Optimum designs from PANDA2 of a uniformly axially compressed cylindrical shell with a composite truss-core sandwich wall and verification of the design by BIGBOSOR4

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16 March, 2009

PANEL GEOMETRY IN THE AXIAL (L1) DIRECTION

Truss-core sandwich wall with extra segments (b2):

```
          < b2 >  ---- Seg. 3 ---->
---------======------------------------=====---------<-Upper skin
        /-Seg6>\S                  /       \       ^   middle
       /         \e              4/         \      !   surface
      /          . \g.          g/           \     !
     /           !\ \          e/  /          \    h =height from
    /              \ \2       S/  /            \   !  midsurface
   /                 \        /!/               \  !  to midsurface
  /  --- Seg. 1----> \<Seg5-/  "                 \V
==-------------------======------------------------==<-Lower skin
                     < b2 >                          midsurface
  <---------- b ----------->
```

A single module consists of Seg. 1 through Seg. 6.
Seg. 4 has the same wall construction as Seg. 2.
Seg. 5 has wall construction = Seg. 1.
Seg. 6 has wall construction = Seg. 3.

EXPLODED VIEW, SHOWING LAYERS and (SEGMENT, NODE) NUMBERS

```
                    Layer No. 1-.
                               .
(Segment, Node)   (6,11)        .                  (3,11)
       (6,1)======== (3,1)---------------------------
                                 .
                                  ._Layer No. j
                 (2.11)\                               /(4,1)
                        \<------- layer k --------->/
        Layer No. 1 --> \                          /
                         \                        /
                          \                      /
                           \                    /<-- Layer
                            \                  /      No. 1
     Layer No. 1 -.          \                /
                 .            \              /
                  .       (2,1)\           /(4,11)
                   .       (1,11)      (5,1)
    (1,1)--------------------   ========
               .               (5,11)
                ._ Layer No. m
```

Sketch of the truss-core sandwich cross section when B2 > 0.0

nasatruss.OPM (abridged)

These sketches form part of nasatruss.OPM when print index, NPRINT = 2

```
 ***********************************************
          PANEL GEOMETRY IN THE AXIAL (L1) DIRECTION

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-------=====-------------------------=========--------<-Upper skin
       /-Seg6>\S                    /      \      ^    middle
      /        \e                 4/        \     !    surface
     /        . \g.              g/          \    !
    /         !\ \              e/  /         \   h =height from
   /            \ \2           S/  /           \  !  midsurface
  /               \            /!/              \ !  to midsurface
 /   --- Seg. 1----> \<Seg5-/  "                 \V
==---------------------=====-----------------------==<-Lower skin
                      < b2 >                          midsurface
  <---------- b ----------->

A single module consists of Seg. 1 through Seg. 6.
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Seg. 5 has wall construction = Seg. 1.
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   EXPLODED VIEW, SHOWING LAYERS and (SEGMENT, NODE) NUMBERS

                    Layer No. 1-.
                                .
(Segment, Node)   (6,11)         .                    (3,11)
       (6,1)========  (3,1)--------------------------

                                  .
                                   ._Layer No. j
                (2,11)\                                /(4,1)
                       \<-------- layer k --------->/
        Layer No. 1 --> \                           /
                         \                         /
                          \                       /
                           \                     /<-- Layer
    Layer No. 1 -.          \                   /      No. 1
                 .           \                 /
                  .           (2,1)\          /(4,11)
                   .           (1,11)    (5,1)
  (1,1)--------------------        ========
               .                   (5,11)
                ._ Layer No. m
```

Truss-Core sandwich geometry

Fig 0

Table 0 (abridged nasatruss.OPM file)

nasatruss.OPM (abridged, with NPRINT = 2)

Optimized wall laminates for the shell with general buckling modal
imperfection amplitude, Wimp = plus or minus 0.125 inch.
(This output appears near the end of the nasatruss.OPM fille
when the print index, NPRINT, is set equal to 2 in the nasatruss.OPT file).

===

WALL PROPERTIES (Segment numbering below refers to the topmost of the sketches above.)

STR/ RNG	TYPE	SEG. NO.	LAYER NO.	LAYER TYPE	THICKNESS	WINDING ANGLE	MATERAL TYPE	CRACKING RATIO	
SKN	C	1	1	1	5.2000E-03	4.5000E+01	1	1.0000E+00	
SKN	C	1	2	2	5.2000E-03	-4.5000E+01	1	1.0000E+00	
SKN	C	1	3	3	5.2000E-03	9.0000E+01	1	1.0000E+00	
SKN	C	1	4	2	5.2000E-03	-4.5000E+01	1	1.0000E+00	
SKN	C	1	5	1	5.2000E-03	4.5000E+01	1	1.0000E+00	
SKN	C	1	6	4	5.2000E-03	4.5000E+01	1	1.0000E+00	
SKN	C	1	7	5	5.2000E-03	-4.5000E+01	1	1.0000E+00	
SKN	C	1	8	6	1.5600E-02	0.0000E+00	1	1.0000E+00	
SKN	C	1	9	7	1.5600E-02	9.0000E+01	1	1.0000E+00	
SKN	C	1	10	6	1.5600E-02	0.0000E+00	1	1.0000E+00	
SKN	C	1	11	5	5.2000E-03	-4.5000E+01	1	1.0000E+00	
SKN	C	1	12	4	5.2000E-03	4.5000E+01	1	1.0000E+00	— layer #m
TOTAL THICKNESS OF SEG.				1 =	9.3600E-02				
STR	C	2	1	1	5.2000E-03	4.5000E+01	1	1.0000E+00	
STR	C	2	2	2	5.2000E-03	-4.5000E+01	1	1.0000E+00	
STR	C	2	3	3	5.2000E-03	9.0000E+01	1	1.0000E+00	
STR	C	2	4	2	5.2000E-03	-4.5000E+01	1	1.0000E+00	
STR	C	2	5	1	5.2000E-03	4.5000E+01	1	1.0000E+00	
STR	C	2	6	2	5.2000E-03	-4.5000E+01	1	1.0000E+00	
STR	C	2	7	1	5.2000E-03	4.5000E+01	1	1.0000E+00	
STR	C	2	8	3	5.2000E-03	9.0000E+01	1	1.0000E+00	
STR	C	2	9	1	5.2000E-03	4.5000E+01	1	1.0000E+00	
STR	C	2	10	2	5.2000E-03	-4.5000E+01	1	1.0000E+00	— layer no. k
TOTAL THICKNESS OF SEG.				2 =	5.2000E-02				
STR	C	3	1	4	5.2000E-03	4.5000E+01	1	1.0000E+00	
STR	C	3	2	5	5.2000E-03	-4.5000E+01	1	1.0000E+00	
STR	C	3	3	6	1.5600E-02	0.0000E+00	1	1.0000E+00	
STR	C	3	4	7	1.5600E-02	9.0000E+01	1	1.0000E+00	
STR	C	3	5	6	1.5600E-02	0.0000E+00	1	1.0000E+00	
STR	C	3	6	5	5.2000E-03	-4.5000E+01	1	1.0000E+00	
STR	C	3	7	4	5.2000E-03	4.5000E+01	1	1.0000E+00	
STR	C	3	8	2	5.2000E-03	-4.5000E+01	1	1.0000E+00	
STR	C	3	9	1	5.2000E-03	4.5000E+01	1	1.0000E+00	
STR	C	3	10	3	5.2000E-03	9.0000E+01	1	1.0000E+00	
STR	C	3	11	1	5.2000E-03	4.5000E+01	1	1.0000E+00	
STR	C	3	12	2	5.2000E-03	-4.5000E+01	1	1.0000E+00	— layer no. j
TOTAL THICKNESS OF SEG.				3 =	9.3600E-02				

for m, k, j see lower fig on the previous page

See segment numbering schema on previous page, and layer numbering scheme.

March 16, 2009

RUN STREAM

RUN STREAM USED TO OBTAIN "nasatruss" RESULTS
WITH ICONSV = 1 AND IQUICK = 0

These results are for a composite truss-core sandwich cylindrical shell under uniform axial compression. The truss-core cross section is of the type shown in Fig. 0, with a typical composite layup as listed in Table 0.

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

There are two parts to this investigation:

PART 1: Optimize a PERFECT shell with buckling factors of safety greater than unity:
general buckling factor of safety= 2.154
local buckling factors of safety - 1.560

PART 2: Optimize an IMPERFECT shell with a general buckling modal imperfection shape with amplitude, Wimp, and with all buckling factors of safety set equal to 0.999.

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

ICONSV = 1
IQUICK = 0
througout this study

PART 1 runstream: Wimp = 0.0 ; f.s. > 1.0

```
cd .../<panda2workingspace>
panda2log        (activate panda2 command set)
begin            table 1
setup
decide           table 2
mainsetup        table 3
pandaopt         1st pandaopt
pandaopt         2nd pandaopt   (See Fig. 1 for the values
pandaopt         3rd pandaopt    of the objective for each
pandaopt         4th pandaopt    of the six executions of
pandaopt         5th pandaopt    pandaopt).
pandaopt         6th pandaopt
chooseplot       table 4
diplot           (diplot yields nasatruss.3.ps and nasatruss.5.ps,
                  two postscript files "plotted" in Figs. 2 and 1,
                  respectively.)

(edit the nasatruss.OPT file: change ITYPE from 1 to 2)
mainsetup
pandaopt         (produces nasatruss.OPM: abridged version in Table 5)
change           table 6: purpose is to save the optimum design.
panel            table 7: purpose is to generate a BIGBOSOR4 model.
cp nasatruss.ALL .../<bigbosor4workingspace>
cd .../<bigbosor4workingspace>
bigbosor4log     (activate the bigbosor4 command set)
bigbosorall      (produces the nasatruss.OUT file: Table 8=abridged version)
bosorplot        (produces Fig. 3)
bosorplot        (produces Fig. 4)
cleanup          (cleans up bigbosor4 files)
cd .../<panda2workingspace>
panel            table 9; purpose is to generate another BIGBOSOR4 model.
cp nasatruss.ALL .../<bigbosor4workingspace>
cd .../<bigbosor4workingspace>
bigbosorall      (produces the nasatruss.OUT  Table 10 = abridged version)
bosorplot        (produces Fig. 5)
bosorplot        (produces Fig. 6)
bosorplot        (produces Fig. 7)
bosorplot        (produces Fig. 8)
cleanup          (cleans up bigbosor4 files)
cd .../<panda2workingspace>
panel            table 11; purpose is to generate another BIGBOSOR4 model.
cp nasatruss.ALL .../<bigbosor4workingspace>
cd .../<bigbosor4workingspace>
```

```
bigbosorall      (produces the nasatruss.OUT  Table 12 = abridged version)
bosorplot        (produces Fig. 9)
resetup          table 13, top portion: prepare to get more buckling modes
bigrestart       (produces the 2nd part of Table 13)
cleanup          (cleans up bigbosor4 files)
cd .../<panda2workingspace>
change           table 14: change T(3) to the closest value to the
                           optimum value that represents an integral
                           number of plies.
setup
mainsetup
pandaopt         (produces nasatruss.OPM: abridged version in Table 15)

(We haven't yet executed SUPEROPT. Maybe the optimum design found
 after only 6 executions of pandaopt (Fig. 1) is not a global optimum.)

cleanpan         (cleans up nasatruss files.)
begin            table 1
setup
decide           table 2
(edit the nasatruss.OPT file: change ITYPE from 2 to 1)
mainsetup        table 3
superopt         (use 5 pandaopts per autochange)
chooseplot       (choose to plot only the objective v. iterations)
diplot           (produces nasatruss.5.ps, plotted in Fig. 10)

(It turns out that the best design determined after one
execution of SUPEROPT is essentially the same as the optimum
determined after the first 6 executions of pandaopt. Therefore,
we do no more for PART 1 of this investigation.)

cleanpan         (cleans up nasatruss files.)
-----------------------------------------------------------------
```

SUPEROPT run takes about 20 minutes on my LINUX machine.

PART 2 runstream: Wimp > 0.0 (general buckling modal imperfections)

```
cd .../<panda2workingspace>
panda2log        (activate panda2 command set)
begin            table 1
setup
decide           table 2

(We first use a general buckling modal imperfection
 with amplitude, Wimp = 0.25 inch.)

mainsetup        table 16   (use 2 Load Sets: (+) & (-) Wimp!)
superopt         (use 5 pandaopts/autochange)
chooseplot       (choose to plot only the objective)
diplot           (produces nasatruss.5.ps, plotted in Fig. 11)
(Edit nasatruss.OPT by changing ITYPE from 1 to 2).
mainsetup
pandaopt         (produces nasatruss.OPM: abridged version in Table 17.
                  We decide the shell is too heavy and that we should
                  use a smaller amplitude, Wimp)
cleanpan         (cleans up nasatruss files.)

begin            table 1
setup
decide           table 2

(We next use a general buckling modal imperfection
 with amplitude, Wimp = 0.125 inch.)

mainsetup        table 18
superopt         (use 5 pandaopts/autochange)
chooseplot       (choose to plot only the objective)
diplot           (produces nasatruss.5.ps, plotted in Fig. 12)
(Edit nasatruss.OPT by changing ITYPE from 1 to 2).
mainsetup
pandaopt         (produces nasatruss.OPM: abridged version in Table 19.)
change           table 20: save the optimum design.
panel            table 21: purpose is to generate a BIGBOSOR4 model.
cp nasatruss.ALL .../<bigbosor4workingspace>
cd .../<bigbosor4workingspace>
bigbosor4log     (activate the bigbosor4 command set)
bigbosorall
resetup          (table 22, top portion)
bigrestart       (produces nasatruss.OUT: table 22 abridged output)
```

Load Set #1 Load Set #2

Wimp = ±0.25"

Wimp = ±0.125"

```
bosorplot        (produces Fig. 13)
bosorplot        (produces Fig. 14)
cleanup          (cleans up bigbosor4 files)
cd .../<panda2workingspace>
panel            table 23; purpose is to generate another BIGBOSOR4 model.
cp nasatruss.ALL .../<bigbosor4workingspace>
cd .../<bigbosor4workingspace>
bigbosorall      (produces the nasatruss.OUT  Table 24 = abridged version)
bosorplot        (produces Fig. 15)
bosorplot        (produces Fig. 16)
bosorplot        (produces Fig. 17)
cleanup          (cleans up bigbosor4 files)
cd .../<panda2workingspace>
change           table 25: change T(7) to the closest value to the
                           optimum value that represents an integral
                           number of plies.
setup
mainsetup
pandaopt         (produces nasatruss.OPM: abridged version in Table 26)
```

(Edit the nasatruss.OPT file: only one load set and set the amplitude of the general buckling modal imperfection equal to 0.0).

```
mainsetup
pandaopt         (produces nasatruss.OPM: abridged version in Table 27)
```

Wimp = 0.0

(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).

```
panel2           table 28
cp nasatruss.ALL .../<bigbosor4workingspace>
cd .../<bigbosor4workingspace>
bigbosorall      (produces the nasatruss.OUT  Table 29 = abridged version)
bosorplot        (produces Fig. 18)
cleanup          (cleans up bigbosor4 files)
```

(Next, do a design sensitivity analysis. We are interested in the effect of the degree of "slant" in Segments 2 and 4 (See Fig. 0) on the general buckling load factor. The effect on general buckling is almost entirely due to the transverse shear deformation (t.s.d.) effect. When there is no slant, that is, when the webs are vertical (at 90 degrees) there exists a very, very small G23 (circumferential transverse shear deformation). Therefore, for that geometry the general buckling load factor should be very small. It is, as we see from Fig. 18).

(Produce a new nasatruss.OPT file).

```
mainsetup        table 30
pandaopt         (produces a nasatruss.OPM file. It's long and so is
                  not listed here).
chooseplot       (choose to plot only the general buckling margin)
diplot           (produces nasatruss.3.ps file: plotted in Fig. 19).
cleanup
=================== end of nasatruss investigation =====================
```

In the course of this study several modifications to PANDA2 were made (dated Feb. & March, 2009 in the .../panda2/doc/panda2.news file). You will need the March, 2009 version of PANDA2.

Table 1 nasatruss.BEG

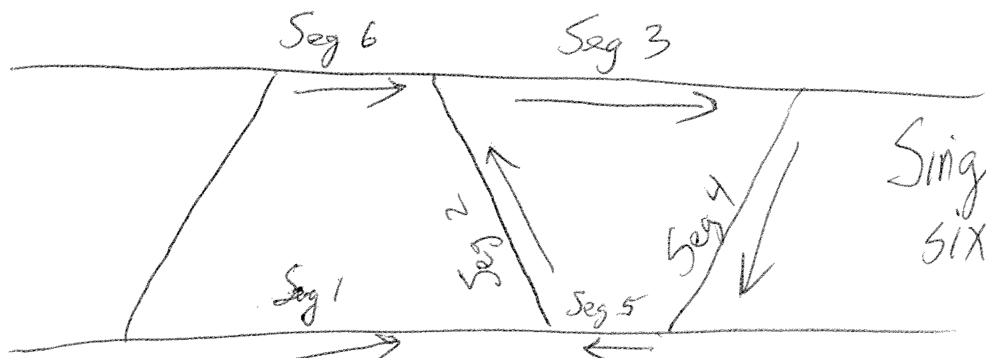
```
     n           $ Do you want a tutorial session and tutorial output?
      96         $ Panel length normal to the plane of the screen, L1
 150.7960        $ Panel length in the plane of the screen, L2
     C           $ Identify type of stiffener along L1 (N,T,J,Z,R,A,C,G)
 3.700000        $ pitch of truss core, b
0.7000000        $ width over which truss core contacts each face sheet, b2
 1.400000        $ height of truss, h
     n           $ Are the segs. of width b2 thicker than face sheets?
 1000000.        $ What force/(axial length) will cause web peel-off?
     n           $ Is the next group of layers to be a "default group" (12 layers!)?
      12         $ 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?
0.5200000E-02    $ thickness for layer index no.( 1)
      45         $ winding angle (deg.) for layer index no.( 1)
       1         $ material index (1,2,...) for layer index no.( 1)
       2         $ layer index (1,2,...), for layer no.( 2)
     y           $ Is this a new layer type?
0.5200000E-02    $ thickness for layer index no.( 2)
     -45         $ winding angle (deg.) for layer index no.( 2)
       1         $ material index (1,2,...) for layer index no.( 2)
       3         $ layer index (1,2,...), for layer no.( 3)
     y           $ Is this a new layer type?
0.5200000E-02    $ thickness for layer index no.( 3)
      90         $ winding angle (deg.) for layer index no.( 3)
       1         $ material index (1,2,...) for layer index no.( 3)
       2         $ layer index (1,2,...), for layer no.( 4)
     n           $ Is this a new layer type?
       1         $ layer index (1,2,...), for layer no.( 5)
     n           $ Is this a new layer type?
       4         $ layer index (1,2,...), for layer no.( 6)
     y           $ Is this a new layer type?
0.5200000E-02    $ thickness for layer index no.( 4)
      45         $ winding angle (deg.) for layer index no.( 4)
       1         $ material index (1,2,...) for layer index no.( 4)
       5         $ layer index (1,2,...), for layer no.( 7)
     y           $ Is this a new layer type?
0.5200000E-02    $ thickness for layer index no.( 5)
     -45         $ winding angle (deg.) for layer index no.( 5)
       1         $ material index (1,2,...) for layer index no.( 5)
       6         $ layer index (1,2,...), for layer no.( 8)
     y           $ Is this a new layer type?
0.5200000E-02    $ thickness for layer index no.( 6)
       0         $ winding angle (deg.) for layer index no.( 6)
       1         $ material index (1,2,...) for layer index no.( 6)
       7         $ layer index (1,2,...), for layer no.( 9)
     y           $ Is this a new layer type?
0.5200000E-02    $ thickness for layer index no.( 7)
      90         $ winding angle (deg.) for layer index no.( 7)
       1         $ material index (1,2,...) for layer index no.( 7)
       6         $ layer index (1,2,...), for layer no.(10)
     n           $ Is this a new layer type?
       5         $ layer index (1,2,...), for layer no.(11)
     n           $ Is this a new layer type?
       4         $ layer index (1,2,...), for layer no.(12)
     n           $ Is this a new layer type?
     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!)?
      10         $ 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?
       2         $ layer index (1,2,...), for layer no.( 2)
     n           $ Is this a new layer type?
       3         $ layer index (1,2,...), for layer no.( 3)
     n           $ Is this a new layer type?
       2         $ layer index (1,2,...), for layer no.( 4)
     n           $ Is this a new layer type?
       1         $ layer index (1,2,...), for layer no.( 5)
     n           $ Is this a new layer type?
       2         $ layer index (1,2,...), for layer no.( 6)
     n           $ Is this a new layer type?
       1         $ layer index (1,2,...), for layer no.( 7)
     n           $ Is this a new layer type?
       3         $ layer index (1,2,...), for layer no.( 8)
     n           $ Is this a new layer type?
       1         $ layer index (1,2,...), for layer no.( 9)
```

"Input for BEGIN"

Table I (p. 2 of 2)

```
     n          $ Is this a new layer type?
       2        $ layer index (1,2,...), for layer no.(10)
     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!)?
      12        $ number of layers in the next group in Segment no.( 3)
     n          $ Can winding (layup) angles ever be decision variables?
       4        $ layer index (1,2,...), for layer no.( 1)
     n          $ Is this a new layer type?
       5        $ layer index (1,2,...), for layer no.( 2)
     n          $ Is this a new layer type?
       6        $ layer index (1,2,...), for layer no.( 3)
     n          $ Is this a new layer type?
       7        $ layer index (1,2,...), for layer no.( 4)
     n          $ Is this a new layer type?
       6        $ layer index (1,2,...), for layer no.( 5)
     n          $ Is this a new layer type?
       5        $ layer index (1,2,...), for layer no.( 6)
     n          $ Is this a new layer type?
       4        $ layer index (1,2,...), for layer no.( 7)
     n          $ Is this a new layer type?
       2        $ layer index (1,2,...), for layer no.( 8)
     n          $ Is this a new layer type?
       1        $ layer index (1,2,...), for layer no.( 9)
     n          $ Is this a new layer type?
       3        $ layer index (1,2,...), for layer no.(10)
     n          $ Is this a new layer type?
       1        $ layer index (1,2,...), for layer no.(11)
     n          $ Is this a new layer type?
       2        $ layer index (1,2,...), for layer no.(12)
     n          $ Is this a new layer type?
     n          $ Any more layers or groups of layers in Segment no.( 3)
     y          $ Is the panel curved in the plane of the screen (Y for cyls.)?
      48        $ Radius of curvature (cyl. rad.) in the plane of screen, R
     n          $ Is panel curved normal to plane of screen? (answer N)
     n          $ Is this material isotropic (Y or N)?
0.1851110E+08   $ modulus in the fiber direction,  E1( 1)
 1640000.       $ modulus transverse to fibers,    E2( 1)
 870600.0       $ in-plane shear modulus,           G( 1)
0.2660000E-01   $ small Poisson's ratio,           NU( 1)
 870600.0       $ out-of-plane shear modulus,     G13( 1)
 870600.0       $ out-of-plane shear modulus,     G23( 1)
0.2500000E-06   $ thermal expansion along fibers,  A1( 1)
0.1620000E-04   $ transverse thermal expansion,    A2( 1)
     280        $ residual stress temperature (positive),TEMPTUR( 1)
     n          $ Want to specify  maximum effective stress ?
  200798        $ maximum tensile stress along fibers, matl( 1)
  185925        $ max compressive stress along fibers, matl( 1)
    3350        $ max tensile stress normal to fibers, matl( 1)
   16400        $ max compress stress normal to fibers,matl( 1)
   17357        $ maximum  shear  stress  in  material type( 1)
0.5700000E-02   $ weight density (greater than 0!) of material type( 1)
     n          $ Is lamina cracking permitted along fibers (type H(elp))?
       2        $ Prebuckling: choose 0=bending included; 2=use membrane theory
       0        $ Buckling: choose 0=simple support or 1=clamping
```

Input for BEGIN



Single module has six segments

Table 2 nasatruss.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)
  9.000000       $ Upper bound of variable no.( 1)
       y         $ Any more decision variables (Y or N) ?
          2      $ Choose a decision variable (1,2,3,...)
 0.1000000       $ Lower bound of variable no.( 2)
          7      $ Upper bound of variable no.( 2)
       y         $ Any more decision variables (Y or N) ?
          3      $ Choose a decision variable (1,2,3,...)
 0.1000000       $ 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,...)
0.5200000E-02    $ Lower bound of variable no.( 4)
0.1560000E-01    $ Upper bound of variable no.( 4)
       y         $ Any more decision variables (Y or N) ?
          6      $ Choose a decision variable (1,2,3,...)
0.5200000E-02    $ Lower bound of variable no.( 6)
0.1560000E-01    $ Upper bound of variable no.( 6)
       y         $ Any more decision variables (Y or N) ?
          7      $ Choose a decision variable (1,2,3,...)
0.5200000E-02    $ Lower bound of variable no.( 7)
0.1560000E-01    $ Upper bound of variable no.( 7)
       y         $ Any more decision variables (Y or N) ?
          9      $ Choose a decision variable (1,2,3,...)
0.5200000E-02    $ Lower bound of variable no.( 9)
0.1560000E-01    $ Upper bound of variable no.( 9)
       y         $ Any more decision variables (Y or N) ?
         10      $ Choose a decision variable (1,2,3,...)
0.5200000E-02    $ Lower bound of variable no.(10)
0.1560000E-01    $ Upper bound of variable no.(10)
       n         $ Any more decision variables (Y or N) ?
       y         $ Any linked variables (Y or N) ?
          5      $ Choose a linked variable (1,2,3,...)
          4      $ To which variable is this variable linked?
  1.000000       $ 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)?
       y         $ Any more linked variables (Y or N) ?
          8      $ Choose a linked variable (1,2,3,...)
          7      $ To which variable is this variable linked?
  1.000000       $ 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) ?
       y         $ Any inequality relations among variables? (type H)
       n         $ Want to see an example of how to calculate C0, C1, D1,..?
          1      $ Identify the type of inequality expression (1 or 2)
  1.000000       $ Give a value to the constant, C0
       n         $ Are there any cross product terms in the inequality expression?
          2      $ Choose a variable from the list above (1, 2, 3,...)
 -1.000000       $ Choose a value for the coefficient, C1
          1      $ Choose a value for the power, D1
       y         $ Any more terms in the expression: C0 +C1*v1**D1 +C2*v2**D2 +...
          1      $ Choose a variable from the list above (1, 2, 3,...)
 0.5000000       $ Choose a value for the coefficient, Cn
          1      $ Choose a value for the power, Dn
       n         $ Any more terms in the expression: C0 +C1*v1**D1 +C2*v2**D2 +...
       n         $ Are there any more inequality expressions?
       y         $ Any escape variables (Y or N) ?
       y         $ Want to have escape variables chosen by default?
```

B2 < 0.5 B   input for DECIDE

T(5) = T(4)

T(2) = T(1)

PART 1

Optimize the shell as <u>perfect</u> with general buckling load factor of safety = 2.154 & local buckling load factors = 1.56

Table 3

nasatruss, OPT

n	$ Do you want a tutorial session and tutorial output?
-5000	$ 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)
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?
2.154000	$ Factor of safety for general instability, FSGEN(1)
1.560000	$ Minimum load factor for local buckling (Type H for HELP), FSLOC(1)
1.560000	$ Minimum load factor for stiffener buckling (Type H), FSBSTR(1)
1.270000	$ 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	$ Resultant (e.g. lb/in) normal to the plane of screen, Nx0(1)
0	$ 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	$ Uniform applied pressure [positive upward. See H(elp)], p(1)
0	$ Out-of-roundness, Wimpg1=(Max.diameter-Min.diam)/4, Wimpg1(1)
0	$ Initial buckling modal general imperfection amplitude, Wimpg2(1)
0	$ 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)?
n	$ Do you want a "complete" analysis (type H for "Help")?
n	$ Have you rerun DECIDE with new decision variables and lower bounds?
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	$ 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]?
0	$ Choose (0=transverse inextensional; 1=transverse extensional)
1	$ Choose ICONSV = -1 or 0 or 1 or H(elp), ICONSV
1	$ 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)

input for MAINSETUP

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Note:
ICONSV = 1
IQUICK = 0

Table 4 nasatruss.CPL

