Optimum designs from PANDA2 of a uniformly axially compressed cylindrical shell with internal stringers and internal rings both with rectangular cross sections, and verification of the designs by BIGBOSOR4 and STAGS

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ABSTRACT

The purpose of this report is to serve as a guide for people who want to set up and run PANDA2 models, to optimize shells with PANDA2, and to verify the optimum designs obtained with PANDA2 by running BIGBOSOR4 and STAGS. Every step in the procedure is set down in a runstream. Many explanations are included as to why certain steps are being taken. A long appendix, Appendix 2, is included which gives results from an execution of PANDA2 for a previously optimized design. The runstream listed at the beginning of this report has three parts: Part 1 includes a PANDA2 run of a fixed design, the cylindrical shell tested by NASA in 2008, followed by results from BIGBOSOR4 and STAGS for the same design. In Part 1 the cylindrical shell is assumed to be perfect. This design serves as the starting design for an optimization of the cylindrical shell with a general buckling modal imperfection with amplitude, Wimp = plus and minus 0.125 inch. This optimization is conducted in Part 2. Also, in Part 2 the optimum design obtained by PANDA2 is evaluated by runs of BIGBOSOR4 and STAGS. Part 2 includes many different linear and nonlinear STAGS models, all of them generated automatically by the PANDA2 processor called STAGSUNIT. Part 3 is analogous to Part 2, although it is much shorter. In Part 3 the cylindrical shell is optimized with a much smaller general buckling modal imperfection, the amplitude of which is Wimp = plus and minus 0.050 inch. The ring spacing in the Part 3 design is maintained at the value determined from the optimization in Part 2. The optimized shell in Part 2 represents the configuration in the neighborhoods of weld lands, where the imperfection ampltiude is largest. The optimized shell in Part 3 represents the configuration in the acreage of the shell remote from weld lands, where the imperfection amplitude is much smaller.

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RUN STREAM

RUN STREAM USED TO OBTAIN "nasaortho" and "nasaortho2"
RESULTS WITH IQUICK = 0 .

===

Most results are obtained with the PANDA2 "conservativeness index", ICONSV = 1. When ICONSV is different from 1 it will be noted. For an explanation of the "conservativeness index", ICONSV, see Item no. 676 in the file, ...panda2/doc/panda2.news.

These results are for a metallic internally orthogrid-stiffened cylindrical shell under uniform axial compression. The stringers and rings have rectangular cross sections. The rings can have different height and thickness from those of the stringers. The rings and stringers are internal.

NOTE: With PANDA2 always model a complete (360-degree) cylindrical shell as a panel that subtends 180 degrees.

Note!

There are three parts to this investigation:

PART 1: Find the design margins for the starting design of the PERFECT shell, which has the dimensions and loading and boundary conditions of part of the first test specimen tested by NASA in 2008: the part ("acreage") of the shell that is remote from the weld lands. Case name = "nasaortho".

PART 2: Optimize an IMPERFECT shell with a general buckling modal imperfection with amplitude, Wimp = plus and minus 0.125 inch. The starting design is that featured in PART 1. The optimized imperfect shell represents a proposed design of the shell in the neighborhoods of the weld lands because the imperfection with amplitude, Wimp = plus and minus 0.125 inch, is similar to the amplitude of the largest imperfection found in the neighborhoods of the weld lands. This part is by far the longest because a lot of STAGS models are explored. Case name = "nasaortho".

PART 3: Optimize an IMPERFECT shell with a general buckling modal imperfection with amplitude, Wimp = plus and minus 0.050 inch and with the ring spacing, B(RNG), equal to that found from PART 2. The optimized imperfect shell represents a proposed design of the acreage of the shell remote from the weld lands because the smaller imperfection amplitude, Wimp = 0.05 inch, is similar to the largest imperfection found in the acreage of the test specimen remote from the weld lands. Case name = "nasaortho2".

Most of the time on this project was spent on running various STAGS models of the designs obtained by PANDA2. The PANDA2 processor called STAGSUNIT was used to generate STAGS models.

No work was done in setting up STAGS models that represent a combination of the optimized shells developed in PARTS 2 and 3. This task should be performed by interested researchers, engineers, and designers at NASA or elsewhere.

Assume that the PANDA2 executions are in a directory called <panda2workingspace>.

PART 1 runstream: Evaluate the test 1 configuration, which is used as the starting design in nasaortho.BEG in PART 2.

(pp. 3-5)
Tables 1-16
Figures 1-10

```
cd .../<panda2workingspace>
panda2log        (activate panda2 command set)
begin            table 1  p. 22, 23
```

[Note: We used three different material designators even though the entire shell is fabricated from only one actual material. The panel skin is made of Material 1; the stringers are made of Material 2; the rings are made of Material 3 . I did this so that there will appear in the list of margins a margin for the effective stress in the skin (matl=1), a margin for the effective stress in the stringers (matl=2), and a margin for the effective stress in the rings (matl=3). By means of this "trick" we can learn which part of the shell has the most critical stress margin.]

[Another note: In these configurations there are no faying flanges. None the less, in BEGIN PANDA2 asks for the width, B2, of the stringer base, which is where the faying flange would be if there were one. We make the stringer base width, B2, equal to one third the spacing between the stingers, B(STR), for a reason: this is the most efficient allocation of width from the point of view of discretization of the single skin-stringer module (See Fig. 22b on p. 526 of the long 1987 paper on PANDA2: Computers & Structures, Vol. 25, pp 469-605, 1987, for an example of a discretized single skin-stringer module). With B2 = B(STR)/3 the panel skin in the single module is divided into three segments of equal width. Therefore, the nodal point spacing in the skin is uniform.]

```
setup
decide           table 2  p. 24
```

[Note: an "equality constraint" is established in DECIDE that during optimization cycles the width, B2, of the stringer base will always remain equal to one third the spacing, B(STR), between stringers. Hence, B2 is not a decision variable but is linked to B(STR) with the linking constant equal to 0.3333.]

```
mainsetup        table 3 (the shell is perfect and ITYPE = 2)  p. 25
pandaopt         table 4  p. 26, 27
```

(Note that there is a tiny amount of hoop loading, Ny, and a small amount of in-plane shear loading, Nxy, that PANDA2 automatically adds in order to prevent numerical difficulties in cases for which only axial compression is specified by the user.)

(Next, generate a BIGBOSOR4 model in which the part of the cylindrical shell BETWEEN ADJACENT RINGS is investigated. The cylindrical shell is modeled as part of a huge torus. See Appendix 1 for how this is done. The PANDA2 processor called PANEL is used to generate a valid input file for BIGBOSOR4. This file is called nasaortho.ALL). Appendix 1 = pp. 241-244

```
panel   table 5; purpose is to generate a BIGBOSOR4 huge torus model.  p. 28
```

(The "huge torus" model is described in detail in AIAA Paper 2007-2216, 48th AIAA Structures Meeting, Honolulu, Hawaii, 2007. The relevant pages from that paper are reproduced in Appendix 1.)

(The panel length in the plane of the screen is the length around part of the circumference of the cylindrical shell. It should be equal to an integral number of stringer spacings. PANEL generates a valid input file for BIGBOSOR4 called nasaortho.ALL. The panel length normal to the plane of the paper in Fig. 1 is equal to the spacing between adjacent rings.)

```
cp nasaortho.ALL .../<bigbosor4workingspace> .
cd .../<bigbosor4workingspace>
bigbosor4log     (activate the bigbosor4 command set)
bigbosorall      (produces the nasaortho.OUT.)
resetup          (input, nasaortho.RES, is top part of Table 6)
bigrestart       (output, nasaortho.OUT, is bottom part of Table 6)  p. 29
```

(We use the BIGBOSOR4 processors, resetup and bigrestart in order to get an output file, nasaortho.OUT, which is very small and

```
for which it is easy to find the eigenvalues and wave numbers.
You have to run bigbosorall once, however, before you can use
resetup/bigrestart, since these are "re-start" processors. You
don't have to look at the output from bigbosorall.)

bosorplot       (produces Fig. 1, this is inter-ring buckling.)  p.30
bosorplot       (produces Fig. 2, this is sort of like local buckling)  p.31
cleanup         (cleans up bigbosor4 files)
cd .../<panda2workingspace>

(Next, generate a BIGBOSOR4 model in which the stringers are
smeared out and the rings are modeled as shell branches. The PANDA2
processor called PANEL2 is used. The BIGBOSOR4 model includes the
entire cylindrical shell.)

panel2   table 7; generate a BIGBOSOR4 model of the entire shell.  p.32

[Note: the axial length of the shell is taken to be 68.00 inches
rather than 68.75 inches (the actual length) because there is an
integral number of ring spacings in the length, 68.00 inches.
PANEL2 generates a valid input file for BIGBOSOR4, nasaortho.ALL.]

cp nasaortho.ALL .../<bigbosor4workingspace> .
cd .../<bigbosor4workingspace>
bigbosorall     (produces the nasaortho.OUT. Table 8=abridged file)  p.33
bosorplot       (produces Fig. 3. The shell is clamped top and bottom.)  p.34
cleanup         (cleans up bigbosor4 files)

(Next, set up and run various STAGS models of linear buckling.
The PANDA2 processor, STAGSUNIT, is used to generate valid
input files, *.bin and *.inp, for STAGS, in which "*" = "nasaortho".)

(The first STAGS model is a general buckling model and inter-ring
buckling model. The stringers are smeared out and the rings are
modeled as shell units.)

stagsunit       table 9; produces *.bin and *.inp files for STAGS.  p.35

(Note: there must be an integral number of ring spacings along
the axial length of the STAGS model and exactly an integral number
of stringers over the 360-degree circumference of the cylindrical shell.
The panel length in the plane of the screen that is included in the
STAGS model must be equal to an integral number of stringer spacings.
STAGSUNIT produces two STAGS input files: nasaortho.bin and
nasaortho.inp.)

(You may want to edit the nasaortho.bin file to change the
number of eigenvalues to be found and the eigenvalue SHIFT.)

cp nasaortho.bin .../<stagsworkingspace> .
cp nasaortho.inp .../<stagsworkingspace> .
cd <stagsworkingspace>
stags -b nasaortho      (execute STAGS; produces *.out2 file)

[Inspect the nasaortho.out2 file. Search for the strings,
"roots" and "CONV". Look at the eigenvalues and compare
with the corresponding buckling eigenvalues from
PANDA2 (margins) and BIGBOSOR4 (buckling load factors).
Check to see if any roots have been skipped.]

[Next, get a plot of the critical eigenvector. First,
set up an input file for the STAGS postprocessor, STAPL:
nasaortho.pin (Table 10).]  p.36
stapl nasaortho          (generates nasaortho.pdf)
acroread nasaortho.pdf   (Fig. 4)  p.37
[Edit the nasaortho.pin file to get an end view:
nasaortho.pin (Table 11).]  p.38
stapl nasaortho          (generates nasaortho.pdf)
acroread nasaortho.pdf   (Fig. 5)  p.39

(Fig. 5 shows a variation of the amplitude of the
general buckling mode with circumferential coordinate.
Get rid of this circumferential variation by doing
the following:)

cd .../<panda2workingspace>
(Edit the file, nasaortho.STG listed in Table 9 by
changing the last line: "1      $ Edges normal.....".
```

```
Change the "1" to "0". "0" allows in-plane warping of
the two straight edges of the STAGS model.)

stagsunit        table 9 with the 1 in the last line changed to 0;
                 produces *.bin & *.inp for STAGS

(You may want to edit the nasaortho.bin file to change the
number of eigenvalues to be found and the eigenvalue SHIFT.)

cp nasaortho.bin .../<stagsworkingspace> .
cp nasaortho.inp .../<stagsworkingspace> .
cd <stagsworkingspace>
stags -b nasaortho       (execute STAGS; produces *.out2)
stapl nasaortho          (Table 11; produces nasaortho.pdf file)
acroread nasaortho.pdf   (Fig. 6)  p.40

cd .../<panda2workingspace>

[Set up a 3 stringer bay x 3 ring bay STAGS model
for local buckling (buckling between adjacent
stringers and between adjacent rings)]

stagsunit        Table 12; produces *.bin & *.inp for STAGS.  p.41

(You may want to edit the nasaortho.bin file to change the
number of eigenvalues to be found and the eigenvalue SHIFT.)

cp nasaortho.bin .../<stagsworkingspace> .
cp nasaortho.inp .../<stagsworkingspace> .
cd <stagsworkingspace>
stags -b nasaortho       (execute STAGS; produces *.out2 file)
stapl nasaortho          (Table 13; produces nasaortho.pdf file)  p.42
acroread nasaortho.pdf   (Fig. 7; this is a general buckling mode.)  p.43

(Edit the nasaortho.bin file to compute multiple eigenvalues
in order to find one or more local buckling modes. The new
nasaortho.bin file is listed in Table 14.)  p.44

stags -b nasaortho       (execute STAGS; produces *.out2 file)
(Inspect the nasaortho.out2 file. Abridged version in Table 15)  p.45
stapl nasaortho          (produces nasaortho.pdf file)
acroread nasaortho.pdf   (Fig. 8; another general buckling mode)  p.46
stapl nasaortho          (produces another nasaortho.pdf file)
acroread nasaortho.pdf   (Fig. 9; This looks like a local buckling mode.)  p.47
(Get an end view. Edit the nasaortho.pin file: Table 16)  p.48
stapl nasaortho          (produces another nasaortho.pdf file)
acroread nasaortho.pdf   (Fig. 10; looks more like local than general buckling)  p.49
```

[A NOTE ABOUT STAGS MODELS PRODUCED BY THE PANDA2 PROCESSOR, STAGSUNIT: One of the main objectives in the creation of STAGSUNIT was to be able to generate automatically STAGS models that occupy any sub-region of the complete shell that was previously optimized by PANDA2. Great care was taken with boundary conditions to ensure that the "patch" included in the STAGS model would represent with reasonable accuracy a piece embedded in the actual complete shell structure that was optimized with PANDA2. This required great care especially in cases in which significant applied in-plane shear loading is present. Being able to extract a small "patch" out of the entire shell structure permits accurate determination of the most local buckling predicted by PANDA2. We will see more examples of this "patch" modeling in Part 2.]

(End of PART 1)

(Next, optimize an IMPERFECT shell. The imperfection has the shape of the general buckling mode with an amplitude, Wimp = plus and minus 0.125 inch.) In the presence of a general buckling modal imperfection there must be at least two load cases in the *.OPT file (input for MAINSETUP). The plus Wimp is processed in Load Case 1, and the minus Wimp is processed in Load Case 2. This shell represents the parts of the shell in the neighborhoods of the weld lands where the imperfection amplitude is largest.)

PART 2 runstream: pp. 6-19, Figs 11-87, Tables 17-70

```
cd .../<panda2workingspace>
panda2log          (activate panda2 command set)
begin              table 1  p.22,23
setup
decide             table 2 —— p.24
mainsetup          table 17. Notice the two load cases. —— p.51,52
superopt           (produces nasaortho.OPP file. Look at it.)
chooseplot         table 18; produces input files for diplot. — p.53
diplot             (diplot yields nasaortho.5.ps, a
                    postscript file "plotted" in Fig. 11) p.54

(Edit the nasaortho.OPT file: change ITYPE from 1 to 2)

mainsetup          (table 17, except ITYPE is now equal to 2)
pandaopt           (produces nasaortho.OPM: abridged version in Table 19) p.55-57

(Edit the nasaortho.OPT file again, this time eliminating
the second load set and in the first load set changing the amplitude
of the initial buckling modal general imperfection from 0.125 to 0.0.
We do this so that we can compare PANDA2 buckling margins with results
from BIGBOSOR4 and STAGS for the optimized shell with Wimp set equal
to zero.)

mainsetup          table 20 p.58
pandaopt           (produces nasaortho.OPM: abridged version in Table 21) p.59,60
change             table 22: purpose is to save the optimum design. p.61

(Note: ALWAYS use CHANGE to save your optimized designs. That way
you can easily "resurrect" these designs at some time in the future.)

(Next, we want to generate tables that show various knockdown
factors used in PANDA2. There are two kinds of knockdown factors:

1. knockdown factors to compensate for the approximate nature of
the various theories used in PANDA2. These knockdown factors have
nothing to do with initial imperfections.

2. knockdown factors because of initial imperfections that
affect local, inter-ring, and general buckling load factors.)

(Edit the nasaortho.OPT file: change NPRINT from 0 to 2)

mainsetup          table 20, except that NPRINT = 2)
pandaopt           (produces nasaortho.OPM: abridged versions in Tables 23 & 24) pp.62-64

(Generate Tables 23 and 24 by extracting various parts of
the long output file, nasaortho.OPM, that includes knockdown factors). pp.62-64

(In order to see how the knockdown factors and margins depend on
the PANDA2 "conservative index", ICONSV, see Tables 69 and 70.) pp 206-209

(Next, set up and run various BIGBOSOR4 models as was done in Part 1.)

panel   table 25: purpose is to generate a BIGBOSOR4 huge torus model. p.65
cp nasaortho.ALL .../<bigbosor4workingspace> .
cd .../<bigbosor4workingspace>
bigbosor4log       (activate the bigbosor4 command set)
bigbosorall        (produces the nasaortho.OUT file)
resetup            (input for resetup is in the top part of Table 26) p.66
bigrestart         (produces the bottom part of Table 26) p.66-67
bosorplot          (produces Fig. 12) —— p.68
cleanup            (cleans up bigbosor4 files)
cd .../<panda2workingspace>

panel   table 27: purpose is to generate a BIGBOSOR4 huge torus model. p.69
cp nasaortho.ALL .../<bigbosor4workingspace> .
cd .../<bigbosor4workingspace>
bigbosor4log       (activate the bigbosor4 command set)
bigbosorall        (produces the nasaortho.OUT file)
resetup            (input for resetup is in the top part of Table 28) p.70
bigrestart         (produces the bottom part of Table 28) p.70-71
bosorplot          (produces Fig. 13) —— p.72
cleanup            (cleans up bigbosor4 files)
cd .../<panda2workingspace>

panel2   table 29: purpose is to generate a BIGBOSOR4 model of shell.
(Note: the stringers are smeared out and the rings are shell branches.) p.73
```

cp nasaortho.ALL .../<bigbosor4workingspace> .
cd .../<bigbosor4workingspace>

bigbosor4log (activate the bigbosor4 command set)
bigbosorall (produces nasaortho.OUT. Abridged version in Table 30) p.74
bosorplot (produces Fig. 14: general buckling) p.75
bosorplot (produces Fig. 15: inter-ring buckling) p.76
cleanup (cleans up bigbosor4 files)

