The use of BIGBOSOR4 to obtain predictions of stress and buckling of deep submergence shells

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ABSTRACT

Several BIGBOSOR4 models are set up for stress and buckling of some sample deep submergence shells of a type that might be of interest to the DOER company. No DOER-developed designs have been used. The geometries are 1. spherical, 2. cylindrical, and 3. combined spherical-cylindrical. The loading is uniform external pressure similar to that (actually slightly less than that) experienced in the deepest part of the ocean. The material is assumed to be titanium with a maximum allowable effective stress of 120000 psi. The shell wall material is assumed to be elastic. Creep is not considered in this informal report. BIGBOSOR4 handles stress, buckling and vibration of elastic shells of revolution. It is found that the most critical condition in all cases is maximum stress in the shell wall. Buckling is not critical for such highly loaded shells because the shell wall has to be very thick to keep the maximum effective stress below the allowable elastic limit. Buckling is not critical even if one uses conservative knockdown factors to compensate for the presence of unknown imperfections. The analyses conducted here do not consider fracture of the shell wall or accidental concentrated loads that the deep submergence vehicle might experience while at depth during service.

BRIEF DISCUSSION

Table 1 lists the cover and three pages from the 7th edition (2002) of ROARK [1]. The pages reproduced in Table 1 are especially applicable to the simple shell geometries explored here.

Here BIGBOSOR4 [2,3] is used for the analysis.

In the simplest models, the spherical shell by itself and the cylindrical shell by itself (pp. 11 - 31), the boundary conditions used in the analysis preserve the membrane prebuckling state. For the spherical shell the prebuckled state is uniform shrinkage of the shell under the uniform external pressure, and the uniform stress is close to pr/2t, in which r is the radius and t is the wall thickness of the spherical shell. For the cylindrical shell modeled by itself the pressure acts on the curved surface (the middle surface is assumed here), and there is also an axial compression equal to pr/2 (axial resultant, Nx). The hoop resultant, Ny, is equal to pr. For the models in which a spherical dome and the cylindrical shell are both included, symmetry conditions are imposed at the midlength of the cylindrical shell, and half the length of the cylindrical shell is included in the model.

The most elaborate BIGBOSOR4 model (pp. 51 - 61) allows for varying nodal point spacing within each of the two shell segments in the combined spherical-cylindrical model as well as meridional variation of location of the reference surface with respect to the left-most surface as we "travel" in the direction of increasing meridional arc length, as well as meridional variation of shell wall thickness near the junction between the spherical shell and the cylindrical shell.

The predictions from BIGBOSOR4 for the simple models (sphere by itself, cylinder by itself) are in good agreement with the "classical" formulas listed in Roark [1].

It is proposed to set up an automated optimization scheme with the user of GENOPT [4] and BIGBOSOR4 [3], as has been accomplished for several cases recently in work done for the NASA Langley Research Center. The automated optimization would, it is hoped, determine the best variation of wall thickness and material distribution relative to the reference surface in the neighborhood of the junction between the spherical shell and the cylindrical shell. The objective would be minimum weight of the combined spherical-cylindrical shell structure. Minimization of weight would occur in the presence of stress and buckling design constraints. The optimization would be for the most elaborate BIGBOSOR4 model explored in this report.

REFERENCES

[1] Warren C. Young and Richard G. Budynas, ROARK'S FORMULAS FOR STRESS AND STRAIN, 7th Edtion, McGraw-Hill, 2002

[2] David Bushnell, Stress, stability and vibration of complex, branched shells of revolution, Computers & Structures, Vol. 4, pp. 499 - 435, 1974

[3] David Bushnell, Automated optimum design of shells of revolution with application to ring-stiffened cylindrical shells with wavy walls", AIAA paper 2000-1663, 41st AIAA Structures Meeting, Atlanta, GA, April 2000. Also see Lockheed Martin report, same title, LMMS P525674, November 1999

[4] David Bushnell, "GENOPT--A program that writes user-friendly optimization code", International Journal of Solids and Structures, Vol. 26, No. 9/10, pp. 1173-1210, 1990. The same paper is contained in a bound volume of papers from the International Journal of Solids and Structures published in memory of Professor Charles D. Babcock, formerly with the California Institute of Technology.

SEVENTH EDITION

ROARK'S FORMULAS FOR STRESS AND STRAIN

Young Budynas

McGraw Hill

Table 1 (4 pages)

SEVENTH EDITION

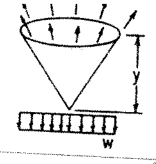
ROARK'S FORMULAS FOR STRESS AND STRAIN

Warren C. Young

Richard G. Budynas

4

Table 1
p. 2 of 4

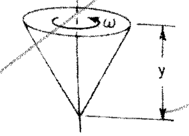


$\Delta R = \frac{}{Et\cos\alpha}\left(\sin^2\alpha - \frac{1}{2}\right)$

$\Delta y = \frac{wR^2}{2Et\cos^2\alpha}\left[\frac{1}{2\sin\alpha} + \nu(1-\sin\alpha) - 2\sin^2\alpha\right]$

$\psi = \frac{wR\sin\alpha}{2Et\cos^2\alpha}(4\sin^2\alpha - 1 - 2\nu\cos^2\alpha)$

2f. Uniform rotation, ω rad/s, about central axis



δ_m = mass density

$\sigma_1 = 0$

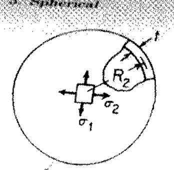
$\sigma_2 = \delta_m R^2\omega^2$

$\Delta R = \frac{\delta_m R^3\omega^2}{E}$

$\Delta y = \frac{-\delta_m R^3\omega^2}{E\cos\alpha}\left(\sin\alpha + \frac{\nu}{3\sin\alpha}\right)$

$\psi = \frac{\delta_m R^2\omega^2\tan\alpha}{E}(3+\nu)$

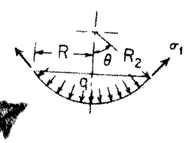
3. Spherical



$\frac{R_2}{t} > 10$

Prebuckling Stress in Spherical shell.

3a. Uniform internal or external pressure, q force/unit area; tangential edge support



$\sigma_1 = \sigma_2 = \frac{qR_2}{2t}$ ← $\sigma = pr/2t$ = stress in spherical shell

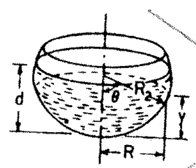
$\Delta R = \frac{qR_2^2(1-\nu)\sin\theta}{2Et}$

$\Delta R_2 = \frac{qR_2^2(1-\nu)}{2Et}$

$\Delta y = \frac{qR_2^2(1-\nu)(1-\cos\theta)}{2Et}$

$\psi = 0$

3b. Filled to depth d with liquid of density δ force/unit volume; tangential edge support



At any level y below the liquid surface, $y < d$

$\sigma_1 = \frac{\delta R_2^2}{6t}\left(3\frac{d}{R_2} - 1 + \frac{2\cos^2\theta}{1+\cos\theta}\right)$

$\sigma_2 = \frac{\delta R_2^2}{6t}\left[3\frac{d}{R_2} - 5 + \frac{(3+2\cos\theta)2\cos\theta}{1+\cos\theta}\right]$ (*Note:* See the note in case 2b regarding the discrepancy in the meridional slope at $y = d$)

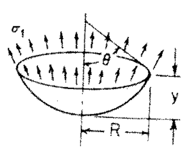
$\Delta R = \frac{\delta R_2^3\sin\theta}{6Et}\left[3(1-\nu)\frac{d}{R_2} - 5 + \nu + 2\cos\theta\,\frac{3+(2-\nu)\cos\theta}{1+\cos\theta}\right]$

$\Delta y = \frac{\delta R_2^3}{6Et}\left\{3(1-\nu)\left[\frac{d}{R_2}(1-\cos\theta) + \cos\theta\right] - (2-\nu)\cos^2\theta + (1+\nu)\left(1 + 2\ln\frac{2}{1+\cos\theta}\right)\right\}$

$\psi = \frac{-\delta R_2^2}{Et}\sin\theta$ Weight of liquid $= P = \delta\pi d^2\left(R_2 - \frac{d}{3}\right)$

At any level y above the liquid level use case 3d with the load equal to the entire weight of the liquid

3c. Own weight, δ force/unit volume; tangential top edge support



$\sigma_1 = \frac{\delta R_2}{1+\cos\theta}$, $\sigma_2 = -\delta R_2\left(\frac{1}{1+\cos\theta} - \cos\theta\right)$

Max tensile $\sigma_2 = \frac{\delta R_2}{2}$ at $\theta = 0$

$\sigma_2 = 0$ at $\theta = 51.83°$

$\Delta R = \frac{-\delta R_2^2\sin\theta}{E}\left(\frac{1+\nu}{1+\cos\theta} - \cos\theta\right)$

$\Delta y = \frac{\delta R_2^2}{E}\left[\sin^2\theta + (1+\nu)\ln\frac{2}{1+\cos\theta}\right]$

$\psi = \frac{-\delta R_2}{E}(2+\nu)\sin\theta$

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Table1 (p.3 of 4)

ıld the bellows. The overall
thin equivalent cylinder can
EI/l^2 for the Euler load. In a
ıe effect of pressure on the

in, a wall thickness of 0.015 in,
in length. The ends are rigidly
oduce a squirming instability is
$\nu = 0.3$.

5 in, length = 40 in, $b = \frac{40}{120} =$

$1 - 0.3^2) = 4.90$

$\frac{333)(60)\sqrt{0.91}}{)^6)(0.015^2)} = -0.00163P$

$E_1 t_1$ were loaded in compres-

$-0.00163P$

7 lb/in

is $I_1 = \pi R^3 t_1$ (see Table A.1,

$\frac{80.7)}{} = 7565$ lb

n^2

ıused by this pressure are

$= 34.400$ lb/in^2

$= 36.060$ lb/in^2

ıe corrugated tube should
sure of 96.3 lb/in^2.

Roark

13.6 Thick Shells of Revolution

If the wall thickness of a vessel is more than about one-tenth the radius, the meridional and hoop stresses cannot be considered uniform throughout the thickness of the wall and the radial stress cannot be considered negligible. These stresses in thick vessels, called *wall stresses*, must be found by formulas that are quite different from those used in finding membrane stresses in thin vessels.

It can be seen from the formulas for cases 1a and 1b of Table 13.5 that the stress σ_2 at the inner surface of a thick cylinder approaches q as the ratio of outer to inner radius approaches infinity. It is apparent, therefore, that if the stress is to be limited to some specified value σ, the pressure must never exceed $q = \sigma$, no matter how thick the wall is made. To overcome this limitation, the material at and near the inner surface must be put into a state of initial compression. This can be done by shrinking on one or more jackets (as explained in Sec. 3.12 and in the example which follows) or by subjecting the vessel to a high internal pressure that stresses the inner part into the plastic range and, when removed, leaves residual compression there and residual tension in the outer part. This procedure is called *autofrettage*, or *self-hooping*. If many successive jackets are superimposed on the original tube by shrinking or wrapping, the resulting structure is called a *multilayer vessel*. Such a construction has certain advantages, but it should be noted that the formulas for hoop stresses are based on the assumption that an isotropic material is used. In a multilayered vessel the effective radial modulus of elasticity is less than the tangential modulus, and in consequence the hoop stress at and near the outer wall is less than the formula would indicate; therefore, the outer layers of material contribute less to the strength of the vessel than might be supposed.

Cases 1e and 1f if in Table 13.5 represent radial body-force loading, which can be superimposed to give results for centrifugal loading, etc. (see Sec. 16.2). Case 1f is directly applicable to thick-walled disks with embedded electrical conductors used to generate magnetic fields. In many such cases the magnetic field varies linearly through the wall to zero at the outside. If there is a field at the outer turn, cases 1e and 1f can be superimposed in the necessary proportions.

The tabulated formulas for elastic wall stresses are accurate for both thin and thick vessels, but formulas for predicted yield pressures do not always agree closely with experimental results (Refs. 21, 34–37, and 39). The expression for q_y given in Table 13.5 is based on the minimum strain-energy theory of elastic failure. The expression for bursting pressure

$$q_u = 2\sigma_u \frac{a - b}{a + b} \qquad (13.6\text{-}1)$$

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Table 1 (p.4 of 4)

TABLE 15.2 Formulas for elastic stability of plates and shells (*Continued*)

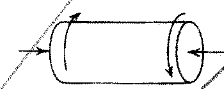
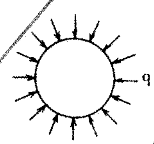
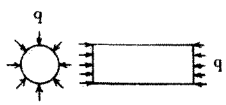
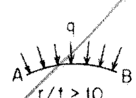
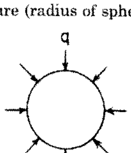
Form of plate or shell and manner of loading	Manner of support	Formulas for critical unit compressive stress σ', unit shear stress τ', load P', bending moment M', or unit external pressure q' at which elastic buckling occurs
18. Thin-walled circular tube under uniform longitudinal compression σ and uniform circumferential shear τ due to torsion (case 15 combined with case 17)  $\frac{r}{t} > 10$	18a. Edges hinged as in case 17a. 18b. Edges clamped as in case 17b.	The equation $1 - \frac{\sigma'}{\sigma'_o} = \left(\frac{\tau'}{\tau'_o}\right)^n$ holds, where σ' and τ' are the critical compressi[...] combined loading, σ'_o is the critical compressive stress for the cylinder under co[...] τ'_o is the critical shear stress for the cylinder under torsion alone (case 17a or 17[...] Tests indicate that n is approximately 3. If σ is tensile, then σ' should be cons[...] (See also Ref. 26. For square tube, see Ref. 32)
19. Thin tube under uniform lateral external pressure (radius of tube = r)  $\frac{r}{t} > 10$	19a. Very long tube with free ends; length l	$q' = \frac{1}{4}\frac{E}{1-\nu^2}\frac{t^3}{r^3}$ Applicable when $l > 4.90r\sqrt{\frac{r}{t}}$
	19b. Short tube, of length l, ends held circular, but not otherwise constrained, or long tube held circular at intervals l	$q' = 0.807\frac{Et^2}{lr}\sqrt[4]{\left(\frac{1}{1-\nu^2}\right)^3\frac{t^2}{r^2}}$ approximate formula
20. Thin tube with closed ends under uniform external pressure, lateral and longitudinal (length of tube = l; radius of tube = r)  $\frac{r}{t} > 10$	20a. Ends held circular	$q' = \frac{E\frac{t}{r}}{1+\frac{1}{2}\left(\frac{\pi r}{nl}\right)^2}\left\{\frac{1}{n^2\left[1+\left(\frac{nl}{\pi r}\right)^2\right]^2} + \frac{n^2t^2}{12r^2(1-\nu^2)}\left[1+\left(\frac{\pi r}{nl}\right)^2\right]^2\right\}$ (Refs. 19, 20) where n = number of lobes formed by the tube in buckling. To determine q' for tubes of a given t/r, plot a group of curves, one curve for each integral value of n of 2 or more, with l/r as ordinates and q' as abscissa; that curve of the group which gives the least value of q' is then used to find the q' corresponding to a given l/r. If $60 < \left(\frac{l}{r}\right)^2\left(\frac{r}{t}\right) < 2.5\left(\frac{r}{t}\right)^2$, the critical pressure can be approximated by $q' = \frac{0.92E}{\left(\frac{l}{r}\right)\left(\frac{r}{t}\right)^{2.5}}$ (Ref. 81) **For other approximations see ref. 109** **Values of experimentally determined critical pressures range 20% above and below the theoretical values given by the expressions above. A recommended probable minimum critical pressure is $0.80q'$.**
21. Curved panel under uniform radial pressure (radius of curvature r, central angle 2α, when 2α = arc AB/r) 	21a. Curved edges free, straight edges at A and B simply supported (i.e., hinged)	$q' = \frac{Et^3\left(\frac{\pi^2}{\alpha^2}-1\right)}{12r^3(1-\nu^2)}$ (Ref. 1)
	21b. Curved edges free, straight edges at A and B clamped	Here k is found from the equation $k\tan\alpha\cot k\alpha = 1$ and has the following values: $q' = \frac{Et^3(k^2-1)}{12r^3(1-\nu^2)}$ (Ref. 1) α: 15°, 30°, 60°, 90°, 120°, 150°, 180° k: 17.2, 8.62, 4.37, 3.0, 2.36, 2.07, 2.0
22. Thin sphere under uniform external pressure (radius of sphere = r)  r/t > 10	22a. No constraint	$q' = \frac{2Et^2}{r^2\sqrt{3(1-\nu^2)}}$ (for ideal case) (Refs. 1, 37) $q' = \frac{0.365Et^2}{r^2}$ (probable actual minimum q') knockdown ≈ 0.3 For spherical cap, half-central angle ϕ between 20 and 60°, R/t between 400 and 2000, $q' = [1 - 0.00875(\phi° - 20°)]\left(1 - 0.000175\frac{R}{t}\right)(0.3E)\left(\frac{t}{R}\right)^2$ (Empirical formula, Ref. 43)
23. Thin truncated conical shell with [...]	23a. Ends held circular	q' can be found from the formula of case 20a if the slant length of the cone is substituted for the length of the [...]

Table 2 (3 pages) RUN STREAM

doer.runstream

```
[A number of stress and buckling cases were run with
 the use of BIGBOSOR4. All of the shells are PERFECT.
 All of the cases have uniform external hydrostatic
 pressure.

 Here is a summary of the BIGBOSOR4 analyses conducted:
-----------------------------------------------------------------
                                                         input file
1. Stress in spherical shell of thickness 1.25 inches    doer4.ALL
   Tables 3 and 4 and Fig. 1
2. Buckling of spherical shell of thickness 0.5 inch     doer2.ALL
   Tables 5 and 6 and Figs. 2 and 3
3. Buckling of spherical shell of thickness 1.25 inch    doer3.ALL
   Table 7 and Fig. 4
4. Stress in cylindrical shell of thickness 2.5 in.      doer1.ALL
   Tables 8 and 9 and Fig. 5
5. Buckling of cylindrical shell of thickness 2.5 in.    doer0.ALL
   Tables 10 and 11 and Fig. 6
6. Stress in spherical-cylindrical combination           doer6.ALL
   uniform thickness in each segment: t(1) = 1.25, t(2) = 2.5 inches
   Fig. 7, Table 12, and Figs. 8, 9, 10, 11, 12
7. Buckling in spherical-cylindrical combination         doer5.ALL
   uniform thickness in each segment: t(1) = 1.25, t(2) = 2.5 inches
   Tables 13 and 14 and Fig. 13
8. Stress in spherical-cylindrical combination           doer7.ALL
   variable nodal point spacing and ZVAL in Seg. 1 only
   Table 15, Figs. 14 and 15
9. Stress in spherical-cylindrical combination           doer8.ALL
   variable nodal point spacing and ZVAL and thickness
   in both Segments 1 and 2.
   Table 16 and Figs. 16 and 17
10.Same as Item 9, except for buckling                   doer9.ALL
   Tables 17 and 18 and Fig. 18]
--------------------------------------------------------------------

                  RUN STREAM
==================================================================
bigbosor4log     (activate the BIGBOSOR4 commands)

---------------------------------------------------------
The BIGBOSOR4 commands, in the general order in which
you would probably use them (except in GENOPT applications), are:

help4            (get information on BOSOR4.)
input            (you provide segment-by-seg. input)
assemble         (concatenates segment data files)
bigbosorall      (batch run of pre, main, post proc.)
bosorplot        (batch run for generating plot files)
resetup          (input for restart run, same model)
bigrestart               (batch run of main & postprocessors)
cleanup          (delete all except for .DOC file)
getsegs          (generate segment files from .DOC)
modify           (modify a segment file)
-----------------------------------------------------------

input            (begin an interactive session in which you
                  provide input data interactively. NOTE:
                  if you have a valid *.ALL file, you don't
                  need to execute INPUT).

assemble         (the *.SEGi, i = 1, 2, 3, . . . are concatenated.
                  NOTE: if you have a valid *.ALL file you don't
                  need to execute ASSEMBLE).

bigbosorall      (execute BIGBOSOR4. Table 3 is input. Table 4
                  is abridged output.

bosor4plot       (You can obtain the plot shown in Fig. 1)

cleanup          (cleans up the doer4.files, saving doer4.ALL
                  and doer4.DOC)
```

```
bigbosorall      (execute BIGBOSOR4. Table 5 is input. Table 6
                  is abridged output.

bosor4plot       (You can obtain the plots shown in Figs. 2 and 3)

cleanup          (cleans up the doer2.files, saving doer2.ALL
                  and doer2.DOC)

[Next, you can copy the doer2.ALL into doer3.ALL, then edit
 the doer3.ALL file to increase ZVAL for the thicker shell.]

bigbosorall      (execute BIGBOSOR4. doer3.ALL is input. Table 7
                  is abridged output.

bosor4plot       (You can obtain the plot shown in Fig. 4)

cleanup          (cleans up the doer3.files, saving doer3.ALL
                  and doer3.DOC)

bigbosorall      (execute BIGBOSOR4. Table 8 is input. Table 9
                  is abridged output.

bosor4plot       (You can obtain the plot shown in Fig. 5)

cleanup          (cleans up the doer1.files, saving doer1.ALL
                  and doer1.DOC)

bigbosorall      (execute BIGBOSOR4. Table 10 is input. Table 11
                  is abridged output.

bosor4plot       (You can obtain the plot shown in Fig. 6)

cleanup          (cleans up the doer0.files, saving doer0.ALL
                  and doer0.DOC)

[Next, generate input data for the combined spherical-cylindrical
 shell model in which there are 2 segments, as shown in Fig. 7.
 Initially, we assume that the wall thickness is uniform in each
 of the two shell segments: t(spherical segment) = t(1) = 1.25 inches;
 t(cylindrical segment) = t(2) = 2.5 inches.]


bigbosorall      (execute BIGBOSOR4. Table 12 is input. The
                  output file, doer6.OUT, is not listed here;
                  only plots are given.)

bosor4plot       (You can obtain the plots shown in Figs. 8 - 12)

cleanup          (cleans up the doer6.files, saving doer6.ALL
                  and doer6.DOC)

bigbosorall      (execute BIGBOSOR4. Table 13 is input. Table 14
                  is the abridged output file.)

bosor4plot       (You can obtain the plot shown in Fig. 13)

cleanup          (cleans up the doer5.files, saving doer5.ALL
                  and doer5.DOC)

bigbosorall      (execute BIGBOSOR4. Table 15 is input. The
                  output file, doer7.OUT, is not listed here.)

bosor4plot       (You can obtain the plots shown in Figs. 14 and 15)

cleanup          (cleans up the doer7.files, saving doer7.ALL
                  and doer7.DOC)

bigbosorall      (execute BIGBOSOR4. Table 16 is input. The
                  output file, doer8.OUT, is not listed here.)

bosor4plot       (You can obtain the plots shown in Figs. 16 and 17)

cleanup          (cleans up the doer8.files, saving doer8.ALL
                  and doer8.DOC)

bigbosorall      (execute BIGBOSOR4. Table 17 is input. Table 18
                  is the abridged output file.)
```

```
bosor4plot      (You can obtain the plot shown in Fig. 18)

cleanup         (cleans up the doer9.files, saving doer9.ALL
                 and doer9.DOC)
======================================================================
```

Table 3 (2 pages) Spherical Shell Stress BIGBOSOR4 input file

doer4.ALL

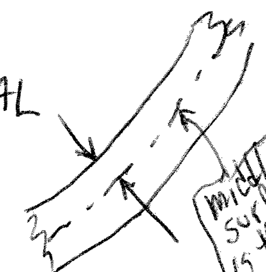
thickness = 1.25"

radius = 20.0"

```
spherical shell (axisymmetric stress analysis, INDIC=0)
        0       $ INDIC = analysis type indicator
        1       $ NPRT = output options (1=minimum, 2=medium, 3=maximum)
        1       $ ISTRES= output control (0=resultants, 1=sigma, 2=epsilon)
        1       $ NSEG  = number of shell segments (less than 295)
   H            $
   H            $ SEGMENT NUMBER    1    1    1    1    1    1    1    1
   H            $ NODAL POINT DISTRIBUTION FOLLOWS...
       91       $ NMESH = number of node points (5 = min.; 98 = max.)( 1)
        3       $ NTYPEH= control integer (1 or 3) for nodal point spacing
   H            $ REFERENCE SURFACE GEOMETRY FOLLOWS...
        2       $ NSHAPE= indicator (1,2 or 4) for geometry of meridian
        0       $ R1     = radius at beginning of segment (see p. 66)
        0       $ Z1     = global axial coordinate at beginning of segment
       20       $ R2     = radius at end of segment
       20       $ Z2     = global axial coordinate at end of segment
        0       $ RC     = radius from axis of rev. to center of curvature
       20       $ ZC     = axial coordinate of center of curvature
 -1.000000      $ SROT=indicator for direction of increasing arc (-1. or +1.)
   H            $ IMPERFECTION SHAPE FOLLOWS...
        0       $ IMP   = indicator for imperfection (0=none, 1=some)
   H            $ REFERENCE SURFACE LOCATION RELATIVE TO WALL
        3       $ NTYPEZ= control (1 or 3) for reference surface location
    0.625       $ ZVAL  = distance from leftmost surf. to reference surf.
   N            $ Do you want to print out r(s), r'(s), etc. for this segment?
   H            $ DISCRETE RING INPUT FOLLOWS...
        0       $ NRINGS= number (max=20) of discrete rings in this segment
        0       $ K=elastic foundation modulus (e.g. lb/in**3)in this seg.
   H            $ LINE LOAD INPUT FOLLOWS...
        0       $ LINTYP= indicator (0, 1, 2 or 3) for type of line loads
   H            $ DISTRIBUTED LOAD INPUT FOLLOWS...
        1       $ IDISAB= indicator (0, 1, 2 or 3) for load set A and B
   H            $ SURFACE LOAD INPUT FOR LOAD SET "A" FOLLOWS
        1       $ NLTYPE=control (0,1,2,3) for type of surface loading
        2       $ NPSTAT= number of meridional callouts for surface loading
        0       $ NLOAD(1)=indicator for meridional traction (0=none, 1=some)
        0       $ NLOAD(2)=indicator for circumferential traction
        1       $ NLOAD(3)=indicator for normal pressure    (0=none, 1=some)
       -1       $ PN(i)   = normal pressure (p.74) at ith callout, PN( 1)
       -1       $ PN(i)   = normal pressure (p.74) at ith callout, PN( 2)
        2       $ NTYPE = control for meaning of loading callout (2=z, 3=r)
        0       $ Z(I)  = axial coordinate of Ith loading callout, z( 1)
       20       $ Z(I)  = axial coordinate of Ith loading callout, z( 2)
   H            $ SHELL WALL CONSTRUCTION FOLLOWS...
        2       $ NWALL=index (1, 2, 4, 5, 6, 7, 8, 9, 10) for wall construction
 0.1600000E+08  $ E      = Young's modulus for skin
 0.2500000      $ U      = Poisson's ratio for skin
 0.4144000E-03  $ SM =mass density of skin (e.g. alum.=.00025 lb-sec**2/in**4)
        0       $ ALPHA = coefficient of thermal expansion
        0       $ NRS  = control (0 or 1) for addition of smeared stiffeners
        0       $ NSUR   = control for thickness input (0 or 1 or -1)
   N            $ Do you want to print out ref. surf. location and thickness?
   N            $ Do you want to print out the C(i,j) at meridional stations?
   N            $ Do you want to print out distributed loads along meridian?
   H            $
   H            $ GLOBAL DATA BEGINS...
        0       $ NLAST = plot options  (-1=none, 0=geometry, 1=u,v,w)
   N            $ Are there any regions for which you want expanded plots?
        0       $ P      = pressure or surface traction multiplier
    15000       $ DP     = pressure or surface traction multiplier increment
        0       $ TEMP   = temperature rise multiplier
        0       $ DTEMP  = temperature rise multiplier increment
        2       $ Number of load steps
        0       $ OMEGA  = angular vel. about axis of revolution (rad/sec)
        0       $ DOMEGA = angular velocity increment (rad/sec)
   H            $ CONSTRAINT CONDITIONS FOLLOW....
        1       $ How many segments in the structure?
   H            $
   H            $ CONSTRAINT CONDITIONS FOR SEGMENT NO.    1    1    1    1
   H            $ POLES INPUT FOLLOWS...
        1       $ Number of poles (places where r=0) in SEGMENT( 1)
        1       $ IPOLE = nodal point number of pole, IPOLE( 1)
   H            $ INPUT FOR CONSTRAINTS TO GROUND FOLLOWS...
        1       $ At how many stations is this segment constrained to ground?
       91       $ INODE = nodal point number of constraint to ground, INODE( 1)
        1       $ IUSTAR=axial displacement constraint (0 or 1 or 2)
        0       $ IVSTAR=circumferential displacement(0=free,1=0,2=imposed)
        0       $ IWSTAR=radial displacement(0=free,1=constrained,2=imposed)
```

t = 1.25"

ZVAL



middle surface is the ref. surface in this case

pressure multiplier

titanium

0 means the ref. surface is the middle surface, so $t = 2.0 \times zval = 0.625 \times 2.0$

