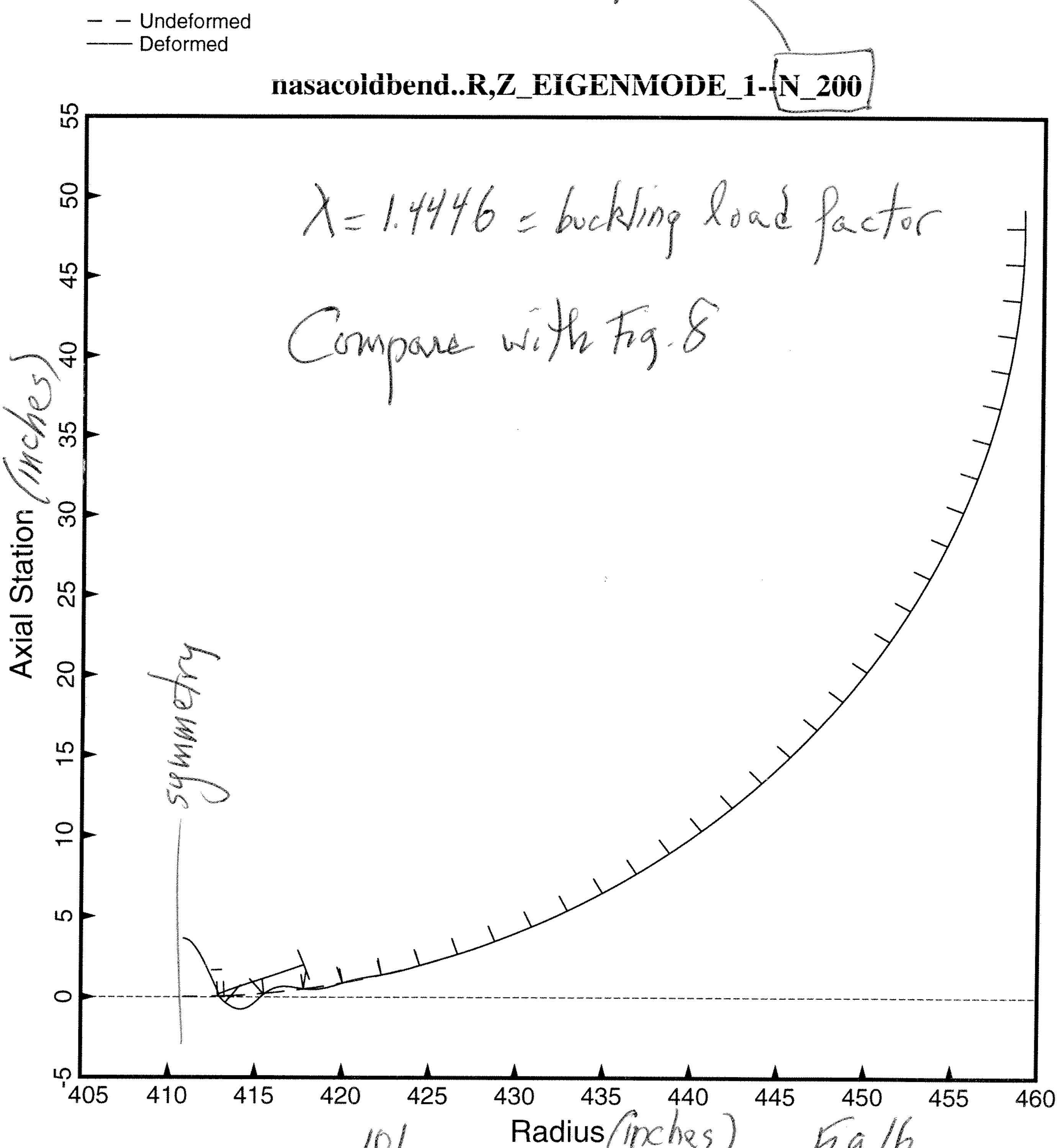
inter-ring buckling

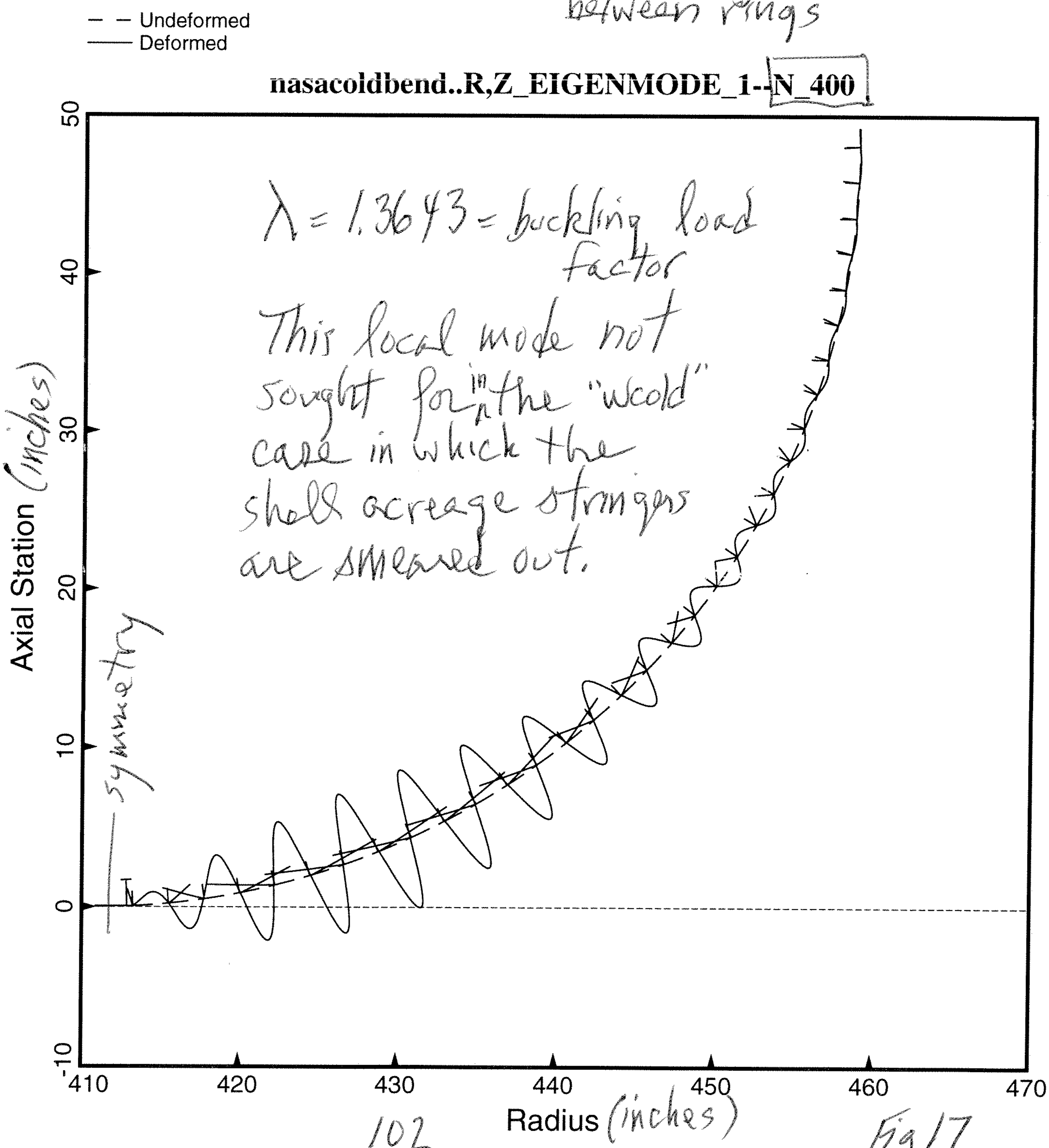
2 axial half waves between rings



101

Fig. 16

inter-ring buckling
4 axial halfwaves
between rings



102

Fig. 17

inter-ring buckling

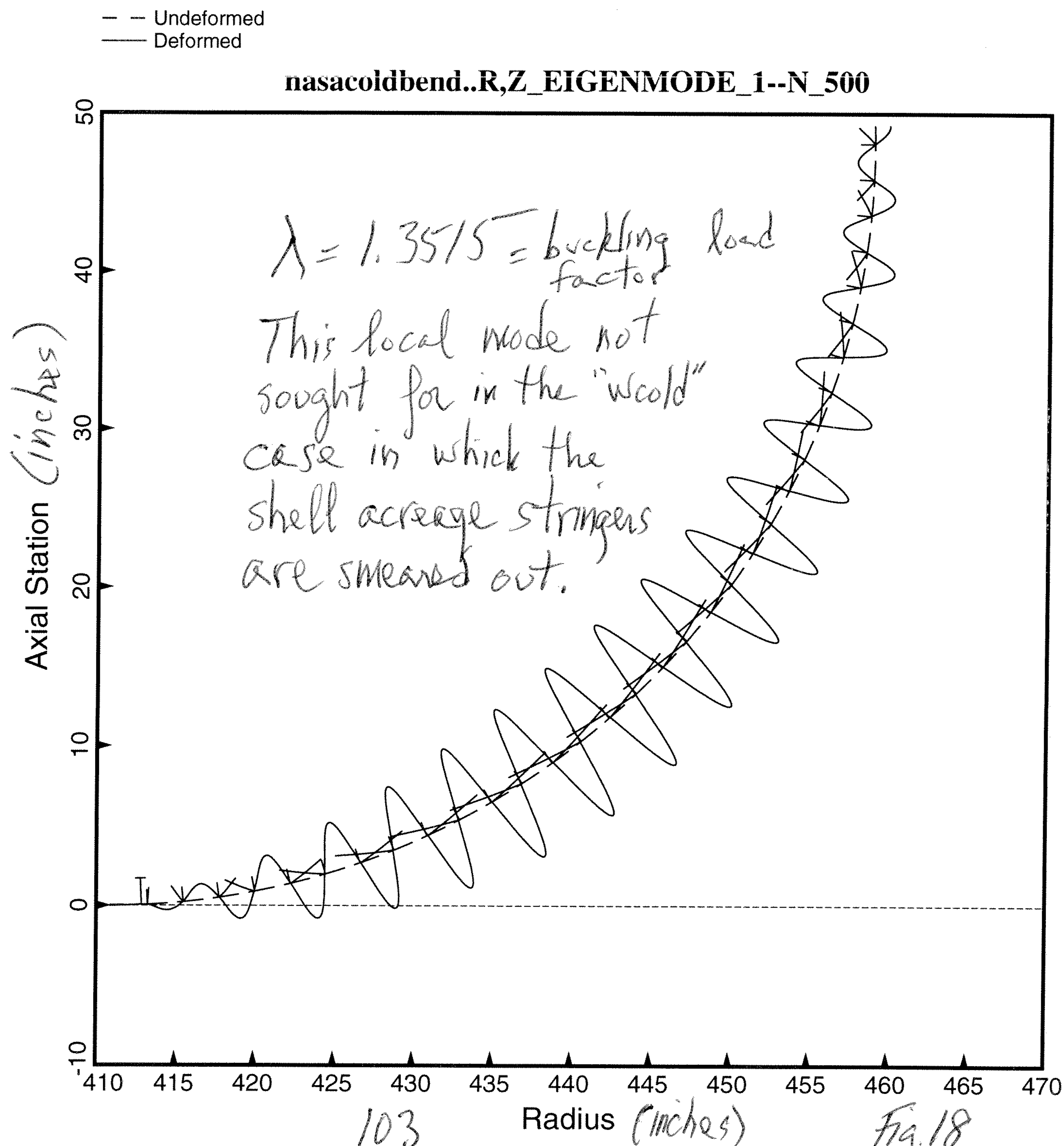


Fig. 18

APPENDIX I

results from the case,
"nasacoldbend"

&

the cold-bending theory
(no weld lands)

20 April, 2009

Table ~~E~~ a1

The case, "nasacoldbend", is the same as the case called "nasaortho" except that design constraints have been introduced into PANDA2 to account for possible buckling of internal rings and internal sub-rings during the cold-bending fabrication process. These new constraints generate a heavier optimum design than for the case, "nasaortho", which was run before the new cold-bending ring buckling constraints existed. Please see Item No. 790 in the file, ...panda2/doc/panda2.news, for details.

most of it included here in Table a2.