```
n          $ Do you want a tutorial session and tutorial output?
n          $ Any design variables to be plotted v. iterations (Y or N)?
y          $ Any design margins to be plotted (Y or N)?
    1      $ For which load set (1 - 5) do you want behavior/margins?
    1      $ Choose a sub-case (1 or 2) within this load set
    1      $ Choose a margin to be plotted v. iterations (1,2,3,..)
y          $ Any more margins to be plotted (Y or N) ?
    2      $ Choose a margin to be plotted v. iterations (1,2,3,..)
y          $ Any more margins to be plotted (Y or N) ?
    3      $ Choose a margin to be plotted v. iterations (1,2,3,..)
y          $ Any more margins to be plotted (Y or N) ?
    4      $ Choose a margin to be plotted v. iterations (1,2,3,..)
y          $ Any more margins to be plotted (Y or N) ?
    5      $ Choose a margin to be plotted v. iterations (1,2,3,..)
y          $ Any more margins to be plotted (Y or N) ?
    6      $ Choose a margin to be plotted v. iterations (1,2,3,..)
y          $ Any more margins to be plotted (Y or N) ?
    7      $ Choose a margin to be plotted v. iterations (1,2,3,..)
y          $ Any more margins to be plotted (Y or N) ?
    8      $ Choose a margin to be plotted v. iterations (1,2,3,..)
y          $ Any more margins to be plotted (Y or N) ?
    9      $ Choose a margin to be plotted v. iterations (1,2,3,..)
y          $ Any more margins to be plotted (Y or N) ?
   10      $ Choose a margin to be plotted v. iterations (1,2,3,..)
y          $ Any more margins to be plotted (Y or N) ?
   11      $ Choose a margin to be plotted v. iterations (1,2,3,..)
y          $ Any more margins to be plotted (Y or N) ?
   12      $ Choose a margin to be plotted v. iterations (1,2,3,..)
y          $ Any more margins to be plotted (Y or N) ?
   13      $ Choose a margin to be plotted v. iterations (1,2,3,..)
y          $ Any more margins to be plotted (Y or N) ?
   14      $ Choose a margin to be plotted v. iterations (1,2,3,..)
y          $ Any more margins to be plotted (Y or N) ?
   15      $ Choose a margin to be plotted v. iterations (1,2,3,..)
y          $ Any more margins to be plotted (Y or N) ?
   16      $ Choose a margin to be plotted v. iterations (1,2,3,..)
n          $ Any more margins to be plotted (Y or N) ?
   1       $ Give maximum value (positive) to be included in plot frame.
y          $ Do you want a plot of the objective v. iterations (Y/N)?
```

input for CHOOSEPLOT

Results from 6 pandaopts

nasatruss.5.ps

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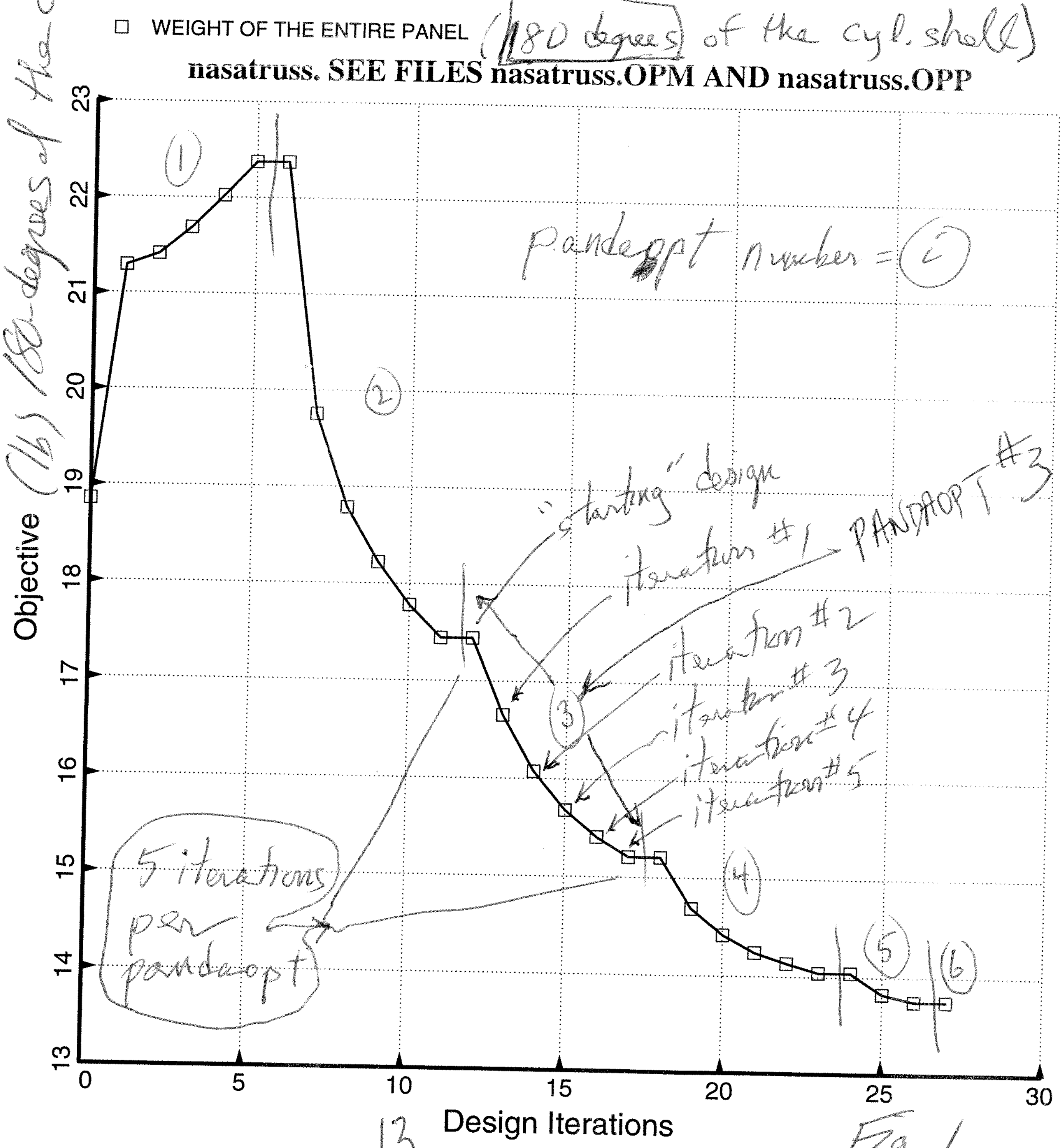


Fig. 1

nasatruss, 3.ps

PERFECT SHELL

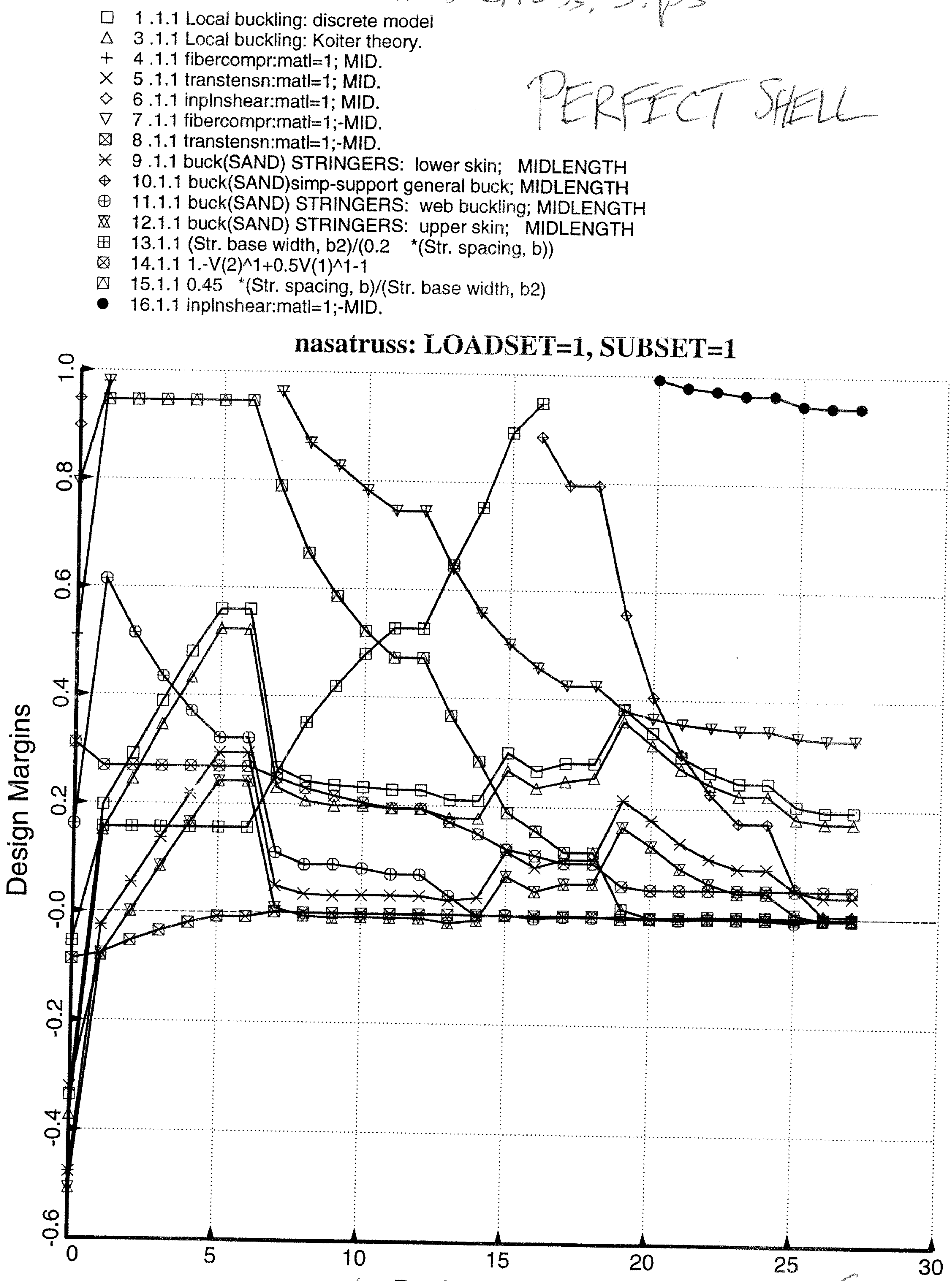


Fig.2

Table 5 (2 pages) nasatruss.OPM (abridged)

nasatruss.OPM (abridged file for optimum design)

****

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

PERFECT SHELL

```
ANALYSIS: ITYPE=2;  IQUICK=0;  LOAD SET 1;  SUBCASE 1:
LOADING: Nx, Ny, Nxy, Mx, My =  -5.00E+03 -5.00E-03  2.50E+01  0.00E+00  0.00E+00
         Nxo, Nyo, pressure  =   0.00E+00  0.00E+00 -1.04E-04
BUCKLING LOAD FACTORS FOR LOCAL BUCKLING FROM KOITER v. BOSOR4 THEORY:
 Local buckling load factor from KOITER theory =  1.8465E+00 (flat skin)
 Local buckling load factor from BOSOR4 theory =  1.8616E+00 (flat skin)
```

"→" = critical or near-critical margins

See Table 9 & Figs 5-8 for BIGBOSOR4 versions of this mode

MARGINS FOR CURRENT DESIGN: LOAD CASE NO. 1, SUBCASE NO. 1

MAR. NO.	MARGIN VALUE	DEFINITION
→ 1	1.93E-01	Local buckling from discrete model-1.,M=67 axial halfwaves;FS=1.56
2	9.64E+00	local wide-column bucking, discrete model(m=1 axial halfwav);FS=2
→ 3	1.84E-01	Local buckling from Koiter theory,M=70 axial halfwaves;FS=1.56
4	3.30E+00	fibertensn:matl=1,SKN,Dseg=2,node=1,layer=3,z=-0.0159; MID.;FS=1.27
5	3.27E-01	fibercompr:matl=1,STR,Dseg=3,node=6,layer=3,z=-0.0245; MID.;FS=1.27
→ 6	-2.12E-03	transtensn:matl=1,SKN,Dseg=1,node=7,layer=10,z=0.0245; MID.;FS=1.27
7	5.52E+00	transcompr:matl=1,SKN,Dseg=1,node=7,layer=3,z=-0.0278; MID.;FS=1.27
8	9.43E-01	inplnshear:matl=1,SKN,Dseg=2,node=1,layer=1,z=-0.0263; MID.;FS=1.27
9	3.30E+00	fibertensn:matl=1,SKN,Iseg=2,at:TIP,layer=8,z=0.0132;-MID.;FS=1.27
10	3.28E-01	fibercompr:matl=1,STR,Iseg=3,at:n=11,layer=5,z=0.0015;-MID.;FS=1.27
→ 11	-1.85E-03	transtensn:matl=1,STR,Iseg=3,at:n=11,layer=5,z=0.0015;-MID.;FS=1.27
12	5.53E+00	transcompr:matl=1,STR,Iseg=3,at:n=11,layer=10,z=0.0278;-MID.;FS=1.2
13	9.43E-01	inplnshear:matl=1,SKN,Iseg=2,at:TIP,layer=10,z=0.0237;-MID.;FS=1.27
14	2.36E+05	buckling marg. skin Iseg.(width-wise wide col.)MID.;FS=1.56
15	5.09E+06	buckling marg. stringer Iseg.(width-wise wide col.)MID.;FS=1.56
16	2.36E+05	buckling marg. skin Iseg.(width-wise wide col.)NOPO;FS=1.56
17	5.09E+06	buckling marg. stringer Iseg.(width-wise wide col.)NOPO;FS=1.56
→ 18	3.86E-02	buck.(SAND); STRINGERS: lower skin; M=60;N=1;slope=0.04;FS=1.56
→ 19	-2.02E-02	buck.(SAND);simp-support general buck;M=1;N=4;slope=0.;FS=2.154
→ 20	-1.06E-03	buck.(SAND); STRINGERS: web buckling;M=64;N=1;slope=-0.01;FS=1.56
→ 21	4.17E-02	buck.(SAND); STRINGERS: upper skin; M=60;N=1;slope=0.02;FS=1.56
22	1.85E+02	(Max.allowable ave.axial strain)/(ave.axial strain) -1; FS=1.
→ 23	-3.10E-04	0.45 *(Stringer spacing, b)/(Stringer base width, b2)-1;FS=1.
24	1.25E+00	(Str. base width, b2)/(0.2 *(Str. spacing, b))-1; FS=1.
→ 25	4.99E-02	1.-V(2)^1+0.5V(1)^1-1

General buckling mode; See Fig. 4 for BIGBOSOR4 version

M = axial halfwaves
N = circumf. halfwaves

*********** ALL 1 LOAD SETS PROCESSED ***********

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	3.0826E+00	9.00E+00	B(STR):pitch of truss core, b: seg=NA, layer=NA
2	Y	N	N	0	0.00E+00	1.00E-01	1.3876E+00	7.00E+00	B2(STR):width over which truss core contacts each fa
3	Y	N	N	0	0.00E+00	1.00E-01	5.7880E-01	2.00E+00	H(STR):height of truss, h: WEB seg=2 , layer=NA
4	Y	Y	N	0	0.00E+00	5.20E-03	5.2000E-03	1.56E-02	T(1)(SKN):thickness for layer index no.(1): SKN seg=1
5	N	N	Y	4	1.00E+00	0.00E+00	5.2000E-03	0.00E+00	T(2)(SKN):thickness for layer index no.(2): SKN seg=1
6	Y	Y	N	0	0.00E+00	5.20E-03	5.5074E-03	1.56E-02	T(3)(SKN):thickness for layer index no.(3): SKN seg=1
7	Y	Y	N	0	0.00E+00	5.20E-03	5.2000E-03	1.56E-02	T(4)(SKN):thickness for layer index no.(4): SKN seg=1
8	N	N	Y	7	1.00E+00	0.00E+00	5.2000E-03	0.00E+00	T(5)(SKN):thickness for layer index no.(5): SKN seg=1
9	Y	Y	N	0	0.00E+00	5.20E-03	5.2000E-03	1.56E-02	T(6)(SKN):thickness for layer index no.(6): SKN seg=1
10	Y	Y	N	0	0.00E+00	5.20E-03	1.5600E-02	1.56E-02	T(7)(SKN):thickness for layer index no.(7): SKN seg=1

CURRENT VALUE OF THE OBJECTIVE FUNCTION:

VAR. NO.	STR/ RNG	SEG. NO.	LAYER NO.	CURRENT VALUE	DEFINITION
		0	0	1.375E+01	WEIGHT OF THE ENTIRE PANEL

```
TOTAL WEIGHT OF SKIN            =  1.3752E+01
TOTAL WEIGHT OF SUBSTIFFENERS   =  0.0000E+00
TOTAL WEIGHT OF STRINGERS       =  0.0000E+00
```

Optimum design after 6 pandaopts!

180 degrees!

15

Compare with PART2 value: 1.748E+01 lb. listed in Table 19.

Table 5 (p. 2 of 2)

```
 TOTAL WEIGHT OF RINGS                               =    0.0000E+00
 SPECIFIC WEIGHT (WEIGHT/AREA) OF STIFFENED PANEL=    9.4995E-04
IN ORDER TO AVOID FALSE CONVERGENCE OF THE DESIGN, BE SURE TO
RUN  PANDAOPT  MANY TIMES DURING AN OPTIMIZATION. INSPECT THE
nasatruss.OPP  FILE AFTER EACH OPTIMIZATION RUN. OR BETTER YET,
RUN SUPEROPT.
******************** END OF nasatruss.OPM FILE ****************
```

Table 6 nasatruss.CHG (nasatruss.chg1)

```
      n          $ Do you want a tutorial session and tutorial output?
      y          $ Do you want to change any values in Parameter Set No. 1?
         1       $ Number of parameter to change (1, 2, 3, . .)
  3.082600       $ New value of the parameter
      y          $ Want to change any other parameters in this set?
         2       $ Number of parameter to change (1, 2, 3, . .)
  1.387600       $ New value of the parameter
      y          $ Want to change any other parameters in this set?
         3       $ Number of parameter to change (1, 2, 3, . .)
 0.5788000       $ New value of the parameter
      y          $ Want to change any other parameters in this set?
         4       $ Number of parameter to change (1, 2, 3, . .)
 0.5200000E-02   $ New value of the parameter
      y          $ Want to change any other parameters in this set?
         5       $ Number of parameter to change (1, 2, 3, . .)
 0.5200000E-02   $ New value of the parameter
      y          $ Want to change any other parameters in this set?
         6       $ Number of parameter to change (1, 2, 3, . .)
 0.5507400E-02   $ New value of the parameter
      y          $ Want to change any other parameters in this set?
         7       $ Number of parameter to change (1, 2, 3, . .)
 0.5200000E-02   $ New value of the parameter
      y          $ Want to change any other parameters in this set?
         8       $ Number of parameter to change (1, 2, 3, . .)
 0.5200000E-02   $ New value of the parameter
      y          $ Want to change any other parameters in this set?
         9       $ Number of parameter to change (1, 2, 3, . .)
 0.5200000E-02   $ New value of the parameter
      y          $ Want to change any other parameters in this set?
        10       $ Number of parameter to change (1, 2, 3, . .)
 0.1560000E-01   $ New value of the parameter
      n          $ Want to change any other parameters in this set?
      n          $ Do you want to change values of "fixed" parameters?
      n          $ Do you want to change values of allowables?
```

input for CHANGE
in order to save the optimum design

PERFECT SHELL

This is later changed to ~~the~~ the closest thickness that corresponds to an integral number of plies, in this case changed to 0.0052, the thickness of one ply. (See Table 14).

Table 7

nasatruss.panl

```
n                $ Do you want a tutorial session and tutorial output?
73.9824          $ 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
      0          $ 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?
```

nasatruss.PAN = input for PANEL

(to set up BIGBOSOR4 input file, nasatruss.ALL)

general buckling model

24 modules = 24 x B = 24 x 3.0826

SEE the Appendix 1 for a discussion about the type of BIGBOSOR4 model that the PANDA2 processor called PANEL sets up: a huge "torus" model.

Table 8 output from BIGBOSOR4 (general buckling model)

```
nasatruss.OUT (abridged)

 BUCKLING LOADS FOLLOW
 CIRCUMFERENTIAL WAVE NUMBER, N =        100

 EIGENVALUES =
    1.83833E+00      2.06602E+00      3.15807E+00
```

N=100 in the huge "torus" model (See APPENDIX 1) is the same as M=1 axial halfwave in the PANDA2 model of general buckling (Margin #19 in Table 5).

BIGBOSOR4 model of PERFECT SHELL

PANDA2 GENERAL Buckling load factor in Table 5:

(Margin 19 + 1) × f.s. = 2.11092 (f.s. = 2.1547)

Compare with Table 5, Margin No. 19

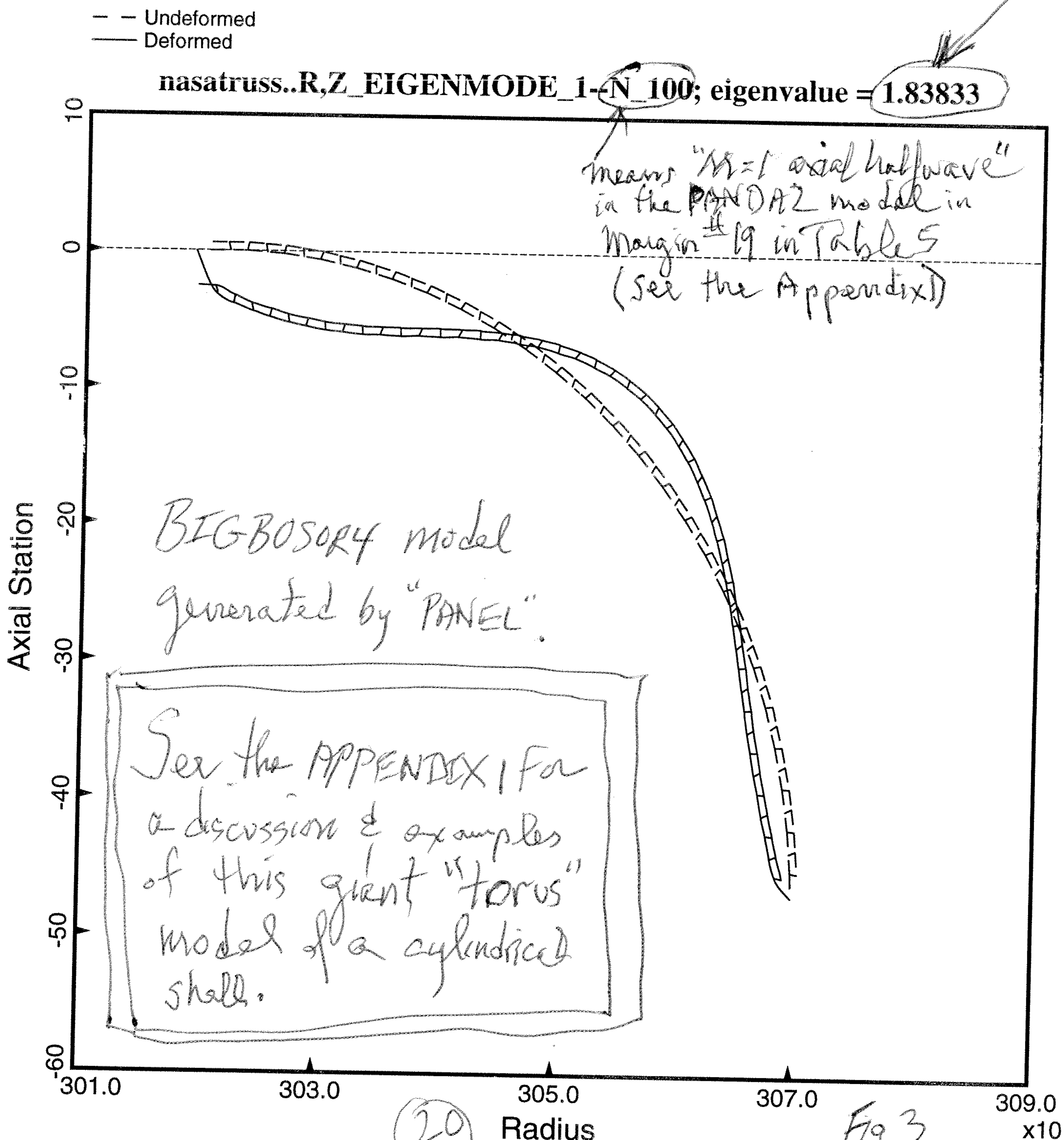


Fig 3

BIG-BOSOR4 model

PANDA2 general buckling load factor in Tables5 = (Margin #19 +1) × f.s. = 2.11092 ← PANDA2 | BOSOR4 →

2.1547

Compare with Tables5, margin 19

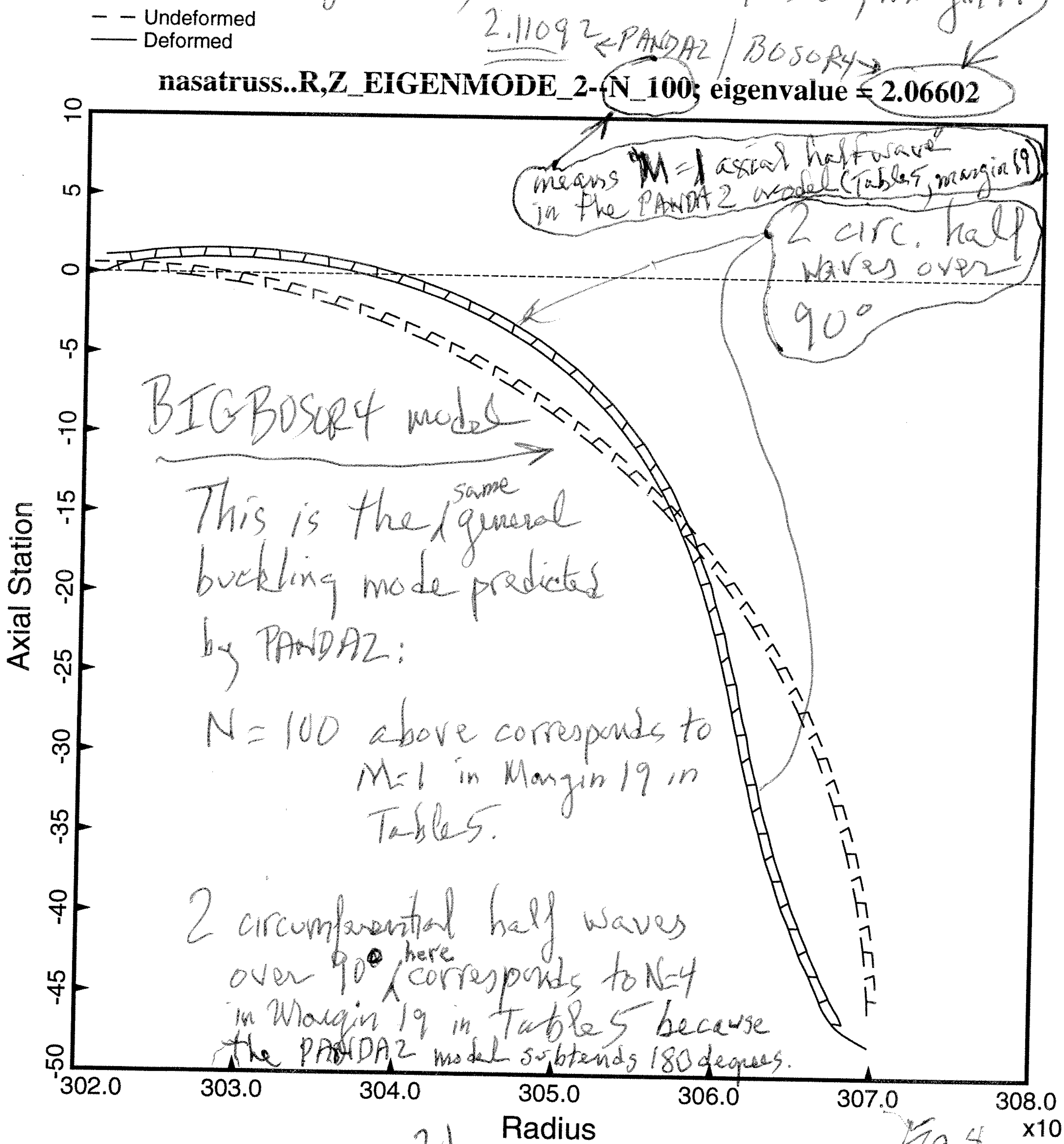


Fig. 4

Table 9

nasatruss.pan2

