106E-02  6.3241E-02  6.0413E-02  5.8680E-02  5.7581E-02  5.6823E-02
RUN 3: 5.6823E-02  5.5575E-02  5.4570E-02  5.3962E-02  5.3782E-02  5.3727E-02
RUN 4: 5.3727E-02  5.3615E-02  5.3536E-02  5.3464E-02  5.3414E-02  5.3399E-02
RUN 5: 5.3399E-02
****************** END OF THE  SPHERE3.OPP FILE *****************
```

TABLE 2: RESULTS FROM A ONE SET OF 5 DESIGN ITERATIONS (ONE "OPTIMIZE" RUN)

```
***************** THE SPHERE.OPT FILE FOLLOWS ********************
     N          $ Do you want a tutorial session and tutorial output?
        1       $ NPRINT= output index (0=GOOD, 1=ok, 2=debug, 3=too much)
        1       $ Choose type of analysis (1=opt., 2=fixed design)
        5       $ How many design iterations in this run (3 to 25)?
************ END OF THE  SPHERE3.OPT  FILE **********

******** BEGINNING OF THE  SPHERE3.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 SPHERE3.  Results are stored in the file  SPHERE3.OPM.
Please inspect SPHERE3.OPM before doing more design iterations.
**********************************************************

STRUCTURAL ANALYSIS FOR DESIGN ITERATION NO.   0:
 BEHAVIOR FOR LOAD SET NUMBER, ILOADX= 1
   1         1.921564      general instability load factor: BUCGEN(1)
   2         2.844445      local buckling load factor: BUCLOC(1)
   3         1.012002      load factor for stiffener buckling: BUCSTF(1)
   4         55942.34      stress in the skin of the spherical shell: SIGSKN(1)
```

```
    5          64472.57       stress in the stiffeners: SIGSTF(1)

          SUMMARY OF INFORMATION FROM OPTIMIZATION ANALYSIS
 VAR. DEC. ESCAPE LINK. LINKED  LINKING    LOWER     CURRENT     UPPER    VARIABLE
  NO. VAR.  VAR.  VAR.    TO   CONSTANT    BOUND      VALUE      BOUND
   1   Y     Y     N      0    0.00E+00  1.00E-01 7.5584E-01  5.00E+00   TSKIN
   2   Y     Y     N      0    0.00E+00  2.00E-01 2.8665E-01  5.00E+00   TSTIFF
   3   Y     N     N      0    0.00E+00  1.00E-02 2.4902E+00  1.00E+01   HEIGHT
   4   Y     N     N      0    0.00E+00  1.00E+00 9.5659E+00  5.00E+01   SPACNG

 ***** RESULTS FOR LOAD SET NO.  1  ******
 THOSE MARGINS LESS THAN UNITY CORRESPONDING TO CURRENT DESIGN
 MAR.   CURRENT
 NO.     VALUE              DEFINITION
  1    9.216E-01  BUCGEN(1 )/(ABUCG(1 ) X FSBUCG(1 )) -1; F.S.=  1.00
  2    1.200E-02  BUCSTF(1 )/(ABUCST(1 ) X FSBUCC(1 )) -1; F.S.=  1.00
  3    1.031E-03  ASIGSK(1 )/(SIGSKN(1 ) X FSSIGA(1 )) -1; F.S.=  1.50
  4    8.573E-02  ASIGST(1 )/(SIGSTF(1 ) X FSSIGB(1 )) -1; F.S.=  1.20

 **************************************************
 ******************** DESIGN OBJECTIVE ******************
 *************                               ***********
    CURRENT VALUE OF THE OBJECTIVE FUNCTION:
 VAR.  CURRENT
 NO.    VALUE               DEFINITION
  1   5.682E-02  weight/area of the stiffened spherical shell: WEIGHT

 *************                               ************
 ******************** DESIGN OBJECTIVE ******************
 ***************************************************

    ADS CHANGED THE DESIGN

 STRUCTURAL ANALYSIS FOR DESIGN ITERATION NO.   1:
  BEHAVIOR FOR LOAD SET NUMBER, ILOADX= 1
    1          1.483423       general instability load factor: BUCGEN(1)
    2          2.595868       local buckling load factor: BUCLOC(1)
    3          1.022377       load factor for stiffener buckling: BUCSTF(1)
    4          55736.69       stress in the skin of the spherical shell: SIGSKN(1)
    5          64235.55       stress in the stiffeners: SIGSTF(1)

          SUMMARY OF INFORMATION FROM OPTIMIZATION ANALYSIS
 VAR. DEC. ESCAPE LINK. LINKED  LINKING    LOWER     CURRENT     UPPER    VARIABLE
  NO. VAR.  VAR.  VAR.    TO   CONSTANT    BOUND      VALUE      BOUND
   1   Y     Y     N      0    0.00E+00  1.00E-01 7.9281E-01  5.00E+00   TSKIN
   2   Y     Y     N      0    0.00E+00  2.00E-01 2.5882E-01  5.00E+00   TSTIFF
   3   Y     N     N      0    0.00E+00  1.00E-02 2.2412E+00  1.00E+01   HEIGHT
   4   Y     N     N      0    0.00E+00  1.00E+00 1.0522E+01  5.00E+01   SPACNG

 ***** RESULTS FOR LOAD SET NO.  1  ******
 THOSE MARGINS LESS THAN UNITY CORRESPONDING TO CURRENT DESIGN
 MAR.   CURRENT
 NO.     VALUE              DEFINITION
  1    4.834E-01  BUCGEN(1 )/(ABUCG(1 ) X FSBUCG(1 )) -1; F.S.=  1.00
  2    2.238E-02  BUCSTF(1 )/(ABUCST(1 ) X FSBUCC(1 )) -1; F.S.=  1.00
  3    4.724E-03  ASIGSK(1 )/(SIGSKN(1 ) X FSSIGA(1 )) -1; F.S.=  1.50
  4    8.974E-02  ASIGST(1 )/(SIGSTF(1 ) X FSSIGB(1 )) -1; F.S.=  1.20

 **************************************************
 ******************** DESIGN OBJECTIVE ******************
```

```
*************                              ***********
   CURRENT VALUE OF THE OBJECTIVE FUNCTION:
VAR.   CURRENT
NO.     VALUE              DEFINITION
 1    5.557E-02  weight/area of the stiffened spherical shell: WEIGHT

*************                              ************
******************* DESIGN OBJECTIVE ******************
*****************************************************

   ADS CHANGED THE DESIGN

STRUCTURAL ANALYSIS FOR DESIGN ITERATION NO.   2:
 BEHAVIOR FOR LOAD SET NUMBER, ILOADX= 1
   1          1.193805       general instability load factor: BUCGEN(1)
   2          2.324517       local buckling load factor: BUCLOC(1)
   3          1.019671       load factor for stiffener buckling: BUCSTF(1)
   4          55873.46       stress in the skin of the spherical shell: SIGSKN(1)
   5          64393.18       stress in the stiffeners: SIGSTF(1)

         SUMMARY OF INFORMATION FROM OPTIMIZATION ANALYSIS
VAR. DEC. ESCAPE LINK. LINKED  LINKING    LOWER     CURRENT     UPPER    VARIABLE
 NO. VAR.  VAR.   VAR.    TO   CONSTANT   BOUND      VALUE      BOUND
  1   Y     Y      N      0    0.00E+00  1.00E-01 8.1124E-01  5.00E+00   TSKIN
  2   Y     Y      N      0    0.00E+00  2.00E-01 2.3812E-01  5.00E+00   TSTIFF
  3   Y     N      N      0    0.00E+00  1.00E-02 2.0621E+00  1.00E+01   HEIGHT
  4   Y     N      N      0    0.00E+00  1.00E+00 1.1364E+01  5.00E+01   SPACNG

***** RESULTS FOR LOAD SET NO.  1  ******
THOSE MARGINS LESS THAN UNITY CORRESPONDING TO CURRENT DESIGN
MAR.   CURRENT
NO.     VALUE              DEFINITION
 1    1.938E-01  BUCGEN(1 )/(ABUCG(1 ) X FSBUCG(1 )) -1; F.S.=  1.00
 2    1.967E-02  BUCSTF(1 )/(ABUCST(1 ) X FSBUCC(1 )) -1; F.S.=  1.00
 3    2.265E-03  ASIGSK(1 )/(SIGSKN(1 ) X FSSIGA(1 )) -1; F.S.=  1.50
 4    8.707E-02  ASIGST(1 )/(SIGSTF(1 ) X FSSIGB(1 )) -1; F.S.=  1.20

*****************************************************
******************* DESIGN OBJECTIVE ******************
*************                              ***********
   CURRENT VALUE OF THE OBJECTIVE FUNCTION:
VAR.   CURRENT
NO.     VALUE              DEFINITION
 1    5.457E-02  weight/area of the stiffened spherical shell: WEIGHT

*************                              ************
******************* DESIGN OBJECTIVE ******************
*****************************************************

   ADS CHANGED THE DESIGN

STRUCTURAL ANALYSIS FOR DESIGN ITERATION NO.   3:
 BEHAVIOR FOR LOAD SET NUMBER, ILOADX= 1
   1          1.027182       general instability load factor: BUCGEN(1)
   2          2.109349       local buckling load factor: BUCLOC(1)
   3          1.012271       load factor for stiffener buckling: BUCSTF(1)
   4          55945.97       stress in the skin of the spherical shell: SIGSKN(1)
   5          64476.75       stress in the stiffeners: SIGSTF(1)

         SUMMARY OF INFORMATION FROM OPTIMIZATION ANALYSIS
```

VAR. NO.	DEC. VAR.	ESCAPE VAR.	LINK. VAR.	LINKED TO	LINKING CONSTANT	LOWER BOUND	CURRENT VALUE	UPPER BOUND	VARIABLE
1	Y	Y	N	0	0.00E+00	1.00E-01	8.2277E-01	5.00E+00	TSKIN
2	Y	Y	N	0	0.00E+00	2.00E-01	2.2346E-01	5.00E+00	TSTIFF
3	Y	N	N	0	0.00E+00	1.00E-02	1.9410E+00	1.00E+01	HEIGHT
4	Y	N	N	0	0.00E+00	1.00E+00	1.2092E+01	5.00E+01	SPACNG

```
***** RESULTS FOR LOAD SET NO.  1  ******
THOSE MARGINS LESS THAN UNITY CORRESPONDING TO CURRENT DESIGN
MAR.   CURRENT
NO.     VALUE              DEFINITION
 1    2.718E-02  BUCGEN(1 )/(ABUCG(1 ) X FSBUCG(1 )) -1; F.S.=  1.00
 2    1.227E-02  BUCSTF(1 )/(ABUCST(1 ) X FSBUCC(1 )) -1; F.S.=  1.00
 3    9.658E-04  ASIGSK(1 )/(SIGSKN(1 ) X FSSIGA(1 )) -1; F.S.=  1.50
 4    8.566E-02  ASIGST(1 )/(SIGSTF(1 ) X FSSIGB(1 )) -1; F.S.=  1.20

****************************************************
******************** DESIGN OBJECTIVE *******************
*************                            ***********
   CURRENT VALUE OF THE OBJECTIVE FUNCTION:
VAR.   CURRENT
NO.     VALUE              DEFINITION
 1    5.396E-02  weight/area of the stiffened spherical shell: WEIGHT

*************                            ************
******************** DESIGN OBJECTIVE *******************
*****************************************************

   ADS CHANGED THE DESIGN

STRUCTURAL ANALYSIS FOR DESIGN ITERATION NO.   4:
 BEHAVIOR FOR LOAD SET NUMBER, ILOADX= 1
   1         1.000754      general instability load factor: BUCGEN(1)
   2         1.918725      local buckling load factor: BUCLOC(1)
   3         1.000278      load factor for stiffener buckling: BUCSTF(1)
   4         55993.21      stress in the skin of the spherical shell: SIGSKN(1)
   5         64531.20      stress in the stiffeners: SIGSTF(1)
```

SUMMARY OF INFORMATION FROM OPTIMIZATION ANALYSIS

VAR. NO.	DEC. VAR.	ESCAPE VAR.	LINK. VAR.	LINKED TO	LINKING CONSTANT	LOWER BOUND	CURRENT VALUE	UPPER BOUND	VARIABLE
1	Y	Y	N	0	0.00E+00	1.00E-01	8.2524E-01	5.00E+00	TSKIN
2	Y	Y	N	0	0.00E+00	2.00E-01	2.2248E-01	5.00E+00	TSTIFF
3	Y	N	N	0	0.00E+00	1.00E-02	1.9432E+00	1.00E+01	HEIGHT
4	Y	N	N	0	0.00E+00	1.00E+00	1.2711E+01	5.00E+01	SPACNG

```
***** RESULTS FOR LOAD SET NO.  1  ******
THOSE MARGINS LESS THAN UNITY CORRESPONDING TO CURRENT DESIGN
MAR.   CURRENT
NO.     VALUE              DEFINITION
 1    7.545E-04  BUCGEN(1 )/(ABUCG(1 ) X FSBUCG(1 )) -1; F.S.=  1.00
 2    9.187E-01  BUCLOC(1 )/(ABUCL(1 ) X FSBUCL(1 )) -1; F.S.=  1.00
 3    2.785E-04  BUCSTF(1 )/(ABUCST(1 ) X FSBUCC(1 )) -1; F.S.=  1.00
 4    1.212E-04  ASIGSK(1 )/(SIGSKN(1 ) X FSSIGA(1 )) -1; F.S.=  1.50
 5    8.475E-02  ASIGST(1 )/(SIGSTF(1 ) X FSSIGB(1 )) -1; F.S.=  1.20

****************************************************
******************** DESIGN OBJECTIVE *******************
*************                            ***********
   CURRENT VALUE OF THE OBJECTIVE FUNCTION:
```

```
VAR.   CURRENT
NO.     VALUE             DEFINITION
 1    5.378E-02  weight/area of the stiffened spherical shell: WEIGHT

*************                           ************
******************** DESIGN OBJECTIVE ******************
*****************************************************

   ADS CHANGED THE DESIGN

STRUCTURAL ANALYSIS FOR DESIGN ITERATION NO.   5:

         SUMMARY OF INFORMATION FROM OPTIMIZATION ANALYSIS
VAR. DEC. ESCAPE LINK. LINKED  LINKING   LOWER     CURRENT     UPPER    VARIABLE
 NO. VAR.  VAR.  VAR.    TO   CONSTANT   BOUND      VALUE      BOUND
  1   Y     Y     N      0    0.00E+00  1.00E-01 8.2633E-01  5.00E+00   TSKIN
  2   Y     Y     N      0    0.00E+00  2.00E-01 2.2458E-01  5.00E+00   TSTIFF
  3   Y     N     N      0    0.00E+00  1.00E-02 1.9636E+00  1.00E+01   HEIGHT
  4   Y     N     N      0    0.00E+00  1.00E+00 1.3231E+01  5.00E+01   SPACNG

*****************************************************
******************** DESIGN OBJECTIVE ******************
*************                              ***********
  CURRENT VALUE OF THE OBJECTIVE FUNCTION:
VAR.   CURRENT
NO.     VALUE             DEFINITION
 1    5.373E-02  weight/area of the stiffened spherical shell: WEIGHT

*************                           ************
******************** DESIGN OBJECTIVE ******************
*****************************************************

***** RESULTS FOR LOAD SET NO.  1  ******
PARAMETERS WHICH DESCRIBE BEHAVIOR (e.g. stress, buckling load)
BEH.   CURRENT
NO.     VALUE             DEFINITION
 1    1.000E+00    general instability load factor: BUCGEN(1)
 2    1.775E+00    local buckling load factor: BUCLOC(1)
 3    9.981E-01    load factor for stiffener buckling: BUCSTF(1)
 4    5.600E+04    stress in the skin of the spherical shell: SIGSKN(1)
 5    6.454E+04    stress in the stiffeners: SIGSTF(1)

***** RESULTS FOR LOAD SET NO.  1  ******
MARGINS CORRESPONDING TO CURRENT DESIGN (F.S.= FACTOR OF SAFETY)
MAR.   CURRENT
NO.     VALUE             DEFINITION
 1   -1.401E-05  BUCGEN(1 )/(ABUCG(1 ) X FSBUCG(1 )) -1; F.S.=  1.00
 2    7.752E-01  BUCLOC(1 )/(ABUCL(1 ) X FSBUCL(1 )) -1; F.S.=  1.00
 3   -1.902E-03  BUCSTF(1 )/(ABUCST(1 ) X FSBUCC(1 )) -1; F.S.=  1.00
 4    2.468E-05  ASIGSK(1 )/(SIGSKN(1 ) X FSSIGA(1 )) -1; F.S.=  1.50
 5    8.464E-02  ASIGST(1 )/(SIGSTF(1 ) X FSSIGB(1 )) -1; F.S.=  1.20
**********  ALL 1 LOAD CASES PROCESSED ***********
*****************************************************