$15000 = 0.96 \times 64 \frac{lb}{ft^3} \times 35000 ft$

weight of water

ocean depth

Table 3 (p. 2 of 2)

```
    1      $ ICHI=meridional rotation (0=free,1=constrained,2=imposed)
    0      $ D1    = radial component of offset of ground support
    0      $ D2    = axial component of offset of ground support
 N         $ Is this constraint the same for both prebuckling and buckling?
    0      $ IUSTARB= axial displacement for buckling or vibration phase
    1      $ IVSTARB= circ. displacement for buckling or vibration phase
    1      $ IWSTARB= radial displacement for buckling or vibration
    0      $ ICHIB  = meridional rotation for buckling or vibration
 H         $ JUNCTION CONDITION INPUT FOLLOWS...
 N         $ Is this segment joined to any lower-numbered segments?
 H         $ RIGID BODY CONSTRAINT INPUT FOLLOWS...
 Y         $ Given existing constraints, are rigid body modes possible?
 Y         $ Do you wish to prevent rigid body motion?
    1      $ ISEG  = segment no. at which to prevent rigid body motion
   91      $ INODE = node no. at which to prevent rigid body motion
    1      $ IUSTAR= axial n=0 rigid body constraint (0=none, 1=some)
    1      $ IVSTAR= circ. n=0 rigid body constraint (usually equals 1)
    0      $ IWSTAR= radial n=0 rigid body constraint (usually equals 0)
    1      $ ICHI  = meridional rot. rigid body constraint
    1      $ IUSTAR= axial n=1 rigid body constraint (usually equals 1)
    1      $ IVSTAR= circ. n=1 rigid body constraint (usually equals 1)
    0      $ IWSTAR= radial n=1 rigid body constraint (usually equals 0)
    1      $ ICHI  = meridional rot. rigid body constraint
 H         $ "GLOBAL3" QUESTIONS (AT END OF CASE)...
 Y         $ Do you want to list output for segment( 1)
 Y         $ Do you want to list forces in the discrete rings, if any?
```

end of BIGBOSOR4 input file, doorit.ALL

Spherical shell Stress

BIGBOSOR4 prediction

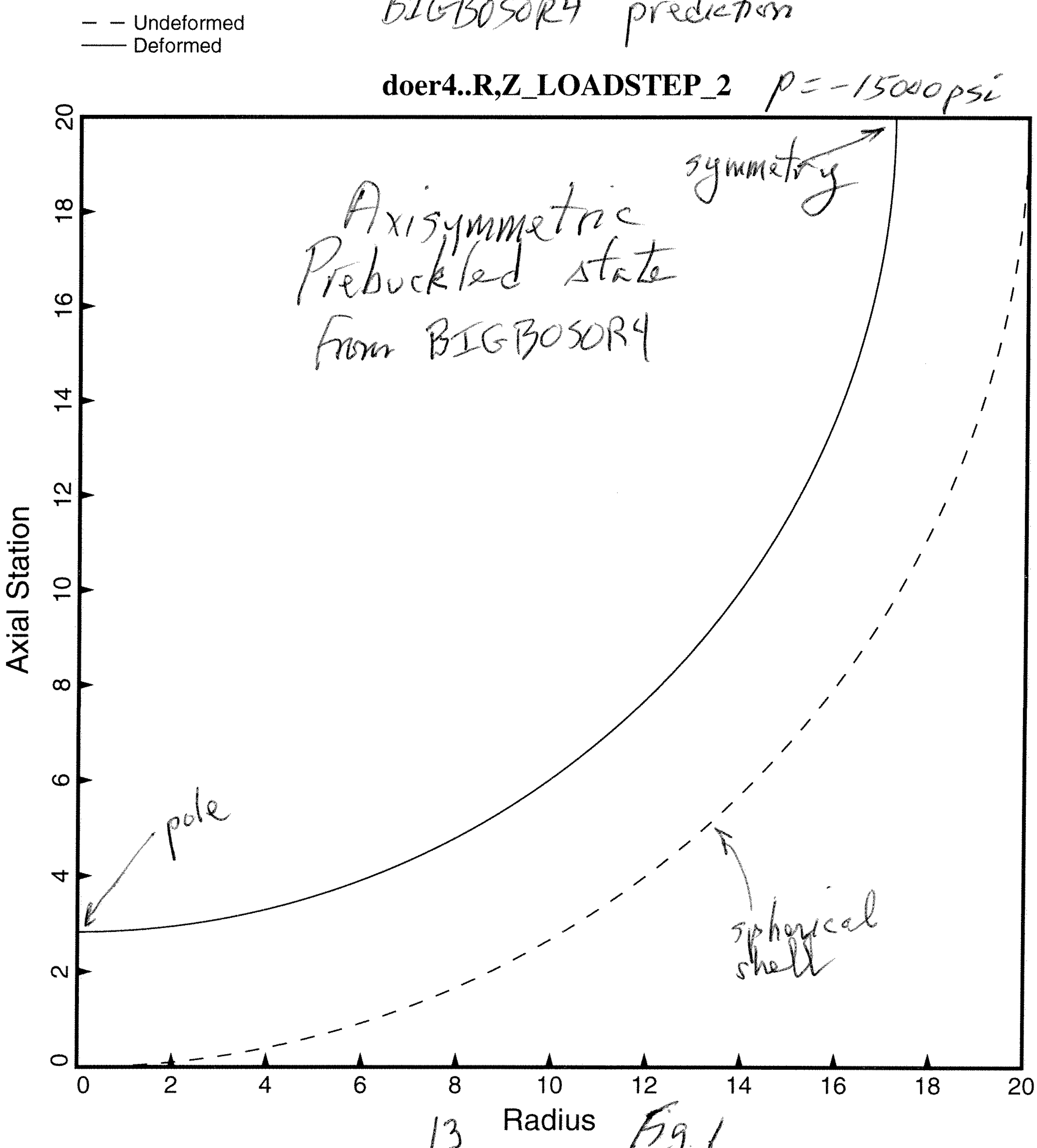


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Fig. 1

Table 4 (2 pages) Spherical Shell Stress

BIGBOSOR4 Output from load step #2

$$pr/2t = \frac{15000 \times 20.0}{2 \times 1.25} = 120000\ psi$$

doer4.OUT (abridged) Axisymmetric stress analysis, $\boxed{\text{INDIC = 0}}$, thickness, t = 1.25 inches, p = -15000 psi.

AXISYMMETRIC PRESTRESS DISTRIBUTION FOR SEGMENT 1

POINT	STATION (ARC LENGTH)	W0 NORMAL DISP.	U0 MERIDIONAL DISPLACEMENT	SIGMA1(IN) MERID. STRESS	SIGMA1(OUT) MERIDIONAL STRESS	SIGMA2(IN) CIRCUMF. STRESS	SIGMA2(OUT) CIRCUMF. STRESS	SIGMAE(IN) VON MISES INNER FIBER	SIGMAE(OUT) EQUIVALENT OUTER FIBER
1	0.000E+00	-1.112E-01	0.000E+00	-1.187E+05	-1.187E+05	-1.187E+05	-1.187E+05	1.187E+05	1.187E+05
2	9.599E-02	-1.112E-01	-8.678E-08	-1.187E+05	-1.187E+05	-1.187E+05	-1.187E+05	1.187E+05	1.187E+05
3	3.534E-01	-1.112E-01	-2.732E-07	-1.187E+05	-1.187E+05	-1.187E+05	-1.187E+05	1.187E+05	1.187E+05
4	6.981E-01	-1.112E-01	-4.861E-07	-1.187E+05	-1.187E+05	-1.187E+05	-1.187E+05	1.187E+05	1.187E+05
5	1.047E+00	-1.112E-01	-6.860E-07	-1.187E+05	-1.187E+05	-1.187E+05	-1.187E+05	1.187E+05	1.187E+05
6	1.396E+00	-1.112E-01	-8.744E-07	-1.187E+05	-1.187E+05	-1.187E+05	-1.187E+05	1.187E+05	1.187E+05
7	1.745E+00	-1.112E-01	-1.053E-06	-1.187E+05	-1.187E+05	-1.187E+05	-1.187E+05	1.187E+05	1.187E+05
8	2.094E+00	-1.112E-01	-1.222E-06	-1.187E+05	-1.187E+05	-1.187E+05	-1.187E+05	1.187E+05	1.187E+05
9	2.443E+00	-1.112E-01	-1.384E-06	-1.187E+05	-1.187E+05	-1.187E+05	-1.187E+05	1.187E+05	1.187E+05
10	2.793E+00	-1.112E-01	-1.537E-06	-1.187E+05	-1.187E+05	-1.187E+05	-1.187E+05	1.187E+05	1.187E+05
11	3.142E+00	-1.112E-01	-1.682E-06	-1.187E+05	-1.187E+05	-1.187E+05	-1.187E+05	1.187E+05	1.187E+05
12	3.491E+00	-1.112E-01	-1.819E-06	-1.187E+05	-1.187E+05	-1.187E+05	-1.187E+05	1.187E+05	1.187E+05
13	3.840E+00	-1.112E-01	-1.950E-06	-1.187E+05	-1.187E+05	-1.187E+05	-1.187E+05	1.187E+05	1.187E+05
14	4.189E+00	-1.112E-01	-2.072E-06	-1.187E+05	-1.187E+05	-1.187E+05	-1.187E+05	1.187E+05	1.187E+05
15	4.538E+00	-1.112E-01	-2.188E-06	-1.187E+05	-1.187E+05	-1.187E+05	-1.187E+05	1.187E+05	1.187E+05
16	4.887E+00	-1.112E-01	-2.296E-06	-1.187E+05	-1.187E+05	-1.187E+05	-1.187E+05	1.187E+05	1.187E+05
17	5.236E+00	-1.112E-01	-2.397E-06	-1.187E+05	-1.187E+05	-1.187E+05	-1.187E+05	1.187E+05	1.187E+05
18	5.585E+00	-1.112E-01	-2.491E-06	-1.187E+05	-1.187E+05	-1.187E+05	-1.187E+05	1.187E+05	1.187E+05
19	5.934E+00	-1.112E-01	-2.579E-06	-1.187E+05	-1.187E+05	-1.187E+05	-1.187E+05	1.187E+05	1.187E+05
20	6.283E+00	-1.112E-01	-2.659E-06	-1.187E+05	-1.187E+05	-1.187E+05	-1.187E+05	1.187E+05	1.187E+05
21	6.632E+00	-1.112E-01	-2.734E-06	-1.187E+05	-1.187E+05	-1.187E+05	-1.187E+05	1.187E+05	1.187E+05
22	6.981E+00	-1.112E-01	-2.802E-06	-1.187E+05	-1.187E+05	-1.187E+05	-1.187E+05	1.187E+05	1.187E+05
23	7.330E+00	-1.112E-01	-2.864E-06	-1.187E+05	-1.187E+05	-1.187E+05	-1.187E+05	1.187E+05	1.187E+05
24	7.679E+00	-1.112E-01	-2.919E-06	-1.187E+05	-1.187E+05	-1.187E+05	-1.187E+05	1.187E+05	1.187E+05
25	8.029E+00	-1.112E-01	-2.969E-06	-1.187E+05	-1.187E+05	-1.187E+05	-1.187E+05	1.187E+05	1.187E+05
26	8.378E+00	-1.112E-01	-3.014E-06	-1.187E+05	-1.187E+05	-1.187E+05	-1.187E+05	1.187E+05	1.187E+05
27	8.727E+00	-1.112E-01	-3.052E-06	-1.187E+05	-1.187E+05	-1.187E+05	-1.187E+05	1.187E+05	1.187E+05
28	9.076E+00	-1.112E-01	-3.086E-06	-1.187E+05	-1.187E+05	-1.187E+05	-1.187E+05	1.187E+05	1.187E+05
29	9.425E+00	-1.112E-01	-3.115E-06	-1.187E+05	-1.187E+05	-1.187E+05	-1.187E+05	1.187E+05	1.187E+05
30	9.774E+00	-1.112E-01	-3.139E-06	-1.187E+05	-1.187E+05	-1.187E+05	-1.187E+05	1.187E+05	1.187E+05
31	1.012E+01	-1.112E-01	-3.158E-06	-1.187E+05	-1.187E+05	-1.187E+05	-1.187E+05	1.187E+05	1.187E+05
32	1.047E+01	-1.112E-01	-3.173E-06	-1.187E+05	-1.187E+05	-1.187E+05	-1.187E+05	1.187E+05	1.187E+05
33	1.082E+01	-1.112E-01	-3.183E-06	-1.187E+05	-1.187E+05	-1.187E+05	-1.187E+05	1.187E+05	1.187E+05
34	1.117E+01	-1.112E-01	-3.190E-06	-1.187E+05	-1.187E+05	-1.187E+05	-1.187E+05	1.187E+05	1.187E+05
35	1.152E+01	-1.112E-01	-3.192E-06	-1.187E+05	-1.187E+05	-1.187E+05	-1.187E+05	1.187E+05	1.187E+05
36	1.187E+01	-1.112E-01	-3.191E-06	-1.187E+05	-1.187E+05	-1.187E+05	-1.187E+05	1.187E+05	1.187E+05
37	1.222E+01	-1.112E-01	-3.186E-06	-1.187E+05	-1.187E+05	-1.187E+05	-1.187E+05	1.187E+05	1.187E+05
38	1.257E+01	-1.112E-01	-3.178E-06	-1.187E+05	-1.187E+05	-1.187E+05	-1.187E+05	1.187E+05	1.187E+05
39	1.292E+01	-1.112E-01	-3.166E-06	-1.187E+05	-1.187E+05	-1.187E+05	-1.187E+05	1.187E+05	1.187E+05
40	1.326E+01	-1.112E-01	-3.151E-06	-1.187E+05	-1.187E+05	-1.187E+05	-1.187E+05	1.187E+05	1.187E+05
41	1.361E+01	-1.112E-01	-3.133E-06	-1.187E+05	-1.187E+05	-1.187E+05	-1.187E+05	1.187E+05	1.187E+05
42	1.396E+01	-1.112E-01	-3.112E-06	-1.187E+05	-1.187E+05	-1.187E+05	-1.187E+05	1.187E+05	1.187E+05
43	1.431E+01	-1.112E-01	-3.088E-06	-1.187E+05	-1.187E+05	-1.187E+05	-1.187E+05	1.187E+05	1.187E+05

Table 4 (p. 2 of 2)

44	1.466E+01	-1.112E-01	-3.061E-06	-1.187E+05	-1.187E+05	-1.187E+05	-1.187E+05	1.187E+05	1.187E+05
45	1.501E+01	-1.112E-01	-3.032E-06	-1.187E+05	-1.187E+05	-1.187E+05	-1.187E+05	1.187E+05	1.187E+05
46	1.536E+01	-1.112E-01	-3.000E-06	-1.187E+05	-1.187E+05	-1.187E+05	-1.187E+05	1.187E+05	1.187E+05
47	1.571E+01	-1.112E-01	-2.966E-06	-1.187E+05	-1.187E+05	-1.187E+05	-1.187E+05	1.187E+05	1.187E+05
48	1.606E+01	-1.112E-01	-2.929E-06	-1.187E+05	-1.187E+05	-1.187E+05	-1.187E+05	1.187E+05	1.187E+05
49	1.641E+01	-1.112E-01	-2.890E-06	-1.187E+05	-1.187E+05	-1.187E+05	-1.187E+05	1.187E+05	1.187E+05
50	1.676E+01	-1.112E-01	-2.848E-06	-1.187E+05	-1.187E+05	-1.187E+05	-1.187E+05	1.187E+05	1.187E+05
51	1.710E+01	-1.112E-01	-2.805E-06	-1.187E+05	-1.187E+05	-1.187E+05	-1.187E+05	1.187E+05	1.187E+05
52	1.745E+01	-1.112E-01	-2.759E-06	-1.187E+05	-1.187E+05	-1.187E+05	-1.187E+05	1.187E+05	1.187E+05
53	1.780E+01	-1.112E-01	-2.712E-06	-1.187E+05	-1.187E+05	-1.187E+05	-1.187E+05	1.187E+05	1.187E+05
54	1.815E+01	-1.112E-01	-2.662E-06	-1.187E+05	-1.187E+05	-1.187E+05	-1.187E+05	1.187E+05	1.187E+05
55	1.850E+01	-1.112E-01	-2.611E-06	-1.187E+05	-1.187E+05	-1.187E+05	-1.187E+05	1.187E+05	1.187E+05
56	1.885E+01	-1.112E-01	-2.557E-06	-1.187E+05	-1.187E+05	-1.187E+05	-1.187E+05	1.187E+05	1.187E+05
57	1.920E+01	-1.112E-01	-2.502E-06	-1.187E+05	-1.187E+05	-1.187E+05	-1.187E+05	1.187E+05	1.187E+05
58	1.955E+01	-1.112E-01	-2.445E-06	-1.187E+05	-1.187E+05	-1.187E+05	-1.187E+05	1.187E+05	1.187E+05
59	1.990E+01	-1.112E-01	-2.387E-06	-1.187E+05	-1.187E+05	-1.187E+05	-1.187E+05	1.187E+05	1.187E+05
60	2.025E+01	-1.112E-01	-2.327E-06	-1.187E+05	-1.187E+05	-1.187E+05	-1.187E+05	1.187E+05	1.187E+05
61	2.059E+01	-1.112E-01	-2.265E-06	-1.187E+05	-1.187E+05	-1.187E+05	-1.187E+05	1.187E+05	1.187E+05
62	2.094E+01	-1.112E-01	-2.202E-06	-1.187E+05	-1.187E+05	-1.187E+05	-1.187E+05	1.187E+05	1.187E+05
63	2.129E+01	-1.112E-01	-2.138E-06	-1.187E+05	-1.187E+05	-1.187E+05	-1.187E+05	1.187E+05	1.187E+05
64	2.164E+01	-1.112E-01	-2.072E-06	-1.187E+05	-1.187E+05	-1.187E+05	-1.187E+05	1.187E+05	1.187E+05
65	2.199E+01	-1.112E-01	-2.005E-06	-1.187E+05	-1.187E+05	-1.187E+05	-1.187E+05	1.187E+05	1.187E+05
66	2.234E+01	-1.112E-01	-1.936E-06	-1.187E+05	-1.187E+05	-1.187E+05	-1.187E+05	1.187E+05	1.187E+05
67	2.269E+01	-1.113E-01	-1.867E-06	-1.187E+05	-1.187E+05	-1.187E+05	-1.187E+05	1.187E+05	1.187E+05
68	2.304E+01	-1.113E-01	-1.796E-06	-1.187E+05	-1.187E+05	-1.187E+05	-1.187E+05	1.187E+05	1.187E+05
69	2.339E+01	-1.113E-01	-1.725E-06	-1.187E+05	-1.187E+05	-1.187E+05	-1.187E+05	1.187E+05	1.187E+05
70	2.374E+01	-1.113E-01	-1.652E-06	-1.187E+05	-1.187E+05	-1.187E+05	-1.187E+05	1.187E+05	1.187E+05
71	2.409E+01	-1.113E-01	-1.579E-06	-1.187E+05	-1.187E+05	-1.187E+05	-1.187E+05	1.187E+05	1.187E+05
72	2.443E+01	-1.113E-01	-1.505E-06	-1.187E+05	-1.187E+05	-1.187E+05	-1.187E+05	1.187E+05	1.187E+05
73	2.478E+01	-1.113E-01	-1.430E-06	-1.187E+05	-1.187E+05	-1.187E+05	-1.187E+05	1.187E+05	1.187E+05
74	2.513E+01	-1.113E-01	-1.354E-06	-1.187E+05	-1.187E+05	-1.187E+05	-1.187E+05	1.187E+05	1.187E+05
75	2.548E+01	-1.113E-01	-1.278E-06	-1.187E+05	-1.187E+05	-1.187E+05	-1.187E+05	1.187E+05	1.187E+05
76	2.583E+01	-1.113E-01	-1.201E-06	-1.187E+05	-1.187E+05	-1.187E+05	-1.187E+05	1.187E+05	1.187E+05
77	2.618E+01	-1.113E-01	-1.124E-06	-1.187E+05	-1.187E+05	-1.187E+05	-1.187E+05	1.187E+05	1.187E+05
78	2.653E+01	-1.113E-01	-1.047E-06	-1.187E+05	-1.187E+05	-1.187E+05	-1.187E+05	1.187E+05	1.187E+05
79	2.688E+01	-1.113E-01	-9.691E-07	-1.187E+05	-1.187E+05	-1.187E+05	-1.187E+05	1.187E+05	1.187E+05
80	2.723E+01	-1.113E-01	-8.912E-07	-1.187E+05	-1.187E+05	-1.187E+05	-1.187E+05	1.187E+05	1.187E+05
81	2.758E+01	-1.113E-01	-8.130E-07	-1.187E+05	-1.187E+05	-1.187E+05	-1.187E+05	1.187E+05	1.187E+05
82	2.793E+01	-1.113E-01	-7.348E-07	-1.187E+05	-1.187E+05	-1.187E+05	-1.187E+05	1.187E+05	1.187E+05
83	2.827E+01	-1.113E-01	-6.567E-07	-1.187E+05	-1.187E+05	-1.187E+05	-1.187E+05	1.187E+05	1.187E+05
84	2.862E+01	-1.113E-01	-5.786E-07	-1.187E+05	-1.187E+05	-1.187E+05	-1.187E+05	1.187E+05	1.187E+05
85	2.897E+01	-1.113E-01	-5.005E-07	-1.187E+05	-1.187E+05	-1.187E+05	-1.187E+05	1.187E+05	1.187E+05
86	2.932E+01	-1.113E-01	-4.225E-07	-1.187E+05	-1.187E+05	-1.187E+05	-1.187E+05	1.187E+05	1.187E+05
87	2.967E+01	-1.113E-01	-3.447E-07	-1.187E+05	-1.187E+05	-1.187E+05	-1.187E+05	1.187E+05	1.187E+05
88	3.002E+01	-1.113E-01	-2.671E-07	-1.187E+05	-1.187E+05	-1.187E+05	-1.187E+05	1.187E+05	1.187E+05
89	3.037E+01	-1.113E-01	-1.897E-07	-1.187E+05	-1.187E+05	-1.187E+05	-1.187E+05	1.187E+05	1.187E+05
90	3.072E+01	-1.113E-01	-1.124E-07	-1.187E+05	-1.187E+05	-1.187E+05	-1.187E+05	1.187E+05	1.187E+05
91	3.106E+01	-1.113E-01	-3.857E-08	-1.187E+05	-1.187E+05	-1.187E+05	-1.187E+05	1.187E+05	1.187E+05
92	3.132E+01	-1.113E-01	-1.444E-09	-1.187E+05	-1.187E+05	-1.187E+05	-1.187E+05	1.187E+05	1.187E+05
93	3.142E+01	-1.113E-01	-1.861E-22	-1.187E+05	-1.187E+05	-1.187E+05	-1.187E+05	1.187E+05	1.187E+05

****** MAXIMUM EFFECTIVE STRESS IN ISOTROPIC WALL ******
STRMAX= 1.1868E+05

Spherical - ~~new~~ buckling
Table 5 (2 pp.) BIGBOSOR4 input file INDIC = 1 dome2.ALL

thinner shell

t = 0.5"
r = 200"

```
spherical shell (buckling analysis)
       1        $ INDIC = analysis type indicator
       1        $ NPRT = output options (1=minimum, 2=medium, 3=maximum)
       1        $ ISTRES= output control (0=resultants, 1=sigma, 2=epsilon)
       1        $ NSEG  = number of shell segments (less than 295)
     H          $
     H          $ SEGMENT NUMBER    1    1    1    1    1    1    1    1
     H          $ NODAL POINT DISTRIBUTION FOLLOWS...
      91        $ NMESH = number of node points (5 = min.; 98 = max.)( 1)
       3        $ NTYPEH= control integer (1 or 3) for nodal point spacing
     H          $ REFERENCE SURFACE GEOMETRY FOLLOWS...
       2        $ NSHAPE= indicator (1,2 or 4) for geometry of meridian
       0        $ R1      = radius at beginning of segment (see p. 66)
       0        $ Z1      = global axial coordinate at beginning of segment
      20        $ R2      = radius at end of segment
      20        $ Z2      = global axial coordinate at end of segment
       0        $ RC      = radius from axis of rev. to center of curvature
      20        $ ZC      = axial coordinate of center of curvature
 -1.000000      $ SROT=indicator for direction of increasing arc (-1. or +1.)
     H          $ IMPERFECTION SHAPE FOLLOWS...
       0        $ IMP    = indicator for imperfection (0=none, 1=some)
     H          $ REFERENCE SURFACE LOCATION RELATIVE TO WALL
       3        $ NTYPEZ= control (1 or 3) for reference surface location
    0.25        $ ZVAL  = distance from leftmost surf. to reference surf.
     N          $ Do you want to print out r(s), r'(s), etc. for this segment?
     H          $ DISCRETE RING INPUT FOLLOWS...
       0        $ NRINGS= number (max=20) of discrete rings in this segment
       0        $ K=elastic foundation modulus (e.g. lb/in**3)in this seg.
     H          $ LINE LOAD INPUT FOLLOWS...
       0        $ LINTYP= indicator (0, 1, 2 or 3) for type of line loads
     H          $ DISTRIBUTED LOAD INPUT FOLLOWS...
       1        $ IDISAB= indicator (0, 1, 2 or 3) for load set A and B
     H          $ SURFACE LOAD INPUT FOR LOAD SET "A" FOLLOWS
       1        $ NLTYPE=control (0,1,2,3) for type of surface loading
       2        $ NPSTAT= number of meridional callouts for surface loading
       0        $ NLOAD(1)=indicator for meridional traction (0=none, 1=some)
       0        $ NLOAD(2)=indicator for circumferential traction
       1        $ NLOAD(3)=indicator for normal pressure     (0=none, 1=some)
      -1        $ PN(i)    = normal pressure (p.74) at ith callout, PN( 1)
      -1        $ PN(i)    = normal pressure (p.74) at ith callout, PN( 2)
       2        $ NTYPE = control for meaning of loading callout (2=z, 3=r)
       0        $ Z(I)  = axial coordinate of Ith loading callout, z( 1)
      20        $ Z(I)  = axial coordinate of Ith loading callout, z( 2)
     H          $ SHELL WALL CONSTRUCTION FOLLOWS...
       2        $ NWALL=index (1, 2, 4, 5, 6, 7, 8, 9, 10) for wall construction
 0.1600000E+08  $ E      = Young's modulus for skin
 0.2500000      $ U      = Poisson's ratio for skin
 0.4144000E-03  $ SM =mass density of skin (e.g. alum.=.00025 lb-sec**2/in**4)
       0        $ ALPHA = coefficient of thermal expansion
       0        $ NRS  = control (0 or 1) for addition of smeared stiffeners
       0        $ NSUR  = control for thickness input (0 or 1 or -1)
     N          $ Do you want to print out ref. surf. location and thickness?
     N          $ Do you want to print out the C(i,j) at meridional stations?
     N          $ Do you want to print out distributed loads along meridian?
     H          $
     H          $ GLOBAL DATA BEGINS...
       0        $ NLAST = plot options  (-1=none, 0=geometry, 1=u,v,w)
     N          $ Are there any regions for which you want expanded plots?
       0        $ N0B   = starting number of circ. waves (buckling analysis)
       0        $ NMINB = minimum number of circ. waves  (buckling analysis)
      20        $ NMAXB = maximum number of circ. waves  (buckling analysis)
       1        $ INCRB = increment in number of circ. waves (buckling)
       1        $ NVEC  = number of eigenvalues for each wave number
  0.000000      $ P      = pressure or surface traction multiplier
  15000.00      $ DP     = pressure or surface traction multiplier increment
       0        $ TEMP   = temperature rise multiplier
       0        $ DTEMP  = temperature rise multiplier increment
       0        $ OMEGA  = angular vel. about axis of revolution (rad/sec)
       0        $ DOMEGA = angular velocity increment (rad/sec)
     H          $ CONSTRAINT CONDITIONS FOLLOW....
       1        $ How many segments in the structure?
     H          $
     H          $ CONSTRAINT CONDITIONS FOR SEGMENT NO.    1    1    1    1
     H          $ POLES INPUT FOLLOWS...
       1        $ Number of poles (places where r=0) in SEGMENT( 1)
       1        $ IPOLE = nodal point number of pole, IPOLE( 1)
     H          $ INPUT FOR CONSTRAINTS TO GROUND FOLLOWS...
       1        $ At how many stations is this segment constrained to ground?
```

Table 5, p. 2 of 2

```
     91         $ INODE = nodal point number of constraint to ground, INODE( 1)
      1         $ IUSTAR=axial displacement constraint (0 or 1 or 2)
      0         $ IVSTAR=circumferential displacement(0=free,1=0,2=imposed)
      0         $ IWSTAR=radial displacement(0=free,1=constrained,2=imposed)
      1         $ ICHI=meridional rotation (0=free,1=constrained,2=imposed)
      0         $ D1     = radial component of offset of ground support
      0         $ D2     = axial component of offset of ground support
  N             $ Is this constraint the same for both prebuckling and buckling?
      0         $ IUSTARB= axial displacement for buckling or vibration phase
      1         $ IVSTARB= circ. displacement for buckling or vibration phase
      1         $ IWSTARB= radial displacement for buckling or vibration
      0         $ ICHIB  = meridional rotation for buckling or vibration
  H             $ JUNCTION CONDITION INPUT FOLLOWS...
  N             $ Is this segment joined to any lower-numbered segments?
  H             $ RIGID BODY CONSTRAINT INPUT FOLLOWS...
  Y             $ Given existing constraints, are rigid body modes possible?
  Y             $ Do you wish to prevent rigid body motion?
      1         $ ISEG   = segment no. at which to prevent rigid body motion
     91         $ INODE = node no. at which to prevent rigid body motion
      1         $ IUSTAR= axial n=0 rigid body constraint (0=none, 1=some)
      1         $ IVSTAR= circ. n=0 rigid body constraint (usually equals 1)
      0         $ IWSTAR= radial n=0 rigid body constraint (usually equals 0)
      1         $ ICHI   = meridional rot. rigid body constraint
      1         $ IUSTAR= axial n=1 rigid body constraint (usually equals 1)
      1         $ IVSTAR= circ. n=1 rigid body constraint (usually equals 1)
      0         $ IWSTAR= radial n=1 rigid body constraint (usually equals 0)
      1         $ ICHI   = meridional rot. rigid body constraint
  H             $ "GLOBAL3" QUESTIONS (AT END OF CASE)...
  Y             $ Do you want to list output for segment( 1)
  Y             $ Do you want to list forces in the discrete rings, if any?
```

end of BIGBOSOR4 file, door2.ALL, for buckling

Table 6

Spherical Shell buckling
BIGBOSOR4 prediction, thinner shell

```
doer3.OUT (abridged)
shell thickness = 0.5 inches, buckling analysis (INDIC=1)
Search for the string, "EIGENVALUE(" in order
to find the following output in the *.OUT

 **** CRITICAL EIGENVALUE AND WAVENUMBER ****
 EIGCRT=  8.0448E-01; NO. OF CIRC. WAVES, NWVCRT=    8
 ****************************************************

 ***** EIGENVALUES AND MODE SHAPES *****
  EIGENVALUE(CIRC. WAVES)
 ========================================
    8.2430E-01(   0)
    8.1199E-01(   1)
    8.1051E-01(   2)
    8.1903E-01(   3)
    8.0759E-01(   4)
    8.2097E-01(   5)
    8.0548E-01(   6)
    8.1514E-01(   7)
    8.0448E-01(   8)
    8.1433E-01(   9)
    8.0489E-01(  10)
    8.1490E-01(  11)
    8.4443E-01(  12)
    8.8992E-01(  13)
    9.4892E-01(  14)
    1.0197E+00(  15)
    1.1010E+00(  16)
    1.1919E+00(  17)
    1.2917E+00(  18)
    1.3998E+00(  19)
    1.5159E+00(  20)
 ========================================
```

← next fig. (at 4)

← minimum eigenvalue. 2nd figure. (at 10)

$p = 15000$ psi

$t = 0.5''$

$r = 20''$

titanium

The "classical" buckling pressure

$$p_{cl} = \frac{2Et^2}{r^2\left(3(1-\nu^2)\right)^{1/2}} = 1.1926 \times \frac{Et^2}{r^2} = 1.1926 \times 10^4 \text{ psi}$$

$\nu = 0.25$

"classical" eigenvalue $= \frac{11926}{15000} = \underline{\underline{0.795}}$

compared to $0.\underline{80}489$ from BOSOR4 here.