(Edit the now fully annotated nasaortho.ALL file to change the boundary conditions at the top and bottom of the model shown in Fig. 14 from clamped to simple support.)

bigbosorall (produces nasaortho.OUT. Abridged version in Table 31) p.77
bosorplot (produces Fig. 16: general buckling) p.78
bosorplot (produces Fig. 17: inter-ring buckling) p.79
cleanup (cleans up bigbosor4 files)

[NOTE: The buckling load factors from PANDA2 for inter-ring and for general buckling (see margins 7 and 13 in the upper part of p. 1 of Table 21) p.59 are significantly lower than those predicted by BIGBOSOR4 from the BIGBOSOR4 model produced by PANEL2. This is mostly because PANDA2 uses conservative knockdown factors to compensate for the approximate nature of the theories used in PANDA2 when the "conservativeness index", ICONSV = 1, which is the case here. See Table 23 for the values of these knockdown factors.] p.62-63

cd .../<panda2workingspace>

(Next, we want to run STAGS models of the optimized design. We cannot simply use the optimum design listed at the bottom of Table 21 and in Table 22 p.59, p.61 because there has to be an integral number of stringers over the 360-degree circumference of the cylindrical shell, and there has to be an integral number of ring spacings over the length of the cylindrical shell. Therefore, we first use CHANGE to change the stringer spacing from that for the optimum design (1.85940 inches in Table 22) p.61 to the CLOSEST spacing that corresponds exactly to an integral number of stringers over 360 degrees (1.861685 inches in Table 32), p.80 and the ring spacing from that of the optimum design (11.772 inches in Table 22) p.61 to the CLOSEST ring spacing that corresponds exactly to an integral number of ring spacings over the 68.75-inch length of the shell (11.45833 inches in Table 32). p.80

change table 32 p.80

(Produce an input file for MAINSETUP that is the same as that listed in Table 17, except that ITYPE = 2 instead of 1).

mainsetup table 17, except TYPE = 2 instead of 1)
pandaopt (produces nasaortho.OPM: abridged version in Table 33a) pp.81-83 pp.81-83

[For a rather complete explanation of what calculations PANDA2 performs for a "fixed" design (the "STAGSworthy" version of the optimum design listed in Table 33a) see Appendix 2. This appendix is very useful for PANDA2 users who want to learn more about what goes on inside PANDA2.] pp. ~~335-366~~ 245-276

(Edit the nasaortho.OPT file again, this time eliminating the second load set and in the first load set changing the amplitude of the initial buckling modal general imperfection from 0.125 to 0.0.)

mainsetup table 20 p.58
pandaopt (produces nasaortho.OPM: abridged version in Table 33b) pp.84-85

(Next, set up and run various STAGS models of linear buckling. The PANDA2 processor, STAGSUNIT, is used to generate valid input files, *.bin and *.inp, for STAGS, in which "*" = "nasaortho". Lots of time on this project was spent on this phase of it. This is a long segment of the run stream because many different STAGS models were explored.) ← Note!

(The first STAGS model is a general buckling model. Both stringers and rings are smeared out in this model: table 34.)

stagsunit table 34; produces *.bin and *.inp files for STAGS. p.86

(You may want to edit the nasaortho.bin file to change the number of eigenvalues to be found and the eigenvalue SHIFT.)

cp nasaortho.bin .../<stagsworkingspace> .
cp nasaortho.inp .../<stagsworkingspace> .
cd <stagsworkingspace>
stags -b nasaortho (execute STAGS; produces *.out2 file)

[Inspect the nasaortho.out2 file. Search for the strings,
"roots" and "CONV". Look at the eigenvalues and compare
with the corresponding buckling eigenvalues from *."out2" file not shown.
PANDA2 (margins) and BIGBOSOR4 (buckling load factors).
Check to see if any roots have been skipped.]

[Next, get a plot of the critical eigenvector. First,
set up an input file for the STAGS postprocessor, STAPL:
nasaortho.pin (Table 10).] p.36
stapl nasaortho (generates nasaortho.pdf)
acroread nasaortho.pdf (Fig. 18) p.87
[Edit the nasaortho.pin file to get an end view:
nasaortho.pin (Table 11).] p.38
stapl nasaortho (generates nasaortho.pdf)
acroread nasaortho.pdf (Fig. 19) p.88

[The critical general buckling mode predicted by STAGS
agrees with that predicted by PANDA2 (Table 33b) and p.84, upper part
by BIGBOSOR4 (Fig. 16)] p.78

cd .../<panda2workingspace>

(The next STAGS model is an inter-ring buckling model. The stringers
are smeared out and the rings are shell units in this model: table 35.) p.89

stagsunit table 35; produces *.bin and *.inp files for STAGS. p.89

(You may want to edit the nasaortho.bin file to change the
number of eigenvalues to be found and the eigenvalue SHIFT.)

cp nasaortho.bin .../<stagsworkingspace> .
cp nasaortho.inp .../<stagsworkingspace> .
cd <stagsworkingspace>
stags -b nasaortho (execute STAGS; produces *.out2 file)

[Inspect the nasaortho.out2 file. Search for the strings,
"roots" and "CONV". Look at the eigenvalues and compare
with the corresponding buckling eigenvalues from
PANDA2 (margins) and BIGBOSOR4 (buckling load factors).
Check to see if any roots have been skipped.]

[Next, get a plot of the critical eigenvector. First,
set up an input file for the STAGS postprocessor, STAPL:
nasaortho.pin (Table 10).] p.36
stapl nasaortho (generates nasaortho.pdf)
acroread nasaortho.pdf (Fig. 20) p.90
[Edit the nasaortho.pin file to get an end view:
nasaortho.pin (Table 11).] p.38
stapl nasaortho (generates nasaortho.pdf)
acroread nasaortho.pdf (Fig. 21) p.91

cd .../<panda2workingspace>

(The next STAGS model is a 3-stringer-bay x 3-ring-bay model.
Both the stringers and the rings are modeled as shell units
in this model: table 36.) p.92

stagsunit table 36; produces *.bin and *.inp files for STAGS. p.92

(You may want to edit the nasaortho.bin file to change the
number of eigenvalues to be found and the eigenvalue SHIFT.)

cp nasaortho.bin .../<stagsworkingspace> .
cp nasaortho.inp .../<stagsworkingspace> .
cd <stagsworkingspace>
stags -b nasaortho (execute STAGS; produces *.out2 file)

[Inspect the nasaortho.out2 file. Search for the strings,
"roots" and "CONV". Look at the eigenvalues and compare
with the corresponding buckling eigenvalues from
PANDA2 (margins) and BIGBOSOR4 (buckling load factors).

Check to see if any roots have been skipped.]

[Next, get a plot of the critical eigenvector. First,
set up an input file for the STAGS postprocessor, STAPL:
nasaortho.pin (Table 10).] p. 36
stapl nasaortho (generates nasaortho.pdf)
acroread nasaortho.pdf (Fig. 22) p. 93

cd .../<panda2workingspace>

(The next STAGS model is a 6-stringer-bay x 1-ring-bay model.
Both the stringers and the rings are modeled as shell units
in this model: table 37.) p. 94

stagsunit table 37; produces *.bin and *.inp files for STAGS. p. 94

(You may want to edit the nasaortho.bin file to change the
number of eigenvalues to be found and the eigenvalue SHIFT.)

cp nasaortho.bin .../<stagsworkingspace> .
cp nasaortho.inp .../<stagsworkingspace> .
cd <stagsworkingspace>
stags -b nasaortho (execute STAGS; produces *.out2 file)

[Inspect the nasaortho.out2 file. Search for the strings,
"roots" and "CONV". Look at the eigenvalues and compare
with the corresponding buckling eigenvalues from
PANDA2 (margins) and BIGBOSOR4 (buckling load factors).
Check to see if any roots have been skipped.]

[Next, get a plot of the critical eigenvector. First,
set up an input file for the STAGS postprocessor, STAPL:
nasaortho.pin (Table 10).] p. 36
stapl nasaortho (generates nasaortho.pdf)
acroread nasaortho.pdf (Fig. 23) p. 95

cd .../<panda2workingspace>

[Next, we want to use STAGS to explore the NONLINEAR
behavior of the optimized shell (that is, the "STAGSworthy"
version of the optimized shell listed in Tables 33a & 33b). pp. 81-85
Because of the relatively closely spaced stringers
(1.861685-inch spacing in Table 32), there are 162 p. 80
stringers in the 360 degrees of circumference of the
cylindrical shell. Therefore, it is impractical to
include the entire cylindrical shell or even 180 degrees
of the shell in the STAGS model which treats all
stringers and rings as shell units. We see from Figs
18 and 19 that the critical general buckling mode found pp. 87, 88
from the model in which all stifferers are smeared has
three axial half waves and six circumferential
half waves over 180 degrees of circumference. This
STAGS prediction agrees with the prediction of
PANDA2. (See Margin No. 13 on the first page of Table 33b). p. 84, upper part
We can predict this critical general buckling mode
from a STAGS model that includes the entire 68.75-inch
length of the shell and that includes only 60 degrees
of circumference, which corresponds to one full
circumferential wave of the critical general buckling
mode. (Actually, we need only include one third the
axial length of the shell and 30 degrees of circumference, pp. 123 - 139
but more on that model later). Table 38 lists the
input for the PANDA2 processor, STAGSUNIT, for the p. 96
60-degree STAGS model in which all the stiffeners are
modeled as shell units. We use this model in a long
series of STAGS linear buckling runs aimed at finding
the critical general buckling mode shape and load
factor. This general buckling mode shape is to be
used later as an imperfection shape in the nonlinear pp. 140 - 173
analysis of the shell, with the amplitude of the
general buckling modal imperfection, Wimp = plus or
minus 0.125 inch. In retrospect it would have been
far more efficient to use a smaller STAGS model for pp. 123-139
searching for the general buckling mode, but we were
optimistic and thought the search wouldn't be as tiresome
as it turned out to be (Table 44).] pp. 108-115

(The first 60-degree STAGS model is a general buckling model.

```
Both stringers and rings are smeared out in this model: table 38.)  p.96

stagsunit        table 38; produces *.bin and *.inp files for STAGS.  p.96

(You may want to edit the nasaortho.bin file to change the
number of eigenvalues to be found and the eigenvalue SHIFT.)

cp nasaortho.bin .../<stagsworkingspace> .
cp nasaortho.inp .../<stagsworkingspace> .
cd <stagsworkingspace>
stags -b nasaortho       (execute STAGS; produces *.out2 file)

[Inspect the nasaortho.out2 file. Search for the strings,
"roots" and "CONV". Look at the eigenvalues and compare
with the corresponding buckling eigenvalues from
PANDA2 (margins) and BIGBOSOR4 (buckling load factors).
Check to see if any roots have been skipped.]

[Next, get a plot of the critical eigenvector. First,
set up an input file for the STAGS postprocessor, STAPL:
nasaortho.pin (Table 10).] p.36
stapl nasaortho          (generates nasaortho.pdf)
acroread nasaortho.pdf   (Fig. 24) p.97
[Edit the nasaortho.pin file to get an end view:
nasaortho.pin (Table 11).]
stapl nasaortho          (generates nasaortho.pdf)
acroread nasaortho.pdf   (Fig. 25) p.98

cd .../<panda2workingspace>

(The next STAGS model is an inter-ring/general buckling model.
The stringers are smeared out and the rings are shell units
in this model: table 39.) p.99

stagsunit        table 39; produces *.bin and *.inp files for STAGS.  p.99

(You may want to edit the nasaortho.bin file to change the
number of eigenvalues to be found and the eigenvalue SHIFT.)

cp nasaortho.bin .../<stagsworkingspace> .
cp nasaortho.inp .../<stagsworkingspace> .
cd <stagsworkingspace>
stags -b nasaortho       (execute STAGS; produces *.out2 file)

(An abridged version of the file, nasaortho.out2, is
listed in Table 40.) p.100

[Inspect the nasaortho.out2 file. Search for the strings,
"roots" and "CONV". Look at the eigenvalues and compare
with the corresponding buckling eigenvalues from
PANDA2 (margins) and BIGBOSOR4 (buckling load factors).
Check to see if any roots have been skipped.]

[Next, get a plot of the critical eigenvector. First,
set up an input file for the STAGS postprocessor, STAPL:
nasaortho.pin (Table 10).] p.36
stapl nasaortho          (generates nasaortho.pdf)
acroread nasaortho.pdf   (Fig. 26) p.101
[Edit the nasaortho.pin file to get the 4th eigenvector:
nasaortho.pin (Table 10 with MODE = 4 instead of 1).]
stapl nasaortho          (generates nasaortho.pdf)
acroread nasaortho.pdf   (Fig. 27) p.102

cd .../<panda2workingspace>

(The next 60-degree STAGS model is an inter-ring/general buckling
model. The stringers are smeared out and the rings are shell units
in this model. The only change from the previous STAGS model
is that ILIN has been changed from 0 to 1. Using ILIN = 1
raises the load factors corresponding to short-wavelength
eigenvectors more than for long-wavelength eigenvectors: table 41.  p.103
Setting ILIN = 1 is not really necessary for STAGS models in which
the stringers are smeared out. However, we do it now in order to
demonstrate its effect on eigenvalues corresponding to inter-ring
buckling and general buckling.)

stagsunit        table 41; produces *.bin and *.inp files for STAGS.  p.103
```

(You may want to edit the nasaortho.bin file to change the
number of eigenvalues to be found and the eigenvalue SHIFT.)

cp nasaortho.bin .../<stagsworkingspace> .
cp nasaortho.inp .../<stagsworkingspace> .
cd <stagsworkingspace>
stags -b nasaortho (execute STAGS; produces *.out2 file)

(An abridged version of the file, nasaortho.out2, is
listed in Table 42. Compare with Table 40.) p.104

[Inspect the nasaortho.out2 file. Search for the strings,
"roots" and "CONV". Look at the eigenvalues and compare
with the corresponding buckling eigenvalues from
PANDA2 (margins) and BIGBOSOR4 (buckling load factors).
Check to see if any roots have been skipped.]

[Next, get a plot of the critical eigenvector. First,
set up an input file for the STAGS postprocessor, STAPL: p.36
nasaortho.pin (Table 10).]
stapl nasaortho (generates nasaortho.pdf)
acroread nasaortho.pdf (Fig. 28) p.105
[Edit the nasaortho.pin file to get the 2nd eigenvector:
nasaortho.pin (Table 10 with MODE = 2 instead of 1).]
stapl nasaortho (generates nasaortho.pdf)
acroread nasaortho.pdf (Fig. 29) p.106

cd .../<panda2workingspace>

(In the next 60-degree STAGS model all the stiffeners are
modeled as shell branches. We use this model to search
for the general buckling mode that is analogous to that
displayed in Fig. 29. This is a tedious process because p.106
there are hundreds of local buckling modes in the spectrum
that includes the one general buckling mode that we are
searching for. You have to have a lot of patience while
you repeatedly run STAGS in a linear buckling option in
your search for the general buckling mode and eigenvalue.
You start using an eigenvalue shift close to the most
accurate value you have so far, which in this case is
the value, 2.5829, given in Fig. 29. Use ILIN = 1 p.106
for the linear buckling STAGS model used in the search
for general buckling. For each STAGS linear buckling
execution use 8 for the number of eigenvalues wanted
in each run. In retrospect it would have been
far more efficient to use a smaller STAGS model for pp. 123-139
searching for the general buckling mode, but we were
optimistic and thought the search wouldn't be as tiresome
as it turned out to be (Table 44).) pp. 108-115

IMPORTANT!

stagsunit table 43; produces *.bin and *.inp files for STAGS. p.107

(You may want to edit the nasaortho.bin file to change the
number of eigenvalues to be found to 8 and to change the
eigenvalue SHIFT. For example, in this first STAGS linear
buckling run, we set SHIFT = 2.575, slightly below the
eigenvalue listed in Fig. 29: 2.5829.) p.106

cp nasaortho.bin .../<stagsworkingspace> .
cp nasaortho.inp .../<stagsworkingspace> .
cd <stagsworkingspace>
stags -b nasaortho (execute STAGS; produces *.out2 file)

[We use STAPL/acroread to look at each converged mode shape
to see if it happens to be the sought-after general buckling
mode analogous to that displayed in Fig. 29. If none of the p.106
8 modes corresponds to general buckling, we change the
value of SHIFT near the bottom of the nasaortho.bin file
and we execute STAGS again. We do this over and over and
over and over again (VERY tedious) until we either find
the general buckling mode or get discouraged and do something
else. The first eight pages of Table 44 (STAGS linear
buckling runs 2 - 35) lists the results of an extensive and pp.108-115
most tiresome search that required about 3 days of calandar
time. We just could not find the general buckling mode!
The typical mode we encountered during the search was
similar to that displayed in Fig. 30. During our search p.117
we encountered several inter-ring buckling modes as

shown in Figs. 31 - 35. We were expecting the general pp. 118-122
buckling eigenvalue to be slightly lower than than
listed in Fig. 29. Therefore, most of our search was for p.106
eigenvalue shifts lower than that. It turns out, as we
shall see later, that the eigenvalue corresponding to
general buckling is somewhat higher than that listed
in Fig. 29, something we did not expect and actually p.106
do not understand. As a result of our long and still
unsuccessful search, we decided to use a much smaller
STAGS model in order to speed up this tedious process.
This much smaller STAGS model includes only one third pp.123-139
of the axial length of the cylindrical shell (one half
axial wavelength of the critical general bucking mode
displayed in Fig. 29) and only about 30 degrees of circumference
(close to one half the circumferential extent of the STAGS
model displayed in Fig. 25). Note that we could not p.98
use EXACTLY 30 degrees because that corresponds to
13.5 stringer spacings. STAGSUNIT only permits an
integral number of stringer spacings. We decided to
include exactly 14 stringer spacings in our "small" model.]

cd .../<panda2workingspace>

(The first approx.30-degree STAGS model is an inter-ring/general buckling
model. The stringers are smeared out and the rings are shell units
in this "small" model. ILIN = 1 (Table 45) p.123

stagsunit table 45; produces *.bin and *.inp files for STAGS. p.123

(You may want to edit the nasaortho.bin file to change the
number of eigenvalues to be found and the eigenvalue SHIFT.)

cp nasaortho.bin .../<stagsworkingspace> .
cp nasaortho.inp .../<stagsworkingspace> .
cd <stagsworkingspace>
stags -b nasaortho (execute STAGS; produces *.out2 file)

(An abridged version of the file, nasaortho.out2, is
listed in Table 46. Compare with Tables 40 and 42.) p.124

[Inspect the nasaortho.out2 file. Search for the strings,
"roots" and "CONV". Look at the eigenvalues and compare
with the corresponding buckling eigenvalues from
PANDA2 (margins) and BIGBOSOR4 (buckling load factors).
Check to see if any roots have been skipped.]