PARAMETERS WHICH ARE ALWAYS FIXED.  NONE CAN BE DECISION VARIAB.
VAR.   CURRENT
NO.     VALUE             DEFINITION
 1    4.500E+01  radius of the spherical shell: RADIUS
 2    7.520E+06  modulus of the skin: ESKIN
 3    5.800E-02  weight density of the skin material: RHOSKN
```

4	3.000E-01	Poisson ratio of the skin material: NUSKIN
5	1.300E+07	modulus of the stiffener material: ESTIFF
6	1.000E-01	Poisson ratio of the stiffener material: NUSTIF
7	5.800E-02	weight density of the stiffener material: RHOSTF
8	1.000E+02	knockdown factor from classical buckling formula: KLOC(1)
9	1.000E+02	knockdown factor from classical buckling formula: KLOC(2)
10	5.000E-01	knockdown factor from classical buckling formula: KLOC(3)
11	4.000E-01	knockdown factor from classical buckling formula: KLOC(4)
12	3.000E-01	knockdown factor from classical buckling formula: KLOC(5)
13	2.500E-01	knockdown factor from classical buckling formula: KLOC(6)
14	2.000E-01	knockdown factor from classical buckling formula: KLOC(7)
15	2.000E-01	knockdown factor from classical buckling formula: KLOC(8)
16	0.000E+00	shallowness parameter of spherical cap: LAMBDA(1)
17	3.000E+00	shallowness parameter of spherical cap: LAMBDA(2)
18	3.100E+00	shallowness parameter of spherical cap: LAMBDA(3)
19	5.000E+00	shallowness parameter of spherical cap: LAMBDA(4)
20	1.000E+01	shallowness parameter of spherical cap: LAMBDA(5)
21	1.500E+01	shallowness parameter of spherical cap: LAMBDA(6)
22	2.000E+01	shallowness parameter of spherical cap: LAMBDA(7)
23	2.000E+02	shallowness parameter of spherical cap: LAMBDA(8)
24	5.000E-01	factor for base-radius of spherical cap: LAMMOD
25	1.000E+00	knockdown factor for general instability: KGEN(1)
26	7.000E-01	knockdown factor for general instability: KGEN(2)
27	6.000E-01	knockdown factor for general instability: KGEN(3)
28	4.700E-01	knockdown factor for general instability: KGEN(4)
29	3.800E-01	knockdown factor for general instability: KGEN(5)
30	3.100E-01	knockdown factor for general instability: KGEN(6)
31	2.800E-01	knockdown factor for general instability: KGEN(7)
32	2.600E-01	knockdown factor for general instability: KGEN(8)
33	2.000E-01	knockdown factor for general instability: KGEN(9)
34	2.000E-01	knockdown factor for general instability: KGEN(10)
35	0.000E+00	tabular values of normalized general imperfection: DELBAR(1)
36	5.000E-02	tabular values of normalized general imperfection: DELBAR(2)
37	1.000E-01	tabular values of normalized general imperfection: DELBAR(3)
38	2.000E-01	tabular values of normalized general imperfection: DELBAR(4)
39	3.000E-01	tabular values of normalized general imperfection: DELBAR(5)
40	4.000E-01	tabular values of normalized general imperfection: DELBAR(6)
41	5.000E-01	tabular values of normalized general imperfection: DELBAR(7)
42	6.000E-01	tabular values of normalized general imperfection: DELBAR(8)
43	1.000E+00	tabular values of normalized general imperfection: DELBAR(9)
44	1.000E+02	tabular values of normalized general imperfection: DELBAR(10)
45	5.000E-01	amplitude of general instability imperfection: WGEN
46	0.000E+00	rotational stiffness parameter for stiffener support: EDGSTF

PARAMETERS WHICH ARE ENVIRONMENTAL FACTORS (e.g. loads, temps.)

VAR. NO.	CURRENT VALUE	DEFINITION
1	2.200E+03	external pressure on the spherical shell: PRESS(1)

PARAMETERS WHICH ARE CLASSIFIED AS ALLOWABLES (e.g. max. stress)

VAR. NO.	CURRENT VALUE	DEFINITION
1	1.000E+00	Allowable for general buckling (Use 1.0): ABUCG(1)
2	1.000E+00	Allowable for local buckling (Use 1.0): ABUCL(1)
3	1.000E+00	allowable for stiffener buckling (use 1.0): ABUCST(1)
4	8.400E+04	Maximum allowable effective stress in the skin: ASIGSK(1)
5	8.400E+04	maximum allowable stress in the stiffeners: ASIGST(1)

PARAMETERS WHICH ARE FACTORS OF SAFETY

VAR. CURRENT

```
NO.      VALUE              DEFINITION
 1     1.000E+00  factor of safety for general instability: FSBUCG(1)
 2     1.000E+00  factor of safety for local buckling: FSBUCL(1)
 3     1.000E+00  factor of safety for stiffener buckling: FSBUCC(1)
 4     1.500E+00  factor of safety for stress in the skin: FSSIGA(1)
 5     1.200E+00  factor of safety for stress in stiffeners: FSSIGB(1)

   0 INEQUALITY CONSTRAINTS WHICH MUST BE SATISFIED


DESCRIPTION OF FILES USED AND GENERATED IN THIS RUN:

SPHERE3.NAM = This file contains only the name of the case.
SPHERE3.OPM = Output data. Please list this file and inspect
              carefully before proceeding.
SPHERE3.OPP = Output file containing evolution of design and
              margins since the beginning of optimization cycles.
SPHERE3.CBL = Labelled common blocks for analysis.
             (This is an unformatted sequential file.)
SPHERE3.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 SPHERE3.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
********************* END OF SPHERE3.OPM FILE *****************
```

TABLE 3: RESULTS WITH OUTPUT OPTION NPRINT = 2 FOR ANALYSIS OF FIXED DESIGN

```
************ THE SPHERE3.OPT FILE FOLLOWS *****************
     N        $ Do you want a tutorial session and tutorial output?
        2     $ NPRINT= output index (0=GOOD, 1=ok, 2=debug, 3=too much)
        2     $ Choose type of analysis (1=opt., 2=fixed design)
        5     $ How many design iterations in this run (3 to 25)?
************ END OF THE  SPHERE3.OPT  FILE ***********

******** BEGINNING OF THE  SPHERE3.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 SPHERE3.  Results are stored in the file  SPHERE3.OPM.
Please inspect SPHERE3.OPM before doing more design iterations.
************************************************************


STRUCTURAL ANALYSIS FOR DESIGN ITERATION NO.   0:
 BEHAVIOR FOR LOAD SET NUMBER, ILOADX= 1

WALL PROPERTIES OF STIFFENED SPHERICAL SHELL:
modulus of skin,                                ESKIN=  7.5200E+06
thickness of skin,                              TSKIN=  8.3388E-01
stiffener spacing,                             SPACNG=  1.7803E+01
```

```
modulus of stiffeners,                                   ESTIFF=  1.3000E+07
thickness of stiffeners,                                 TSTIFF=  2.4262E-01
height of stiffeners,                                    HEIGHT=  2.1227E+00
extensional stiffness of the stiffened wall,                C11=  7.4777E+06
bending     stiffness of the stiffened wall,                C44=  1.4399E+06
effective modulus of stiffened shell wall,                 EEFF=  4.3727E+06
effective thickness of stiffened shell wall,               TEFF=  1.5201E+00

PARAMETERS FOR GENERAL BUCKLING OF STIFFENED SHELL:
normalized imperfection amplitude,                  WGEN/TEFF=  3.2893E-01
knockdown factor for initial imperfections,              COEF=  3.5975E-01
radius of spherical shell,                             RADIUS=  4.5000E+01
applied pressure,                                       PRESS=  2.2000E+03
critical pressure(Fig.296 of Bushnell book),            PCRIT=  2.1984E+03
general instability load factor,                       BUCGEN=  9.9928E-01
   1        0.9992761       general instability load factor: BUCGEN(1 )

PARAMETERS FOR LOCAL BUCKLING OF SPHERICAL CAP:
factor for determination of baseplane radius,LAMMOD=  5.0000E-01
"effective" radius of base plane of cap,           REFF=  8.9015E+00
height of apex of cap above its base plane,        HEFF=  8.8919E-01
shallowness parameter of spherical cap,          LAMBDA=  2.6547E+00
fraction of pressure absorbed by the skin,       1/FACT=  9.4342E-01
knockdown factor for initial imperfections,        COEF=  1.0000E+02
critical pressure (Fig. 30 of Bushnell book),     PCRIT=  3.3132E+05
buckling load factor for shallow cap,              BCAP=  1.5060E+02
crit. stress for plate (MDC G4295, Eq(4.1.4), SIGCR=  5.5918E+04
stress in the skin of the spherical shell,          SIG=  5.6002E+04
buckling load factor for triangular plate,       BPLATE=  9.9850E-01
local buckling load factor,                      BUCLOC=  9.9850E-01
   2        0.9984983       local buckling load factor: BUCLOC(1 )
   3        0.9967351       load factor for stiffener buckling: BUCSTF(1 )

PARAMETERS FOR STRESS IN THE SKIN:
fraction of pressure borne by the skin,            FACT=  9.4342E-01
stress in the skin (from pR/(2t)),               SIGSKN=  5.6002E+04
allowable stress in the skin,                    ASIGSK=  8.4000E+04
factor of safety for stress in the skin,         FSSIGA=  1.5000E+00
   4        56002.32        stress in the skin of the spherical shell: SIGSKN(1 )

PARAMETERS FOR STRESS IN THE STIFFENERS:
stress in the stiffeners,                        SIGSTF=  6.4542E+04
allowable stress in the stiffeners,              ASIGST=  8.4000E+04
factor of safety for stress in the stiffener,FSSIGB=  1.2000E+00
   5        64541.69        stress in the stiffeners: SIGSTF(1 )

PARAMETERS FOR WEIGHT/AREA OF SHELL WALL:
weight of the skin,                               WSKIN=  4.8365E-02
weight of the stiffeners,                        WSTIFF=  5.0334E-03
total weight/surface area of the shell wall, WEIGHT=  5.3399E-02
```

SUMMARY OF INFORMATION FROM OPTIMIZATION ANALYSIS

VAR. NO.	DEC. VAR.	ESCAPE VAR.	LINK. VAR.	LINKED TO	LINKING CONSTANT	LOWER BOUND	CURRENT VALUE	UPPER BOUND	VARIABLE
1	Y	Y	N	0	0.00E+00	1.00E-01	8.3388E-01	5.00E+00	TSKIN
2	Y	Y	N	0	0.00E+00	2.00E-01	2.4262E-01	5.00E+00	TSTIFF
3	Y	N	N	0	0.00E+00	1.00E-02	2.1227E+00	1.00E+01	HEIGHT
4	Y	N	N	0	0.00E+00	1.00E+00	1.7803E+01	5.00E+01	SPACNG

***** RESULTS FOR LOAD SET NO. 1 ******

(Lines skipped to save space - they are the same as those at the end of Table 2.)

APPENDICES

A – F

APPENDIX A - the SPHERE.INP file

The following list represents input data for the GENTEXT processor of the GENOPT system (See Ref. [7]). This file is created during the GENOPT user's interactive session.

```
*************** THE SPHERE.INP FILE FOLLOWS *****************
      5  $ starting prompt index in the file SPHERE.PRO
      5  $ increment for prompt index
      0  $ Type of prompt: 0="help" paragraph, 1=one-line prompt
=======================================================
y         $ Are there more lines in the "help" paragraph?
MINIMUM WEIGHT DESIGN OF ISOGRID-STIFFENED SPHERICAL SHELLS
y         $ Are there more lines in the "help" paragraph?
UNDER UNIFORM EXTERNAL PRESSURE
y         $ Are there more lines in the "help" paragraph?
by
y         $ Are there more lines in the "help" paragraph?
David Bushnell, Dept 93-30, B251, Lockeed Research,
y         $ Are there more lines in the "help" paragraph?
Palo Alto, CA 94304, January, 1990
y         $ Are there more lines in the "help" paragraph?
=======================================================
y         $ Are there more lines in the "help" paragraph?
This program is for optimization of stiffened spherical shells
y         $ Are there more lines in the "help" paragraph?
under uniform external pressure. The stiffeners are assumed to
y         $ Are there more lines in the "help" paragraph?
be blades and are arranged in an isogrid pattern in order to
y         $ Are there more lines in the "help" paragraph?
maintain isotropy of the stiffened wall.  In this way formulas
y         $ Are there more lines in the "help" paragraph?
and tables applicable to buckling of monocoque isotropic spherical
y         $ Are there more lines in the "help" paragraph?
shells can be applied, with proper definition of effective
y         $ Are there more lines in the "help" paragraph?
modulus and thickness, to buckling of the stiffened spherical
y         $ Are there more lines in the "help" paragraph?
shell.  The skin of the shell and the stiffeners are assumed
y         $ Are there more lines in the "help" paragraph?
to be of isotropic material, with different material properties
y         $ Are there more lines in the "help" paragraph?
in skin and stiffeners. Only membrane prebuckling states are
y         $ Are there more lines in the "help" paragraph?
considered. The theory used follows, for the most part, that
y         $ Are there more lines in the "help" paragraph?
given in Ref. 1, with the exception that skin and stiffeners
y         $ Are there more lines in the "help" paragraph?
may be of different material. The effect of transverse shear
y         $ Are there more lines in the "help" paragraph?
deformation is ignored.
y         $ Are there more lines in the "help" paragraph?
The following behaviors constrain the design:
y         $ Are there more lines in the "help" paragraph?
1. general instability of the stiffened shell (Refs. 1,2,3)
y         $ Are there more lines in the "help" paragraph?
2. local buckling between stiffeners          (Refs. 1,3,4)
```

```
y         $ Are there more lines in the "help" paragraph?
(a) buckling of shallow spherical cap          (Ref. 3)
y         $ Are there more lines in the "help" paragraph?
(b) buckling of triangular plate               (Refs. 1,4)
y         $ Are there more lines in the "help" paragraph?
3. buckling of stiffeners                      (Refs. 5,6)
y         $ Are there more lines in the "help" paragraph?
4. stress in the skin                          (Ref. 1)
y         $ Are there more lines in the "help" paragraph?
5. stress in the stiffeners                    (Ref. 1)
y         $ Are there more lines in the "help" paragraph?
The system of programs, BEGIN, DECIDE, MAINSETUP, OPTIMIZE,
y         $ Are there more lines in the "help" paragraph?
CHANGE, CHOOSEPLOT, DIPLOT, for the minimum-weight design
y         $ Are there more lines in the "help" paragraph?
of isogrid-blade-stiffened spherical shells under uniform
y         $ Are there more lines in the "help" paragraph?
external pressure was written with use of GENOPT (Ref. 7).
y         $ Are there more lines in the "help" paragraph?
*** REFERENCES ***
y         $ Are there more lines in the "help" paragraph?
[1] Meyer, R.R., Harwood, O.P., Harmon, M.B., Orlando, J.I.,
y         $ Are there more lines in the "help" paragraph?
ISOGRID DESIGN HANDBOOK, MDC G4295, MacDonnell Douglas
y         $ Are there more lines in the "help" paragraph?
Astronautics, Huntington Beach, CA, December 1972
y         $ Are there more lines in the "help" paragraph?
[2] Bushnell, D., "Dynamic response of two-layered cylindrical
y         $ Are there more lines in the "help" paragraph?
shells to time-dependent loads", AIAA Journal, Vol. 3, No. 9
y         $ Are there more lines in the "help" paragraph?
pp 1698-1703, 1965
y         $ Are there more lines in the "help" paragraph?
[3] Bushnell, D., COMPUTERIZED BUCKLING ANALYSIS OF SHELLS, Nijhoff
y         $ Are there more lines in the "help" paragraph?
The Netherlands, 1985
y         $ Are there more lines in the "help" paragraph?
[4] Gerard, G. and Becker, H., "HANDBOOK OF STRUCTURAL STABILITY,
y         $ Are there more lines in the "help" paragraph?
Part I - Buckling of Flat Plates", NACA TN-3781, July 1957
y         $ Are there more lines in the "help" paragraph?
[5] Roark, S., FORMULAS FOR STRESS AND STRAIN, 3rd Edition,
y         $ Are there more lines in the "help" paragraph?
McGraw-Hill, 1954
y         $ Are there more lines in the "help" paragraph?
[6] Timoshenko, S. and Gere, J.M., THEORY OF ELASTIC STABILITY,
y         $ Are there more lines in the "help" paragraph?
2nd Edition, McGraw-Hill, 1971
y         $ Are there more lines in the "help" paragraph?
[7] Bushnell, D., "GENOPT - a program that writes user-friendly
y         $ Are there more lines in the "help" paragraph?
optimization code", to appear, Int. J. Solids and Structures, 1990
n         $ Are there more lines in the "help" paragraph?
      1   $ Type of prompt: 0="help" paragraph, 1=one-line prompt