With the new cold-bending ring buckling constraints the optimized design has much stockier rings, as one would expect.

...panda2/case/nasacoldbend.readme

Table a2 (33 pages)

FROM THE FILE, ..panda2/doc/panda2.news...
(NOTE: For the complete list of these panda2.news items see the file, ...panda2/doc/panda2.news. Also see the file, ...panda2/case/nasacoldbend/coldbending.pdf

790. April, 2009 (from ..panda2/doc/panda2.news)

THE INTRODUCTION OF COLD-BENDING RING BUCKLING MARGINS INTO PANDA2

This is an important news item. Often cylindrical shells are fabricated by cold bending a flat plate or sheet into a cylindrical form. NASA fabricates some light-weight stiffened cylindrical shells with use of the following steps:

1. A regular array of "pockets" is "hogged out" of a rather thick flat plate. The "hogged out" flat plate is then a "stiffened" flat plate, with the stiffeners (stringers and rings) being the thicker material between the "pockets".

2. The "hogged out" plate is then cold bent into a cylindrical shell, or rather into a part of a cylindrical shell, say a panel subtending 120 degrees or something like that. The cold-bending is applied usually with the stiffeners on the inside. In this process the plate is bent into a radius, call it "RCOLD", which is smaller than the design radius, call it "RCYL". Upon elastic spring-back the final radius should be close to RCYL.

3. An annealing process is applied to the cold-bent cylindrical panel.

4. A number of cylindrical panels fabricated in this way are welded together to form a complete (360-degree) cylindrical shell.

This news item is concerned with Step 2. The question arises, "How can the designer determine the best "slenderness" (height-to-thickness ratio) of the rings, which experience potentially destabilizing hoop compression during the cold-bending process?" The designer wants the rings to be thick enough so that they do not buckle during the cold-bending process, but not so thick as to represent an unnecessary weight penalty. This question does not arise in the case of the stringers because they do not bend during the cold bending process.

In order to provide an answer to this question, three new design margins have been introduced into PANDA2 in Load Set 1, Subcase 1, In the list of margins presented for Load Set 1, Subcase 1 the three new margins (for an optimized shell without internal sub-rings) appear as follows:

```
17  6.59E-01 Cold-bending ring buckling, closed form soln; N=154;FS=1.1
18  6.41E-01 Cold-bending ring buckling, "skin"-ring module; N=92 ;FS=1.1
19  1.43E-03 Cold-bending ring buckling, skin-ring module; N=61 ;FS=1.1
```

If there are internal sub-rings, then there is an additional cold-bending buckling margin of the form:

```
31 -2.46E-04 Cold-bending subring buckling, closed form soln; N=102;FS=1.1
```

The first of the three margins listed above (Margin 17) is derived from a "closed form" analysis in which it is assumed that the skin plays no role in the buckling. A polynomial expression in assumed for the distribution of normal deflection of the internal ring web. This polynomial has three undetermined coefficients. An eigenvalue problem of rank 3 is set up and solved for the three real eigenvalues, the lowest positive one of which is the critical ring web buckling load factor. These computations are carried out in SUBROUTINE COLDBD, which is called from SUBROUTINE STRUCT.

The new SUBROUTINE COLDBD first computes iteratively what the cold-bending radius, RCOLD, is, that is, the radius, RCOLD, such that after elastic spring-back the final radius is close to the nominal (design) radius, RCYL, of the fabricated cylindrical shell.

Next, SUBROUTINE COLDBD computes the effective wall stiffnesses (the 6 x 6 integrated constitutive matrices, Cij) of the skin, ring web, and ring outstanding flange (if any) to be used in the various buckling analyses leading to the three new margins listed above.

The second of the three margins listed above is derived from a discretized single-module "skin"-ring module of the type described in the paper, "Additional buckling solutions in PANDA2", AIAA Paper AIAA-99-1233, 40th AIAA Structures Meeting, 1999, pp. 302-345; (See pp. 318 - 321 and Fig. 30). The word, "skin", is in quotes because "skin" represents the skin plus smeared stringers (and smeared substiffeners, if any). The prebuckling distribution of stress resultants over the "skin" ring module is derived in the new SUBROUTINE COLDBD. Also, the elastic-plastic integrated 6 x 6 constitutive matrices Cij (called CXCOLD and CYCOLD) for the "skin"-ring module segments ("skin", ring web, ring outstanding flange) are computed in SUBROUTINE COLDBD. The critical elastic-plastic cold-bending buckling load factor is obtained over a range of circumferential wave numbers in search of the critical (lowest) eigenvalue (buckling load factor).

The third of the three margins listed above is derived from the same type of model as the second. In this case the stringers are eliminated. Therefore, the buckling model is a discretized skin-ring single module model with smeared sub-stiffeners, if any. The word, skin, is not in quotes because in this model the shell skin without any smeared stiffeners forms the first part of the discretized module. This margin is usually the most critical of the three. Buckling load factors from this third model are more accurate than the first model, the "closed-form" model, because the deformation of the panel skin in the cold-bending buckling mode is accounted for, whereas in the "closed-form" model the skin is assumed to remain underformed during buckling. The third model is more conservative than the second model because the stringers are neglected (sub-stiffeners are smeared). The third model is appropriate, however, because the critical circumferential wavelength of the cold-bending buckling mode is restricted to be less than or equal to the spacing between the stringers.

The cold-bending buckling analysis is entered only if the PANDA2 user chooses that he or she wants to provide input data for a stress-strain "curve" for Material Type 1 . The nonlinear stress-strain curve is used ONLY in the cold-bending ring buckling analysis. All the other buckling and stress margins computed by PANDA2 are still based on elastic material behavior.

The prompting file, .../execute/PROMPT.DAT, was modified as follows:

```
----------------------------------------------------------------
238.1 Want to supply a stress-strain "curve" for this mat'l (H)?
238.2
      Please use elastic properties only unless you want to
      simulate the cold-bending fabrication process. (See Item
      No. 790 in the file, ...panda2/doc/panda2.news).

      The stress-strain curve is used ONLY in the analysis of
      cold-bending. (See Item No. 790 in ...panda2/doc/panda2.news).
      PANDA2 does not account for plasticity or nonlinear stress-
      strain curves in its ordinary buckling and stress analyses,
      even if you choose to provide a stress-strain curve here..

      The stress-strain curve is used ONLY for generating a buckling
      constraint condition for buckling of an INTERNAL Tee-shaped or
      rectangular ring during the cold-bending of a flat plate with
      "hogged out" pockets that form stiffeners into a cylindrical
      panel.

      If you want to simulate the cold-bending process:

      1. The entire structure must be fabricated from the same
         isotropic material. (You can supply more than one
         material type in the PANDA2 model, but all material types
         must have the same isotropic elastic properties.)

      2. If in the PANDA2 model you plan to introduce more than
         one material type (in order to identify what the maximum
         stresses are in the various parts of the shell structure)
         the stress-strain curve must be supplied ONLY FOR THE
```

FIRST MATERIAL TYPE in the PANDA2 model, that is, for material index no. 1 . All other material types must correspond to elastic, isotropic materials with the same elastic properties as those of material type 1 .

NOTE: The stress-strain curve is assumed to be the same for both tension and compression.

239.0

The stress-strain curve is used ONLY in the analysis of cold-bending. (See Item No. 790 in ...panda2/doc/panda2.news). PANDA2 does not account for plasticity or nonlinear stress-strain curves in its ordinary buckling and stress analyses. The stress-strain curve is used ONLY for generating a buckling constraint condition for buckling of an INTERNAL Tee-shaped or rectangular ring during the cold-bending of a flat plate with "hogged out" pockets that form stiffeners into a cylindrical panel.

If you want to simulate the cold-bending process:

1. The entire structure must be fabricated from the same isotropic material. (You can supply more than one material type in the PANDA2 model, but all material types must have the same isotropic elastic properties.)

2. If in the PANDA2 model you plan to introduce more than one material type (in order to identify what the maximum stresses are in the various parts of the shell structure) the stress-strain curve must be supplied ONLY FOR THE FIRST MATERIAL TYPE in the PANDA2 model, that is, for material index no. 1 . All other material types must correspond to elastic, isotropic materials with the same elastic properties as those of material type 1 .

NOTE: The stress-strain curve is assumed to be the same for both tension and compression.

Next, supply a table of (strain, stress) values, starting with (0., 0.). Maximum of 20 (strain, stress) pairs permitted.

240.1 strain coordinate for stress-strain "curve", strain
240.2

NOTE: the first strain entry must be zero.
NOTE: the second strain entry (the first non-zero entry) must have the value: strain(2) = stress(proportional limit)/E.

241.1 stress coordinate for stress-strain "curve", stress
241.2

NOTE: the first stress entry must be zero.
NOTE: the second stress entry (the first non-zero entry) must have the value: stress(2) = stress(proportional limit).

242.1 any more (strain, stress) pairs (Y or N)?

(lines skipped to save space)

270.1 Does cold bending include the outstanding ring flange?
270.2

If there are no outstanding ring flanges, answer "N". If the final fabricated panel or shell has rings with outstanding flanges, then read on.

The cylindrical shell may be cold bent before outstanding flanges are welded on to the tips of the ring webs, or the outstanding ring flanges may be present during the cold bending process. If only the ring webs exist when the cold bending process takes place, then the analysis of buckling during the cold-bending process will be undertaken with the assumption that the flanges are made of very, very soft material and experience no prebuckling compression at all.

271.1 ring web radial compression, FN1WEB
271.2

When the flat plate with "hogged out" pockets is formed into a cylindrical panel by cold bending, there may, during the cold-bending process, occur a compressive radial resultant,

Table a2 (p.4 of 33)

FN1WEB, generated. FN1WEB (units=force/length) is the maximum radial compression in a ring web during the cold-bending process.

It is best for now to use zero: FN1WEB = 0.