$t = 0.5$ inch.
$r = 20.0$ inches.

Spherical shell buckling for thinner shell

BIGBOSOR4 prediction

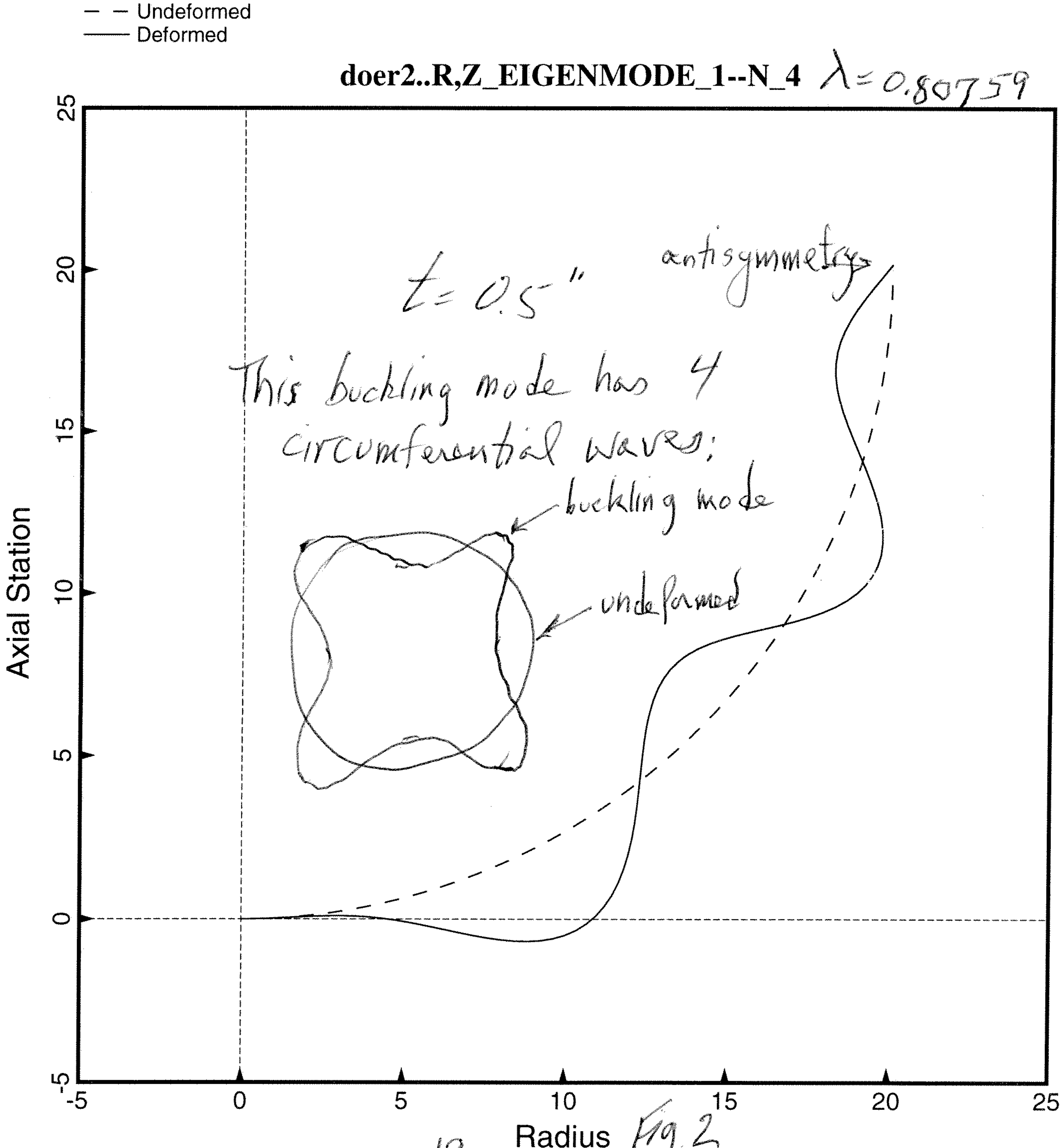


Fig. 2

Spherical shell buckling for thinner shell

BIGBOSOR4 prediction

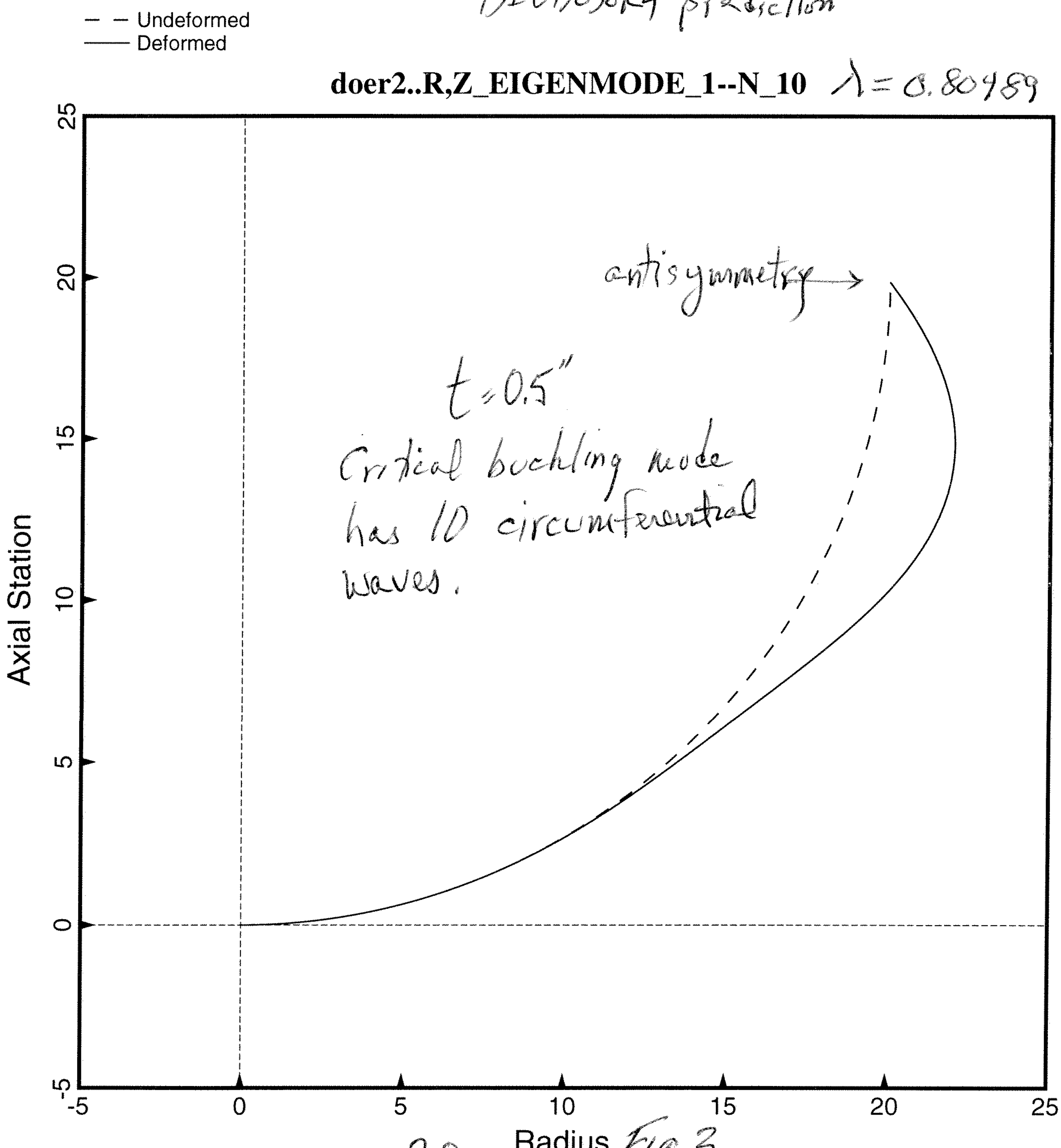


Fig. 3

Table 7

Spherical shell buckling, thicker shell
BIGBOSOR4 prediction

```
doer3.OUT (abridged)
shell thickness = 1.25 inches, buckling analysis (INDIC=1)
Search for the string, "EIGENVALUE(" in order
to find the following output in the *.OUT

 **** CRITICAL EIGENVALUE AND WAVENUMBER ****
 EIGCRT=  4.8230E+00; NO. OF CIRC. WAVES, NWVCRT=    4
 ****************************************************

 ***** EIGENVALUES AND MODE SHAPES *****
  EIGENVALUE(CIRC. WAVES)
 =======================================
    4.9856E+00(   0)
    4.8554E+00(   1)
    4.8415E+00(   2)
    4.9439E+00(   3)
    4.8230E+00(   4)
    4.9442E+00(   5)
    4.8285E+00(   6)
    5.0580E+00(   7)
    5.5344E+00(   8)
    6.2027E+00(   9)
    7.0305E+00(  10)
    7.9976E+00(  11)
    9.0910E+00(  12)
    1.0302E+01(  13)
    1.1624E+01(  14)
    1.3054E+01(  15)
    1.4588E+01(  16)
    1.6224E+01(  17)
    1.7960E+01(  18)
    1.9794E+01(  19)
    2.1727E+01(  20)
 =======================================
```

$p = 15000$ psi

$t = 1.25''$

$r = 20.0''$

← lowest eigenvalue (see next figure)

BOSOR4 buckling pressure = $4.823 \times 15000 = 72345$ psi

$$p_{cl} = \frac{2Et^2}{r^2\left(3(1-\nu^2)\right)^{1/2}} = 1.1926 \times \frac{Et^2}{r^2} = 74537.5 \text{ psi}$$

0.25

$t = 1.25$ inches

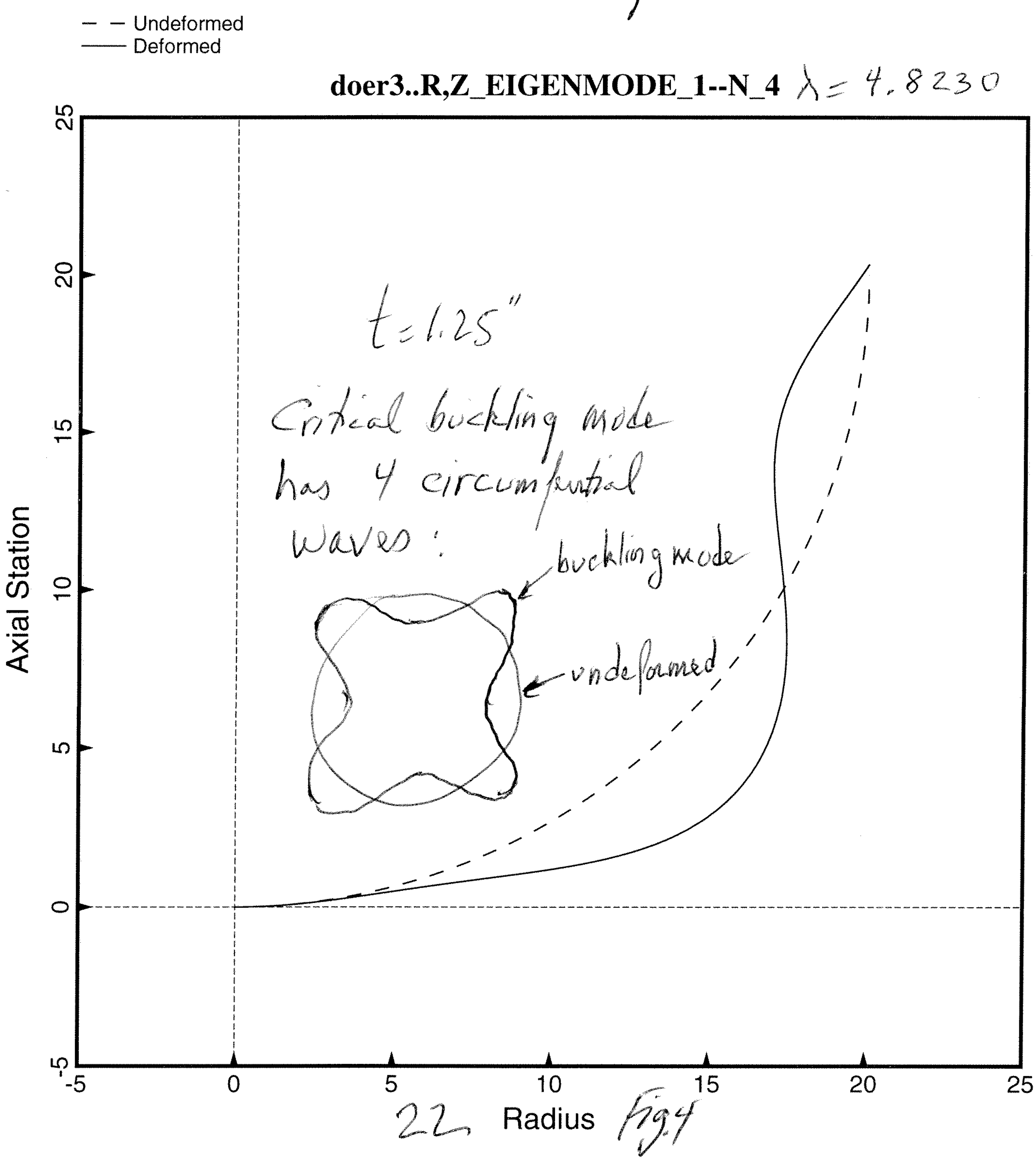
$r = 20.0$ inches

$\nu = 0.25$

Note: At pressure, $p = 15000$ psi, if the spherical pressure hull were made of titanium with maximum allowable effective stress = 120000 psi, it would have to be so thick ($t = 1.25''$) that buckling would not occur before "failure" caused by excessive stress.

Spherical shell buckling,
thicker shell

BIGBOSOR4 prediction



22 Fig. 4

Table 8 (2 pages) input file for BIGBOSOR4 [doer1.ALL]

Cylindrical shell stress

t = 2.50"
r = 20"

need ring to "hang" load onto.

pr/2

```
cylindrical shell (axisymmetric stress analysis,INDIC=0)
      0        $ INDIC = analysis type indicator
      1        $ NPRT = output options (1=minimum, 2=medium, 3=maximum)
      1        $ ISTRES= output control (0=resultants, 1=sigma, 2=epsilon)
      1        $ NSEG  = number of shell segments (less than 295)
    H          $
    H          $ SEGMENT NUMBER    1    1    1    1    1    1    1    1
    H          $ NODAL POINT DISTRIBUTION FOLLOWS...
     51        $ NMESH = number of node points (5 = min.; 98 = max.)( 1)
      3        $ NTYPEH= control integer (1 or 3) for nodal point spacing
    H          $ REFERENCE SURFACE GEOMETRY FOLLOWS...
      1        $ NSHAPE= indicator (1,2 or 4) for geometry of meridian
     20        $ R1      = radius at beginning of segment (see p. 66)
      0        $ Z1      = global axial coordinate at beginning of segment
     20        $ R2      = radius at end of segment
     20        $ Z2      = global axial coordinate at end of segment
    H          $ IMPERFECTION SHAPE FOLLOWS...
      0        $ IMP   = indicator for imperfection (0=none, 1=some)
    H          $ REFERENCE SURFACE LOCATION RELATIVE TO WALL
      3        $ NTYPEZ= control (1 or 3) for reference surface location
  1.250000     $ ZVAL  = distance from leftmost surf. to reference surf.
    N          $ Do you want to print out r(s), r'(s), etc. for this segment?
    H          $ DISCRETE RING INPUT FOLLOWS...
      1        $ NRINGS= number (max=20) of discrete rings in this segment
      2        $ NTYPE = control for identification of ring location (2=z, 3=r)
      0        $ Z(I)  = axial coordinate of Ith ring, z( 1)
      0        $ NTYPER= type (-1 or 0 or 1 or 2 or 4 or 5) of discrete ring no.( 1)
      0        $ K=elastic foundation modulus (e.g. lb/in**3)in this seg.
    H          $ LINE LOAD INPUT FOLLOWS...
      1        $ LINTYP= indicator (0, 1, 2 or 3) for type of line loads
      0        $ NLOAD(1)=indicator for axial load or disp.(0=none,1=some)
      0        $ NLOAD(2)=indicator for shear load or disp.(0=none,1=some)
      0        $ NLOAD(3)=indicator for radial load or disp.(0 or 1)
      0        $ NLOAD(4)=indicator for line moment or rotation (0 or 1)
      1        $ NLOAD(1)=indicator for axial load or disp. increment(0 or 1)
      0        $ NLOAD(2)= should be zero
      0        $ NLOAD(3)=indicator for radial load or disp. increment(0 or 1)
      0        $ NLOAD(4)=indicator for moment or rot. increment (0 or 1)
  -150000      $ DV(i)=axial load or displacement increment, DV( 1)
    H          $ DISTRIBUTED LOAD INPUT FOLLOWS...
      1        $ IDISAB= indicator (0, 1, 2 or 3) for load set A and B
    H          $ SURFACE LOAD INPUT FOR LOAD SET "A" FOLLOWS
      1        $ NLTYPE=control (0,1,2,3) for type of surface loading
      2        $ NPSTAT= number of meridional callouts for surface loading
      0        $ NLOAD(1)=indicator for meridional traction (0=none, 1=some)
      0        $ NLOAD(2)=indicator for circumferential traction
      1        $ NLOAD(3)=indicator for normal pressure     (0=none, 1=some)
     -1        $ PN(i)    = normal pressure (p.74) at ith callout, PN( 1)
     -1        $ PN(i)    = normal pressure (p.74) at ith callout, PN( 2)
      2        $ NTYPE = control for meaning of loading callout (2=z, 3=r)
      0        $ Z(I)  = axial coordinate of Ith loading callout, z( 1)
     20        $ Z(I)  = axial coordinate of Ith loading callout, z( 2)
    H          $ SHELL WALL CONSTRUCTION FOLLOWS...
      2        $ NWALL=index (1, 2, 4, 5, 6, 7, 8, 9, 10) for wall construction
 0.1600000E+08 $ E     = Young's modulus for skin
 0.2500000     $ U     = Poisson's ratio for skin
 0.4144000E-03 $ SM =mass density of skin (e.g. alum.=.00025 lb-sec**2/in**4)
      0        $ ALPHA = coefficient of thermal expansion
      0        $ NRS  = control (0 or 1) for addition of smeared stiffeners
      0        $ NSUR   = control for thickness input (0 or 1 or -1)
    N          $ Do you want to print out ref. surf. location and thickness?
    N          $ Do you want to print out the C(i,j) at meridional stations?
    N          $ Do you want to print out distributed loads along meridian?
    H          $
    H          $ GLOBAL DATA BEGINS...
      0        $ NLAST = plot options  (-1=none, 0=geometry, 1=u,v,w)
    N          $ Are there any regions for which you want expanded plots?
      0        $ P      = pressure or surface traction multiplier
   15000       $ DP     = pressure or surface traction multiplier increment
      0        $ TEMP   = temperature rise multiplier
      0        $ DTEMP  = temperature rise multiplier increment
      2        $ Number of load steps
      0        $ OMEGA  = angular vel. about axis of revolution (rad/sec)
      0        $ DOMEGA = angular velocity increment (rad/sec)
    H          $ CONSTRAINT CONDITIONS FOLLOW....
      1        $ How many segments in the structure?
    H          $
    H          $ CONSTRAINT CONDITIONS FOR SEGMENT NO.    1    1    1    1
```

```
H          $ POLES INPUT FOLLOWS...
   0       $ Number of poles (places where r=0) in SEGMENT( 1)
H          $ INPUT FOR CONSTRAINTS TO GROUND FOLLOWS...
   2       $ At how many stations is this segment constrained to ground?
   1       $ INODE = nodal point number of constraint to ground, INODE( 1)
   0       $ IUSTAR=axial displacement constraint (0 or 1 or 2)
   0       $ IVSTAR=circumferential displacement(0=free,1=0,2=imposed)
   0       $ IWSTAR=radial displacement(0=free,1=constrained,2=imposed)
   1       $ ICHI=meridional rotation (0=free,1=constrained,2=imposed)
   0       $ D1    = radial component of offset of ground support
   0       $ D2    = axial component of offset of ground support
N          $ Is this constraint the same for both prebuckling and buckling?
   0       $ IUSTARB= axial displacement for buckling or vibration phase
   1       $ IVSTARB= circ. displacement for buckling or vibration phase
   1       $ IWSTARB= radial displacement for buckling or vibration
   0       $ ICHIB  = meridional rotation for buckling or vibration
  51       $ INODE = nodal point number of constraint to ground, INODE( 2)
   1       $ IUSTAR=axial displacement constraint (0 or 1 or 2)
   0       $ IVSTAR=circumferential displacement(0=free,1=0,2=imposed)
   0       $ IWSTAR=radial displacement(0=free,1=constrained,2=imposed)
   1       $ ICHI=meridional rotation (0=free,1=constrained,2=imposed)
   0       $ D1    = radial component of offset of ground support
   0       $ D2    = axial component of offset of ground support
Y          $ Is this constraint the same for both prebuckling and buckling?
H          $ JUNCTION CONDITION INPUT FOLLOWS...
N          $ Is this segment joined to any lower-numbered segments?
H          $ RIGID BODY CONSTRAINT INPUT FOLLOWS...
Y          $ Given existing constraints, are rigid body modes possible?
Y          $ Do you wish to prevent rigid body motion?
   1       $ ISEG  = segment no. at which to prevent rigid body motion
  51       $ INODE = node no. at which to prevent rigid body motion
   1       $ IUSTAR= axial n=0 rigid body constraint (0=none, 1=some)
   1       $ IVSTAR= circ. n=0 rigid body constraint (usually equals 1)
   0       $ IWSTAR= radial n=0 rigid body constraint (usually equals 0)
   1       $ ICHI  = meridional rot. rigid body constraint
   1       $ IUSTAR= axial n=1 rigid body constraint (usually equals 1)
   1       $ IVSTAR= circ. n=1 rigid body constraint (usually equals 1)
   0       $ IWSTAR= radial n=1 rigid body constraint (usually equals 0)
   1       $ ICHI  = meridional rot. rigid body constraint
H          $ "GLOBAL3" QUESTIONS (AT END OF CASE)...
Y          $ Do you want to list output for segment( 1)
Y          $ Do you want to list forces in the discrete rings, if any?
```

end of doc't. ALC

Cylindrical Shell Stress

output from BIGBOSOR4

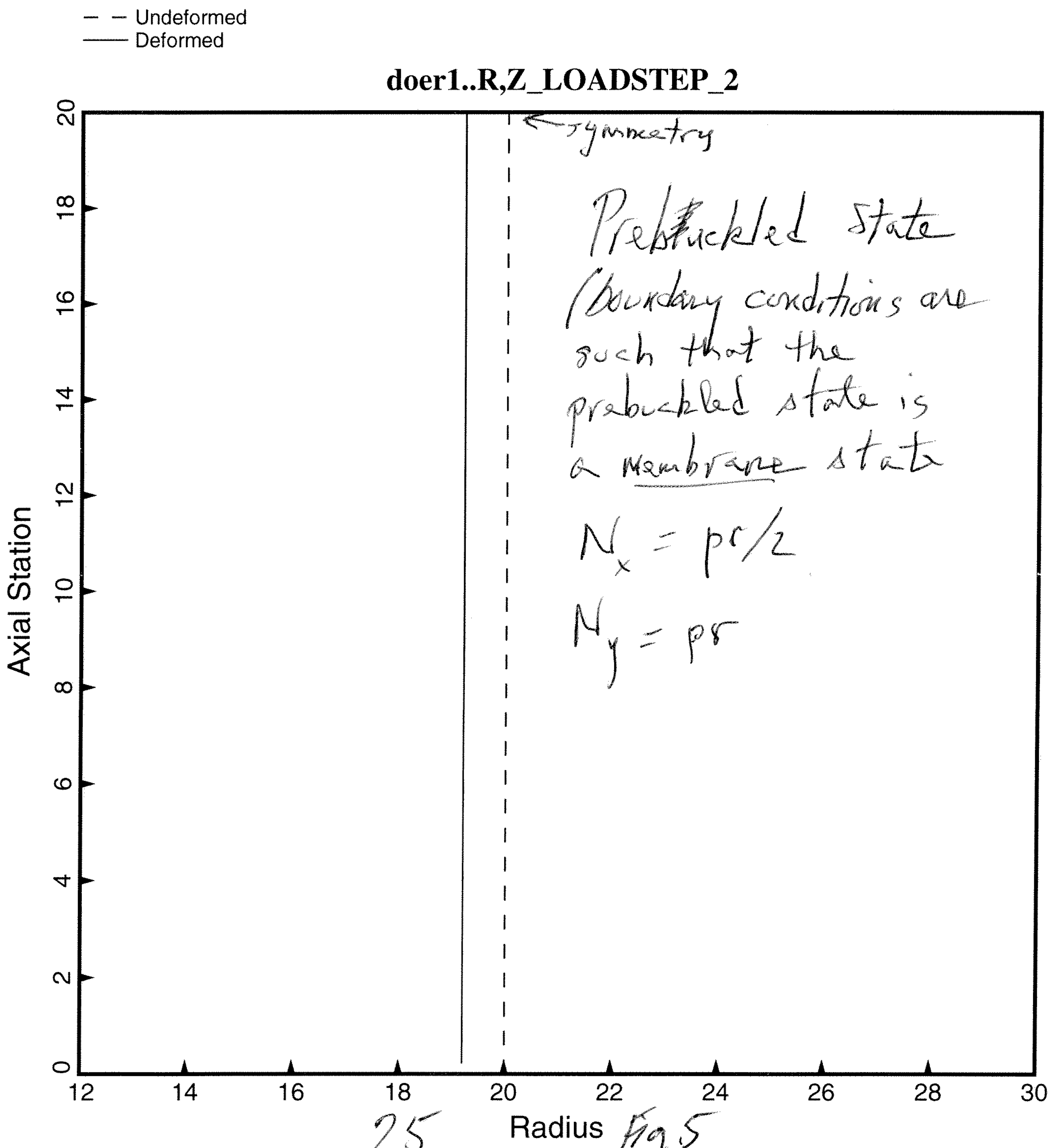


Fig. 5

Table 9(2pp.) Cylindrical Shell Stress

doer1.OUT (abridged) axisymmetric stress (INDIC=0) in cylindrical shell under external hydrostatic pressure. t=2.5"