RADIUS    $ 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  RADIUS  an array?
radius of the spherical shell
```

```
n        $ Do you want to include a "help" paragraph?
y        $ Any more variables for role types  1  or  2   ?   $10
      1  $ Type of prompt: 0="help" paragraph, 1=one-line prompt
TSKIN    $ Name of a variable in the users program (defined below)
      1  $ Role of the variable in the users program
N        $ Is the variable  TSKIN  an array?
thickness of the skin
n        $ Do you want to include a "help" paragraph?
y        $ Any more variables for role types  1  or  2   ?   $15
      1  $ Type of prompt: 0="help" paragraph, 1=one-line prompt
TSTIFF   $ Name of a variable in the users program (defined below)
      1  $ Role of the variable in the users program
N        $ Is the variable  TSTIFF  an array?
thickness of a stiffener
n        $ Do you want to include a "help" paragraph?
y        $ Any more variables for role types  1  or  2   ?   $20
      1  $ Type of prompt: 0="help" paragraph, 1=one-line prompt
HEIGHT   $ Name of a variable in the users program (defined below)
      1  $ Role of the variable in the users program
n        $ Is the variable  HEIGHT  an array?
height of a stiffener
n        $ Do you want to include a "help" paragraph?
y        $ Any more variables for role types  1  or  2   ?   $25
      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 stiffeners
y        $ Do you want to include a "help" paragraph?
SPACNG is the distance between each set of parallel stiffeners.
y        $ Any more lines in the "help" paragraph?
There are three sets of parallel stiffeners, each set oriented at
y        $ Any more lines in the "help" paragraph?
an angle of 60 degrees with respect to the other sets, thereby
y        $ Any more lines in the "help" paragraph?
forming an "isogrid", that is, a grid of equilateral triangles.
y        $ Any more lines in the "help" paragraph?
The length of each side of the quadrilateral triangles formed
y        $ Any more lines in the "help" paragraph?
by the isogrid is given by: LENGTH = 2.*SPACNG/SQRT(3.).
y        $ Any more lines in the "help" paragraph?
Each stiffener is a blade with thickness TSTIFF and height HEIGHT.
y        $ Any more lines in the "help" paragraph?
All stiffeners have the same cross section and are of the same
y        $ Any more lines in the "help" paragraph?
material.  This material may be different from the material of
y        $ Any more lines in the "help" paragraph?
the skin of the spherical shell.
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
ESKIN    $ 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  ESKIN  an array?
modulus of the skin
n        $ Do you want to include a "help" paragraph?
y        $ Any more variables for role types  1  or  2   ?   $35
      1  $ Type of prompt: 0="help" paragraph, 1=one-line prompt
RHOSKN   $ 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  RHOSKN  an array?
 weight density of the skin material
 n        $ Do you want to include a "help" paragraph?
 y        $ Any more variables for role types  1  or  2   ?    $40
       1  $ Type of prompt: 0="help" paragraph, 1=one-line prompt
 NUSKIN   $ 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  NUSKIN  an array?
 Poisson ratio of the skin material
 n        $ Do you want to include a "help" paragraph?
 y        $ Any more variables for role types  1  or  2   ?    $45
       1  $ Type of prompt: 0="help" paragraph, 1=one-line prompt
 ESTIFF   $ 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  ESTIFF  an array?
 modulus of the stiffener material
 n        $ Do you want to include a "help" paragraph?
 y        $ Any more variables for role types  1  or  2   ?    $50
       1  $ Type of prompt: 0="help" paragraph, 1=one-line prompt
 NUSTIF   $ 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  NUSTIF  an array?
 Poisson ratio of the stiffener material
 n        $ Do you want to include a "help" paragraph?
 y        $ Any more variables for role types  1  or  2   ?    $55
       1  $ Type of prompt: 0="help" paragraph, 1=one-line prompt
 RHOSTF   $ 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  RHOSTF  an array?
 weight density of the stiffener material
 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
 KLOC     $ 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  KLOC  an array?
 Y        $ Do you want to establish new dimensions for KLOC ?
       1  $ Number of dimensions in the array,  KLOC
 number of entries in the KLOC vs. LAMBDA table
      30  $ Max. allowable number of rows NROWS in the array, KLOC
 knockdown factor from classical buckling formula
 y        $ Do you want to include a "help" paragraph?
 The classical formula for buckling of a complete spherical
 y        $ Any more lines in the "help" paragraph?
 shell is:
 y        $ Any more lines in the "help" paragraph?
 p(classical) = 2*ESKIN*TSKIN**2/{SQRT[3(1-NUSKIN**2)]*R**2}
 Y        $ Any more lines in the "help" paragraph?
 As shown in Fig. 30, p 29 of COMPUTERIZED BUCKLING ANALYSIS
 Y        $ Any more lines in the "help" paragraph?
 OF SHELLS (Ref. 3), shallow spherical caps buckle at pressures
 y        $ Any more lines in the "help" paragraph?
 considerably lower than p(classical), partly because of
```

```
y        $ Any more lines in the "help" paragraph?
the presence of a boundary of the shallow cap, and
y        $ Any more lines in the "help" paragraph?
partly because of initial geometric imperfections.
y        $ Any more lines in the "help" paragraph?

y        $ Any more lines in the "help" paragraph?
In this program we must calculate the buckling load factor
y        $ Any more lines in the "help" paragraph?
for a shallow spherical cap because local buckling involves
y        $ Any more lines in the "help" paragraph?
only the shallow portion of the spherical shell between
y        $ Any more lines in the "help" paragraph?
adjacent stiffeners.
n        $ Any more lines in the "help" paragraph?
y        $ Any more variables for role types  1  or  2   ?    $70
      1  $ Type of prompt: 0="help" paragraph, 1=one-line prompt
LAMBDA   $ 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  LAMBDA  an array?
N        $ Do you want to establish new dimensions for LAMBDA ?
shallowness parameter of spherical cap
y        $ Do you want to include a "help" paragraph?
See Fig. 30, p 29 of COMPUTERIZED BUCKLING ANALYSIS OF SHELLS.
y        $ Any more lines in the "help" paragraph?
The formula for the shallowness parameter LAMBDA is:
y        $ Any more lines in the "help" paragraph?
LAMBDA = 2*SQRT{SQRT[3(1-NUSKIN**2)]}*SQRT(H/TSKIN)
y        $ Any more lines in the "help" paragraph?
in which H is distance from the base plane of the spherical
y        $ Any more lines in the "help" paragraph?
cap to its apex.
n        $ Any more lines in the "help" paragraph?
y        $ Any more variables for role types  1  or  2   ?    $75
      1  $ Type of prompt: 0="help" paragraph, 1=one-line prompt
LAMMOD   $ 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  LAMMOD  an array?
factor for base-radius of spherical cap
y        $ Do you want to include a "help" paragraph?
Local buckling of the stiffened spherical shell occurs
y        $ Any more lines in the "help" paragraph?
in the triangular region between the stiffeners. However,
y        $ Any more lines in the "help" paragraph?
we do not have any simple formulas for buckling of
y        $ Any more lines in the "help" paragraph?
a spherical cap with a triangular planform.  Therefore,
y        $ Any more lines in the "help" paragraph?
we use a formula for buckling of an axisymmetric spherical
y        $ Any more lines in the "help" paragraph?
cap. The question then is, what should be the base radius
y        $ Any more lines in the "help" paragraph?
r of the shallow spherical cap.  The smallest possible
y        $ Any more lines in the "help" paragraph?
value would be the radius of the cap of circular planform
y        $ Any more lines in the "help" paragraph?
that is inscribed within the equilateral triangle formed
y        $ Any more lines in the "help" paragraph?
```

```
by the stiffeners (r(1) = SPACNG/3).  The largest value would
y         $ Any more lines in the "help" paragraph?
be the radius of the cap of circular planform in which the
y         $ Any more lines in the "help" paragraph?
equilaterial triangle formed by the stiffeners is inscribed
y         $ Any more lines in the "help" paragraph?
(r(2) = 2.*SPACNG/3). The actual radius used in this
y         $ Any more lines in the "help" paragraph?
program is r = r(1)*(1 + LAMMOD).  The user must
y         $ Any more lines in the "help" paragraph?
choose a value of LAMMOD between 0 (inscribed cap) and
y         $ Any more lines in the "help" paragraph?
unity (inscribed equilateral triangle, r(2)).
n         $ Any more lines in the "help" paragraph?
y         $ Any more variables for role types  1  or  2   ?    $80
     1    $ Type of prompt: 0="help" paragraph, 1=one-line prompt
KGEN      $ 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  KGEN  an array?
y         $ Do you want to establish new dimensions for KGEN ?
     1    $ Number of dimensions in the array,  KGEN
number of entries in the table of KGEN v. DELBAR
    30    $ Max. allowable number of rows NROWS in the array, KGEN
knockdown factor for general instability
y         $ Do you want to include a "help" paragraph?
KGEN is a function of the normalized amplitude of the initial
y         $ Any more lines in the "help" paragraph?
imperfection, DELBAR, where DELBAR is the actual imperfection
y         $ Any more lines in the "help" paragraph?
amplitude divided by the effective thickness of the stiffened
y         $ Any more lines in the "help" paragraph?
spherical shell. The effective thickness, calculated in
y         $ Any more lines in the "help" paragraph?
SUBROUTINE BEHX1, is that thickness for which both the
y         $ Any more lines in the "help" paragraph?
extensional and bending stiffnesses of the stiffened shell
y         $ Any more lines in the "help" paragraph?
match those of an equivalent monocoque, isotropic shell.
y         $ Any more lines in the "help" paragraph?
(the modulus of the equivalent monocoque, isotropic shell
y         $ Any more lines in the "help" paragraph?
is also an "effective" quantity - See SUBROUTINE BEHX1).
y         $ Any more lines in the "help" paragraph?
The user is free to choose KGEN v DELBAR from any source.
y         $ Any more lines in the "help" paragraph?
One source is Fig. 296, p. 340 of Ref. 3.
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
DELBAR    $ 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  DELBAR  an array?
n         $ Do you want to establish new dimensions for DELBAR ?
tabular values of normalized general imperfection
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
WGEN      $ 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  WGEN  an array?
 amplitude of general instability imperfection
 y        $ Do you want to include a "help" paragraph?
 NOTE: WGEN is not normalized. It is the amplitude of the
 y        $ Any more lines in the "help" paragraph?
 normal displacement component of the initial global imperfection.
 y        $ Any more lines in the "help" paragraph?
 It is best to use a value that is between 0.5 and 1.0 percent
 y        $ Any more lines in the "help" paragraph?
 of the shell diameter.
 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
 EDGSTF   $ 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  EDGSTF  an array?
 rotational stiffness parameter for stiffener support
 y        $ Do you want to include a "help" paragraph?
 In SUBROUTINE BEHX3 the buckling load factor of a blade
 y        $ Any more lines in the "help" paragraph?
 stiffener elastically supported at its base and free at its
 y        $ Any more lines in the "help" paragraph?
 outer edge (height) is calculated from the formula:
 y        $ Any more lines in the "help" paragraph?
 BUCSTF =
 y        $ Any more lines in the "help" paragraph?
 (0.375+0.7*EDGSTF)*[ESTIFF/(1-NUSTIF**2)]*(TSTIFF/HEIGHT)**2
 y        $ Any more lines in the "help" paragraph?
 in which EDGSTF must have a value between 0 and 1.
 y        $ Any more lines in the "help" paragraph?
 (EDGSTF=0 means hinged, EDGSTF=1 means clamped, and
 y        $ Any more lines in the "help" paragraph?
 EDGSTF between 0 and 1 indicate elastic rotational support.
 y        $ Any more lines in the "help" paragraph?
 The formula for buckling is an amalgam of Formulas 4 and 5
 y        $ Any more lines in the "help" paragraph?
 of Table XVI on pp 312 of Roark (Ref. 5) and Timoshenko (Ref. 6).
 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
 external pressure on the spherical shell
 n        $ Do you want to include a "help" paragraph?
 n        $ Any more variables for role type  3 ?              $
       0  $ Type of prompt: 0="help" paragraph, 1=one-line prompt
 There are five "behaviors" that constrain the optimum design:
 y        $ Are there more lines in the "help" paragraph?
 1. General buckling of the spherical shell
 y        $ Are there more lines in the "help" paragraph?
 2. Local buckling of the skin between stiffeners
 y        $ Are there more lines in the "help" paragraph?
 3. Local buckling of the blade stiffener
 y        $ Are there more lines in the "help" paragraph?
 4. Stress in the skin of the spherical shell
 y        $ Are there more lines in the "help" paragraph?
 5. Stress in the stiffeners of the spherical shell
```

```
n        $ Are there more lines in the "help" paragraph?
      1  $ Type of prompt: 0="help" paragraph, 1=one-line prompt
BUCGEN   $ 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 BUCGEN ?
general instability load factor
y        $ Do you want to include a "help" paragraph?
See SUBROUTINE BEHX1 of the BEHAVIOR.SPHERE library for details
y        $ Any more lines in the "help" paragraph?
on the theory. The method:
y        $ Any more lines in the "help" paragraph?
1. Calculate an effective thickness TEFF and effective
y        $ Any more lines in the "help" paragraph?
modulus EEFF from the theories presented in Refs. 1 and 2.
y        $ Any more lines in the "help" paragraph?
2. Calculate a knockdown factor COEF given the input table
y        $ Any more lines in the "help" paragraph?
KGEN v DELBAR and the actual imperfection amplitude WGEN and
y        $ Are there more lines in the "help" paragraph?
the effective thickness TEFF  (WGEN/TEFF).
y        $ Any more lines in the "help" paragraph?
3. Calculate the buckling pressure from the classical formula
y        $ Any more lines in the "help" paragraph?
p(critical)=2*COEF*EEFF*TEFF**2/{SQRT[3(1-NUEFF**2)]*R**2}
n        $ Any more lines in the "help" paragraph?
      1  $ Type of prompt: 0="help" paragraph, 1=one-line prompt
ABUCG    $ Name of a variable in the users program (defined below)
      5  $ Role of the variable in the users program
Allowable for general buckling (Use 1.0)
y        $ Do you want to include a "help" paragraph?
Use unity for allowables for buckling load factors. Next you will
y        $ Any more lines in the "help" paragraph?
be asked to provide a factor of safety, so that if you want the
y        $ Any more lines in the "help" paragraph?
buckling load factor for general instability to be some multiple
y        $ Any more lines in the "help" paragraph?
of the applied pressure, the factor of safety permits this
y        $ Any more lines in the "help" paragraph?
flexibility.
n        $ Any more lines in the "help" paragraph?
      1  $ Type of prompt: 0="help" paragraph, 1=one-line prompt
FSBUCG   $ Name of a variable in the users program (defined below)
      6  $ Role of the variable in the users program
factor of safety for general instability
n        $ Do you want to include a "help" paragraph?
      2  $ Indicator (1 or 2) for type of constraint
y        $ Any more variables for role type  4 ?                $135
      1  $ Type of prompt: 0="help" paragraph, 1=one-line prompt
BUCLOC   $ 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 BUCLOC ?
local buckling load factor
y        $ Do you want to include a "help" paragraph?
This is the load factor for buckling of the skin between
y        $ Any more lines in the "help" paragraph?
adjacent stiffeners. Details appear in SUBROUTINE BEHX2 of the
y        $ Any more lines in the "help" paragraph?
BEHAVIOR.SPHERE library. The method is:
y        $ Any more lines in the "help" paragraph?
1. Calculate fraction (1/FACT) of the pressure supported by
```