An example of the input file for BEGIN appropriate for a case in which cold-bending will be simulated follows (*.BEG file):

```
-----------------------------------------------------------------
      n          $ Do you want a tutorial session and tutorial output?
  68.75000       $ Panel length normal to the plane of the screen, L1
  150.7960       $ Panel length in the plane of the screen, L2
      r          $ Identify type of stiffener along L1 (N,T,J,Z,R,A,C,G)
  4.000000       $ stiffener spacing, b
  1.333000       $ width of stringer base, b2 (must be > 0, see Help)
 0.3000000       $ height of stiffener (type H for sketch), h
      n          $ Are the stringers cocured with the skin?
  1000000.       $ What force/(axial length) will cause web peel-off?
      n          $ Is the next group of layers to be a "default group" (12 layers!)?
         1       $ number of layers in the next group in Segment no.( 1)
      n          $ Can winding (layup) angles ever be decision variables?
         1       $ layer index (1,2,...), for layer no.( 1)
      y          $ Is this a new layer type?
 0.1000000       $ thickness for layer index no.( 1)
         0       $ winding angle (deg.) for layer index no.( 1)
         1       $ material index (1,2,...) for layer index no.( 1)
      n          $ Any more layers or groups of layers in Segment no.( 1)
      n          $ Is the next group of layers to be a "default group" (12 layers!)?
         1       $ number of layers in the next group in Segment no.( 2)
      n          $ Can winding (layup) angles ever be decision variables?
         1       $ layer index (1,2,...), for layer no.( 1)
      n          $ Is this a new layer type?
      n          $ Any more layers or groups of layers in Segment no.( 2)
      n          $ Is the next group of layers to be a "default group" (12 layers!)?
         1       $ number of layers in the next group in Segment no.( 3)
      n          $ Can winding (layup) angles ever be decision variables?
         2       $ layer index (1,2,...), for layer no.( 1)
      y          $ Is this a new layer type?
 0.1000000       $ thickness for layer index no.( 2)
         0       $ winding angle (deg.) for layer index no.( 2)
         2       $ material index (1,2,...) for layer index no.( 2)
      n          $ Any more layers or groups of layers in Segment no.( 3)
         1       $ choose external (0) or internal (1) stringers
      r          $ Identify type of stiffener along L2  (N, T, J, Z, R, A)
  4.000000       $ stiffener spacing, b
         0       $ width of ring base, b2 (zero is allowed)
 0.3000000       $ height of stiffener (type H for sketch), h
      n          $ Are the rings cocured with the skin?
      n          $ Is the next group of layers to be a "default group" (12 layers!)?
         1       $ number of layers in the next group in Segment no.( 3)
      n          $ Can winding (layup) angles ever be decision variables?
         3       $ layer index (1,2,...), for layer no.( 1)
      y          $ Is this a new layer type?
 0.1000000       $ thickness for layer index no.( 3)
         0       $ winding angle (deg.) for layer index no.( 3)
         3       $ material index (1,2,...) for layer index no.( 3)
      n          $ Any more layers or groups of layers in Segment no.( 3)
         1       $ choose external (0) or internal (1) rings
      y          $ Is the panel curved in the plane of the screen (Y for cyls.)?
  48.00000       $ Radius of curvature (cyl. rad.) in the plane of screen, R
      n          $ Is panel curved normal to plane of screen? (answer N)
      y          $ Is this material isotropic (Y or N)?
 0.1100000E+08 $ Young's modulus,                  E( 1)
 0.3000000       $ Poisson's ratio,                NU( 1)
  4230769        $ transverse shear modulus,      G13( 1)
         0       $ Thermal expansion coeff.,    ALPHA( 1)
         0       $ residual stress temperature (positive),TEMPTUR( 1)
      y          $ Want to supply a stress-strain "curve" for this mat'l (H)?---
  0.000000       $ strain coordinate for stress-strain "curve", strain( 1)     N
  0.000000       $ stress coordinate for stress-strain "curve", stress( 1)     E
      y          $ any more (strain, stress) pairs (Y or N)?                   W
 0.6363600E-02 $ strain coordinate for stress-strain "curve", strain( 2)
  70000.00       $ stress coordinate for stress-strain "curve", stress( 2)     I
      y          $ any more (strain, stress) pairs (Y or N)?                   N
 0.1272730E-01 $ strain coordinate for stress-strain "curve", strain( 3)     P
  100000.0       $ stress coordinate for stress-strain "curve", stress( 3)     U
      y          $ any more (strain, stress) pairs (Y or N)?                   T
```

Table a2 (p.5 of 33)

```
  0.1909090E-01 $ strain coordinate for stress-strain "curve", strain( 4)
   110000.0     $ stress coordinate for stress-strain "curve", stress( 4)     D
      n         $ any more (strain, stress) pairs (Y or N)?                   A
      n         $ Does cold bending include the outstanding ring flange?( 1)  T
   0.000000     $ ring web radial compression, FN1WEB( 1) -------------------A
      y         $ Want to specify  maximum effective stress ?
   70000.00     $ Maximum allowable effective stress in material type( 1)
      n         $ Do you want to take advantage of "bending overshoot"?
  0.9500000E-01 $ weight density (greater than 0!) of material type( 1)
      n         $ Is lamina cracking permitted along fibers (type H(elp))?
      y         $ Is this material isotropic (Y or N)?
  0.1100000E+08 $ Young's modulus,                  E( 2)
  0.3000000     $ Poisson's ratio,                 NU( 2)
   4230769.     $ transverse shear modulus,       G13( 2)
         0      $ Thermal expansion coeff.,     ALPHA( 2)
         0      $ residual stress temperature (positive),TEMPTUR( 2)
      n         $ Want to supply a stress-strain "curve" for this mat'l? (N)
      y         $ Want to specify  maximum effective stress ?
   70000.00     $ Maximum allowable effective stress in material type( 2)
      n         $ Do you want to take advantage of "bending overshoot"?
  0.9500000E-01 $ weight density (greater than 0!) of material type( 2)
      n         $ Is lamina cracking permitted along fibers (type H(elp))?
      y         $ Is this material isotropic (Y or N)?
  0.1100000E+08 $ Young's modulus,                  E( 3)
  0.3000000     $ Poisson's ratio,                 NU( 3)
   4230769.     $ transverse shear modulus,       G13( 3)
         0      $ Thermal expansion coeff.,     ALPHA( 3)
         0      $ residual stress temperature (positive),TEMPTUR( 3)
      n         $ Want to supply a stress-strain "curve" for this mat'l? (N)
      y         $ Want to specify  maximum effective stress ?
   70000.00     $ Maximum allowable effective stress in material type( 3)
      n         $ Do you want to take advantage of "bending overshoot"?
  0.9500000E-01 $ weight density (greater than 0!) of material type( 3)
      n         $ Is lamina cracking permitted along fibers (type H(elp))?
         0      $ Prebuckling: choose 0=bending included; 2=use membrane theory
         1      $ Buckling: choose 0=simple support or 1=clamping
----------------------------------------------------------------------------
```

```
****************** NOTE *************** NOTE *********************
It is by providing the stress-strain curve for Material Type 1 that
the PANDA2 user is "telling" PANDA2 to perform the various
cold-bending ring buckling analyses, if appropriate.
*******************************************************************
```

The input for DECIDE and MAINSETUP remains unchanged.

It is appropriate to conduct cold-bending ring buckling analyses only under the following conditions:

1. The entire structure must be fabricated from a single isotropic material. As described in the modified PROMPT.DAT file above, the PANDA2 user can still use multiple materials in order to generate different stress constraints corresponding to different segments of the structure, but all these materials must have the same isotropic elastic properties and only Material Type 1 has the stress-strain curve. IT IS ASSUMED THAT THE STRESS-STRAIN CURVE FOR MATERIAL TYPE 1 IS THE SAME FOR TENSION AND FOR COMPRESSION. If your material behaves differently in tension and compression, use the compression curve for input data to PANDA2.

2. The rings must be internal and must have either rectangular or Tee-shaped cross sections.

3. The base under the ring has no faying flange. In other words, the base under the ring has the same dimensions and properties as the panel skin midway between rings.

Two types of cold-bending fabrication are covered for shells with rings that have an outstanding flange:

1. The cold-bending process may occur for rings with outstanding flanges present.

2. The cold-bending process occurs before the outstanding flanges are welded to the tips of the ring webs. In this case the simulation of the cold-bending process occurs for a ring with an outstanding flange, but the elastic modulus of this flange is set equal to

Table a2 (p.6 of 33)

FMULT*EELAST, in which FMULT is a very small number and EELAST is the Young's modulus, and the prebuckling compression in the outstanding ring flange due to cold bending is set equal to zero.

The cold-bending ring buckling capability was incorporated into PANDA2 by modifying the following source libraries: arrays.src, begin.src, stoget.src, and store.src. The prompting file, ...panda2/execute/PROMPT.DAT was modified as described above.

In order to incorporate the cold-bending simulation in PANDA2 new dimension statements and labeled common blocks were added, and a rather long section of coding was added to SUBROUTINE STRUCT. This new coding follows:

```
(lines skipped to save space)

        WRITE(IFILE,'(A,/,A,/,A,/,A,/,A,/,A,/,A,/,A,/,A)')
     1 ' CHAPTER 26b Compute the ring web buckling load factor and',
     1 '            circumferential wavelength from cold-bending a',
     1 '            flat "hogged out" plate into a cylindrical panel',
     1 '            with cold-bending radius RCOLD from iterations.',
     1 '            This analysis is performed only for cylindrical',
     1 '            shells with INTERNAL rings with rectangular or',
     1 '            Tee-shaped cross sections. The entire shell must',
     1 '            be fabricated of the same isotropic material.',
     1 '            See Item No.790 in ...panda2/doc/panda2.news .'
C

(lines skipped to save space)
```

Furthermore, three new subroutines were added to the struct.src library. An abridged list of these three new subroutines follows:

```
C=DECK      COLDBD
      SUBROUTINE COLDBD(IFILE,NPRT,IMOD,ILABEL,ILOADS,ICASE,INUMTT,
     1 ICAR,PCWORD,CPLOT,IADDCC,FSAFEP,CONMAX,IPOINC,ICONST,CONSTR,
     1 WORDB,MAXCON,ITYPE,CXCOLD,CYCOLD,CY3CLD,CXCLD0,CXCLD1,
     1 CNXVAR,CNYVAR,WAVLEN,KLAYER,ISUB)
C
C234567890123456789012345678901234567890123456789012345678901234567890
C
C This subroutine is entered only if the rings are internal, have
C rectangular or Tee-shaped cross section, and if a stress-strain
C curve has been provided for material type 1 . If the fabricated
C shell has Tee-shaped rings but the outstanding flange was welded
C on after the cold-bending process, then the outstanding flange is
C present in the model but it's stiffness is reduced by a very
C small factor, FMULT, and its prebuckling compression is zero.
C
C PURPOSE IS TO CONSTRUCT A CONSTRAINT CONDITION FOR
C BUCKLING OF AN INTERNAL RING WITH A RECTANGULAR OR TEE-SHAPED
C CROSS SECTION UNDER THE COLD-BENDING PROCESS.
C NOTE: No faying flange (ring base of width B2(RNG) thicker than
C       the panel skin) is accounted for in this model.
C
C Input data:
C   IFILE  = write out to file, IFILE
C   NPRT   = index for printing verbosity
C   IMOD   = 0 for current design; 1 for perturbed design
C   ILABEL = statement label in SUBROUTINE STRUCT where
C            SUBROUTINE COLDBD is called.
C   ILOADS = load set number
C   ICASE  = load subcase number (1 or 2)
C   FSAFEP = factors of safety associated with design constraints
C   ITYPE  = 1 for optimization, 2 for analysis of "fixed" design
C   SIM, EIM = coordinates of the material stress-strain curve
C   RCOLD  = minimum radius of curvature in the cold-bending process
C   FN1WEB = stress resultant in the ring web in the x-direction
C            (FN1WEB = 0 should probably be used as of this writing).
C   FLGCLD = 0.0 = outstanding flange not included in the cold
C                  bending process
C            1.0 = outstanding flange is included in the cold
C                  bending process
C   B      = ring spacing
C   H      = ring web height
C   WFLANG = width of outstanding ring flange
```