```
  n
73.9824    $ Do you want a tutorial session and tutorial output?
      0    $ Panel length in the plane of the screen, L2
      2    $ Enter control (0 or 1) for stringers at panel edges
      1    $ Enter control (1=sym; 2=s.s.) for boundary condition
     67    $ Enter ILOCAL=0 for panel buckling; 1 for local buckling, ILOCAL
     10    $ Number of halfwaves in the axial direction [see H(elp)],NWAVE
           $ How many eigenvalues (get at least 3) do you want?
```

input for PANEL (to set up a BIGBOSOR4 input file, nasatruss.ALL)

From Table 5, Margin No 1

local buckling model

24 modules: 24x3.0826 inches

See the Appendix 1 for a discussion about the type of BIGBOSOR4 model that the PANDA2 processor called PANEL sets up: a huge "torus" model.

Table 10

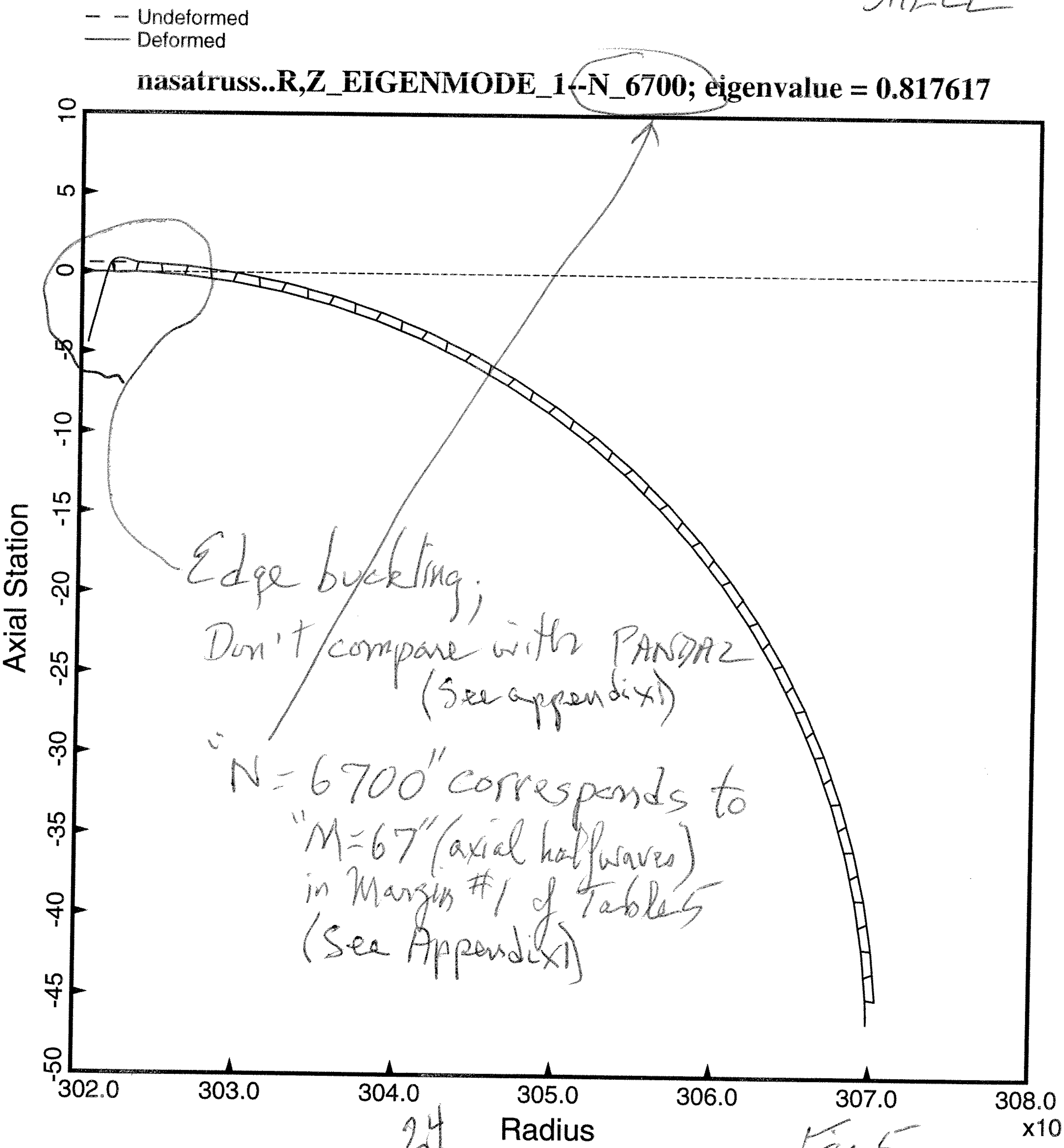
nasatruss.OUT (abridged, local buckling: (from BIGBOSOR4)

```
 BUCKLING LOADS FOLLOW
 CIRCUMFERENTIAL WAVE NUMBER, N =     6700

 EIGENVALUES =
    8.17617E-01    1.94857E+00    2.06709E+00    2.07324E+00    2.07604E+00    2.07988E+00    2.»
08533E+00

 EIGENVALUES =
    2.09219E+00    2.10002E+00    2.10890E+00
```

edge buckling: Don't compare these first 2 eigenvalues with PANDA2 (See Appendix I)

N=6700 in the huge BIGBOSOR4 "torus" model (See Appendix I) is the same as "M=67 halfwaves" in the PANDA2 model of local buckling (Margin #1 in Table 5)

BIGBOSOR4 model of PERFECT SHELL



Edge buckling; Don't compare with PANDA2 (See appendix 1)

"N = 6700" corresponds to "M = 67" (axial halfwaves) in Margin #1 of Table 5 (See Appendix 1)

Fig. 5

BIGBOSOR4 model, PERFECT SHELL

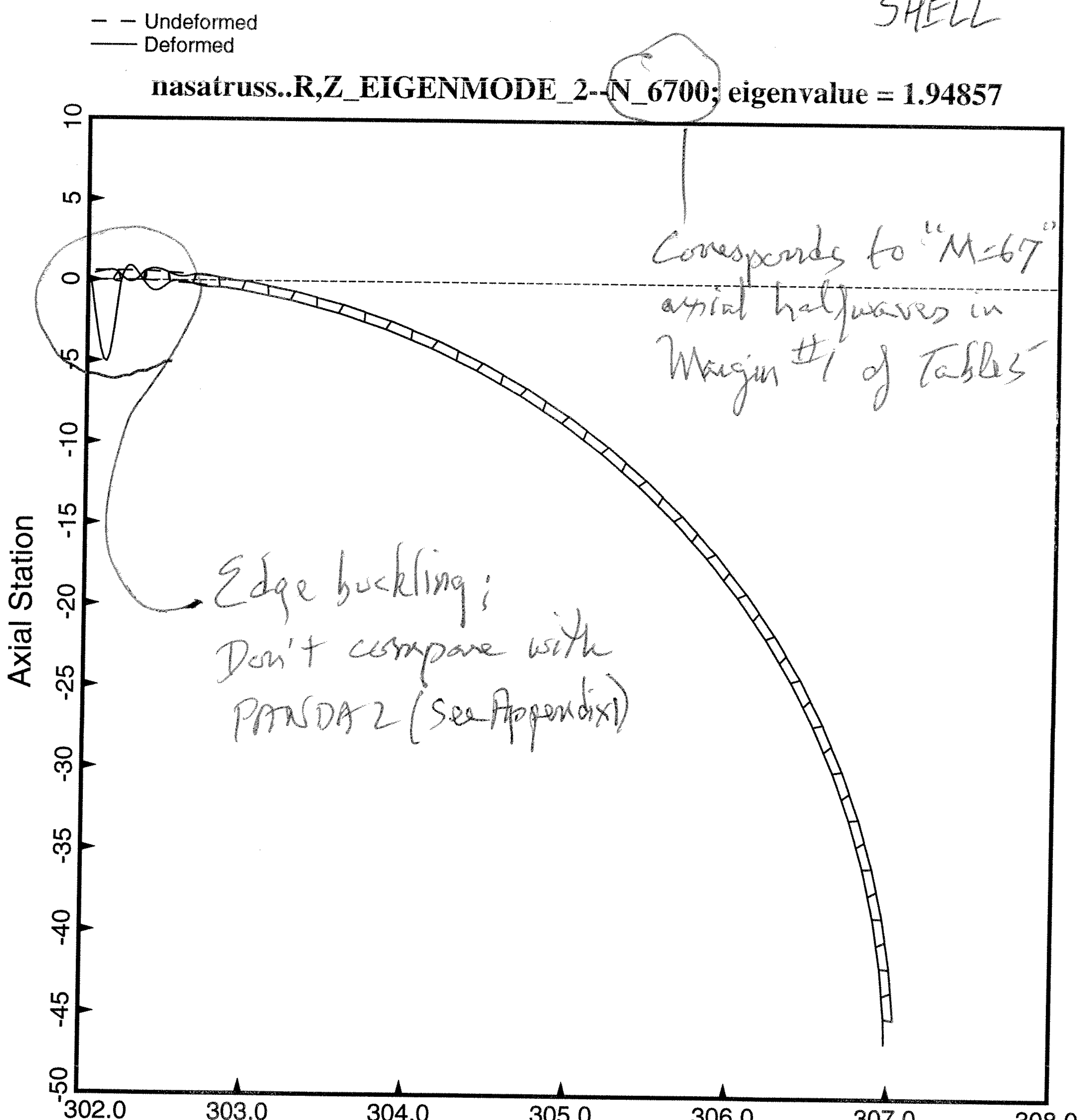


Fig. 6

BIGBUSOR4 model
PERFECT SHELL

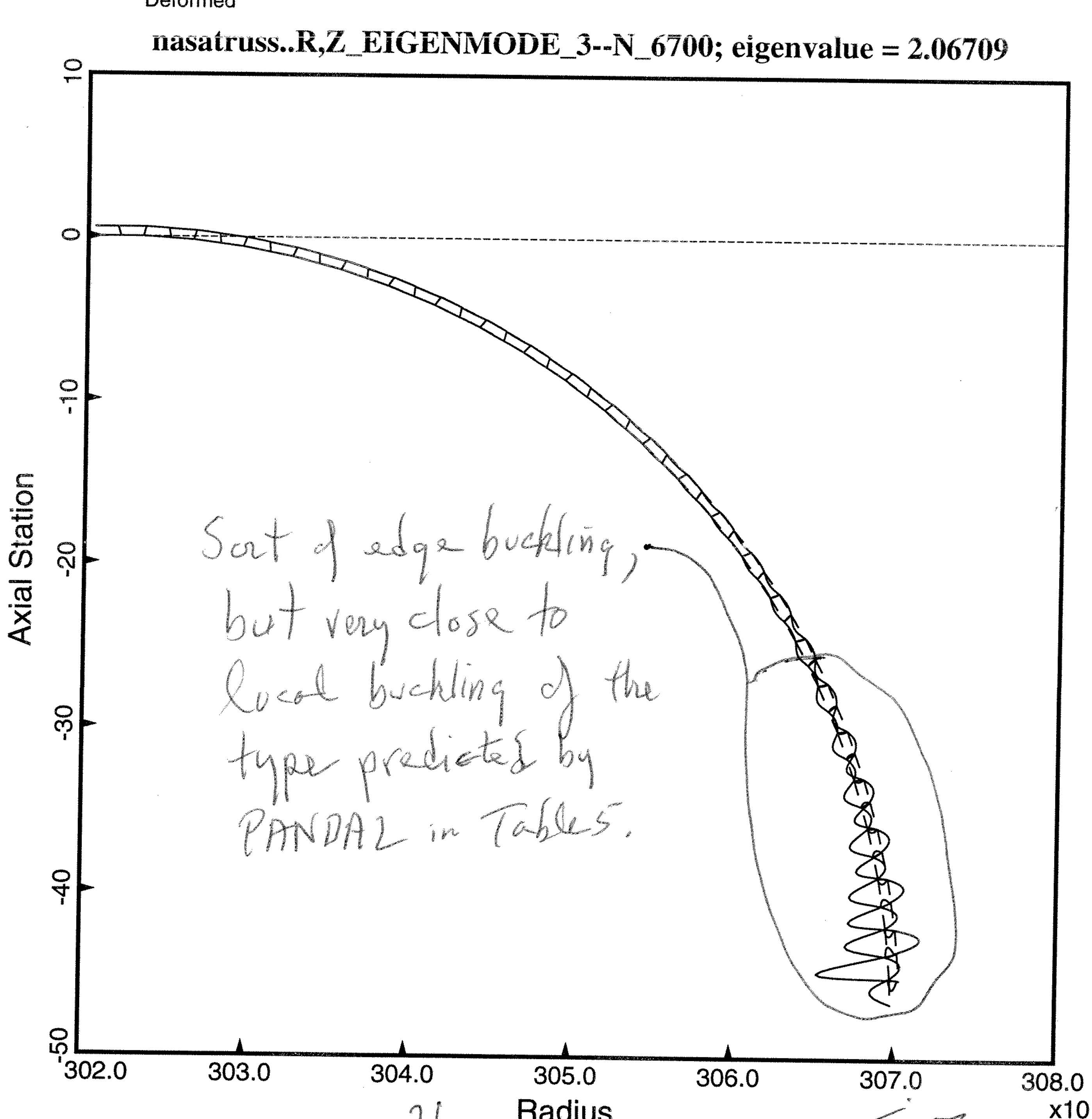


Fig 7

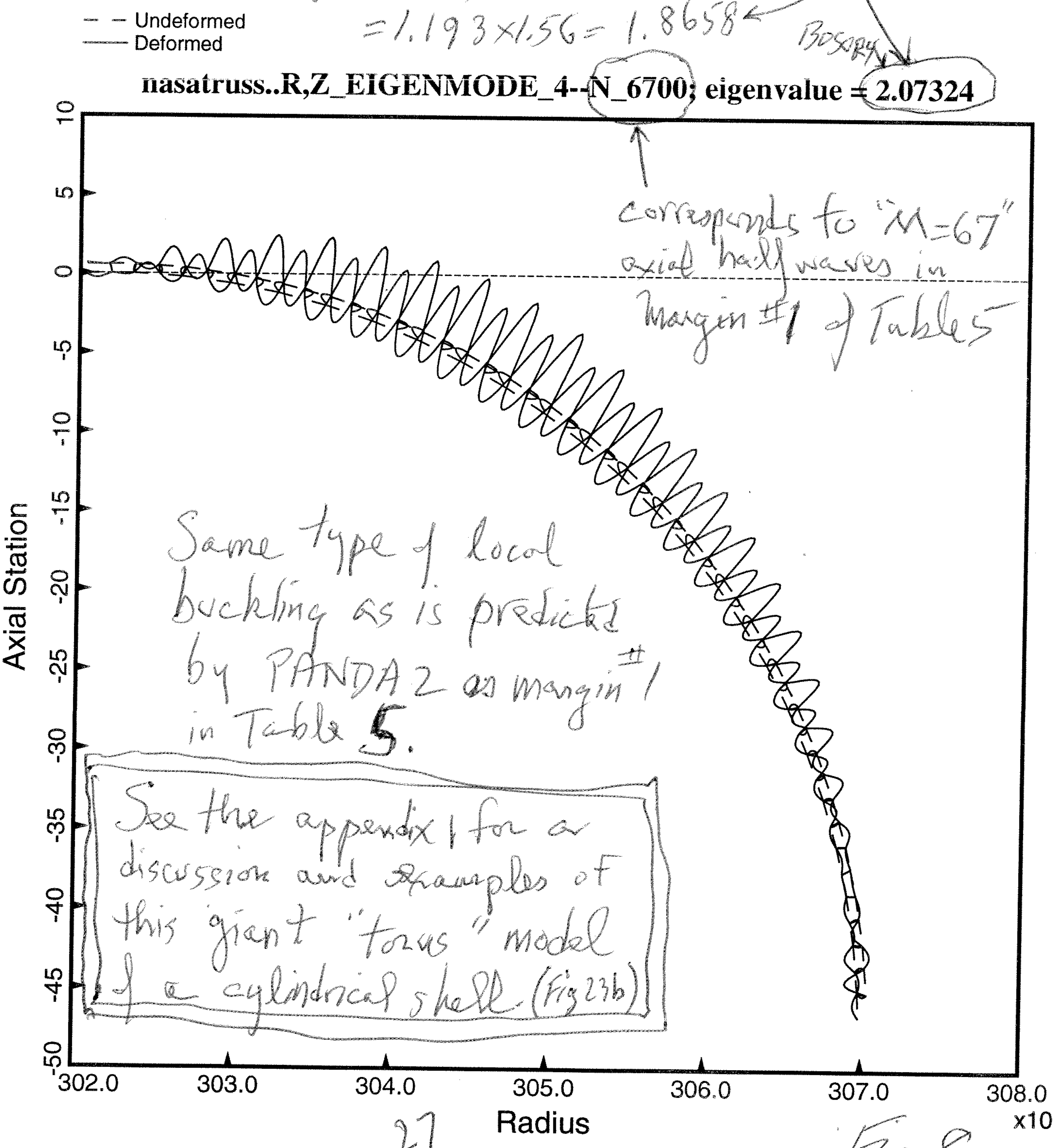
BIGBOSOR4 model,
PERFECT SHELL

PANDA2 local buckling load factor is given by (Margin #1 +1.0) × f.s. ($f.s. = 1.56$)

PANDA2 $= 1.193 \times 1.56 = 1.8658$

Compare with Margin #1, Table 5

BOSOR4



corresponds to "M=67" axial halfwaves in Margin #1 of Table 5

Same type of local buckling as is predicted by PANDA2 as margin #1 in Table 5.

See the appendix 1 for a discussion and examples of this giant "torus" model of a cylindrical shell. (Fig 23b)

Fig. 8

Table 11 nasatruss.pan3

```
n           $ Do you want a tutorial session and tutorial output?
9.2478      $ 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
67          $ Number of halfwaves in the axial direction [see H(elp)],NWAVE
10          $ How many eigenvalues (get at least 3) do you want?
```

input for PANEL.

PANEL generates an input file for BIGBOSOR4:

nasatruss.ALL

local buckling

3 modules = 3 × B = 3 × 3.0826 inches

Table 12 Output from BIGBOSOR4

nasatruss.OUT (abridged, model with three modules)

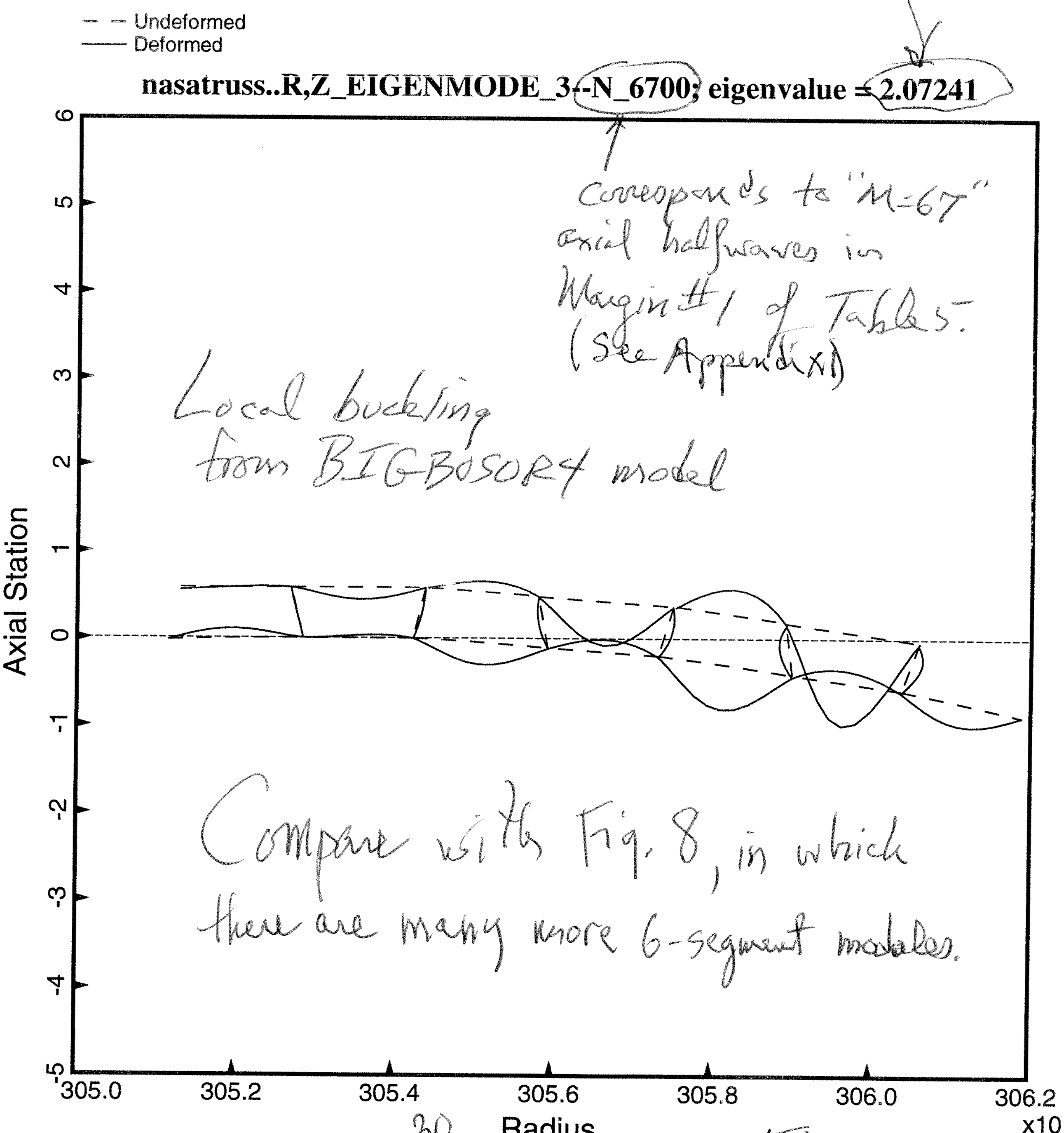
```
 BUCKLING LOADS FOLLOW
 CIRCUMFERENTIAL WAVE NUMBER, N =    6700

 EIGENVALUES =
    8.11064E-01    1.94884E+00    2.07241E+00    2.15856E+00    2.23687E+00    2.26492E+00    2.»
28451E+00

 EIGENVALUES =
    2.38556E+00    3.51022E+00    3.52142E+00
```

edge buckling: Don't compare these 2 values with PANDA2 predictions. (See Appendix)

Compare with Table 10

BIGBOSOR4 model

Compare with the Fig. 8



corresponds to "M=67" axial halfwaves in Margin #1 of Table 5. (See Appendix 1)

Local buckling from BIGBOSOR4 model

Compare with Fig. 8, in which there are many more 6-segment modules.

Fig. 9

Table 13 BIGBOSURY model

nasatruss.RES (input for resetup for local buckling (3 module model):

```
      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?
      3000      $ N0B   = starting number of circ. waves (buckling analysis)
      3000      $ NMINB = minimum number of circ. waves  (buckling analysis)
     10000      $ NMAXB = maximum number of circ. waves  (buckling analysis)
       500      $ INCRB = increment in number of circ. waves (buckling)
         3      $ 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?
```

---

nasatruss.OUT (abridged output from bigrestart):

"edge" buckling modes Don't compare with PANDA2 (See Appendix)

"true" local buckling modes