AXISYMMETRIC PRESTRESS DISTRIBUTION FOR SEGMENT 1

POINT	STATION (ARC LENGTH)	W0 NORMAL DISP.	U0 MERIDIONAL DISPLACEMENT	SIGMA1(IN) MERID. STRESS	SIGMA1(OUT) MERIDIONAL STRESS	SIGMA2(IN) CIRCUMF. STRESS	SIGMA2(OUT) CIRCUMF. STRESS	SIGMAE(IN) VON MISES INNER FIBER	SIGMAE(OUT) EQUIVALENT OUTER FIBER
1	0.000E+00	-1.306E-01	3.729E-02	-5.886E+04	-6.036E+04	-1.192E+05	-1.196E+05	1.033E+05	1.036E+05
2	1.100E-01	-1.306E-01	3.709E-02	-5.889E+04	-6.033E+04	-1.192E+05	-1.196E+05	1.033E+05	1.036E+05
3	4.050E-01	-1.306E-01	3.654E-02	-5.896E+04	-6.025E+04	-1.193E+05	-1.196E+05	1.033E+05	1.036E+05
4	8.000E-01	-1.306E-01	3.580E-02	-5.906E+04	-6.016E+04	-1.193E+05	-1.195E+05	1.033E+05	1.035E+05
5	1.200E+00	-1.306E-01	3.506E-02	-5.915E+04	-6.007E+04	-1.193E+05	-1.195E+05	1.033E+05	1.035E+05
6	1.600E+00	-1.306E-01	3.432E-02	-5.923E+04	-5.999E+04	-1.193E+05	-1.195E+05	1.033E+05	1.035E+05
7	2.000E+00	-1.306E-01	3.357E-02	-5.930E+04	-5.991E+04	-1.193E+05	-1.194E+05	1.033E+05	1.034E+05
8	2.400E+00	-1.306E-01	3.283E-02	-5.937E+04	-5.985E+04	-1.193E+05	-1.194E+05	1.033E+05	1.034E+05
9	2.800E+00	-1.305E-01	3.208E-02	-5.943E+04	-5.978E+04	-1.193E+05	-1.194E+05	1.033E+05	1.034E+05
10	3.200E+00	-1.305E-01	3.134E-02	-5.949E+04	-5.973E+04	-1.193E+05	-1.193E+05	1.033E+05	1.034E+05
11	3.600E+00	-1.305E-01	3.059E-02	-5.954E+04	-5.968E+04	-1.193E+05	-1.193E+05	1.033E+05	1.033E+05
12	4.000E+00	-1.305E-01	2.985E-02	-5.958E+04	-5.964E+04	-1.193E+05	-1.193E+05	1.033E+05	1.033E+05
13	4.400E+00	-1.304E-01	2.911E-02	-5.962E+04	-5.960E+04	-1.193E+05	-1.193E+05	1.033E+05	1.033E+05
14	4.800E+00	-1.304E-01	2.836E-02	-5.965E+04	-5.957E+04	-1.192E+05	-1.192E+05	1.033E+05	1.033E+05
15	5.200E+00	-1.304E-01	2.762E-02	-5.968E+04	-5.954E+04	-1.192E+05	-1.192E+05	1.033E+05	1.033E+05
16	5.600E+00	-1.304E-01	2.687E-02	-5.970E+04	-5.952E+04	-1.192E+05	-1.192E+05	1.032E+05	1.032E+05
17	6.000E+00	-1.303E-01	2.612E-02	-5.972E+04	-5.950E+04	-1.192E+05	-1.192E+05	1.032E+05	1.032E+05
18	6.400E+00	-1.303E-01	2.538E-02	-5.973E+04	-5.949E+04	-1.192E+05	-1.191E+05	1.032E+05	1.032E+05
19	6.800E+00	-1.303E-01	2.463E-02	-5.975E+04	-5.947E+04	-1.192E+05	-1.191E+05	1.032E+05	1.032E+05
20	7.200E+00	-1.303E-01	2.389E-02	-5.976E+04	-5.946E+04	-1.192E+05	-1.191E+05	1.032E+05	1.031E+05
21	7.600E+00	-1.303E-01	2.314E-02	-5.976E+04	-5.946E+04	-1.192E+05	-1.191E+05	1.032E+05	1.031E+05
22	8.000E+00	-1.302E-01	2.240E-02	-5.977E+04	-5.946E+04	-1.191E+05	-1.191E+05	1.032E+05	1.031E+05
23	8.400E+00	-1.302E-01	2.165E-02	-5.977E+04	-5.945E+04	-1.191E+05	-1.190E+05	1.032E+05	1.031E+05
24	8.800E+00	-1.302E-01	2.090E-02	-5.977E+04	-5.945E+04	-1.191E+05	-1.190E+05	1.032E+05	1.031E+05
25	9.200E+00	-1.302E-01	2.016E-02	-5.977E+04	-5.946E+04	-1.191E+05	-1.190E+05	1.031E+05	1.031E+05
26	9.600E+00	-1.302E-01	1.941E-02	-5.976E+04	-5.946E+04	-1.191E+05	-1.190E+05	1.031E+05	1.031E+05
27	1.000E+01	-1.302E-01	1.867E-02	-5.976E+04	-5.946E+04	-1.191E+05	-1.190E+05	1.031E+05	1.031E+05
28	1.040E+01	-1.302E-01	1.792E-02	-5.975E+04	-5.947E+04	-1.191E+05	-1.190E+05	1.031E+05	1.031E+05
29	1.080E+01	-1.301E-01	1.717E-02	-5.975E+04	-5.948E+04	-1.191E+05	-1.190E+05	1.031E+05	1.030E+05
30	1.120E+01	-1.301E-01	1.643E-02	-5.974E+04	-5.948E+04	-1.190E+05	-1.190E+05	1.031E+05	1.030E+05
31	1.160E+01	-1.301E-01	1.568E-02	-5.973E+04	-5.949E+04	-1.190E+05	-1.190E+05	1.031E+05	1.030E+05
32	1.200E+01	-1.301E-01	1.493E-02	-5.972E+04	-5.950E+04	-1.190E+05	-1.190E+05	1.031E+05	1.030E+05
33	1.240E+01	-1.301E-01	1.419E-02	-5.972E+04	-5.951E+04	-1.190E+05	-1.190E+05	1.031E+05	1.030E+05
34	1.280E+01	-1.301E-01	1.344E-02	-5.971E+04	-5.951E+04	-1.190E+05	-1.190E+05	1.031E+05	1.030E+05
35	1.320E+01	-1.301E-01	1.269E-02	-5.970E+04	-5.952E+04	-1.190E+05	-1.190E+05	1.031E+05	1.030E+05
36	1.360E+01	-1.301E-01	1.195E-02	-5.969E+04	-5.953E+04	-1.190E+05	-1.190E+05	1.031E+05	1.030E+05
37	1.400E+01	-1.301E-01	1.120E-02	-5.969E+04	-5.954E+04	-1.190E+05	-1.190E+05	1.031E+05	1.030E+05
38	1.440E+01	-1.301E-01	1.045E-02	-5.968E+04	-5.954E+04	-1.190E+05	-1.190E+05	1.031E+05	1.030E+05
39	1.480E+01	-1.301E-01	9.708E-03	-5.967E+04	-5.955E+04	-1.190E+05	-1.190E+05	1.030E+05	1.030E+05
40	1.520E+01	-1.301E-01	8.961E-03	-5.966E+04	-5.956E+04	-1.190E+05	-1.190E+05	1.030E+05	1.030E+05
41	1.560E+01	-1.301E-01	8.214E-03	-5.966E+04	-5.956E+04	-1.190E+05	-1.190E+05	1.030E+05	1.030E+05
42	1.600E+01	-1.301E-01	7.468E-03	-5.965E+04	-5.957E+04	-1.190E+05	-1.190E+05	1.030E+05	1.030E+05
43	1.640E+01	-1.301E-01	6.721E-03	-5.965E+04	-5.958E+04	-1.190E+05	-1.190E+05	1.030E+05	1.030E+05
44	1.680E+01	-1.301E-01	5.974E-03	-5.964E+04	-5.958E+04	-1.190E+05	-1.190E+05	1.030E+05	1.030E+05
45	1.720E+01	-1.301E-01	5.227E-03	-5.964E+04	-5.959E+04	-1.190E+05	-1.190E+05	1.030E+05	1.030E+05
46	1.760E+01	-1.301E-01	4.481E-03	-5.963E+04	-5.959E+04	-1.190E+05	-1.190E+05	1.030E+05	1.030E+05
47	1.800E+01	-1.301E-01	3.734E-03	-5.963E+04	-5.959E+04	-1.190E+05	-1.190E+05	1.030E+05	1.030E+05
48	1.840E+01	-1.301E-01	2.987E-03	-5.963E+04	-5.960E+04	-1.190E+05	-1.190E+05	1.030E+05	1.030E+05

Table 9, p. 2 / 2

49	1.880E+01	-1.301E-01	2.240E-03	-5.963E+04	-5.960E+04	-1.190E+05	-1.190E+05	1.030E+05	1.030E+05
50	1.920E+01	-1.301E-01	1.494E-03	-5.962E+04	-5.960E+04	-1.190E+05	-1.190E+05	1.030E+05	1.030E+05
51	1.959E+01	-1.301E-01	7.561E-04	-5.962E+04	-5.960E+04	-1.190E+05	-1.190E+05	1.030E+05	1.030E+05
52	1.989E+01	-1.301E-01	2.054E-04	-5.962E+04	-5.960E+04	-1.190E+05	-1.190E+05	1.030E+05	1.030E+05
53	2.000E+01	-1.301E-01	5.929E-20	-5.962E+04	-5.960E+04	-1.190E+05	-1.190E+05	1.030E+05	1.030E+05

****** MAXIMUM EFFECTIVE STRESS IN ISOTROPIC WALL ******

STRMAX= 1.0358E+05

****

Table 10 (2pp.) input file for BIGBOSOR4

doerO.ALL

Cylindrical Shell buckling

```
cylindrical shell (buckling analysis, INDIC = 1)
        1        $ INDIC = analysis type indicator
        1        $ NPRT = output options (1=minimum, 2=medium, 3=maximum)
        1        $ ISTRES= output control (0=resultants, 1=sigma, 2=epsilon)
        1        $ NSEG  = number of shell segments (less than 295)
     H           $
     H           $ SEGMENT NUMBER    1    1    1    1    1    1    1    1
     H           $ NODAL POINT DISTRIBUTION FOLLOWS...
       51        $ NMESH = number of node points (5 = min.; 98 = max.)( 1)
        3        $ NTYPEH= control integer (1 or 3) for nodal point spacing
     H           $ REFERENCE SURFACE GEOMETRY FOLLOWS...
        1        $ NSHAPE= indicator (1,2 or 4) for geometry of meridian
       20        $ R1     = radius at beginning of segment (see p. 66)
        0        $ Z1     = global axial coordinate at beginning of segment
       20        $ R2     = radius at end of segment
       20        $ Z2     = global axial coordinate at end of segment
     H           $ IMPERFECTION SHAPE FOLLOWS...
        0        $ IMP   = indicator for imperfection (0=none, 1=some)
     H           $ REFERENCE SURFACE LOCATION RELATIVE TO WALL
        3        $ NTYPEZ= control (1 or 3) for reference surface location
  1.250000       $ ZVAL  = distance from leftmost surf. to reference surf.
     N           $ Do you want to print out r(s), r'(s), etc. for this segment?
     H           $ DISCRETE RING INPUT FOLLOWS...
        1        $ NRINGS= number (max=20) of discrete rings in this segment
        2        $ NTYPE = control for identification of ring location (2=z, 3=r)
        0        $ Z(I)  = axial coordinate of Ith ring, z( 1)
        0        $ NTYPER= type (-1 or 0 or 1 or 2 or 4 or 5) of discrete ring no.( 1)
        0        $ K=elastic foundation modulus (e.g. lb/in**3)in this seg.
     H           $ LINE LOAD INPUT FOLLOWS...
        1        $ LINTYP= indicator (0, 1, 2 or 3) for type of line loads
        0        $ NLOAD(1)=indicator for axial load or disp.(0=none,1=some)
        0        $ NLOAD(2)=indicator for shear load or disp.(0=none,1=some)
        0        $ NLOAD(3)=indicator for radial load or disp.(0 or 1)
        0        $ NLOAD(4)=indicator for line moment or rotation (0 or 1)
        1        $ NLOAD(1)=indicator for axial load or disp. increment(0 or 1)
        0        $ NLOAD(2)= should be zero
        0        $ NLOAD(3)=indicator for radial load or disp. increment(0 or 1)
        0        $ NLOAD(4)=indicator for moment or rot. increment (0 or 1)
  -150000        $ DV(i)=axial load or displacement increment, DV( 1)
     H           $ DISTRIBUTED LOAD INPUT FOLLOWS...
        1        $ IDISAB= indicator (0, 1, 2 or 3) for load set A and B
     H           $ SURFACE LOAD INPUT FOR LOAD SET "A" FOLLOWS
        1        $ NLTYPE=control (0,1,2,3) for type of surface loading
        2        $ NPSTAT= number of meridional callouts for surface loading
        0        $ NLOAD(1)=indicator for meridional traction (0=none, 1=some)
        0        $ NLOAD(2)=indicator for circumferential traction
        1        $ NLOAD(3)=indicator for normal pressure     (0=none, 1=some)
       -1        $ PN(i)   = normal pressure (p.74) at ith callout, PN( 1)
       -1        $ PN(i)   = normal pressure (p.74) at ith callout, PN( 2)
        2        $ NTYPE = control for meaning of loading callout (2=z, 3=r)
        0        $ Z(I)  = axial coordinate of Ith loading callout, z( 1)
       20        $ Z(I)  = axial coordinate of Ith loading callout, z( 2)
     H           $ SHELL WALL CONSTRUCTION FOLLOWS...
        2        $ NWALL=index (1, 2, 4, 5, 6, 7, 8, 9, 10) for wall construction
 0.1600000E+08   $ E     = Young's modulus for skin
 0.2500000       $ U     = Poisson's ratio for skin
 0.4144000E-03   $ SM =mass density of skin (e.g. alum.=.00025 lb-sec**2/in**4)
        0        $ ALPHA = coefficient of thermal expansion
        0        $ NRS  = control (0 or 1) for addition of smeared stiffeners
        0        $ NSUR   = control for thickness input (0 or 1 or -1)
     N           $ Do you want to print out ref. surf. location and thickness?
     N           $ Do you want to print out the C(i,j) at meridional stations?
     N           $ Do you want to print out distributed loads along meridian?
     H           $
     H           $ GLOBAL DATA BEGINS...
        0        $ NLAST = plot options  (-1=none, 0=geometry, 1=u,v,w)
     N           $ Are there any regions for which you want expanded plots?
        0        $ N0B   = starting number of circ. waves (buckling analysis)
        0        $ NMINB = minimum number of circ. waves  (buckling analysis)
       10        $ NMAXB = maximum number of circ. waves  (buckling analysis)
        1        $ INCRB = increment in number of circ. waves (buckling)
        1        $ NVEC  = number of eigenvalues for each wave number
        0        $ P      = pressure or surface traction multiplier
    15000        $ DP     = pressure or surface traction multiplier increment
        0        $ TEMP   = temperature rise multiplier
        0        $ DTEMP  = temperature rise multiplier increment
        0        $ OMEGA  = angular vel. about axis of revolution (rad/sec)
        0        $ DOMEGA = angular velocity increment (rad/sec)
```

Table 10, p. 2 of 2

```
H          $ CONSTRAINT CONDITIONS FOLLOW....
   1       $ How many segments in the structure?
H          $
H          $ CONSTRAINT CONDITIONS FOR SEGMENT NO.    1    1    1    1
H          $ POLES INPUT FOLLOWS...
   0       $ Number of poles (places where r=0) in SEGMENT( 1)
H          $ INPUT FOR CONSTRAINTS TO GROUND FOLLOWS...
   2       $ At how many stations is this segment constrained to ground?
   1       $ INODE = nodal point number of constraint to ground, INODE( 1)
   0       $ IUSTAR=axial displacement constraint (0 or 1 or 2)
   0       $ IVSTAR=circumferential displacement(0=free,1=0,2=imposed)
   0       $ IWSTAR=radial displacement(0=free,1=constrained,2=imposed)
   1       $ ICHI=meridional rotation (0=free,1=constrained,2=imposed)
   0       $ D1    = radial component of offset of ground support
   0       $ D2    = axial component of offset of ground support
N          $ Is this constraint the same for both prebuckling and buckling?
   0       $ IUSTARB= axial displacement for buckling or vibration phase
   1       $ IVSTARB= circ. displacement for buckling or vibration phase
   1       $ IWSTARB= radial displacement for buckling or vibration
   0       $ ICHIB  = meridional rotation for buckling or vibration
  51       $ INODE = nodal point number of constraint to ground, INODE( 2)
   1       $ IUSTAR=axial displacement constraint (0 or 1 or 2)
   0       $ IVSTAR=circumferential displacement(0=free,1=0,2=imposed)
   0       $ IWSTAR=radial displacement(0=free,1=constrained,2=imposed)
   1       $ ICHI=meridional rotation (0=free,1=constrained,2=imposed)
   0       $ D1    = radial component of offset of ground support
   0       $ D2    = axial component of offset of ground support
Y          $ Is this constraint the same for both prebuckling and buckling?
H          $ JUNCTION CONDITION INPUT FOLLOWS...
N          $ Is this segment joined to any lower-numbered segments?
H          $ RIGID BODY CONSTRAINT INPUT FOLLOWS...
Y          $ Given existing constraints, are rigid body modes possible?
Y          $ Do you wish to prevent rigid body motion?
   1       $ ISEG  = segment no. at which to prevent rigid body motion
  51       $ INODE = node no. at which to prevent rigid body motion
   1       $ IUSTAR= axial n=0 rigid body constraint (0=none, 1=some)
   1       $ IVSTAR= circ. n=0 rigid body constraint (usually equals 1)
   0       $ IWSTAR= radial n=0 rigid body constraint (usually equals 0)
   1       $ ICHI  = meridional rot. rigid body constraint
   1       $ IUSTAR= axial n=1 rigid body constraint (usually equals 1)
   1       $ IVSTAR= circ. n=1 rigid body constraint (usually equals 1)
   0       $ IWSTAR= radial n=1 rigid body constraint (usually equals 0)
   1       $ ICHI  = meridional rot. rigid body constraint
H          $ "GLOBAL3" QUESTIONS (AT END OF CASE)...
Y          $ Do you want to list output for segment( 1)
Y          $ Do you want to list forces in the discrete rings, if any?
```

end of [illegible]. ALL
gw.

Cylindrical Shell buckling
Output from BIGBOSOR4

Table 11

```
doer0.OUT (abridged)
Buckling of cylindrical shell under uniform
hydrostatic pressure, p = 15000 psi.
To find the output below, search for the
string, "EIGENVALUE(".

 **** CRITICAL EIGENVALUE AND WAVENUMBER ****
 EIGCRT=  2.8416E+00; NO. OF CIRC. WAVES, NWVCRT=    3
 ****************************************************

 ***** EIGENVALUES AND MODE SHAPES *****
  EIGENVALUE(CIRC. WAVES)
 =======================================
    1.9183E+01(   0)
    1.7731E+01(   1)
    5.9173E+00(   2)
    2.8416E+00(   3) <--critical buckling eigenvalue & mode (See next Fig.)
    3.6166E+00(   4)
    5.1927E+00(   5)
    7.2185E+00(   6)
    9.6353E+00(   7)
    1.2430E+01(   8)
    1.5599E+01(   9)
    1.9140E+01(  10)
 =======================================
```

Cylindrical Shell Buckling

Output from BIGBOSOR4

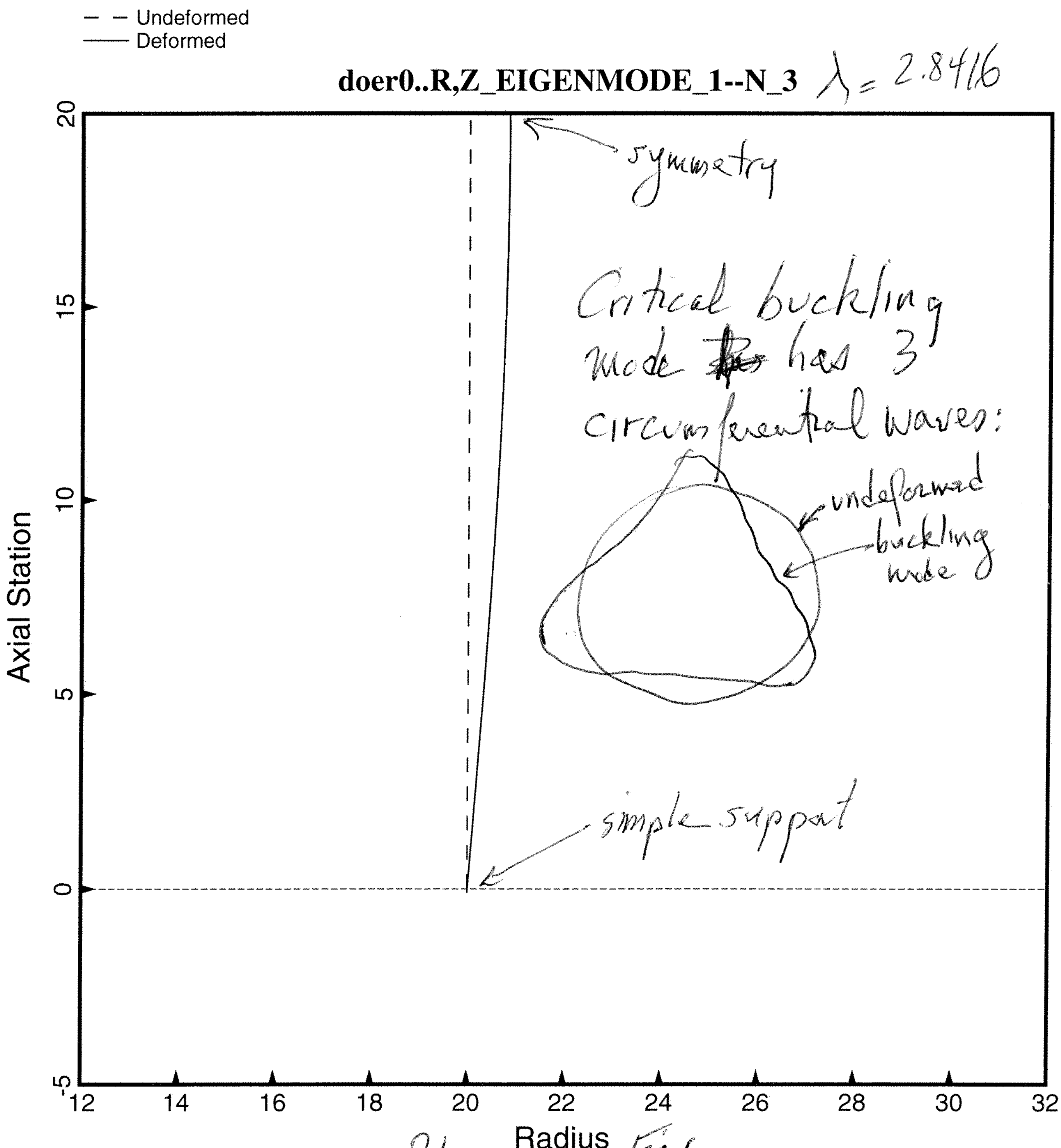


Fig.6

Combined spherical-cylindrical shell

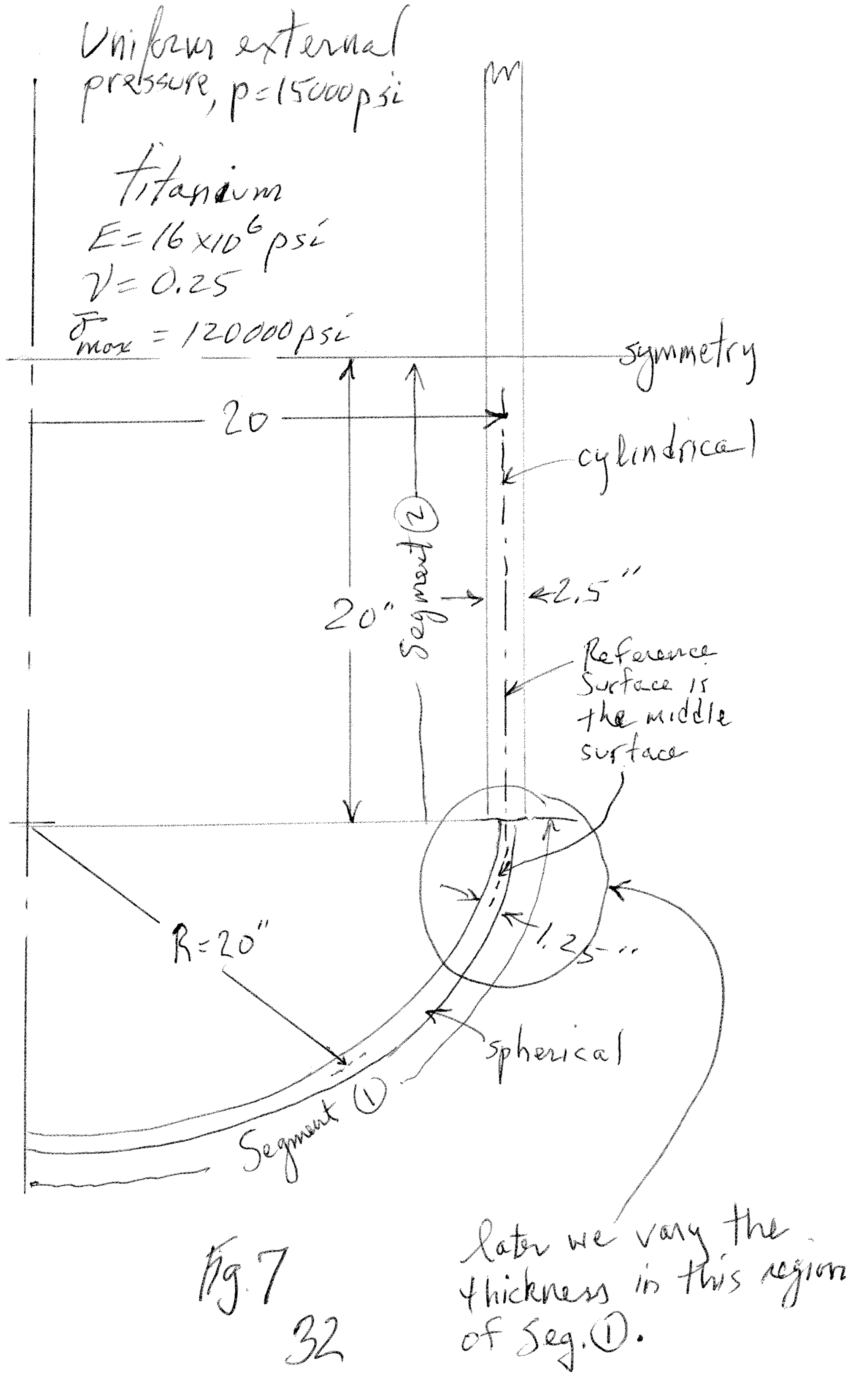


Fig 7

Table 12 (3 pages) input file for BIGBOSOR4

obez6.ALL

Combined Spherical-Cylindrical Shell-stress

```
spherical plus cylindrical shell (axisym. stress analysis)
       0        $ INDIC = analysis type indicator
       1        $ NPRT = output options (1=minimum, 2=medium, 3=maximum)
       1        $ ISTRES= output control (0=resultants, 1=sigma, 2=epsilon)
       2        $ NSEG  = number of shell segments (less than 295)
    H           $
    H           $ SEGMENT NUMBER    1    1    1    1    1    1    1    1
    H           $ NODAL POINT DISTRIBUTION FOLLOWS...
      51        $ NMESH = number of node points (5 = min.; 98 = max.)( 1)
       3        $ NTYPEH= control integer (1 or 3) for nodal point spacing
    H           $ REFERENCE SURFACE GEOMETRY FOLLOWS...
       2        $ NSHAPE= indicator (1,2 or 4) for geometry of meridian
       0        $ R1     = radius at beginning of segment (see p. 66)
       0        $ Z1     = global axial coordinate at beginning of segment
      20        $ R2     = radius at end of segment
      20        $ Z2     = global axial coordinate at end of segment
       0        $ RC     = radius from axis of rev. to center of curvature
      20        $ ZC     = axial coordinate of center of curvature
 -1.000000      $ SROT=indicator for direction of increasing arc (-1. or +1.)
    H           $ IMPERFECTION SHAPE FOLLOWS...
       0        $ IMP   = indicator for imperfection (0=none, 1=some)
    H           $ REFERENCE SURFACE LOCATION RELATIVE TO WALL
       3        $ NTYPEZ= control (1 or 3) for reference surface location
 0.6250000      $ ZVAL  = distance from leftmost surf. to reference surf.
    N           $ Do you want to print out r(s), r'(s), etc. for this segment?
    H           $ DISCRETE RING INPUT FOLLOWS...
       0        $ NRINGS= number (max=20) of discrete rings in this segment
       0        $ K=elastic foundation modulus (e.g. lb/in**3)in this seg.
    H           $ LINE LOAD INPUT FOLLOWS...
       0        $ LINTYP= indicator (0, 1, 2 or 3) for type of line loads
    H           $ DISTRIBUTED LOAD INPUT FOLLOWS...
       1        $ IDISAB= indicator (0, 1, 2 or 3) for load set A and B
    H           $ SURFACE LOAD INPUT FOR LOAD SET "A" FOLLOWS
       1        $ NLTYPE=control (0,1,2,3) for type of surface loading
       2        $ NPSTAT= number of meridional callouts for surface loading
       0        $ NLOAD(1)=indicator for meridional traction (0=none, 1=some)
       0        $ NLOAD(2)=indicator for circumferential traction
       1        $ NLOAD(3)=indicator for normal pressure     (0=none, 1=some)
      -1        $ PN(i)    = normal pressure (p.74) at ith callout, PN( 1)
      -1        $ PN(i)    = normal pressure (p.74) at ith callout, PN( 2)
       2        $ NTYPE = control for meaning of loading callout (2=z, 3=r)
       0        $ Z(I)  = axial coordinate of Ith loading callout, z( 1)
      20        $ Z(I)  = axial coordinate of Ith loading callout, z( 2)
    H           $ SHELL WALL CONSTRUCTION FOLLOWS...
       2        $ NWALL=index (1, 2, 4, 5, 6, 7, 8, 9, 10) for wall construction
 0.1600000E+08  $ E      = Young's modulus for skin
 0.2500000      $ U      = Poisson's ratio for skin
 0.4144000E-03  $ SM =mass density of skin (e.g. alum.=.00025 lb-sec**2/in**4)
       0        $ ALPHA = coefficient of thermal expansion
       0        $ NRS  = control (0 or 1) for addition of smeared stiffeners
       0        $ NSUR   = control for thickness input (0 or 1 or -1)
    N           $ Do you want to print out ref. surf. location and thickness?
    N           $ Do you want to print out the C(i,j) at meridional stations?
    N           $ Do you want to print out distributed loads along meridian?
    H           $
    H           $ SEGMENT NUMBER    2    2    2    2    2    2    2    2
    H           $ NODAL POINT DISTRIBUTION FOLLOWS...
      51        $ NMESH = number of node points (5 = min.; 98 = max.)( 2)
       3        $ NTYPEH= control integer (1 or 3) for nodal point spacing
    H           $ REFERENCE SURFACE GEOMETRY FOLLOWS...
       1        $ NSHAPE= indicator (1,2 or 4) for geometry of meridian
      20        $ R1     = radius at beginning of segment (see p. 66)
      20        $ Z1     = global axial coordinate at beginning of segment
      20        $ R2     = radius at end of segment
      40        $ Z2     = global axial coordinate at end of segment
    H           $ IMPERFECTION SHAPE FOLLOWS...
       0        $ IMP   = indicator for imperfection (0=none, 1=some)
    H           $ REFERENCE SURFACE LOCATION RELATIVE TO WALL
       3        $ NTYPEZ= control (1 or 3) for reference surface location
 1.250000       $ ZVAL  = distance from leftmost surf. to reference surf.
    N           $ Do you want to print out r(s), r'(s), etc. for this segment?
    H           $ DISCRETE RING INPUT FOLLOWS...
       0        $ NRINGS= number (max=20) of discrete rings in this segment
       0        $ K=elastic foundation modulus (e.g. lb/in**3)in this seg.
    H           $ LINE LOAD INPUT FOLLOWS...
       0        $ LINTYP= indicator (0, 1, 2 or 3) for type of line loads
    H           $ DISTRIBUTED LOAD INPUT FOLLOWS...
       1        $ IDISAB= indicator (0, 1, 2 or 3) for load set A and B
```