Table a2 (p.7 of 33)

```
C   TSKIN  = thickness of shell skin
C   TWEB   = thickness of ring web
C   TFLANG = thickness of ring flange
C   EELAST = elastic modulus
C   KLAYER = 1 there are substiffeners
C            0 there are no substiffeners
C
C Important data:
C   BUCKLE = load factor for buckling of the ring under cold bending.
C   WAVLEN = wavelength of the critical buckling mode, hoop direction
C
C Output data:
C   INUMTT,ICAR,PCWORD,CPLOT,IADDCC,CONMAX,IPOINC,ICONST,CONSTR,
C   WORDB,MAXCON  = quantities related to the design constraint
C                   from the "closed-form" solution.
C   CXCOLD(i,j,5) = integrated constitutive matrices for the
C                   cold-bent state for the skin-stringer module for
C                   CXCOLD(i,j,1) = skin with smeared substiffeners
C                   CXCOLD(i,j,2) = skin + stringer faying flange
C                                   + smeared substiffeners
C                   CXCOLD(i,j,3) = stringer web
C                   CXCOLD(i,j,4) = stringer outstanding flange
C                   CXCOLD(i,j,5) = skin with smeared major stringers
C                                   and smeared substiffeners
C
C   CYCOLD(i,j,5) = integrated constitutive matrices for the
C                   cold-bent state for the "skin"-ring module for
C                   CYCOLD(i,j,1) = skin with smeared substiffeners
C                   CYCOLD(i,j,2) = CYCOLD(i,j,1) (no ring fay-flange)
C                   CYCOLD(i,j,3) = ring web
C                   CYCOLD(i,j,4) = ring outstanding flange
C                   CYCOLD(i,j,5) = skin with smeared major rings
C                                   and smeared substiffeners.
C
C   CY3CLD(i,j,k) = integrated constitutive matrices for the
C                   cold-bent state for the ring web at k points
C                   along the web from root to tip, including the
C                   ring web root and the ring web tip.
C
C   CXCLD0(i,j,5) = same as CXCOLD(i,j,5) except that CXCLD0(i,j,1)
C                   and CXCLD0(i,j,5) are for the panel skin alone,
C                   no stringers and no substringers or subrings.
C
C   CXCLD1(i,j,5) = same as CXCLD1(i,j,1)
C
C   CNXVAR(i,j)   = meridional resultant for nodal point i, segment j
C                   in the "skin"-ring module
C   CNYVAR(i,j)   = hoop resultant for nodal point i, segment j
C                   in the "skin"-ring module
C
C23456789012345678901234567890123456789012345678901234567890123456789012
C
C First, we must find the prebuckled state. Then we can
C determine the stability stiffness and load-geometric matrices.
C
C We assume here that the stringers have no effect on the
C process, since they do not bend under the cold-bending process.
C Also, we assume that the height, H, of the web is small compared
C to the radius, RCOLD.
C
C We use a skin-ring module as our geometry. This module has
C three parts:
C Part 1 =shell skin of axial length equal to the ring spacing b
C Part 2 =internal ring web of height h
C Part 3 =outstanding flange of the ring of width w.
C NOTE: It is assumed here that there is no thickened ring base.
C
C The geometry is:
C
C                                                t(skin)
C                                               | | | |
C               The T-ring is INTERNAL          | | | |
C                                               | | | |
C   t(flange)                                   | | | |
C |  | | |                                      | | | |
C |  | | |                                      | | | |
C |  | | |                                      | | | |
```

Table a2 (p. 8 of 33)

```
C |   | |                                       | |  | |
C |   | |        t(web)--\                      | |  | |
C |   | |                |                      | |  | |
C |   --|-----------------------------------------|--  | |
C w   |- - - - - - - - - - - - - - - - - - x<-------|--   b
C |   --|-----------------------------------------|--  | |
C |   | |                ^                      | |  | |
C |   | |                                       | |  | |
C |   |<----------------h------------------->  | |  | |
C |   | |                                       | |  | |
C |   | |                                       | |  | |
C |   | |                        |<-----d-----|--  | |
C |   | |                                       | |  | |
C                                               | |  | |
C                                               | |  | |
C                                               | |  | |
C                                               | |  | |
C
C Cold bending puts the flange of width w in hoop compresion.
C
C
C PREBUCKLING BEHAVIOR
C
C It is assumed that the elastic-plastic material is
C isotropic and has the same stress-strain curve in
C tension and compression.
C
C The theory used in this subroutine is taken from the paper,
C
C Bushnell, David, "Theoretical basis of the panda computer
C program for preliminary design of stiffened panels under combined
C in-plane loads", Computers & Structures, Vol. 27, No. 4,
C pp. 541-563, 1987.
C
C For example, Eqs.(1-3) below are Eqs.(33,34) on p. 550 of that
C paper. The formulas for the instantaneous stiffnesses used here
C are Eqs.(42-45) on p. 551 of that paper.
C
C This subroutine is based on J2 deformation theory. As of this
C writing, we assume that the stress generated during the cold-
C bending process is uniaxial: only hoop stress exists. Therefore,
C we assume that the stress at any point in the skin-ring module
C cross section is given by E x (hoop strain), in which E is
C
C the hoop plastic modulus:
C
C  E = E22;       E22 = a/del;       del = a**2 - b**2      (1)
C
C in which
C
C  a =(1 + 2g/3)/E(elastic);     b = -(nu +g/3)/E(elastic)  (2)
C
C and
C
C  g = 1.5*(E(elastic)/Es - 1).    (Es = the secant modulus) (3)
C
C The hoop strain, call it e, is assumed to vary linearly over
C the skin-ring module from the middle surface of the internal
C ring flange to the middle surface of the shell skin. For
C simplicity, it is assumed that the hoop strain is uniform in
C the ring flange and in the shell skin and equal to the values
C at the middle surfaces of those parts. The hoop strain is
C uniform over the thickness of the ring web but varies linearly
C over the height of the ring web.
C
C As the flat, hogged out plate is bent into a cylindrical form
C the neutral axis for circumferential bending, located the
C distance "d" from the skin middle surface as indicated
C in the sketch above, shifts as plastic flow occurs
C over growing portions of the skin-ring module cross
C section with increasing circumferential bending. Therefore,
C even though we are using deformation theory, we must simulate
C the cold-bending process incrementally. Iterations will be
C needed for each bending increment because we do not know at the
C start of increment i exactly where the neutral axis is for that
C increment. For the first iteration at cold-bending increment i
C we assume that the neutral axis is at the same location as it was
C at the end of increment i - 1. That assumption yields an initial
```

```
C estimate of the distribution of plastic modulus over the
C skin-ring cross section. From this initial estimate we compute
C a new location d of the neutral axis. That new value of d leads
C to a new and better estimate of the distribution of plastic
C modulus, etc. Iterations continue until d no longer changes
C a significant amount from that obtained in the previous
C iteration.
C
C The location, d,  of the neutral axis is computed from:
C
C d = {E(flange)*A(flange)*[h+t(skin)/2] +t(web)*int[E(web)xdx]}/
C     {E(skin)*A(skin) +E(flange)A(flange) +t(web)*int[E(web)dx]}   (4)
C
C in which d = distance from the shell skin middle surface to
c the location of the neutral axis for circumferential bending.
C E(flange), E(web), and E(skin) are the plastic moduli of the
C flange, web, and shell skin, respectively. A(flange) and
C A(skin) are the areas of the flange and skin cross sections, that
C is, A(flange) = t(flange)*w(flange) and A(skin) = t(skin)*b(ring),
C in which w(flange) is the width of the flange, b(ring) is the
C spacing between adjacent rings, and t(flange) and t(skin) are
C the flange and skin thicknesses, respectively. "int[ ]" means
C "integral", and the radial coordinate, x, is measured from
C the shell skin middle surface and increases radially inward,
C as is shown in the sketch above.
C
C Simpson's rule is used to perform the integrations.
C
C Once we have this new estimate of the location of the neutral
C axis, we can compute the distribution of incremental hoop strain
C from the ith cold-bending increment. At each location in the
C skin-ring module cross section the total hoop strain is given
C by the sum of the total strain from the previous converged cold-
C bending increment plus the incremental strain. From the new hoop
C strains we know where we are on the uniaxial stress-strain
C curve and therefore we can compute new values for the plastic
C moduli, E(flange), E(web), and E(skin), From Eqs. (1 - 3).
C
C The total hoop strain for the ith cold-bending increment is
C given by:
C         e(total)(i) = e(total)(i-1) -(x-d)*kappa(i)      (5)
C in which
C         kappa(i) = 1/R(i) - 1/R(i-1)                     (6)
C
C where R(i) is the known radius of curvature at the neutral axis
C at the ith cold-bending increment and R(i-1) is the known radius
C of curvature at the neutral axis at the (i-1)st cold-bending
C increment. We use e(total)(i) to obtain the stress, sigma, from
C the known stress-strain curve. The secant modulus, Es, which
C appears in Eq.(3), is simply given by
C
C         Es = sigma/ABS[e(total)(i)]                      (7)
C
C Given Es we compute g in Eq.(3). Then we compute the plastic
C modulus E from Eq.(1) and (2). We have a value of E for every
C value of x. The value of the plastic modulus E corresponding
C to the flange is E[x = h+t(skin)/2]. The value of the plastic
C modulus E corresponding to the skin is E(x=0).
C
C We keep iterating at the ith cold-bending increment until the
C position of the neutral axis d no longer changes. Then we go
C to the next cold-bending increment. We keep adding cold-bending
C increments until we reach Ro, the smallest radius of curvature
C used in the cold-bending process. Note that this radius may be
C significantly smaller than R, the design radius of the
C cylindrical shell attained after springback from the smaller
C radius, Ro.
C
C We have the stress-strain "curve" as a table of (stress,strain)
C pairs. It is assumed that these tabular points are connected
C by straight line segments.
C
C We compute the properties at NX points along the x-axis from
C x = 0 to x = h + t(skin)/2.
C
C We start with the assumption that the location of d is given
C by the value obtained assuming that no plastic flow has occurred.
C Assuming that the same material is used for the entire structure,
```