```
 BUCKLING LOADS FOLLOW
 CIRCUMFERENTIAL WAVE NUMBER, N =     3000

 EIGENVALUES =
     6.80644E-01    3.18622E+00    3.44258E+00

 BUCKLING LOADS FOLLOW
 CIRCUMFERENTIAL WAVE NUMBER, N =     3500

 EIGENVALUES =
     6.49772E-01    2.74357E+00    3.00782E+00

 BUCKLING LOADS FOLLOW
 CIRCUMFERENTIAL WAVE NUMBER, N =     4000

 EIGENVALUES =
     6.43188E-01    2.44158E+00    2.67921E+00

 BUCKLING LOADS FOLLOW
 CIRCUMFERENTIAL WAVE NUMBER, N =     4500

 EIGENVALUES =
     6.52845E-01    2.23997E+00    2.44877E+00

 BUCKLING LOADS FOLLOW
 CIRCUMFERENTIAL WAVE NUMBER, N =     5000

 EIGENVALUES =
     6.74442E-01    2.10730E+00    2.29101E+00

 BUCKLING LOADS FOLLOW
 CIRCUMFERENTIAL WAVE NUMBER, N =     5500

 EIGENVALUES =
     7.05525E-01    2.02308E+00    2.18568E+00

 BUCKLING LOADS FOLLOW
 CIRCUMFERENTIAL WAVE NUMBER, N =     6000

 EIGENVALUES =
     7.44612E-01    1.97411E+00    2.11881E+00

 BUCKLING LOADS FOLLOW
 CIRCUMFERENTIAL WAVE NUMBER, N =     6500

 EIGENVALUES =
     7.90767E-01    1.95173E+00    2.08094E+00

 BUCKLING LOADS FOLLOW
 CIRCUMFERENTIAL WAVE NUMBER, N =     7000

 EIGENVALUES =
     8.43379E-01    1.95009E+00    2.06567E+00

 BUCKLING LOADS FOLLOW
 CIRCUMFERENTIAL WAVE NUMBER, N =     7500

 EIGENVALUES =
     9.02032E-01    1.96520E+00    2.06854E+00
```

Check to see if 67 axial halfwaves (Table 11) is close to the critical value. It is, so BIGBOSORY & PANDA2 agree.

critical value

Table 13

(p. 2 of 2)

```
BUCKLING LOADS FOLLOW
CIRCUMFERENTIAL WAVE NUMBER, N =      8000

EIGENVALUES =
   9.66437E-01    1.99421E+00    2.08646E+00

BUCKLING LOADS FOLLOW
CIRCUMFERENTIAL WAVE NUMBER, N =      8500

EIGENVALUES =
   1.03639E+00    2.03508E+00    2.11720E+00

BUCKLING LOADS FOLLOW
CIRCUMFERENTIAL WAVE NUMBER, N =      9000

EIGENVALUES =
   1.11173E+00    2.08632E+00    2.15914E+00

BUCKLING LOADS FOLLOW
CIRCUMFERENTIAL WAVE NUMBER, N =      9500

EIGENVALUES =
   1.19237E+00    2.14682E+00    2.21110E+00

BUCKLING LOADS FOLLOW
CIRCUMFERENTIAL WAVE NUMBER, N =     10000

EIGENVALUES =
   1.27820E+00    2.21573E+00    2.27214E+00
```

PANDA2-type local buckling

edge buckling: Don't compare with PANDA2. (See Appendix 1)

Table 14

nasatruss.CHG (nasatruss.chg2)

```
    n           $ Do you want a tutorial session and tutorial output?
    y           $ Do you want to change any values in Parameter Set No. 1?
       6        $ Number of parameter to change (1, 2, 3, . .)
0.5200000E-02   $ New value of the parameter
    n           $ Want to change any other parameters in this set?
    n           $ Do you want to change values of "fixed" parameters?
    n           $ Do you want to change values of allowables?
```

CHANGE Used to make T(3) exactly one ply thick. (T(3) changed from 0.0055074" in Table 5 to 0.0052" which is the thickness of <u>one</u> ply.)

Table 15 nasatruss.OPM (T(3)=0.0052")

nasatruss.OPM (abridged, for the optimum design with T(3) changed from 0.0055074 to 0.0052 (exactly one ply)

****

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 =  -5.00E+03 -5.00E-03  2.50E+01  0.00E+00  0.00E+00
         Nxo, Nyo, pressure  =   0.00E+00  0.00E+00 -1.04E-04
BUCKLING LOAD FACTORS FOR LOCAL BUCKLING FROM KOITER v. BOSOR4 THEORY:
 Local buckling load factor from KOITER theory =  1.8060E+00 (flat skin)
 Local buckling load factor from BOSOR4 theory =  1.8425E+00 (flat skin)
0
MARGINS FOR CURRENT DESIGN: LOAD CASE NO. 1, SUBCASE NO. 1
MAR. MARGIN
NO.  VALUE              DEFINITION
 1  1.81E-01 Local buckling from discrete model-1.,M=67  axial halfwaves;FS=1.56
 2  9.57E+00 local wide-column bucking, discrete model(m=1   axial halfwav);FS=2
 3  1.58E-01 Local buckling from Koiter theory,M=70  axial halfwaves;FS=1.56
 4  3.18E+00 fibertensn:matl=1,SKN,Dseg=2,node=1,layer=3,z=-0.0156; MID.;FS=1.27
 5  3.25E-01 fibercompr:matl=1,STR,Dseg=3,node=6,layer=3,z=-0.0243; MID.;FS=1.27
 6 -4.94E-03 transtensn:matl=1,SKN,Dseg=1,node=7,layer=10,z=0.0243; MID.;FS=1.27
 7  5.49E+00 transcompr:matl=1,SKN,Dseg=1,node=7,layer=3,z=-0.0277; MID.;FS=1.27
 8  9.27E-01 inplnshear:matl=1,SKN,Dseg=2,node=1,layer=1,z=-0.026; MID.;FS=1.27
 9  3.18E+00 fibertensn:matl=1,SKN,Iseg=2,at:TIP,layer=8,z=0.013;-MID.;FS=1.27
10  3.25E-01 fibercompr:matl=1,STR,Iseg=3,at:n=11,layer=5,z=0.0017;-MID.;FS=1.27
11 -4.66E-03 transtensn:matl=1,STR,Iseg=3,at:n=11,layer=5,z=0.0017;-MID.;FS=1.27
12  5.50E+00 transcompr:matl=1,STR,Iseg=3,at:n=11,layer=10,z=0.0277;-MID.;FS=1.2
13  9.28E-01 inplnshear:matl=1,SKN,Iseg=2,at:TIP,layer=10,z=-0.0234;-MID.;FS=1.27
14  3.05E+05 buckling marg.   skin   Iseg.(width-wise wide col.)MID.;FS=1.56
15  4.87E+06 buckling marg. stringer Iseg.(width-wise wide col.)MID.;FS=1.56
16  3.05E+05 buckling marg.   skin   Iseg.(width-wise wide col.)NOPO;FS=1.56
17  4.87E+06 buckling marg. stringer Iseg.(width-wise wide col.)NOPO;FS=1.56
18  2.77E-02 buck.(SAND); STRINGERS:  lower skin;  M=60;N=1;slope=0.04;FS=1.56
19  5.59E-04 buck.(SAND);simp-support general buck;M=1;N=4;slope=0.;FS=2.154
20 -2.16E-02 buck.(SAND); STRINGERS:  web buckling;M=64;N=1;slope=-0.01;FS=1.56
21 -1.49E-02 buck.(SAND); STRINGERS:  upper skin;  M=60;N=1;slope=0.1715;FS=1.56
22  1.84E+02 (Max.allowable ave.axial strain)/(ave.axial strain) -1; FS=1.
23 -3.10E-04 0.45   *(Stringer spacing, b)/(Stringer base width, b2)-1;FS=1.
24  1.25E+00 (Str. base width, b2)/(0.2    *(Str. spacing, b))-1; FS=1.
25  4.99E-02 1.-V(2)^1+0.5V(1)^1-1
***********  ALL 1 LOAD SETS PROCESSED  ***********
****************************************************
```

Compare with Table 5

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	3.0826E+00	9.00E+00	B(STR):pitch of truss core, b: seg=NA, layer=NA
2	Y	N	N	0	0.00E+00	1.00E-01	1.3876E+00	7.00E+00	B2(STR):width over which truss core contacts each fa
3	Y	N	N	0	0.00E+00	1.00E-01	5.7880E-01	2.00E+00	H(STR):height of truss, h: WEB seg=2 , layer=NA
4	Y	Y	N	0	0.00E+00	5.20E-03	5.2000E-03	1.56E-02	T(1)(SKN):thickness for layer index no.(1): SKN seg=1
5	N	N	Y	4	1.00E+00	0.00E+00	5.2000E-03	0.00E+00	T(2)(SKN):thickness for layer index no.(2): SKN seg=1
6	Y	Y	N	0	0.00E+00	5.20E-03	5.2000E-03	1.56E-02	T(3)(SKN):thickness for layer index no.(3): SKN seg=1
7	Y	Y	N	0	0.00E+00	5.20E-03	5.2000E-03	1.56E-02	T(4)(SKN):thickness for layer index no.(4): SKN seg=1
8	N	N	Y	7	1.00E+00	0.00E+00	5.2000E-03	0.00E+00	T(5)(SKN):thickness for layer index no.(5): SKN seg=1
9	Y	Y	N	0	0.00E+00	5.20E-03	5.2000E-03	1.56E-02	T(6)(SKN):thickness for layer index no.(6): SKN seg=1
10	Y	Y	N	0	0.00E+00	5.20E-03	1.5600E-02	1.56E-02	T(7)(SKN):thickness for layer index no.(7): SKN seg=1

was 0.0055074 in Table 5

CURRENT VALUE OF THE OBJECTIVE FUNCTION:

VAR. NO.	STR/ RNG	SEG. NO.	LAYER NO.	CURRENT VALUE	DEFINITION
		0	0	1.368E+01	WEIGHT OF THE ENTIRE PANEL

"legal" optimum design.

180 degrees

(180 degrees)

Table 15, p. 2 of 2   nasatruss.OPM (p. 2 of 2)

```
  TOTAL WEIGHT OF SKIN                                 =   1.3681E+01
  TOTAL WEIGHT OF SUBSTIFFENERS                        =   0.0000E+00
  TOTAL WEIGHT OF STRINGERS                            =   0.0000E+00
  TOTAL WEIGHT OF RINGS                                =   0.0000E+00
  SPECIFIC WEIGHT (WEIGHT/AREA) OF STIFFENED PANEL=   9.4508E-04
 IN ORDER TO AVOID FALSE CONVERGENCE OF THE DESIGN, BE SURE TO
 RUN  PANDAOPT  MANY TIMES DURING AN OPTIMIZATION. INSPECT THE
 nasatruss.OPP  FILE AFTER EACH OPTIMIZATION RUN. OR BETTER YET,
 RUN SUPEROPT.
 ********************* END OF nasatruss.OPM FILE *****************
```

5 pandaopts/autochange
5 iterations/pandaopt
nasatruss.5.ps

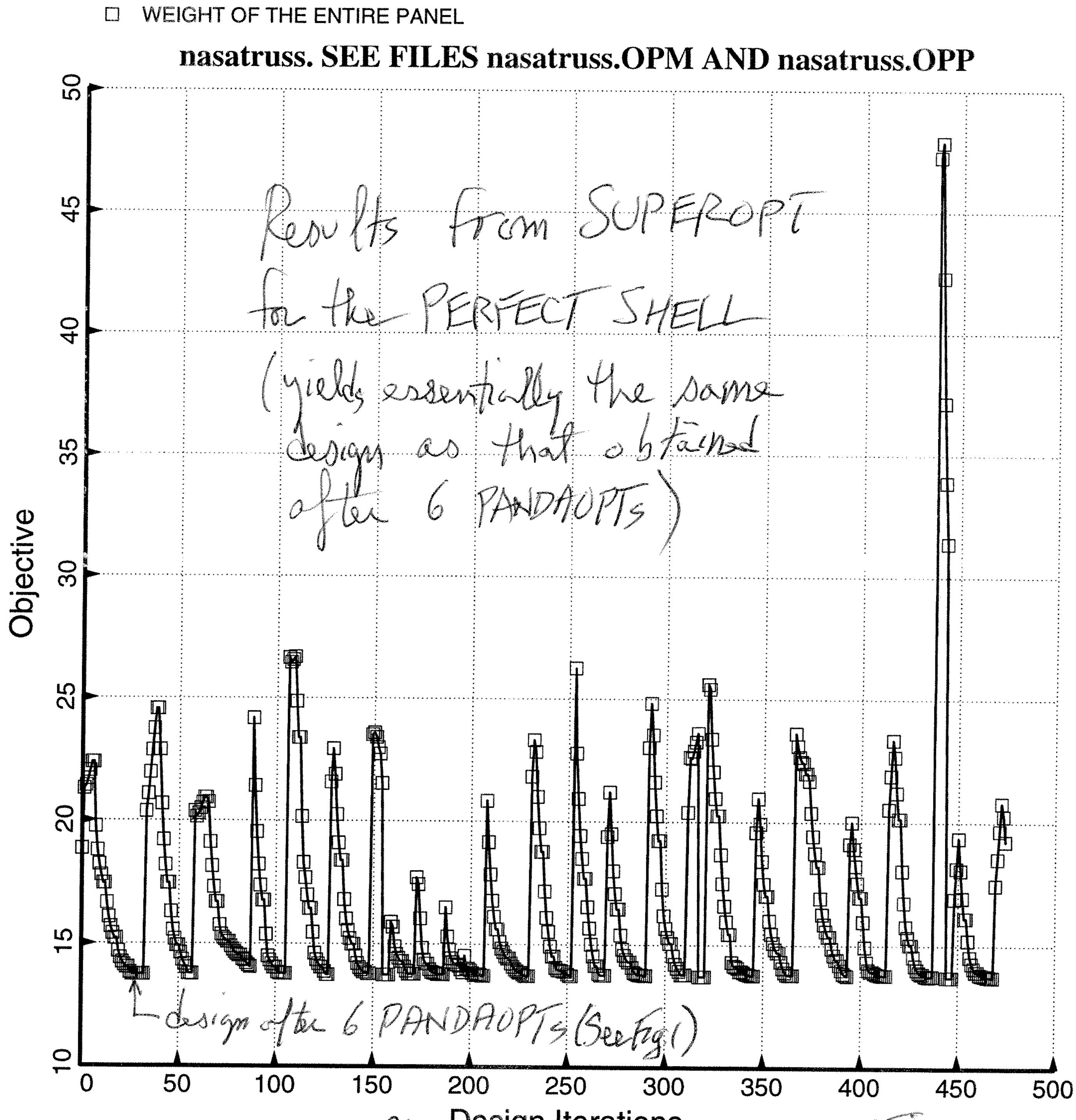


Fig. 10

PART 2

Optimize the shell as imperfect with buckling factors of safety = 0.999

The imperfection is in the shape of the general buckling mode with amplitude, Wimp.

There are two Load Sets:

1. Load Set 1 = + Wimp
2. Load Set 2 = − Wimp

Table 16

nasatruss.OPT (imperfect shell)

Input for MAINSETUP

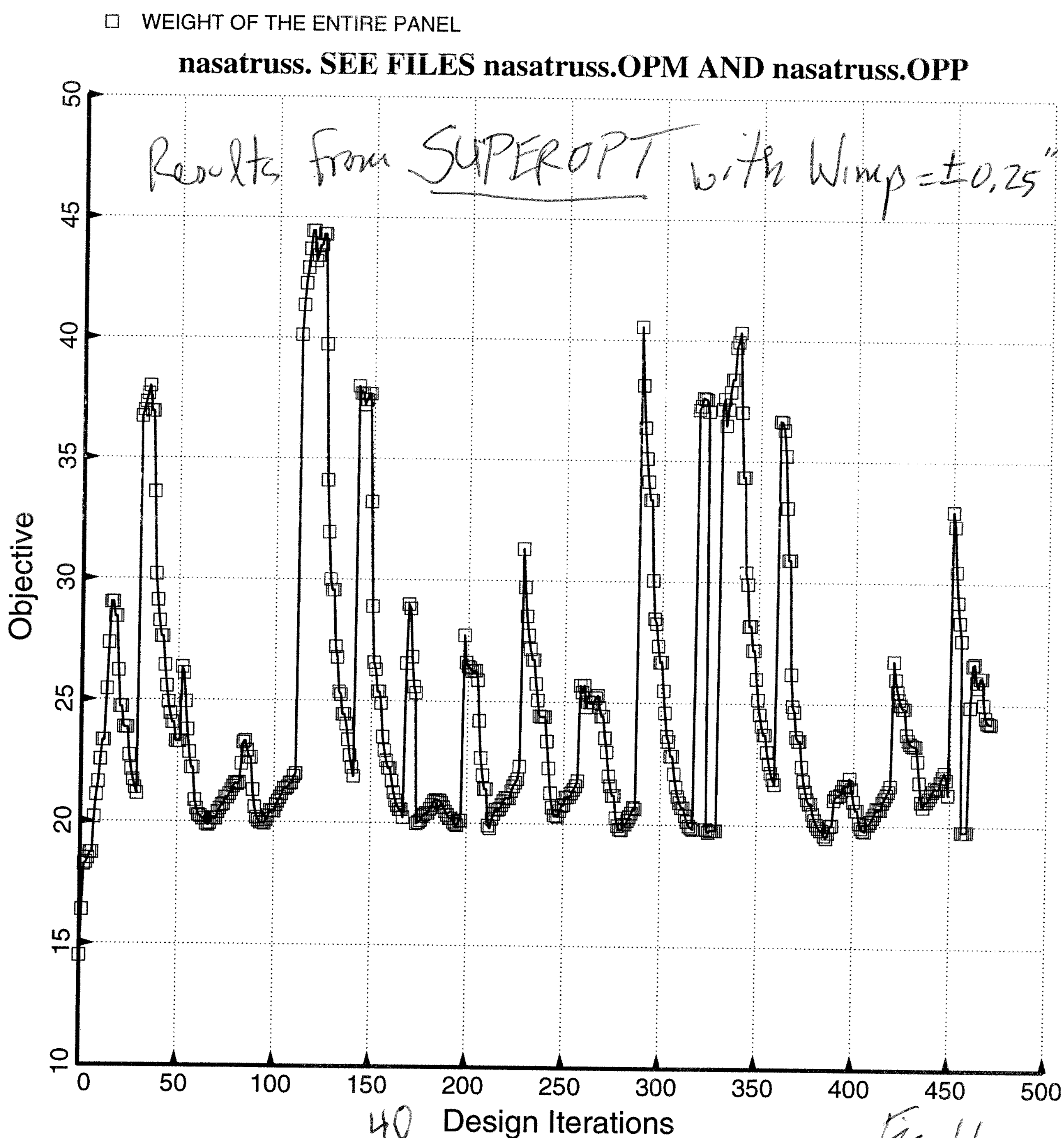
```
          n        $ Do you want a tutorial session and tutorial output?
      -5000        $ Resultant (e.g. lb/in) normal to the plane of screen, Nx( 1)
          0        $ Resultant (e.g. lb/in) in the plane of the screen,    Ny( 1)
          0        $ In-plane shear in load set A,                       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)
          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?
      0.999        $ Factor of safety for general instability, FSGEN( 1)
      0.999        $ Minimum load factor for local buckling (Type H for HELP), FSLOC( 1)
      1.000        $ Minimum load factor for stiffener buckling (Type H), FSBSTR( 1)
   1.270000        $ 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        $ Resultant (e.g. lb/in) normal to the plane of screen, Nx0( 1)
          0        $ 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        $ Uniform applied pressure [positive upward. See H(elp)], p( 1)
          0        $ Out-of-roundness, Wimpg1=(Max.diameter-Min.diam)/4, Wimpg1( 1)
Wimp = 0.25        $ Initial buckling modal general imperfection amplitude, Wimpg2( 1)
          0        $ 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)?
          n        $ Do you want a "complete" analysis (type H for "Help")?
          n        $ Have you rerun DECIDE with new decision variables and lower bounds?
          y        $ Want to provide another load set ?
      -5000        $ 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)
          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?
      0.999        $ Factor of safety for general instability, FSGEN( 1)
      0.999        $ Minimum load factor for local buckling (Type H for HELP), FSLOC( 1)
      1.000        $ Minimum load factor for stiffener buckling (Type H), FSBSTR( 1)
   1.270000        $ 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        $ Resultant (e.g. lb/in) normal to the plane of screen, Nx0( 1)
          0        $ 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        $ Uniform applied pressure [positive upward. See H(elp)], p( 1)
          0        $ Out-of-roundness, Wimpg1=(Max.diameter-Min.diam)/4, Wimpg1( 1)
Wimp = -0.25       $ Initial buckling modal general imperfection amplitude, Wimpg2( 1)
          0        $ 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)?
          n        $ Do you want a "complete" analysis (type H for "Help")?
          n        $ Have you rerun DECIDE with new decision variables and lower bounds?
          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        $ 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]?
          0        $ Choose (0=transverse inextensional; 1=transverse extensional)
          1        $ Choose ICONSV = -1 or 0 or 1 or H(elp), ICONSV
          1        $ 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)
```

NOTE!

Table 16 (p. 2 of 2)

```
     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)
```

5 pandaopts/autochange
5 iterations/pandaopt



40

Fig. 11

Table 17

IMPERFECT SHELL

nasatruss.OPM (abridged, imperfect shell with Wimp=0.25 inch)

Result for the optimum design after SUPEROPT

```
 ***********************************************************
 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 =  -5.00E+03 -5.00E-03  2.50E+01  0.00E+00  0.00E+00
          Nxo, Nyo, pressure  =   0.00E+00  0.00E+00 -1.04E-04
 BUCKLING LOAD FACTORS FOR LOCAL BUCKLING FROM KOITER v. BOSOR4 THEORY:
  Local buckling load factor from KOITER theory =  1.3324E+00 (flat skin)
  Local buckling load factor from BOSOR4 theory =  1.3934E+00 (flat skin)
0
 MARGINS FOR CURRENT DESIGN: LOAD CASE NO. 1, SUBCASE NO. 1
 MAR. MARGIN
 NO.  VALUE                  DEFINITION
 1   3.95E-01 Local buckling from discrete model-1.,M=39  axial halfwaves;FS=0.99
 2   6.16E+00 local wide-column bucking, discrete model(m=1   axial halfwav);FS=0
 3   3.34E-01 Local buckling from Koiter theory,M=38  axial halfwaves;FS=0.999
 4   1.01E+01 fibertensn:matl=1,STR,Dseg=4,node=1,layer=3,z=-0.0187; MID.;FS=1.27
 5   1.41E+00 fibercompr:matl=1,STR,Dseg=3,node=6,layer=3,z=-0.0364; MID.;FS=1.27
 6   5.22E-02 transtensn:matl=1,SKN,Dseg=1,node=7,layer=10,z=0.0364; MID.;FS=1.27
 7   2.82E+00 inplnshear:matl=1,STR,Dseg=4,node=1,layer=1,z=-0.0291; MID.;FS=1.27
 8   1.01E+01 fibertensn:matl=1,SKN,Iseg=2,at:TIP,layer=8,z=0.0146;-MID.;FS=1.27
 9   1.41E+00 fibercompr:matl=1,SKN,Iseg=1,at:n=1,layer=10,z=0.0364;-MID.;FS=1.27
 10 -2.62E-03 transtensn:matl=1,STR,Iseg=3,at:n=1,layer=3,z=-0.0364;-MID.;FS=1.27
 11  2.82E+00 inplnshear:matl=1,SKN,Iseg=2,at:TIP,layer=10,z=0.0265;-MID.;FS=1.27
 12  2.77E+05 buckling marg.   skin   Iseg.(width-wise wide col.)MID.;FS=1.
 13  6.65E+05 buckling marg. stringer Iseg.(width-wise wide col.)MID.;FS=1.
 14  2.77E+05 buckling marg.   skin   Iseg.(width-wise wide col.)NOPO;FS=1.
 15  6.65E+05 buckling marg. stringer Iseg.(width-wise wide col.)NOPO;FS=1.
 16  4.04E-01 buck.(SAND); STRINGERS:  lower skin;  M=34;N=1;slope=0.03;FS=1.
 17  5.07E+00 buck.(SAND);simp-support general buck;M=1;N=3;slope=0.;FS=0.999
 18  1.28E-01 buck.(SAND); STRINGERS:  web buckling;M=34;N=1;slope=-0.04;FS=1.
 19  1.63E-01 buck.(SAND); STRINGERS:  upper skin;  M=34;N=1;slope=0.1244;FS=1.
 20  3.62E+02 (Max.allowable ave.axial strain)/(ave.axial strain) -1; FS=1.
 21  5.73E-03 0.45   *(Stringer spacing, b)/(Stringer base width, b2)-1;FS=1.
 22  1.24E+00 (Str. base width, b2)/(0.2    *(Str. spacing, b))-1; FS=1.
 23  5.26E-02 1.-V(2)^1+0.5V(1)^1-1
```

Wimp=+0.25"

```
 ***********************************************************
 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 2;  SUBCASE 1:
 LOADING: Nx, Ny, Nxy, Mx, My =  -5.00E+03 -5.00E-03  2.50E+01  0.00E+00  0.00E+00
          Nxo, Nyo, pressure  =   0.00E+00  0.00E+00 -1.04E-04
 BUCKLING LOAD FACTORS FOR LOCAL BUCKLING FROM KOITER v. BOSOR4 THEORY:
  Local buckling load factor from KOITER theory =  1.3434E+00 (flat skin)
  Local buckling load factor from BOSOR4 theory =  1.3862E+00 (flat skin)
0
 MARGINS FOR CURRENT DESIGN: LOAD CASE NO. 2, SUBCASE NO. 1
 MAR. MARGIN
 NO.  VALUE                  DEFINITION
 1   3.88E-01 Local buckling from discrete model-1.,M=36  axial halfwaves;FS=0.99
 2   5.91E+00 local wide-column bucking, discrete model(m=1   axial halfwav);FS=0
 3   3.45E-01 Local buckling from Koiter theory,M=37  axial halfwaves;FS=0.999
 4   1.01E+01 fibertensn:matl=1,SKN,Dseg=2,node=1,layer=3,z=-0.0187; MID.;FS=1.27
 5   1.41E+00 fibercompr:matl=1,SKN,Dseg=1,node=11,layer=10,z=0.0364; MID.;FS=1.2
 6   5.32E-02 transtensn:matl=1,STR,Dseg=6,node=11,layer=3,z=-0.0364; MID.;FS=1.2
 7   2.82E+00 inplnshear:matl=1,SKN,Dseg=2,node=1,layer=1,z=-0.0291; MID.;FS=1.27
 8   1.01E+01 fibertensn:matl=1,SKN,Iseg=2,at:TIP,layer=8,z=0.0146;-MID.;FS=1.27
 9   1.41E+00 fibercompr:matl=1,STR,Iseg=3,at:n=1,layer=3,z=-0.0364;-MID.;FS=1.27
 10 -2.62E-03 transtensn:matl=1,SKN,Iseg=1,at:n=1,layer=10,z=0.0364;-MID.;FS=1.27
 11  2.82E+00 inplnshear:matl=1,SKN,Iseg=2,at:TIP,layer=10,z=0.0265;-MID.;FS=1.27
```