```
y        $ Any more lines in the "help" paragraph?
the skin:
y        $ Any more lines in the "help" paragraph?
FACT = 1. + (ESTIFF/ESKIN)*(TSTIFF*HEIGHT/TSKIN*SPACNG)
y        $ Any more lines in the "help" paragraph?
2. Calculate the effective shallowness parameter, EFFLAM,
y        $ Any more lines in the "help" paragraph?
for the portion of spherical shell between stiffeners
y        $ Any more lines in the "help" paragraph?
(base radius r is given by r = 0.333*SPACNG*(1+LAMMOD)).
y        $ Any more lines in the "help" paragraph?
3. Calculate buckling pressure for externally pressurized
y        $ Any more lines in the "help" paragraph?
shallow spherical cap with shallowness parameter EFFLAM:
y        $ Any more lines in the "help" paragraph?
p(critical) = FACT*COEF*2*ESKIN*TSKIN**2/
y        $ Any more lines in the "help" paragraph?
[SQRT(3.*(1.-NUSKIN**2))*RADIUS**2]
y        $ Any more lines in the "help" paragraph?
in which COEF is the knockdown factor interpolated from
y        $ Any more lines in the "help" paragraph?
the input values KLOC v LAMBDA provided from a curve
y        $ Any more lines in the "help" paragraph?
derived from data such as shown in Fig. 30, p 29 of Ref. 3.
y        $ Any more lines in the "help" paragraph?
4. Calculate the buckling load factor: pcrit/PRESS
y        $ Any more lines in the "help" paragraph?
5. Calculate buckling stress for biaxially compressed flat
y        $ Any more lines in the "help" paragraph?
equilateral triangular plate with simply supported edges:
y        $ Any more lines in the "help" paragraph?
SIGCR = 5*PI**2*ESKIN*(TSKIN/A)**2/(12.*(1.-NUSKIN**2))
y        $ Any more lines in the "help" paragraph?
in which  A = 2.*SPACNG/SQRT(3.) is the length of a side
y        $ Any more lines in the "help" paragraph?
of the equilateral triangle. (Ref. 1, Eq.(4.1.4), Ref. 4).
y        $ Any more lines in the "help" paragraph?
6. Calculate the stress in the skin between stiffeners from:
y        $ Any more lines in the "help" paragraph?
SIG    = PRESS*RADIUS/(2.*TSKIN*FACT)
y        $ Any more lines in the "help" paragraph?
7. Calculate the buckling load factor: SIGCR/ABS(SIG)
y        $ Any more lines in the "help" paragraph?
8. Choose the minimum of 4. and 7. as the local buckling
y        $ Any more lines in the "help" paragraph?
load factor.
n        $ Any more lines in the "help" paragraph?
      1  $ Type of prompt: 0="help" paragraph, 1=one-line prompt
ABUCL    $ Name of a variable in the users program (defined below)
      5  $ Role of the variable in the users program
Allowable for local buckling (Use 1.0)
n        $ Do you want to include a "help" paragraph?
      1  $ Type of prompt: 0="help" paragraph, 1=one-line prompt
FSBUCL   $ Name of a variable in the users program (defined below)
      6  $ Role of the variable in the users program
factor of safety for local buckling
n        $ Do you want to include a "help" paragraph?
      2  $ Indicator (1 or 2) for type of constraint
y        $ Any more variables for role type  4 ?            $150
      1  $ Type of prompt: 0="help" paragraph, 1=one-line prompt
```

```
BUCSTF    $ 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 BUCSTF ?
load factor for stiffener buckling
y         $ Do you want to include a "help" paragraph?
The stiffeners can buckle like long, flat plates with one edge
y         $ Any more lines in the "help" paragraph?
elastically supported and the other edge free. Details appear
y         $ Any more lines in the "help" paragraph?
in SUBROUTINE BEHX3 of the BEHAVIOR.SPHERE library. The method
y         $ Any more lines in the "help" paragraph?
is:
y         $ Any more lines in the "help" paragraph?
1. Calculate the critical stress in the long, straight,flat
y         $ Any more lines in the "help" paragraph?
plate from the formula:
y         $ Any more lines in the "help" paragraph?
SIGCR = (0.375+0.7*EDGSTF)*
y         $ Any more lines in the "help" paragraph?
(ESTIFF/(1.-NUSTIF**2))*(TSTIFF/HEIGHT)**2
y         $ Any more lines in the "help" paragraph?
in which EDGSTF is a user-supplied number between 0 and 1.
y         $ Any more lines in the "help" paragraph?
A formula analogous to the above appears in Ref. 1 as
y         $ Any more lines in the "help" paragraph?
Eq. (4.1.7). It originates in Refs. 5 and 6.
y         $ Any more lines in the "help" paragraph?
2. Calculate the current stress in the stiffener from:
y         $ Any more lines in the "help" paragraph?
(See Eq.(4.1.8), p 4.1.005 of MDC G4295), except formula
y         $ Any more lines in the "help" paragraph?
below is valid if there are different moduli in skin and
y         $ Any more lines in the "help" paragraph?
stiffeners:
y         $ Any more lines in the "help" paragraph?
ALPHA = TSTIFF*HEIGHT/(TSKIN*SPACNG)
y         $ Any more lines in the "help" paragraph?
ALPHAS= (ESTIFF/ESKIN)*ALPHA
y         $ Any more lines in the "help" paragraph?
FNUEFF= 1./3.
y         $ Any more lines in the "help" paragraph?
SIG = ESTIFF*PRESS*(RADIUS/2.)*(1.-FNUEFF)/
y         $ Any more lines in the "help" paragraph?
(ESKIN*TSKIN*(1.+ALPHAS))
y         $ Any more lines in the "help" paragraph?
3. Calculate the load factor for stiffener buckling from:
y         $ Any more lines in the "help" paragraph?
BUCSTF(ILOADX) = SIGCR/ABS(SIG)
n         $ Any more lines in the "help" paragraph?
      1   $ Type of prompt: 0="help" paragraph, 1=one-line prompt
ABUCST    $ Name of a variable in the users program (defined below)
      5   $ Role of the variable in the users program
allowable for stiffener buckling (use 1.0)
n         $ Do you want to include a "help" paragraph?
      1   $ Type of prompt: 0="help" paragraph, 1=one-line prompt
FSBUCC    $ Name of a variable in the users program (defined below)
      6   $ Role of the variable in the users program
factor of safety for stiffener buckling
n         $ Do you want to include a "help" paragraph?
      2   $ Indicator (1 or 2) for type of constraint
```

```
y        $ Any more variables for role type  4 ?              $165
      1  $ Type of prompt: 0="help" paragraph, 1=one-line prompt
SIGSKN   $ 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 SIGSKN ?
stress in the skin of the spherical shell
y        $ Do you want to include a "help" paragraph?
The stress is calculated from membrane theory (no bending).
y        $ Any more lines in the "help" paragraph?
Details are given in SUBROUTINE BEHX4 of the BEHAVIOR.SPHERE
y        $ Any more lines in the "help" paragraph?
library.
y        $ Any more lines in the "help" paragraph?
In actual fact there will be some bending of the skin between
y        $ Any more lines in the "help" paragraph?
adjacent stiffeners.  Allow for this by providing a factor
y        $ Any more lines in the "help" paragraph?
of safety greater than unity.
n        $ Any more lines in the "help" paragraph?
      1  $ Type of prompt: 0="help" paragraph, 1=one-line prompt
ASIGSK   $ Name of a variable in the users program (defined below)
      5  $ Role of the variable in the users program
Maximum allowable effective stress in the skin
n        $ Do you want to include a "help" paragraph?
      1  $ Type of prompt: 0="help" paragraph, 1=one-line prompt
FSSIGA   $ 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 the skin
n        $ Do you want to include a "help" paragraph?
      1  $ Indicator (1 or 2) for type of constraint
y        $ Any more variables for role type  4 ?              $180
      1  $ Type of prompt: 0="help" paragraph, 1=one-line prompt
SIGSTF   $ 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 SIGSTF ?
stress in the stiffeners
y        $ Do you want to include a "help" paragraph?
SIGSTF is calculated from membrane theory (no bending).
y        $ Any more lines in the "help" paragraph?
Details are given in SUBROUTINE BEHX5 of the BEHAVIOR.SPHERE
y        $ Any more lines in the "help" paragraph?
library.
y        $ Any more lines in the "help" paragraph?
Provide a factor of safety greater than unity to allow for
y        $ Any more lines in the "help" paragraph?
bending.
n        $ Any more lines in the "help" paragraph?
      1  $ Type of prompt: 0="help" paragraph, 1=one-line prompt
ASIGST   $ Name of a variable in the users program (defined below)
      5  $ Role of the variable in the users program
maximum allowable stress in the stiffeners
n        $ Do you want to include a "help" paragraph?
      1  $ Type of prompt: 0="help" paragraph, 1=one-line prompt
FSSIGB   $ 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 stiffeners
n        $ Do you want to include a "help" paragraph?
      1  $ Indicator (1 or 2) 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/area of the stiffened spherical shell
y        $ Do you want to include a "help" paragraph?
Details are given in SUBROUTINE OBJECT of the BEHAVIOR.SPHERE
y        $ Any more lines in the "help" paragraph?
library.
y        $ Any more lines in the "help" paragraph?
1. Calculate weight per unit surface area of the stiffened
y        $ Any more lines in the "help" paragraph?
spherical shell:
y        $ Any more lines in the "help" paragraph?
WSKIN  = RHOSKN*TSKIN
y        $ Any more lines in the "help" paragraph?
WSTIFF = 3.*RHOSTF*TSTIFF*HEIGHT/SPACNG
y        $ Any more lines in the "help" paragraph?
WEIGHT = WSKIN + WSTIFF
n        $ Any more lines in the "help" paragraph?
******************* END OF THE SPHERE.INP FILE *******************
```

APPENDIX B - the SPHERE.DEF file

The following list is created by GENOPT during the GENTEXT interactive session. It is intended to be referenced by the GENOPT user, although the "end" user may also find it useful.

```
******************* THE SPHERE.DEF FILE FOLLOWS *******************
 YOU ARE USING WHAT I HAVE CALLED "GENOPT" TO GENERATE AN
 OPTIMIZATION PROGRAM FOR A PARTICULAR CLASS OF PROBLEMS.
 THE NAME YOU HAVE CHOSEN FOR THIS CLASS OF PROBLEMS IS: SPHERE

 "GENOPT" (GENeral OPTimization) was written during 1987-1988
 by Dr. David Bushnell, Dept. 93-30, Bldg. 251, (415)424-3237
    Lockheed Missiles and Space Co., 3251 Hanover St.,
    Palo Alto, California, USA  94304

 The optimizer used in GENOPT is called ADS, and was
 written by G. Vanderplaats [B1]. It is based on the method
 of feasible directions [B2].

                         ABSTRACT

 "GENOPT" has the following purposes and properties:
     1. Any relatively simple analysis is "automatically"
        converted into an optimization of whatever system
        can be analyzed with fixed properties. Please note
        that GENOPT is not intended to be used for problems
        that require elaborate data-base management systems
        or large numbers of degrees of freedom.

     2. The optimization problems need not be in fields nor
        jargon familiar to me, the developer of GENOPT.
        Although both example cases (See the files
        PLATE.CAS    and    PANEL.CAS)
        are in the field of structural analysis, GENOPT is
        not limited to that field.

     3. GENOPT is a program that writes other programs. These
```

programs, WHEN AUGMENTED BY USER-SUPPLIED CODING, form a program system that should be user-friendly in the GENOPT-user"s field. In this instance the user of GENOPT must later supply FORTRAN coding that calculates behavior in the problem class called "SPHERE".

4. Input data and textual material are elicited from the user of GENOPT in a general enough way so that he or she may employ whatever data, definitions, and "help" paragraphs will make subsequent use of the program system thus generated easy by those less familiar with the class of problems "SPHERE" than the GENOPT user.

5. The program system generated by GENOPT has the same general architecture as previous programs written for specific applications by the developer [B3 - B6]. That is, the command set is:

```
BEGIN      (User supplies starting design, loads,
            control integers, material properties,
            etc. in an interactive-help mode.)

DECIDE     (User chooses decision and linked
            variables and inequality constraints
            that are not based on behavior.)

MAINSETUP  (User chooses output option, whether
            to perform analysis of a fixed design
            or to optimize, and number of design
            iterations.)

OPTIMIZE   (The program system performs, in a batch
            mode, the work specified in MAINSETUP.

CHANGE     (User changes certain parameters)

CHOOSEPLOT (User selects which quantities to plot
            vs. design iterations.)

DIPLOT     (User generates plots)

CLEANSPEC  (User cleans out unwanted files.)
```

A typical runstream is:

```
GENOPTLOG   (activate command set)
BEGIN       (provide starting design, loads, etc.)
DECIDE      (choose decision variables and bounds)
MAINSETUP   (choose print option and analysis type)
OPTIMIZE    (launch batch run for n design iterations)
OPTIMIZE    (launch batch run for n design iterations)
OPTIMIZE    (launch batch run for n design iterations)
OPTIMIZE    (launch batch run for n design iterations)
OPTIMIZE    (launch batch run for n design iterations)
OPTIMIZE    (launch batch run for n design iterations)
OPTIMIZE    (launch batch run for n design iterations)
CHANGE      (change some variables for new starting pt)
OPTIMIZE    (launch batch run for n design iterations)
OPTIMIZE    (launch batch run for n design iterations)
OPTIMIZE    (launch batch run for n design iterations)
```

```
OPTIMIZE     (launch batch run for n design iterations)
OPTIMIZE     (launch batch run for n design iterations)
CHOOSEPLOT   (choose which variables to plot)
DIPLOT       (plot variables v. iterations)
CHOOSEPLOT   (choose additional variables to plot)
DIPLOT       (plot more variables v design iterations)
CLEANSPEC    (delete extraneous files for specific case)
```

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

REFERENCES

[B1] Vanderplaats, G. N., "ADS--a FORTRAN program for automated design synthesis, Version 2.01", Engineering Design Optimization, Inc, Santa Barbara, CA, January, 1987

[B2] Vanderplaats, G. N. and Sugimoto, H., "A general-purpose optimization program for engineering design", Computers and Structures, Vol. 24, pp 13-21, 1986

[B3] Bushnell, D., "BOSOR4: Program for stress, stability, and vibration of complex, branched shells of revolution", in STRUCTURAL ANALYSIS SYSTEMS, Vol. 2, edited by A. Niku-Lari, pp. 25-54, (1986)

[B4] Bushnell, D., "BOSOR5: Program for buckling of complex, branched shells of revolution including large deflections, plasticity and creep," in STRUCTURAL ANALYSIS SYSTEMS, Vol. 2, edited by A. Niku-Lari, pp. 55-67, (1986)

[B5] Bushnell, D., "PANDA2--program for minimum weight design of stiffened, composite, locally buckled panels", COMPUTERS AND STRUCTURES, vol. 25, No. 4, pp 469-605, 1987

[B6] Bushnell, D., "Improved optimum design of dewar supports", COMPUTERS and STRUCTURES, Vol. 29, No. 1, pp. 1-56 (1988)

[B7] Bushnell, D., "GENOPT--A program that writes user-friendly optimization code", to appear, International Journal of Solids and Structures, 1990. Also to appear in a bound volume of papers from the International Journal of Solids and Structures published in the memory of Professor Charles D. Babcock, formerly with the California Institute of Technology.