Table a2 (p.10 of 33)

```
C we have, from Eq.(4):
C
C  d(elastic) = {A(flange)*[h+t(skin)/2] + A(web)*[h+t(skin)]/2}/
C               {A(skin) + A(web) + A(flange)}                    (5)
C
C The minimum radius to which the originally flat, "hogged out",
C plate is bent, called "RCOLD" here, is determined iteratively.
C We keep iterating until the radius after elastic spring-back is
C within 5 per cent of the design radius, RCYL. RCYL is the input
C datum that the PANDA2 user gives in response to the prompt,
C
C  Radius of curvature (cyl. rad.) in the plane of screen, R
C
C Once RCOLD has been determined all the elastic-plastic stiffnesses,
C E11, E12, E22, G12 and the 6 x 6 matrices of integrated constitutive
C coefficients, CXCOLD(i,j,k), CYCOLD(i,j,k), CY3CLD(i,j,ix), and
C CXCLD0(i,j,k), and the prebuckling elastic-plastic stress resultants,
C CNXVAR(i,k) and CNYVAR(i,k) can be determined. These quantities are
C defined above. They are to be used in the discretized "skin"-ring
C single module model and in the discretized skin-ring single module
C model, for which critical buckling load factors are determined later
C in SUBROUTINE STRUCT.
C
C At this point in the calculations, the "closed-form" buckling solution
C can be obtained. The critical buckling load factor from this model is
C called "BUCKLE" and the circumferential wavelength of the critical
C buckling mode is called "WAVLEN". The length, WAVLEN, is used later
C to determine the circumferential length of the discretized "skin"-ring
C and skin-ring module models.
C
C Notice that sometimes we refer to the "skin"-ring module model and
C other times we refer to the skin-ring module model. The two models
C are topologically identical. "skin" means "skin+smeared stringers".
C The string, skin, without the quotes means "panel skin without
C smeared stiffeners".
C
  (lines skipped to save space)

C
      IF (NPRT.GE.0) WRITE(IFILE,'(/,A,/,A,/,A)')
     1'*** BEGIN SUBROUTINE COLDBD (COLD-BENDING RING BUCKLING) ****',
     1' See Item No. 790 of the file, ...panda2/doc/panda2.news',
     1' Buckling from COLDBD ("closed-form" solution) is Model no. 1'
C
      IF (RCOLD.GT.10.E+16) THEN
         WRITE(IFILE,'(A,/,A,/,A,/,A,1P,E12.4)')
     1 ' SUBROUTINE COLDBD is used only if the shell is fabricated',
     1 ' by cold-bending a "hogged out" flat plate into a cylindrical',
     1 ' panel. In that case the cold-bending radius, RCOLD, must be',
     1 ' less than 10.E+16. Your value of RCOLD=',RCOLD
         CALL ERREX
      ENDIF
C
  (lines skipped to save space)

      DIFF = ABS(EAXIAL - EINPUT)/EAXIAL
      IF (DIFF.GT.0.01) THEN
         WRITE(IFILE,'(A,/,A,/,A,1P,2E12.4,/,A)')
     1 ' You are allowed to simulate cold bending only for an',
     1 ' isotropic material. In your case E1 is not equal to E2.',
     1 ' In your case: E1, E2 =', E1,E2,
     1 ' Please correct your input data.'
         CALL ERREX
      ENDIF
C
      EELAST = SIM(2)/EIM(2)
      DIFF = ABS(EINPUT - EELAST)/EINPUT
      IF (DIFF.GT.0.01) THEN
         WRITE(IFILE,'(A,/,A,/,A,1P,2E12.4,/,A)')
     1 ' The second point on your stress-strain curve does not',
     1 ' match your elastic modulus, EINPUT, for this material:',
     1 ' EINPUT, SIM(2)/EIM(2) =',EINPUT,SIM(2)/EIM(2),
     1 ' Please correct either EINPUT or the stress-strain curve.'
C234567890123456789012345678901234567890123456789012345678901234567890 12
         CALL ERREX
      ENDIF
C
      FNU    = FFNU(M)
```

```
C
      GINPUT = EINPUT/(2.*(1.+FNU))
      DIFF = ABS(GELAST - GINPUT)/EAXIAL
      IF (DIFF.GT.0.01) THEN
         WRITE(IFILE,'(A,/,A,/,A,1P,3E12.4,/,A)')
     1 ' You are allowed to simulate cold bending only for an',
     1 ' isotropic material. In your case the shear modulus, G,',
     1 ' is not equal to E2/[2.(1+nu)]. Your G,E2,nu=',G,E2,FNU,
     1 ' Please correct your input data.'
         CALL ERREX
      ENDIF
C
      NLAY = NLAYER(3,2)
      IF (NLAY.GT.1) THEN
         WRITE(IFILE,'(A,I2')
     1 ' Only one layer is allowed in the web. NLAY=',NLAY
         CALL ERREX
      ENDIF
      K = LTYPE(1,3,2)
      M = MATL(1)
      EWEB = E2(M)
      DIFF = ABS(EINPUT - EWEB)/EINPUT
      IF (DIFF.GT.0.01) THEN
         WRITE(IFILE,'(A,/,A,/,A,1P,2E12.4,/,A)')
     1 ' The elastic modulus of the ring web must be the same as that',
     1 ' for the panel skin in order to simulate cold-bending.',
     1 ' In your case the moduli for skin and web are:',
     1 ' EINPUT,EWEB=',EINPUT,EWEB,
     1 ' Please correct your input data.'
         CALL ERREX
      ENDIF
C23456789012345678901234567890123456789012345678901234567890123456789012
C     TWEB = TT(K)
      TWEB = TY(3)
C     WRITE(IFILE,'(A,/,2I6,1P,4E12.4)')
C    1' NSS,K,TWEB,E1(M),E2(M),GGG(M)=',NSS,K,TWEB,E1(M),E2(M),GGG(M)
C
      TFLANG = 0.
      IF (ISTIF(2).EQ.1.AND.FLGCLD.GT.0.1) THEN
       NLAY = NLAYER(4,2)
       IF (NLAY.GT.1) THEN
         WRITE(IFILE,'(A,I2')
     1 ' Only one layer is allowed in the outstanding flange.NLAY=',NLAY
         CALL ERREX
       ENDIF
       K = LTYPE(1,4,2)
       M = MATL(1)
       EFLANG = E2(M)
       DIFF = ABS(EINPUT - EFLANG)/EINPUT
       IF (DIFF.GT.0.01) THEN
         WRITE(IFILE,'(A,/,A,/,A,1P,2E12.4,/,A)')
     1 ' The elastic modulus of the ring flange must be the same as',
     1 ' that for the panel skin in order to simulate cold-bending.',
     1 ' In your case the moduli for skin and flange are:',
     1 ' EINPUT,EFLANG=',EINPUT,EFLANG,
     1 ' Please correct your input data.'
         CALL ERREX
       ENDIF
C      TFLANG = TT(K)
       TFLANG = TY(4)
C      WRITE(IFILE,'(A,/,2I6,1P,4E12.4)')
C    1' K,M,TFLANG,E1(M),E2(M),GGG(M)=',K,M,TFLANG,E1(M),E2(M),GGG(M)
      ENDIF
C
      AFLANG= WFLANG*TFLANG
      AWEB  = H*TWEB
      ASKIN = B*TSKIN
      ISUB = 0
      IF (KLAYER.GT.0.AND.ISTFSB(2).NE.0) THEN
         ASKIN =ASKIN + HSUB(2,1,1)*TSUB(2,1,1)*BSUB(2,1,1)/B
         IF (INTEXT(1).EQ.1.AND.INTXSB(2).EQ.0) ISUB = 1
         IF (INTEXT(1).EQ.0.AND.INTXSB(2).EQ.1) ISUB = 1
         IF (NPRT.EQ.2) THEN
            IF (ISUB.EQ.0) WRITE(IFILE,'(A)')
     1      ' Sub-rings are external. Hence, no cold-bending buckling.'
            IF (ISUB.NE.0) WRITE(IFILE,'(A)')
     1      ' Sub-rings are internal. Hence, yes cold-bending buckling.'
         ENDIF
```

```
C  If ISUB = 1 the sub-ring is internal.
      ENDIF
      ATOTAL = AFLANG + AWEB + ASKIN
C234567890123456789012345678901234567890123456789012345678901234567890123456789012
C DELAST = location of the reference surface for elastic material.
C
      DELAST =(AFLANG*(H+TSKIN/2.) +AWEB*(H+TSKIN+TSKIN**2/(4.*H))/2.)/
     1                                                            ATOTAL
      IF (NPRT.GE.2) WRITE(IFILE,'(A,1P,E12.4)')
     1' Location of neutral axis for elastic material, DELAST=',DELAST
      D = DELAST
      NBEND = 2
      NX = 11
C
C  NOTE: NX must be the same as the number of nodal points used
C        in the discretized "skin"-ring and skin-ring module models.
C
      DX = (H + TSKIN/2.)/FLOAT(NX - 1)
      IBACK = 0
      IF (IMOD.EQ.0) THEN
C
C  Starting value for the cold-bending radius before springback: RCOLD
C
         RCOLD = 2.*ABS(RCYL)/3.
      ELSE
C
C  RCLDSV is the converged cold-bending radius, RCOLD, for the current
C         design, that is, the design when IMOD = 0
C
         RCOLD = RCLDSV
      ENDIF
      KOUNT = 0
   15 CONTINUE
C
C  Beginning of the convergence loop for cold-bending radius,
C  RCOLD
C
      KOUNT = KOUNT + 1
      RHIST(IKOUNT) = RCOLD
      DO 20 IX = 1,NX
         ETOTL2(IX) = 0.
   20 CONTINUE
      CURTOT = 1./RCOLD
      DCURV  = CURTOT/FLOAT(NBEND - 1)
C
      DO 500 IBEND = 2,NBEND
         IF (NPRT.GE.2) WRITE(IFILE,'(/,A,I4)') ' IBEND=',IBEND
         ITER = 0
   30    CONTINUE
C
C  Beginning of the convergence loop for the location, d, of
C  the neutral axis for circumferential bending. "d" is the
C  radial distance from the panel skin middle surface to the
C  location of this neutral axis. d is D in this subroutine.
C
         ITER = ITER + 1
         X = -DX
C
C  IX is the nodal point number on the ring web middle surface.
C  in this model the ring web is assumed to extend from the
C  middle surface of the shell skin to the middle surface of
C  the ring outstanding flange.
C
         DO 200 IX = 1,NX
            X = X + DX
            ETOTAL(IX) = ETOTL2(IX) -(X-D)*DCURV
C
C  ETOTAL(IX) is the hoop strain at x = (IX-1)*DX
C  Given ETOTAL, find SIG2  (NSS = number of points in ss curve,
C                            including the origin.)
            DO 50 I = 2,NSS
               IF (ABS(ETOTAL(IX)).LT.EIM(I)) THEN
                  II = I
                  II1 = II - 1
                  GO TO 51
               ENDIF
   50       CONTINUE
   51       CONTINUE
```