Wimp=-0.25"

Table 17 (p. 2 of 2)

```
12   5.23E+00 buckling marg.   skin    Iseg.(width-wise wide col.)MID.;FS=1.
13   6.65E+05 buckling marg. stringer Iseg.(width-wise wide col.)MID.;FS=1.
14   2.77E+05 buckling marg.   skin    Iseg.(width-wise wide col.)NOPO;FS=1.
15   6.65E+05 buckling marg. stringer Iseg.(width-wise wide col.)NOPO;FS=1.
16   1.89E-01 buck.(SAND); STRINGERS:  lower skin;  M=34;N=1;slope=0.03;FS=1.
17   5.07E+00 buck.(SAND);simp-support general buck;M=1;N=3;slope=0.;FS=0.999
18   1.29E-01 buck.(SAND); STRINGERS:  web buckling;M=34;N=1;slope=-0.04;FS=1.
19   4.35E-01 buck.(SAND); STRINGERS:  upper skin;  M=37;N=1;slope=0.1294;FS=1.
20   3.62E+02 (Max.allowable ave.axial strain)/(ave.axial strain) -1; FS=1.
 ***********  ALL 2 LOAD SETS PROCESSED  ***********
 ****************************************************


            SUMMARY OF INFORMATION FROM OPTIMIZATION ANALYSIS
 VAR. DEC. ESCAPE LINK. LINKED  LINKING    LOWER    CURRENT      UPPER        DEFINITION
  NO. VAR.  VAR.  VAR.    TO    CONSTANT   BOUND     VALUE       BOUND
   1   Y     N     N      0    0.00E+00  1.00E+00 5.0803E+00  9.00E+00        B(STR):pitch of tr»
uss core, b:    seg=NA, layer=NA
   2   Y     N     N      0    0.00E+00  1.00E-01 2.2731E+00  7.00E+00       B2(STR):width over »
which truss core contacts each fa
   3   Y     N     N      0    0.00E+00  1.00E-01 2.0000E+00  2.00E+00        H(STR):height of t»
russ, h: WEB seg=2 , layer=NA
   4   Y     Y     N      0    0.00E+00  5.20E-03 5.2000E-03  1.56E-02     T(1 )(SKN):thickness f»
or layer index no.(1 ): SKN seg=1
   5   N     N     Y      4    1.00E+00  0.00E+00 5.2000E-03  0.00E+00     T(2 )(SKN):thickness f»
or layer index no.(2 ): SKN seg=1
   6   Y     Y     N      0    0.00E+00  5.20E-03 8.3111E-03  1.56E-02     T(3 )(SKN):thickness f»
or layer index no.(3 ): SKN seg=1
   7   Y     Y     N      0    0.00E+00  5.20E-03 5.2000E-03  1.56E-02     T(4 )(SKN):thickness f»
or layer index no.(4 ): SKN seg=1
   8   N     N     Y      7    1.00E+00  0.00E+00 5.2000E-03  0.00E+00     T(5 )(SKN):thickness f»
or layer index no.(5 ): SKN seg=1
   9   Y     Y     N      0    0.00E+00  5.20E-03 1.5600E-02  1.56E-02     T(6 )(SKN):thickness f»
or layer index no.(6 ): SKN seg=1
  10   Y     Y     N      0    0.00E+00  5.20E-03 1.5600E-02  1.56E-02     T(7 )(SKN):thickness f»
or layer index no.(7 ): SKN seg=1

   CURRENT VALUE OF THE OBJECTIVE FUNCTION:
 VAR. STR/ SEG. LAYER    CURRENT
 NO.  RNG  NO.   NO.      VALUE            DEFINITION
            0     0    1.978E+01  WEIGHT OF THE ENTIRE PANEL

  TOTAL WEIGHT OF SKIN                                =    1.9777E+01
  TOTAL WEIGHT OF SUBSTIFFENERS                       =    0.0000E+00
  TOTAL WEIGHT OF STRINGERS                           =    0.0000E+00
  TOTAL WEIGHT OF RINGS                               =    0.0000E+00
  SPECIFIC WEIGHT (WEIGHT/AREA) OF STIFFENED PANEL=        1.3661E-03
 IN ORDER TO AVOID FALSE CONVERGENCE OF THE DESIGN, BE SURE TO
 RUN  PANDAOPT  MANY TIMES DURING AN OPTIMIZATION. INSPECT THE
 nasatruss.OPP  FILE AFTER EACH OPTIMIZATION RUN. OR BETTER YET,
 RUN SUPEROPT.
 ******************** END OF nasatruss.OPM FILE *****************
```

Optimum design with Wimp = ±0.25" after one execution of SUPEROPT

Too heavy. Next, use a smaller imperfection amplitude.

Weight of 180 degrees of cylindrical shell

Table18 nasatruss.OPT

```
      n          $ Do you want a tutorial session and tutorial output?
  -5000          $ 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)
      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?
  0.999          $ Factor of safety for general instability, FSGEN( 1)
  0.999          $ Minimum load factor for local buckling (Type H for HELP), FSLOC( 1)
  1.000          $ Minimum load factor for stiffener buckling (Type H), FSBSTR( 1)
  1.270000       $ 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          $ Resultant (e.g. lb/in) normal to the plane of screen, Nx0( 1)
      0          $ 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          $ Uniform applied pressure [positive upward. See H(elp)], p( 1)
      0          $ Out-of-roundness, Wimpg1=(Max.diameter-Min.diam)/4, Wimpg1( 1)
  0.125          $ Initial buckling modal general imperfection amplitude, Wimpg2( 1)
      0          $ 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)?
      n          $ Do you want a "complete" analysis (type H for "Help")?
      n          $ Have you rerun DECIDE with new decision variables and lower bounds?
      y          $ Want to provide another load set ?
  -5000          $ 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)
      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?
  0.999          $ Factor of safety for general instability, FSGEN( 1)
  0.999          $ Minimum load factor for local buckling (Type H for HELP), FSLOC( 1)
  1.000          $ Minimum load factor for stiffener buckling (Type H), FSBSTR( 1)
  1.270000       $ 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          $ Resultant (e.g. lb/in) normal to the plane of screen, Nx0( 1)
      0          $ 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          $ Uniform applied pressure [positive upward. See H(elp)], p( 1)
      0          $ Out-of-roundness, Wimpg1=(Max.diameter-Min.diam)/4, Wimpg1( 1)
 -0.125          $ Initial buckling modal general imperfection amplitude, Wimpg2( 1)
      0          $ 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)?
      n          $ Do you want a "complete" analysis (type H for "Help")?
      n          $ Have you rerun DECIDE with new decision variables and lower bounds?
      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          $ 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]?
      0          $ 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)
```

Wimp

Note!

Wimp

Smaller imperfection amplitude Wimp = ± 0.125"

Table 18 (p. 2 of 2)

```
     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)
```

5 panelopts/autochange
5 iterations/panelopt

□ WEIGHT OF THE ENTIRE PANEL

nasatruss. SEE FILES nasatruss.OPM AND nasatruss.OPP

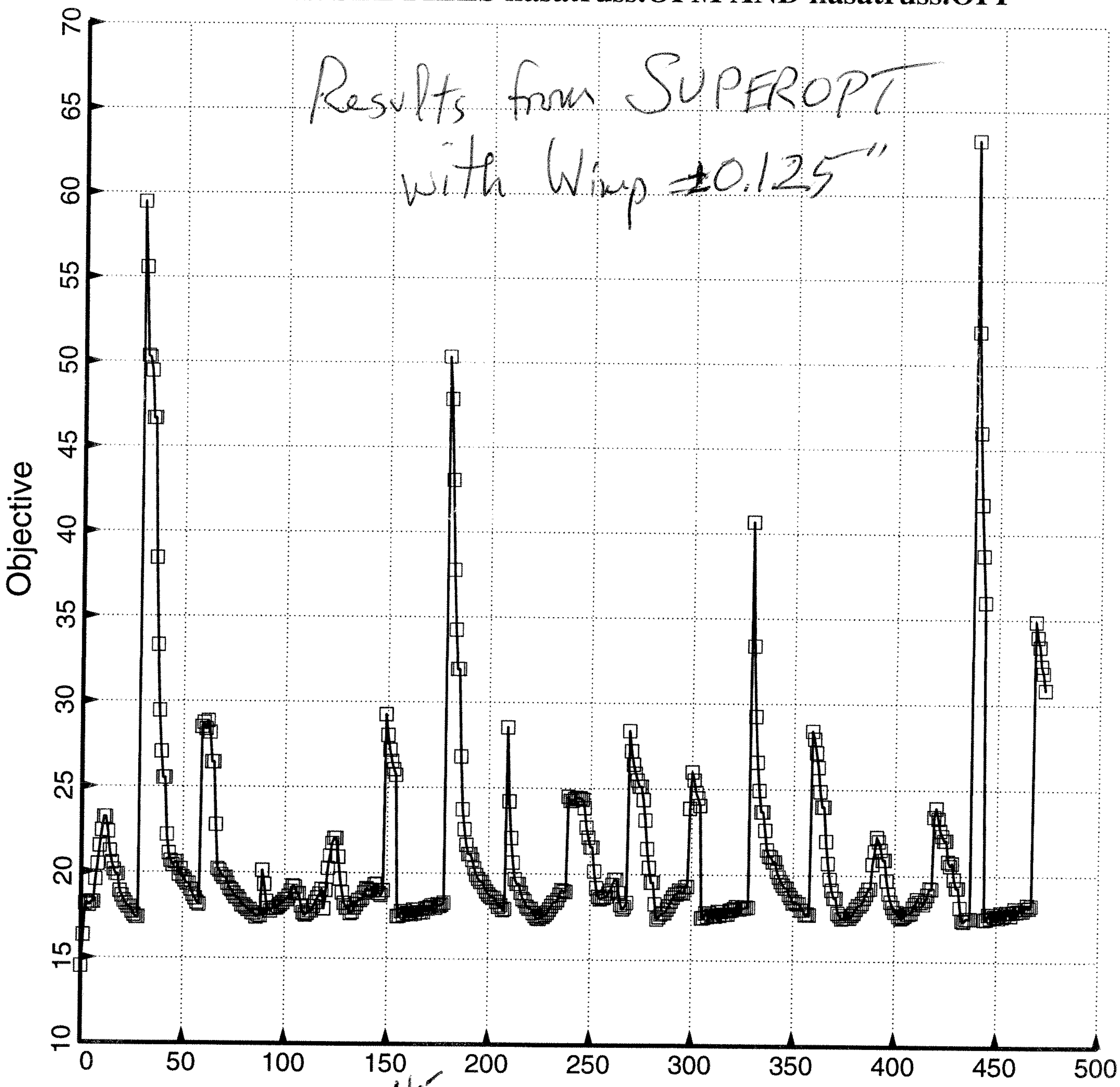


Fig. 12

Table 19 Optimized shell with Wimp = ± 0.125"

```
nasatruss.OPM (abridged, imperfect shell with Wimp=0.125 inch)

 ***********************************************************
 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 =  -5.00E+03 -5.00E-03  2.50E+01  0.00E+00  0.00E+00
          Nxo, Nyo, pressure  =   0.00E+00  0.00E+00 -1.04E-04
 BUCKLING LOAD FACTORS FOR LOCAL BUCKLING FROM KOITER v. BOSOR4 THEORY:
  Local buckling load factor from KOITER theory =  1.1178E+00 (flat skin)
  Local buckling load factor from BOSOR4 theory =  1.1438E+00 (flat skin)

 MARGINS FOR CURRENT DESIGN: LOAD CASE NO. 1, SUBCASE NO. 1
 MAR. MARGIN
 NO.  VALUE                 DEFINITION
  1  1.45E-01 Local buckling from discrete model-1.,M=38  axial halfwaves;FS=0.99
  2  5.12E+00 local wide-column bucking, discrete model(m=1   axial halfwav);FS=0
  3  1.19E-01 Local buckling from Koiter theory,M=36  axial halfwaves;FS=0.999
  4  7.59E+00 fibertensn:matl=1,STR,Dseg=4,node=1,layer=3,z=-0.0156; MID.;FS=1.27
  5  1.36E+00 fibercompr:matl=1,STR,Dseg=3,node=6,layer=3,z=-0.0338; MID.;FS=1.27
  6  4.05E-02 transtensn:matl=1,SKN,Dseg=1,node=7,layer=10,z=0.0338; MID.;FS=1.27
  7  2.57E+00 inplnshear:matl=1,STR,Dseg=4,node=1,layer=1,z=-0.026; MID.;FS=1.27
  8  7.60E+00 fibertensn:matl=1,SKN,Iseg=2,at:TIP,layer=8,z=0.013;-MID.;FS=1.27
  9  1.36E+00 fibercompr:matl=1,SKN,Iseg=1,at:n=1,layer=10,z=0.0338;-MID.;FS=1.27
 10 -1.61E-02 transtensn:matl=1,STR,Iseg=3,at:n=1,layer=3,z=-0.0338;-MID.;FS=1.27
 11  2.57E+00 inplnshear:matl=1,SKN,Iseg=2,at:TIP,layer=10,z=0.0234;-MID.;FS=1.27
 12  2.06E+05 buckling marg.   skin   Iseg.(width-wise wide col.)MID.;FS=1.
 13  8.16E+05 buckling marg. stringer Iseg.(width-wise wide col.)MID.;FS=1.
 14  2.06E+05 buckling marg.   skin   Iseg.(width-wise wide col.)NOPO;FS=1.
 15  8.16E+05 buckling marg. stringer Iseg.(width-wise wide col.)NOPO;FS=1.
 16  1.45E-01 buck.(SAND); STRINGERS:  lower skin;  M=33;N=1;slope=0.04;FS=1.
 17  2.71E+00 buck.(SAND);simp-support general buck;M=2;N=4;slope=0.;FS=0.999
 18  3.75E-02 buck.(SAND); STRINGERS:  web buckling;M=36;N=1;slope=-0.05;FS=1.
 19 -1.60E-02 buck.(SAND); STRINGERS:  upper skin;  M=30;N=1;slope=0.;FS=1.
 20  3.42E+02 (Max.allowable ave.axial strain)/(ave.axial strain) -1; FS=1.
 21 -1.42E-03 0.45    *(Stringer spacing, b)/(Stringer base width, b2)-1;FS=1.
 22  1.25E+00 (Str. base width, b2)/(0.2    *(Str. spacing, b))-1; FS=1.
 23  4.94E-02 1.-V(2)^1+0.5V(1)^1-1
```

Wimp = +0.125"

general buckling mode

Compare with BIGBOSOR4 versions in Figs. 13, 14, & 18.

```
 ***********************************************************
 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 2;  SUBCASE 1:
 LOADING: Nx, Ny, Nxy, Mx, My =  -5.00E+03 -5.00E-03  2.50E+01  0.00E+00  0.00E+00
          Nxo, Nyo, pressure  =   0.00E+00  0.00E+00 -1.04E-04
 BUCKLING LOAD FACTORS FOR LOCAL BUCKLING FROM KOITER v. BOSOR4 THEORY:
  Local buckling load factor from KOITER theory =  1.0994E+00 (flat skin)
  Local buckling load factor from BOSOR4 theory =  1.1365E+00 (flat skin)

 MARGINS FOR CURRENT DESIGN: LOAD CASE NO. 2, SUBCASE NO. 1
 MAR. MARGIN
 NO.  VALUE                 DEFINITION
  1  1.38E-01 Local buckling from discrete model-1.,M=35  axial halfwaves;FS=0.99
  2  4.98E+00 local wide-column bucking, discrete model(m=1   axial halfwav);FS=0
  3  1.01E-01 Local buckling from Koiter theory,M=35  axial halfwaves;FS=0.999
  4  7.59E+00 fibertensn:matl=1,SKN,Dseg=2,node=1,layer=8,z=0.0156; MID.;FS=1.27
  5  1.36E+00 fibercompr:matl=1,SKN,Dseg=1,node=7,layer=10,z=0.0338; MID.;FS=1.27
  6  4.17E-02 transtensn:matl=1,SKN,Dseg=1,node=7,layer=8,z=-0.0109; MID.;FS=1.27
  7  2.57E+00 inplnshear:matl=1,SKN,Dseg=2,node=1,layer=10,z=0.026; MID.;FS=1.27
  8  7.60E+00 fibertensn:matl=1,SKN,Iseg=2,at:TIP,layer=8,z=0.013;-MID.;FS=1.27
  9  1.36E+00 fibercompr:matl=1,STR,Iseg=3,at:n=1,layer=3,z=-0.0338;-MID.;FS=1.27
 10 -1.61E-02 transtensn:matl=1,STR,Iseg=3,at:n=1,layer=3,z=-0.0338;-MID.;FS=1.27
 11  2.57E+00 inplnshear:matl=1,SKN,Iseg=2,at:TIP,layer=10,z=0.0234;-MID.;FS=1.27
```

local buckling mode. Fig. 17 for BIGBOSOR4 version

Wimp = -0.125"

Table 19 (p. 2 of 2)

```
12  4.20E+00 buckling marg.   skin   Iseg.(width-wise wide col.)MID.;FS=1.
13  8.16E+05 buckling marg. stringer Iseg.(width-wise wide col.)MID.;FS=1.
14  2.06E+05 buckling marg.   skin   Iseg.(width-wise wide col.)NOPO;FS=1.
15  8.16E+05 buckling marg. stringer Iseg.(width-wise wide col.)NOPO;FS=1.
16  2.14E+05 buckling marg. stringer Iseg.(width-wise wide col.)NOPO;FS=1.
17 -1.78E-02 buck.(SAND); STRINGERS:  lower skin;  M=30;N=1;slope=0.04;FS=1.
18  2.71E+00 buck.(SAND);simp-support general buck;M=2;N=4;slope=0.;FS=0.999
19  3.78E-02 buck.(SAND); STRINGERS:  web buckling;M=36;N=1;slope=-0.05;FS=1.
20  1.98E-01 buck.(SAND); STRINGERS:  upper skin;  M=36;N=1;slope=0.04;FS=1.
21  3.42E+02 (Max.allowable ave.axial strain)/(ave.axial strain) -1; FS=1.
 ***********  ALL 2 LOAD SETS PROCESSED  ***********
 ****************************************************

        SUMMARY OF INFORMATION FROM OPTIMIZATION ANALYSIS
 VAR. DEC. ESCAPE LINK. LINKED  LINKING    LOWER     CURRENT     UPPER       DEFINITION
  NO. VAR.  VAR.  VAR.    TO    CONSTANT   BOUND      VALUE      BOUND
   1   Y     N     N      0    0.00E+00  1.00E+00  5.1924E+00  9.00E+00        B(STR):pitch of tr»
uss core, b:     seg=NA, layer=NA
   2   Y     N     N      0    0.00E+00  1.00E-01  2.3399E+00  7.00E+00        B2(STR):width over »
which truss core contacts each fa
   3   Y     N     N      0    0.00E+00  1.00E-01  1.4172E+00  2.00E+00        H(STR):height of t»
russ, h: WEB seg=2 , layer=NA
   4   Y     Y     N      0    0.00E+00  5.20E-03  5.2000E-03  1.56E-02    T(1 )(SKN):thickness f»
or layer index no.(1 ): SKN seg=1
   5   N     N     Y      4    1.00E+00  0.00E+00  5.2000E-03  0.00E+00    T(2 )(SKN):thickness f»
or layer index no.(2 ): SKN seg=1
   6   Y     Y     N      0    0.00E+00  5.20E-03  5.2000E-03  1.56E-02    T(3 )(SKN):thickness f»
or layer index no.(3 ): SKN seg=1
   7   Y     Y     N      0    0.00E+00  5.20E-03  5.2000E-03  1.56E-02    T(4 )(SKN):thickness f»
or layer index no.(4 ): SKN seg=1
   8   N     N     Y      7    1.00E+00  0.00E+00  5.2000E-03  0.00E+00    T(5 )(SKN):thickness f»
or layer index no.(5 ): SKN seg=1
   9   Y     Y     N      0    0.00E+00  5.20E-03  1.5600E-02  1.56E-02    T(6 )(SKN):thickness f»
or layer index no.(6 ): SKN seg=1
  10   Y     Y     N      0    0.00E+00  5.20E-03  1.3491E-02  1.56E-02    T(7 )(SKN):thickness f»
or layer index no.(7 ): SKN seg=1
0
   CURRENT VALUE OF THE OBJECTIVE FUNCTION:
 VAR. STR/ SEG. LAYER    CURRENT
 NO.  RNG  NO.   NO.      VALUE          DEFINITION
            0     0    1.748E+01   WEIGHT OF THE ENTIRE PANEL

  TOTAL WEIGHT OF SKIN                                =    1.7479E+01
  TOTAL WEIGHT OF SUBSTIFFENERS                       =    0.0000E+00
  TOTAL WEIGHT OF STRINGERS                           =    0.0000E+00
  TOTAL WEIGHT OF RINGS                               =    0.0000E+00
  SPECIFIC WEIGHT (WEIGHT/AREA) OF STIFFENED PANEL=    1.2074E-03
 IN ORDER TO AVOID FALSE CONVERGENCE OF THE DESIGN, BE SURE TO
 RUN  PANDAOPT  MANY TIMES DURING AN OPTIMIZATION. INSPECT THE
 nasatruss.OPP  FILE AFTER EACH OPTIMIZATION RUN. OR BETTER YET,
 RUN SUPEROPT.
 ******************** END OF nasatruss.OPM FILE *****************
```

(180°)

Optimum design with Wimp = ± 0.125" after one execution of SUPEROPT

Compare with the 180-degree weight from PART 1: 1.375E+01 (Table 5)

180 degrees of the cylindrical shell

Table 20 nasatruss, CHG

```
       n          $ Do you want a tutorial session and tutorial output?
       y          $ Do you want to change any values in Parameter Set No. 1?
          1       $ Number of parameter to change (1, 2, 3, . .)
  5.192400        $ New value of the parameter
       y          $ Want to change any other parameters in this set?
          2       $ Number of parameter to change (1, 2, 3, . .)
  2.339900        $ New value of the parameter
       y          $ Want to change any other parameters in this set?
          3       $ Number of parameter to change (1, 2, 3, . .)
  1.417200        $ New value of the parameter
       y          $ Want to change any other parameters in this set?
          4       $ Number of parameter to change (1, 2, 3, . .)
0.5200000E-02     $ New value of the parameter
       y          $ Want to change any other parameters in this set?
          5       $ Number of parameter to change (1, 2, 3, . .)
0.5200000E-02     $ New value of the parameter
       y          $ Want to change any other parameters in this set?
          6       $ Number of parameter to change (1, 2, 3, . .)
0.5200000E-02     $ New value of the parameter
       y          $ Want to change any other parameters in this set?
          7       $ Number of parameter to change (1, 2, 3, . .)
0.5200000E-02     $ New value of the parameter
       y          $ Want to change any other parameters in this set?
          8       $ Number of parameter to change (1, 2, 3, . .)
0.5200000E-02     $ New value of the parameter
       y          $ Want to change any other parameters in this set?
          9       $ Number of parameter to change (1, 2, 3, . .)
0.1560000E-01     $ New value of the parameter
       y          $ Want to change any other parameters in this set?
         10       $ Number of parameter to change (1, 2, 3, . .)
0.1349100E-01     $ New value of the parameter
       n          $ Want to change any other parameters in this set?
       n          $ Do you want to change values of "fixed" parameters?
       n          $ Do you want to change values of allowables?
```

input for CHANGE (in order to save the optimum designs obtained with Wimp = ± 0.125")

This thickness will later be changed to an integral number of plies: 3 plies = 0.0156". (See Table 25)

Table 21 nasatruss.pan4

```
    n         $ Do you want a tutorial session and tutorial output?
77.886        $ 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
      0       $ Enter ILOCAL=0 for panel buckling; 1 for local buckling, ILOCAL
      2       $ Number of halfwaves in the axial direction [see H(elp)],NWAVE
     10       $ How many eigenvalues (get at least 3) do you want?
```

input for PANEL, which generates an input file for BIGBOSOR4, nasatruss.ALL

see Margin 17 in Table 19

General buckling

15 modules = 15 x B = 15 x 5.1924"

Table 22 Output from BIGBOSOR4

nasatruss.RES (input for resetup for general buckling):

```
     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       $ N0B   = starting number of circ. waves (buckling analysis)
      100       $ NMINB = minimum number of circ. waves  (buckling analysis)
      500       $ NMAXB = maximum number of circ. waves  (buckling analysis)
      100       $ INCRB = increment in number of circ. waves (buckling)
        3       $ 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?
------------------------------------------------------------------
```

nasatruss.OUT (abridged output from BIGBOSOR4 from BIGRESTART:

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

 EIGENVALUES =
    2.00324E+00    2.38033E+00    3.38339E+00

 BUCKLING LOADS FOLLOW
 CIRCUMFERENTIAL WAVE NUMBER, N =     200

 EIGENVALUES =
    2.48527E+00    2.69735E+00    2.97785E+00

 BUCKLING LOADS FOLLOW
 CIRCUMFERENTIAL WAVE NUMBER, N =     300

 EIGENVALUES =
    2.94958E+00    3.29822E+00    3.43222E+00

 BUCKLING LOADS FOLLOW
 CIRCUMFERENTIAL WAVE NUMBER, N =     400

 EIGENVALUES =
    2.22128E+00    4.03391E+00    4.04888E+00

 BUCKLING LOADS FOLLOW
 CIRCUMFERENTIAL WAVE NUMBER, N =     500

 EIGENVALUES =
    1.60241E+00    4.75166E+00    4.77319E+00
```

critical value

PANDA2 mode.

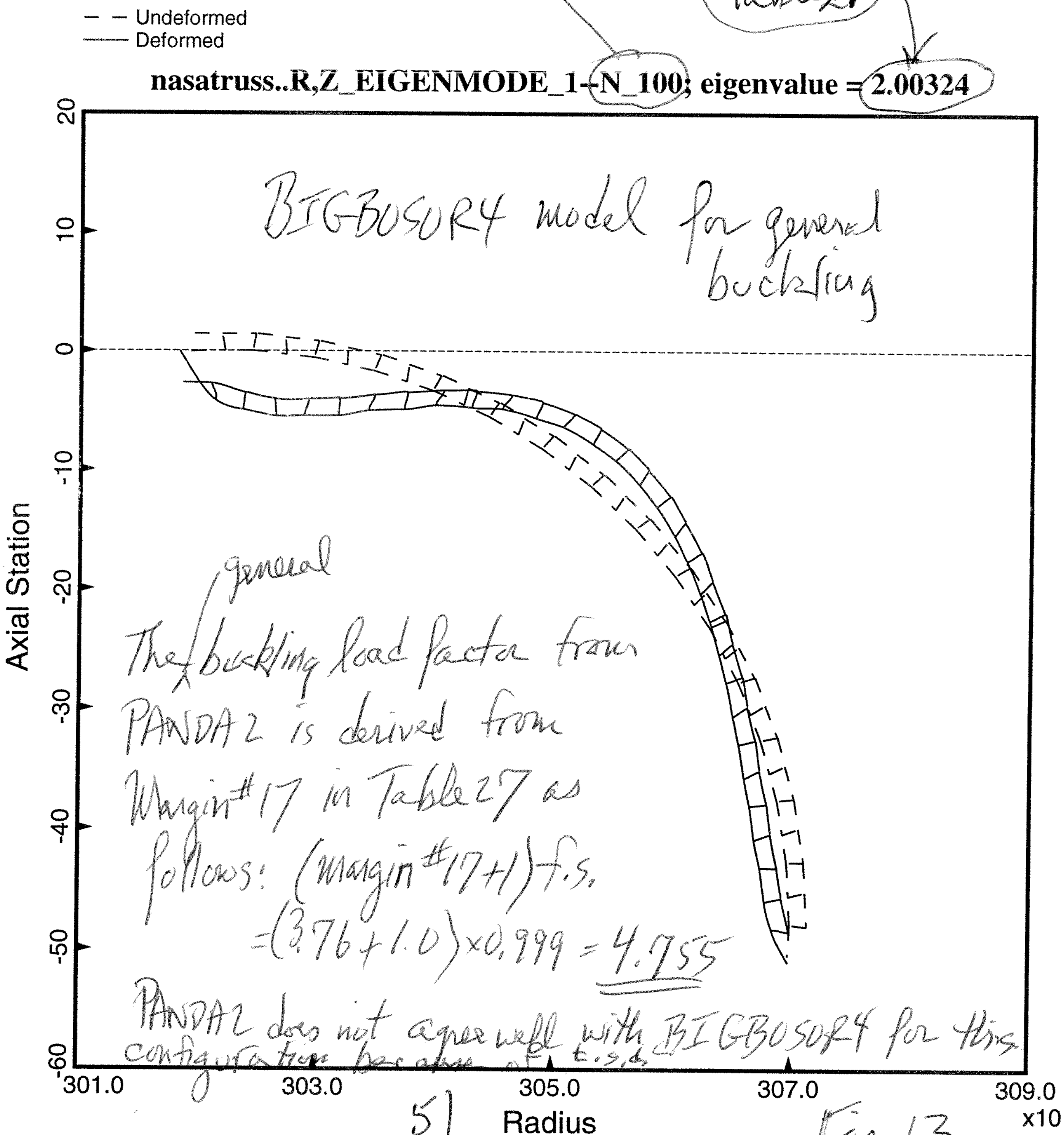
edge buckling: Do not compare with PANDA2 (see Appendix1)

Compare with Margin #17 in Table 19.
This BIGBOSOR4 model gives a much lower prediction for general buckling than PANDA2 does, probably because of the approximate nature of PANDA2's handling of the effect of t.s.d. (transverse shear deformation).

General buckling from BIGBOSOR4

corresponds to M=1 axial halfwave. (PANDA2 predicts M=2 = critical.)

Compare with Margin17 in Table27



BIGBOSOR4 model for general buckling

The general buckling load factor from PANDA2 is derived from Margin#17 in Table27 as follows: (margin#17+1) f.s. =(3.76+1.0)×0.999 = 4.755

PANDA2 does not agree well with BIGBOSOR4 for this configuration because of e.g.,

Fig. 13

General buckling from BIGBOSORY

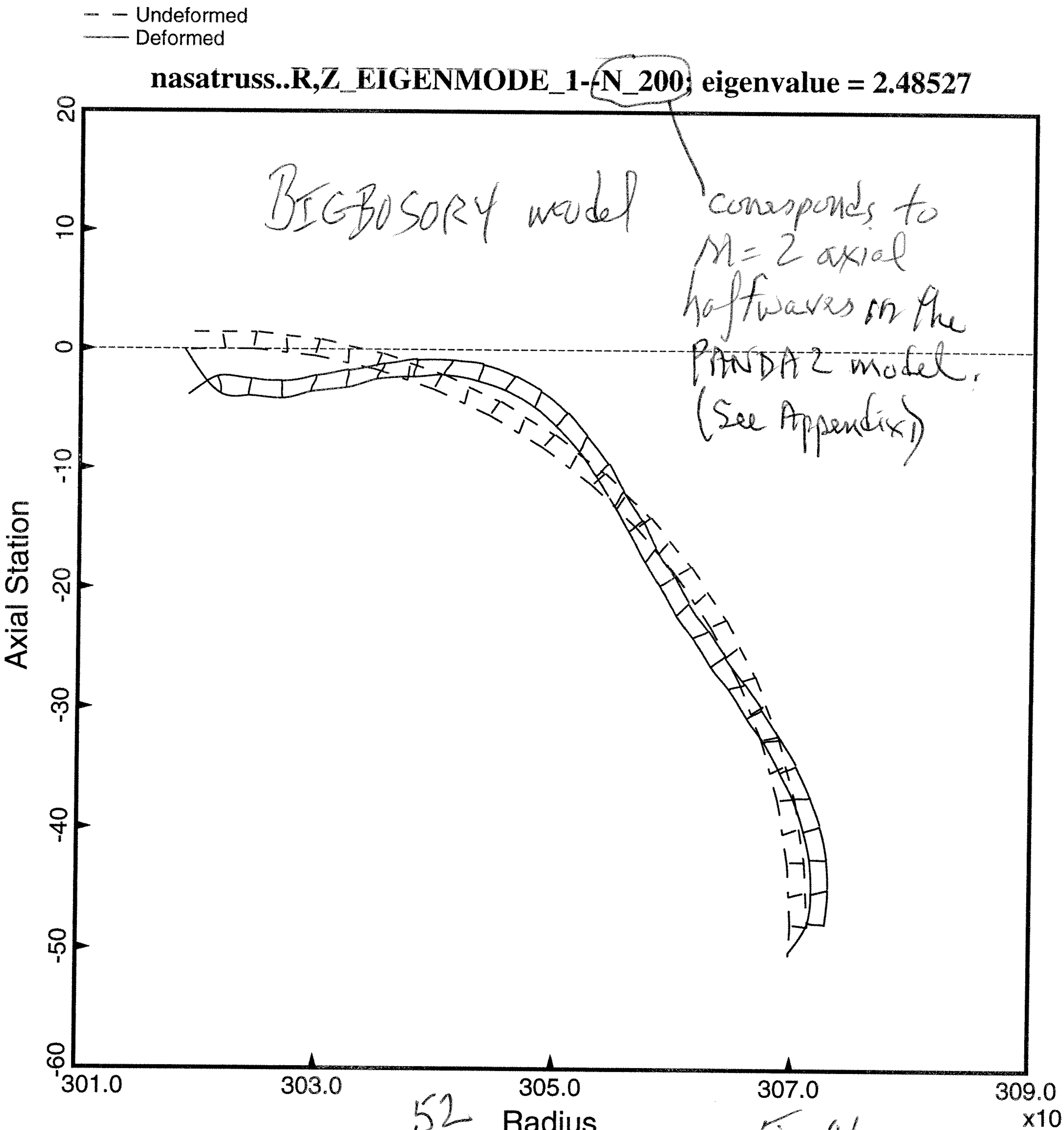


Fig. 14

Table 23   nasatruss.PAN

```
   n          $ Do you want a tutorial session and tutorial output?
 77.886       $ 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
     35       $ Number of halfwaves in the axial direction [see H(elp)],NWAVE
     10       $ How many eigenvalues (get at least 3) do you want?
```

See Margin #1 in Table 19

input for PANEL, which generates an input file for BIGBOSOR4, nasatruss.ALL

local buckling

15 modules = 15 × B = 15 × 5.1924"

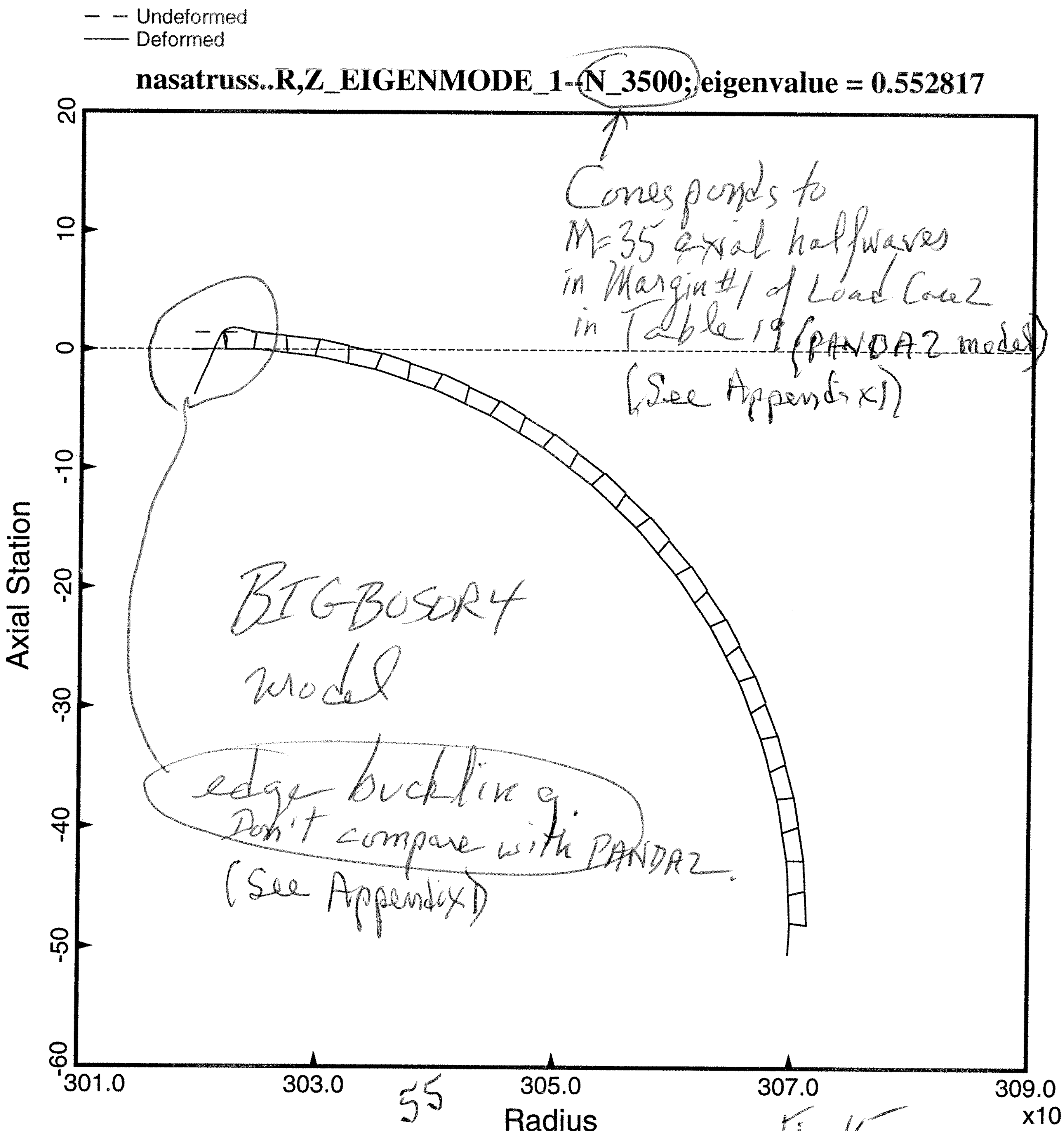
Table 24 Output from BIGBOSOR4

nasatruss.OUT (abridged output from BIGBOSOR4

```
 BUCKLING LOADS FOLLOW
 CIRCUMFERENTIAL WAVE NUMBER, N =    3500

 EIGENVALUES =
    5.52817E-01    1.16435E+00    1.28773E+00    1.29062E+00    1.29531E+00    1.30185E+00    1.»
31024E+00

 EIGENVALUES =
    1.32013E+00    1.33131E+00    1.34364E+00
```

edge buckles. ← These values are not to be compared with PANDA2 predictions. (See Appendix)

2



Undeformed
Deformed
nasatruss..R,Z_EIGENMODE_1--N_3500; eigenvalue = 0.552817
Corresponds to
M=35 axial halfwaves
in Margin#1 of Load Case 2
in Table 19 (PANDA2 model)
(See Appendix I)
BIGBOSOR4
model
edge buckling
Don't compare with PANDA2.
(See Appendix I)
Axial Station
Radius
x10
20
10
0
-10
-20
-30
-40
-50
-60
301.0
303.0
305.0
307.0
309.0

Fig. 15

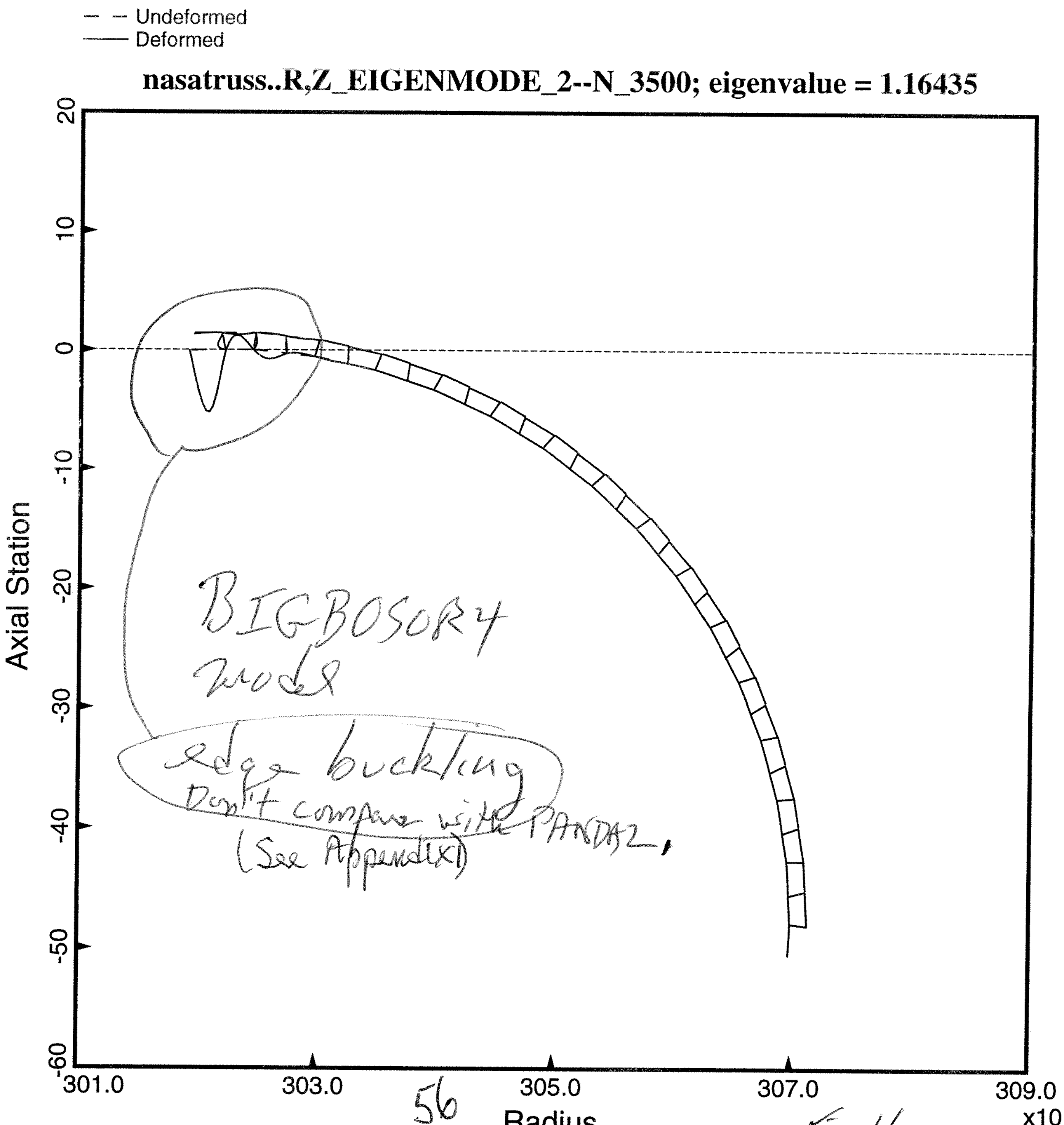

– – Undeformed
—— Deformed
nasatruss..R,Z_EIGENMODE_2--N_3500; eigenvalue = 1.16435
Axial Station
20
10
0
-10
-20
-30
-40
-50
-60
301.0
303.0
305.0
307.0
309.0
x10
Radius
BIGBOSOR4
model
edge buckling
Don't compare with PANDA2,
(See Appendix)

Fig. 16

BIGBOSOR4 model

Compare with Margin #1 in Table 27

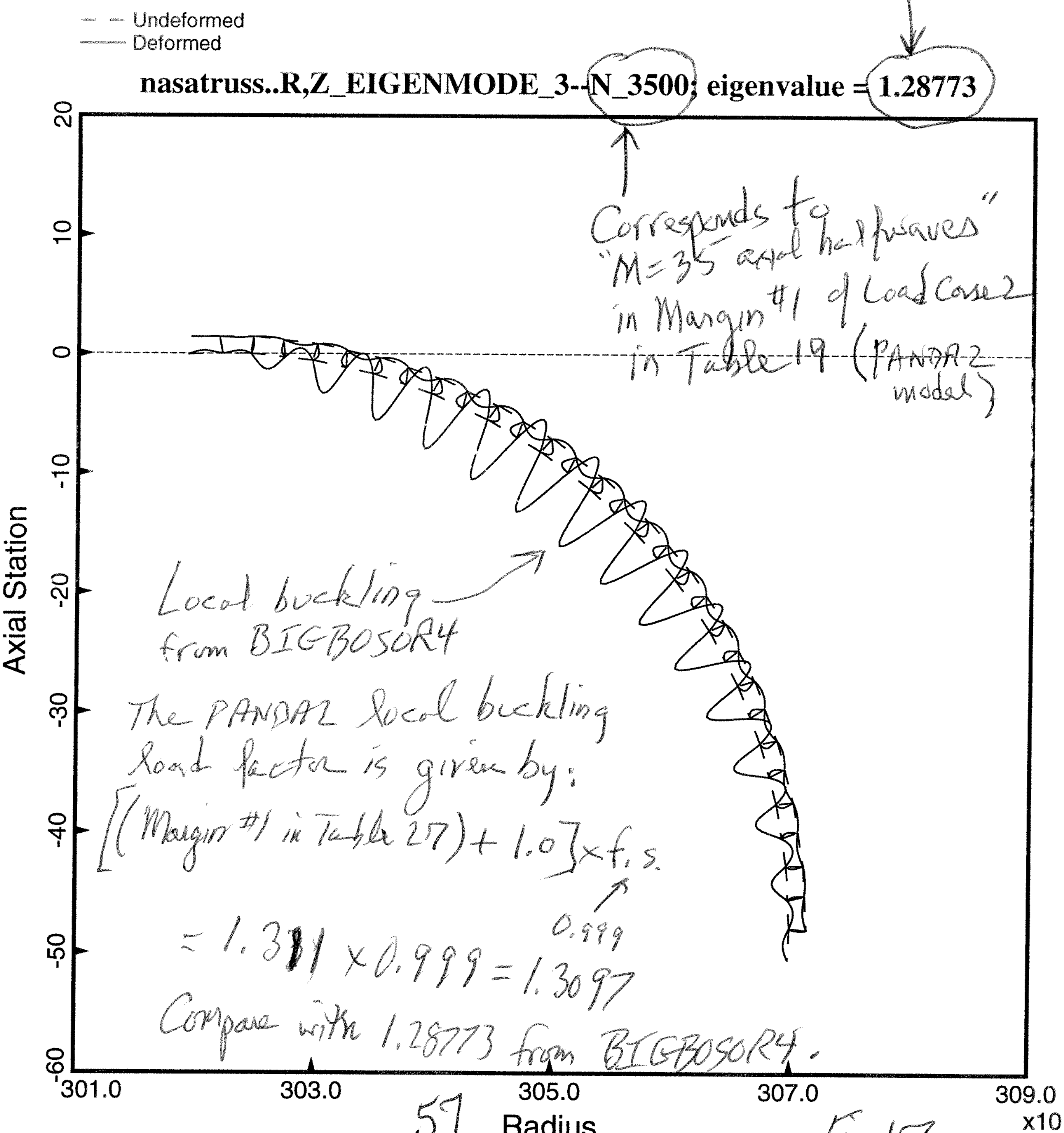


Fig. 17

Table 25 input for CHANGE

```
      n         $ Do you want a tutorial session and tutorial output?
      y         $ Do you want to change any values in Parameter Set No. 1?
T(7)     10     $ Number of parameter to change (1, 2, 3, . .)
  0.1560000E-01 $ New value of the parameter
      n         $ Want to change any other parameters in this set?
      n         $ Do you want to change values of "fixed" parameters?
      n         $ Do you want to change values of allowables?
```

make T(7) (Table 19, p.2) have exactly 3 plies.

3 X 0.0052"

Table 26 Output from PANDAOPT

nasatruss.OPM (abridged, with "legal" layup, that is with T(7) changed from its optimized value, 0.013491 inch, to a thickness exactly equal to three plies, 0.0156 inch.)

```
 ************************************************************
 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 =  -5.00E+03 -5.00E-03  2.50E+01  0.00E+00  0.00E+00
          Nxo, Nyo, pressure  =   0.00E+00  0.00E+00 -1.04E-04
 BUCKLING LOAD FACTORS FOR LOCAL BUCKLING FROM KOITER v. BOSOR4 THEORY:
  Local buckling load factor from KOITER theory =  1.1956E+00 (flat skin)
  Local buckling load factor from BOSOR4 theory =  1.2192E+00 (flat skin)

 MARGINS FOR CURRENT DESIGN: LOAD CASE NO. 1, SUBCASE NO. 1
 MAR. MARGIN
 NO.  VALUE              DEFINITION
 1   2.20E-01 Local buckling from discrete model-1.,M=35  axial halfwaves;FS=0.99
 2   5.22E+00 local wide-column bucking, discrete model(m=1   axial halfwav);FS=0
 3   1.97E-01 Local buckling from Koiter theory,M=36  axial halfwaves;FS=0.999
 4   7.59E+00 fibertensn:matl=1,STR,Dseg=4,node=1,layer=3,z=-0.0156; MID.;FS=1.27
 5   1.36E+00 fibercompr:matl=1,STR,Dseg=3,node=6,layer=3,z=-0.0347; MID.;FS=1.27
 6   4.53E-02 transtensn:matl=1,SKN,Dseg=1,node=7,layer=10,z=0.0347; MID.;FS=1.27
 7   2.57E+00 inplnshear:matl=1,STR,Dseg=4,node=1,layer=1,z=-0.026; MID.;FS=1.27
 8   7.59E+00 fibertensn:matl=1,SKN,Iseg=2,at:TIP,layer=8,z=0.013;-MID.;FS=1.27
 9   1.36E+00 fibercompr:matl=1,SKN,Iseg=1,at:n=1,layer=10,z=0.0347;-MID.;FS=1.27
10  -1.08E-02 transtensn:matl=1,STR,Iseg=3,at:n=1,layer=3,z=-0.0347;-MID.;FS=1.27
11   2.56E+00 inplnshear:matl=1,SKN,Iseg=2,at:TIP,layer=10,z=0.0234;-MID.;FS=1.27
12   2.26E+05 buckling marg.   skin   Iseg.(width-wise wide col.)MID.;FS=1.
13   8.16E+05 buckling marg. stringer Iseg.(width-wise wide col.)MID.;FS=1.
14   2.26E+05 buckling marg.   skin   Iseg.(width-wise wide col.)NOPO;FS=1.
15   8.16E+05 buckling marg. stringer Iseg.(width-wise wide col.)NOPO;FS=1.
16   2.29E-01 buck.(SAND); STRINGERS:  lower skin;  M=33;N=1;slope=0.03;FS=1.
17   2.78E+00 buck.(SAND);simp-support general buck;M=2;N=4;slope=0.;FS=0.999
18   3.72E-02 buck.(SAND); STRINGERS:  web buckling;M=36;N=1;slope=-0.05;FS=1.
19   5.09E-02 buck.(SAND); STRINGERS:  upper skin;  M=30;N=1;slope=0.;FS=1.
20   3.45E+02 (Max.allowable ave.axial strain)/(ave.axial strain) -1; FS=1.
21  -1.42E-03 0.45    *(Stringer spacing, b)/(Stringer base width, b2)-1;FS=1.
22   1.25E+00 (Str. base width, b2)/(0.2    *(Str. spacing, b))-1; FS=1.
23   4.94E-02 1.-V(2)^1+0.5V(1)^1-1


 ************************************************************
 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 2;  SUBCASE 1:
 LOADING: Nx, Ny, Nxy, Mx, My =  -5.00E+03 -5.00E-03  2.50E+01  0.00E+00  0.00E+00
          Nxo, Nyo, pressure  =   0.00E+00  0.00E+00 -1.04E-04
 BUCKLING LOAD FACTORS FOR LOCAL BUCKLING FROM KOITER v. BOSOR4 THEORY:
  Local buckling load factor from KOITER theory =  1.1718E+00 (flat skin)
  Local buckling load factor from BOSOR4 theory =  1.2103E+00 (flat skin)

 MARGINS FOR CURRENT DESIGN: LOAD CASE NO. 2, SUBCASE NO. 1
 MAR. MARGIN
 NO.  VALUE              DEFINITION
 1   2.11E-01 Local buckling from discrete model-1.,M=35  axial halfwaves;FS=0.99
 2   5.09E+00 local wide-column bucking, discrete model(m=1   axial halfwav);FS=0
 3   1.73E-01 Local buckling from Koiter theory,M=35  axial halfwaves;FS=0.999
 4   7.59E+00 fibertensn:matl=1,SKN,Dseg=2,node=1,layer=3,z=-0.0156; MID.;FS=1.27
 5   1.36E+00 fibercompr:matl=1,SKN,Dseg=1,node=11,layer=10,z=0.0347; MID.;FS=1.2
 6   4.66E-02 transtensn:matl=1,STR,Dseg=6,node=11,layer=3,z=-0.0347; MID.;FS=1.2
 7   2.57E+00 inplnshear:matl=1,SKN,Dseg=2,node=1,layer=1,z=-0.026; MID.;FS=1.27
 8   7.59E+00 fibertensn:matl=1,SKN,Iseg=2,at:TIP,layer=8,z=0.013;-MID.;FS=1.27
 9   1.36E+00 fibercompr:matl=1,STR,Iseg=3,at:n=1,layer=3,z=-0.0347;-MID.;FS=1.27
```

Table 26 (p. 2 of 2)