```
==============================================================
                 TABLE B1       "GENOPT" COMMANDS
==============================================================
    HELPG          (get information on GENOPT.)
    GENTEXT        (GENOPT user generate a prompt file, program
                    fragments [see TABLE B5], programs [see
                    TABLE B4]., and this and other files
                    [see TABLE B5 and the rest of this file.])
```

```
GENPROGRAMS   (GENOPT user generate absolute elements:
               BEGIN.EXE, DECIDE.EXE, MAINSETUP.EXE,
               OPTIMIZE.EXE, CHANGE.EXE, STORE.EXE,
               CHOOSEPLOT.EXE, DIPLOT.EXE.)
GETLIB        (GENOPT user generate a relocatable elemnt.)
BEGIN         (end user provide starting data.)
DECIDE        (end user choose decision variables, bounds,
               linked variables,inequality constraints.)
MAINSETUP     (end user set up strategy parameters.)
OPTIMIZE      (end user perform optimization, batch mode.)
CHANGE        (end user change some parameters.)
CHOOSEPLOT    (end user choose which variables to plot v.
               design iterations.)
DIPLOT        (end user obtain plots.)
INSERT        (GENOPT user add parameters to the problem.)
CLEANGEN      (GENOPT user cleanup your GENeric files.)
CLEANSPEC     (end user cleanup your SPECific case files)
```

Please consult the following sources for more
information about GENOPT:

1. GENOPTST.ORY and HOWTO.RUN and GENOPT.NEWS
2. Sample cases: (2 cases: PLATE.CAS, PANEL.CAS)
3. NAME.DEF file, where NAME is the name chosen by the GENOPT-user for a class of problems. (In this case NAME = SPHERE)
4. GENOPT.HLP file (type HELPG)

==

TABLE B2 GLOSSARY OF VARIABLES USED IN "SPHERE"

ARRAY ?	NUMBER OF (ROWS,COLS)	ROLE	PROMPT NUMBER (SPHERE.PRO)	NAME	DEFINITION OF VARIABLE
n	(0, 0)	2	10	RADIUS	= radius of the spherical shell
n	(0, 0)	1	15	TSKIN	= thickness of the skin
n	(0, 0)	1	20	TSTIFF	= thickness of a stiffener
n	(0, 0)	1	25	HEIGHT	= height of a stiffener
n	(0, 0)	1	30	SPACNG	= spacing of the stiffeners
n	(0, 0)	2	35	ESKIN	= modulus of the skin
n	(0, 0)	2	40	RHOSKN	= weight density of the skin materia
n	(0, 0)	2	45	NUSKIN	= Poisson ratio of the skin material
n	(0, 0)	2	50	ESTIFF	= modulus of the stiffener material
n	(0, 0)	2	55	NUSTIF	= Poisson ratio of the stiffener mat
n	(0, 0)	2	60	RHOSTF	= weight density of the stiffener ma
n	(0, 0)	2	65	IKLOC	= number of entries in the KLOC vs.
y	(30, 0)	2	70	KLOC	= knockdown factor from classical bu
y	(30, 0)	2	75	LAMBDA	= shallowness parameter of spherical
n	(0, 0)	2	80	LAMMOD	= factor for base-radius of spherica
n	(0, 0)	2	85	IKGEN	= number of entries in the table of
y	(30, 0)	2	90	KGEN	= knockdown factor for general insta
y	(30, 0)	2	95	DELBAR	= tabular values of normalized gener
n	(0, 0)	2	100	WGEN	= amplitude of general instability i
n	(0, 0)	2	105	EDGSTF	= rotational stiffness parameter for
n	(0, 0)	2	110	NCASES	= Number of load cases (number of en
y	(20, 0)	3	115	PRESS	= external pressure on the spherical
y	(20, 0)	4	125	BUCGEN	= general instability load factor
y	(20, 0)	5	130	ABUCG	= Allowable for general buckling (Us
y	(20, 0)	6	135	FSBUCG	= factor of safety for general insta

```
   y   (  20,    0)    4     140    BUCLOC   = local buckling load factor
   y   (  20,    0)    5     145    ABUCL    = Allowable for local buckling (Use
   y   (  20,    0)    6     150    FSBUCL   = factor of safety for local bucklin
   y   (  20,    0)    4     155    BUCSTF   = load factor for stiffener buckling
   y   (  20,    0)    5     160    ABUCST   = allowable for stiffener buckling (
   y   (  20,    0)    6     165    FSBUCC   = factor of safety for stiffener buc
   y   (  20,    0)    4     170    SIGSKN   = stress in the skin of the spherica
   y   (  20,    0)    5     175    ASIGSK   = Maximum allowable effective stress
   y   (  20,    0)    6     180    FSSIGA   = factor of safety for stress in the
   y   (  20,    0)    4     185    SIGSTF   = stress in the stiffeners
   y   (  20,    0)    5     190    ASIGST   = maximum allowable stress in the st
   y   (  20,    0)    6     195    FSSIGB   = factor of safety for stress in sti
   n   (   0,    0)    7     200    WEIGHT   = weight/area of the stiffened spher
==============================================================================
```

```
==============================================================
      TABLE B3   SEVEN ROLES THAT VARIABLES PLAY
==============================================================
   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).
==============================================================
```

The purpose of GENTEXT is to generate a file of prompting phrases and helps called SPHERE.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 B4   FILE OF PROMPTING PHRASES AND HELPS AND
           SOURCE CODE LIBRARIES GENERATED BY "GENTEXT"
==============================================================
 SPHERE.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 SPHERE.
               The Prompt Numbers listed in TABLE B2 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 statements, 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 B2) 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 function, 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 B5: CONTENTS OF SMALL FILES CREATED BY "GENTEXT"

FILE NAME	DEFINITION OF FILE CONTENTS
SPHERE.PRO	Prompts and help paragraphs for interactive input to the user-developed optimization code.
SPHERE.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.
SPHERE.INP	Image of interactive input for user-developed program, generated to save time in case you make a mistake during input.
SPHERE.COM	Labelled common blocks generated specifically for the user-developed class of problems.
SPHERE.WRI	Part of subroutine for writing labelled common blocks in SUBROUTINE STORCM (in Library STOGET).
SPHERE.REA	Part of subroutine for reading labelled common blocks in SUBROUTINE GETCOM (in Library STOGET).

SPHERE.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.

SPHERE.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.

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

SPHERE.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.

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

SPHERE.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 files PLATE.CAS and PANEL.CAS for further information. Brief explanation of the two cases follows:

1. PLATE.CAS - - A simple case involving minimum-weight design of flat, rectangular, isotropic plates under multiple load sets, subject to stress, buckling, vibration, and maximum displacement constraints, and constraints on area and aspect ratio. New coding is introduced only into skeletal subroutines BEHX1, BEHX2, BEHX3,...BEHXn and OBJECT. A linear interpolator, INTERP, from UTIL.NEW is used.

2. PANEL.CAS - - A more complex case involving minimum-weight design of cylindrical stringer and ring stiffened panels made of laminated composite material and subject to multiple sets of in-plane loads. Coding is borrowed from the previously developed PANDA2 libraries [B5]. STRUCT.NEW is modified, SUBROUTINE TRANFR is used to translate data names, SUBROUTINES BEHX1, BEHX2, BEHX3,...BEHX18 are not changed, but SUBROUTINE OBJECT is completed.

******************* END OF SPHERE.DEF FILE ********************

APPENDIX C - the SPHERE.PRO file

The following list is created by GENOPT during the interactive GENTEXT session. It contains the data names, definitions, and "help" paragraphs created by the GENOPT user. This is the prompt file for input data from the "end" user during his or her use of the BEGIN processor.

******************* THE SPHERE.PRO FILE FOLLOWS *****************

```
  5.0
      ============================================================
      MINIMUM WEIGHT DESIGN OF ISOGRID-STIFFENED SPHERICAL SHELLS
                 UNDER UNIFORM EXTERNAL PRESSURE

                 David Bushnell, Dept. 93-30, B251
             Lockheed Palo Alto Research Laboratory
                         January, 1990
      ============================================================
      This program is for optimization of stiffened spherical shells
```

under uniform external pressure. The stiffeners are assumed to be blades and are arranged in an isogrid pattern in order to maintain isotropy of the stiffened wall. In this way formulas and tables applicable to buckling of monocoque isotropic spherical shells can be applied, with proper definition of effective modulus and thickness, to buckling of the stiffened spherical shell. The skin of the shell and the stiffeners are assumed to be of isotropic material, with different material properties in skin and stiffeners. Only membrane prebuckling states are considered. The theory used follows, for the most part, that given in Ref. 1, with the exception that skin and stiffeners may be of different material. The effect of transverse shear deformation is ignored.

The following behaviors constrain the design:

1. general instability of the stiffened shell (Refs. 1,2,3)
2. local buckling between stiffeners (Refs. 1,3,4)
   (a) buckling of shallow spherical cap (Ref. 3)
   (b) buckling of triangular plate (Refs. 1,4)
3. buckling of stiffeners (Refs. 5,6)
4. stress in the skin (Ref. 1)
5. stress in the stiffeners (Ref. 1)

The system of programs, BEGIN, DECIDE, MAINSETUP, OPTIMIZE, CHANGE, CHOOSEPLOT, DIPLOT, for the minimum-weight design of isogrid-blade-stiffened spherical shells under uniform external pressure was written with use of GENOPT (Ref. 7).

*** REFERENCES ***

[1] Meyer, R.R., Harwood, O.P., Harmon, M.B., Orlando, J.I., ISOGRID DESIGN HANDBOOK, MDC G4295, MacDonnell Douglas Astronautics, Huntington Beach, CA, December 1972

[2] Bushnell, D., "Dynamic response of two-layered cylindrical shells to time-dependent loads", AIAA Journal, Vol. 3, No. 9 pp 1698-1703, 1965

[3] Bushnell, D., COMPUTERIZED BUCKLING ANALYSIS OF SHELLS, Nijhoff The Netherlands, 1985

[4] Gerard, G. and Becker, H., "HANDBOOK OF STRUCTURAL STABILITY, Part I - Buckling of Flat Plates", NACA TN-3781, July 1957

[5] Roark, S., FORMULAS FOR STRESS AND STRAIN, 3rd Edition, McGraw-Hill, 1954

[6] Timoshenko, S. and Gere, J.M., THEORY OF ELASTIC STABILITY, 2nd Edition, McGraw-Hill, 1971

[7] Bushnell, D., "GENOPT - a program that writes user-friendly optimization code", to appear, Int. J. Solids and Structures, 1990

10.1 radius of the spherical shell: RADIUS
15.1 thickness of the skin: TSKIN
20.1 thickness of a stiffener: TSTIFF
25.1 height of a stiffener: HEIGHT
30.1 spacing of the stiffeners: SPACNG
30.2

SPACNG is the distance between each set of parallel stiffeners. There are three sets of parallel stiffeners, each set oriented at an angle of 60 degrees with respect to the other sets, thereby forming an "isogrid", that is, a grid of equilateral triangles. The length of each side of the quadrilateral triangles formed by the isogrid is given by: LENGTH = 2.*SPACNG/SQRT(3.). Each stiffener is a blade with thickness TSTIFF and height HEIGHT. All stiffeners have the same cross section and are of the same material. This material may be different from the material of the skin of the spherical shell.

35.1 modulus of the skin: ESKIN
40.1 weight density of the skin material: RHOSKN
45.1 Poisson ratio of the skin material: NUSKIN
50.1 modulus of the stiffener material: ESTIFF
55.1 Poisson ratio of the stiffener material: NUSTIF
60.1 weight density of the stiffener material: RHOSTF
65.1 Number IKLOC of rows in the array KLOC: IKLOC
70.1 knockdown factor from classical buckling formula: KLOC
70.2

The classical formula for buckling of a complete spherical shell is:

p(classical) = 2*ESKIN*TSKIN**2/{SQRT[3(1-NUSKIN**2)]*R**2}

As shown in Fig. 30, p 29 of COMPUTERIZED BUCKLING ANALYSIS OF SHELLS (Ref. 3), shallow spherical caps buckle at pressures considerably lower than p(classical), partly because of the presence of a boundary of the shallow cap, and partly because of initial geometric imperfections.

In this program we must calculate the buckling load factor for a shallow spherical cap because local buckling involves only the shallow portion of the spherical shell between adjacent stiffeners.

75.1 shallowness parameter of spherical cap: LAMBDA
75.2

See Fig. 30, p 29 of COMPUTERIZED BUCKLING ANALYSIS OF SHELLS. The formula for the shallowness parameter LAMBDA is:

LAMBDA = 2*SQRT{SQRT[3(1-NUSKIN**2)]}*SQRT(H/TSKIN)

in which H is distance from the base plane of the spherical cap to its apex.

80.1 factor for base-radius of spherical cap: LAMMOD
80.2

Local buckling of the stiffened spherical shell occurs in the triangular region between the stiffeners. However, we do not have any simple formulas for buckling of a spherical cap with a triangular planform. Therefore, we use a formula for buckling of an axisymmetric spherical cap. The question then is, what should be the base radius r of the shallow spherical cap. The smallest possible value would be the radius of the cap of circular planform that is inscribed within the equilateral triangle formed by the stiffeners (r(1) = SPACNG/3). The largest value would be the radius of the cap of circular planform in which the equilateral triangle formed by the stiffeners is inscribed (r(2) = 2.*SPACNG/3). The actual radius used in this program is r = r(1)*(1 + LAMMOD). The user must choose a value of LAMMOD between 0 (inscribed cap) and unity (inscribed equilateral triangle, r(2)).

85.1 Number IKGEN of rows in the array KGEN: IKGEN
90.1 knockdown factor for general instability: KGEN
90.2

KGEN is a function of the normalized amplitude of the initial imperfection, DELBAR, where DELBAR is the actual imperfection amplitude divided by the effective thickness of the stiffened spherical shell. The effective thickness, calculated in

SUBROUTINE BEHX1, is that thickness for which both the extensional and bending stiffnesses of the stiffened shell match those of an equivalent monocoque, isotropic shell. (the modulus of the equivalent monocoque, isotropic shell is also an "effective" quantity - See SUBROUTINE BEHX1). The user is free to choose KGEN v DELBAR from any source. One source is Fig. 296, p. 340 of Ref. 3.

95.1 tabular values of normalized general imperfection: DELBAR
100.1 amplitude of general instability imperfection: WGEN
100.2

NOTE: WGEN is not normalized. It is the amplitude of the normal displacement component of the initial global imperfection. It is best to use a value that is between 0.5 and 1.0 percent of the shell diameter.

105.1 rotational stiffness parameter for stiffener support: EDGSTF
105.2

In SUBROUTINE BEHX3 the buckling load factor of a blade stiffener elastically supported at its base and free at its outer edge (height) is calculated from the formula:

```
   BUCSTF =
   (0.375+0.7*EDGSTF)*[ESTIFF/(1-NUSTIF**2)]*(TSTIFF/HEIGHT)**2
```

in which EDGSTF must have a value between 0 and 1. (EDGSTF=0 means hinged, EDGSTF=1 means clamped, and EDGSTF between 0 and 1 indicate elastic rotational support. The formula for buckling is an amalgam of Formulas 4 and 5 of Table XVI on pp 312 of Roark (Ref. 5) and Timoshenko (Ref. 6).

110.1 Number NCASES of load cases (environments): NCASES
115.1 external pressure on the spherical shell: PRESS

120.0

There are five "behaviors" that constrain the optimum design:
1. General buckling of the spherical shell
2. Local buckling of the skin between stiffeners
3. Local buckling of the blade stiffener
4. Stress in the skin of the spherical shell
5. Stress in the stiffeners of the spherical shell

125.0 general instability load factor: BUCGEN
125.2

See SUBROUTINE BEHX1 of the BEHAVIOR.SPHERE library for details on the theory. The method:
1. Calculate an effective thickness TEFF and effective modulus EEFF from the theories presented in Refs. 1 and 2.
2. Calculate a knockdown factor COEF given the input table KGEN v DELBAR and the actual imperfection amplitude WGEN and effective thickness TEFF (WGEN/TEFF).
3. Calculate the buckling pressure from the classical formula

```
   p(critical)=2*COEF*EEFF*TEFF**2/{SQRT[3(1-NUEFF**2)]*R**2}
```

130.1 Allowable for general buckling (Use 1.0): ABUCG
130.2

Use unity for allowables for buckling load factors. Next you will be asked to provide a factor of safety, so that if you want the buckling load factor for general instability to be some multiple of the applied pressure, the factor of safety permits this flexibility.

135.1 factor of safety for general instability: FSBUCG
140.0 local buckling load factor: BUCLOC
140.2

This is the load factor for buckling of the skin between adjacent stiffeners. Details appear in SUBROUTINE BEHX2 of the BEHAVIOR.SPHERE library. The method is:

1. Calculate fraction (1/FACT) of the pressure supported by the skin:

```
FACT = 1. + (ESTIFF/ESKIN)*(TSTIFF*HEIGHT/TSKIN*SPACNG)
```

2. Calculate the effective shallowness parameter, EFFLAM, for the portion of spherical shell between stiffeners (base radius r is given by r = 0.333*SPACNG*(1+LAMMOD)).

3. Calculate buckling pressure for externally pressurized shallow spherical cap with shallowness parameter EFFLAM:

```
p(critical) = FACT*COEF*2*ESKIN*TSKIN**2/
                 [SQRT(3.*(1.-NUSKIN**2))*RADIUS**2]
```

in which COEF is the knockdown factor interpolated from the input values KLOC v LAMBDA provided from a curve derived from data such as shown in Fig. 30, p 29 of Ref. 3.

4. Calculate the buckling load factor: pcrit/PRESS

5. Calculate buckling stress for biaxially compressed flat equilateral triangular plate with simply supported edges:

```
SIGCR = 5*PI**2*ESKIN*(TSKIN/A)**2/(12.*(1.-NUSKIN**2))
```

in which A = 2.*SPACNG/SQRT(3.) is the length of a side of the equilateral triangle. (Ref. 1, Eq.(4.1.4), Ref. 4).

6. Calculate the stress in the skin between stiffeners from:

```
SIG   = PRESS*RADIUS/(2.*TSKIN*FACT)
```

7. Calculate the buckling load factor: SIGCR/ABS(SIG)

8. Choose the minimum of 4. and 7. as the local buckling load factor.

145.1 Allowable for local buckling (Use 1.0): ABUCL
150.1 factor of safety for local buckling: FSBUCL
155.0 load factor for stiffener buckling: BUCSTF
155.2

The stiffeners can buckle like long, flat plates with one edge elastically supported and the other edge free. Details appear in SUBROUTINE BEHX3 of the BEHAVIOR.SPHERE library. The method is:

1. Calculate the critical stress in the long, straight,flat plate from the formula:

```
SIGCR = (0.375+0.7*EDGSTF)*
              (ESTIFF/(1.-NUSTIF**2))*(TSTIFF/HEIGHT)**2
```

in which EDGSTF is a user-supplied number between 0 and 1. A formula analogous to the above appears in Ref. 1 as Eq. (4.1.7). It originates in Refs. 5 and 6.

2. Calculate the current stress in the stiffener from: (See Eq.(4.1.8), p 4.1.005 of MDC G4295), except formula below is valid if there are different moduli in skin and stiffeners:

```
ALPHA = TSTIFF*HEIGHT/(TSKIN*SPACNG)
ALPHAS= (ESTIFF/ESKIN)*ALPHA
FNUEFF= 1./3.
SIG = ESTIFF*PRESS*(RADIUS/2.)*(1.-FNUEFF)/
                          (ESKIN*TSKIN*(1.+ALPHAS))
```

3. Calculate the load factor for stiffener buckling from:

```
BUCSTF(ILOADX) = SIGCR/ABS(SIG)
```

160.1 allowable for stiffener buckling (use 1.0): ABUCST
165.1 factor of safety for stiffener buckling: FSBUCC

```
170.0 stress in the skin of the spherical shell: SIGSKN
170.2
      The stress is calculated from membrane theory (no bending).
      Details are given in SUBROUTINE BEHX4 of the BEHAVIOR.SPHERE
      library.
      In actual fact there will be some bending of the skin between
      adjacent stiffeners.  Allow for this by providing a factor
      of safety greater than unity.