Table a2 (p.13-33)

```
           SIDIFF = SIM(II) - SIM(II1)
           EIDIFF = EIM(II) - EIM(II1)
C  SIG2 is the uniaxial stress corresponding to the strain, ETOTAL(IX)
C  We obtain SIG2 from the strss-strain curve.
           SIG2 =SIM(II1) +SIDIFF*(ABS(ETOTAL(IX)) -EIM(II1))/EIDIFF
C23456789012345678901234567890123456789012345678901234567890123456789012
C  The secant modulus is ES:
           ES = SIG2/ABS(ETOTAL(IX))
           EELAST = SIM(2)/EIM(2)
C
C NOTE: The first non-zero point on your stress-strain curve MUST agree
C       with the elastic modulus of the isotropic material, that is,
C       EELAST must equal to Young's modulus, E. (called EINPUT here).
C
C The quantities, g, aa, bb, del,EPLAST, are from Eqs.(34) and (33) of
C the paper;
C Bushnell, David, "Theoretical basis of the panda computer
C program for preliminary design of stiffened panels under combined
C in-plane loads", Computers & Structures, Vol. 27, No. 4,
C pp. 541-563, 1987.
C EPLAST(IX) is the hoop plastic modulus at the IXth nodal point in the
C ring web.
           g = 1.5*(EELAST/ES - 1.0)
           aa = (1.0 + 2.*g/3.)/EELAST
           bb = (FNU +g/3.)/EELAST
           del = aa**2 - bb**2
           EPLAST(IX) = aa/del
           EPROD(IX) = EPLAST(IX)*X
C          WRITE(IFILE,'(A,I3,/,(1P,5E12.4))')
C    1 ' IX,ETOTAL(IX),ES,X,g,aa,bb,del,EPLAST(IX),EPROD(IX)=',IX,
C    1     ETOTAL(IX),ES,X,g,aa,bb,del,EPLAST(IX),EPROD(IX)
C
  200    CONTINUE
C
C  Numerical integration of int[E(web)dx]
         CALL SIMPSN(IFILE,NX,DX,EPLAST,EPINT)
C  Numerical integration of int[E(web)xdx]
         CALL SIMPSN(IFILE,NX,DX,EPROD,EPXINT)
C
C        WRITE(IFILE,'(A,I3,1P,3E12.4)')
C    1 ' NX,DX,EPINT,EPXINT=',NX,DX,EPINT,EPXINT
C
         DPAST = D
C
C  D = location of the neutral axis including plasticity.
C
         D = (EPLAST(NX)*AFLANG*(H+TSKIN/2.) +TWEB*EPXINT)/
     1        (EPLAST(1)*ASKIN +EPLAST(NX)*AFLANG +TWEB*EPINT)
         IF (NPRT.GE.2) WRITE(IFILE,'(A,I3,A,1P,E12.4)')
     1 ' Iteration=',ITER,' Location of neutral axis, d=',D
         DIFF = ABS((D - DPAST)/D)
         IF (ITER.GT.30) THEN
            WRITE(IFILE,'(A)')
     1      ' No convergence of the location d of the neutral axis.'
            CALL ERREX
         ENDIF
         IF (ITER.LT.2) GO TO 30
         IF (DIFF.GT.0.01) GO TO 30
C
C  Location, D, of the neutral axis for circumferential elastic-
C  plastic bending has converged.
C
  250    CONTINUE
         DO 300 IX = 1,NX
            ETOTL2(IX) = ETOTAL(IX)
  300    CONTINUE
  500 CONTINUE
C
C23456789012345678901234567890123456789012345678901234567890123456789012
C
C  The following "instantaneous" moduli are needed for
C  the buckling analysis:
C  E11 instantaneous modulus in the plane of the web in
C      the x-direction
C  E12 instantaneous "Poisson-type" modulus
C  E22 instantaneous modulus in the plane of the web in
C      the y-drection (circumferential direction)
C  G   in-plane shear modulus
```