```
10 -1.08E-02 transtensn:matl=1,STR,Iseg=3,at:n=1,layer=3,z=-0.0347;-MID.;FS=1.27
11  2.56E+00 inplnshear:matl=1,SKN,Iseg=2,at:TIP,layer=10,z=0.0234;-MID.;FS=1.27
12  4.32E+00 buckling marg.   skin    Iseg.(width-wise wide col.)MID.;FS=1.
13  8.16E+05 buckling marg. stringer Iseg.(width-wise wide col.)MID.;FS=1.
14  2.26E+05 buckling marg.   skin    Iseg.(width-wise wide col.)NOPO;FS=1.
15  8.16E+05 buckling marg. stringer Iseg.(width-wise wide col.)NOPO;FS=1.
16  2.31E+05 buckling marg. stringer Iseg.(width-wise wide col.)NOPO;FS=1.
17  4.91E-02 buck.(SAND); STRINGERS:  lower skin;  M=30;N=1;slope=0.04;FS=1.
18  2.78E+00 buck.(SAND);simp-support general buck;M=2;N=4;slope=0.;FS=0.999
19  3.75E-02 buck.(SAND); STRINGERS:  web buckling;M=36;N=1;slope=-0.05;FS=1.
20  2.88E-01 buck.(SAND); STRINGERS:  upper skin;  M=36;N=1;slope=0.04;FS=1.
21  3.45E+02 (Max.allowable ave.axial strain)/(ave.axial strain) -1; FS=1.
 ***********  ALL 2 LOAD SETS PROCESSED  ***********
 *****************************************************

          SUMMARY OF INFORMATION FROM OPTIMIZATION ANALYSIS
 VAR. DEC. ESCAPE LINK. LINKED  LINKING    LOWER     CURRENT     UPPER        DEFINITION
  NO. VAR.  VAR.   VAR.   TO    CONSTANT   BOUND      VALUE      BOUND
   1   Y     N      N     0    0.00E+00  1.00E+00 5.1924E+00  9.00E+00      B(STR):pitch of tr»
uss core, b:     seg=NA, layer=NA
   2   Y     N      N     0    0.00E+00  1.00E-01 2.3399E+00  7.00E+00      B2(STR):width over »
which truss core contacts each fa
   3   Y     N      N     0    0.00E+00  1.00E-01 1.4172E+00  2.00E+00      H(STR):height of t»
russ, h: WEB seg=2 , layer=NA
   4   Y     Y      N     0    0.00E+00  5.20E-03 5.2000E-03  1.56E-02    T(1 )(SKN):thickness f»
or layer index no.(1 ): SKN seg=1
   5   N     N      Y     4    1.00E+00  0.00E+00 5.2000E-03  0.00E+00    T(2 )(SKN):thickness f»
or layer index no.(2 ): SKN seg=1
   6   Y     Y      N     0    0.00E+00  5.20E-03 5.2000E-03  1.56E-02    T(3 )(SKN):thickness f»
or layer index no.(3 ): SKN seg=1
   7   Y     Y      N     0    0.00E+00  5.20E-03 5.2000E-03  1.56E-02    T(4 )(SKN):thickness f»
or layer index no.(4 ): SKN seg=1
   8   N     N      Y     7    1.00E+00  0.00E+00 5.2000E-03  0.00E+00    T(5 )(SKN):thickness f»
or layer index no.(5 ): SKN seg=1
   9   Y     Y      N     0    0.00E+00  5.20E-03 1.5600E-02  1.56E-02    T(6 )(SKN):thickness f»
or layer index no.(6 ): SKN seg=1
  10   Y     Y      N     0    0.00E+00  5.20E-03 1.5600E-02  1.56E-02    T(7 )(SKN):thickness f»
or layer index no.(7 ): SKN seg=1

   CURRENT VALUE OF THE OBJECTIVE FUNCTION:
 VAR. STR/ SEG. LAYER    CURRENT
 NO.  RNG  NO.   NO.      VALUE            DEFINITION
            0     0    1.783E+01   WEIGHT OF THE ENTIRE PANEL

  TOTAL WEIGHT OF SKIN                              =    1.7827E+01
  TOTAL WEIGHT OF SUBSTIFFENERS                     =    0.0000E+00
  TOTAL WEIGHT OF STRINGERS                         =    0.0000E+00
  TOTAL WEIGHT OF RINGS                             =    0.0000E+00
  SPECIFIC WEIGHT (WEIGHT/AREA) OF STIFFENED PANEL=     1.2315E-03
 IN ORDER TO AVOID FALSE CONVERGENCE OF THE DESIGN, BE SURE TO
 RUN  PANDAOPT  MANY TIMES DURING AN OPTIMIZATION. INSPECT THE
 nasatruss.OPP  FILE AFTER EACH OPTIMIZATION RUN. OR BETTER YET,
 RUN SUPEROPT.
 ********************* END OF nasatruss.OPM FILE ****************
```

Was 0.013491
in Table 19 (see T(7))

Table 27 nasatruss.OPM with Wimp=0.

nasatruss.OPM (abridged, with "legal" layup, that is with T(7) changed from its optimized value, 0.013491 inch, to a thickness exactly equal to three plies, 0.0156 inch and with Wimp = 0.0.)

```
 ***********************************************************
 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 =  -5.00E+03 -5.00E-03  2.50E+01  0.00E+00  0.00E+00
          Nxo, Nyo, pressure  =   0.00E+00  0.00E+00 -1.04E-04
 BUCKLING LOAD FACTORS FOR LOCAL BUCKLING FROM KOITER v. BOSOR4 THEORY:
  Local buckling load factor from KOITER theory =  1.2869E+00 (flat skin)
  Local buckling load factor from BOSOR4 theory =  1.3096E+00 (flat skin)
0
 MARGINS FOR CURRENT DESIGN: LOAD CASE NO. 1, SUBCASE NO. 1
 MAR. MARGIN
 NO.  VALUE              DEFINITION
  1  3.11E-01 Local buckling from discrete model-1.,M=38  axial halfwaves;FS=0.99
  2  2.61E+01 local wide-column bucking, discrete model(m=1   axial halfwav);FS=0
  3  2.88E-01 Local buckling from Koiter theory,M=36  axial halfwaves;FS=0.999
  4  8.21E+00 fibertensn:matl=1,SKN,Dseg=2,node=1,layer=3,z=-0.0156; MID.;FS=1.27
  5  1.49E+00 fibercompr:matl=1,STR,Dseg=3,node=6,layer=3,z=-0.0347; MID.;FS=1.27
  6  4.84E-02 transtensn:matl=1,SKN,Dseg=1,node=7,layer=10,z=0.0347; MID.;FS=1.27
  7  2.77E+00 inplnshear:matl=1,SKN,Dseg=2,node=1,layer=1,z=-0.026; MID.;FS=1.27
  8  8.22E+00 fibertensn:matl=1,SKN,Iseg=2,at:TIP,layer=8,z=0.013;-MID.;FS=1.27
  9  1.49E+00 fibercompr:matl=1,STR,Iseg=3,at:n=11,layer=5,z=0.0121;-MID.;FS=1.27
 10  4.89E-02 transtensn:matl=1,STR,Iseg=3,at:n=11,layer=3,z=-0.0191;-MID.;FS=1.2
 11  2.77E+00 inplnshear:matl=1,SKN,Iseg=2,at:TIP,layer=10,z=0.0234;-MID.;FS=1.27
 12  2.26E+05 buckling marg.   skin   Iseg.(width-wise wide col.)MID.;FS=1.
 13  8.16E+05 buckling marg. stringer Iseg.(width-wise wide col.)MID.;FS=1.
 14  2.26E+05 buckling marg.   skin   Iseg.(width-wise wide col.)NOPO;FS=1.
 15  8.16E+05 buckling marg. stringer Iseg.(width-wise wide col.)NOPO;FS=1.
 16  1.59E-01 buck.(SAND); STRINGERS:  lower skin;  M=33;N=1;slope=0.03;FS=1.
 17  3.76E+00 buck.(SAND);simp-support general buck;M=2;N=4;slope=0.;FS=0.999
 18  7.20E-02 buck.(SAND); STRINGERS:  web buckling;M=36;N=1;slope=-0.02;FS=1.
 19  1.60E-01 buck.(SAND); STRINGERS:  upper skin;  M=33;N=1;slope=0.02;FS=1.
 20  3.45E+02 (Max.allowable ave.axial strain)/(ave.axial strain) -1; FS=1.
 21 -1.42E-03 0.45   *(Stringer spacing, b)/(Stringer base width, b2)-1;FS=1.
 22  1.25E+00 (Str. base width, b2)/(0.2    *(Str. spacing, b))-1; FS=1.
 23  4.94E-02 1.-V(2)^1+0.5V(1)^1-1
 ***********  ALL 1 LOAD SETS PROCESSED  ***********
 **************************************************
```

compare with BIGBOSOR4 prediction in Fig. 17.

general buckling mode shape!

0.999

Buckling load factor = (margin + 1.0) f.s.

= (3.76 + 1.0) x 0.999

= 4.755

does not agree well with BIGBOSOR4 prediction in Figs. 13 & 14, because of transverse shear deformation (t.s.d.)

Table 28 input for PANEL2: nasatruss.PAN

```
n        $ Do you want a tutorial session and tutorial output?
  96     $ Length of the ring-stiffened cylindrical shell, L1
-5000    $ 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
   2     $ 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 for PANEL2: model in which the wall properties between rings are smeared out.

PANEL2 produces a BIG BOSOR4 model of a cylindrical shell with smeared inter-ring wall properties. See p. 318-320 & p. 322 & Fig. 30 of the paper "Additional buckling solutions in PANDA2", AIAA Paper 99-1233, 40th AIAA SDM Meeting, 1999. Also, see Fig. 21(b) in Appendix 1.

Table 29 output from BIGBOSOR4

nasatruss.OUT (abridged output from a bigbosor4 model
generated by panel2: the wall properties are smeared.

```
 ***** EIGENVALUES AND MODE SHAPES *****
  EIGENVALUE(CIRC. WAVES)
 =======================================
    8.0872E+00(   2)
    6.7702E+00(   3)
    6.1991E+00(   4) <--critical value
    6.9323E+00(   5)
    7.8174E+00(   6)
    9.1744E+00(   7)
    1.0849E+01(   8)
    1.2714E+01(   9)
    1.4724E+01(  10)
    1.6859E+01(  11)
    1.9103E+01(  12)
    2.1439E+01(  13)
    2.3853E+01(  14)
    2.6331E+01(  15)
    2.8860E+01(  16)
    3.1428E+01(  17)
    3.4024E+01(  18)
    3.6636E+01(  19)
    3.9255E+01(  20)
 =======================================
```

buckling load factors from BIGBOSOR4

PANDA2 gives 4.76 as a buckling load factor including t.s.d. effect

Compare with margin #17 in Table 27

BIGBOSOR4 model generated by PANEL2

BIGBOSOR4 prediction: no t.s.d. effect.

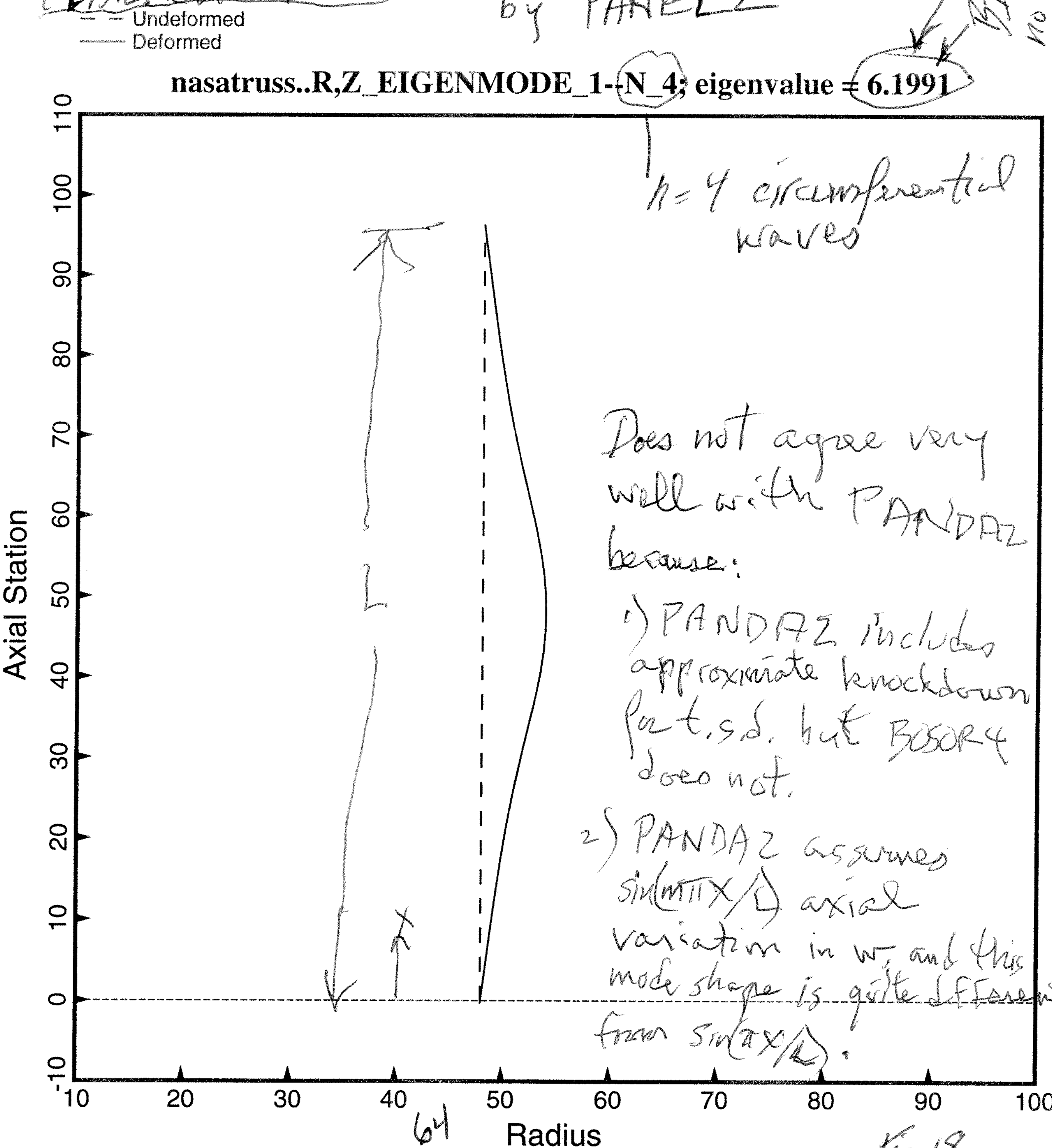


Fig. 18

Table 30 nasatruss.OPT (design sensitivity)

```
   n        $ Do you want a tutorial session and tutorial output?
 -5000      $ 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)
     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?
0.999       $ Factor of safety for general instability, FSGEN( 1)
0.999       $ Minimum load factor for local buckling (Type H for HELP), FSLOC( 1)
1.000       $ Minimum load factor for stiffener buckling (Type H), FSBSTR( 1)
1.270000    $ 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      $ Resultant (e.g. lb/in) normal to the plane of screen, Nx0( 1)
     0      $ 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      $ Uniform applied pressure [positive upward. See H(elp)], p( 1)
     0      $ Out-of-roundness, Wimpg1=(Max.diameter-Min.diam)/4, Wimpg1( 1)
  0.00      $ Initial buckling modal general imperfection amplitude, Wimpg2( 1)
     0      $ 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)?
   n        $ Do you want a "complete" analysis (type H for "Help")?
   n        $ Have you rerun DECIDE with new decision variables and lower bounds?
   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        $ 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]?
     0      $ Choose (0=transverse inextensional; 1=transverse extensional)
     1      $ Choose ICONSV = -1 or 0 or 1 or H(elp), ICONSV
     4      $ 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?
     1      $ Choose one of the load sets:  ILOAD
     1      $ Choose one of the sub cases (1  or  2):  ICASE
     2      $ Choose a design variable (1, 2, 3, ...), IBVAR
2.500000    $ Starting value of the design parameter, VARBEG
2.700000    $ Ending value of the design parameter, VAREND
   y        $ Do you want to use the default for the number of steps?
```

This is BZ (See Fig 0).

Input for Mainsetup for design sensitivity option (ITYPE = 4)

Effect of transverse shear deformation (t.s.d.) on general buckling margins.

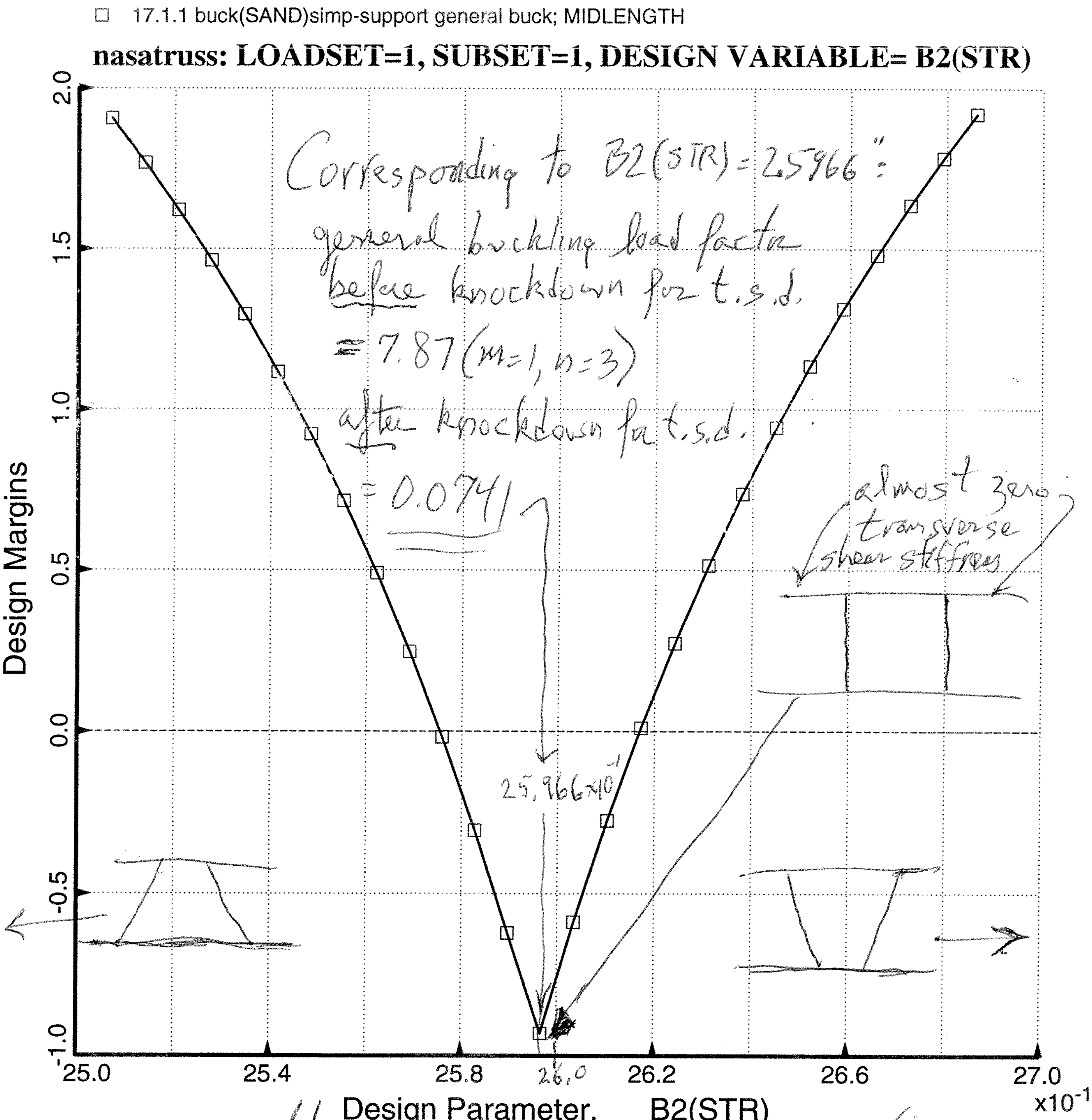


Fig. 19

APPENDIX 1

From AIAA Paper 2007-2216, 48th SDM Meeting, 2007

halfwaves, **dm**, in the PANDA2 model, as listed in Part 1 of Table 8 for example, the imperfection amplitude used by PANDA2 is different in this particular case from that to be used in the STAGS nonlinear models. With the "yes, change imperfection" option, the amplitude of the general buckling modal imperfection in the PANDA2 models is plus or minus **0.25/(m+dm)**, in which **dm** can be either positive, zero, or negative. From part 1 of Table 8 we see that in this particular case the amplitude of the general buckling modal imperfection in the PANDA2 model is **0.25/(m+dm) = 0.25/(5 – 0.41628) = 0.054541 inches.** The STAGS model of the imperfect shell is somewhat conservative relative to the PANDA2 model in this case because it has a general buckling modal imperfection with a somewhat higher amplitude, Wimp = 0.0625 inch, compared to the PANDA2 amplitude, Wimp = 0.054541 inch.

12.2.2 Results from linear buckling analyses with BIGBOSOR4 [14F]

There are PANDA2 processors, PANEL (Fig. 36, p. 539 of [1A]) and PANEL2 (Fig. 33 of [1G]), by means of which input files for BOSOR4 (or BIGBOSOR4) [14] are generated automatically. Figures 20b, 21b, and 23b pertain to this sub-section.

The **PANEL** processor generates an input file, *.ALL, for the BIGBOSOR4 [14F] **buckling analysis of the portion of the optimized stiffened cylindrical shell between rings** (multiple skin-stringer modules each module of which is similar to the one module shown in Fig. 4). The sector of the stringer-stiffened portion of the cylindrical shell shown in Figs. 20b and 23b is modeled as a segment of a toroidal shell ([26], also see Fig. 192, p. 221 of [8]) with a large radius R to the center of meridional curvature. (R is close to 286 inches in this case). Figures 23b and 20b display **local** and **bending-torsion** buckling modes, respectively, predicted by BIGBOSOR4. BIGBOSOR4 computes buckling load factors (eigenvalues) over a user-specified range of circumferential wave numbers, N, as listed in the table inserted on the right-hand side of Fig. 23b. In the BIGBOSOR4 model generated by PANEL there are no rings. The rings are replaced by anti-symmetry (simple support) boundary conditions, that is, two adjacent rings are replaced by two nodal lines in the trigonometric circumferential variation of buckling modal displacements. These two nodal lines lie parallel to the plane of the paper. The spacing between them is equal to the ring spacing, of course. In Figs. 23b and 20b **m**, the number of axial halfwaves between rings, is listed in the title: **m** = 11 in Fig. 23b and **m** = 2 in Fig. 20b. N = 100 x **m** is the number of **full** waves around the entire circumference of the huge toroidal shell. N = 100 corresponds a circumferential **halfwavelength** equal to the ring spacing, which is 9.375 inches in Case 2 (Table 4). (NOTE: the ring spacing and the circumferential halfwavelength of a buckling mode in this "huge torus" model are measured **normal** to the plane of the paper. The average horizontal radius, R(ave), from the axis of revolution of the huge torus to the halfway point along the meridional arc of the multi-module model displayed in Figs. 23b and 20b can be computed as follows: 2 x pi x R(ave) = 2 x 100 x 9.375 inches. Therefore, R(ave) = 298.4 inches.) The critical **local** buckling mode (Fig. 23b) has N = 1100 circumferential full waves around the circumference of the huge toroidal shell. Hence, there are **m** = 11 halfwaves between rings. The critical **bending-torsion** buckling mode (Fig. 20b) has 200 circumferential full waves around the circumference of the huge toroidal shell. Therefore **m** = 2 halfwaves between rings. The buckling load factors (eigenvalues), Eig(local) = 1.0862 (Fig. 23b) and Eig(bending-torsion) = 1.289 (Fig. 20b), agree well with the PANDA2 margins listed in Table 7: Margin No. 1 (Sub-case 1) = 0.0636 (corresponding load factor = 1.0636) and Margin No. 2 (Sub-case 2) = 0.291 (corresponding load factor= 1.291), respectively. The small inserts in Figs. 20b and 23b show buckling modes that correspond to **edge buckling**. These modes have eigenvalues that are lower than that corresponding to buckling over the entire toroidal sector. However, they are not of interest in the comparison of predictions from BIGBOSOR4 with those from PANDA2 and STAGS because edge buckling of the types displayed in the small inserts in Figs. 20b and 23b is not permitted in the PANDA2 and STAGS models.

The **PANEL2** processor generates a BIGBOSOR4 input file, *.ALL, for the **buckling analysis of the entire optimized stiffened shell**. In this model the stringers are smeared out in the manner of Baruch and Singer [12] and the rings are modeled as branched shell structures. The shell is simply supported along the two curved ends. Figure 21b shows the critical **general** buckling mode predicted by BIGBOSOR4. The mode shape, **(m,n)** = (M,N) = (4,6), agrees with that predicted by PANDA2, as seen from Margin No. 11 in the top part of Table 7. Margin No. 11 = 0.890, which corresponds to a load factor 1.890. This load factor agrees very well with the load factor from BIGBOSOR4: Eig(general) = 1.8767, listed in both the title and in the small table inserted in Fig. 21b.