175.1 Maximum allowable effective stress in the skin: ASIGSK
180.1 factor of safety for stress in the skin: FSSIGA
185.0 stress in the stiffeners: SIGSTF
185.2
      SIGSTF is calculated from membrane theory (no bending).
      Details are given in SUBROUTINE BEHX5 of the BEHAVIOR.SPHERE
      library.
      Provide a factor of safety greater than unity to allow for
      bending.

190.1 maximum allowable stress in the stiffeners: ASIGST
195.1 factor of safety for stress in stiffeners: FSSIGB
200.0 weight/area of the stiffened spherical shell: WEIGHT
200.2
      Details are given in SUBROUTINE OBJECT of the BEHAVIOR.SPHERE
      library.
      1. Calculate weight per unit surface area of the stiffened
      spherical shell:
         WSKIN  = RHOSKN*TSKIN
         WSTIFF = 3.*RHOSTF*TSTIFF*HEIGHT/SPACNG
         WEIGHT = WSKIN + WSTIFF

999.0 DUMMY ENTRY TO MARK END OF FILE
********************* END OF THE SPHERE.PRO FILE *******************
```

APPENDIX D - the BEHAVIOR.NEW file

The following list was partly created by GENOPT and partly created by the GENOPT user:

1. GENOPT created the introductory material and all coding in each subroutine that preceeds the comment "INSERT SUBROUTINE STATEMENTS HERE".

2. The GENOPT user inserted his/her comments and algorithms for the prediction of behavior and objective immediately following the comment "INSERT SUBROUTINE STATEMENTS HERE".

```
****************** THE BEHAVIOR.NEW FILE FOLLOWS *******************
=DECK      BEHAVIOR.NEW
  This library contains the skeletons of subroutines called SUBROUTINE
  BEHXn, n = 1, 2, 3, . . . that will yield predictions of behavioral
  responses of various systems to environments (loads).

  You may complete the subroutines by writing algorithms that yield the
  responses, each of which plays a part in constraining the design to a
  feasible region. Examples of responses are: stress, buckling, drag,
  vibration, deformation, clearances, etc.

  A skeleton routine called SUBROUTINE OBJECT is also provided for any
```

objective function (e.g. weight, deformation, conductivity) you may wish to create.

A skeleton routine called SUBROUTINE USRCON is also provided for any user-written constraint condition you may wish to write: This is an INEQUALITY condition that involves any program variables. However, note that this kind of thing is done automatically in the program DECIDE, so try DECIDE first to see if your particular constraint conditions can be accommodated more easily there.

Please note that you do not have to modify BEHAVIOR.NEW in any way, but may instead prefer to insert your subroutines into the skeletal libraries ADDCODEn.NEW, n=1,2,... and appropriate common blocks, dimension and type statements and calls to these subroutines in the library STRUCT.NEW. This strategy is best if your FORTRAN input to GENOPT contains quite a bit of software previously written by yourself or others, and/or the generation of behavioral constraints is more easily accomplished via another architecture than that provided for in the BEHAVIOR.NEW library. (See instructions in the libraries ADDCODEn.NEW and STRUCT.NEW for this procedure.)

```
=========================================================================
=DECK      BEHX1
     SUBROUTINE BEHX1  (IFILE,NPRINX,IMODX,ILOADX,PHRASE)

   PURPOSE: OBTAIN general instability load factor

  YOU MUST WRITE CODE THAT, USING THE VARIABLES IN THE LABELLED COMMON
  BLOCKS AS INPUT, ULTIMATELY YIELDS THE RESPONSE VARIABLE FOR THE ith
  LOAD CASE, ILOADX:

     BUCGEN(ILOADX)

  AS OUTPUT. THE ith CASE REFERS TO ith ENVIRONMENT (e.g. load combination)

   DEFINITIONS OF INPUT DATA:
    IMODX = DESIGN CONTROL INTEGER:
     IMODX = 0 MEANS BASELINE DESIGN
     IMODX = 1 MEANS PERTURBED DESIGN
    IFILE = FILE FOR OUTPUT LIST:
    NPRINX= OUTPUT CONTROL INTEGER:
     NPRINX=0 MEANS SMALLEST AMOUNT
     NPRINX=1 MEANS MEDIUM AMOUNT
     NPRINX=2 MEANS LOTS OF OUTPUT

     ILOADX = ith LOADING COMBINATION
     PHRASE = general instability load factor

   OUTPUT:

     BUCGEN(ILOADX)

      CHARACTER*80 PHRASE
  INSERT ADDITIONAL COMMON BLOCKS:
   The following labelled common blocks constitute the SPHERE.COM file,
   which is created by GENOPT:
     COMMON/FV01/RADIUS,TSKIN,TSTIFF,HEIGHT,SPACNG,ESKIN,RHOSKN,NUSKIN
     REAL RADIUS,TSKIN,TSTIFF,HEIGHT,SPACNG,ESKIN,RHOSKN,NUSKIN
     COMMON/FV12/KLOC(30),IKLOC
     REAL KLOC
```

```
      COMMON/FV13/LAMBDA(30)
      REAL LAMBDA
      COMMON/FV15/KGEN(30),IKGEN
      REAL KGEN
      COMMON/FV16/DELBAR(30)
      REAL DELBAR
      COMMON/FV19/PRESS(20)
      REAL PRESS
      COMMON/FV22/BUCGEN(20),ABUCG(20),FSBUCG(20)
      REAL BUCGEN,ABUCG,FSBUCG
      COMMON/FV25/BUCLOC(20),ABUCL(20),FSBUCL(20)
      REAL BUCLOC,ABUCL,FSBUCL
      COMMON/FV28/BUCSTF(20),ABUCST(20),FSBUCC(20)
      REAL BUCSTF,ABUCST,FSBUCC
      COMMON/FV31/SIGSKN(20),ASIGSK(20),FSSIGA(20)
      REAL SIGSKN,ASIGSK,FSSIGA
      COMMON/FV34/SIGSTF(20),ASIGST(20),FSSIGB(20)
      REAL SIGSTF,ASIGST,FSSIGB
      COMMON/FV09/ESTIFF,NUSTIF,RHOSTF,LAMMOD,WGEN,EDGSTF,WEIGHT
      REAL ESTIFF,NUSTIF,RHOSTF,LAMMOD,WGEN,EDGSTF,WEIGHT
 End of file SPHERE.COM of labelled common blocks created by GENOPT
 NOTE: In the following subroutines the labelled common blocks listed
       above are included via an INCLUDE statement: INCLUDE 'SPHERE.COM'

 INSERT SUBROUTINE STATEMENTS HERE.

 First, calculate the effective thickness and effective modulus
 of the stiffened spherical shell. These "effective" quantities
 are the thickness and modulus of a monocoque, isotropic wall
 that has the same extensional and bending stiffnesses as those
 of the stiffened wall with the "isogrid" pattern of blade
 stiffeners.  NOTE: This subroutine is valid ONLY for an isogrid
 of blade stiffeners.

 The extensional stiffness is given by:
   Extensional stiffness = C11 = E(eff)*t(eff)/(1-nu(eff)**2)

 The bending stiffness is given by:
   Bending stiffness = C44 = E(eff)*t(eff)**3/[12(1-nu(eff)**2]

 In this analysis it will be assumed that the effective Poisson
 ratio is 1/3 (See "ISOGRID DESIGN HANDBOOK", MDC G4295, DEC. 1972,
 by McDonnell Douglas Astronautics, Huntington Beach, CA 92647,
 p 2.0.004, Eq. (2.1.12).  It is assumed that the skin and the
 isogrid have the same effective Poisson's ratio.

 First, calculate the extensional stiffness C11 of the stiffened
 shell wall...

      ALPHA = TSTIFF*HEIGHT/(TSKIN*SPACNG)
      ALPHAS= (ESTIFF/ESKIN)*ALPHA
      FNUEFF= 1./3.
      C11SKN= ESKIN*TSKIN/(1.- FNUEFF**2)
      C11   = C11SKN*(1. + ALPHAS)

 Next, calculate the bending stiffness C44 of the stiffened shell
 wall.  The theory here is taken from D. Bushnell, "Dynamic
 response of two-layered cylindrical shells to time-dependent
 loads", AIAA Journal, Vol. 3, No. 9, pp 1698-1703 (1965),
 Eq. (2.36). The isogrid-stiffened shell wall is assumed to
```

consist of two layers: Layer No. 1 is the isotropic skin and Layer No. 2 is an isotropic, homogeneous skin of reduced effective modulus, E2, and thickness equal to the height of the stiffeners, HEIGHT.

```
(a) The effective modulus of the isogrid "layer" is given by
     (See Eq. 2.1.12 of MDC G4295):
    E2 = ESTIFF*TSTIFF/SPACNG
(b) The other quantities in Equation (2.36) of the old AIAA paper
     are:
    E1 = ESKIN
    D1 = TSKIN
    D2 = HEIGHT
(b) Calculate the bending rigidity C44:
    C44 = (1./3.)*(1./(1.-FNUEFF**2))*( E1*D1**3 +E2*D2**3
   1      -0.75*(E1*D1**2 -E2*D2**2)**2/(E1*D1 +E2*D2) )
```

Next, calculate the effective thickness and effective modulus...

```
    TEFF = SQRT(12.*C44/C11)
    EEFF = (1.-FNUEFF**2)*SQRT(C11**3/(12.*C44))

    IF (IMODX.EQ.0.AND.NPRINX.GT.1)
   1  WRITE(IFILE,10) ESKIN,TSKIN,
   1  SPACNG,ESTIFF,TSTIFF,HEIGHT,C11,C44,EEFF,TEFF
 10 FORMAT(/' WALL PROPERTIES OF STIFFENED SPHERICAL SHELL:'/
   1' modulus of skin,                                 ESKIN=',1PE12.4/
   1' thickness of skin,                               TSKIN=',1PE12.4/
   1' stiffener spacing,                              SPACNG=',1PE12.4/
   1' modulus of stiffeners,                          ESTIFF=',1PE12.4/
   1' thickness of stiffeners,                        TSTIFF=',1PE12.4/
   1' height of stiffeners,                           HEIGHT=',1PE12.4/
   1' extensional stiffness of the stiffened wall,       C11=',1PE12.4/
   1' bending     stiffness of the stiffened wall,       C44=',1PE12.4/
   1' effective modulus of stiffened shell wall,        EEFF=',1PE12.4/
   1' effective thickness of stiffened shell wall,      TEFF=',1PE12.4)
```

Next, calculate the general instability load factor of the imperfect, stiffened spherical shell. The formula for the critical pressure of an imperfect, isotropic, monocoque spherical shell is:

```
p(critical) =COEF*2*EEFF*TEFF**2/[SQRT(3.*(1.-FNUEFF**2))*RADIUS**2]
```

(See p. 330 and p. 340 (Fig. 296) of COMPUTERIZED BUCKLING ANALYSIS OF SHELLS). The quantity COEF is a knockdown factor for initial geometric imperfections. COEF is calculated by linear interpolation (SUBROUTINE INTERP) of the tabular values (KGEN,DELBAR) for knockdown KGEN v normalized imperfection amplitude DELBAR. The tabular values (KGEN,DELBAR) might be taken, for example, from Fig. 296, p. 340 of COMPUTERIZED BUCKLING ANALYSIS OF SHELLS, or from some other suitable source known to the user.

Next, interpolate (linearly) to find the knockdown factor COEF...

```
   CALL INTERP(IFILE,IKGEN,DELBAR,KGEN,WGEN/TEFF,COEF)
```

The critical external pressure is...

```
   PCRIT =COEF*2.*EEFF*TEFF**2/(SQRT(3.*(1.-FNUEFF**2))*RADIUS**2)
```

The general instability load factor, BUCGEN, is given by:

```
   BUCGEN(ILOADX) = PCRIT/ABS(PRESS(ILOADX))
```

```
      IF (IMODX.EQ.0.AND.NPRINX.GT.1)
     1  WRITE(IFILE,20) WGEN/TEFF,COEF,RADIUS,PRESS(ILOADX),PCRIT,
     1                  BUCGEN(ILOADX)
   20 FORMAT(/' PARAMETERS FOR GENERAL BUCKLING OF STIFFENED SHELL:'/
     1' normalized imperfection amplitude,          WGEN/TEFF=',1PE12.4/
     1' knockdown factor for initial imperfections,      COEF=',1PE12.4/
     1' radius of spherical shell,                     RADIUS=',1PE12.4/
     1' applied pressure,                               PRESS=',1PE12.4/
     1' critical pressure(Fig.296 of Bushnell book),    PCRIT=',1PE12.4/
     1' general instability load factor,               BUCGEN=',1PE12.4)

      RETURN
      END



=DECK      BEHX2
      SUBROUTINE BEHX2  (IFILE,NPRINX,IMODX,ILOADX,PHRASE)

    PURPOSE: OBTAIN local buckling load factor

   YOU MUST WRITE CODE THAT, USING THE VARIABLES IN THE LABELLED COMMON
   BLOCKS AS INPUT, ULTIMATELY YIELDS THE RESPONSE VARIABLE FOR THE ith
   LOAD CASE, ILOADX:

      BUCLOC(ILOADX)

   AS OUTPUT. THE ith CASE REFERS TO ith ENVIRONMENT (e.g. load com-
   bination).

      ILOADX = ith LOADING COMBINATION
      PHRASE = local buckling load factor

    OUTPUT:

      BUCLOC(ILOADX)

       CHARACTER*80 PHRASE
   INSERT ADDITIONAL COMMON BLOCKS:
      INCLUDE 'SPHERE.COM'

   INSERT SUBROUTINE STATEMENTS HERE.

   The local buckling load factor is taken to be the lowest of
   either of two values:

    1. buckling load factor of a shallow spherical cap with base radius
       greater than or equal to SPACNG/3 and less than or equal
       to 2*SPACNG/3 (inscribed cap or inscribed triangle, respectively).

    2. buckling load factor of a flat plate with equilateral triangular
       planform simply supported along its three edges and subject to
       uniform biaxial compression.