$t_{sphere} = 1.25''$

$t_{cyl} = 2.5''$

Table 12, p.2 of 3

```
    H         $ SURFACE LOAD INPUT FOR LOAD SET "A" FOLLOWS
       1      $ NLTYPE=control (0,1,2,3) for type of surface loading
       2      $ NPSTAT= number of meridional callouts for surface loading
       0      $ NLOAD(1)=indicator for meridional traction (0=none, 1=some)
       0      $ NLOAD(2)=indicator for circumferential traction
       1      $ NLOAD(3)=indicator for normal pressure     (0=none, 1=some)
-1.000000     $ PN(i)   = normal pressure (p.74) at ith callout, PN( 1)
-1.000000     $ PN(i)   = normal pressure (p.74) at ith callout, PN( 2)
       2      $ NTYPE = control for meaning of loading callout (2=z, 3=r)
      20      $ Z(I)  = axial coordinate of Ith loading callout, z( 1)
      40      $ Z(I)  = axial coordinate of Ith loading callout, z( 2)
    H         $ SHELL WALL CONSTRUCTION FOLLOWS...
       2      $ NWALL=index (1, 2, 4, 5, 6, 7, 8, 9, 10) for wall construction
0.1600000E+08 $ E     = Young's modulus for skin
0.2500000     $ U     = Poisson's ratio for skin
0.4144000E-03 $ SM =mass density of skin (e.g. alum.=.00025 lb-sec**2/in**4)
       0      $ ALPHA = coefficient of thermal expansion
       0      $ NRS  = control (0 or 1) for addition of smeared stiffeners
       0      $ NSUR   = control for thickness input (0 or 1 or -1)
    N         $ Do you want to print out ref. surf. location and thickness?
    N         $ Do you want to print out the C(i,j) at meridional stations?
    N         $ Do you want to print out distributed loads along meridian?
    H         $
    H         $ GLOBAL DATA BEGINS...
       1      $ NLAST = plot options  (-1=none, 0=geometry, 1=u,v,w)
    N         $ Are there any regions for which you want expanded plots?
       0      $ P      = pressure or surface traction multiplier
   15000      $ DP     = pressure or surface traction multiplier increment
       0      $ TEMP   = temperature rise multiplier
       0      $ DTEMP  = temperature rise multiplier increment
       2      $ Number of load steps
       0      $ OMEGA  = angular vel. about axis of revolution (rad/sec)
       0      $ DOMEGA = angular velocity increment (rad/sec)
    H         $ CONSTRAINT CONDITIONS FOLLOW....
       2      $ How many segments in the structure?
    H         $
    H         $ CONSTRAINT CONDITIONS FOR SEGMENT NO.    1    1    1    1
    H         $ POLES INPUT FOLLOWS...
       1      $ Number of poles (places where r=0) in SEGMENT( 1)
       1      $ IPOLE = nodal point number of pole, IPOLE( 1)
    H         $ INPUT FOR CONSTRAINTS TO GROUND FOLLOWS...
       0      $ At how many stations is this segment constrained to ground?
    H         $ JUNCTION CONDITION INPUT FOLLOWS...
    N         $ Is this segment joined to any lower-numbered segments?
    H         $
    H         $ CONSTRAINT CONDITIONS FOR SEGMENT NO.    2    2    2    2
    H         $ POLES INPUT FOLLOWS...
       0      $ Number of poles (places where r=0) in SEGMENT( 2)
    H         $ INPUT FOR CONSTRAINTS TO GROUND FOLLOWS...
       1      $ At how many stations is this segment constrained to ground?
      51      $ INODE = nodal point number of constraint to ground, INODE( 1)
       1      $ IUSTAR=axial displacement constraint (0 or 1 or 2)
       0      $ IVSTAR=circumferential displacement(0=free,1=0,2=imposed)
       0      $ IWSTAR=radial displacement(0=free,1=constrained,2=imposed)
       1      $ ICHI=meridional rotation (0=free,1=constrained,2=imposed)
       0      $ D1    = radial component of offset of ground support
       0      $ D2    = axial component of offset of ground support
    Y         $ Is this constraint the same for both prebuckling and buckling?
    H         $ JUNCTION CONDITION INPUT FOLLOWS...
    Y         $ Is this segment joined to any lower-numbered segments?
       1      $ At how may stations is this segment joined to previous segs.?
       1      $ INODE = node in current segment (ISEG) of junction, INODE( 1)
       1      $ JSEG  = segment no. of lowest segment involved in junction
      51      $ JNODE = node in lowest segmnt (JSEG) of junction
       1      $ IUSTAR= axial displacement (0=not slaved, 1=slaved)
       1      $ IVSTAR= circumferential displacement (0=not slaved, 1=slaved)
       1      $ IWSTAR= radial displacement (0=not slaved, 1=slaved)
       1      $ ICHI  = meridional rotation (0=not slaved, 1=slaved)
       0      $ D1    = radial component of juncture gap
       0      $ D2    = axial component of juncture gap
    Y         $ Is this constraint the same for both prebuckling and buckling?
    H         $ RIGID BODY CONSTRAINT INPUT FOLLOWS...
    Y         $ Given existing constraints, are rigid body modes possible?
    Y         $ Do you wish to prevent rigid body motion?
       2      $ ISEG  = segment no. at which to prevent rigid body motion
      51      $ INODE = node no. at which to prevent rigid body motion
       1      $ IUSTAR= axial n=0 rigid body constraint (0=none, 1=some)
       1      $ IVSTAR= circ. n=0 rigid body constraint (usually equals 1)
```

Table 12, p. 3 of 3

```
   0       $ IWSTAR= radial n=0 rigid body constraint (usually equals 0)
   1       $ ICHI  = meridional rot. rigid body constraint
   1       $ IUSTAR= axial n=1 rigid body constraint (usually equals 1)
   1       $ IVSTAR= circ. n=1 rigid body constraint (usually equals 1)
   0       $ IWSTAR= radial n=1 rigid body constraint (usually equals 0)
   1       $ ICHI  = meridional rot. rigid body constraint
H          $ "GLOBAL3" QUESTIONS (AT END OF CASE)...
Y          $ Do you want to list output for segment( 1)
Y          $ Do you want to list output for segment( 2)
Y          $ Do you want to list forces in the discrete rings, if any?
```

end of doen6.ALL

Combined spherical-cylindrical shell

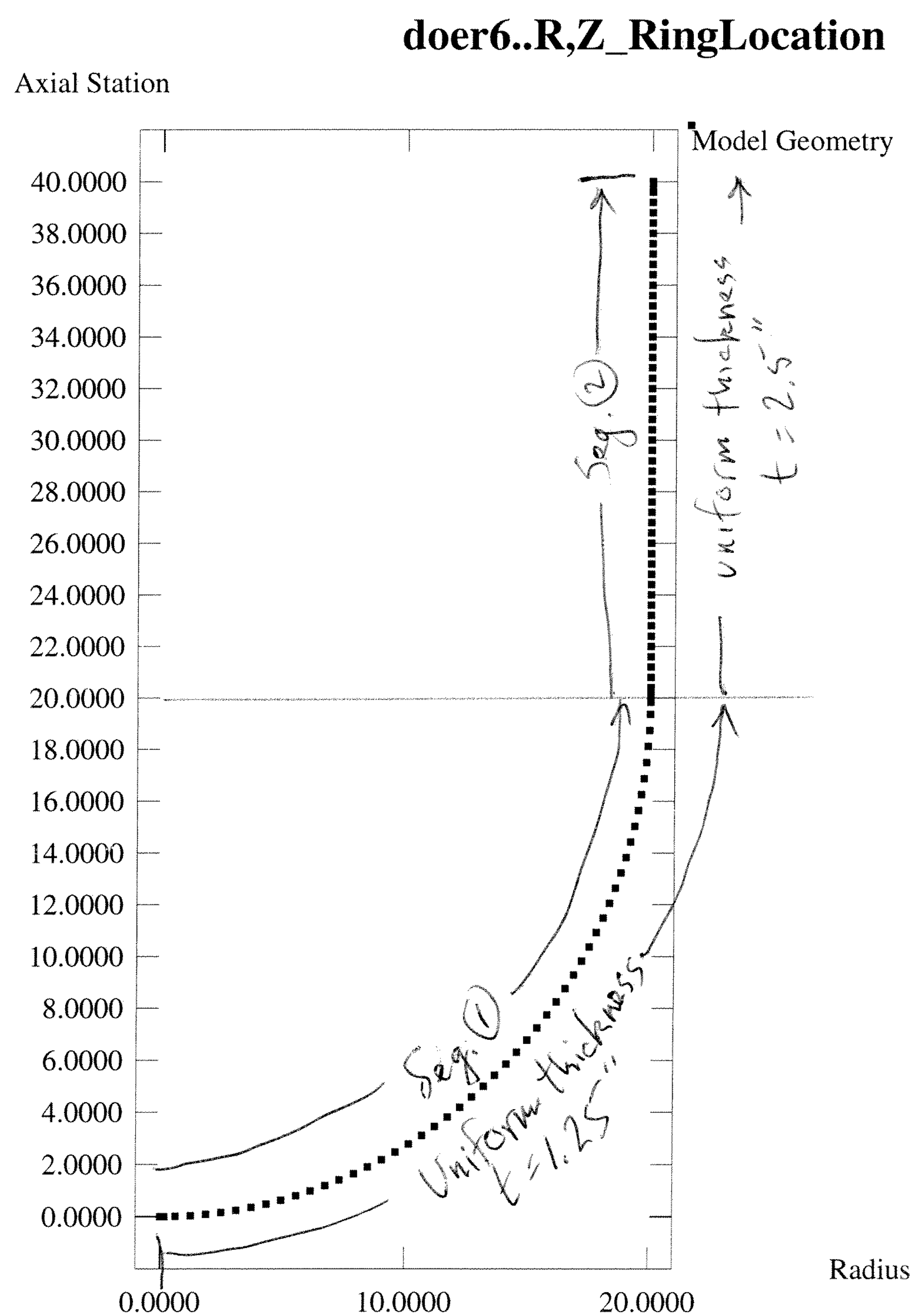


Fig. 8

Combined spherical-cylindrical shell - stress

Output from BIGBOSOR4

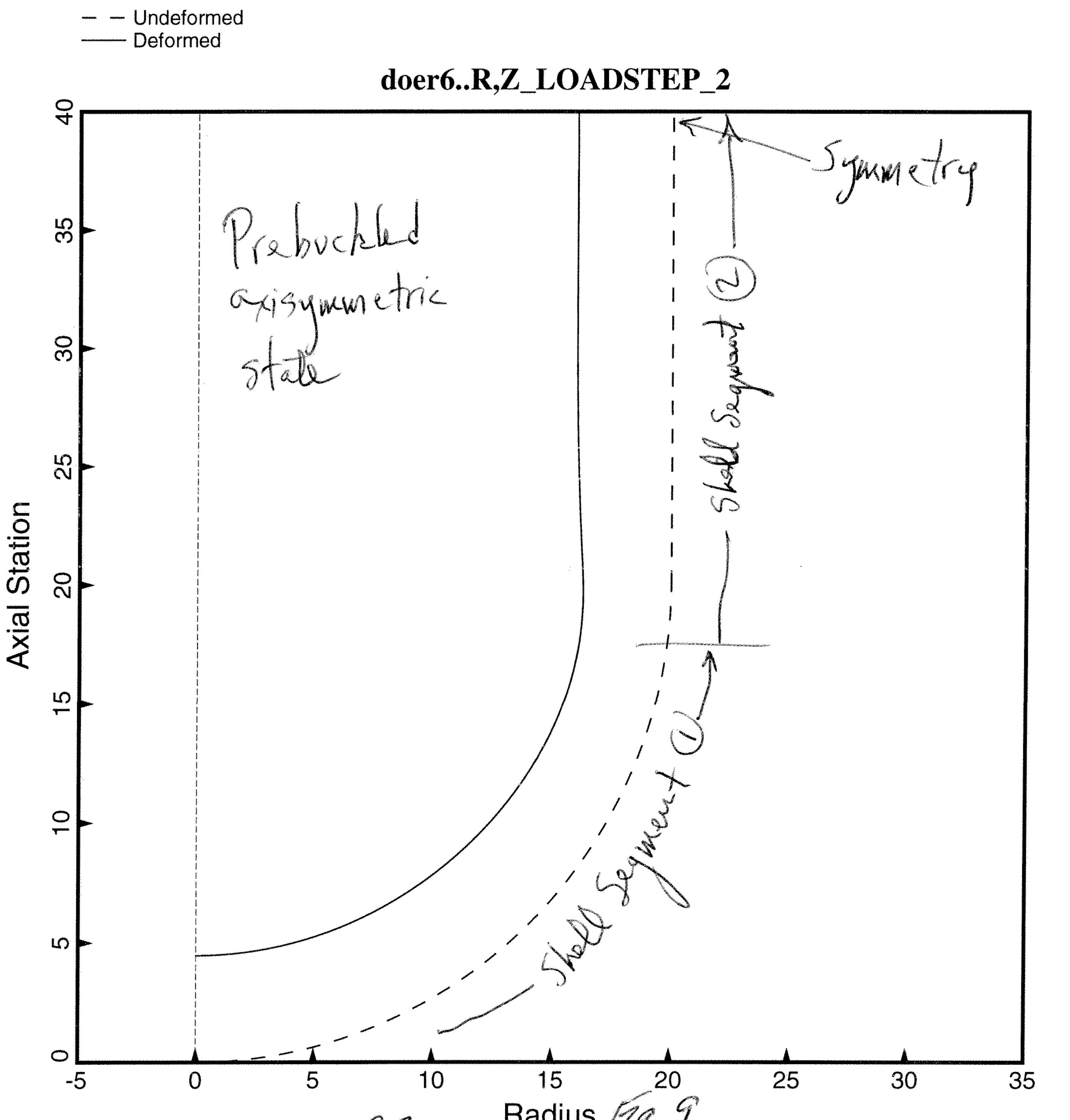


Fig. 9

Combined spherical-cylindrical shell-stress

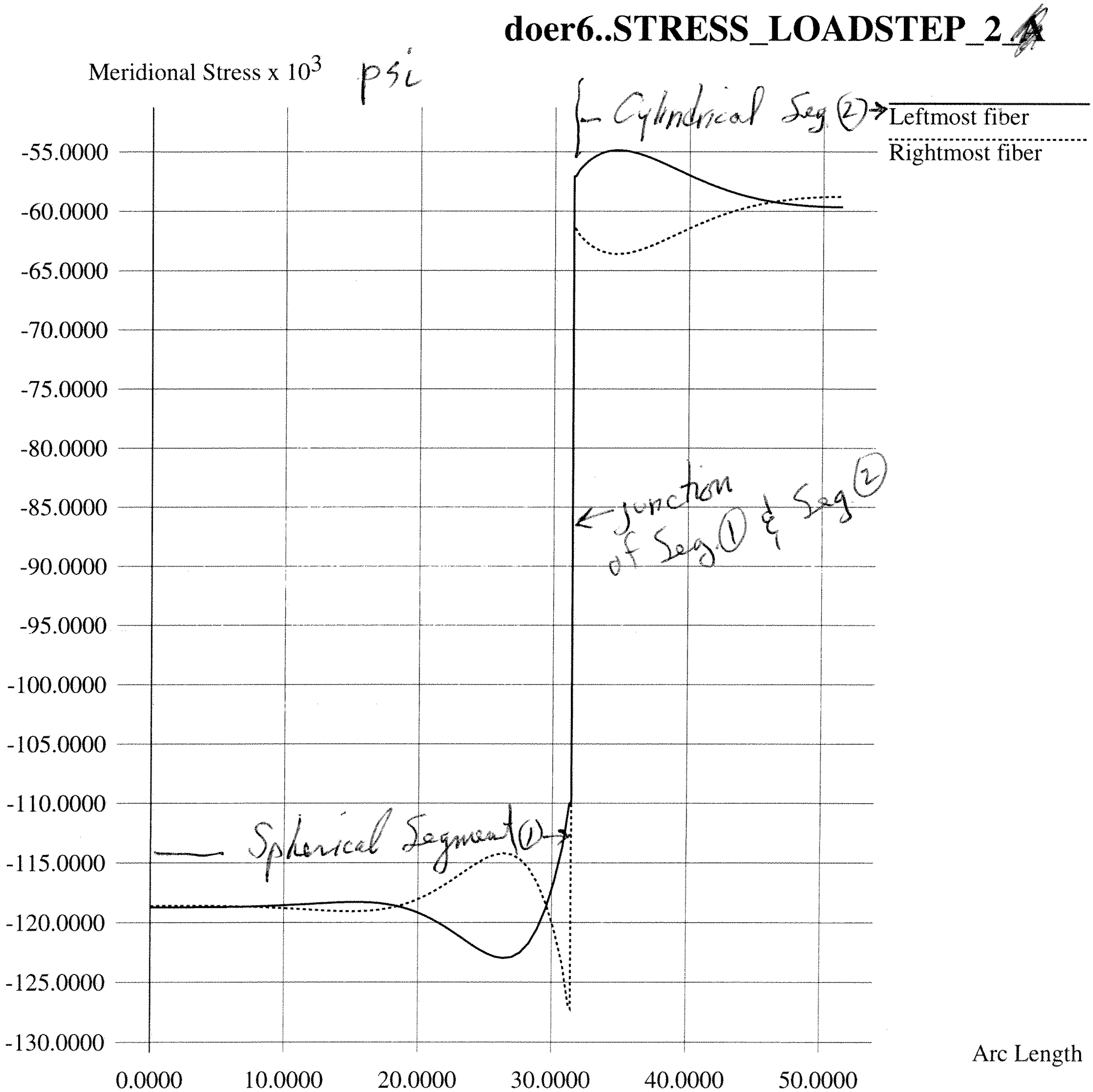


Fig. 10

Combined spherical-cylindrical shell - stress

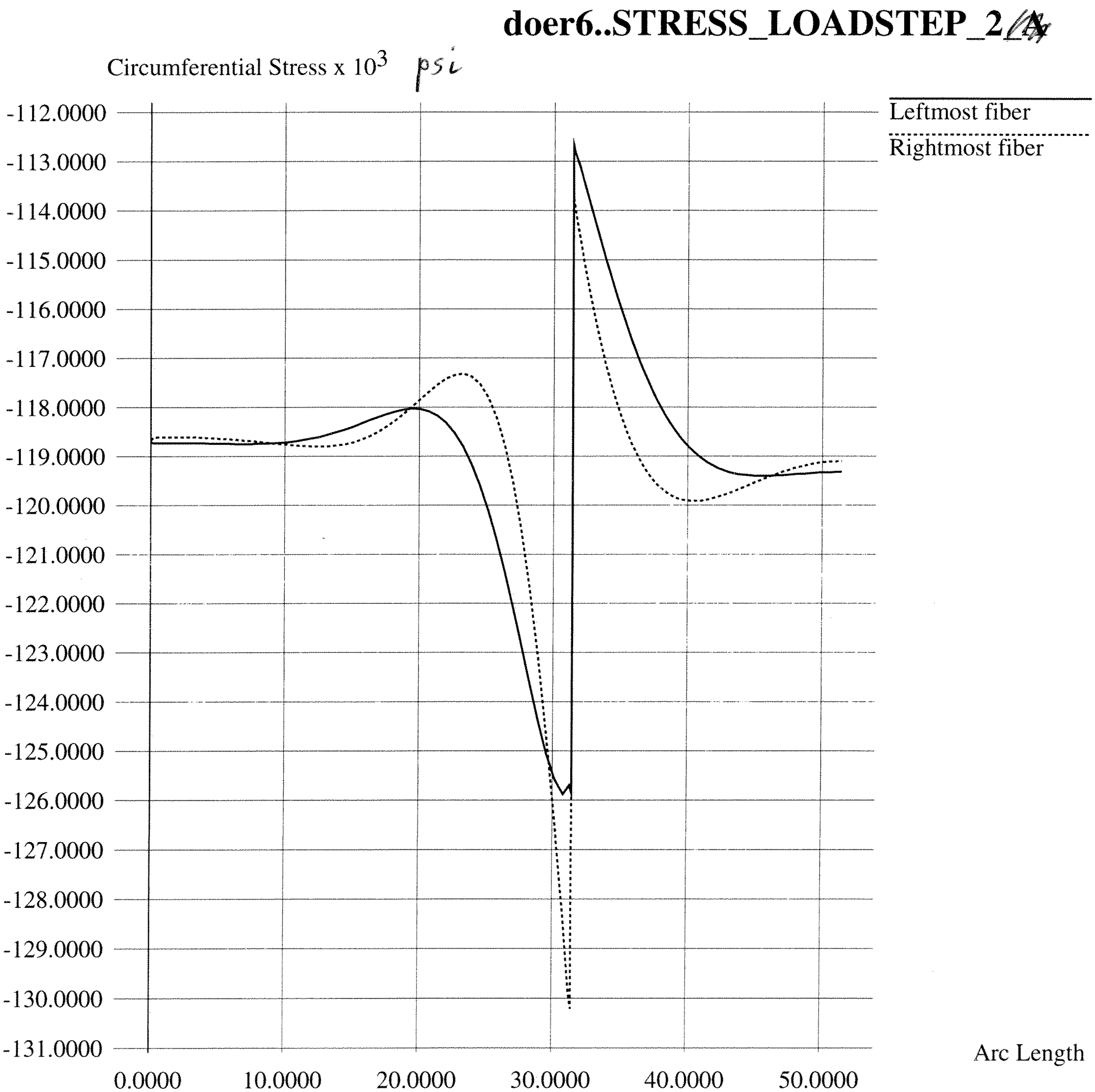


Fig. 11

Combined spherical-cylindrical shell-stress

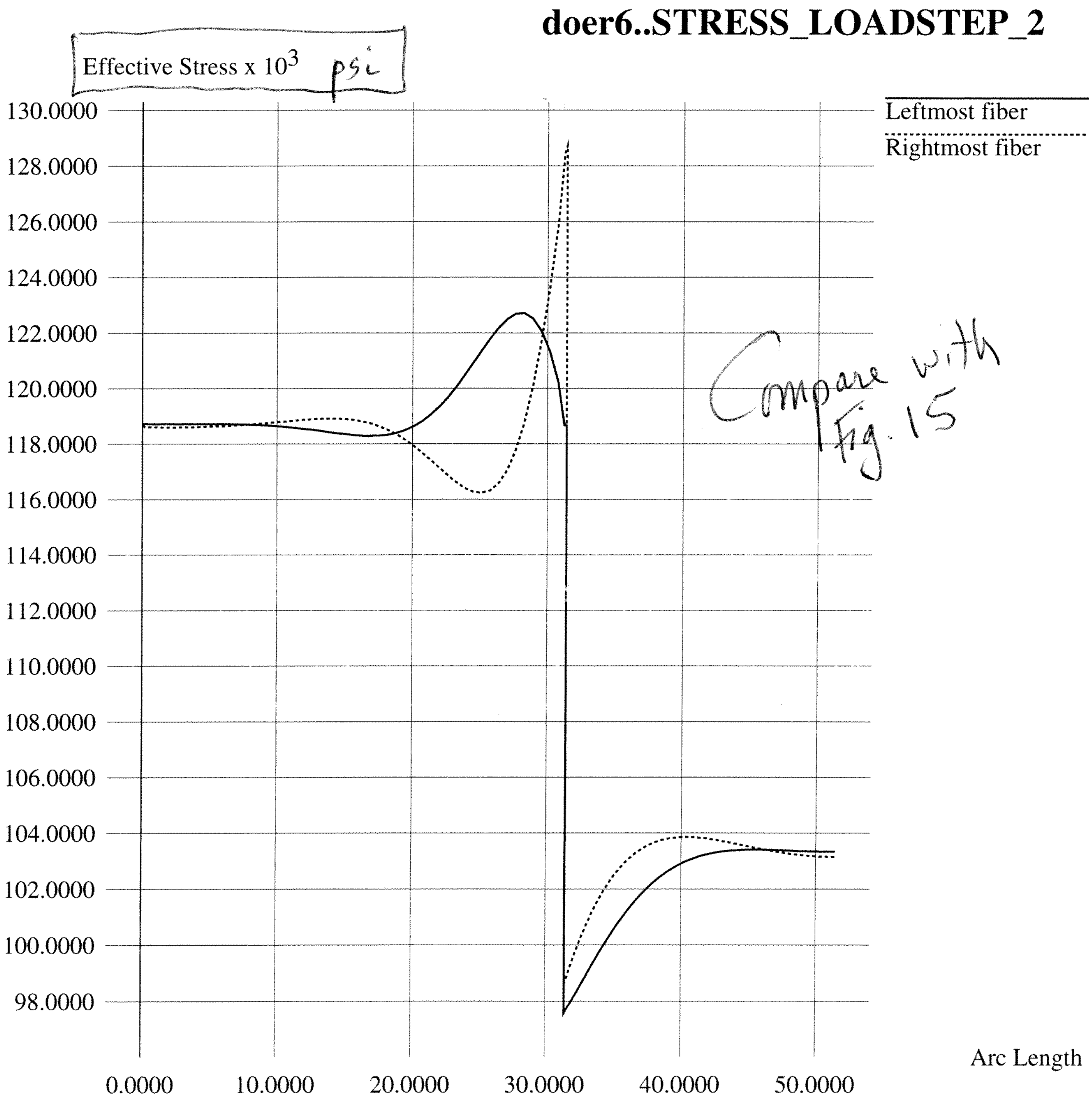


Fig. 12

Table 13 (3 pages) Input file for BIGBOSOR4 | does 5. ALL

Combined spherical-cylindrical shell-buckling

Uniform thickness in each of the two shell segments:

$t_1 = 1.25$

$t_2 = 2.50$

```
spherical plus cylindrical shell (buckling analysis)
       1        $ INDIC = analysis type indicator
       1        $ NPRT = output options (1=minimum, 2=medium, 3=maximum)
       1        $ ISTRES= output control (0=resultants, 1=sigma, 2=epsilon)
       2        $ NSEG  = number of shell segments (less than 295)
    H           $
    H           $ SEGMENT NUMBER    1    1    1    1    1    1    1    1
    H           $ NODAL POINT DISTRIBUTION FOLLOWS...
      51        $ NMESH = number of node points (5 = min.; 98 = max.)( 1)
       3        $ NTYPEH= control integer (1 or 3) for nodal point spacing
    H           $ REFERENCE SURFACE GEOMETRY FOLLOWS...
       2        $ NSHAPE= indicator (1,2 or 4) for geometry of meridian
       0        $ R1      = radius at beginning of segment (see p. 66)
       0        $ Z1      = global axial coordinate at beginning of segment
      20        $ R2      = radius at end of segment
      20        $ Z2      = global axial coordinate at end of segment
       0        $ RC      = radius from axis of rev. to center of curvature
      20        $ ZC      = axial coordinate of center of curvature
 -1.000000      $ SROT=indicator for direction of increasing arc (-1. or +1.)
    H           $ IMPERFECTION SHAPE FOLLOWS...
       0        $ IMP    = indicator for imperfection (0=none, 1=some)
    H           $ REFERENCE SURFACE LOCATION RELATIVE TO WALL
       3        $ NTYPEZ= control (1 or 3) for reference surface location
 0.6250000      $ ZVAL  = distance from leftmost surf. to reference surf.
    N           $ Do you want to print out r(s), r'(s), etc. for this segment?
    H           $ DISCRETE RING INPUT FOLLOWS...
       0        $ NRINGS= number (max=20) of discrete rings in this segment
       0        $ K=elastic foundation modulus (e.g. lb/in**3)in this seg.
    H           $ LINE LOAD INPUT FOLLOWS...
       0        $ LINTYP= indicator (0, 1, 2 or 3) for type of line loads
    H           $ DISTRIBUTED LOAD INPUT FOLLOWS...
       1        $ IDISAB= indicator (0, 1, 2 or 3) for load set A and B
    H           $ SURFACE LOAD INPUT FOR LOAD SET "A" FOLLOWS
       1        $ NLTYPE=control (0,1,2,3) for type of surface loading
       2        $ NPSTAT= number of meridional callouts for surface loading
       0        $ NLOAD(1)=indicator for meridional traction (0=none, 1=some)
       0        $ NLOAD(2)=indicator for circumferential traction
       1        $ NLOAD(3)=indicator for normal pressure     (0=none, 1=some)
      -1        $ PN(i)    = normal pressure (p.74) at ith callout, PN( 1)
      -1        $ PN(i)    = normal pressure (p.74) at ith callout, PN( 2)
       2        $ NTYPE = control for meaning of loading callout (2=z, 3=r)
       0        $ Z(I)  = axial coordinate of Ith loading callout, z( 1)
      20        $ Z(I)  = axial coordinate of Ith loading callout, z( 2)
    H           $ SHELL WALL CONSTRUCTION FOLLOWS...
       2        $ NWALL=index (1, 2, 4, 5, 6, 7, 8, 9, 10) for wall construction
 0.1600000E+08  $ E      = Young's modulus for skin
 0.2500000      $ U      = Poisson's ratio for skin
 0.4144000E-03  $ SM =mass density of skin (e.g. alum.=.00025 lb-sec**2/in**4)
       0        $ ALPHA = coefficient of thermal expansion
       0        $ NRS  = control (0 or 1) for addition of smeared stiffeners
       0        $ NSUR   = control for thickness input (0 or 1 or -1)
    N           $ Do you want to print out ref. surf. location and thickness?
    N           $ Do you want to print out the C(i,j) at meridional stations?
    N           $ Do you want to print out distributed loads along meridian?
    H           $
    H           $ SEGMENT NUMBER    2    2    2    2    2    2    2    2
    H           $ NODAL POINT DISTRIBUTION FOLLOWS...
      51        $ NMESH = number of node points (5 = min.; 98 = max.)( 2)
       3        $ NTYPEH= control integer (1 or 3) for nodal point spacing
    H           $ REFERENCE SURFACE GEOMETRY FOLLOWS...
       1        $ NSHAPE= indicator (1,2 or 4) for geometry of meridian
      20        $ R1      = radius at beginning of segment (see p. 66)
      20        $ Z1      = global axial coordinate at beginning of segment
      20        $ R2      = radius at end of segment
      40        $ Z2      = global axial coordinate at end of segment
    H           $ IMPERFECTION SHAPE FOLLOWS...
       0        $ IMP    = indicator for imperfection (0=none, 1=some)
    H           $ REFERENCE SURFACE LOCATION RELATIVE TO WALL
       3        $ NTYPEZ= control (1 or 3) for reference surface location
  1.250000      $ ZVAL  = distance from leftmost surf. to reference surf.
    N           $ Do you want to print out r(s), r'(s), etc. for this segment?
    H           $ DISCRETE RING INPUT FOLLOWS...
       0        $ NRINGS= number (max=20) of discrete rings in this segment
       0        $ K=elastic foundation modulus (e.g. lb/in**3)in this seg.
    H           $ LINE LOAD INPUT FOLLOWS...
       0        $ LINTYP= indicator (0, 1, 2 or 3) for type of line loads
    H           $ DISTRIBUTED LOAD INPUT FOLLOWS...
       1        $ IDISAB= indicator (0, 1, 2 or 3) for load set A and B
```

Table 13, p 2 of 3

```
   H          $ SURFACE LOAD INPUT FOR LOAD SET "A" FOLLOWS
      1       $ NLTYPE=control (0,1,2,3) for type of surface loading
      2       $ NPSTAT= number of meridional callouts for surface loading
      0       $ NLOAD(1)=indicator for meridional traction (0=none, 1=some)
      0       $ NLOAD(2)=indicator for circumferential traction
      1       $ NLOAD(3)=indicator for normal pressure     (0=none, 1=some)
-1.000000     $ PN(i)   = normal pressure (p.74) at ith callout, PN( 1)
-1.000000     $ PN(i)   = normal pressure (p.74) at ith callout, PN( 2)
      2       $ NTYPE = control for meaning of loading callout (2=z, 3=r)
     20       $ Z(I)  = axial coordinate of Ith loading callout, z( 1)
     40       $ Z(I)  = axial coordinate of Ith loading callout, z( 2)
   H          $ SHELL WALL CONSTRUCTION FOLLOWS...
      2       $ NWALL=index (1, 2, 4, 5, 6, 7, 8, 9, 10) for wall construction
0.1600000E+08 $ E     = Young's modulus for skin
0.2500000     $ U     = Poisson's ratio for skin
0.4144000E-03 $ SM =mass density of skin (e.g. alum.=.00025 lb-sec**2/in**4)
      0       $ ALPHA = coefficient of thermal expansion
      0       $ NRS  = control (0 or 1) for addition of smeared stiffeners
      0       $ NSUR   = control for thickness input (0 or 1 or -1)
   N          $ Do you want to print out ref. surf. location and thickness?
   N          $ Do you want to print out the C(i,j) at meridional stations?
   N          $ Do you want to print out distributed loads along meridian?
   H          $
   H          $ GLOBAL DATA BEGINS...
      0       $ NLAST = plot options  (-1=none, 0=geometry, 1=u,v,w)
   N          $ Are there any regions for which you want expanded plots?
      0       $ N0B   = starting number of circ. waves (buckling analysis)
      0       $ NMINB = minimum number of circ. waves  (buckling analysis)
     20       $ NMAXB = maximum number of circ. waves  (buckling analysis)
      1       $ INCRB = increment in number of circ. waves (buckling)
      1       $ NVEC  = number of eigenvalues for each wave number
      0       $ P       = pressure or surface traction multiplier
  15000       $ DP      = pressure or surface traction multiplier increment
      0       $ TEMP    = temperature rise multiplier
      0       $ DTEMP   = temperature rise multiplier increment
      0       $ OMEGA   = angular vel. about axis of revolution (rad/sec)
      0       $ DOMEGA = angular velocity increment (rad/sec)
   H          $ CONSTRAINT CONDITIONS FOLLOW....
      2       $ How many segments in the structure?
   H          $
   H          $ CONSTRAINT CONDITIONS FOR SEGMENT NO.    1    1    1    1
   H          $ POLES INPUT FOLLOWS...
      1       $ Number of poles (places where r=0) in SEGMENT( 1)
      1       $ IPOLE = nodal point number of pole, IPOLE( 1)
   H          $ INPUT FOR CONSTRAINTS TO GROUND FOLLOWS...
      0       $ At how many stations is this segment constrained to ground?
   H          $ JUNCTION CONDITION INPUT FOLLOWS...
   N          $ Is this segment joined to any lower-numbered segments?
   H          $
   H          $ CONSTRAINT CONDITIONS FOR SEGMENT NO.    2    2    2    2
   H          $ POLES INPUT FOLLOWS...
      0       $ Number of poles (places where r=0) in SEGMENT( 2)
   H          $ INPUT FOR CONSTRAINTS TO GROUND FOLLOWS...
      1       $ At how many stations is this segment constrained to ground?
     51       $ INODE = nodal point number of constraint to ground, INODE( 1)
      1       $ IUSTAR=axial displacement constraint (0 or 1 or 2)
      0       $ IVSTAR=circumferential displacement(0=free,1=0,2=imposed)
      0       $ IWSTAR=radial displacement(0=free,1=constrained,2=imposed)
      1       $ ICHI=meridional rotation (0=free,1=constrained,2=imposed)
      0       $ D1     = radial component of offset of ground support
      0       $ D2     = axial component of offset of ground support
   Y          $ Is this constraint the same for both prebuckling and buckling?
   H          $ JUNCTION CONDITION INPUT FOLLOWS...
   Y          $ Is this segment joined to any lower-numbered segments?
      1       $ At how may stations is this segment joined to previous segs.?
      1       $ INODE = node in current segment (ISEG) of junction, INODE( 1)
      1       $ JSEG  = segment no. of lowest segment involved in junction
     51       $ JNODE = node in lowest segmnt (JSEG) of junction
      1       $ IUSTAR= axial displacement (0=not slaved, 1=slaved)
      1       $ IVSTAR= circumferential displacement (0=not slaved, 1=slaved)
      1       $ IWSTAR= radial displacement (0=not slaved, 1=slaved)
      1       $ ICHI  = meridional rotation (0=not slaved, 1=slaved)
      0       $ D1     = radial component of juncture gap
      0       $ D2     = axial component of juncture gap
   Y          $ Is this constraint the same for both prebuckling and buckling?
   H          $ RIGID BODY CONSTRAINT INPUT FOLLOWS...
   Y          $ Given existing constraints, are rigid body modes possible?
   Y          $ Do you wish to prevent rigid body motion?
```

Table 13, p. 3 of 3

```
  2      $ ISEG  = segment no. at which to prevent rigid body motion
 51      $ INODE = node no. at which to prevent rigid body motion
  1      $ IUSTAR= axial n=0 rigid body constraint (0=none, 1=some)
  1      $ IVSTAR= circ. n=0 rigid body constraint (usually equals 1)
  0      $ IWSTAR= radial n=0 rigid body constraint (usually equals 0)
  1      $ ICHI  = meridional rot. rigid body constraint
  1      $ IUSTAR= axial n=1 rigid body constraint (usually equals 1)
  1      $ IVSTAR= circ. n=1 rigid body constraint (usually equals 1)
  0      $ IWSTAR= radial n=1 rigid body constraint (usually equals 0)
  1      $ ICHI  = meridional rot. rigid body constraint
H        $ "GLOBAL3" QUESTIONS (AT END OF CASE)...
Y        $ Do you want to list output for segment( 1)
Y        $ Do you want to list output for segment( 2)
Y        $ Do you want to list forces in the discrete rings, if any?
```

end of door5.ALL

Table 14 Combined spherical-cylindrical shell-buckling
Output from BIGBOSOR4

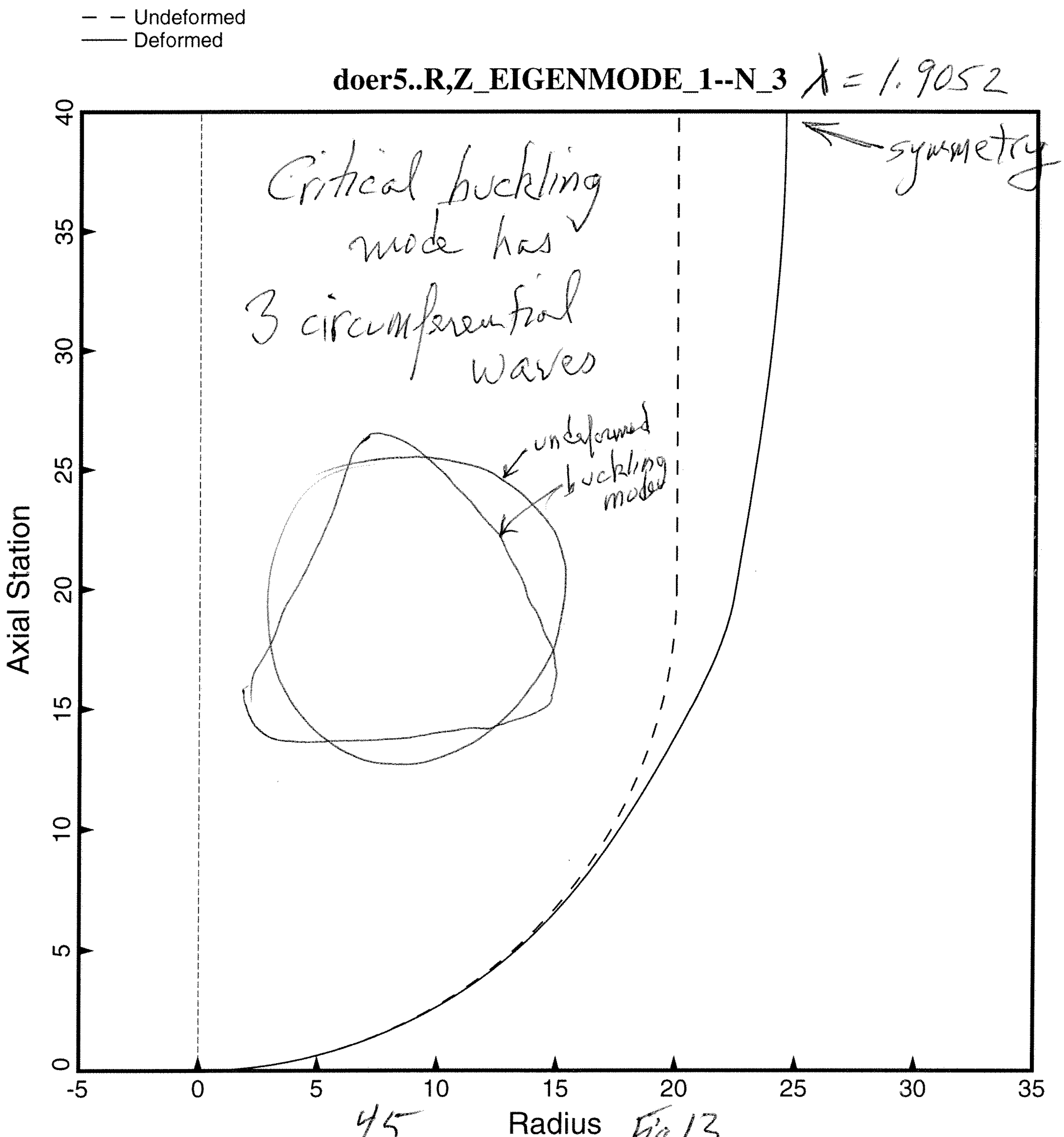
```
doer5.OUT (abridged) spherical plus cylindrical shell
buckling (INDIC = 1) analysis.
Search for the string, "EIGENVALUE(" in order to
find the following output data.


 **** CRITICAL EIGENVALUE AND WAVENUMBER ****
 EIGCRT=  1.9052E+00; NO. OF CIRC. WAVES, NWVCRT=    3
 ****************************************************

 ***** EIGENVALUES AND MODE SHAPES *****
  EIGENVALUE(CIRC. WAVES)
 =======================================
    5.0684E+00(   0)
    5.0205E+00(   1)
    2.2192E+00(   2)
    1.9052E+00(   3) <--critical buckling eigenvalue & mode
    2.9690E+00(   4)
    4.4438E+00(   5)
    5.0476E+00(   6)
    5.2879E+00(   7)
    5.7614E+00(   8)
    6.4252E+00(   9)
    7.2476E+00(  10)
    8.2076E+00(  11)
    9.2914E+00(  12)
    1.0490E+01(  13)
    1.1796E+01(  14)
    1.3205E+01(  15)
    1.4714E+01(  16)
    1.6321E+01(  17)
    1.8023E+01(  18)
    1.9818E+01(  19)
    2.1707E+01(  20)
 =======================================
```

(See next Fig.)

$t_1 = 1.25''$, $t_2 = 1.50''$ uniform thicknesses

Combined spherical-cylindrical shell - buckling

Output from BIGBOSOR4



45 Fig.13

input file for BIGBOSOR4 Table 15 (3pp)

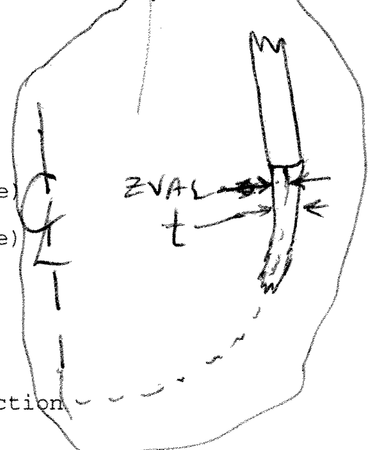
door7.ALL

Combined spherical-cylindrical shell - varying thickness in Seg. 1 - stress

```
spherical plus cylindrical shell (axisym. stress analysis)
      0        $ INDIC = analysis type indicator
      1        $ NPRT = output options (1=minimum, 2=medium, 3=maximum)
      1        $ ISTRES= output control (0=resultants, 1=sigma, 2=epsilon)
      2        $ NSEG  = number of shell segments (less than 295)
   H           $
   H           $ SEGMENT NUMBER    1    1    1    1    1    1    1    1
   H           $ NODAL POINT DISTRIBUTION FOLLOWS...
     91        $ NMESH = number of node points (5 = min.; 98 = max.)( 1)
      1        $ NTYPEH= control integer (1 or 3) for nodal point spacing
      4        $ NHVALU= number of callouts for nodal point spacing
      1        $ IHVALU(I)= Ith callout for nodal point spacing, IHVALU( 1)
     30        $ IHVALU(I)= Ith callout for nodal point spacing, IHVALU( 2)
     31        $ IHVALU(I)= Ith callout for nodal point spacing, IHVALU( 3)
     90        $ IHVALU(I)= Ith callout for nodal point spacing, IHVALU( 4)
  1.000000     $ HVALU=meridional arc length between nodal points,HVALU( 1)
  1.000000     $ HVALU=meridional arc length between nodal points,HVALU( 2)
 0.5000000     $ HVALU=meridional arc length between nodal points,HVALU( 3)
 0.5000000     $ HVALU=meridional arc length between nodal points,HVALU( 4)
   H           $ REFERENCE SURFACE GEOMETRY FOLLOWS...
      2        $ NSHAPE= indicator (1,2 or 4) for geometry of meridian
      0        $ R1     = radius at beginning of segment (see p. 66)
      0        $ Z1     = global axial coordinate at beginning of segment
     20        $ R2     = radius at end of segment
     20        $ Z2     = global axial coordinate at end of segment
      0        $ RC     = radius from axis of rev. to center of curvature
     20        $ ZC     = axial coordinate of center of curvature
 -1.000000     $ SROT=indicator for direction of increasing arc (-1. or +1.)
   H           $ IMPERFECTION SHAPE FOLLOWS...
      0        $ IMP   = indicator for imperfection (0=none, 1=some)
   H           $ REFERENCE SURFACE LOCATION RELATIVE TO WALL
      1        $ NTYPEZ= control (1 or 3) for reference surface location
      5        $ NZVALU= number of meridional callouts for ref. surf.
      2        $ NTYPE = control for meaning of callout (2=z, 3=r)
  0.000000     $ Z(I)  = axial coordinate of Ith callout, z( 1)
     10        $ Z(I)  = axial coordinate of Ith callout, z( 2)
     13        $ Z(I)  = axial coordinate of Ith callout, z( 3)
     16        $ Z(I)  = axial coordinate of Ith callout, z( 4)
     20        $ Z(I)  = axial coordinate of Ith callout, z( 5)
 0.6250000     $ ZVAL  = distance from leftmost surf. to ref. surf.,ZVAL( 1)
 0.6250000     $ ZVAL  = distance from leftmost surf. to ref. surf.,ZVAL( 2)
 0.8250000     $ ZVAL  = distance from leftmost surf. to ref. surf.,ZVAL( 3)
  1.100000     $ ZVAL  = distance from leftmost surf. to ref. surf.,ZVAL( 4)
  1.250000     $ ZVAL  = distance from leftmost surf. to ref. surf.,ZVAL( 5)
   N           $ Do you want to print out r(s), r'(s), etc. for this segment?
   H           $ DISCRETE RING INPUT FOLLOWS...
      0        $ NRINGS= number (max=20) of discrete rings in this segment
      0        $ K=elastic foundation modulus (e.g. lb/in**3)in this seg.
   H           $ LINE LOAD INPUT FOLLOWS...
      0        $ LINTYP= indicator (0, 1, 2 or 3) for type of line loads
   H           $ DISTRIBUTED LOAD INPUT FOLLOWS...
      1        $ IDISAB= indicator (0, 1, 2 or 3) for load set A and B
   H           $ SURFACE LOAD INPUT FOR LOAD SET "A" FOLLOWS
      1        $ NLTYPE=control (0,1,2,3) for type of surface loading
      2        $ NPSTAT= number of meridional callouts for surface loading
      0        $ NLOAD(1)=indicator for meridional traction (0=none, 1=some)
      0        $ NLOAD(2)=indicator for circumferential traction
      1        $ NLOAD(3)=indicator for normal pressure     (0=none, 1=some)
     -1        $ PN(i)    = normal pressure (p.74) at ith callout, PN( 1)
     -1        $ PN(i)    = normal pressure (p.74) at ith callout, PN( 2)
      2        $ NTYPE = control for meaning of loading callout (2=z, 3=r)
      0        $ Z(I)  = axial coordinate of Ith loading callout, z( 1)
     20        $ Z(I)  = axial coordinate of Ith loading callout, z( 2)
   H           $ SHELL WALL CONSTRUCTION FOLLOWS...
      2        $ NWALL=index (1, 2, 4, 5, 6, 7, 8, 9, 10) for wall construction
 0.1600000E+08 $ E      = Young's modulus for skin
 0.2500000     $ U      = Poisson's ratio for skin
 0.4144000E-03 $ SM =mass density of skin (e.g. alum.=.00025 lb-sec**2/in**4)
      0        $ ALPHA = coefficient of thermal expansion
      0        $ NRS   = control (0 or 1) for addition of smeared stiffeners
      0        $ NSUR   = control for thickness input (0 or 1 or -1)
   N           $ Do you want to print out ref. surf. location and thickness?
   N           $ Do you want to print out the C(i,j) at meridional stations?
   N           $ Do you want to print out distributed loads along meridian?
   H           $
   H           $ SEGMENT NUMBER    2    2    2    2    2    2    2    2
   H           $ NODAL POINT DISTRIBUTION FOLLOWS...
     51        $ NMESH = number of node points (5 = min.; 98 = max.)( 2)
```

Varying nodal pt. spacing in Seg. 1

middle surface variation in Seg. 1



middle surface & thickness varies in Seg. 1

Table 15, p. 243

```
      3        $ NTYPEH= control integer (1 or 3) for nodal point spacing
   H           $ REFERENCE SURFACE GEOMETRY FOLLOWS...
      1        $ NSHAPE= indicator (1,2 or 4) for geometry of meridian
     20        $ R1     = radius at beginning of segment (see p. 66)
     20        $ Z1     = global axial coordinate at beginning of segment
     20        $ R2     = radius at end of segment
     40        $ Z2     = global axial coordinate at end of segment
   H           $ IMPERFECTION SHAPE FOLLOWS...
      0        $ IMP   = indicator for imperfection (0=none, 1=some)
   H           $ REFERENCE SURFACE LOCATION RELATIVE TO WALL
      3        $ NTYPEZ= control (1 or 3) for reference surface location
 1.250000      $ ZVAL  = distance from leftmost surf. to reference surf.
   N           $ Do you want to print out r(s), r'(s), etc. for this segment?
   H           $ DISCRETE RING INPUT FOLLOWS...
      0        $ NRINGS= number (max=20) of discrete rings in this segment
      0        $ K=elastic foundation modulus (e.g. lb/in**3)in this seg.
   H           $ LINE LOAD INPUT FOLLOWS...
      0        $ LINTYP= indicator (0, 1, 2 or 3) for type of line loads
   H           $ DISTRIBUTED LOAD INPUT FOLLOWS...
      1        $ IDISAB= indicator (0, 1, 2 or 3) for load set A and B
   H           $ SURFACE LOAD INPUT FOR LOAD SET "A" FOLLOWS
      1        $ NLTYPE=control (0,1,2,3) for type of surface loading
      2        $ NPSTAT= number of meridional callouts for surface loading
      0        $ NLOAD(1)=indicator for meridional traction (0=none, 1=some)
      0        $ NLOAD(2)=indicator for circumferential traction
      1        $ NLOAD(3)=indicator for normal pressure    (0=none, 1=some)
-1.000000      $ PN(i)   = normal pressure (p.74) at ith callout, PN( 1)
-1.000000      $ PN(i)   = normal pressure (p.74) at ith callout, PN( 2)
      2        $ NTYPE = control for meaning of loading callout (2=z, 3=r)
     20        $ Z(I)  = axial coordinate of Ith loading callout, z( 1)
     40        $ Z(I)  = axial coordinate of Ith loading callout, z( 2)
   H           $ SHELL WALL CONSTRUCTION FOLLOWS...
      2        $ NWALL=index (1, 2, 4, 5, 6, 7, 8, 9, 10) for wall construction
0.1600000E+08  $ E     = Young's modulus for skin
0.2500000      $ U     = Poisson's ratio for skin
0.4144000E-03  $ SM =mass density of skin (e.g. alum.=.00025 lb-sec**2/in**4)
      0        $ ALPHA = coefficient of thermal expansion
      0        $ NRS  = control (0 or 1) for addition of smeared stiffeners
      0        $ NSUR   = control for thickness input (0 or 1 or -1)
   N           $ Do you want to print out ref. surf. location and thickness?
   N           $ Do you want to print out the C(i,j) at meridional stations?
   N           $ Do you want to print out distributed loads along meridian?
   H           $
   H           $ GLOBAL DATA BEGINS...
      1        $ NLAST = plot options  (-1=none, 0=geometry, 1=u,v,w)
   N           $ Are there any regions for which you want expanded plots?
      0        $ P      = pressure or surface traction multiplier
  15000        $ DP     = pressure or surface traction multiplier increment
      0        $ TEMP   = temperature rise multiplier
      0        $ DTEMP  = temperature rise multiplier increment
      2        $ Number of load steps
      0        $ OMEGA  = angular vel. about axis of revolution (rad/sec)
      0        $ DOMEGA = angular velocity increment (rad/sec)
   H           $ CONSTRAINT CONDITIONS FOLLOW....
      2        $ How many segments in the structure?
   H           $
   H           $ CONSTRAINT CONDITIONS FOR SEGMENT NO.    1    1    1    1
   H           $ POLES INPUT FOLLOWS...
      1        $ Number of poles (places where r=0) in SEGMENT( 1)
      1        $ IPOLE = nodal point number of pole, IPOLE( 1)
   H           $ INPUT FOR CONSTRAINTS TO GROUND FOLLOWS...
      0        $ At how many stations is this segment constrained to ground?
   H           $ JUNCTION CONDITION INPUT FOLLOWS...
   N           $ Is this segment joined to any lower-numbered segments?
   H           $
   H           $ CONSTRAINT CONDITIONS FOR SEGMENT NO.    2    2    2    2
   H           $ POLES INPUT FOLLOWS...
      0        $ Number of poles (places where r=0) in SEGMENT( 2)
   H           $ INPUT FOR CONSTRAINTS TO GROUND FOLLOWS...
      1        $ At how many stations is this segment constrained to ground?
     51        $ INODE = nodal point number of constraint to ground, INODE( 1)
      1        $ IUSTAR=axial displacement constraint (0 or 1 or 2)
      0        $ IVSTAR=circumferential displacement(0=free,1=0,2=imposed)
      0        $ IWSTAR=radial displacement(0=free,1=constrained,2=imposed)
      1        $ ICHI=meridional rotation (0=free,1=constrained,2=imposed)
      0        $ D1    = radial component of offset of ground support
      0        $ D2    = axial component of offset of ground support
   Y           $ Is this constraint the same for both prebuckling and buckling?
```