[Next, get a plot of the critical eigenvectors. First,
set up an input file for the STAGS postprocessor, STAPL:
nasaortho.pin (Table 10).] p.36
stapl nasaortho (generates nasaortho.pdf)
acroread nasaortho.pdf (Fig. 36) p.125
[Edit the nasaortho.pin file to get the 2nd eigenvector:
nasaortho.pin (Table 10 with MODE = 2 instead of 1).]
stapl nasaortho (generates nasaortho.pdf)
acroread nasaortho.pdf (Fig. 37) p.126
[Edit the nasaortho.pin file to get an end view:
nasaortho.pin (Table 11 with MODE = 2 instead of 1).]
stapl nasaortho (generates nasaortho.pdf)
acroread nasaortho.pdf (Fig. 38) p.127

cd .../<panda2workingspace>

(In the next approx.30-degree STAGS model all the stiffeners
are modeled as shell branches. We use this model to search F.29 F.38
for the general buckling mode that is analogous to that
displayed in Figs. 29 and 38. This is a tedious process because p.106 & 127
there are many, many local buckling modes in the spectrum
that includes the one general buckling mode that we are
searching for. You have to have a lot of patience while
you repeatedly run STAGS in a linear buckling option in
your search for the general buckling mode and eigenvalue.
Start exploring with eigenvalue shifts in the lower end (STAGS run26, pp.113,114)
of the range used in Table 44. Use ILIN = 1 . For each
STAGS linear buckling execution use 8 for the number of
eigenvalues wanted in each run.)

stagsunit table 47; produces *.bin and *.inp files for STAGS. p.128

[You may want to edit the nasaortho.bin file to change the number of eigenvalues to be found to 8 and to change the eigenvalue SHIFT. For example, in this first STAGS linear buckling run, we set SHIFT = 2.4314, which is the eigenvalue found from the 60-degree STAGS model that corresponds to the critical inter-ring buckling mode. (See STAGS run no. 26 at the bottom of p. 6 and the top of p. 7 of Table 44.)] p. 114, top p. 114, top.

```
cp nasaortho.bin .../<stagsworkingspace> .
cp nasaortho.inp .../<stagsworkingspace> .
cd <stagsworkingspace>
stags -b nasaortho       (execute STAGS; produces *.out2 file)
```

[We use STAPL/acroread to look at each converged mode shape to see if it happens to be the sought-after general buckling mode analogous to that displayed in Figs. 29 and 38. If none of the 8 modes corresponds to general buckling, we change the value of SHIFT near the bottom of the nasaortho.bin file and we execute STAGS again. We do this over and over and over and over again (VERY tedious) until we either find the general buckling mode or get discouraged and do something else. Table 48 lists the results of an extensive and most tiresome search that required about 1 day of calandar time. We finally found the general buckling mode (bottom of page 3 of Table 48), and surprisingly its eigenvalue is higher than that for the model with smeared stringers. (See Fig. 38). The general buckling mode is hidden in a "thicket" of local buckling modes of the type shown in Fig. 39, inter-ring buckling modes of the types displayed in Figs. 40 and 41, and combined local/inter-ring buckling modes of the types shown in Figs. 42 and 43. The general buckling mode is shown in Figs. 44 and 45.] pp. 129-132 p. 131 p. 127 p. 133 p. 134, 135 p. 136, 137 p. 138, 139

```
cd .../<panda2workingspace>
```

(Now go back to the 60-degree STAGS model with all stiffeners modeled as shell branches. From the 30-degree STAGS model we now know that we should extend the search starting at the high end of the eigenvalue range explored for the 60-degree STAGS model, results for which are listed in Table 44. See STAGS run no. 7 on p. 2 of Table 44.) pp. 108-115 p. 109

```
stagsunit      table 43; produces *.bin and *.inp files for STAGS.
cp nasaortho.bin .../<stagsworkingspace> .
cp nasaortho.inp .../<stagsworkingspace> .
cd <stagsworkingspace>
stags -b nasaortho       (execute STAGS; produces *.out2 file)
```

p. 107

[We use STAPL/acroread to look at each converged mode shape to see if it happens to be the sought-after general buckling mode analogous to that displayed in Figs. 29 and 38. If none of the 8 modes corresponds to general buckling, we change the value of SHIFT near the bottom of the nasaortho.bin file and we execute STAGS again. We do this over and over again until we finally discover the general buckling mode. The results from this exploration are entered on the last page of Table 44 as STAGS runs 36 - 39. We find the general buckling mode! (See Figs. 46a and 46b).] p. 140, p. 142 p. 106, p. 127 p. 116

(Next, while still in the STAGS working space, we copy the nasaortho.bin and nasaortho.inp files to temporary locations, calling them nasa.bin and nasa.inp. Then we delete all "nasaortho" files, then restore them. Here are the commands:)

```
cp nasaortho.bin nasa.bin
cp nasaortho.inp nasa.inp
'rm' nasaortho.*
cp nasa.bin nasaortho.bin
cp nasa.inp nasaortho.inp
```

(We edit the nasaortho.bin file so that we have the file as listed in Table 49. Then we execute STAGS for linear buckling.) p. 141

```
stags -b nasaortho       (execute STAGS; produces *.out2 file)
```

(Executing STAPL with the use of Table 10 as input, we again obtain the same general buckling mode as that displayed in Figs. 46a and 46b. This general buckling mode shape will become the FIRST buckling modal imperfection.) p.140, p.142

(We edit the nasaortho.bin file again so that now we have the file as listed in Table 50. The eigenvalue shift, 2.431432, corresponds to the critical inter-ring buckling mode displayed in Fig. 35. Then we execute STAGS for linear buckling (INDIC=1). p.143 p.122

```
stags -b nasaortho      (execute STAGS; produces *.out2 file)
```

(Executing STAPL with the use of Table 10 as input, we again obtain the same critical inter-ring buckling mode as that displayed in Fig. 35. This inter-ring buckling mode shape will become the SECOND buckling modal imperfection.) p.122

(We edit the nasaortho.bin file a third time so that now we have the file as listed in Table 51. We are looking for the lowest eigenvalue with ILIN = 1 (which ordinarily we should not do). Then we execute STAGS for linear buckling.) p.144 for local buckling

```
stags -b nasaortho      (execute STAGS; produces *.out2 file)
```

(Executing STAPL with the use of Table 10 as input, we obtain the critical local buckling mode. This local buckling mode was found with ILIN = 1, which is something that should not be done if the critical local buckling mode is to be used as an imperfection shape. The critical local buckling mode with ILIN = 1 is plotted in Fig. 47. Notice that the eigenvalue is 1.7661.) p.145

(In order to produce a critical local buckling mode that may be used as an imperfection shape, we need to re-execute STAGSUNIT with ILIN changed from 1 to 0. Note that in any nonlinear STAGS analysis ILIN should be set to 0 anyway. We do the following:)

```
cd .../<panda2workingspace>
stagsunit       table 43 except that ILIN= 0 instead of 1
cp nasaortho.bin .../<stagsworkingspace> .
cp nasaortho.inp .../<stagsworkingspace> .
cd <stagsworkingspace>
stags -b nasaortho      (execute STAGS; produces *.out2 file)
```

[Execute STAPL with Table 10 input. The critical (lowest) local buckling mode and eigenvalue appear in Fig. 48. Note that the critical eigenvalue, 1.3654, is significantly smaller than the critical local buckling eigenvalue determined with use of ILIN = 1: 1.7661 in Fig. 47. The first eigenvalue (root) does not represent a very good imperfection shape. We decide to use the 5th eigenvector shown in Fig. 49 as a local buckling imperfection shape instead of the first eigenvector. This becomes the THIRD imperfection shape to be used in the STAGS nonlinear analysis.] p.146 p.145 p.147

[Next, perform a nonlinear STAGS analysis (INDIC = 3).] The input file, nasaortho.bin, is listed in Table 52. The other required input file, nasaortho.inp, is obtained by suitably editing the nasaortho.inp file used for the linear buckling analysis. The portion of the nasaortho.inp file in which changes occur is listed in Table 53. There are two places where changes must be made: p.148 p.149

1. The number of imperfections, NIMPFS, on the B-2 record must be changed from 0 to 3, and

2. Three new B-5 records must be introduced as listed in Table 53. NOTE: You don't always have to have 3 imperfection shapes, of course. We happen to be doing that in this example. Also, note that the amplitudes of the inter-ring buckling modal imperfection and of the local buckling modal imperfection are very, very small. These tiny imperfections act as "triggers": their presence tends to keep bifurcation points off of the nonlinear equilibrium path, thereby making it more likely that the Riks nonlinear continuation will retain zero roots as the nonlinear equilibrium path is followed.]

```
stags -b nasaortho      (execute STAGS; produces *.out2 file)
```

[An abridged version of nasaortho.out2 is listed in Table 54. p.150
The STAGS postprocessor, STAPL, is used to generate the plots
shown in Figs. 50 - 53. Then 2nd and 3rd nonlinear STAGS runs pp.151-154
are executed. The results are summarized in Table 55, and the p.155
first nonlinear buckling mode at Load Step no. 17 is displayed
in Fig. 54. Then a 4th nonlinear STAGS run is executed, with p.156
results from the nasaortho.out2 file summarized at the bottom
of Table 56. STAGS was unable to find a converged nonlinear pp.157-158
solution for a load factor PA higher than 1.27888. (Load Step
No. 30 at the end of Table 56). The first nonlinear buckling p.158
mode at Step 30 is shown in Fig. 55, and the equilibrium state p.159
of the shell at Load Step 30 is shown in Figs. 56 - 60. The pp.160-165
input for the STAGS postprocessor, STAPL, for inner fiber
effective stress is listed in Table 57. At Load Step 30 there p.162
exists significant stringer deformation at the inward lobes
of the overall deformation pattern.]

[NOTE: In Fig. 51 we see that at the design load, PA = 1.0 p.152
(Nx = -2219 lb/in) STAGS predicts an inward maximum normal
deflection that is almost twice the maximum outward normal
deflection, this in spite of the overall Poisson radial
expansion (positive w) of the axially compressed shell. IT IS
EMPHASIZED THAT PANDA2 CANNOT PREDICT THIS BEHAVIOR. THE APPROXIMATE
THEORY USED IN PANDA2 IS BASED ON THE ASSUMPTION THAT AS
THE SHELL WITH A GENERAL BUCKLING MODAL IMPERFECTION IS
LOADED IN AXIAL COMPRESSION, THE AMPLITUDE OF THE IMPERFECTION
SHAPE GROWS HYPERBOLICALLY, that is, w = Wimp/(eigenvalue - 1)
in which "eigenvalue" is the general buckling load factor.
(See Equation (13) on p. 494 of the paper "Approximate method...",
Computers & Structures, Vol 59, pp. 489-527, 1996). In PANDA2 The
shape of the overall deformation is assumed to remain unchanged
as the loading is increased. Therefore, since the general
buckling mode shape is assumed in PANDA2 to vary trigonometrically
in both the axial and circumferential coordinate directions,
the outward deflection remains equal to the inward deflection.
It is obvious from Fig. 51 that this is not a very accurate p.152
picture of what happens in nature. It is for reasons such as
this that the PANDA2 user is ALWAYS urged to check his/her
optimum designs obtained with PANDA2 by running a general-
purpose program such as STAGS. It is essential that whatever
general-purpose program is chosen be capable of handling nonlinear
behavior.] Very important!!!

[Next, we want to plot the sidesway at the tip of one of the
stringers as a function of the load factor, PA. In order to
do this, we must have a nodal point number or numbers for which pp. 166-173
to plot the normal displacement w vs. PA. We take the following
steps:

1. Obtain a "zoomed" plot with only a few of the shell units
included in the model. Table 58 is the input for STAPL and p.166
Fig. 61 shows the "zoomed" plot. p.167

2. Note points for which we want to generate plots of normal
deflection w at the stringer tip. Two such points are indicated
in Fig. 61. At this time we do not know the nodal point numbers p.167
corresponding to these two locations, even though the numbers
are indicated in Fig. 61.

3. Generate a nasaortho.pdf file that has the nodal point
numbers on it. The input data for STAPL are listed in Table 59. p.168
We include the three shell units, 15, 16, and 33 [two of the
central stringers (units 15 and 16) and the central ring (unit 33)]
in order to know where we are in the structure.

4. Get a "zoomed" plot of the resulting nasaortho.pdf file.
This plot is displayed in Fig. 62. p.169

5. From Fig. 61 we have determined that the two points where
the stringer sidesway is maximum lie four mesh intervals from p.167
the intersection of the stringer (shell unit 16) with the
central ring (shell unit 33), including the circumferential
mesh line at the intersection. From Fig. 62 we can see (barely!) p.169
that the two nodal points we want plots for are Node 19767 and
Node 19797.]

[Table 60 lists the input data for the STAGS post-processor p.170
called "xytrans", which is used to generate the "x-y" plot

My son!

of stringer sidesway versus load factor PA. Execution of xytrans with this input generates the file called "nasaortho.plt" (or "nasaortho.plt.n", n = 1, 2, 3, etc. if we have executed xytrans several times in succession). The nasaortho.plt file is listed in Table 61. This file is copied to the panda2 case p.171 working area and suitably edited for plotting with Bill Bushnell's excellent "x-y" plot software called ../bin/plotps.linux. Table 62 lists typical input data for plotps.linux. The command, p.172

../bin/plotps.linux < nasaortho.input > nasaortho.ps

generates the postscript file, nasaortho.ps, which yields the plot displayed in Fig. 63. The sequence of commands to p.173 generate the desired plot of stringer sidesway v. PA is:]

xytrans (table 60, nasaortho.pxy, is input; nasaortho.plt is output) p.170, p.171
cp nasaortho.plt .../<panda2workingspace> .
cd .../<panda2workingspace>
cp nasaortho.plt nasaortho.input
(Edit the nasaortho.input file to yield Table 62) p.172
../bin/plotps.linux < nasaortho.input > nasaortho.ps
gv nasaortho.ps (to see Fig. 63 on your screen) p.173

(Next, we want to use STAGSUNIT to generate a STAGS model that has a NONUNIFORM MESH. We want to concentrated the mesh in the central region of the panel shown in Figs. 46a and 46b.) p.140, p.142

stagsunit table 63 is input. Note that ILIN = 1 p.174

(Edit the nasaortho.bin file. Use as the initial eigenvalue shift 2.608979, which is the eigenvalue given in Figs. 46a and 46b, the model with uniform mesh.) p.140, p.142

cp nasaortho.bin .../<stagsworkingspace> .
cp nasaortho.inp .../<stagsworkingspace> .
cd <stagsworkingspace>
stags -b nasaortho (execute STAGS; produces *.out2 file)

(We plot the model, that is, the nasaortho_m.pdf file. The STAGS model, nasaortho_m.pdf, is shown in Figs. 64 and 65.) pp ~~64,65~~ 175, 176

(We use STAPL/acroread to look at each converged mode shape to see if it happens to be the sought-after general buckling mode analogous to that displayed in Figs. 46a and 46b. If none p.140,142 of the 8 modes corresponds to general buckling, we change the value of SHIFT near the bottom of the nasaortho.bin file and we execute STAGS again. We do this over and over again until we finally discover the general buckling mode. The results from this exploration are listed in Table 64. The p.177 general buckling mode corresponds to the eigenvalue, 2.601934.)