   First, calculate the local instability load factor of the
   imperfect, monocoque, isotropic, shallow spherical cap
   that represents the portion of spherical shell between
   adjacent stiffeners. Although the actual local area has
```

an equilateral triangular planform, the technology used here applies to shallow spherical caps with circular planform. The formula for the critical pressure of an imperfect, isotropic, monocoque, shallow spherical cap is:

```
p(critical) =
    FACT*COEF*2*ESKIN*TSKIN**2/[SQRT(3.*(1.-NUSKIN**2))*RADIUS**2]
```

(See p. 330 and p. 29 (Fig. 30) of COMPUTERIZED BUCKLING ANALYSIS OF SHELLS). The quantity FACT accounts for the fact that only part of the total membrane force in the stiffened spherical shell is "seen" by the skin. The quantity COEF is a knockdown factor that accounts for three effects:

(1) the shell is a shallow cap and not a complete spherical shell.
(2) the shallow cap is imperfect.
(3) the extent of the spherical cap (shallowness parameter EFFLAM) lies somewhere between the shallowness parameter for a circular cap incsribed within the equilateral triangle formed by three adjacent stiffeners (base radius r = SPACNG/3.) and the shallowness parameter for a circular cap in which is inscribed the equilateral triangle formed by three adjacent stiffeners (base radius r = 2.*SPACNG/3.)

COEF is calculated by linear interpolation (SUBROUTINE INTERP) of the tabular values (KLOC,LAMBDA) for knockdown KLOC v cap shallowness parameter LAMBDA. The tabular values (KLOC,LAMBDA) might be taken, for example, from Fig. 30, p. 29 of COMPUTERIZED BUCKLING ANALYSIS OF SHELLS, or from some other suitable source known to the user.

First, calculate FACT, which accounts for the proportion of the membrane force taken by the skin of the stiffened shell...

```
   ALPHA = TSTIFF*HEIGHT/(TSKIN*SPACNG)
   ALPHAS= (ESTIFF/ESKIN)*ALPHA
   FACT  = 1. + ALPHAS
```

Next, calculate the effective shallowness parameter, EFFLAM, of the portion of skin between adjacent stiffeners. REFF is the radius of base plane of the "effective" cap. HEFF is the height of the apex of the cap over its base plane. The formula for the shallowness parameter LAMBDA appears in Fig. 30, p. 29 of COMPUTERIZED BUCKLING ANALYSIS OF SHELLS.

```
   REFF = (1. + LAMMOD)*SPACNG/3.
   HEFF = RADIUS - SQRT(RADIUS**2 - REFF**2)
   EFFLAM = 2.*SQRT(SQRT(3.*(1.-NUSKIN**2)))*SQRT(HEFF/TSKIN)
```

```
Next, interpolate (linearly) to find the knockdown factor COEF...
 If the cap is shallow get knockdown factor from shallow cap
 results, such as shown in Fig. 30, p 29 of COMPUTERIZED BUCKLING
 ANALYSIS OF SHELLS...
      CALL INTERP(IFILE,IKLOC,LAMBDA,KLOC,EFFLAM,COEF1)
      FACT1 = FACT
 If the cap is "deep"  get knockdown factor from complete spherical
 shell results, such as shown in Fig. 296, p 340 of COMPUTERIZED...
      CALL INTERP(IFILE,IKGEN,DELBAR,KGEN,WGEN/TSKIN,COEF2)
      FACT2 = 1.0
      IF (EFFLAM.LT.10.) THEN
       Shallow cap parameters...
```

```
         FACT = FACT1
         COEF = COEF1
      ELSE
         IF (EFFLAM.GT.14.) THEN
          Complete monocoque spherical shell parameters...
            FACT = FACT2
            COEF = COEF2
         ELSE
          Mixture of shallow cap and complete shell parameters...
            FACT = FACT1 + 0.25*(EFFLAM-10.)*(FACT2-FACT1)
            COEF = COEF1 + 0.25*(EFFLAM-10.)*(COEF2-COEF1)
         ENDIF
      ENDIF
 The critical external pressure is...
    PCRIT =
   1 FACT*COEF*2.*ESKIN*TSKIN**2/(SQRT(3.*(1.-NUSKIN**2))*RADIUS**2)
 The local instability load factor, BCAP, is given by:
    BCAP = PCRIT/ABS(PRESS(ILOADX))
```

Next, compute the local buckling load factor for a flat plate of triangular planform, simply supported along its three edges, and subjected to uniform biaxial compression. The theory is used in MDC G4295, Dec. 1972, and originates from NACA TN-3781, July 1957, by Gerard and Becker: "Handbook of Structural Stability, Part I - Buckling of Flat Plates". The length of each side of the equilateral triangle is A. The formula for critical stress SIGCR is given as Eq.(4.1.4) in MDC G4295.

```
    FCOEF = 5.0
    A     = 2.*SPACNG/SQRT(3.)
    PI    = 3.1415927
 The critical buckling stress is...
    SIGCR = FCOEF*PI**2*ESKIN*(TSKIN/A)**2/(12.*(1.-NUSKIN**2))
 The stress in the skin of the stiffened wall is...
    SIG   = PRESS(1)*RADIUS/(2.*TSKIN*(1.+ALPHAS))
 The buckling load factor is...
    BPLATE= SIGCR/ABS(SIG)
    BMIN  = MIN(BCAP,BPLATE)
    IF (EFFLAM.LT.4.) THEN
     Choose the smallest of BCAP and BPLATE for the local buckling
     load factor...
       BUCLOC(ILOADX) = BMIN
    ELSE
       IF (EFFLAM.GT.6.) THEN
        Choose the shallow cap model because there is too much curvature
        in the shallow region for the flat plate buckling formula to
        apply...
          BUCLOC(ILOADX) = BCAP
       ELSE
        Use mixture theory for (4.LE.EFFLAM.LE.6)...
          BUCLOC(ILOADX) = BMIN + 0.5*(EFFLAM-4.)*(BCAP-BMIN)
       ENDIF
    ENDIF
 If the portion between stiffeners is very, very shallow, use the
 flat plate buckling formula...
    IF (EFFLAM.LT.2.5) BUCLOC(ILOADX) = BPLATE

    IF (IMODX.EQ.0.AND.NPRINX.GT.1) WRITE(IFILE,10)
   1   LAMMOD,REFF,HEFF,EFFLAM,1./FACT,COEF,PCRIT,BCAP,
   1   SIGCR,SIG,BPLATE,BUCLOC(ILOADX)
```

```
 10 FORMAT(/' PARAMETERS FOR LOCAL BUCKLING OF SPHERICAL CAP:'/
   1' factor for determination of baseplane radius,LAMMOD=',1PE12.4/
   1' "effective" radius of base plane of cap,        REFF=',1PE12.4/
   1' height of apex of cap above its base plane,     HEFF=',1PE12.4/
   1' shallowness parameter of spherical cap,       LAMBDA=',1PE12.4/
   1' fraction of pressure absorbed by the skin,    1/FACT=',1PE12.4/
   1' knockdown factor for initial imperfections,     COEF=',1PE12.4/
   1' critical pressure (Fig. 30 of Bushnell book), PCRIT=',1PE12.4/
   1' buckling load factor for shallow cap,           BCAP=',1PE12.4/
   1' crit. stress for plate (MDC G4295, Eq(4.1.4), SIGCR=',1PE12.4/
   1' stress in the skin of the spherical shell,       SIG=',1PE12.4/
   1' buckling load factor for triangular plate,    BPLATE=',1PE12.4/
   1' local buckling load factor,                   BUCLOC=',1PE12.4)

    RETURN
    END
```

```
=DECK      BEHX3
      SUBROUTINE BEHX3  (IFILE,NPRINX,IMODX,ILOADX,PHRASE)

   PURPOSE: OBTAIN load factor for stiffener buckling

  YOU MUST WRITE CODE THAT, USING THE VARIABLES IN THE LABELLED COMMON
  BLOCKS AS INPUT, ULTIMATELY YIELDS THE RESPONSE VARIABLE FOR THE ith
  LOAD CASE, ILOADX:

      BUCSTF(ILOADX)

  AS OUTPUT. THE ith CASE REFERS TO ith ENVIRONMENT (e.g. load com-
  bination).

      PHRASE = load factor for stiffener buckling

   OUTPUT:

      BUCSTF(ILOADX)

       CHARACTER*80 PHRASE
  INSERT ADDITIONAL COMMON BLOCKS:
      INCLUDE 'SPHERE.COM'

  INSERT SUBROUTINE STATEMENTS HERE.

  The blade stiffeners are assumed to be straight, long, flat
  plates with one edge elastically supported (where the blade
  intersects the skin) and the other edge free.  The formula
  for buckling is taken from Roark, FORMULAS FOR STRESS AND
  STRAIN, 3rd Edition, McGraw-Hill, 1954, Table XVI, p. 312, Formulas
  4 (simple-support, free) and 5 (clamped, free). Roark gives
  a formula for buckling stress:
    SIGMA(crit) = k*[ESTIFF/(1-NUSTIF**2)]*(TSTIFF/HEIGHT)**2
  in which k is a coefficient that depends on the aspect ratio
  of the plate. For long plates:
  (a) k = 0.375 if the plate is simply supported (MDC G4295, 4.1.7),
  (b) k = 1.1   if the plate is clamped (Roark Table XVI, Formula 5).

  Here for k we use:
```

```
k = 0.375 + 0.7*EDGSTF

in which EDGSTF is a number between 0. and 1. provided by the
user.  If EDGSTF = 0. the stiffeners are assumed to be hinged
at their lines of intersection with the skin; if EDGSTF = 1.
the stiffeners are assumed to be clamped at their lines of
intersection with the skin. The number 0.375 comes from Eq.(4.1.7)
of MDC G4295, p 4.1.004.  The number 0.7 comes from Roark.

Calculate critical stress in the stiffener:
   SIGCR =
  1 (0.375+0.7*EDGSTF)*(ESTIFF/(1.-NUSTIF**2))*(TSTIFF/HEIGHT)**2

Calculate current stress in the stiffener
(See Eq.(4.1.8), p 4.1.005 of MDC G4295), except formula below
is valid if there are different moduli in skin and stiffeners:
   ALPHA = TSTIFF*HEIGHT/(TSKIN*SPACNG)
   ALPHAS= (ESTIFF/ESKIN)*ALPHA
   FNUEFF= 1./3.
   SIG = ESTIFF*PRESS(1)*(RADIUS/2.)*(1.-FNUEFF)/
  1                                        (ESKIN*TSKIN*(1.+ALPHAS))
Calculate load factor for stiffener buckling:
   BUCSTF(ILOADX) = SIGCR/ABS(SIG)

   IF (IMODX.EQ.0.AND.IPRINX.GT.1)
  1 WRITE(IFILE,10) EDGSTF,SIG,SIGCR,BUCSTF(ILOADX)
10 FORMAT(/' PARAMETERS FOR BUCKLING OF STIFFENER:'/
  1' parameter between 0 and 1 for edge support,  EDGSTF=',1PE12.4/
  1' stress in the stiffener,                        SIG=',1PE12.4/
  1' critical stress (Roark, Table XVI, nos. 4,5), SIGCR=',1PE12.4/
  1' stiffener buckling load factor,              BUCSTF=',1PE12.4)

   RETURN
   END



=DECK      BEHX4
     SUBROUTINE BEHX4  (IFILE,NPRINX,IMODX,ILOADX,PHRASE)

  PURPOSE: OBTAIN stress in the skin of the spherical shell

 YOU MUST WRITE CODE THAT, USING THE VARIABLES IN THE LABELLED COMMON
 BLOCKS AS INPUT, ULTIMATELY YIELDS THE RESPONSE VARIABLE FOR THE ith
 LOAD CASE, ILOADX:

    SIGSKN(ILOADX)

 AS OUTPUT. THE ith CASE REFERS TO ith ENVIRONMENT (e.g. load com-
 bination).

    PHRASE = stress in the skin of the spherical shell

  OUTPUT:

    SIGSKN(ILOADX)

     CHARACTER*80 PHRASE
```

```
  INSERT ADDITIONAL COMMON BLOCKS:
     INCLUDE 'SPHERE.COM'

  INSERT SUBROUTINE STATEMENTS HERE.

  Calculate stress in the skin.  The formula used is for
  membrane stress. It is analogous to the formula given in
  Eq. (4.1.5), p 4.1.004 of MDC G4295, except that it is valid
  if skin and stiffeners have different moduli:

     SIGMA = PRESS*RADIUS/(2.*TSKIN*(1.+ ALPHAS))

  in which ALPHAS is a factor that accounts for the fact that
  only part of the internal membrane force, PRESS*RADIUS/2,
  generated by the pressure is carried by the skin.

     ALPHA = TSTIFF*HEIGHT/(TSKIN*SPACNG)
     ALPHAS= (ESTIFF/ESKIN)*ALPHA
     FACT = 1./(1.+ALPHAS)
     SIGSKN(ILOADX) = PRESS(ILOADX)*RADIUS/(2.*TSKIN*(1.+ALPHAS))

     IF (IMODX.EQ.0.AND.NPRINX.GT.1)
    1  WRITE(IFILE,10) FACT,SIGSKN(ILOADX),ASIGSK(1),FSSIGA(1)
  10 FORMAT(/' PARAMETERS FOR STRESS IN THE SKIN:'/
    1' fraction of pressure borne by the skin,          FACT=',1PE12.4/
    1' stress in the skin (from pR/(2t)),             SIGSKN=',1PE12.4/
    1' allowable stress in the skin,                  ASIGSK=',1PE12.4/
    1' factor of safety for stress in the skin,       FSSIGA=',1PE12.4)

     RETURN
     END



=DECK      BEHX5
     SUBROUTINE BEHX5  (IFILE,NPRINX,IMODX,ILOADX,PHRASE)

   PURPOSE: OBTAIN stress in the stiffeners

  YOU MUST WRITE CODE THAT, USING THE VARIABLES IN THE LABELLED COMMON
  BLOCKS AS INPUT, ULTIMATELY YIELDS THE RESPONSE VARIABLE FOR THE ith
  LOAD CASE, ILOADX:

     SIGSTF(ILOADX)

  AS OUTPUT. THE ith CASE REFERS TO ith ENVIRONMENT (e.g. load com-
  bination).

     PHRASE = stress in the stiffeners

   OUTPUT:

     SIGSTF(ILOADX)

      CHARACTER*80 PHRASE
  INSERT ADDITIONAL COMMON BLOCKS:
     INCLUDE 'SPHERE.COM'

  INSERT SUBROUTINE STATEMENTS HERE.
```

```
Calculate current stress in the stiffener. The formula used is
analogous to that given in Eq.(4.1.8) of MDC G4295, except that
the formula given here is valid when skin and stiffeners have
different moduli.

   ALPHA = TSTIFF*HEIGHT/(TSKIN*SPACNG)
   ALPHAS= (ESTIFF/ESKIN)*ALPHA
   FNUEFF= 1./3.
   SIGSTF(ILOADX) = ESTIFF*PRESS(1)*(RADIUS/2.)*(1.-FNUEFF)/
  1                                        (ESKIN*TSKIN*(1.+ALPHAS))

   IF (IMODX.EQ.0.AND.NPRINX.GT.1)
  1  WRITE(IFILE,10) SIGSTF(ILOADX),ASIGST(1),FSSIGB(1)
10 FORMAT(/' PARAMETERS FOR STRESS IN THE STIFFENERS:'/
  1' stress in the stiffeners,                  SIGSTF=',1PE12.4/
  1' allowable stress in the stiffeners,        ASIGST=',1PE12.4/
  1' factor of safety for stress in the stiffener,FSSIGB=',1PE12.4)

   RETURN
   END
```

```
=DECK      USRCON
    SUBROUTINE USRCON(INUMTT,IMODX,CONMAX,ICONSX,IPOINC,CONSTX,
   1  WORDCX,WORDMX,PCWORD,CPLOTX,ICARX,IFILEX)
 PURPOSE: GENERATE USER-WRITTEN INEQUALITY CONSTRAINT CONDITION USING
 ANY COMBINATION OF PROGRAM VARIABLES. YOU MUST WRITE CODE THAT, USING
 THE VARIABLES IN THE LABELLED COMMON BLOCKS AS INPUT, ULTIMATELY
 YIELDS A CONSTRAINT CONDITION, CALLED "CONX" IN THIS ROUTINE.
    DIMENSION WORDCX(*),WORDMX(*),IPOINC(*),CONSTX(*)
    DIMENSION PCWORD(*),CPLOTX(*)
    CHARACTER*80 WORDCX,WORDMX,PCWORD
 INSERT ADDITIONAL COMMON BLOCKS:
    INCLUDE 'SPHERE.COM'

    CONX = 0.0

 INSERT USER-WRITTEN STATEMENTS HERE. THE CONSTRAINT CONDITION THAT
 YOU CALCULATE IS CALLED "CONX"

    IF (CONX.EQ.0.0) RETURN
    IF (CONX.LT.0.0) THEN
       WRITE(IFILEX,*)' CONX MUST BE GREATER THAN ZERO.'
       CALL EXIT
    ENDIF

 DO NOT CHANGE THE FOLLOWING STATEMENTS, EXCEPT WORDC

    ICARX = ICARX + 1
    INUMTT = INUMTT + 1
    WORDCX(ICARX) = ' USER: PROVIDE THIS.'
    CPLOTX(ICARX) = CONX - 1.
    CALL BLANKX(WORDCX(ICARX),IENDP)
    PCWORD(ICARX)  = WORDCX(ICARX)(1:IENDP)//' -1'
    IF (IMODX.EQ.0.AND.CONX.GT.CONMAX) GO TO 200
    IF (IMODX.EQ.1.AND.IPOINC(INUMTT).EQ.0) GO TO 200
    ICONSX = ICONSX + 1
```

```
      IF (IMODX.EQ.0) IPOINC(INUMTT) = 1
      CONSTX(ICONSX) = CONX
      WORDMX(ICONSX)  = WORDCX(ICARX)(1:IENDP)//' -1'
  200 CONTINUE
   END OF USRCON
      RETURN
      END


=DECK      OBJECT
      SUBROUTINE OBJECT(IFILE,NPRINX,IMODX,OBJGEN,PHRASE)
    PURPOSE:weight/area of the stiffened spherical shell

   YOU MUST WRITE CODE THAT, USING THE VARIABLES IN THE LABELLED COMMON
   BLOCKS AS INPUT, ULTIMATELY YIELDS THE OBJECTIVE FUNCTION

         WEIGHT

   AS OUTPUT. MAKE SURE TO INCLUDE AT THE END OF THE SUBROUTINE, THE
   STATEMENT: OBJGEN = WEIGHT

    DEFINITION OF PHRASE:
      PHRASE = weight/area of the stiffened spherical shell

       CHARACTER*80 PHRASE
   INSERT ADDITIONAL COMMON BLOCKS:
      INCLUDE 'SPHERE.COM'

   INSERT SUBROUTINE STATEMENTS HERE.