$t_2 = 2.5''$ uniform in Seg. 2

Table 15, p. 3 of 3

```
H          $ JUNCTION CONDITION INPUT FOLLOWS...
Y          $ Is this segment joined to any lower-numbered segments?
   1       $ At how may stations is this segment joined to previous segs.?
   1       $ INODE = node in current segment (ISEG) of junction, INODE( 1)
   1       $ JSEG  = segment no. of lowest segment involved in junction
  91       $ JNODE = node in lowest segmnt (JSEG) of junction
   1       $ IUSTAR= axial displacement (0=not slaved, 1=slaved)
   1       $ IVSTAR= circumferential displacement (0=not slaved, 1=slaved)
   1       $ IWSTAR= radial displacement (0=not slaved, 1=slaved)
   1       $ ICHI  = meridional rotation (0=not slaved, 1=slaved)
   0       $ D1    = radial component of juncture gap
   0       $ D2    = axial component of juncture gap
Y          $ Is this constraint the same for both prebuckling and buckling?
H          $ RIGID BODY CONSTRAINT INPUT FOLLOWS...
Y          $ Given existing constraints, are rigid body modes possible?
Y          $ Do you wish to prevent rigid body motion?
   2       $ ISEG  = segment no. at which to prevent rigid body motion
  51       $ INODE = node no. at which to prevent rigid body motion
   1       $ IUSTAR= axial n=0 rigid body constraint (0=none, 1=some)
   1       $ IVSTAR= circ. n=0 rigid body constraint (usually equals 1)
   0       $ IWSTAR= radial n=0 rigid body constraint (usually equals 0)
   1       $ ICHI  = meridional rot. rigid body constraint
   1       $ IUSTAR= axial n=1 rigid body constraint (usually equals 1)
   1       $ IVSTAR= circ. n=1 rigid body constraint (usually equals 1)
   0       $ IWSTAR= radial n=1 rigid body constraint (usually equals 0)
   1       $ ICHI  = meridional rot. rigid body constraint
H          $ "GLOBAL3" QUESTIONS (AT END OF CASE)...
Y          $ Do you want to list output for segment( 1)
Y          $ Do you want to list output for segment( 2)
Y          $ Do you want to list forces in the discrete rings, if any?
```

end of doev7.ALL

Combined spherical-cylindrical shell-varying thickness in Seg. 1 - stress

Output from BIGBOSOR4

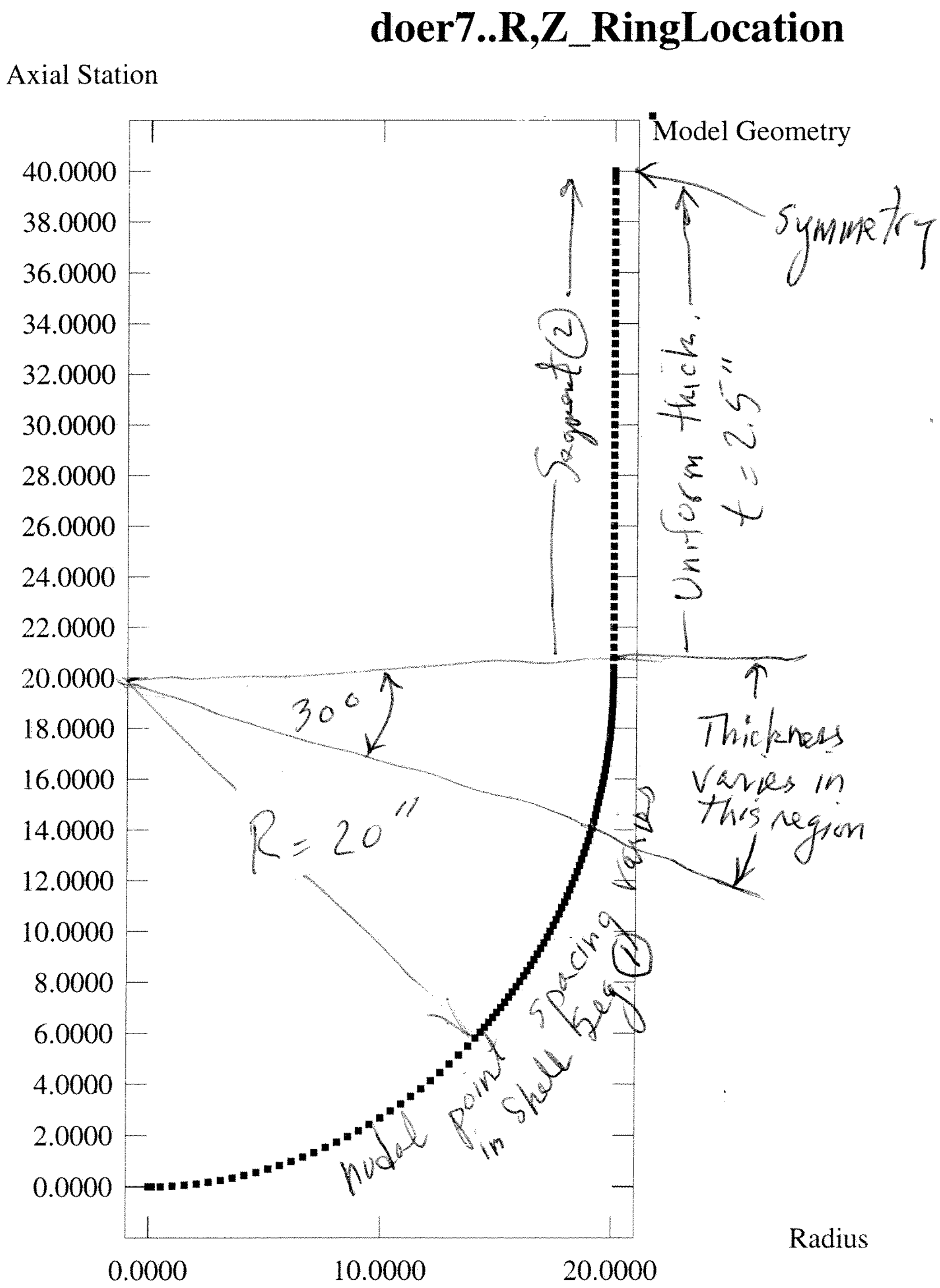


Fig. 14

Combined spherical-cylindrical shell - varying thickness in Seg. ① - stress

Output from BIGBOSOR4

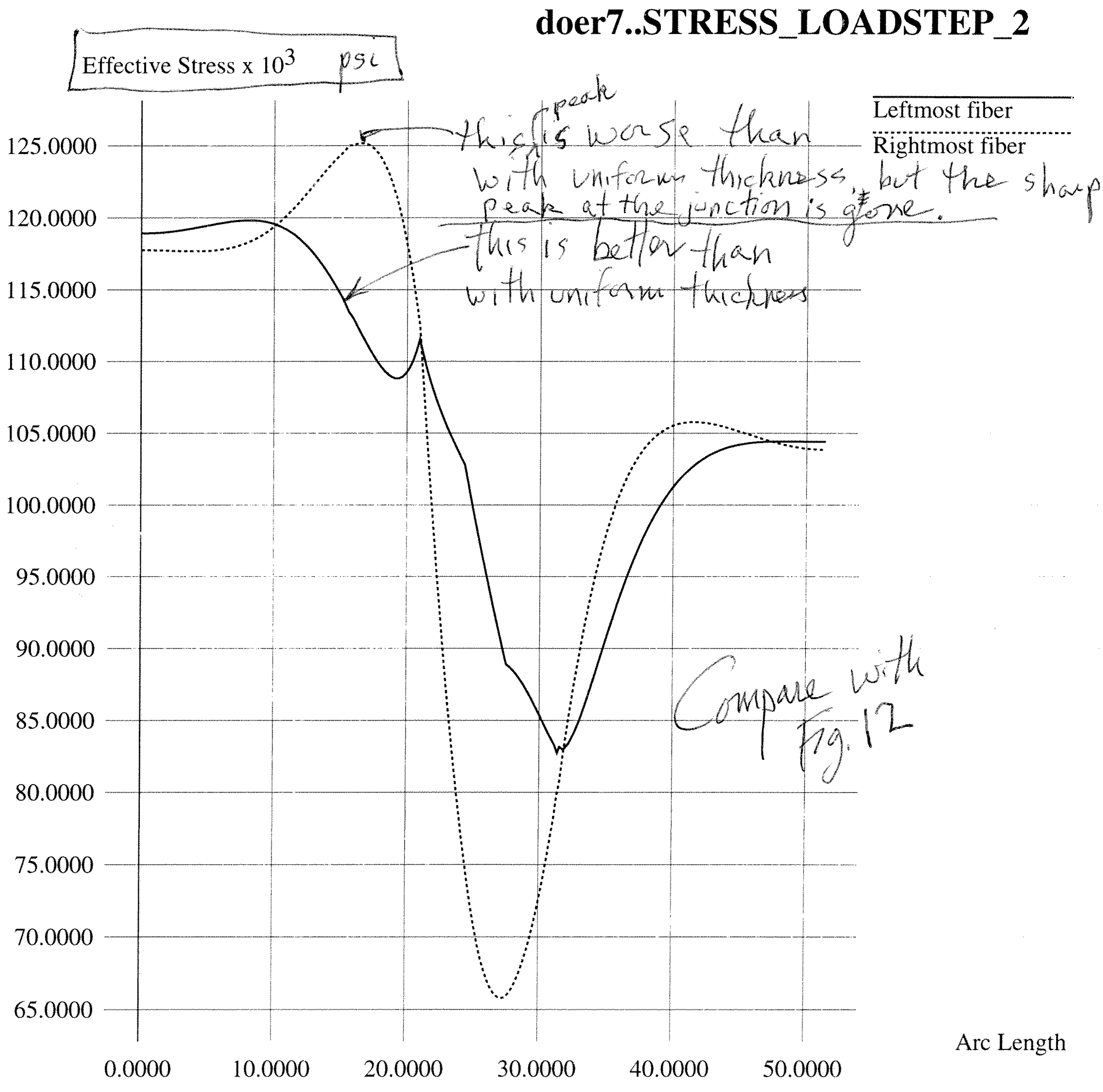


Fig. ~~13~~ 15

Table 16 (3pp): Combined spherical-cylindrical shell - varying thickness in Segs 1 & 2

doer8.ALL

```
spherical plus cylindrical shell, variable wall in segs 1 and 2, INDIC=0
         0        $ INDIC = analysis type indicator
         1        $ NPRT = output options (1=minimum, 2=medium, 3=maximum)
         1        $ ISTRES= output control (0=resultants, 1=sigma, 2=epsilon)
         2        $ NSEG  = number of shell segments (less than 295)
      H           $
      H           $ SEGMENT NUMBER    1    1    1    1    1    1    1    1
      H           $ NODAL POINT DISTRIBUTION FOLLOWS...
        91        $ NMESH = number of node points (5 = min.; 98 = max.)( 1)
         1        $ NTYPEH= control integer (1 or 3) for nodal point spacing
         4        $ NHVALU= number of callouts for nodal point spacing
         1        $ IHVALU(I)= Ith callout for nodal point spacing, IHVALU( 1)
        30        $ IHVALU(I)= Ith callout for nodal point spacing, IHVALU( 2)
        31        $ IHVALU(I)= Ith callout for nodal point spacing, IHVALU( 3)
        90        $ IHVALU(I)= Ith callout for nodal point spacing, IHVALU( 4)
  1.000000        $ HVALU=meridional arc length between nodal points,HVALU( 1)
  1.000000        $ HVALU=meridional arc length between nodal points,HVALU( 2)
 0.5000000        $ HVALU=meridional arc length between nodal points,HVALU( 3)
 0.5000000        $ HVALU=meridional arc length between nodal points,HVALU( 4)
      H           $ REFERENCE SURFACE GEOMETRY FOLLOWS...
         2        $ NSHAPE= indicator (1,2 or 4) for geometry of meridian
         0        $ R1     = radius at beginning of segment (see p. 66)
         0        $ Z1     = global axial coordinate at beginning of segment
        20        $ R2     = radius at end of segment
        20        $ Z2     = global axial coordinate at end of segment
         0        $ RC     = radius from axis of rev. to center of curvature
        20        $ ZC     = axial coordinate of center of curvature
 -1.000000        $ SROT=indicator for direction of increasing arc (-1. or +1.)
      H           $ IMPERFECTION SHAPE FOLLOWS...
         0        $ IMP   = indicator for imperfection (0=none, 1=some)
      H           $ REFERENCE SURFACE LOCATION RELATIVE TO WALL
         1        $ NTYPEZ= control (1 or 3) for reference surface location
         5        $ NZVALU= number of meridional callouts for ref. surf.
         2        $ NTYPE = control for meaning of callout (2=z, 3=r)
  0.000000        $ Z(I)  = axial coordinate of Ith callout, z( 1)
        10        $ Z(I)  = axial coordinate of Ith callout, z( 2)
        13        $ Z(I)  = axial coordinate of Ith callout, z( 3)
        16        $ Z(I)  = axial coordinate of Ith callout, z( 4)
        20        $ Z(I)  = axial coordinate of Ith callout, z( 5)
 0.6250000        $ ZVAL  = distance from leftmost surf. to ref. surf.,ZVAL( 1)
 0.6250000        $ ZVAL  = distance from leftmost surf. to ref. surf.,ZVAL( 2)
 0.7250000        $ ZVAL  = distance from leftmost surf. to ref. surf.,ZVAL( 3)
 0.8250000        $ ZVAL  = distance from leftmost surf. to ref. surf.,ZVAL( 4)
  1.000000        $ ZVAL  = distance from leftmost surf. to ref. surf.,ZVAL( 5)
      N           $ Do you want to print out r(s), r'(s), etc. for this segment?
      H           $ DISCRETE RING INPUT FOLLOWS...
         0        $ NRINGS= number (max=20) of discrete rings in this segment
         0        $ K=elastic foundation modulus (e.g. lb/in**3)in this seg.
      H           $ LINE LOAD INPUT FOLLOWS...
         0        $ LINTYP= indicator (0, 1, 2 or 3) for type of line loads
      H           $ DISTRIBUTED LOAD INPUT FOLLOWS...
         1        $ IDISAB= indicator (0, 1, 2 or 3) for load set A and B
      H           $ SURFACE LOAD INPUT FOR LOAD SET "A" FOLLOWS
         1        $ NLTYPE=control (0,1,2,3) for type of surface loading
         2        $ NPSTAT= number of meridional callouts for surface loading
         0        $ NLOAD(1)=indicator for meridional traction (0=none, 1=some)
         0        $ NLOAD(2)=indicator for circumferential traction
         1        $ NLOAD(3)=indicator for normal pressure     (0=none, 1=some)
        -1        $ PN(i)   = normal pressure (p.74) at ith callout, PN( 1)
        -1        $ PN(i)   = normal pressure (p.74) at ith callout, PN( 2)
         2        $ NTYPE = control for meaning of loading callout (2=z, 3=r)
         0        $ Z(I)  = axial coordinate of Ith loading callout, z( 1)
        20        $ Z(I)  = axial coordinate of Ith loading callout, z( 2)
      H           $ SHELL WALL CONSTRUCTION FOLLOWS...
         2        $ NWALL=index (1, 2, 4, 5, 6, 7, 8, 9, 10) for wall construction
0.1600000E+08     $ E     = Young's modulus for skin
0.2500000         $ U     = Poisson's ratio for skin
0.4144000E-03     $ SM =mass density of skin (e.g. alum.=.00025 lb-sec**2/in**4)
         0        $ ALPHA = coefficient of thermal expansion
         0        $ NRS  = control (0 or 1) for addition of smeared stiffeners
        -1        $ NSUR   = control for thickness input (0 or 1 or -1)
         1        $ NTYPET= index (1 or 3) for type of input for thickness
         5        $ NTVALU= number of callouts along segment for thickness
         2        $ NTYPE = control for meaning of thickness callout (2=z, 3=r)
         0        $ Z(I)  = axial coordinate of Ith thickness callout, z( 1)
        10        $ Z(I)  = axial coordinate of Ith thickness callout, z( 2)
        13        $ Z(I)  = axial coordinate of Ith thickness callout, z( 3)
        16        $ Z(I)  = axial coordinate of Ith thickness callout, z( 4)
```

Table 16, p. 293

```
      20          $ Z(I)  = axial coordinate of Ith thickness callout, z( 5)
  1.250000        $ TVAL(i) = thickness at Ith callout, TVAL( 1)
  1.250000        $ TVAL(i) = thickness at Ith callout, TVAL( 2)
  1.450000        $ TVAL(i) = thickness at Ith callout, TVAL( 3)
  1.650000        $ TVAL(i) = thickness at Ith callout, TVAL( 4)
  2.000000        $ TVAL(i) = thickness at Ith callout, TVAL( 5)
     N            $ Do you want to print out ref. surf. location and thickness?
     N            $ Do you want to print out the C(i,j) at meridional stations?
     N            $ Do you want to print out distributed loads along meridian?
     H            $
     H            $ SEGMENT NUMBER    2    2    2    2    2    2    2    2
     H            $ NODAL POINT DISTRIBUTION FOLLOWS...
      51          $ NMESH = number of node points (5 = min.; 98 = max.)( 2)
       1          $ NTYPEH= control integer (1 or 3) for nodal point spacing
       4          $ NHVALU= number of callouts for nodal point spacing
       1          $ IHVALU(I)= Ith callout for nodal point spacing, IHVALU( 1)
      25          $ IHVALU(I)= Ith callout for nodal point spacing, IHVALU( 2)
      26          $ IHVALU(I)= Ith callout for nodal point spacing, IHVALU( 3)
      50          $ IHVALU(I)= Ith callout for nodal point spacing, IHVALU( 4)
 0.5000000        $ HVALU=meridional arc length between nodal points,HVALU( 1)
 0.5000000        $ HVALU=meridional arc length between nodal points,HVALU( 2)
  1.000000        $ HVALU=meridional arc length between nodal points,HVALU( 3)
  1.000000        $ HVALU=meridional arc length between nodal points,HVALU( 4)
     H            $ REFERENCE SURFACE GEOMETRY FOLLOWS...
       1          $ NSHAPE= indicator (1,2 or 4) for geometry of meridian
      20          $ R1     = radius at beginning of segment (see p. 66)
      20          $ Z1     = global axial coordinate at beginning of segment
      20          $ R2     = radius at end of segment
      40          $ Z2     = global axial coordinate at end of segment
     H            $ IMPERFECTION SHAPE FOLLOWS...
       0          $ IMP   = indicator for imperfection (0=none, 1=some)
     H            $ REFERENCE SURFACE LOCATION RELATIVE TO WALL
       1          $ NTYPEZ= control (1 or 3) for reference surface location
       5          $ NZVALU= number of meridional callouts for ref. surf.
       2          $ NTYPE = control for meaning of callout (2=z, 3=r)
      20          $ Z(I)  = axial coordinate of Ith callout, z( 1)
      22          $ Z(I)  = axial coordinate of Ith callout, z( 2)
      25          $ Z(I)  = axial coordinate of Ith callout, z( 3)
      30          $ Z(I)  = axial coordinate of Ith callout, z( 4)
      40          $ Z(I)  = axial coordinate of Ith callout, z( 5)
  1.000000        $ ZVAL  = distance from leftmost surf. to ref. surf.,ZVAL( 1)
  1.100000        $ ZVAL  = distance from leftmost surf. to ref. surf.,ZVAL( 2)
  1.200000        $ ZVAL  = distance from leftmost surf. to ref. surf.,ZVAL( 3)
  1.250000        $ ZVAL  = distance from leftmost surf. to ref. surf.,ZVAL( 4)
  1.250000        $ ZVAL  = distance from leftmost surf. to ref. surf.,ZVAL( 5)
     N            $ Do you want to print out r(s), r'(s), etc. for this segment?
     H            $ DISCRETE RING INPUT FOLLOWS...
       0          $ NRINGS= number (max=20) of discrete rings in this segment
       0          $ K=elastic foundation modulus (e.g. lb/in**3)in this seg.
     H            $ LINE LOAD INPUT FOLLOWS...
       0          $ LINTYP= indicator (0, 1, 2 or 3) for type of line loads
     H            $ DISTRIBUTED LOAD INPUT FOLLOWS...
       1          $ IDISAB= indicator (0, 1, 2 or 3) for load set A and B
     H            $ SURFACE LOAD INPUT FOR LOAD SET "A" FOLLOWS
       1          $ NLTYPE=control (0,1,2,3) for type of surface loading
       2          $ NPSTAT= number of meridional callouts for surface loading
       0          $ NLOAD(1)=indicator for meridional traction (0=none, 1=some)
       0          $ NLOAD(2)=indicator for circumferential traction
       1          $ NLOAD(3)=indicator for normal pressure     (0=none, 1=some)
 -1.000000        $ PN(i)    = normal pressure (p.74) at ith callout, PN( 1)
 -1.000000        $ PN(i)    = normal pressure (p.74) at ith callout, PN( 2)
       2          $ NTYPE = control for meaning of loading callout (2=z, 3=r)
      20          $ Z(I)  = axial coordinate of Ith loading callout, z( 1)
      40          $ Z(I)  = axial coordinate of Ith loading callout, z( 2)
     H            $ SHELL WALL CONSTRUCTION FOLLOWS...
       2          $ NWALL=index (1, 2, 4, 5, 6, 7, 8, 9, 10) for wall construction
0.1600000E+08 $ E      = Young's modulus for skin
0.2500000     $ U      = Poisson's ratio for skin
0.4144000E-03 $ SM =mass density of skin (e.g. alum.=.00025 lb-sec**2/in**4)
       0          $ ALPHA = coefficient of thermal expansion
       0          $ NRS  = control (0 or 1) for addition of smeared stiffeners
      -1          $ NSUR   = control for thickness input (0 or 1 or -1)
       1          $ NTYPET= index (1 or 3) for type of input for thickness
       5          $ NTVALU= number of callouts along segment for thickness
       2          $ NTYPE = control for meaning of thickness callout (2=z, 3=r)
      20          $ Z(I)  = axial coordinate of Ith thickness callout, z( 1)
      22          $ Z(I)  = axial coordinate of Ith thickness callout, z( 2)
      25          $ Z(I)  = axial coordinate of Ith thickness callout, z( 3)
```

Varying nodal point spacing in Seg. 2

middle surface variation in Seg. 2

thickness varies in Seg. 2

Table 16 (p. 3 of 3)

```
   30       $ Z(I)  = axial coordinate of Ith thickness callout, z( 4)
   40       $ Z(I)  = axial coordinate of Ith thickness callout, z( 5)
 2.000000   $ TVAL(i) = thickness at Ith callout, TVAL( 1)
 2.200000   $ TVAL(i) = thickness at Ith callout, TVAL( 2)
 2.400000   $ TVAL(i) = thickness at Ith callout, TVAL( 3)
 2.500000   $ TVAL(i) = thickness at Ith callout, TVAL( 4)
 2.500000   $ TVAL(i) = thickness at Ith callout, TVAL( 5)
   N        $ Do you want to print out ref. surf. location and thickness?
   N        $ Do you want to print out the C(i,j) at meridional stations?
   N        $ Do you want to print out distributed loads along meridian?
   H        $
   H        $ GLOBAL DATA BEGINS...
    1       $ NLAST = plot options  (-1=none, 0=geometry, 1=u,v,w)
   N        $ Are there any regions for which you want expanded plots?
    0       $ P      = pressure or surface traction multiplier
  15000     $ DP     = pressure or surface traction multiplier increment
    0       $ TEMP   = temperature rise multiplier
    0       $ DTEMP  = temperature rise multiplier increment
    2       $ Number of load steps
    0       $ OMEGA  = angular vel. about axis of revolution (rad/sec)
    0       $ DOMEGA = angular velocity increment (rad/sec)
   H        $ CONSTRAINT CONDITIONS FOLLOW....
    2       $ How many segments in the structure?
   H        $
   H        $ CONSTRAINT CONDITIONS FOR SEGMENT NO.    1    1    1    1
   H        $ POLES INPUT FOLLOWS...
    1       $ Number of poles (places where r=0) in SEGMENT( 1)
    1       $ IPOLE = nodal point number of pole, IPOLE( 1)
   H        $ INPUT FOR CONSTRAINTS TO GROUND FOLLOWS...
    0       $ At how many stations is this segment constrained to ground?
   H        $ JUNCTION CONDITION INPUT FOLLOWS...
   N        $ Is this segment joined to any lower-numbered segments?
   H        $
   H        $ CONSTRAINT CONDITIONS FOR SEGMENT NO.    2    2    2    2
   H        $ POLES INPUT FOLLOWS...
    0       $ Number of poles (places where r=0) in SEGMENT( 2)
   H        $ INPUT FOR CONSTRAINTS TO GROUND FOLLOWS...
    1       $ At how many stations is this segment constrained to ground?
   51       $ INODE = nodal point number of constraint to ground, INODE( 1)
    1       $ IUSTAR=axial displacement constraint (0 or 1 or 2)
    0       $ IVSTAR=circumferential displacement(0=free,1=0,2=imposed)
    0       $ IWSTAR=radial displacement(0=free,1=constrained,2=imposed)
    1       $ ICHI=meridional rotation (0=free,1=constrained,2=imposed)
    0       $ D1     = radial component of offset of ground support
    0       $ D2     = axial component of offset of ground support
   Y        $ Is this constraint the same for both prebuckling and buckling?
   H        $ JUNCTION CONDITION INPUT FOLLOWS...
   Y        $ Is this segment joined to any lower-numbered segments?
    1       $ At how may stations is this segment joined to previous segs.?
    1       $ INODE = node in current segment (ISEG) of junction, INODE( 1)
    1       $ JSEG  = segment no. of lowest segment involved in junction
   91       $ JNODE = node in lowest segmnt (JSEG) of junction
    1       $ IUSTAR= axial displacement (0=not slaved, 1=slaved)
    1       $ IVSTAR= circumferential displacement (0=not slaved, 1=slaved)
    1       $ IWSTAR= radial displacement (0=not slaved, 1=slaved)
    1       $ ICHI  = meridional rotation (0=not slaved, 1=slaved)
    0       $ D1    = radial component of juncture gap
    0       $ D2    = axial component of juncture gap
   Y        $ Is this constraint the same for both prebuckling and buckling?
   H        $ RIGID BODY CONSTRAINT INPUT FOLLOWS...
   Y        $ Given existing constraints, are rigid body modes possible?
   Y        $ Do you wish to prevent rigid body motion?
    2       $ ISEG  = segment no. at which to prevent rigid body motion
   51       $ INODE = node no. at which to prevent rigid body motion
    1       $ IUSTAR= axial n=0 rigid body constraint (0=none, 1=some)
    1       $ IVSTAR= circ. n=0 rigid body constraint (usually equals 1)
    0       $ IWSTAR= radial n=0 rigid body constraint (usually equals 0)
    1       $ ICHI  = meridional rot. rigid body constraint
    1       $ IUSTAR= axial n=1 rigid body constraint (usually equals 1)
    1       $ IVSTAR= circ. n=1 rigid body constraint (usually equals 1)
    0       $ IWSTAR= radial n=1 rigid body constraint (usually equals 0)
    1       $ ICHI  = meridional rot. rigid body constraint
   H        $ "GLOBAL3" QUESTIONS (AT END OF CASE)...
   Y        $ Do you want to list output for segment( 1)
   Y        $ Do you want to list output for segment( 2)
   Y        $ Do you want to list forces in the discrete rings, if any?
```