(Next, while still in the STAGS working space, we copy the nasaortho.bin and nasaortho.inp files to temporary locations, calling them nasa.bin and nasa.inp. Then we delete all "nasaortho" files, then restore them. Here are the commands:)

cp nasaortho.bin nasa.bin
cp nasaortho.inp nasa.inp
'rm' nasaortho.*
cp nasa.bin nasaortho.bin
cp nasa.inp nasaortho.inp

(We edit the nasaortho.bin file so that we have the file as listed in Table 65. Then we execute STAGS for p.178 linear buckling.)

stags -b nasaortho (execute STAGS; produces *.out2 file)

(Executing STAPL, we obtain the same general buckling mode and eigenvalue as that listed near the bottom of Table 64. The general p.177 buckling mode shape is plotted in Figs. 66 - 68. This general buckling pp.179-181 mode shape will become the buckling modal imperfection in the nonlinear STAGS run(s) to follow.)

(Next, we want to do a STAGS nonlinear analysis of the shell with a linear general buckling modal imperfection shape with amplitude, Wimp = -0.125 inch, that is, we want an imperfection shape that

is the negative of the mode shape displayed in Figs. 66 and 67. pp. 179,180
First, we must go back to the panda2 working space and re-execute
STAGSUNIT with ILIN changed from 1, as it is in Table 63, to 0,
as it is in Table 66. It is essential that ILIN = 0 in nonlinear p.182
STAGS runs. Otherwise the STAGS nonlinear predictions will be
unconservative.)

cd .../<panda2workingspace>
stagsunit   table 66 is input for STAGSUNIT p.182

(Edit the nasaortho.bin file to only find one eigenvalue
and to set the eigenvalue shift to 1.3).

cp nasaortho.bin .../<stagsworkingspace> .
cp nasaortho.inp .../<stagsworkingspace> .
cd <stagsworkingspace>
stags -b nasaortho   (execute STAGS; produces *.out2 file)

(The STAGS linear buckling analysis followed by execution of
STAPL with Table 10 as input yields Fig. 69). p.183

[Next, we provide a new nasaortho.bin file, the one listed
in Table 52. Then we edit nasaortho.inp to set the number of p.148
imperfections NIMPFS to 1 instead of zero and to add the
following B-5 record:

C Begin B-4, B-5 input data, if any...
 -0.125   0 1 1 $B-5 WIMPFA, IMSTEP, IMMODE, IMRUN (1st imperf.)

then we execute the nonlinear (INDIC=3) STAGS case]:

stags -b nasaortho   (execute STAGS; produces *.out2 file)

[The nonlinear buckling eigenvalue and eigenvector at PA = 1.0 are pp.184,185,186
plotted in Fig. 70, Figures 71 and 72 show one of the central
stringers on which are plotted the inner fiber (Fig. 71) and outer
fiber (Fig. 72) effective stress.] STAGS predicts a lower
stress at the stringer tip than does PANDA2:

STAGS stress at stringer tip = approximately 33000 psi pp.185,186

PANDA2 stress at stringer tip = 55043 psi (ICONSV = 1)
PANDA2 stress at stringer tip = 51034 psi (ICONSV = 0)
PANDA2 stress at stringer tip = 42622 psi (ICONSV =-1)

The values of stress from PANDA2 are computed from the formula:

(actual effective stress) = (max. allowable stress)/[(margin+1) x f.s]
                    55043 = 70000/[(0.273 + 1)*0.999] for ICONSV = 1
                    51043 = 70000/[(0.373 + 1)*0.999] for ICONSV = 0
                    42622 = 70000/[(0.644 + 1)*0.999] for ICONSV =-1

in which the margins, 0.273, 0.373, and 0.644, are listed on p.A16 of Appendix 2 p.350
in the detailed section on CHAPTERS 13 and 14 included in connection with
Table 33a. STAGS predicts lower stress at the stiffener tip for the p.81-83
following reasons:

1. In Fig. 51 STAGS predicts less outward deflection w than is predicted p.152
by PANDA2: from STAGS, w(outward) = 0.09239; from PANDA2 = 0.1557 (ICONSV= 1)
           from STAGS, w(outward) = 0.09239; from PANDA2 = 0.1375 (ICONSV= 0)
           from STAGS, w(outward) = 0.09239; from PANDA2 = 0.0916 (ICONSV=-1)

2. In Figs. 71 and 72 the effective stress is not really the stress at the pp.185,186
tip of the stringer, but near the tip because the stress is computed at
the 9 integration points of the STAGS 480 finite element.]

3. The maximum stress from a contour plot underestimates the maximum stress
from the STAGS postprocessor, xytrans. (Compare the maximum effective stress
shown in Fig. 85a with that shown in Fig. 87, for example.)
p.202 p.205

(Next, we want to use STAGSUNIT to generate a STAGS model that
has the same nonuniform mesh as is shown in Figs. 64 and 65 except pp.175,176
that there are no stringers with an extra dense mesh, as is the
case in Table 63. ILIN is again equal to unity to "filter out" p.174
some local buckling eigenmodes. The new input to STAGSUNIT is
listed in Table 67. p.187

```
stagsunit        table 67 is input. Note that ILIN = 1
```
p.187

(Edit the nasaortho.bin file. Use as the initial eigenvalue shift 2.601934, which is the eigenvalue given in Figs. 66 and 67 corresponding to the model with nonuniform mesh and with extra mesh density in four of the central stringers, as shown in Figs.71 and 72, for examples.) p.179 p.180 pp. 185,186

```
cp nasaortho.bin .../<stagsworkingspace> .
cp nasaortho.inp .../<stagsworkingspace> .
cd <stagsworkingspace>
stags -b nasaortho       (execute STAGS; produces *.out2 file)
```

(We use STAPL/acroread to look at each converged mode shape to see if it happens to be the sought-after general buckling mode analogous to that displayed in Figs. 66 and 67. If none of the 8 modes corresponds to general buckling, we change the value of SHIFT near the bottom of the nasaortho.bin file and we execute STAGS again. We do this over and over again until we finally discover the general buckling mode. The results from this exploration are listed in Table 68. The general buckling mode corresponds to the eigenvalue, 2.607991, listed on page 2 of Table 68.) p.189 pp.179,180 pp.188,189

(Next, while still in the STAGS working space, we copy the nasaortho.bin and nasaortho.inp files to temporary locations, calling them nasa.bin and nasa.inp. Then we delete all "nasaortho" files, then restore them. Here are the commands:)

```
cp nasaortho.bin nasa.bin
cp nasaortho.inp nasa.inp
'rm' nasaortho.*
cp nasa.bin nasaortho.bin
cp nasa.inp nasaortho.inp
```

(We edit the nasaortho.bin file so that we have the file as listed in Table 65 except that the eigenvalue shift is equal to 2.607991 instead of 2.601934. Then we execute STAGS for linear buckling.)

```
stags -b nasaortho       (execute STAGS; produces *.out2 file)
```

(Executing STAPL, we obtain the same general buckling mode and eigenvalue as that listed on page 2 of Table 68. The general buckling mode shape is plotted in Figs. 73 and 74. This general buckling mode shape will become the negative of the buckling modal imperfection in the nonlinear STAGS run(s) to follow. Notice that the general buckling mode happens to have the opposite sign of that shown in Figs. 66 and 67. Compare Fig. 74 with Fig. 67.) pp.190,191 pp.179,180

(Next, we want to do a STAGS nonlinear analysis of the shell with a linear general buckling modal imperfection shape with amplitude, Wimp = -0.125 inch, that is, we want an imperfection shape that is the negative of the mode shape displayed in Figs. 73 and 74. First, we must go back to the panda2 working space and re-execute STAGSUNIT with ILIN changed from 1, as it is in Table 67, to 0 . It is essential that the user set ILIN = 0 in all nonlinear STAGS models. Otherwise, STAGS will predict unconservative results.) pp. 190-191

```
cd .../<panda2workingspace>
stagsunit        table 67, with ILIN = 0 instead of 1, is input for STAGSUNIT
```

[Next, we provide a new nasaortho.bin file, the one listed in Table 52. Then we edit nasaortho.inp to set the number of imperfections NIMPFS to 1 instead of zero and to add the following B-5 record: p.148

```
C Begin B-4, B-5 input data, if any...
 -0.125   0  1  1   $B-5 WIMPFA, IMSTEP, IMMODE, IMRUN (1st imperf.)
```

Then we execute the nonlinear (INDIC=3) STAGS case]:

```
stags -b nasaortho       (execute STAGS; produces *.out2 file)
```

(STAPL generates the nonlinear deformation at Load Step 12, that is, at the design load, PA = 1.0. It is displayed in Fig. 75. Figs. 76, 77, and 78 show the closest eigenvalue and eigenvector at PA = 1.0. Fig. 77 and 78 are analogous to Figs. 52 and 53 for the STAGS model with p.192, p.193,194,195 p.153,152 F.52, F.53

the uniform mesh.)

We do a STAGS nonlinear restart at Load Step 12 and continue loading:

```
stags -b nasaortho      (execute STAGS; produces *.out2 file)
```

(Figures 79 - 85a and 85b show the state of the shell at Load Step 30, which corresponds to load factor, PA = 1.275). pp. 196-203

We want to plot the effective stress in the panel skin as a function of the load factor, PA. First, we have to find out for which finite element we want the plot. We choose the finite element that exhibits the highest effective stress in the entire model at the load factor, PA = 1.275. Figure 85b indicates the element for which we want to plot the effective stress. This element is in the region of dense mesh, and we note that it is located 10 finite elements "up" and 9 finite elements "over" from the corner of the dense region closest to the bottom of Fig. 85b. As shown in Fig. 86, this is finite element number 2912. The STAGS postprocessor, xytrans, is used to generate the data in Fig. 87. Figure 87 is generated in a manner that is completely analogous to the way in which Fig. 63 is generated. The only difference is that with Figure 87 we have to specify a finite element, whereas in Figure 63 we had to specify a nodal point. (NOTE: Sometimes the nodal points are hard to see in a plot because, for the 480 finite element in STAGS, there are many more of them than there are finite elements.) p. 203 p. 204 p. 205 p. 173

DEPENDENCE OF RESULTS ON THE "CONSERVATIVENESS INDEX", ICONSV, FOR THE OPTIMUM DESIGN LISTED IN TABLE 33b pp. 81-83

Table 69 lists inter-ring and general buckling load factors for ICONSV = 1 and 0 and the general buckling load factor for ICONSV = -1. (The inter-ring data for ICONSV = -1 are the same as for ICONSV = 0 in this particular case). pp. 206, 207

Table 70 lists the margins for Load Case 1, Subcase 1 corresponding to ICONSV = 1, 0, and -1. ICONSV = 1 is the recommended value. However, weight can be saved through the use of ICONSV = 0 and ICONSV = -1. If the PANDA2 user can verify his designs by application of a general purpose computer program such as STAGS to optimum designs previously obtained by PANDA2, then he or she is urged to try optimizing with ICONSV = 0 and ICONSV = -1. In this case the margins increase from ICONSV = 1 to ICONSV = 0 to ICONSV = -1 because we are applying these different values of ICONSV to the SAME DESIGN: that design optimized with the use of the recommended value, ICONSV = 1. pp. 208, 209

(End of the loooong PART 2)

(Next, optimize an IMPERFECT shell again. The imperfection again has the shape of the general buckling mode with an amplitude, Wimp = plus and minus 0.050 inch. The plus Wimp is processed in Load Case 1, and the minus Wimp is processed in Load Case 2. This shell represents the acreage remote from any weld land ~~because a much smaller imperfection amplitude, Wimp = plus and minus 0.050 inch, is specified than that specified in Part 2. The name of the case in Part 3 is "nasaortho2".)~~

PART 3 runstream: pp. 19-20, Figures 88-97, Tables 71-83

```
cd .../<panda2workingspace>
panda2log        (activate panda2 command set)
begin            table 71
```
p. 211, 212

(NOTE: use the ring spacing determined in Part 2 because we want the rings to be continuous in the regions near and away from the weld lands.)

```
setup
decide           table 72
```
p. 213

(NOTE: Compare with Table 2. Notice that B(RNG) is no longer a decision variable.)

```
mainsetup        table 73  p.214, 215
pandaopt         produces nasaortho2.OPM and nasaortho2.OPP
pandaopt         produces nasaortho2.OPM and nasaortho2.OPP
pandaopt         produces nasaortho2.OPM and nasaortho2.OPP
(Inspect the nasaortho2.OPP file. See Table 74 for an abridged version)  pp.216, 217
chooseplot       table 75; produces input files for diplot.  p.218
diplot           (diplot yields nasaortho2.3.ps, nasaorth2.4.ps, nasaortho2.5.ps,
                  postscript files "plotted" in Figs. 88, 89, 90)  pp.219-221
chooseplot       table 76; produces input files for diplot.  p.222
diplot           (diplot yields nasaortho2.3.ps and nasaortho2.4.ps,
                  postscript files "plotted" in Figs. 91 and 92)  pp.223, 224

superopt         (produces nasaortho2.OPP file. Look at it.)
chooseplot       table 18; produces an input file for diplot.  p.53
diplot           (diplot yields nasaortho2.5.ps, a
                  postscript file "plotted" in Fig. 93)  p.225

(Edit the nasaortho2.OPT  change ITYPE from 1 to 2)

mainsetup        (table 73, except ITYPE is now equal to 2)
pandaopt         (produces nasaortho2.OPM: abridged version in Table 77)  pp.226-228

(Edit the nasaortho2.OPT file again, this time eliminating
the second load set and in the first load set changing the amplitude
of the initial buckling modal general imperfection from 0.050 to 0.0.)

mainsetup        table 20  p.58
pandaopt         (produces nasaortho2.OPM: abridged version in Table 78)  pp.229-230
change           table 79: purpose is to save the optimum design.  p.231

(Next, generate a BIGBOSOR4 model in which the part of the
cylindrical shell BETWEEN ADJACENT RINGS is investigated.
The cylindrical shell is modeled as part of a huge torus.
See Appendix 1 for how this is done. The PANDA2
processor called PANEL is used to generate a valid input
file for BIGBOSOR4. This file is called nasaortho2.ALL).

panel   table 80: purpose is to generate a BIGBOSOR4 huge torus model.  p.232
cp nasaortho2.ALL .../<bigbosor4workingspace> .
cd .../<bigbosor4workingspace>
bigbosor4log     (activate the bigbosor4 command set)
bigbosorall      (produces the nasaortho2.OUT file)
resetup          (input for resetup is in the top part of Table 81)  p.233 ~~234~~
bigrestart       (produces the bottom part of Table 81)  p.234
bosorplot        (produces Fig. 94) p.235
bosorplot        (produces Fig. 95) p.236
cleanup          (cleans up bigbosor4 files)
cd .../<panda2workingspace>

(Next, generate a BIGBOSOR4 model in which the wall properties of
the shell wall between adjacent rings are smeared out. The PANDA2
processor called PANEL2 is used. The BIGBOSOR4 model includes the
entire cylindrical shell. The rings are modeled as shell branches.)

panel2   table 82: purpose is to generate a BIGBOSOR4 model of shell.  p.237
cp nasaortho2.ALL .../<bigbosor4workingspace> .
cd .../<bigbosor4workingspace>
bigbosor4log     (activate the bigbosor4 command set)
bigbosorall      (produces nasaortho2.OUT. Abridged version in Table 83)  p.238
bosorplot        (produces Fig. 96: general buckling) p.239
bosorplot        (produces Fig. 97: inter-ring buckling) p.240
cleanup          (cleans up bigbosor4 files)
=========================================================================
```

No STAGS models were run for PART 3. This is left as an exercise for the student!