Table a2 (p.14/33)

```
C
C  First, find the instantaneous moduli for the web:
C
      SIG12 = 0.
      SIG1 = FN1/TWEB
C
      DO 600 IX = 1,NX
         XCOORD(IX) = DX*FLOAT(IX - 1)
         DO 550 I = 2,NSS
            IF (ABS(ETOTAL(IX)).LT.EIM(I)) THEN
               II = I
               II1 = II - 1
               GO TO 551
            ENDIF
  550    CONTINUE
  551    CONTINUE
         SIDIFF = SIM(II) - SIM(II1)
         EIDIFF = EIM(II) - EIM(II1)
         SIG2 =SIM(II1) +SIDIFF*(ABS(ETOTAL(IX)) -EIM(II1))/EIDIFF
         ES = SIG2/ABS(ETOTAL(IX))
         ETT = SIDIFF/EIDIFF
         CALL SMOOTH(NSS,ABS(ETOTAL(IX)),II,EIM,SIM,EIM,ETT)
         ET = ETT
C
C  ET is the tangent modulus. The same "smoothing" technique for ET
C  is used here as that used in the original PANDA computer program
C  (1987 paper, "Theoretical basis..." cited above). SUBROUTINE
C  SMOOTH was taken from the PANDA software.
C
         FMULT = 1.0
         IF (ETOTAL(IX).LT.0.) FMULT = -1.0
         SIG2 = FMULT*SIG2
         SIGMA(IX) = SIG2
C
C  SIGMA(IX) is the hoop stress at nodal point IX in the ring web.
C
C  NOTE: Since the material of panel skin, ring web, and ring
C  outstanding flange is the same, and since the ring web is
C  assumed to extend from the middle surface of the panel skin
C  to the middle surface of the outstanding ring flange, the
C  stress, SIGMA(1), is the stress in the panel skin (assumed
C  to be uniform in the axial direction), and the stress, SIGMA(NX),
C  is the stress in the outstanding flange of the ring (assumed
C  to be uniform along the width of the flange). The axial
C  stress in the panel skin and ring outstanding flange is assumed to
C  remain zero during the cold-bending process. It is assumed that
C  the hoop stress does not vary through the thickness of the
C  panel skin or through the thickness of the ring outstanding flange.
C  The assumption of uniform hoop stress through the thickness of
C  the panel "skin" is a questionable assumption in the case of a
C  panel skin reinforced by sub-rings. Can one really assume that
C  the hoop stress during cold bending is uniform over the panel
C  skin as well as over the height of the sub-rings? Only for very
C  stubby sub-rings! None-the-less, that is the assumption we
C  make here.
C
C  FHOOP(IX) is the hoop resultant in the ring web at nodal point IX
C
         FHOOP(IX) = SIG2*TWEB
C  SBAR is the "effective" (VonMises) stress:
         SBAR = SQRT(SIG1*SIG1 + SIG2*SIG2 - SIG1*SIG2 + 3.*SIG12**2)
C
C The quantities, gprime, g, s1, s2, aa, bb, del, E11, E12, E22, G12,
C are from Eqs.(45), (44), (43), and (42) of the paper:
C Bushnell, David, "Theoretical basis of the panda computer
C program for preliminary design of stiffened panels under combined
C in-plane loads", Computers & Structures, Vol. 27, No. 4,
C pp. 541-563, 1987.
C These are the "instantaneous" quantities used in the stability
C equations:

         gprime = 2.25*EELAST*(1./ET - 1./ES)/SBAR**2
         g = 1.5*(EELAST/ES - 1.0)
         s1 = (2.*SIG1 -SIG2)/3.
         s2 = (2.*SIG2 -SIG1)/3.
         aa = (1.+2.*g/3. +gprime*s2**2)/EELAST
         bb = (FNU +g/3. -gprime*s1*s2)/EELAST
         cc = (1.+2.*g/3. +gprime*s1**2)/EELAST
```

```
         del= aa*cc - bb**2
         E11(IX) = aa/del
         E12(IX) = bb/del
         E22(IX) = cc/del
         G12(IX) = GELAST*(1.+FNU)/(1.+FNU +g +2.*gprime*SIG12**2)
         FMPROD(IX) = FHOOP(IX)*(D-XCOORD(IX))
  600 CONTINUE
C end of the loop over IX, the number of nodal points on the ring web.
C
      CALL SIMPSN(IFILE,NX,DX,FHOOP,FWEB)
      CALL SIMPSN(IFILE,NX,DX,FMPROD,FMWEB)
C
C23456789012345678901234567890123456789012345678901234567890123456789012
      FCESKN = SIGMA(1)*TSKIN*B
      FCEFLG = SIGMA(NX)*TFLANG*WFLANG
      FORCE = FWEB + FCESKN + FCEFLG
      FMOMNT= FMWEB + FCESKN*D + FCEFLG*(D-XCOORD(NX))
C
C  get curvature change, CURBCK, due to spring-back
C  assumption: the sping-back process is entirely elastic.
C
C  First, compute the elastic bending stiffness of a single module
C  about the neutral axis for elastic bending:
      FMULT = 1
      IF (FLGCLD.LT.0.1.OR.ISTIF(2).NE.1) FMULT = 0.00001
C
C  NOTE: FMULT is very small if the ring outstanding flange is
C        welded to the web tip AFTER completion of cold-bending.
C
C  EICLD is the circumferential bending stiffness, "EI".
C
      EICLD =       EELAST*TSKIN**3*B/12.
     1             +EELAST*(H+TSKIN/2.)**3*TWEB/12.
     1       +FMULT*EELAST*TFLANG**3*WFLANG/12.
     1             +EELAST*TSKIN*B*DELAST**2
     1             +EELAST*H*TWEB*((H+TSKIN/2.)/2.-DELAST)**2
     1       +FMULT*EELAST*WFLANG*TFLANG*(H+TSKIN/2.-DELAST)**2
C
      ARCYL = ABS(RCYL)
      ARCOLD = ABS(RCOLD)
C
C  CURBCK is the curvatue change due to elastic spring-back.
C
C     CURBCK = ABS((FMOMNT/B)/C55N)
      CURBCK = ABS(FMOMNT/EICLD)
      CUREND = 1./ARCOLD - CURBCK
      RADEND = 1./CUREND
C
C  RADEND is the radius of the cold-bent panel after elastic
C  spring-back.
C
      FACTR = 0.5
C  NOTE: with FACTR = 1.0 the process often did not converge.
      DIFF = (RADEND - ARCYL)/RADEND
      IF (NPRT.GE.2) WRITE(IFILE,'(A,I3,1P4E12.4)')
     1' KOUNT,RCOLD,RADEND,ARCYL,DIFF=', KOUNT,RCOLD,RADEND,ARCYL,DIFF
      IF (IBACK.EQ.0.AND.KOUNT.LT.10.AND.EELAST/SIM(2).GT.10.0
     1 .AND.ABS(DIFF).GT.0.05) THEN
         IF (DIFF.LT.0.0) RCOLD = MIN((1.-FACTR*DIFF)*ARCOLD,ARCYL)
         IF (DIFF.GT.0.0) RCOLD = (1.-FACTR*DIFF)*ARCOLD
C       Iterate again to obtain a better value of RCOLD...
         GO TO 15
      ENDIF
C
C  Either RCOLD converged or KOUNT reached its maximum value, 10:
C
      IF (KOUNT.EQ.10) THEN
         WRITE(IFILE,'(/,A,/,A,/,A,/,1P,(5E12.4),/,A)')
     1' ***************** CONVERGENCE FAILURE *****************',
     1' Cold-bending radius, RCOLD, fails to converge. Run abort.',
     1' History of RCOLD =',(RHIST(I),I=1,KOUNT),
     1' *******************************************************'
         CALL ERREX
      ENDIF
C
C   We now have a satisfactory value for the cold-bending
C   radius, RCOLD, before elastic springback.
C   Iterations for RCOLD have converged to within 5 per cent,
```

```
C   which means that the radius after elastic spring-back is
C   within 5 per cent of the design radius, ABS(RCYL). (ABS(RCYL)
C   is an input datum provided by the PANDA2 user).
C
      IF (IBACK.EQ.0) THEN
C
C   In our determination of RCOLD we used the smallest possible
C   value of NBEND: NBEND = 2 (cold bending from flat to RCOLD in
C   just one step). Now we increase NBEND from 2 to 3 and recompute
C   the elastic-plastic properties, E11(IX), E12(IX), E22(IX),
C   G12(IX), SIGMA(IX), and FHOOP(IX), IX = 1,NX, at RCOLD
C   a bit more accurately. NOTE: We do not iterate on RCOLD in this
C   step. We first save RCOLD (RCLDSV) for use with the perturbed
C   design (when IMOD = 1).
C
         IF (IMOD.EQ.0) RCLDSV = RCOLD
         NBEND = 3
         IBACK = 1
         GO TO 15
      ENDIF
C
   (lines skipped to save space)
C
C  Next, obtain the C(i,j) and the CNXVAR and CNYVAR for the
C  converged cold-bent state:
C
      CALL MOVER(CX,1,CXCOLD,1,180)
      CALL MOVER(CX,1,CXCLD1,1,180)
      CALL MOVER(CX(1,1,1),1,CXCLD1(1,1,5),1,36)
      CALL MOVER(CY,1,CYCOLD,1,180)
      CALL MOVER(CX,1,CXCLD0,1,180)
      CALL MOVER(CSKIN,1,CXCLD0(1,1,1),1,36)
      CALL MOVER(CSKIN,1,CXCLD0(1,1,5),1,36)
C
      E22LIN = EELAST/(1.-FNU**2)
      E11LIN = E22LIN
      E12LIN = FNU*E22LIN
      IF (NPRT.GE.2) WRITE(IFILE,'(/,A,1P,3E12.4)')
     1' E11LIN, E12LIN, E22LIN=',E11LIN, E12LIN, E22LIN
C
C  First, do the ring web:
      DO 700 IX = 1,NX
         CALL MOVER(CY(1,1,3),1,CY3CLD(1,1,IX),1,36)
         DIFF = ABS(E22LIN - E22(IX))/E22LIN
C  If the cold-bending process remains entirely elastic, DIFF=0.0
         IF (NPRT.GE.2)
     1   WRITE(IFILE,'(A,I3,1P,E12.4)')' Ring Web: IX,DIFF=',IX,DIFF
         IF (DIFF.GT.0.05) THEN
            CY3CLD(1,1,IX) = E11(IX)*CY(1,1,3)/E11LIN
            CY3CLD(1,2,IX) = E12(IX)*CY(1,2,3)/E12LIN
            CY3CLD(2,1,IX) = CY3CLD(1,2,IX)
            CY3CLD(2,2,IX) = E22(IX)*CY(2,2,3)/E22LIN
            CY3CLD(3,3,IX) = G12(IX)*CY(3,3,3)/GELAST
            CY3CLD(4,4,IX) = E11(IX)*CY(4,4,3)/E11LIN
            CY3CLD(4,5,IX) = E12(IX)*CY(4,5,3)/E12LIN
            CY3CLD(5,4,IX) = CY3CLD(4,5,IX)
            CY3CLD(5,5,IX) = E22(IX)*CY(5,5,3)/E22LIN
            CY3CLD(6,6,IX) = G12(IX)*CY(6,6,3)/GELAST
         ENDIF
         CNXVAR(IX,3)   = FN1
         CNYVAR(IX,3)   = FHOOP(IX)
  700 CONTINUE
C end of the loop over IX, the nodal points along the ring web.
C
C  Next, do the shell skin and ring outstanding flange:
C
C First, do the shell skin:
C NOTE: We assume that the elastic-plastic moduli in the
C       skin are the same as those at Node Point 1 in the
C       ring web.
      DIFF = ABS(E22LIN - E22(1))/E22LIN
C  If the cold-bending process remains entirely elastic, DIFF=0.0
      IF (NPRT.GE.2)
     1 WRITE(IFILE,'(A,1P,E12.4)')' Shell skin: DIFF=',DIFF
      IF (DIFF.GT.0.05) THEN
         CXCOLD(1,1,1) = E11(1)*CX(1,1,1)/E11LIN
         CXCOLD(1,2,1) = E12(1)*CX(1,2,1)/E12LIN
         CXCOLD(2,1,1) = CXCOLD(1,2,1)
```

```
         CXCOLD(2,2,1) = E22(1)*CX(2,2,1)/E22LIN
         CXCOLD(3,3,1) = G12(1)*CX(3,3,1)/GELAST
         CXCOLD(4,4,1) = E11(1)*CX(4,4,1)/E11LIN
         CXCOLD(4,5,1) = E12(1)*CX(4,5,1)/E12LIN
         CXCOLD(5,4,1) = CXCOLD(4,5,1)
         CXCOLD(5,5,1) = E22(1)*CX(5,5,1)/E22LIN
         CXCOLD(6,6,1) = G12(1)*CX(6,6,1)/GELAST
         CXCOLD(1,1,5) = E11(1)*CX(1,1,5)/E11LIN
         CXCOLD(1,2,5) = E12(1)*CX(1,2,5)/E12LIN
         CXCOLD(2,1,5) = CXCOLD(1,2,5)
         CXCOLD(2,2,5) = E22(1)*CX(2,2,5)/E22LIN
         CXCOLD(3,3,5) = G12(1)*CX(3,3,5)/GELAST
         CXCOLD(4,4,5) = E11(1)*CX(4,4,5)/E11LIN
         CXCOLD(4,5,5) = E12(1)*CX(4,5,5)/E12LIN
         CXCOLD(5,4,5) = CXCOLD(4,5,5)
         CXCOLD(5,5,5) = E22(1)*CX(5,5,5)/E22LIN
         CXCOLD(6,6,5) = G12(1)*CX(6,6,5)/GELAST
         CALL MOVER(CXCOLD(1,1,1),1,CXCLD1(1,1,1),1,36)
         CALL MOVER(CXCLD1(1,1,1),1,CXCLD1(1,1,5),1,36)
C
C  CSKIN(i,j) are the integrated constitutive quantities
C  for the panel skin without any smeared stiffeners or
C  sub-stiffeners. As of this writing, the stiffness
C  matrix, CXCLD0(i,j) is not used anywhere to compute
C  ring buckling under the cold-bending process.
C
         CXCLD0(1,1,1) = E11(1)*CSKIN(1,1)/E11LIN
         CXCLD0(1,2,1) = E12(1)*CSKIN(1,2)/E12LIN
         CXCLD0(2,1,1) = CXCLD0(1,2,1)
         CXCLD0(2,2,1) = E22(1)*CSKIN(2,2)/E22LIN
         CXCLD0(3,3,1) = G12(1)*CSKIN(3,3)/GELAST
         CXCLD0(4,4,1) = E11(1)*CSKIN(4,4)/E11LIN
         CXCLD0(4,5,1) = E12(1)*CSKIN(4,5)/E12LIN
         CXCLD0(5,4,1) = CXCLD0(4,5,1)
         CXCLD0(5,5,1) = E22(1)*CSKIN(5,5)/E22LIN
         CXCLD0(6,6,1) = G12(1)*CSKIN(6,6)/GELAST
         CXCLD0(1,1,5) = E11(1)*CSKIN(1,1)/E11LIN
         CXCLD0(1,2,5) = E12(1)*CSKIN(1,2)/E12LIN
         CXCLD0(2,1,5) = CXCLD0(1,2,5)
         CXCLD0(2,2,5) = E22(1)*CSKIN(2,2)/E22LIN
         CXCLD0(3,3,5) = G12(1)*CSKIN(3,3)/GELAST
         CXCLD0(4,4,5) = E11(1)*CSKIN(4,4)/E11LIN
         CXCLD0(4,5,5) = E12(1)*CSKIN(4,5)/E12LIN
         CXCLD0(5,4,5) = CXCLD0(4,5,5)
         CXCLD0(5,5,5) = E22(1)*CSKIN(5,5)/E22LIN
         CXCLD0(6,6,5) = G12(1)*CSKIN(6,6)/GELAST
      ENDIF
C   end of (DIFF.GT.0.05) condition
C
      NSEGX = 4
      IF (ISTIF(2).EQ.1) NSEGX = 5
C
C NOTE: If there are sub-rings SIGMA(1)*TSKIN is a conservative
C value for CNYVAR because it leaves out the hoop tension in the
C subrings. Therefore, in this model there is less hoop tension
C than there would be in the actual structure with subrings.
C
      CALL MOVER(SIGMA(1)*TSKIN,0,CNYVAR(1,1),1,23)
      CALL MOVER(SIGMA(1)*TSKIN,0,CNYVAR(1,2),1,23)
      CALL MOVER(SIGMA(1)*TSKIN,0,CNYVAR(1,NSEGX),1,23)
      CALL MOVER(0.,0,CNXVAR(1,1),1,23)
      CALL MOVER(0.,0,CNXVAR(1,2),1,23)
      CALL MOVER(0.,0,CNXVAR(1,NSEGX),1,23)
C
C   ISTIF(2) = 1 means the ring is Tee shaped. NOTE:
C   no faying flange is accounted for in this application!
C
      IF (ISTIF(2).NE.1) GO TO 730
C
C Next, do the ring outstanding flange of the Tee-shaped ring:
      FMULT = 1.0
      IF (FLGCLD.LT.0.1) THEN
         FMULT = 0.00001
         DO 720 I = 1,6
         DO 710 J = 1,6
            CYCOLD(I,J,4) = FMULT*CYCOLD(I,J,4)
  710    CONTINUE
  720    CONTINUE
```