Thickness varies in Seg. 2

end of doer8.ALL

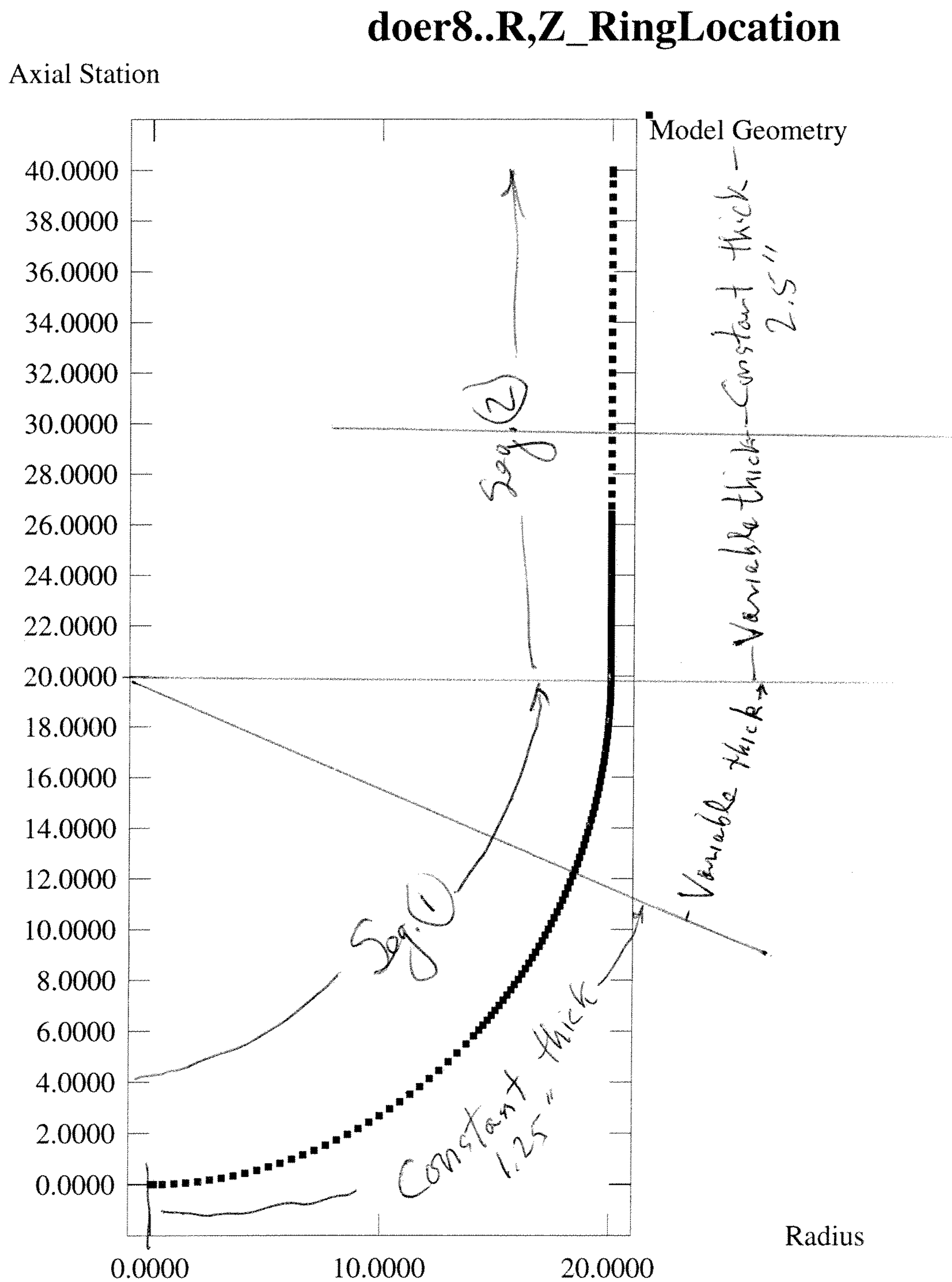

doer8..R,Z_RingLocation
Axial Station
Model Geometry
40.0000
38.0000
36.0000
34.0000
32.0000
30.0000
28.0000
26.0000
24.0000
22.0000
20.0000
18.0000
16.0000
14.0000
12.0000
10.0000
8.0000
6.0000
4.0000
2.0000
0.0000
0.0000
10.0000
20.0000
Radius
Seg. 2
Seg. 1
Constant thick 1.25"
Variable thick
Variable thick
Constant thick 2.5"

Fig 16

54

doer8..STRESS_LOADSTEP_2

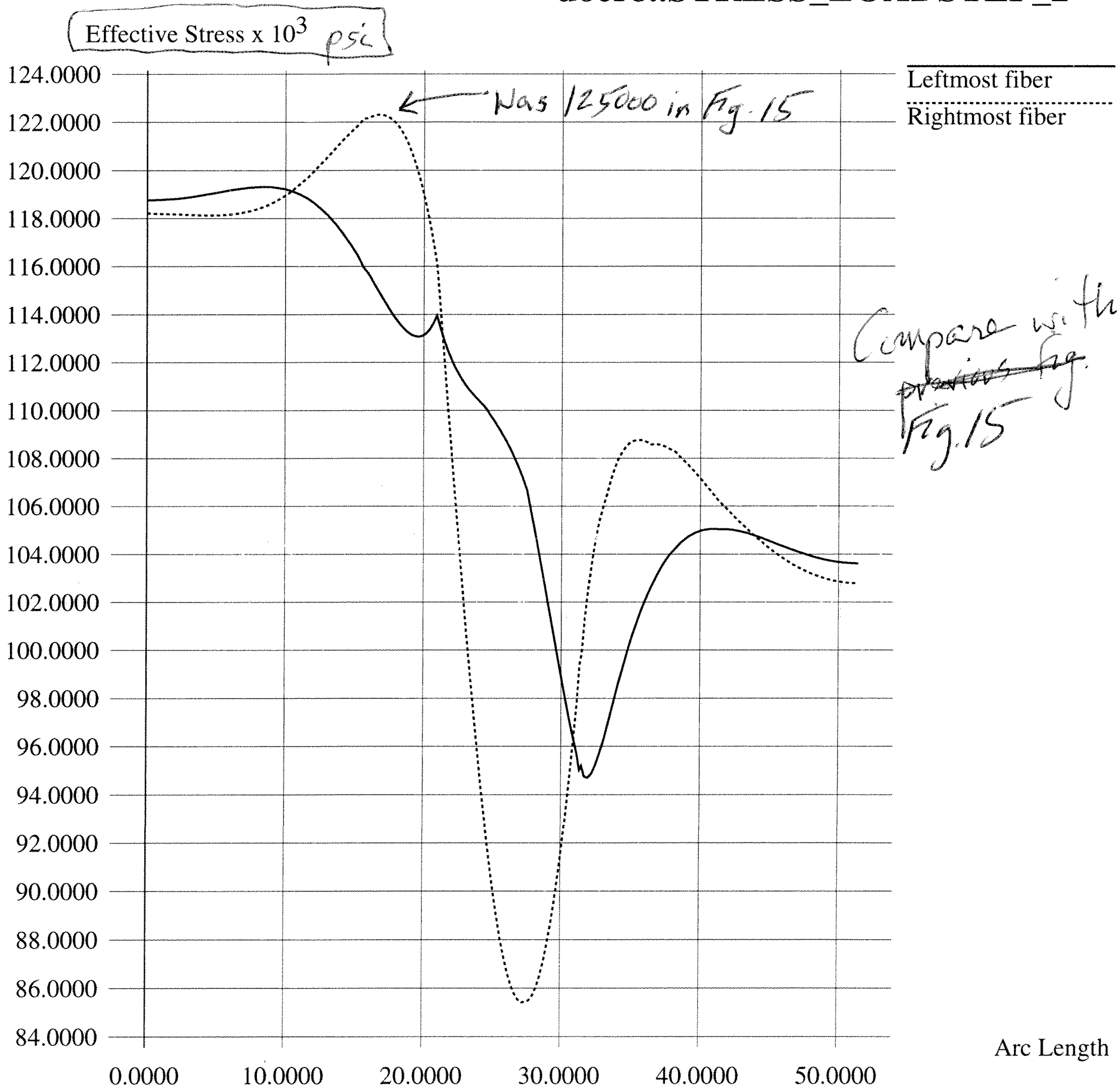


Fig. 17

input to BIGBOSOR4 [Table 17 (4 pp.)] [door9.ALL]

```
spherical plus cylindrical shell, variable wall in segs 1 and 2, INDIC=0
        1        $ INDIC = analysis type indicator
        1        $ NPRT = output options (1=minimum, 2=medium, 3=maximum)
        1        $ ISTRES= output control (0=resultants, 1=sigma, 2=epsilon)
        2        $ NSEG  = number of shell segments (less than 295)
     H           $
     H           $ SEGMENT NUMBER    1    1    1    1    1    1    1    1
     H           $ NODAL POINT DISTRIBUTION FOLLOWS...
       91        $ NMESH = number of node points (5 = min.; 98 = max.)( 1)
        1        $ NTYPEH= control integer (1 or 3) for nodal point spacing
        4        $ NHVALU= number of callouts for nodal point spacing
        1        $ IHVALU(I)= Ith callout for nodal point spacing, IHVALU( 1)
       30        $ IHVALU(I)= Ith callout for nodal point spacing, IHVALU( 2)
       31        $ IHVALU(I)= Ith callout for nodal point spacing, IHVALU( 3)
       90        $ IHVALU(I)= Ith callout for nodal point spacing, IHVALU( 4)
  1.000000       $ HVALU=meridional arc length between nodal points,HVALU( 1)
  1.000000       $ HVALU=meridional arc length between nodal points,HVALU( 2)
 0.5000000       $ HVALU=meridional arc length between nodal points,HVALU( 3)
 0.5000000       $ HVALU=meridional arc length between nodal points,HVALU( 4)
     H           $ REFERENCE SURFACE GEOMETRY FOLLOWS...
        2        $ NSHAPE= indicator (1,2 or 4) for geometry of meridian
        0        $ R1      = radius at beginning of segment (see p. 66)
        0        $ Z1      = global axial coordinate at beginning of segment
       20        $ R2      = radius at end of segment
       20        $ Z2      = global axial coordinate at end of segment
        0        $ RC      = radius from axis of rev. to center of curvature
       20        $ ZC      = axial coordinate of center of curvature
 -1.000000       $ SROT=indicator for direction of increasing arc (-1. or +1.)
     H           $ IMPERFECTION SHAPE FOLLOWS...
        0        $ IMP    = indicator for imperfection (0=none, 1=some)
     H           $ REFERENCE SURFACE LOCATION RELATIVE TO WALL
        1        $ NTYPEZ= control (1 or 3) for reference surface location
        5        $ NZVALU= number of meridional callouts for ref. surf.
        2        $ NTYPE = control for meaning of callout (2=z, 3=r)
  0.000000       $ Z(I)  = axial coordinate of Ith callout, z( 1)
       10        $ Z(I)  = axial coordinate of Ith callout, z( 2)
       13        $ Z(I)  = axial coordinate of Ith callout, z( 3)
       16        $ Z(I)  = axial coordinate of Ith callout, z( 4)
       20        $ Z(I)  = axial coordinate of Ith callout, z( 5)
 0.6250000       $ ZVAL  = distance from leftmost surf. to ref. surf.,ZVAL( 1)
 0.6250000       $ ZVAL  = distance from leftmost surf. to ref. surf.,ZVAL( 2)
 0.7250000       $ ZVAL  = distance from leftmost surf. to ref. surf.,ZVAL( 3)
 0.8250000       $ ZVAL  = distance from leftmost surf. to ref. surf.,ZVAL( 4)
  1.000000       $ ZVAL  = distance from leftmost surf. to ref. surf.,ZVAL( 5)
     N           $ Do you want to print out r(s), r'(s), etc. for this segment?
     H           $ DISCRETE RING INPUT FOLLOWS...
        0        $ NRINGS= number (max=20) of discrete rings in this segment
        0        $ K=elastic foundation modulus (e.g. lb/in**3)in this seg.
     H           $ LINE LOAD INPUT FOLLOWS...
        0        $ LINTYP= indicator (0, 1, 2 or 3) for type of line loads
     H           $ DISTRIBUTED LOAD INPUT FOLLOWS...
        1        $ IDISAB= indicator (0, 1, 2 or 3) for load set A and B
     H           $ SURFACE LOAD INPUT FOR LOAD SET "A" FOLLOWS
        1        $ NLTYPE=control (0,1,2,3) for type of surface loading
        2        $ NPSTAT= number of meridional callouts for surface loading
        0        $ NLOAD(1)=indicator for meridional traction (0=none, 1=some)
        0        $ NLOAD(2)=indicator for circumferential traction
        1        $ NLOAD(3)=indicator for normal pressure     (0=none, 1=some)
       -1        $ PN(i)    = normal pressure (p.74) at ith callout, PN( 1)
       -1        $ PN(i)    = normal pressure (p.74) at ith callout, PN( 2)
        2        $ NTYPE = control for meaning of loading callout (2=z, 3=r)
        0        $ Z(I)  = axial coordinate of Ith loading callout, z( 1)
       20        $ Z(I)  = axial coordinate of Ith loading callout, z( 2)
     H           $ SHELL WALL CONSTRUCTION FOLLOWS...
        2        $ NWALL=index (1, 2, 4, 5, 6, 7, 8, 9, 10) for wall construction
 0.1600000E+08   $ E      = Young's modulus for skin
 0.2500000       $ U      = Poisson's ratio for skin
 0.4144000E-03   $ SM =mass density of skin (e.g. alum.=.00025 lb-sec**2/in**4)
        0        $ ALPHA = coefficient of thermal expansion
        0        $ NRS  = control (0 or 1) for addition of smeared stiffeners
       -1        $ NSUR   = control for thickness input (0 or 1 or -1)
        1        $ NTYPET= index (1 or 3) for type of input for thickness
        5        $ NTVALU= number of callouts along segment for thickness
        2        $ NTYPE = control for meaning of thickness callout (2=z, 3=r)
        0        $ Z(I)  = axial coordinate of Ith thickness callout, z( 1)
       10        $ Z(I)  = axial coordinate of Ith thickness callout, z( 2)
       13        $ Z(I)  = axial coordinate of Ith thickness callout, z( 3)
       16        $ Z(I)  = axial coordinate of Ith thickness callout, z( 4)
```

Table 17 (p. 244)

```
       20        $ Z(I)  = axial coordinate of Ith thickness callout, z( 5)
  1.250000       $ TVAL(i) = thickness at Ith callout, TVAL( 1)
  1.250000       $ TVAL(i) = thickness at Ith callout, TVAL( 2)
  1.450000       $ TVAL(i) = thickness at Ith callout, TVAL( 3)
  1.650000       $ TVAL(i) = thickness at Ith callout, TVAL( 4)
  2.000000       $ TVAL(i) = thickness at Ith callout, TVAL( 5)
     N           $ Do you want to print out ref. surf. location and thickness?
     N           $ Do you want to print out the C(i,j) at meridional stations?
     N           $ Do you want to print out distributed loads along meridian?
     H           $
     H           $ SEGMENT NUMBER    2    2    2    2    2    2    2    2
     H           $ NODAL POINT DISTRIBUTION FOLLOWS...
       51        $ NMESH = number of node points (5 = min.; 98 = max.)( 2)
        1        $ NTYPEH= control integer (1 or 3) for nodal point spacing
        4        $ NHVALU= number of callouts for nodal point spacing
        1        $ IHVALU(I)= Ith callout for nodal point spacing, IHVALU( 1)
       25        $ IHVALU(I)= Ith callout for nodal point spacing, IHVALU( 2)
       26        $ IHVALU(I)= Ith callout for nodal point spacing, IHVALU( 3)
       50        $ IHVALU(I)= Ith callout for nodal point spacing, IHVALU( 4)
 0.5000000       $ HVALU=meridional arc length between nodal points,HVALU( 1)
 0.5000000       $ HVALU=meridional arc length between nodal points,HVALU( 2)
  1.000000       $ HVALU=meridional arc length between nodal points,HVALU( 3)
  1.000000       $ HVALU=meridional arc length between nodal points,HVALU( 4)
     H           $ REFERENCE SURFACE GEOMETRY FOLLOWS...
        1        $ NSHAPE= indicator (1,2 or 4) for geometry of meridian
       20        $ R1     = radius at beginning of segment (see p. 66)
       20        $ Z1     = global axial coordinate at beginning of segment
       20        $ R2     = radius at end of segment
       40        $ Z2     = global axial coordinate at end of segment
     H           $ IMPERFECTION SHAPE FOLLOWS...
        0        $ IMP   = indicator for imperfection (0=none, 1=some)
     H           $ REFERENCE SURFACE LOCATION RELATIVE TO WALL
        1        $ NTYPEZ= control (1 or 3) for reference surface location
        5        $ NZVALU= number of meridional callouts for ref. surf.
        2        $ NTYPE = control for meaning of callout (2=z, 3=r)
       20        $ Z(I)  = axial coordinate of Ith callout, z( 1)
       22        $ Z(I)  = axial coordinate of Ith callout, z( 2)
       25        $ Z(I)  = axial coordinate of Ith callout, z( 3)
       30        $ Z(I)  = axial coordinate of Ith callout, z( 4)
       40        $ Z(I)  = axial coordinate of Ith callout, z( 5)
  1.000000       $ ZVAL  = distance from leftmost surf. to ref. surf.,ZVAL( 1)
  1.100000       $ ZVAL  = distance from leftmost surf. to ref. surf.,ZVAL( 2)
  1.200000       $ ZVAL  = distance from leftmost surf. to ref. surf.,ZVAL( 3)
  1.250000       $ ZVAL  = distance from leftmost surf. to ref. surf.,ZVAL( 4)
  1.250000       $ ZVAL  = distance from leftmost surf. to ref. surf.,ZVAL( 5)
     N           $ Do you want to print out r(s), r'(s), etc. for this segment?
     H           $ DISCRETE RING INPUT FOLLOWS...
        0        $ NRINGS= number (max=20) of discrete rings in this segment
        0        $ K=elastic foundation modulus (e.g. lb/in**3)in this seg.
     H           $ LINE LOAD INPUT FOLLOWS...
        0        $ LINTYP= indicator (0, 1, 2 or 3) for type of line loads
     H           $ DISTRIBUTED LOAD INPUT FOLLOWS...
        1        $ IDISAB= indicator (0, 1, 2 or 3) for load set A and B
     H           $ SURFACE LOAD INPUT FOR LOAD SET "A" FOLLOWS
        1        $ NLTYPE=control (0,1,2,3) for type of surface loading
        2        $ NPSTAT= number of meridional callouts for surface loading
        0        $ NLOAD(1)=indicator for meridional traction (0=none, 1=some)
        0        $ NLOAD(2)=indicator for circumferential traction
        1        $ NLOAD(3)=indicator for normal pressure     (0=none, 1=some)
 -1.000000       $ PN(i)    = normal pressure (p.74) at ith callout, PN( 1)
 -1.000000       $ PN(i)    = normal pressure (p.74) at ith callout, PN( 2)
        2        $ NTYPE = control for meaning of loading callout (2=z, 3=r)
       20        $ Z(I)  = axial coordinate of Ith loading callout, z( 1)
       40        $ Z(I)  = axial coordinate of Ith loading callout, z( 2)
     H           $ SHELL WALL CONSTRUCTION FOLLOWS...
        2        $ NWALL=index (1, 2, 4, 5, 6, 7, 8, 9, 10) for wall construction
0.1600000E+08    $ E      = Young's modulus for skin
0.2500000        $ U      = Poisson's ratio for skin
0.4144000E-03    $ SM =mass density of skin (e.g. alum.=.00025 lb-sec**2/in**4)
        0        $ ALPHA = coefficient of thermal expansion
        0        $ NRS  = control (0 or 1) for addition of smeared stiffeners
       -1        $ NSUR   = control for thickness input (0 or 1 or -1)
        1        $ NTYPET= index (1 or 3) for type of input for thickness
        5        $ NTVALU= number of callouts along segment for thickness
        2        $ NTYPE = control for meaning of thickness callout (2=z, 3=r)
       20        $ Z(I)  = axial coordinate of Ith thickness callout, z( 1)
       22        $ Z(I)  = axial coordinate of Ith thickness callout, z( 2)
       25        $ Z(I)  = axial coordinate of Ith thickness callout, z( 3)
```

Table 17 (p. 3 of 4)

```
      30        $ Z(I)  = axial coordinate of Ith thickness callout, z( 4)
      40        $ Z(I)  = axial coordinate of Ith thickness callout, z( 5)
2.000000        $ TVAL(i) = thickness at Ith callout, TVAL( 1)
2.200000        $ TVAL(i) = thickness at Ith callout, TVAL( 2)
2.400000        $ TVAL(i) = thickness at Ith callout, TVAL( 3)
2.500000        $ TVAL(i) = thickness at Ith callout, TVAL( 4)
2.500000        $ TVAL(i) = thickness at Ith callout, TVAL( 5)
   N            $ Do you want to print out ref. surf. location and thickness?
   N            $ Do you want to print out the C(i,j) at meridional stations?
   N            $ Do you want to print out distributed loads along meridian?
   H            $
   H            $ GLOBAL DATA BEGINS...
      1         $ NLAST = plot options  (-1=none, 0=geometry, 1=u,v,w)
   N            $ Are there any regions for which you want expanded plots?
      0         $ N0B   = starting number of circ. waves (buckling analysis)
      0         $ NMINB = minimum number of circ. waves  (buckling analysis)
     20         $ NMAXB = maximum number of circ. waves  (buckling analysis)
      1         $ INCRB = increment in number of circ. waves (buckling)
      1         $ NVEC  = number of eigenvalues for each wave number
      0         $ P      = pressure or surface traction multiplier
  15000         $ DP     = pressure or surface traction multiplier increment
      0         $ TEMP   = temperature rise multiplier
      0         $ DTEMP  = temperature rise multiplier increment
      0         $ OMEGA  = angular vel. about axis of revolution (rad/sec)
      0         $ DOMEGA = angular velocity increment (rad/sec)
   H            $ CONSTRAINT CONDITIONS FOLLOW....
      2         $ How many segments in the structure?
   H            $
   H            $ CONSTRAINT CONDITIONS FOR SEGMENT NO.    1    1    1    1
   H            $ POLES INPUT FOLLOWS...
      1         $ Number of poles (places where r=0) in SEGMENT( 1)
      1         $ IPOLE = nodal point number of pole, IPOLE( 1)
   H            $ INPUT FOR CONSTRAINTS TO GROUND FOLLOWS...
      0         $ At how many stations is this segment constrained to ground?
   H            $ JUNCTION CONDITION INPUT FOLLOWS...
   N            $ Is this segment joined to any lower-numbered segments?
   H            $
   H            $ CONSTRAINT CONDITIONS FOR SEGMENT NO.    2    2    2    2
   H            $ POLES INPUT FOLLOWS...
      0         $ Number of poles (places where r=0) in SEGMENT( 2)
   H            $ INPUT FOR CONSTRAINTS TO GROUND FOLLOWS...
      1         $ At how many stations is this segment constrained to ground?
     51         $ INODE = nodal point number of constraint to ground, INODE( 1)
      1         $ IUSTAR=axial displacement constraint (0 or 1 or 2)
      0         $ IVSTAR=circumferential displacement(0=free,1=0,2=imposed)
      0         $ IWSTAR=radial displacement(0=free,1=constrained,2=imposed)
      1         $ ICHI=meridional rotation (0=free,1=constrained,2=imposed)
      0         $ D1    = radial component of offset of ground support
      0         $ D2    = axial component of offset of ground support
   Y            $ Is this constraint the same for both prebuckling and buckling?
   H            $ JUNCTION CONDITION INPUT FOLLOWS...
   Y            $ Is this segment joined to any lower-numbered segments?
      1         $ At how may stations is this segment joined to previous segs.?
      1         $ INODE = node in current segment (ISEG) of junction, INODE( 1)
      1         $ JSEG  = segment no. of lowest segment involved in junction
     91         $ JNODE = node in lowest segmnt (JSEG) of junction
      1         $ IUSTAR= axial displacement (0=not slaved, 1=slaved)
      1         $ IVSTAR= circumferential displacement (0=not slaved, 1=slaved)
      1         $ IWSTAR= radial displacement (0=not slaved, 1=slaved)
      1         $ ICHI  = meridional rotation (0=not slaved, 1=slaved)
      0         $ D1    = radial component of juncture gap
      0         $ D2    = axial component of juncture gap
   Y            $ Is this constraint the same for both prebuckling and buckling?
   H            $ RIGID BODY CONSTRAINT INPUT FOLLOWS...
   Y            $ Given existing constraints, are rigid body modes possible?
   Y            $ Do you wish to prevent rigid body motion?
      2         $ ISEG  = segment no. at which to prevent rigid body motion
     51         $ INODE = node no. at which to prevent rigid body motion
      1         $ IUSTAR= axial n=0 rigid body constraint (0=none, 1=some)
      1         $ IVSTAR= circ. n=0 rigid body constraint (usually equals 1)
      0         $ IWSTAR= radial n=0 rigid body constraint (usually equals 0)
      1         $ ICHI  = meridional rot. rigid body constraint
      1         $ IUSTAR= axial n=1 rigid body constraint (usually equals 1)
      1         $ IVSTAR= circ. n=1 rigid body constraint (usually equals 1)
      0         $ IWSTAR= radial n=1 rigid body constraint (usually equals 0)
      1         $ ICHI  = meridional rot. rigid body constraint
   H            $ "GLOBAL3" QUESTIONS (AT END OF CASE)...
   Y            $ Do you want to list output for segment( 1)
```

Table 17 (p. 4 of 4)

```
    Y          $ Do you want to list output for segment( 2)
    Y          $ Do you want to list forces in the discrete rings, if any?
```

end of daer9.ALL

Table 18

```
doer9.OUT (abridged)
Buckling with variable nodal point spacing
and variable reference surface location and
variable thickness in both Segments 1 and 2.

Search for the string, "EIGENVALUE(" to find
the following output in the doer9.OUT file:

 **** CRITICAL EIGENVALUE AND WAVENUMBER ****
 EIGCRT=  1.8899E+00; NO. OF CIRC. WAVES, NWVCRT=    3
 ****************************************************

 ***** EIGENVALUES AND MODE SHAPES *****
  EIGENVALUE(CIRC. WAVES)
 =======================================
    5.1205E+00(   0)
    5.0877E+00(   1)
    2.3005E+00(   2)
    1.8899E+00(   3) <--critical buckling eigenvalue & mode,
    2.9291E+00(   4)
    4.4128E+00(   5)
    5.6031E+00(   6)
    6.1813E+00(   7)
    7.0168E+00(   8)
    8.0821E+00(   9)
    9.3511E+00(  10)
    1.0805E+01(  11)
    1.2430E+01(  12)
    1.4217E+01(  13)
    1.6159E+01(  14)
    1.8253E+01(  15)
    2.0493E+01(  16)
    2.2879E+01(  17)
    2.5408E+01(  18)
    2.8077E+01(  19)
    3.0887E+01(  20)
 =======================================
```

See next fig.

Variable thickness in
both segs. 1 & 2

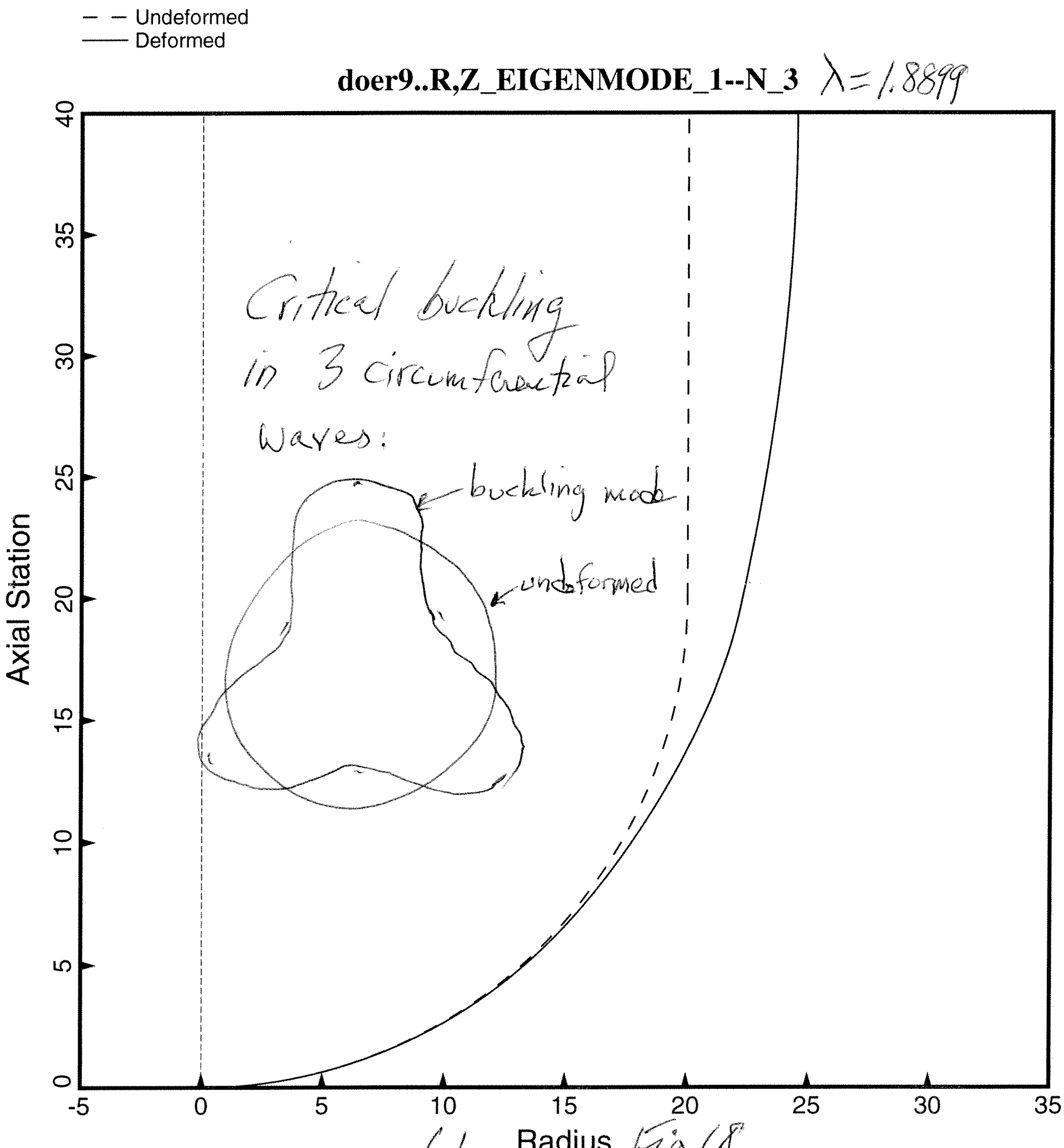


 Fig 18