PART 1

Table 1 (2 pages) nasaortho.BEG

```
      n        $ Do you want a tutorial session and tutorial output?
 68.75000      $ Panel length normal to the plane of the screen, L1
 150.7960      $ Panel length in the plane of the screen, L2
      r        $ Identify type of stiffener along L1 (N,T,J,Z,R,A,C,G)
 4.000000      $ stiffener spacing, b
    1.333      $ width of stringer base, b2 (must be > 0, see Help)
    0.3        $ height of stiffener (type H for sketch), h
      n        $ Are the stringers cocured with the skin?
 1000000.      $ What force/(axial length) will cause web peel-off?
      n        $ Is the next group of layers to be a "default group" (12 layers!)?
      1        $ number of layers in the next group in Segment no.( 1)
      n        $ Can winding (layup) angles ever be decision variables?
      1        $ layer index (1,2,...), for layer no.( 1)
      y        $ Is this a new layer type?
0.1000000      $ thickness for layer index no.( 1)
      0        $ winding angle (deg.) for layer index no.( 1)
      1        $ material index (1,2,...) for layer index no.( 1)
      n        $ Any more layers or groups of layers in Segment no.( 1)
      n        $ Is the next group of layers to be a "default group" (12 layers!)?
      1        $ number of layers in the next group in Segment no.( 2)
      n        $ Can winding (layup) angles ever be decision variables?
      1        $ layer index (1,2,...), for layer no.( 1)
      n        $ Is this a new layer type?
      n        $ Any more layers or groups of layers in Segment no.( 2)
      n        $ Is the next group of layers to be a "default group" (12 layers!)?
      1        $ number of layers in the next group in Segment no.( 3)
      n        $ Can winding (layup) angles ever be decision variables?
      2        $ layer index (1,2,...), for layer no.( 1)
      y        $ Is this a new layer type?
0.1000000      $ thickness for layer index no.( 2)
      0        $ winding angle (deg.) for layer index no.( 2)
      2        $ material index (1,2,...) for layer index no.( 2)
      n        $ Any more layers or groups of layers in Segment no.( 3)
      1        $ choose external (0) or internal (1) stringers
      r        $ Identify type of stiffener along L2  (N, T, J, Z, R, A)
 4.000000      $ stiffener spacing, b
      0        $ width of ring base, b2 (zero is allowed)
0.3000000      $ height of stiffener (type H for sketch), h
      n        $ Are the rings cocured with the skin?
      n        $ Is the next group of layers to be a "default group" (12 layers!)?
      1        $ number of layers in the next group in Segment no.( 3)
      n        $ Can winding (layup) angles ever be decision variables?
      3        $ layer index (1,2,...), for layer no.( 1)
      y        $ Is this a new layer type?
0.1000000      $ thickness for layer index no.( 3)
      0        $ winding angle (deg.) for layer index no.( 3)
      3        $ material index (1,2,...) for layer index no.( 3)
      n        $ Any more layers or groups of layers in Segment no.( 3)
      1        $ choose external (0) or internal (1) rings
      y        $ Is the panel curved in the plane of the screen (Y for cyls.)?
 48.00000      $ Radius of curvature (cyl. rad.) in the plane of screen, R
      n        $ Is panel curved normal to plane of screen? (answer N)
      y        $ Is this material isotropic (Y or N)?
0.1100000E+08  $ Young's modulus,                   E( 1)
0.3000000      $ Poisson's ratio,                  NU( 1)
 4230769       $ transverse shear modulus,        G13( 1)
      0        $ Thermal expansion coeff.,      ALPHA( 1)
      0        $ residual stress temperature (positive),TEMPTUR( 1)
      n        $ Want to supply a stress-strain "curve" for this mat'l? (N)
      y        $ Want to specify  maximum effective stress ?
 70000.00      $ Maximum allowable effective stress in material type( 1)
      n        $ Do you want to take advantage of "bending overshoot"?
0.9500000E-01  $ weight density (greater than 0!) of material type( 1)
      n        $ Is lamina cracking permitted along fibers (type H(elp))?
      y        $ Is this material isotropic (Y or N)?
0.1100000E+08  $ Young's modulus,                   E( 2)
0.3000000      $ Poisson's ratio,                  NU( 2)
 4230769.      $ transverse shear modulus,        G13( 2)
      0        $ Thermal expansion coeff.,      ALPHA( 2)
      0        $ residual stress temperature (positive),TEMPTUR( 2)
      n        $ Want to supply a stress-strain "curve" for this mat'l? (N)
      y        $ Want to specify  maximum effective stress ?
 70000.00      $ Maximum allowable effective stress in material type( 2)
      n        $ Do you want to take advantage of "bending overshoot"?
0.9500000E-01  $ weight density (greater than 0!) of material type( 2)
      n        $ Is lamina cracking permitted along fibers (type H(elp))?
      y        $ Is this material isotropic (Y or N)?
0.1100000E+08  $ Young's modulus,                   E( 3)
```

I used three materials to be able to see where the max. σ is.

The starting design is the NASA test 1 configuration in the shell acreage remote from the weld lands.

```
0.3000000      $ Poisson's ratio,                    NU( 3)
 4230769.      $ transverse shear modulus,          G13( 3)
      0        $ Thermal expansion coeff.,        ALPHA( 3)
      0        $ residual stress temperature (positive),TEMPTUR( 3)
   n           $ Want to supply a stress-strain "curve" for this mat'l? (N)
 y             $ Want to specify  maximum effective stress ?
 70000.00      $ Maximum allowable effective stress in material type( 3)
   n           $ Do you want to take advantage of "bending overshoot"?
0.9500000E-01 $ weight density (greater than 0!) of material type( 3)
   n           $ Is lamina cracking permitted along fibers (type H(elp))?
      0        $ Prebuckling: choose 0=bending included; 2=use membrane theory
      1        $ Buckling: choose 0=simple support or 1=clamping
```

Input for BEGIN

This starting design is the NASA test specimen #1 (Wimp = 0.0 and ~~acreage~~ acreage remote from the weld lands)

Table 2 nasaortho.DEC

```
    n          $ Do you want a tutorial session and tutorial output?
    n          $ Want to use default for thickness decision variables (type H(elp)?
       1       $ Choose a decision variable (1,2,3,...)
 1.000000      $ Lower bound of variable no.( 1)
 10.00000      $ Upper bound of variable no.( 1)
    y          $ Any more decision variables (Y or N) ?
       3       $ Choose a decision variable (1,2,3,...)
0.1000000E-01  $ Lower bound of variable no.( 3)
 2.000000      $ Upper bound of variable no.( 3)
    y          $ Any more decision variables (Y or N) ?
       4       $ Choose a decision variable (1,2,3,...)
0.1000000E-01  $ Lower bound of variable no.( 4)
 1.000000      $ Upper bound of variable no.( 4)
    y          $ Any more decision variables (Y or N) ?
       5       $ Choose a decision variable (1,2,3,...)
0.1000000E-01  $ Lower bound of variable no.( 5)
 1.000000      $ Upper bound of variable no.( 5)
    y          $ Any more decision variables (Y or N) ?
       6       $ Choose a decision variable (1,2,3,...)
 1.000000      $ Lower bound of variable no.( 6)
 30.00000      $ Upper bound of variable no.( 6)
    y          $ Any more decision variables (Y or N) ?
       8       $ Choose a decision variable (1,2,3,...)
0.1000000E-01  $ Lower bound of variable no.( 8)
 2.000000      $ Upper bound of variable no.( 8)
    y          $ Any more decision variables (Y or N) ?
       9       $ Choose a decision variable (1,2,3,...)
0.1000000E-01  $ Lower bound of variable no.( 9)
 1.000000      $ Upper bound of variable no.( 9)
    n          $ Any more decision variables (Y or N) ?
    y          $ Any linked variables (Y or N) ?
       2       $ Choose a linked variable (1,2,3,...)
       1       $ To which variable is this variable linked?
0.3333000      $ Assign a value to the linking coefficient, C(j)
    n          $ Any other decision variables in the linking expression?
    n          $ Any constant C0 in the linking expression (Y or N)?
    n          $ Any more 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?
```

input for DECIDE

note: There is no real stringer base, that is, no real faying flange. Therefore, we set B2 equal to a value that maximizes the beneficial distribution of nodal points in the discretized single module skin/stringer model. $B2 = \frac{1}{3} B$ is the best relationship between B2 & B if there is no stringer faying flange.

Table 3 nasaortho.OPT

```
     n          $ Do you want a tutorial session and tutorial output?
 -2219.000      $ Resultant (e.g. lb/in) normal to the plane of screen, Nx( 1)
       0        $ Resultant (e.g. lb/in) in the plane of the screen,    Ny( 1)
       0        $ In-plane shear in load set A,                        Nxy( 1)
     n          $ Does the axial load vary in the L2 direction?
       0        $ Applied axial moment resultant (e.g. in-lb/in), Mx( 1)
       0        $ Applied hoop moment resultant (e.g. in-lb/in), My( 1)
     y          $ Want to include effect of transverse shear deformation?
       0        $ IQUICK = quick analysis indicator (0 or 1)
     y          $ Do you want to vary M for minimum local buckling load?
     n          $ Do you want to choose a starting M for local buckling?
     y          $ Do you want to perform a "low-axial-wavenumber" search?
 0.9990000      $ Factor of safety for general instability, FSGEN( 1)
 0.9990000      $ Factor of safety for panel (between rings) instability, FSPAN( 1)
 0.9990000      $ Minimum load factor for local buckling (Type H for HELP), FSLOC( 1)
  1.000000      $ Minimum load factor for stiffener buckling (Type H), FSBSTR( 1)
  1.000000      $ Factor of safety for stress, FSSTR( 1)
     y          $ Do you want "flat skin" discretized module for local buckling?
     n          $ Do you want wide-column buckling to constrain the design?
  0.000000      $ Resultant (e.g. lb/in) normal to the plane of screen, Nx0( 1)
  0.000000      $ Resultant (e.g. lb/in) in the plane of the screen,    Ny0( 1)
       0        $ Axial load applied along the (0=neutral plane), (1=panel skin)
  0.000000      $ Uniform applied pressure [positive upward. See H(elp)], p( 1)
  0.000000      $ Out-of-roundness, Wimpg1=(Max.diameter-Min.diam)/4, Wimpg1( 1)
  0.000000      $ Initial buckling modal general imperfection amplitude, Wimpg2( 1)
  0.000000      $ Initial buckling modal inter-ring imperfection amplitude,Wpan( 1)
 0.1000000E-06  $ Initial local imperfection amplitude (must be positive), Wloc( 1)
     n          $ Do you want PANDA2 to change imperfection amplitudes (see H(elp))?( 1)
     y          $ Do you want PANDA2 to find the general imperfection shape?( 1)
  1.000000      $ Maximum allowable average axial strain (type H for HELP)( 1)
     N          $ Is there any thermal "loading" in this load set (Y/N)?
     Y          $ Do you want a "complete" analysis (type H for "Help")?
     N          $ Want to provide another load set ?
     N          $ Do you want to impose minimum TOTAL thickness of any segment?
     N          $ Do you want to impose maximum TOTAL thickness of any segment?
     N          $ Do you want to impose minimum TOTAL thickness of any segment?
     N          $ Do you want to impose maximum TOTAL thickness of any segment?
     N          $ Use reduced effective stiffness in panel skin (H(elp), Y or N)?
       0        $ NPRINT= output index (-1=min. 0=good, 1=ok, 2=more, 3=too much)
       1        $ Index for type of shell theory (0 or 1 or 2), ISAND
     Y          $ Does the postbuckling axial wavelength of local buckles change?
     Y          $ Want to suppress general buckling mode with many axial waves?
     N          $ Do you want to double-check PANDA-type eigenvalues [type (H)elp]?
       1        $ Choose (0=transverse inextensional; 1=transverse extensional)
       1        $ Choose ICONSV = -1 or 0 or 1 or H(elp), ICONSV
       2        $ Choose type of analysis (ITYPE = 1 or 2 or 3 or 4 or 5)
     Y          $ Do you want to prevent secondary buckling (mode jumping)?
     N          $ Do you want to use the "alternative" buckling solution?
       5        $ How many design iterations permitted in this run (5 to 25)?
  1.000000      $ MAXMAR. Plot only those margins less than MAXMAR (Type H)
     N          $ Do you want to reset total iterations to zero (Type H)?
       1        $ Index for objective (1=min. weight, 2=min. distortion)
  1.000000      $ FMARG (Skip load case with min. margin greater than FMARG)
```

Wimp=0

Input for MAINSETUP
"Fixed" design (not optimization)

Wimp=0 now.

NASA test 1 specimen (assumed perfect)

Table 4 (2 pages) nasaortho.OPM (abridged) (Wimp = 0.0)

nasaortho.OPM (abridged, starting design, which is the NASA test article)

```
 ************************************************************
 CHAPTER 28 Present design, loading, and margins for the
            current load set and subcase. See Table 6 in
 Bushnell, D.
 "Optimization of an axially compressed ring and stringer
 stiffened cylindrical shell with a general buckling modal
 imperfection", AIAA Paper 2007-2216, 48th AIAA SDM Meeting,
 Honolulu, Hawaii, April 2007

 ANALYSIS: ITYPE=2;  IQUICK=0;  LOAD SET 1;  SUBCASE 1:
 LOADING: Nx, Ny, Nxy, Mx, My =  -2.22E+03 -2.22E-03  1.11E+01  0.00E+00  0.00E+00
          Nxo, Nyo, pressure  =   0.00E+00  0.00E+00  4.62E-05
 BUCKLING LOAD FACTORS FOR LOCAL BUCKLING FROM KOITER v. BOSOR4 THEORY:
  Local buckling load factor from KOITER theory =  1.2277E+00 (flat skin)
  Local buckling load factor from BOSOR4 theory =  1.2245E+00 (flat skin)
0
 MARGINS FOR CURRENT DESIGN: LOAD CASE NO. 1, SUBCASE NO. 1
 MAR. MARGIN
 NO.  VALUE              DEFINITION
 1  2.26E-01 Local buckling from discrete model-1.,M=1   axial halfwaves;FS=0.99
 2  2.29E-01 Local buckling from Koiter theory,M=1   axial halfwaves;FS=0.999
 3  2.41E+00 eff.stress:matl=1,SKN,Dseg=1,node=1,layer=1,z=-0.05; MID.;FS=1.
 4  2.32E+00 eff.stress:matl=2,STR,Dseg=3,node=11,layer=1,z=0.05; MID.;FS=1.
 5  3.23E-01 (m=1   lateral-torsional buckling load factor)/(FS)-1;FS=0.999
 6  2.05E-03 Inter-ring bucklng, discrete model, n=14  circ.halfwaves;FS=0.999
 7  2.41E+00 eff.stress:matl=1,SKN,Iseg=1,at:n=1,layer=1,z=-0.05;-MID.;FS=1.
 8  2.32E+00 eff.stress:matl=2,STR,Iseg=3,at:TIP,layer=1,z=0.;-MID.;FS=1.
 9  1.12E+01 eff.stress:matl=3,RNG,Iseg=3,at:TIP,layer=1,z=0.;-MID.;FS=1.
10 -1.18E-01 buck.(SAND);simp-support general buck;M=7;N=15;slope=0.;FS=0.999
11  9.17E-01 buck.(SAND);rolling with smear rings; M=25;N=1;slope=0.;FS=0.999
12  3.46E+01 buck.(SAND);rolling only of stringers;M=139;N=0;slope=0.;FS=1.4
13  5.36E+02 (Max.allowable ave.axial strain)/(ave.axial strain) -1; FS=1.
```

compare Fig. 9 STAGS

compare Fig. 1 BIGBOSOR4

compare Fig. 3, 4, 6

BIGBOSOR4 STAGS

```
 ************************************************************
 CHAPTER 28 Present design, loading, and margins for the
            current load set and subcase. See Table 6 in
 Bushnell, D.
 "Optimization of an axially compressed ring and stringer
 stiffened cylindrical shell with a general buckling modal
 imperfection", AIAA Paper 2007-2216, 48th AIAA SDM Meeting,
 Honolulu, Hawaii, April 2007

 ANALYSIS: ITYPE=2;  IQUICK=0;  LOAD SET 1;  SUBCASE 2:
 LOADING: Nx, Ny, Nxy, Mx, My =  -2.22E+03 -2.22E-03  1.11E+01  0.00E+00  0.00E+00
          Nxo, Nyo, pressure  =   0.00E+00  0.00E+00  4.62E-05
 BUCKLING LOAD FACTORS FOR LOCAL BUCKLING FROM KOITER v. BOSOR4 THEORY:
  Local buckling load factor from KOITER theory =  1.2237E+00 (flat skin)
  Local buckling load factor from BOSOR4 theory =  1.2230E+00 (flat skin)
0
 MARGINS FOR CURRENT DESIGN: LOAD CASE NO. 1, SUBCASE NO. 2
 MAR. MARGIN
 NO.  VALUE              DEFINITION
 1  2.24E-01 Local buckling from discrete model-1.,M=1   axial halfwaves;FS=0.99
 2  2.25E-01 Local buckling from Koiter theory,M=1   axial halfwaves;FS=0.999
 3  2.39E+00 eff.stress:matl=1,STR,Dseg=4,node=11,layer=1,z=0.05; RNGS;FS=1.
 4  2.43E+00 eff.stress:matl=2,STR,Dseg=3,node=1,layer=1,z=-0.05; RNGS;FS=1.
 5  3.19E-01 (m=1   lateral-torsional buckling load factor)/(FS)-1;FS=0.999
 6  2.47E-03 Inter-ring bucklng, discrete model, n=14  circ.halfwaves;FS=0.999
 7  2.40E+00 eff.stress:matl=1,SKN,Iseg=2,at:n=6,layer=1,z=0.05;-RNGS;FS=1.
 8  2.44E+00 eff.stress:matl=2,STR,Iseg=3,at:ROOT,layer=1,z=0.;-RNGS;FS=1.
 9  1.11E+01 eff.stress:matl=3,RNG,Iseg=3,at:TIP,layer=1,z=0.;-RNGS;FS=1.
10  9.11E-01 buck.(SAND);rolling with smear rings; M=25;N=1;slope=0.;FS=0.999
11  3.64E+01 buck.(SAND);rolling only of stringers;M=139;N=0;slope=0.;FS=1.4
12  5.34E+02 (Max.allowable ave.axial strain)/(ave.axial strain) -1; FS=1.
 ***********  ALL 1 LOAD SETS PROCESSED  ***********
 ****************************************************
```

starting design

SUMMARY OF INFORMATION FROM OPTIMIZATION ANALYSIS

VAR. NO.	DEC. VAR.	ESCAPE VAR.	LINK. VAR.	LINKED TO	LINKING CONSTANT	LOWER BOUND	CURRENT VALUE	UPPER BOUND	DEFINITION
1	Y	N	N	0	0.00E+00	1.00E+00	4.0000E+00	1.00E+01	B(STR):stiffener s» pacing, b: STR seg=NA, layer=NA
2	N	N	Y	1	3.33E-01	0.00E+00	1.3330E+00	0.00E+00	B2(STR):width of st»

Table 4 (p. 2 of 2)

```
ringer base, b2 (must be > 0, se
e
   3   Y     N     N      0     0.00E+00   1.00E-02  3.0000E-01   2.00E+00        H(STR):height of s»
tiffener (type H for sketch), h:

   4   Y     Y     N      0     0.00E+00   1.00E-02  1.0000E-01   1.00E+00    T(1 )(SKN):thickness f»
or layer index no.(1 ): SKN seg=
1
   5   Y     Y     N      0     0.00E+00   1.00E-02  1.0000E-01   1.00E+00    T(2 )(STR):thickness f»
or layer index no.(2 ): STR seg=3
   6   Y     N     N      0     0.00E+00   1.00E+00  4.0000E+00   3.00E+01        B(RNG):stiffener s»
pacing, b: RNG seg=NA, layer=NA
   7   N     N     N      0     0.00E+00   0.00E+00  0.0000E+00   0.00E+00       B2(RNG):width of ri»
ng base, b2 (zero is allowed): RN
   8   Y     N     N      0     0.00E+00   1.00E-02  3.0000E-01   2.00E+00        H(RNG):height of s»
tiffener (type H for sketch), h:
   9   Y     Y     N      0     0.00E+00   1.00E-02  1.0000E-01   1.00E+00    T(3 )(RNG):thickness f»
or layer index no.(3 ): RNG seg=3
0
   CURRENT VALUE OF THE OBJECTIVE FUNCTION:
 VAR. STR/ SEG. LAYER    CURRENT
 NO.  RNG  NO.   NO.      VALUE              DEFINITION
            0     0     1.133E+02   WEIGHT OF THE ENTIRE PANEL

  TOTAL WEIGHT OF SKIN                                =    9.8489E+01
  TOTAL WEIGHT OF SUBSTIFFENERS                       =    0.0000E+00
  TOTAL WEIGHT OF STRINGERS                           =    7.3866E+00
  TOTAL WEIGHT OF RINGS                               =    7.3866E+00
  SPECIFIC WEIGHT (WEIGHT/AREA) OF STIFFENED PANEL=        1.0925E-02
 IN ORDER TO AVOID FALSE CONVERGENCE OF THE DESIGN, BE SURE TO
 RUN  PANDAOPT  MANY TIMES DURING AN OPTIMIZATION. INSPECT THE
 nasaortho.OPP  FILE AFTER EACH OPTIMIZATION RUN. OR BETTER YET,
 RUN SUPEROPT.
 ******************** END OF nasaortho.OPM FILE *****************
```

Starting design

NASA test 1 Specimen (Wimp = 0.0)

Output from PANDAOPT for "fixed" design (ITYPE = 2 in *.OPT file)

Table 5 nasaortho.PAN

```
    n          $ Do you want a tutorial session and tutorial output?
 76.00000      $ Panel length in the plane of the screen, L2
       0       $ Enter control (0 or 1) for stringers at panel edges
       2       $ Enter control (1=sym; 2=s.s.) for boundary condition
       1       $ Enter ILOCAL=0 for panel buckling; 1 for local buckling, ILOCAL
       1       $ Number of halfwaves in the axial direction [see H(elp)],NWAVE
       3       $ How many eigenvalues (get at least 3) do you want?
```

Input for PANEL
(produces an input file, nasaortho.ALL, for BIGBOSOR4)

(huge "torus" model) = See Figs 1 & 2

In this huge "torus" model the axial length of cylindrical shell being modeled is the length between adjacent rings.