   Calculate weight per unit surface area of the stiffened
   spherical shell...
      WSKIN  = RHOSKN*TSKIN
      WSTIFF = 3.*RHOSTF*TSTIFF*HEIGHT/SPACNG
      WEIGHT = WSKIN + WSTIFF

      OBJGEN =WEIGHT

      IF (IMODX.EQ.0.AND.NPRINX.GT.1)
     1  WRITE(IFILE,10) WSKIN,WSTIFF,WEIGHT
   10 FORMAT(/' PARAMETERS FOR WEIGHT/AREA OF SHELL WALL:'/
     1' weight of the skin,                           WSKIN=',1PE12.4/
     1' weight of the stiffeners,                    WSTIFF=',1PE12.4/
     1' total weight/surface area of the shell wall, WEIGHT=',1PE12.4)

      RETURN
      END
********************** END OF THE BEHAVIOR.NEW FILE ********************
```

APPENDIX E - the HOWTO.RUN file

The following list instructs the "end" user how to use the program system SPHERE created by GENOPT and the GENOPT user.

```
******************** THE HOWTO.RUN FILE FOLLOWS ************************
                          HOWTO.RUN
```

by

David Bushnell

INSTRUCTIONS FOR RUNNING THE GENOPT-GENERATED PROGRAM SYSTEM FOR MINIMUM-WEIGHT DESIGN OF STIFFENED SPHERICAL SHELLS UNDER UNIFORM EXTERNAL PRESSURE

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INSTRUCTIONS:

1. You must include the following statements in your LOGIN.COM:

```
$ GENOPTCASE :==SET DEFAULT [USERNAME2.GENOPTCASE]
$ ASSIGN DSK2:[BUSHNELL.GENOPT] GENOPT
$ ASSIGN USERDISK:[USERNAME2.GENOPTCASE]  GENOPTCASE
$ GENOPTLOG  :== @GENOPT:GENPROMPT
```

in which:
USERNAME2 refers to the end user.
("end user" is defined in the file called GENOPTST.ORY, which you should read for background information.)

2. Create the subdirectory:

[USERNAME2.GENOPTCASE]

3. For background information on how this program system was generated, print and read the file GENOPT:GENOPTST.ORY. Also print the file GENOPT.HLP and use the interactive HELP utility by giving the command HELPG. List and read the two files with example cases:
   (a) PLATE.CAS - a relatively simple example
   (b) PANEL.CAS - a more complex example

4. When you are ready to begin, go to the subdirectory called

[USERNAME2.GENOPTCASE]

and type the command GENOPTLOG. This activates the GENOPT command menu.

5. The command GENOPTLOG activates the following set of commands:

BEGIN (User supplies starting design, loads, control integers, material properties, etc. in an interactive-help mode.)

DECIDE (User chooses decision and linked variables and inequality constraints that are not based on behavior.)

MAINSETUP (User chooses output option, whether to perform analysis of a fixed design or to optimize, and number of design iterations.)

OPTIMIZE (The program system performs, in a batch mode, the work specified in MAINSETUP.

CHANGE (User changes certain parameters)

CHOOSEPLOT (User selects which quantities to plot vs. design iterations.)

DIPLOT (User generates plots for laser printer)

CLEANSPEC (User cleans out unwanted files.)

6. A typical runstream is:

```
GENOPTLOG        (activate command set)
BEGIN            (provide starting design, loads, etc.)
DECIDE           (choose decision variables and bounds)
MAINSETUP        (choose print option and analysis type)
OPTIMIZE         (launch batch run for n design iterations)
OPTIMIZE         (launch batch run for n design iterations)
OPTIMIZE         (launch batch run for n design iterations)
OPTIMIZE         (launch batch run for n design iterations)
OPTIMIZE         (launch batch run for n design iterations)
OPTIMIZE         (launch batch run for n design iterations)
OPTIMIZE         (launch batch run for n design iterations)
CHANGE           (change some variables for new starting point)
OPTIMIZE         (launch batch run for n design iterations)
OPTIMIZE         (launch batch run for n design iterations)
OPTIMIZE         (launch batch run for n design iterations)
OPTIMIZE         (launch batch run for n design iterations)
OPTIMIZE         (launch batch run for n design iterations)
CHOOSEPLOT       (choose which variables to plot)
DIPLOT           (plot variables v. iterations on laser printer)
CHOOSEPLOT       (choose additional variables to plot)
DIPLOT           (plot additional variables v design iterations)
CLEANSPEC        (delete extraneous files for specific case)
```

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

7. During operation of the GENOPT system, you will launch batch runs. If you are in the subdirectory [USERNAME2.GENOPTCASE] just hit return when it asks you where you want results. **Also, hit return when it asks** you where GENOPT is stored.

8. References:

[E1] Bushnell, D., "GENOPT--A program that writes user-friendly optimization code", to appear, International Journal of Solids and

Structures, 1989. Also to appear in a bound volume of papers from the International Journal of Solids and Structures published in the memory of Professor Charles D. Babcock, formerly with the California Institute of Technology.

[E2] Bushnell, D., " Minimum weight design of isogrid-stiffened spherical shells under uniform external pressure.", in the file DSK2:[BUSHNELL.GENOPTCASE]SPHERE.PRO

[E3] Bushnell, D., the files called:

```
    DSK2:[BUSHNELL.GENOPTCASE]BEHAVIOR.SPHERE - theory used.
    DSK2:[BUSHNELL.GENOPTCASE]SPHERE.PRO       - variables used.
    DSK2:[BUSHNELL.GENOPTCASE]SPHERE3.BEG      - sample case input data
                                                 for BEGIN.
    DSK2:[BUSHNELL.GENOPTCASE]SPHERE3.DEC      - sample case input data
                                                 for DECIDE.
    DSK2:[BUSHNELL.GENOPTCASE]SPHERE3.OPT      - sample case input data
                                                 for MAINSETUP.
    DSK2:[BUSHNELL.GENOPTCASE]SPHERE3.CPL      - sample case input data
                                                 for CHOOSEPLOT.
    DSK2:[BUSHNELL.GENOPTCASE]SPHERE3.DIP      - sample case input data
                                                 for DIPLOT.
```

****************** END OF THE HOWTO.RUN FILE ***************************

APPENDIX F - SPHERE3.* files

The following files are input data for a specific case called SPHERE3. These files are created by the program system SPHERE during execution by the "end" user of the processors BEGIN, DECIDE, MAINSETUP, CHOOSEPLOT and DIPLOT.

APPENDIX F1 - the SPHERE3.BEG file

The following list represents input data for the BEGIN processor.

```
******************** THE SPHERE3.BEG FILE FOLLOWS ********************
     N          $ Do you want a tutorial session and tutorial output?
       45       $ radius of the spherical shell: RADIUS
        1       $ thickness of the skin: TSKIN
       0.5      $ thickness of a stiffener: TSTIFF
        5       $ height of a stiffener: HEIGHT
        5       $ spacing of the stiffeners: SPACNG
 0.7520000E+07 $ modulus of the skin: ESKIN
 0.0580000      $ weight density of the skin material: RHOSKN
 0.3000000      $ Poisson ratio of the skin material: NUSKIN
 0.1300000E+08 $ modulus of the stiffener material: ESTIFF
 0.1000000      $ Poisson ratio of the stiffener material: NUSTIF
 0.0580000      $ weight density of the stiffener material: RHOSTF
        8       $ Number IKLOC  of rows in the array  KLOC: IKLOC
  100.0000      $ knockdown factor from classical buckling formula: KLOC( 1)
  100.0000      $ knockdown factor from classical buckling formula: KLOC( 2)
 0.5000000      $ knockdown factor from classical buckling formula: KLOC( 3)
 0.4000000      $ knockdown factor from classical buckling formula: KLOC( 4)
 0.3000000      $ knockdown factor from classical buckling formula: KLOC( 5)
 0.2500000      $ knockdown factor from classical buckling formula: KLOC( 6)
 0.2000000      $ knockdown factor from classical buckling formula: KLOC( 7)
```

```
  0.2000000     $ knockdown factor from classical buckling formula: KLOC( 8)
          0     $ shallowness parameter of spherical cap: LAMBDA( 1)
          3     $ shallowness parameter of spherical cap: LAMBDA( 2)
        3.1     $ shallowness parameter of spherical cap: LAMBDA( 3)
          5     $ shallowness parameter of spherical cap: LAMBDA( 4)
         10     $ shallowness parameter of spherical cap: LAMBDA( 5)
         15     $ shallowness parameter of spherical cap: LAMBDA( 6)
         20     $ shallowness parameter of spherical cap: LAMBDA( 7)
        200     $ shallowness parameter of spherical cap: LAMBDA( 8)
  0.5000000     $ factor for base-radius of spherical cap: LAMMOD
         10     $ Number IKGEN  of rows in the array  KGEN: IKGEN
          1     $ knockdown factor for general instability: KGEN( 1)
  0.7000000     $ knockdown factor for general instability: KGEN( 2)
  0.6000000     $ knockdown factor for general instability: KGEN( 3)
  0.4700000     $ knockdown factor for general instability: KGEN( 4)
  0.3800000     $ knockdown factor for general instability: KGEN( 5)
  0.3100000     $ knockdown factor for general instability: KGEN( 6)
  0.2800000     $ knockdown factor for general instability: KGEN( 7)
  0.2600000     $ knockdown factor for general instability: KGEN( 8)
  0.2000000     $ knockdown factor for general instability: KGEN( 9)
  0.2000000     $ knockdown factor for general instability: KGEN(10)
          0     $ tabular values of normalized general imperfection: DELBAR( 1)
  0.5000000E-01 $ tabular values of normalized general imperfection: DELBAR( 2)
  0.1000000     $ tabular values of normalized general imperfection: DELBAR( 3)
  0.2000000     $ tabular values of normalized general imperfection: DELBAR( 4)
  0.3000000     $ tabular values of normalized general imperfection: DELBAR( 5)
  0.4000000     $ tabular values of normalized general imperfection: DELBAR( 6)
  0.5000000     $ tabular values of normalized general imperfection: DELBAR( 7)
  0.6000000     $ tabular values of normalized general imperfection: DELBAR( 8)
   1.000000     $ tabular values of normalized general imperfection: DELBAR( 9)
        100     $ tabular values of normalized general imperfection: DELBAR(10)
  0.5000000     $ amplitude of general instability imperfection: WGEN
  0.0000000E+00 $ rotational stiffness parameter for stiffener support: EDGSTF
          1     $ Number NCASES of load cases (environments): NCASES
       2200     $ external pressure on the spherical shell: PRESS( 1)
          1     $ Allowable for general buckling (Use 1.0): ABUCG( 1)
          1     $ factor of safety for general instability: FSBUCG( 1)
          1     $ Allowable for local buckling (Use 1.0): ABUCL( 1)
          1     $ factor of safety for local buckling: FSBUCL( 1)
          1     $ allowable for stiffener buckling (use 1.0): ABUCST( 1)
          1     $ factor of safety for stiffener buckling: FSBUCC( 1)
    84000.0     $ Maximum allowable effective stress in the skin: ASIGSK( 1)
   1.500000     $ factor of safety for stress in the skin: FSSIGA( 1)
    84000.0     $ maximum allowable stress in the stiffeners: ASIGST( 1)
   1.200000     $ factor of safety for stress in stiffeners: FSSIGB( 1)
****************** END OF THE SPHERE3.BEG FILE ****************************
```

APPENDIX F2 - the SPHERE3.DEC file

The following list represents input data for the DECIDE processor.

```
******************** THE SPHERE3.DEC FILE FOLLOWS ********************
     N          $ Do you want a tutorial session and tutorial output?
          1     $ Choose a decision variable (1,2,3,...)
  0.1000000     $ Lower bound of variable no.( 1)
          5     $ Upper bound of variable no.( 1)
     Y          $ Any more decision variables (Y or N) ?
          2     $ Choose a decision variable (1,2,3,...)
  0.2000000     $ Lower bound of variable no.( 2)
```

```
      5        $ Upper bound of variable no.( 2)
    Y          $ Any more decision variables (Y or N) ?
      3        $ Choose a decision variable (1,2,3,...)
 0.0100000     $ Lower bound of variable no.( 3)
     10        $ Upper bound of variable no.( 3)
    Y          $ Any more decision variables (Y or N) ?
      4        $ Choose a decision variable (1,2,3,...)
      1        $ Lower bound of variable no.( 4)
     50        $ Upper bound of variable no.( 4)
    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?
********************** END OF THE SPHERE.DEC FILE ************************
```

APPENDIX F3 - the SPHERE3.OPT file

The following list represents input data for the MAINSETUP processor.

```
********************* THE SPHERE3.OPT FILE FOLLOWS *********************
    N          $ Do you want a tutorial session and tutorial output?
      1        $ NPRINT= output index (0=GOOD, 1=ok, 2=debug, 3=too much)
      1        $ Choose type of analysis (1=opt., 2=fixed design)
      5        $ How many design iterations in this run (3 to 25)?
********************* END OF THE SPHERE3.OPT FILE *********************
```

APPENDIX F4 - the SPHERE3.CPL file

The following list represents input data for the CHOOSEPLOT processor.

```
********************* THE SPHERE3.CPL FILE FOLLOWS *********************
    N          $ Do you want a tutorial session and tutorial output?
    Y          $ Any design variables to be plotted v. iterations (Y or N)?
      1        $ Choose a variable to be plotted v. iterations (1,2,3,..)
    Y          $ Any more design variables to be plotted (Y or N) ?
      2        $ Choose a variable to be plotted v. iterations (1,2,3,..)
    N          $ Any more design variables to be plotted (Y or N) ?
    Y          $ Any design margins to be plotted v. iterations (Y or N)?
      1        $ Choose a margin to be plotted v. iterations (1,2,3,..)
    Y          $ Any more margins to be plotted (Y or N) ?
      2        $ Choose a margin to be plotted v. iterations (1,2,3,..)
    Y          $ Any more margins to be plotted (Y or N) ?
      3        $ Choose a margin to be plotted v. iterations (1,2,3,..)
    Y          $ Any more margins to be plotted (Y or N) ?
      4        $ Choose a margin to be plotted v. iterations (1,2,3,..)
    Y          $ Any more margins to be plotted (Y or N) ?
      5        $ Choose a margin to be plotted v. iterations (1,2,3,..)
    N          $ Any more margins to be plotted (Y or N) ?
********************** END OF THE SPHERE3.CPL FILE *********************
```

APPENDIX F5 - the SPHERE3.DIP file

The following list represents input data for the DIPLOT processor.

```
********************* THE SPHERE3.DIP FILE FOLLOWS *********************
    N          $ Do you want a tutorial session and tutorial output?
      6        $ Choose device number (2 - 6) (Type H for HELP)
********************* END OF THE SPHERE3.DIP FILE  *********************
```