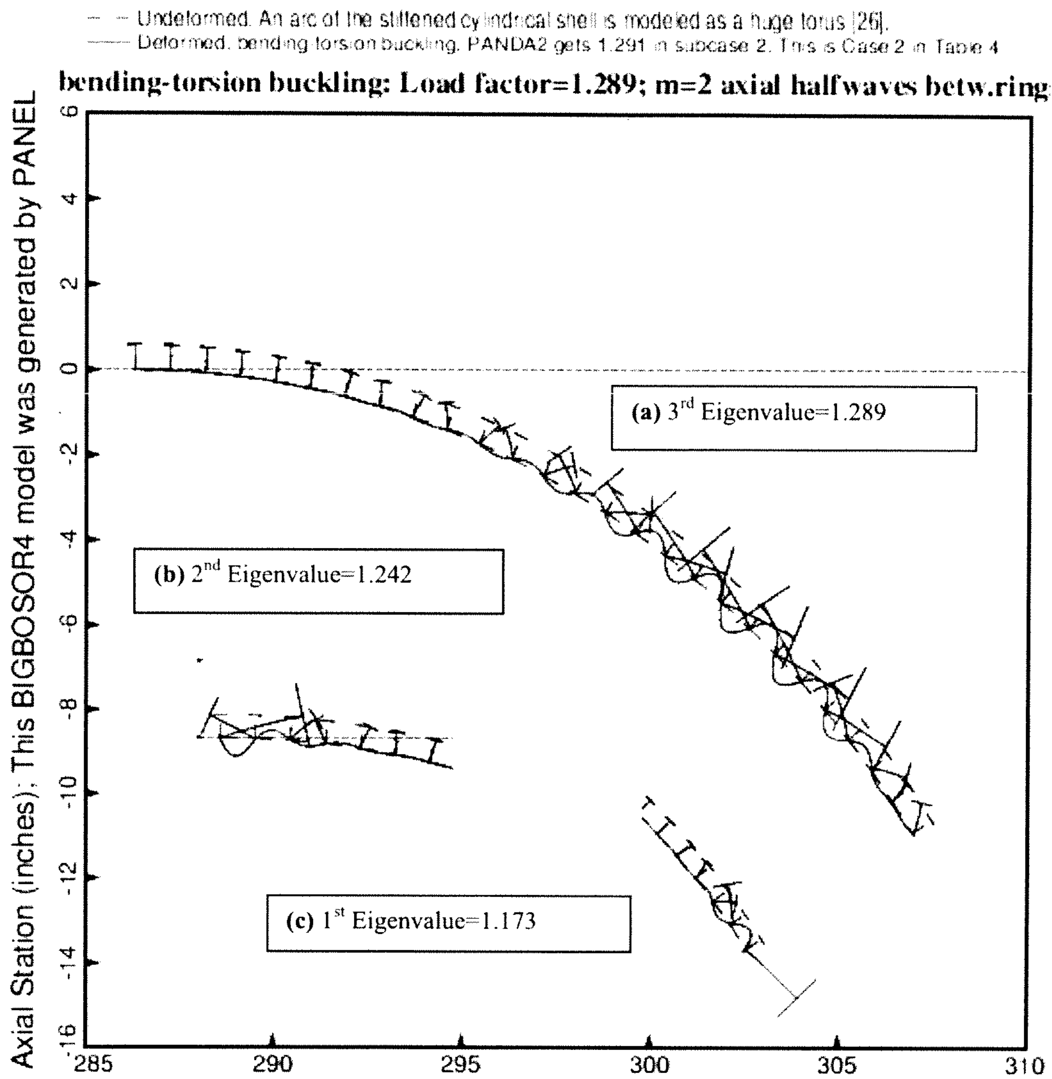


FIG. 20b BIGBOSOR4 [14] model of buckling between rings; Radius (inche

FIG. 20b BIGBOSOR4 model of Case 2 in Table 4: Results from a BIGBOSOR4 model generated by the PANDA2 processor called PANEL. This figure shows bending-torsion buckling between rings (same buckling mode as that corresponding to PANDA2's Margin 2 in both the upper and lower parts of Table 7). This BIGBOSOR4 model is a huge toroidal segment [26] with radius to the center of meridional curvature of about 286 inches. The axial variation of the critical buckling modal displacement is trigonometric with **m** = 2 axial halfwaves between rings (N=200 circumferential waves around the huge torus). The axial coordinate direction for the cylindrical shell is normal to the plane of the paper in this figure. The "critical" buckling mode of interest **(a)** happens to correspond, in this particular case, to the 3rd eigenvalue computed for N = 200. The 1st and 2nd eigenvalues for N = 200, inserts **(c)** and **(b)**, correspond to edge buckling, not permitted in the PANDA2 or STAGS models and therefore not of interest in the comparison of predictions from BIGBOSOR4 with those from PANDA2 and STAGS.

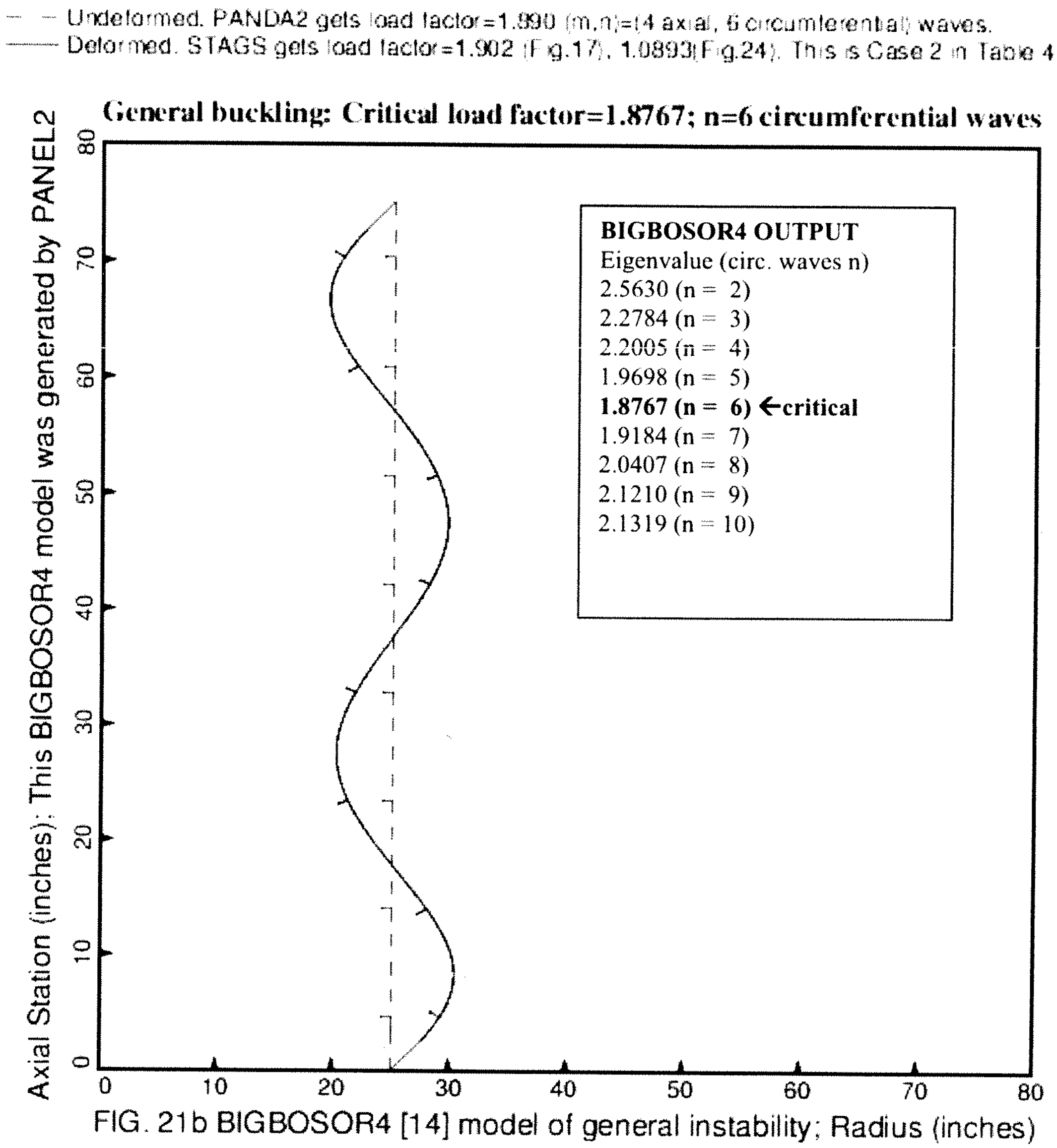


Fig. 21b BIGBOSOR4 model of Case 2 in Table 4: Results from a BIGBOSOR4 model generated by the PANDA2 processor called PANEL2. This figure shows the critical general buckling mode for Case 2 (same as that corresponding to PANDA2's Margin 11 in the upper part of Table 7). The outstanding flanges of the internal rings are very narrow and therefore are hardly visible in this figure. Circumferential variation of the buckling modal displacement, trigonometric with **n** = 6 full circumferential waves, is in the coordinate direction normal to the plane of the paper in this figure.

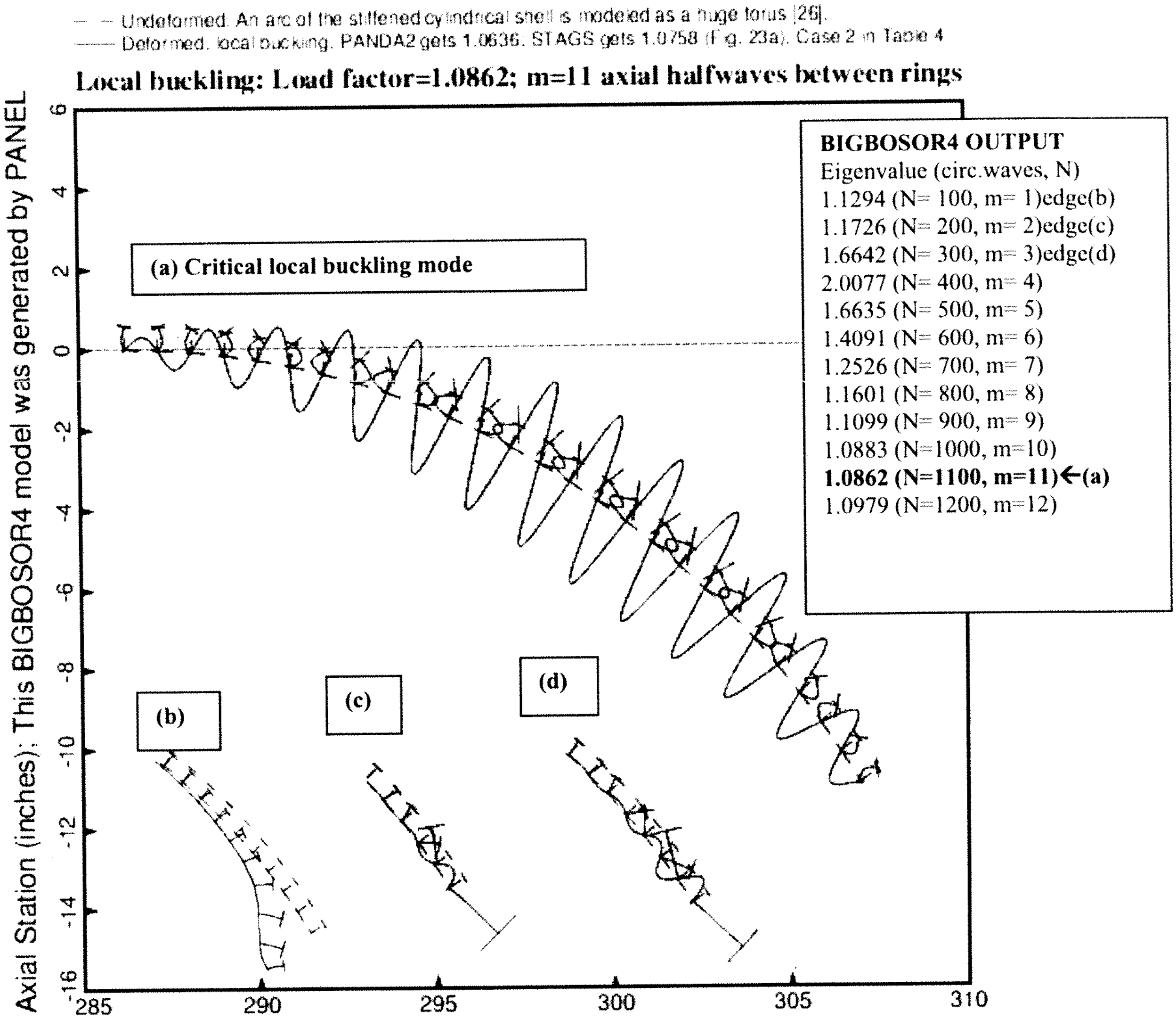


FIG. 23b BIGBOSOR4 [14] model of buckling between rings; Radius (inche

FIG. 23b BIGBOSOR4 model of Case 2 in Table 4: Results from a BIGBOSOR4 model generated by the PANDA2 processor called PANEL. This figure shows local buckling between rings (same critical buckling mode as that listed as PANDA2's Margin 1 in both the upper and lower parts of Table 7). The BIGBOSOR4 "torus" model is the same as that displayed in Fig. 20b. Only the critical number of axial halfwaves between rings, **m**=11, is different from that given in Fig. 20b. The three inserts, **(b), (c), (d),** near the bottom of the figure show "edge" buckling modes corresponding to **m** = 1, 2, and 3 axial halfwaves between rings. The buckling modes for all other **m** resemble that displayed in **(a)**. Since edge buckling is not permitted in the PANDA2 and STAGS models, the edge buckling modes, **(b), (c), (d),** are not of interest and are therefore disregarded in the comparison of BIGBOSOR4 predictions with those from PANDA2 and STAGS.

APPENDIX 2

APPENDIX 2

Why should you use only 5 iterations for each execution of PANDAOPT?

Figures 1 and 10 of this report show results when 5 iterations were used for each execution of PANDAOPT. In particular, notice from Fig. 10 that many different "starting" designs are used. You can tell a "starting design" because it is represented as a spike in the plot of objective vs design iteration during the SUPEROPT run.

If you use 25 iterations per execution of PANDAOPT, then most of the iterations are wasted because the design doesn't change much during the last 15 or so iterations (See Fig. A1). The explanation of why this is so is given in the long 1987 PANDA2 paper, page 582 of which is reproduced as Fig. A3.

If you use 25 iterations per execution of PANDAOPT in an execution of SUPEROPT, you don't get many "starting" designs" (spikes in the plot). Therefore, you don't get a very complete search of the design space in order to find a global optimum design. Most of the iterations are wasted because the "windows" shown in Fig. A3 are very, very small. ~~and~~ During most of the iterations the design is not permitted to change very much. This is clear from Fig. A2.

Compare Fig. A2 with Fig. 10 in the report. Fig. 10 shows many new starting designs during the SUPEROPT execution, therefore, a more thorough search of design space for the global optimum design.

That is why you should almost always use 5 iterations per execution of PANDAOPT. There may be occasions when you want to use more, but in my experience it hardly ever is necessary.

The number of iterations per execution of pandaopt is specified by the user near the end of the *.OPT file. See Table 3, for example.

6 pandaopts with 25 iterations per pandaopt: a bad practice.

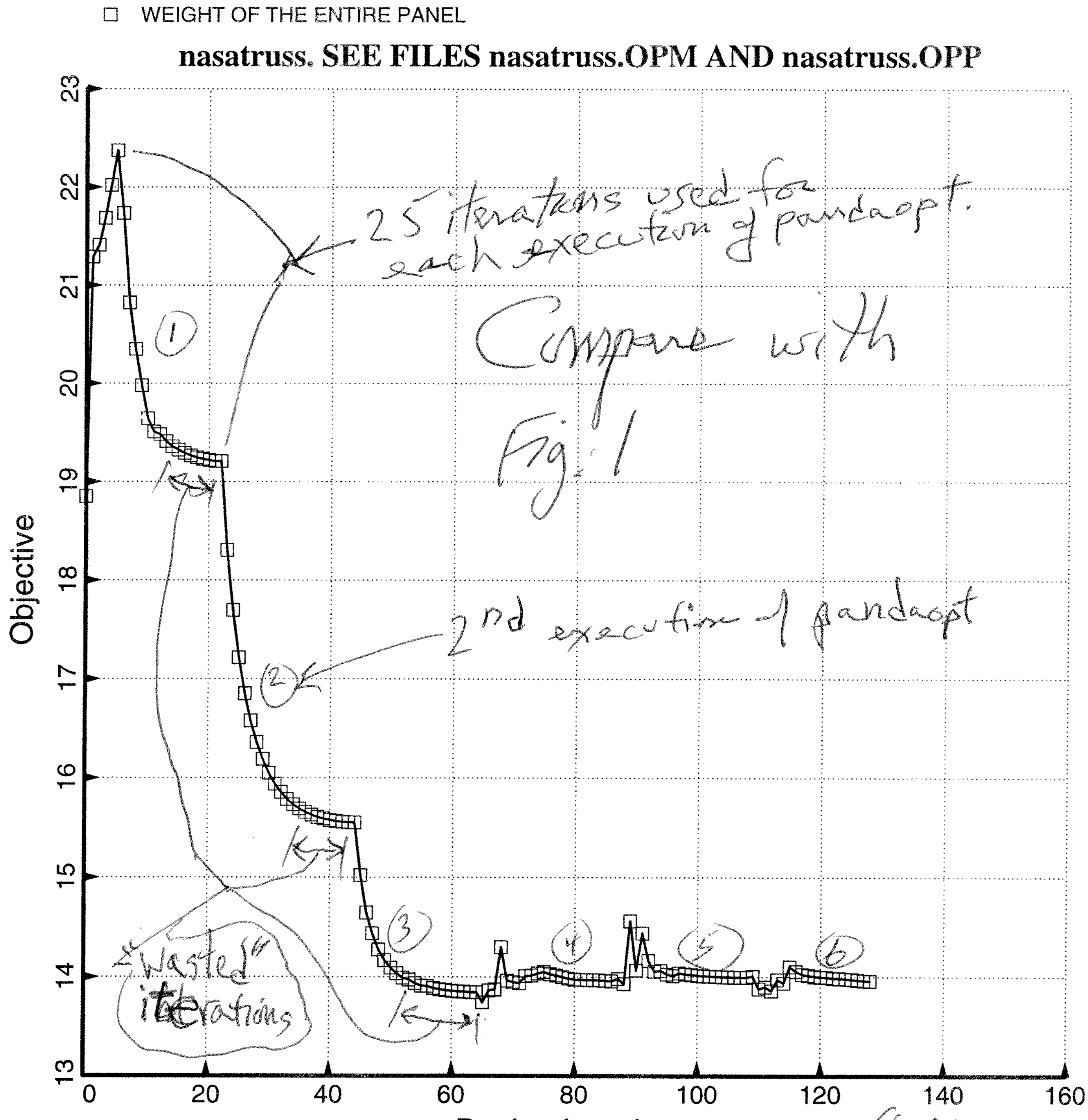


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Fig. A1

Execution of SUPEROPT in a case in which 25 iterations per pandaopt are specified in the *.OPT file: a bad practice.

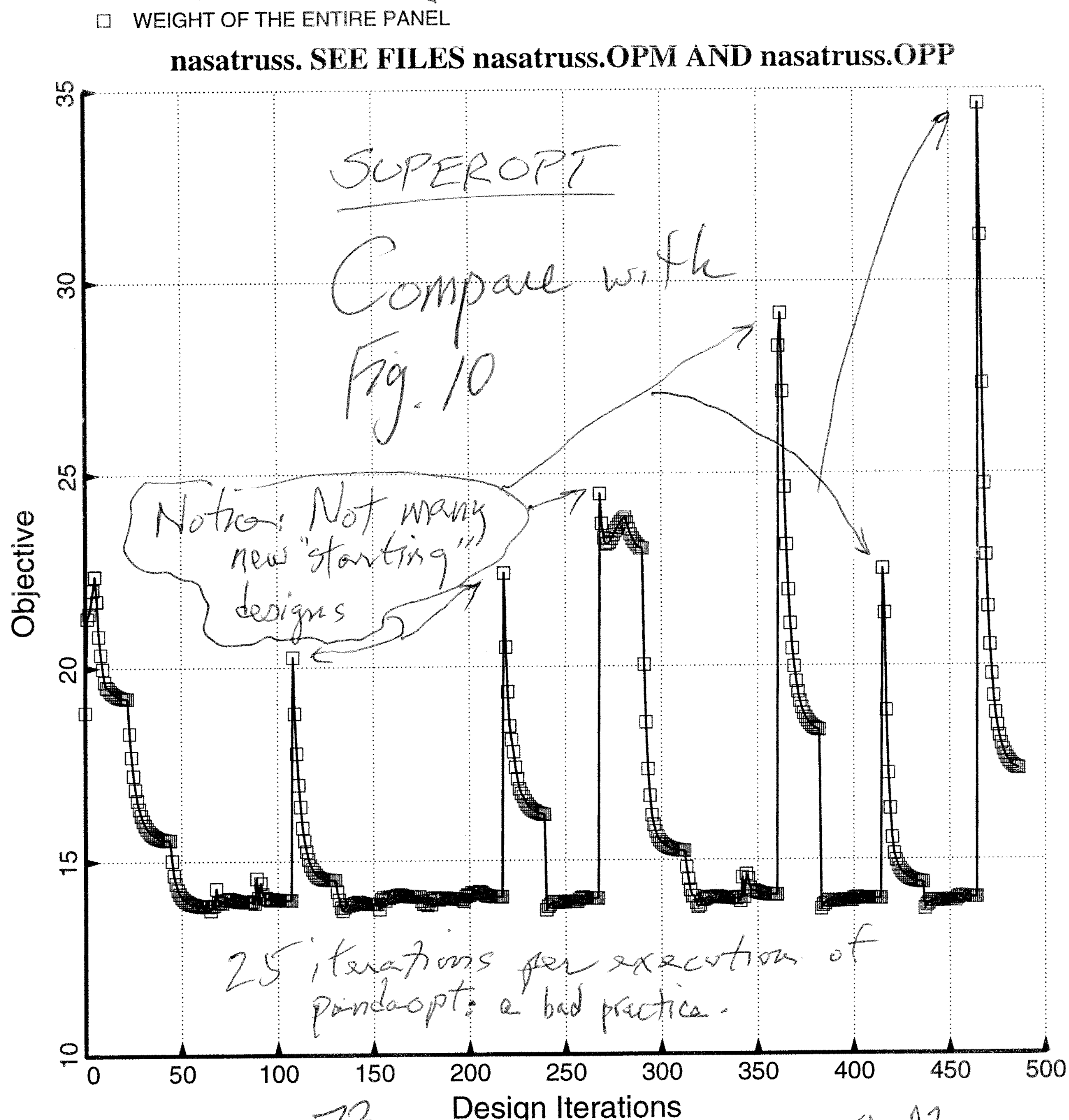

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Fig A2

From Computers & Structures, 1987, page 582

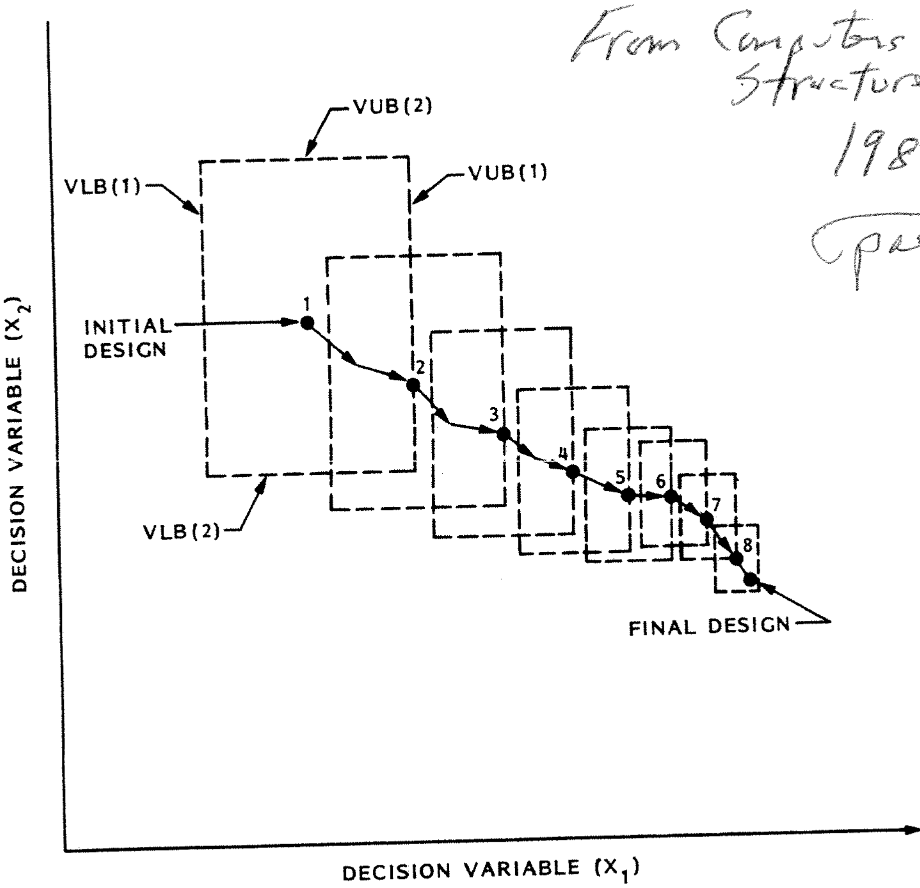

Fig. 83. Schematic of the evolution of a design with two decision variables, X_1 and X_2. With each iteration, the optimizer, CONMIN, establishes a 'window' of permitted excursion of the decision variables. In PANDA2 this 'window' shrinks by a factor of 0.8 for each design iteration. Upon re-execution of PANDAOPT the 'window' is re-expanded to its original size, which depends upon lower and upper bounds supplied by the user and certain strategies used by CONMIN. replaced by ADS now

This was written before SUPEROPT existed.

~~excursions of the decision variables in order to prevent wild swings in the design as it evolves.~~ The example shown in Fig. 83 shows eight iterations, and the last design point is labeled 'FINAL DESIGN'. Note, however, that the 'window' of permitted excursions is rather small. To the user it may appear that design iterations have converged, whereas actually they may not have. On the other hand, they really may have converged. This can easily be checked simply by executing PANDAOPT again. When this is done, the 'window' of permitted excursions is re-expanded to its original size, the new starting design is the last design obtained in the previous set of iterations, and new iterations proceed as before. The user should keep executing PANADOPT until the objective does not change very much. When the user is satisfied with the current design, he or she should then take one additional set of design iterations in which the number of iterations is larger than the number used previously, say twice or three times as many.

~~After the user is satisfied with the preliminary design obtained with the IQUICK = 1 option, he or she should pursue further design iterations with IQUICK = 0. Lower factors of safety can generally be used with the IQUICK = 0 option, especially for buckling between rings, because the wide column buckling model is used with this option. This model is more conservative than the smeared-stringer model used with the IQUICK = 1 option, since it neglects the curvature of the panel and it accounts for local deformations of the panel module cross section as it buckles in the wide-column mode. However, note that some factor greater than unity should generally be used because PANDA2 does not account for local initial imperfections and the important effect of these on overall buckling, particularly for cases in which local and general buckling occur at loads that are close. (See [34] for the recent addition of capability to handle initial imperfections.)~~

~~21.5 *Results with IQUICK* = 1 (*step* 7.1)~~

~~The leftmost portions of Figs 84–89 give results obtained with IQUICK = 1. The 25 iterations are performed in three sets of five each followed by one set of 10. A total of about 8 min of CPU time on the~~

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FIG A3