NOTE!

Table 6 input & output resetup / bigrestart

nasaortho.RES (input data for BIGBOSOR4 processor called resetup):

```
     N         $ Do you want response at resonance to base excitation?
        1      $ NPRT = output options (1=minimum, 2=medium, 3=maximum)
        0      $ ISTRES= output control (0=resultants, 1=sigma, 2=epsilon)
        0      $ NLAST = plot options  (-1=none, 0=geometry, 1=u,v,w)
     N         $ Are there any regions for which you want expanded plots?
      100      $ NOB   = starting number of circ. waves (buckling analysis)
      100      $ NMINB = minimum number of circ. waves  (buckling analysis)
      100      $ NMAXB = maximum number of circ. waves  (buckling analysis)
      100      $ INCRB = increment in number of circ. waves (buckling)
       20      $ NVEC  = number of eigenvalues for each wave number
     Y         $ Do you want to suppress listing the prebuckling resultants?
     Y         $ Do you want to suppress listing the buckling modes?
-----------------------------------------------------------------------------
```

nasaortho.OUT (abridged output from BIGBOSOR4 processor called bigrestart):

```
 BUCKLING LOADS FOLLOW
 CIRCUMFERENTIAL WAVE NUMBER, N =      100

 EIGENVALUES =
    1.30581E+00    1.32068E+00    1.33468E+00    1.34753E+00    1.35939E+00    1.36976E+00    1.»
37915E+00
  like interring
     buckling

 EIGENVALUES =
    1.38739E+00    1.39542E+00    1.39933E+00    1.40807E+00    1.42150E+00    1.42104E+00    1.»
43818E+00
                                   sort of like
                                  local buckling

 EIGENVALUES =
    1.45860E+00    1.48449E+00    1.51915E+00    1.57029E+00    2.38579E+00    2.55557E+00
```

BIGBOSOR4 results

corresponds to m=1 axial halfwaves between rings (see Appendix 1)

BIGBOSOR4 huge "torus" model (Figs 1 & 2)

resetup & bigrestart are useful BIGBOSOR4 processors. You can gets lots of eigenvalues without much output.

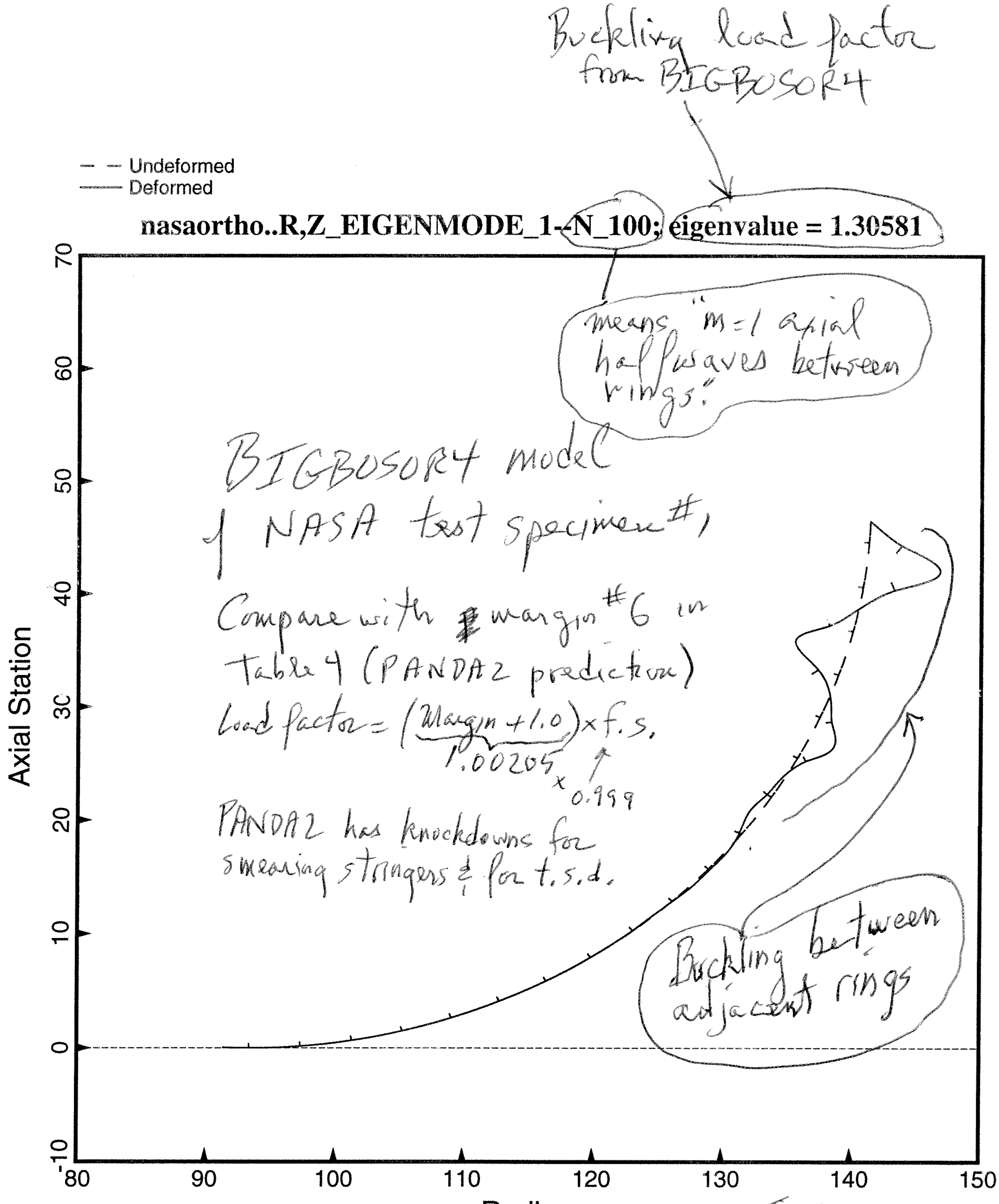
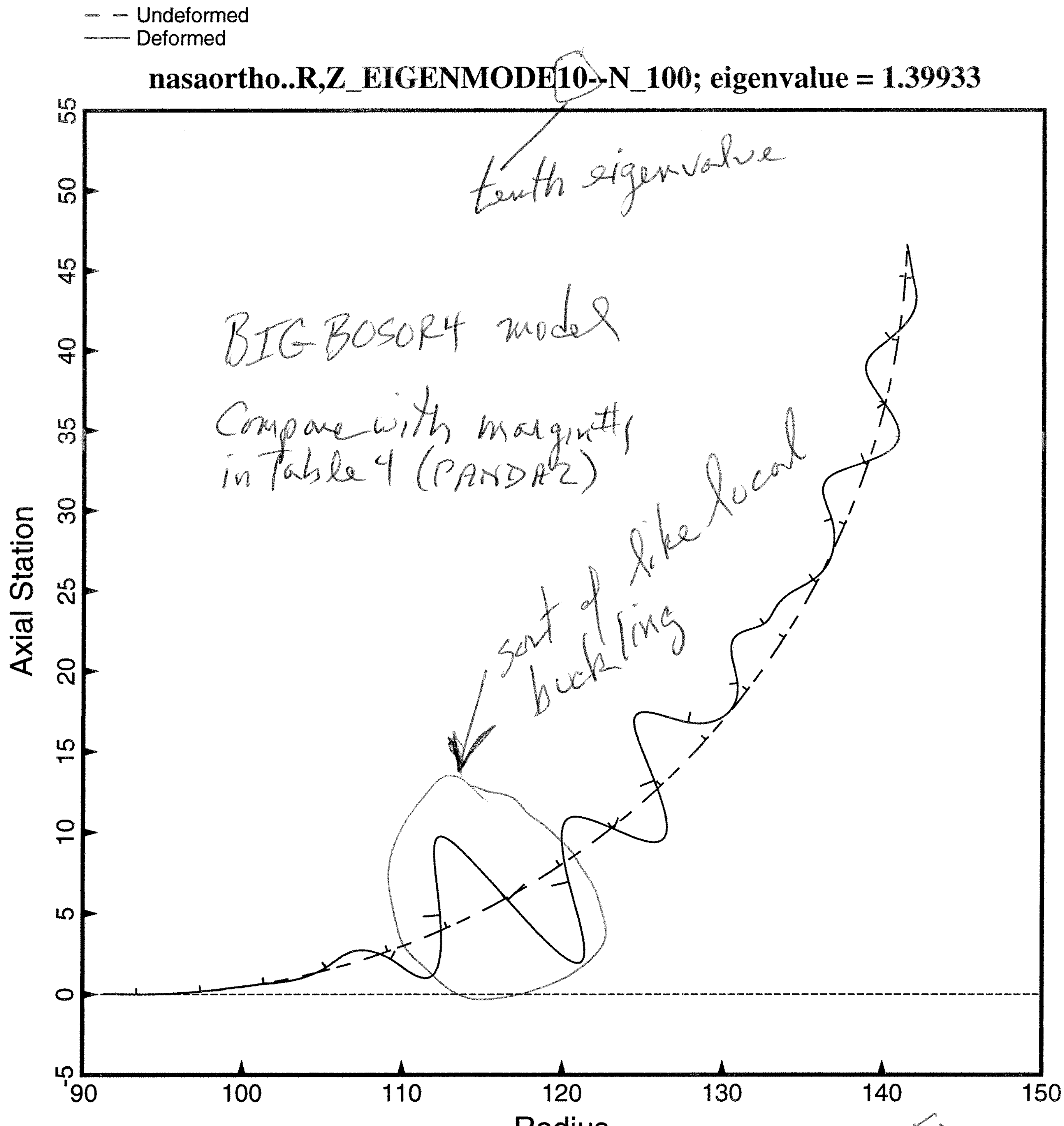

Buckling load factor from BIGBOSOR4
Undeformed
Deformed
nasaortho..R,Z_EIGENMODE_1--N_100; eigenvalue = 1.30581
means "m=1 axial halfwaves between rings"
BIGBOSOR4 model of NASA test specimen #1
Compare with margin #6 in Table 4 (PANDA2 prediction)
Load factor = (Margin + 1.0) × f.s.
1.00205
× 0.999
PANDA2 has knockdowns for smearing stringers & for t.s.d.
Buckling between adjacent rings
Axial Station
Radius
-10
0
10
20
30
40
50
60
70
80
90
100
110
120
130
140
150

Fig. 1



Undeformed
Deformed
nasaortho..R,Z_EIGENMODE10--N_100; eigenvalue = 1.39933
tenth eigenvalue
BIG BOSOR4 model
Compare with margins in Table 4 (PANDA2)
sort of like local buckling
Axial Station
Radius
55
50
45
40
35
30
25
20
15
10
5
0
-5
90
100
110
120
130
140
150

Fig. 2

Table 7 input to PANEL2: nasaortho.PAN

```
      n          $ Do you want a tutorial session and tutorial output?
 68.00000        $ Length of the ring-stiffened cylindrical shell, L1
        1        $ Choose BOSOR4 model: INDIC=1 or INDIC=4; INDIC
    -2219        $ Axial resultant Nx in Load Set A, Nx
        0        $ Axial resultant Nxo in Load Set B, Nxo
        0        $ Normal pressure p
        1        $ IABP = 1 if pressure in Load Set A; IABP=0 otherwise. IABP
        3        $ Enter control (1=sym; 2=s.s.; 3=clamp) for buckling b.c.
        2        $ Starting number of circumferential waves [see H(elp)],N0B
       20        $ Ending number of circumferential waves [see H(elp)],NMAXB
        1        $ Increment in number of circumferential waves, INCRB
        1        $ Number of eigenvalues for each circ. wavenumber, NVEC
```

Input to PANEL2:
BIGBOSOR4 Model of entire shell with smeared stringers. Rings are branched shell segments,
(See Fig. 3)

Table 8 output from BIGBOSOR4

nasaortho.OUT (abridged output from bigbosorall

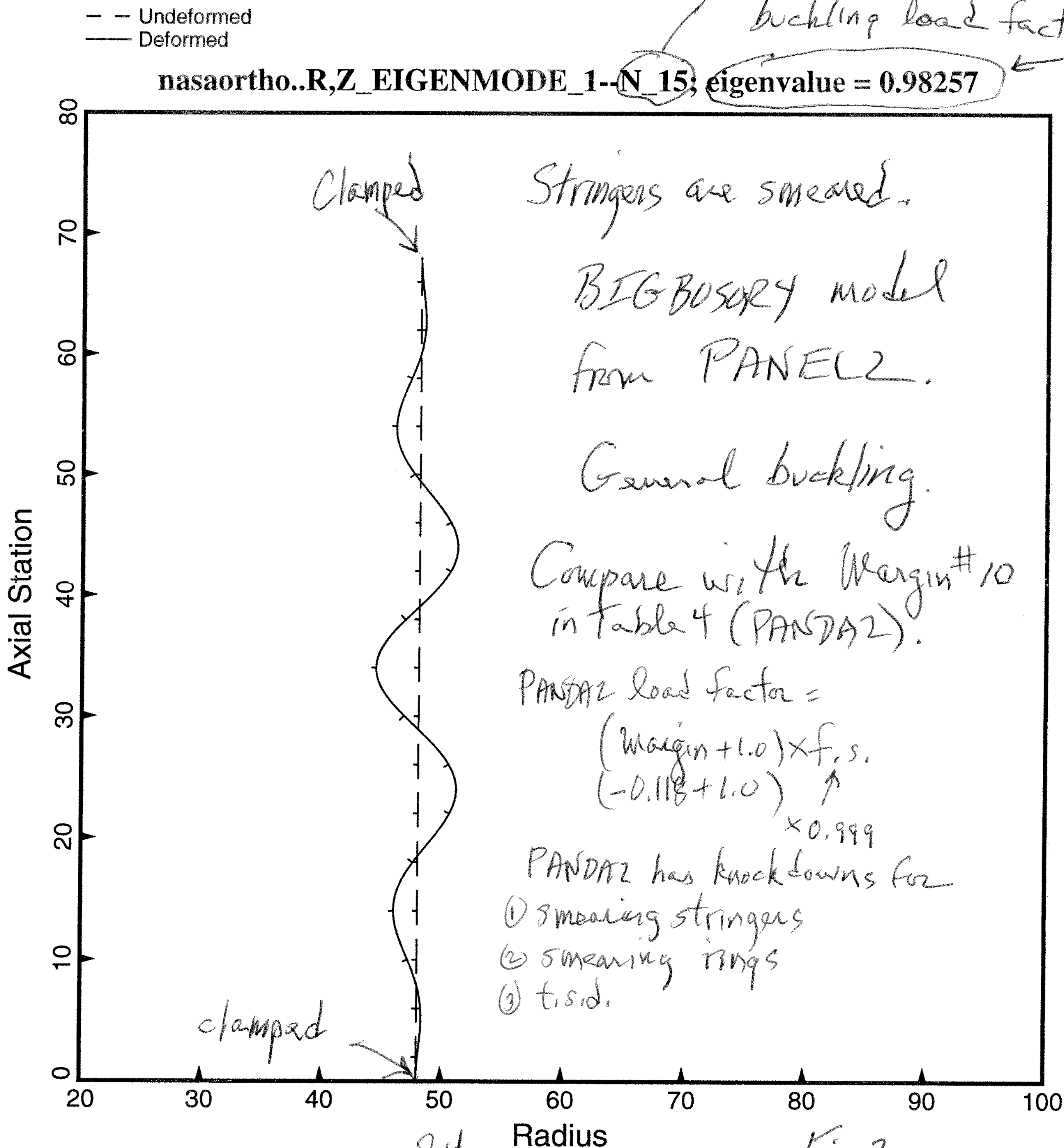
```
 ***** EIGENVALUES AND MODE SHAPES *****
  EIGENVALUE(CIRC. WAVES)
 =======================================
     1.5089E+00(   2)
     1.4948E+00(   3)
     1.4751E+00(   4)
     1.4495E+00(   5)
     1.4176E+00(   6)
     1.3805E+00(   7)
     1.3373E+00(   8)
     1.2880E+00(   9)
     1.2323E+00(  10)
     1.1701E+00(  11)
     1.0965E+00(  12)
     1.0327E+00(  13)
     9.9608E-01(  14)
     9.8257E-01(  15) <--critical value
     9.8771E-01(  16)
     1.0087E+00(  17)
     1.0406E+00(  18)
     1.0849E+00(  19)
     1.1391E+00(  20)
 =======================================
```

(See next figure)

NASA test 1 configuration

15 circumferential waves

buckling load factor



Stringers are smeared.

BIGBOSOR4 model from PANEL2.

General buckling.

Compare with the Margin #10 in Table 4 (PANDA2).

PANDA2 load factor =
(Margin + 1.0) × f.s.
(−0.118 + 1.0) × 0.999

PANDA2 has knockdowns for
① smearing stringers
② smearing rings
③ t.s.d.

Fig. 3

Table 9 nasaortho.STG

NASA test 1 configuration

```
    n        $ Do you want a tutorial session and tutorial output?
       1     $ Choose type of STAGS analysis (1,3,4,5,6),INDIC
       0     $ Restart from ISTARTth load step (0=1st nonlinear soln), ISTART
 1.000000    $ Local buckling load factor from PANDA2, EIGLOC
    y        $ Are the dimensions in this case in inches?
       0     $ Nonlinear (0) or linear (1) kinematic relations?, ILIN
       0     $ Type 1 for closed (360-deg) cyl. shell, 0 otherwise, ITOTAL
 68.00000    $ X-direction length of the STAGS model of the panel: XSTAGS
 148.785     $ Panel length in the plane of the screen, L2
    y        $ Is the nodal point spacing uniform along the stringer axis?
    101      $ Number of nodes in the X-direction: NODEX
   -2219     $ Resultant (e.g. lb/in) normal to the plane of screen, Nx
       0     $ Resultant (e.g. lb/in) in the plane of the screen,    Ny
       0     $ In-plane shear in load set A,                        Nxy
       0     $ Normal pressure in STAGS model in Load Set A, p
       0     $ Resultant (e.g. lb/in) normal to the plane of screen, Nx0
       0     $ Resultant (e.g. lb/in) in the plane of the screen,    Ny0
       0     $ Normal pressure in STAGS model in Load Set B, p0
 1.000000    $ Starting load factor for Load System A, STLD(1)
 0.000000    $ Load factor increment for Load System A, STEP(1)
 1.000000    $ Maximum load factor for Load System A, FACM(1)
       0     $ Starting load factor for Load System B, STLD(2)
       0     $ Load factor increment for Load System B, STEP(2)
       0     $ Maximum load factor for Load System B, FACM(2)
       1     $ How many eigenvalues do you want? NEIGS
    480      $ Choose element type (410 or 411 or 480) for panel skin
    n        $ Have you obtained buckling modes from STAGS for this case?
     75      $ Number of stringers in STAGS model of 360-deg. cylinder
     18      $ Number of rings in the STAGS model of the panel
    y        $ Are there rings at the ends of the panel?
       2     $ Number of finite elements between adjacent stringers
       2     $ Number of finite elements between adjacent rings
       3     $ Stringer model: 1 or 2 or 3 or 4 or 5(Type H(elp))
       3     $ Ring model: 1 or 2 or 3 or 4 or 5 (Type H(elp))
      -1     $ Reference surface of cyl: 1=outer, 0=middle, -1=inner
    n        $ Do you want to use fasteners (they are like rigid links)?
note y       $ Are the stringers to be "smeared out"?
    n        $ Are the rings to be "smeared out"?
       3     $ Number of nodes over height of stiffener webs, NODWEB
       5     $ Number of nodes over width of stringer flange, NDFLGS
       5     $ Number of nodes over width of ring flange, NDFLGR
    n        $ Do you want stringer(s) with a high nodal point density?
    n        $ Do you want ring(s) with a high nodal point density?
    n        $ Is there plasticity in this STAGS model?
    y        $ Do you want to use the "least-squares" model for torque?
    y        $ Is stiffener sidesway permitted at the panel edges?
    n        $ Do you want symmetry conditions along the straight edges?
note → 1     $ Edges normal to screen (0) in-plane deformable; (1) rigid
```

close to 180° (37 stringer spacings at 4.02124" per spacing)

almost full axial length of the shell (17 ring spacings of 4" each)

Input for STAGSUNIT

STAGSUNIT produces STAGS input files, nasaortho.bin & nasaortho.inp

Table 10 nasaortho.pin

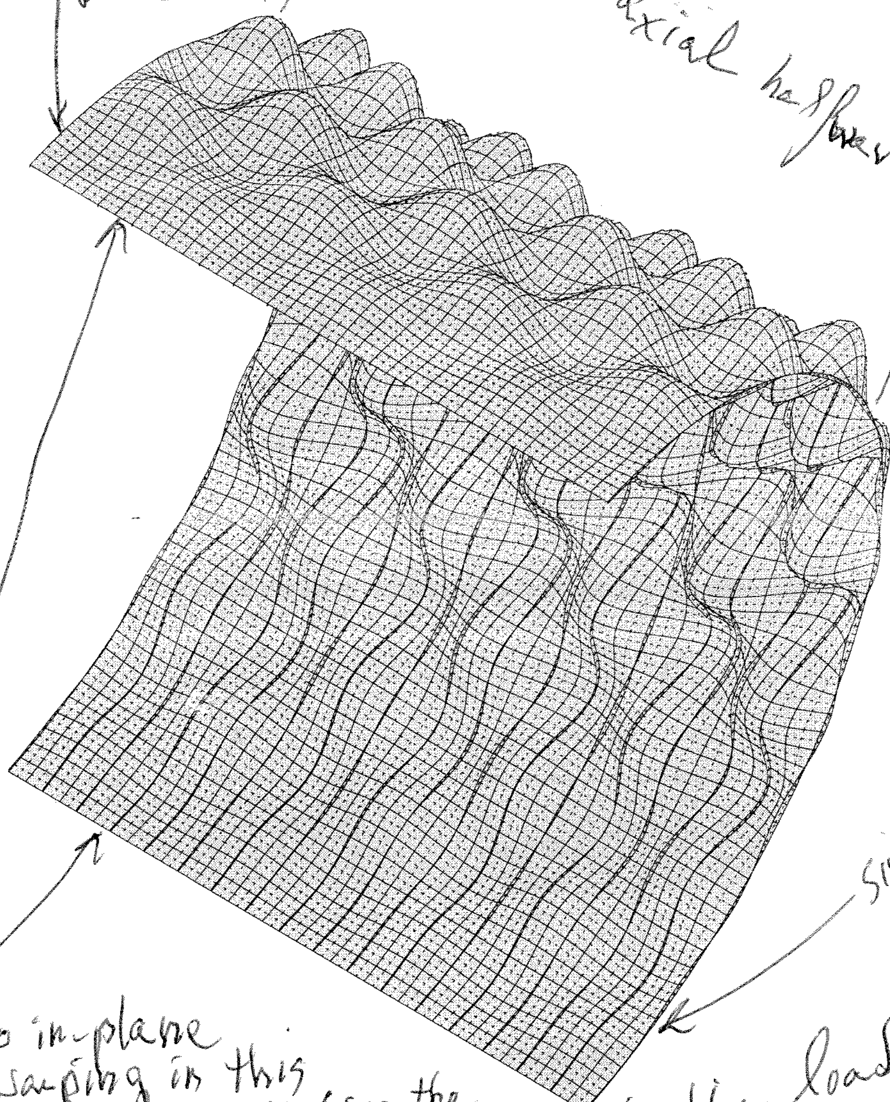
```
linear buckling of perfect shell from STAGS
  1  0  1  0  $PL-2  NPLOT,IPREP,IPRS,KDEV
     1     0     4     0     1  $PL-3  KPLOT,NUNIT,ITEM,STEP,MODE
    0.0    3  $PL-5  DSCALE,NROTS
  1    -35.84    $PL-6  IROT,ROT
  2    180.14    $PL-6  IROT,ROT
  3     35.63    $PL-6  IROT,ROT
```

Input for STAGS processor called STAPL

STAGS results: General buckling mode, NASA test 1 configuration

simply-supported along curved edges

Seven axial halfwaves



The general buckling mode agrees with PANDA2.

simply supported along the curved edges.

no in-plane warping in this particular case (see the last line in Table 9)

linear buckling load factor. Compare with BIGBOSOR4 (Fig. 3) Compare with PANDA2 (Margin #10 in Table 4)

solution scale = 0.6648E+01

$\boxed{\text{mode 1, pcr = 0.10019E+01}}$

step 0 eigenvector deformed geometry

linear buckling of perfect shell from STAGS

Θ x -35.84
Θ y -179.86
Θ z 35.63

1.761E+01

x y z

Fig. 4

Table11 nasaortho.pin

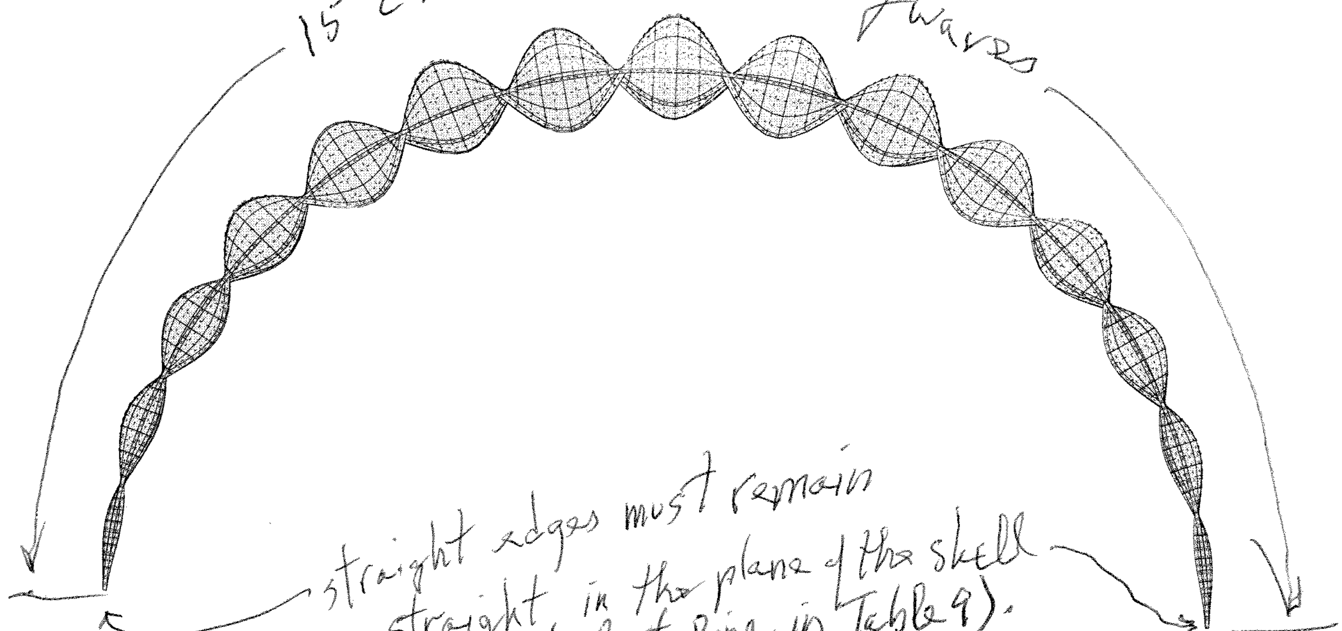
```
linear buckling of perfect shell from STAGS
  1  0  1  0  $PL-2  NPLOT,IPREP,IPRS,KDEV
     1     0     4     0     1  $PL-3  KPLOT,NUNIT,ITEM,STEP,MODE
    0.0   3  $PL-5  DSCALE,NROTS
  1      0.00    $PL-6  IROT,ROT
  2     90.00    $PL-6  IROT,ROT
  3      0.00    $PL-6  IROT,ROT
```

Input for STAGS processor, STAPL

STAGS result

The general buckling mode agrees with PANDA2 & BIGBOSOR4.

15 circumferential halfwaves



straight edges must remain straight in the plane of the shell (see the last line in Table 9).

solution scale = 0.4792E+01
mode 1, $\boxed{\text{pcr} = 0.10019\text{E}+01}$ general buckling
step 0 eigenvector deformed geometry
linear buckling of perfect shell from STAGS

Θ x 0.00
Θ y 90.00
Θ z 0.00

y
x z

1.597E+01

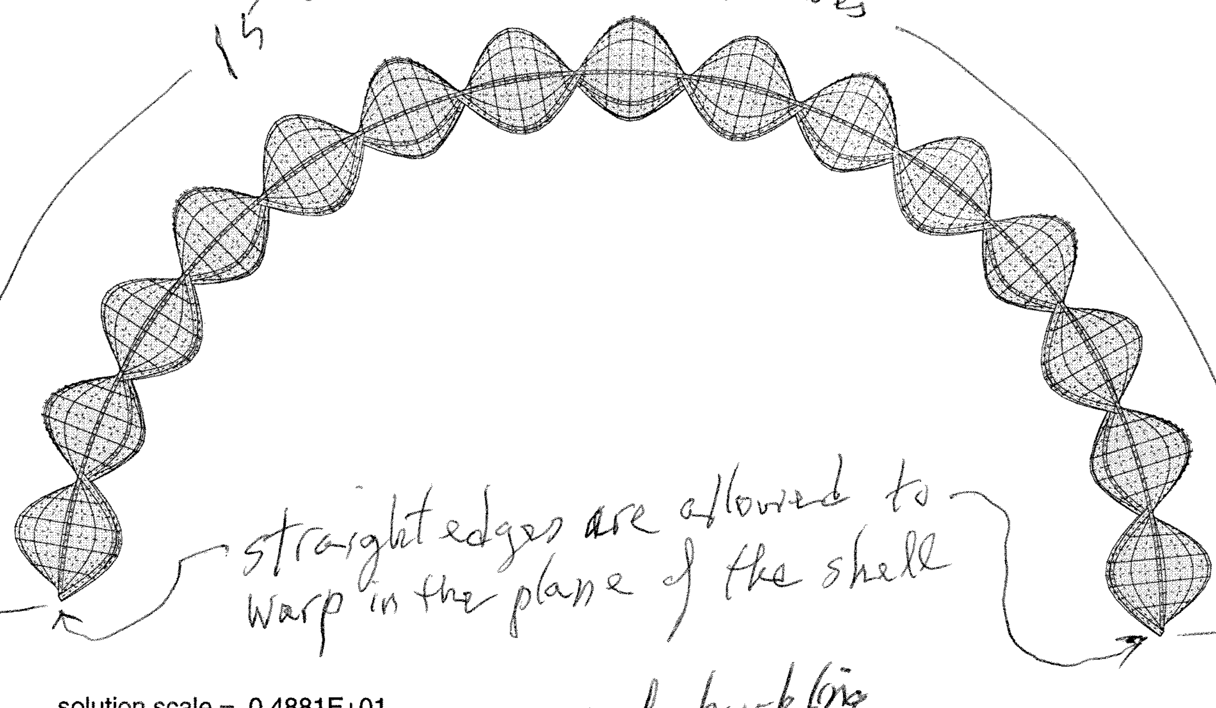
Fig. 5

STAGS result: General buckling.

Compare with Fig. 3 (BIGBOSOR4)
Compare with Margin #10 in Table 4 (PANDA2)
PANDA2 load factor = (Margin + 1.0) x f.s.

-0.118 0.999

15 circumferential halfwaves



straight edges are allowed to warp in the plane of the shell

solution scale = 0.4881E+01
mode 1, $\boxed{\text{pcr = 0.99094E+00}}$ general buckling
step 0 eigenvector deformed geometry
linear buckling of perfect shell from STAGS

Θ x 0.00
Θ y 90.00
Θ z 0.00

y
x z

1.597E+01

Fig. 6

Table 12 nasaortho. STG

```
 n          $ Do you want a tutorial session and tutorial output?
    1       $ Choose type of STAGS analysis (1,3,4,5,6),INDIC
    0       $ Restart from ISTARTth load step (0=1st nonlinear soln), ISTART
1.000000    $ Local buckling load factor from PANDA2, EIGLOC
 y          $ Are the dimensions in this case in inches?
    0       $ Nonlinear (0) or linear (1) kinematic relations?, ILIN
    0       $ Type 1 for closed (360-deg) cyl. shell, 0 otherwise, ITOTAL
12.0        $ X-direction length of the STAGS model of the panel: XSTAGS
12.0        $ Panel length in the plane of the screen, L2
 y          $ Is the nodal point spacing uniform along the stringer axis?
  101       $ Number of nodes in the X-direction: NODEX
 -2219      $ Resultant (e.g. lb/in) normal to the plane of screen, Nx
    0       $ Resultant (e.g. lb/in) in the plane of the screen,    Ny
    0       $ In-plane shear in load set A,                         Nxy
    0       $ Normal pressure in STAGS model in Load Set A, p
    0       $ Resultant (e.g. lb/in) normal to the plane of screen, Nx0
    0       $ Resultant (e.g. lb/in) in the plane of the screen,    Ny0
    0       $ Normal pressure in STAGS model in Load Set B, p0
1.000000    $ Starting load factor for Load System A, STLD(1)
0.000000    $ Load factor increment for Load System A, STEP(1)
1.000000    $ Maximum load factor for Load System A, FACM(1)
    0       $ Starting load factor for Load System B, STLD(2)
    0       $ Load factor increment for Load System B, STEP(2)
    0       $ Maximum load factor for Load System B, FACM(2)
    1       $ How many eigenvalues do you want? NEIGS
  480       $ Choose element type (410 or 411 or 480) for panel skin
 n          $ Have you obtained buckling modes from STAGS for this case?
   75       $ Number of stringers in STAGS model of 360-deg. cylinder
    4       $ Number of rings in the STAGS model of the panel
 y          $ Are there rings at the ends of the panel?
   10       $ Number of finite elements between adjacent stringers
   10       $ Number of finite elements between adjacent rings
    3       $ Stringer model: 1 or 2 or 3 or 4 or 5(Type H(elp))
    3       $ Ring model: 1 or 2 or 3 or 4 or 5 (Type H(elp))
   -1       $ Reference surface of cyl: 1=outer, 0=middle, -1=inner
 n          $ Do you want to use fasteners (they are like rigid links)?
 n          $ Are the stringers to be "smeared out"?
 n          $ Are the rings to be "smeared out"?
    5       $ Number of nodes over height of stiffener webs, NODWEB
    5       $ Number of nodes over width of stringer flange, NDFLGS
    5       $ Number of nodes over width of ring flange, NDFLGR
 n          $ Do you want stringer(s) with a high nodal point density?
 n          $ Do you want ring(s) with a high nodal point density?
 n          $ Is there plasticity in this STAGS model?
 y          $ Do you want to use the "least-squares" model for torque?
 y          $ Is stiffener sidesway permitted at the panel edges?
 n          $ Do you want symmetry conditions along the straight edges?
    0       $ Edges normal to screen (0) in-plane deformable; (1) rigid
```

note

3 stringer bays X 3 ring bays

with stringer spacing = ring spacing = 4.0"

Input for STAGSUNIT

NASA test 1 configuration

Table 13 nasaortho.pin

```
linear buckling of perfect shell from STAGS
  1  0  0  0   $PL-2  NPLOT,IPREP,IPRS,KDEV
     1    0      4      0      1  $PL-3   KPLOT,NUNIT,ITEM,STEP,MODE
    0.0    3   $PL-5  DSCALE,NROTS
  1    -35.84    $PL-6  IROT,ROT
  2   180.14    $PL-6  IROT,ROT
  3     35.63    $PL-6  IROT,ROT
```

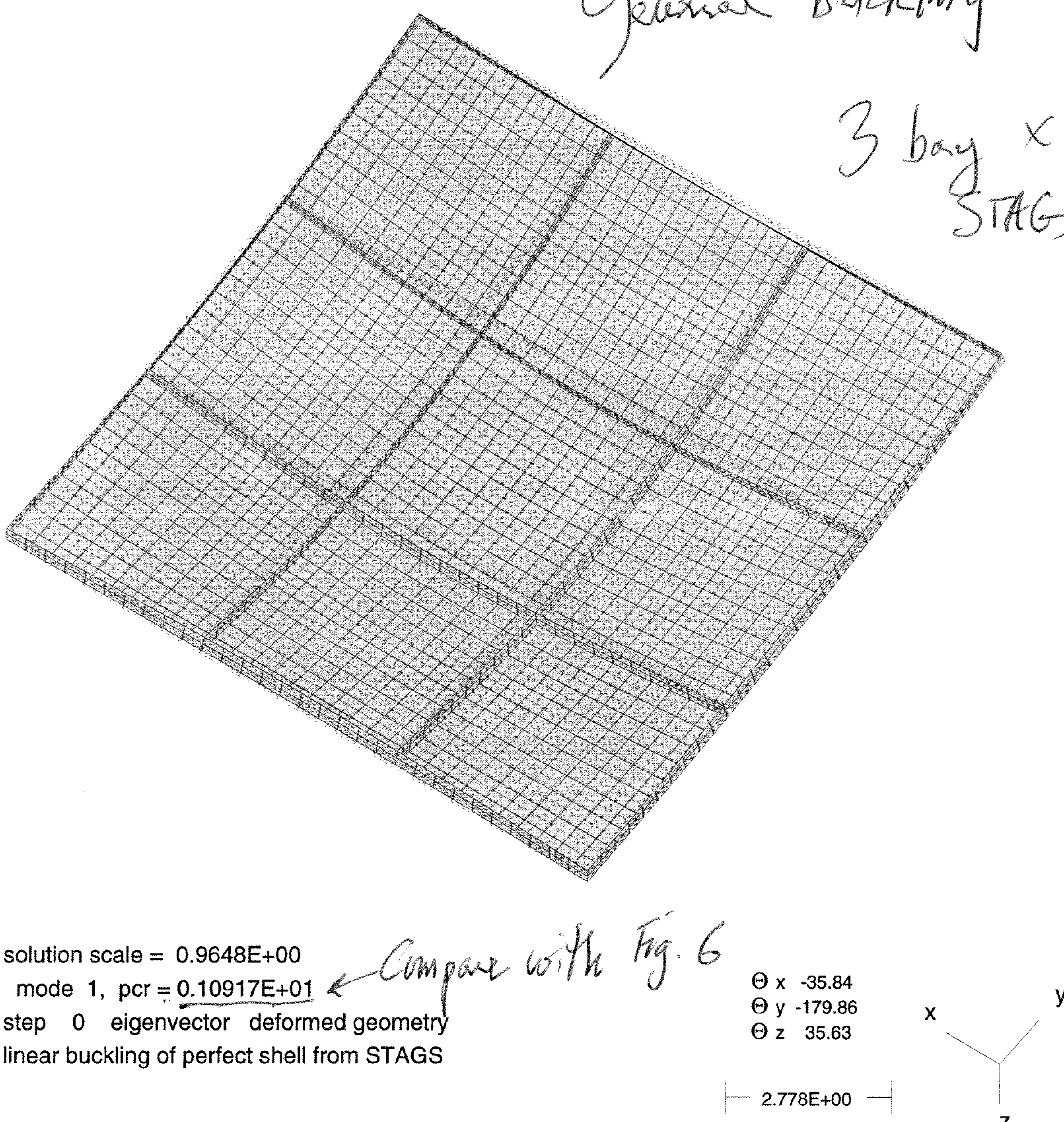
plot both undeformed & deformed

Input for STAGS processor, STAPL

STAGS result
NASA test 1 configuration

General buckling

3 bay x 3 bay
STAGS model.



solution scale = 0.9648E+00
mode 1, pcr = 0.10917E+01 ← Compare with Fig. 6
step 0 eigenvector deformed geometry
linear buckling of perfect shell from STAGS

Fig. 7

Table 14 nasaortho.bin

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

taken from the previous figure.

to try to find a local buckling mode.

Input file for STAGS

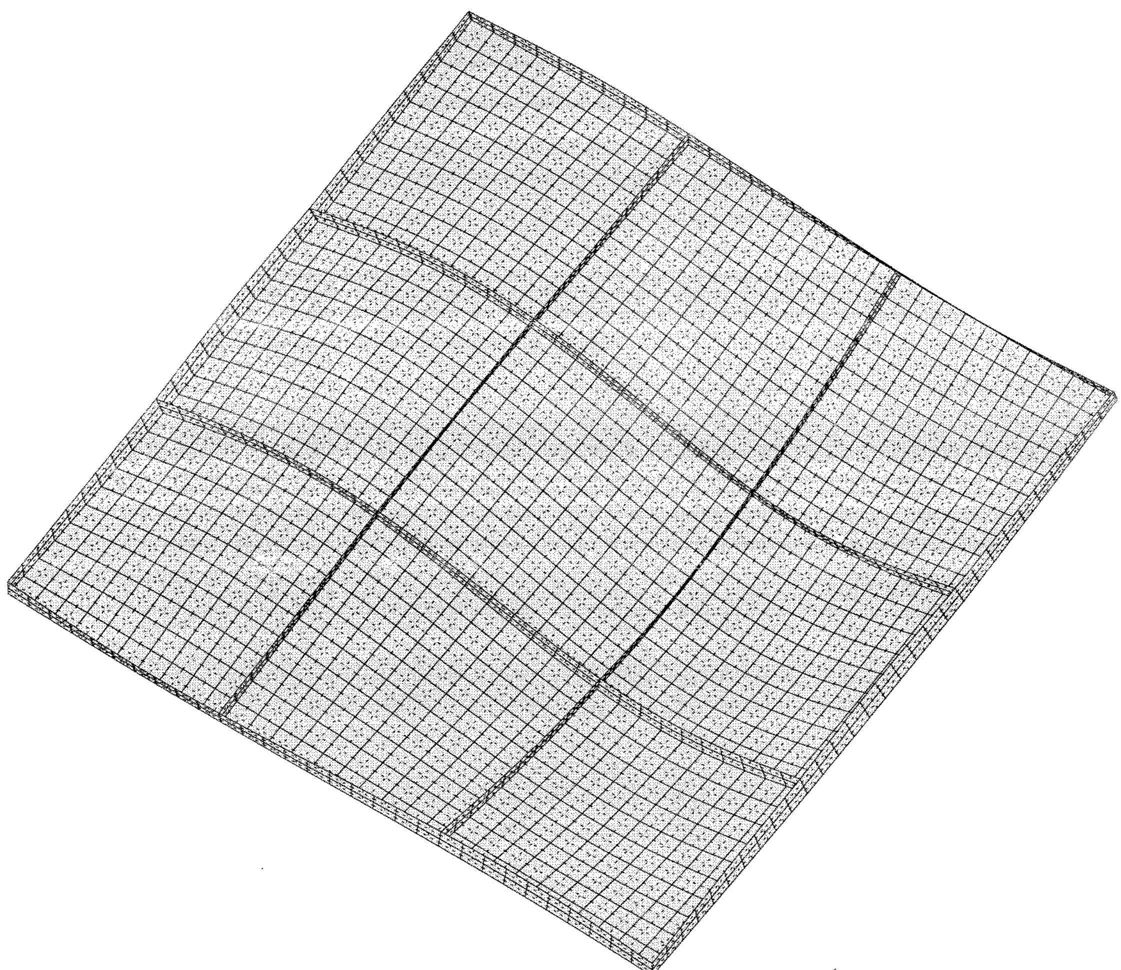
Find more linear buckling modes

Table 15 output from STAGS

nasaortho.out2 (abridged output from STAGS)

```
 CONVERGENCE HAS BEEN OBTAINED FOR EIGENVALUES  1 THROUGH    4
                        CRITICAL LOAD FACTOR COMBINATION
   NO.     EIGENVALUE    LOAD SYSTEM A  LOAD SYSTEM B     @DOF
     1   1.091717E+00   1.091717E+00   0.000000E+00    11222
     2   1.142530E+00   1.142530E+00   0.000000E+00     5334
     3   1.305781E+00   1.305781E+00   0.000000E+00    18468 ← 1st local mode
     4   1.346507E+00   1.346507E+00   0.000000E+00     3754
```

STAGS result:
another general buckling mode



general buckling mode.

solution scale = 0.9646E+00
mode 2, $\boxed{\text{pcr} = 0.11425\text{E}+01}$
step 0 eigenvector deformed geometry
linear buckling of perfect shell from STAGS

Θ x -35.84
Θ y -179.86
Θ z 35.63

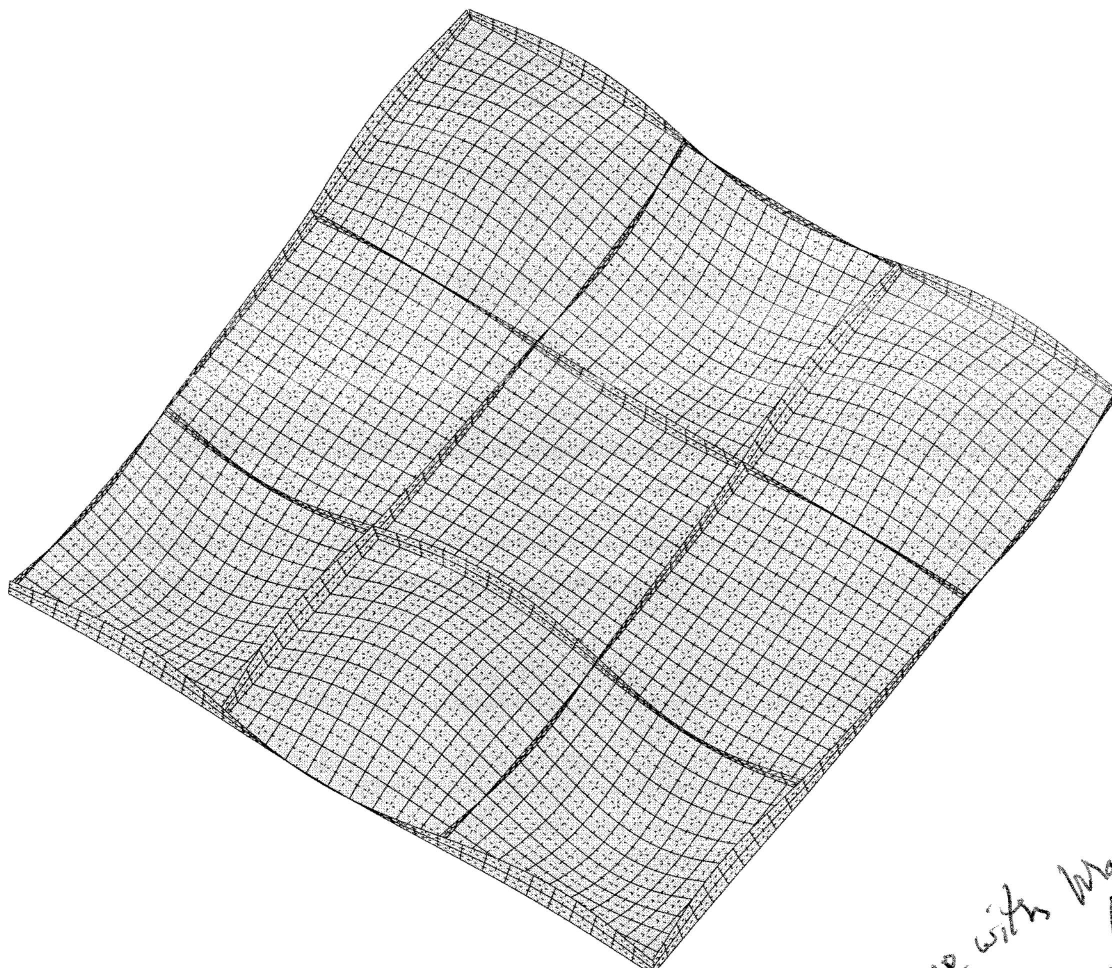
x y z

2.778E+00

Fig. 8

STAGS result

NASA test1 configuration



solution scale = 0.9379E+00

mode 3, pcr = 0.13058E+01 ← local buckling. Compare with Margin #1 in Table 4 (PANDA2)

(Margin+1.) × f.s. = load factor

(0.226 + 1.) × 0.999 =

step 0 eigenvector deformed geometry

linear buckling of perfect shell from STAGS

Θ x -35.84
Θ y -179.86
Θ z 35.63

2.778E+00

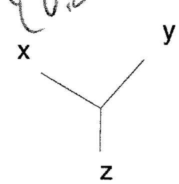


Fig. 9

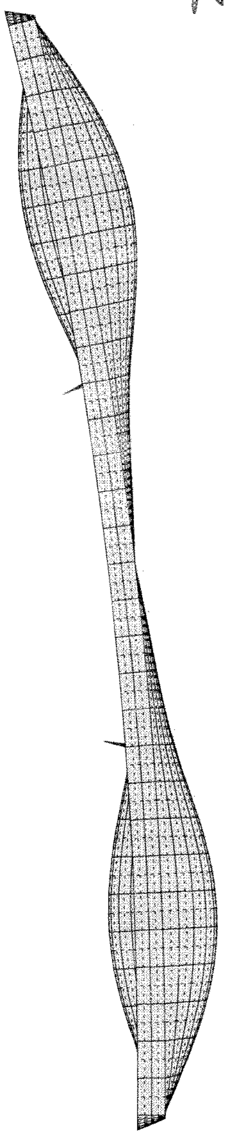
Table 16 nasaortho.pin

```
linear buckling of perfect shell from STAGS
  1  0  1  0  $PL-2  NPLOT,IPREP,IPRS,KDEV
     1     0     4     0     3  $PL-3  KPLOT,NUNIT,ITEM,STEP,MODE
    0.0    3  $PL-5  DSCALE,NROTS
  1    0.00   $PL-6  IROT,ROT
  2    90.0   $PL-6  IROT,ROT
  3     0.0   $PL-6  IROT,ROT
```

Input for STAPL

STAGS result
local buckling.

NASA Test 1 configuration



End view. Same
mode as previous figure.

local buckling

solution scale = 0.5939E+00
mode 3, $\boxed{\text{pcr} = 0.13058\text{E}+01}$
step 0 eigenvector deformed geometry
linear buckling of perfect shell from STAGS

Θ x 0.00
Θ y 90.00
Θ z 0.00

y
x z

2.000E+00

Fig. 10

PART 2

Optimize the shell for the acreage in the ~~m~~ neighborhoods of the weld lands.

(Wimp = ± 0.125")