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```
      ENDIF
C
      DIFF = ABS(E22LIN - E22(NX))/E22LIN
C  If the cold-bending process remains entirely elastic, DIFF=0.0
      IF (NPRT.GE.2) WRITE(IFILE,'(A,I3,1P,E12.4)')
     1' Ring outstanding flange: NX,DIFF=',NX,DIFF
C
C NOTE: We assume that the elastic-plastic moduli in the outstanding
C       ring flange are the same as those at Node Point NX in the
C       ring web.
C
      IF (DIFF.GT.0.05) THEN
         CYCOLD(1,1,4) = FMULT*E11(NX)*CY(1,1,4)/E11LIN
         CYCOLD(1,2,4) = FMULT*E12(NX)*CY(1,2,4)/E12LIN
         CYCOLD(2,1,4) = CYCOLD(1,2,4)
         CYCOLD(2,2,4) = FMULT*E22(NX)*CY(2,2,4)/E22LIN
         CYCOLD(3,3,4) = FMULT*G12(NX)*CY(3,3,4)/GELAST
         CYCOLD(4,4,4) = FMULT*E11(NX)*CY(4,4,4)/E11LIN
         CYCOLD(4,5,4) = FMULT*E12(NX)*CY(4,5,4)/E12LIN
         CYCOLD(5,4,4) = CYCOLD(4,5,4)
         CYCOLD(5,5,4) = FMULT*E22(NX)*CY(5,5,4)/E22LIN
         CYCOLD(6,6,4) = FMULT*G12(NX)*CY(6,6,4)/GELAST
      ENDIF
      CALL MOVER(SIGMA(1)*TFLANG,0,CNYVAR(1,4),1,23)
      IF (FLGCLD.LT.0.1) CALL MOVER(0.,0,CNYVAR(1,4),1,23)
      CALL MOVER(0.,0,CNXVAR(1,4),1,23)
C
  730 CONTINUE
C
C STABILITY EQUATIONS FOR THE "CLOSED FORM" SOLUTION
C
C Find the elements of the stiffness and load-geometric matrices
C before integration over the web height corresponding
C to the assumed buckling modal displacement in the ring web.
C The buckling modal displacement in the ring web is assumed to
C be:
C  w = [a3*H**3*S**2*(S -3.) +a4*H**4*S**2*(S**2 -6.)
C                  +a5*H**5*S**2*(S**3 -10.)]*sin(N*pi*y/L)    (8)
C
C in which w is the normal displacement (rolling) of the web,
C H is the height of the web, and s = x/H, with x being the
C coordinate in the plane of the web from the web root (x=0) to the
C web tip (x = h). L is the length of the web in the circumferential
C coordinate direction, y. N is the number of circumferential
C half waves over the circumferential length, L.
C
C It is assumed that the panel skin experiences no out-of-plane
C deformation in the buckling mode. Only the web and the outstanding
C flange, if any, participate in the buckling mode.
C
C a3, a4, a5 are undetermined coefficients with the following units:
C  a3 has units 1/in**2;  a4 has units 1/in**3;  a5 has units 1/in**4
C
C NOTE: The assumed displacement pattern, Eq. (8), was originally planned
C for a ring that has no outstanding flange. In that case the curvature
C w,xx at the web tip should be zero because the web tip is free, Indeed,
C w,xx is zero at the web tip even if there exists an outstanding flange.
C Therefore, Eq.(8) may be a poor choice for a ring buckling mode. The
C prediction of buckling may be either unconservative or conservative when
C an outstanding flange exists. (NOTE: This dilemma does not exist in
C the case of the discretized "skin"-ring and skin-ring single module
C models processed later in SUBROUTINE STRUCT. Therefore, the PANDA2 user
C does not have to worry about generating unconservative designs.)
C
C Also, the analysis is based on the assumption that the loading of the
C web is uniaxial: loading only in the hoop direction (y direction). If
C there is a significant FN1 (in-plane loading of the web normal to the
C shell skin surface), the theory used here may be inadequate.
C
C The cold-bending ring web buckling problem is an eigenvalue problem
C of the following form:
C
C              {[A] - lambda x [B]}q = 0.                      (9)
C
C in which [A] is the 3 x 3 stiffness matrix and [B] is the 3 x 3
C load-geometric matrix. The system of rank 3 represented by Eq.(9)
C is obtained by minimizing the total potential energy, U - W, with
C respect to the undetermined coefficients, a3, a4, and a5, in Eq.(8).
```

```
C
C It is assumed that the web buckling mode can be captured by only
C normal deflections w that vary along the s-coordinate as given in
C Eq.(8) and that vary in the circumferential direction y trigonometrically
C as sin(n*pi*y/l). The strain energy of buckling is given by
C
C (H/2)*int[C(4,4)*w,ss^2 +2C(4,5)*w,ss*w,yy
C                          +C(5,5)*w,yy^2 +4C6,6)*w,sy^2]dyds   (10)
C
C in which w,ss, w,sy, w,yy represent second partial derivatives of w with
C respect to the coordinate directions s and y, and the C(i,j) are the
C bending stiffnesses of the cold-bent ring web..
C
C The work done by the prebuckling resultants, N1 and N2, during the
C buckling displacements w is given by
C
C (H/2)*int[N1*w,s^2 + N2*w,y^2)]dyds                            (11)
C
C Minimization of U - W with respect to the undetermined coefficients
C a3, a4, a5 yields the coefficients A(i,j) and B(i,j) listed below.
C
c Integration over s is performed by Simpson's rule (in SUBROUTINE
C SIMPSN, which is used elsewhere in PANDA2 and which is located in
C the util.src library).
C
      PI = 3.1415927
      FL = CIRC
      DS = 1./FLOAT(NX-1)
C
C In the following several statements we compute a
C circumferential length of ring, FL, that usually
C represents only a small part of the entire shell.
C We do this so that we don't have to search over
C a large quantity of wave numbers to find the critical
C cold-bending ring web buckling mode.
C
      NWVMAX = FL/H
      IF (NWVMAX.GT.10) THEN
         FL = 10.*CIRC/FLOAT(NWVMAX)
      ENDIF
      NWVMAX = FL/H
      IF (NWVMAX.GT.10) THEN
         FL = 10.*FL/FLOAT(NWVMAX)
      ENDIF
      NWVMAX = 2.*FL/H
C
      BUCKLE = 10.E+16
C
      IF (IMOD.EQ.0) THEN
         NBEG = 1
         NEND = NWVMAX
      ELSE
C
C For the perturbed design (IMOD = 1) we use only the critical
C number of circumferential halfwaves, NCRIT3, determined for
C the unperturbed (current) design.
C
         NBEG = NCRIT3
         NEND = NCRIT3
      ENDIF
C
      DO 1000 NWAVE = NBEG,NEND
C
       FN = NWAVE
       S = -DS
C
       DO 800 IX = 1,NX
C
C Some frequently used combinations:
C
         C44 = E11(IX)*TWEB**3/12.
         C45 = E12(IX)*TWEB**3/12.
         C55 = E22(IX)*TWEB**3/12.
         C66 = G12(IX)*TWEB**3/12.
         FN2 = FHOOP(IX)
         S = S + DS
         C  = FN*PI/FL
         S1 =  H*6.*(S - 1.)
```

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```
      S3 =  C**2*H**3*S**2*(S - 3.)
      S36 = C*H**2*S*(3.*S - 6.)
      S21 = H*12.*H*(S**2 - 1.)
      S26 = C**2*H**3*S**2*H*(S**2 - 6.)
      S31 = H*20.*H**2*(S**3 - 1.)
      S310= C**2*H**3*S**2*H**2*(S**3 - 10.)
      S320= C*H**2*S*H**2*(5.*S**3 - 20.)
      S212= C*H**2*S*H*(4.*S**2 - 12.)
C
      A11(IX) = S1*S1*C44 +S3*S1*C45 +S1*S3*C45 +S3*S3*C55
     1                                          +S36*S36*4.*C66
      A12(IX) = S1*S21*C44 +S3*S21*C45 +S1*S26*C45 +S3*S26*C55
     1                                          +S36*S212*4.*C66
      A13(IX) = S1*S31*C44 +S3*S31*C45 +S1*S310*C45 +S3*S310*C55
     1                                          +S36*S320*4.*C66
C
      A22(IX) = S21*S21*C44 +S26*S21*C45 +S21*S26*C45 +S26*S26*C55
     1                                          +S212*S212*4.*C66
      A23(IX) = S21*S31*C44 +S26*S31*C45 +S21*S310*C45 +S26*S310*C55
     1                                          +S212*S320*4.*C66
C
      A33(IX) = S31*S31*C44 +S310*S31*C45 + S31*S310*C45 +S310*S310*C55
     1                                          +S320*S320*4.*C66
C
      B11(IX) = S3*S3*FN2/C**2 + S36*S36*FN1/C**2
      B12(IX) = S3*S26*FN2/C**2 +S36*S212*FN1/C**2
      B13(IX) = S3*S310*FN2/C**2 +S36*S320*FN1/C**2
C
      B22(IX) = S26*S26*FN2/C**2 +S212*S212*FN1/C**2
      B23(IX) = S26*S310*FN2/C**2 +S212*S320*FN1/C**2
C
      B33(IX) = S310*S310*FN2/C**2 +S320*S320*FN1/C**2
C
  800 CONTINUE
C  end of the loop over IX
C
C The Aij and Bij have yet to be integrated over the height of the web.
C
C   Next, integrate the Aij and Bij using Simpson's rule:
C
    CALL SIMPSN(IFILE,NX,DS,A11,ASTF(1,1))
    CALL SIMPSN(IFILE,NX,DS,A12,ASTF(1,2))
    CALL SIMPSN(IFILE,NX,DS,A13,ASTF(1,3))
    CALL SIMPSN(IFILE,NX,DS,A22,ASTF(2,2))
    CALL SIMPSN(IFILE,NX,DS,A23,ASTF(2,3))
    CALL SIMPSN(IFILE,NX,DS,A33,ASTF(3,3))
C
    CALL SIMPSN(IFILE,NX,DS,B11,BSTF(1,1))
    CALL SIMPSN(IFILE,NX,DS,B12,BSTF(1,2))
    CALL SIMPSN(IFILE,NX,DS,B13,BSTF(1,3))
    CALL SIMPSN(IFILE,NX,DS,B22,BSTF(2,2))
    CALL SIMPSN(IFILE,NX,DS,B23,BSTF(2,3))
    CALL SIMPSN(IFILE,NX,DS,B33,BSTF(3,3))
C
    IF (ISTIF(2).EQ.1) THEN
C
C  Next, find the contributions of the outstanding flange, if any, to
C  the stiffness and load-geometric matrices. Note that the following
C  quantities INCLUDE integration over the width of the outstanding
C  ring flange. We can do the integration in "closed form" because it
C  is assumed that the prebuckled state of the outstanding flange is
C  uniform both along the width of the flange and through the thickness
C  of the flange.
C
C  The following formulas are based on the assumption that the flange
C  cross section does not deform in the buckling mode. The flange
C  centroid experiences a rotation equal to dw/dx of the web at the
C  tip of the web and an axial displacement equal to w of the web at
C  the tip of the web.
C
C
C  The following "instantaneous" moduli are needed for
C  the buckling analysis:
C  E11 instantaneous modulus in the plane of the flange in
C      the vertical direction (along the flange width)
C  E12 instantaneous "Poisson-type" modulus
C  E22 instantaneous modulus in the plane of the flange in
C      the y-drection (circumferential direction)
```

Table a2 (p.21 of 33)

```
C  G   in-plane shear modulus
C
C  First, find the instantaneous moduli for the flange:
C
  (lines skipped to save space)
C
C The cold-bending ring web buckling problem is an eigenvalue problem
C of the following form:
C
C              {[A] - lambda*[B]}q = 0.                    (9)
C
C in which [A] is the 3 x 3 stiffness matrix and [B] is the 3 x 3
C load-geometric matrix. A cubic equation in the eigenvalue, lambda,
C is obtained by setting the determinate of the matrix [A -lambda*B]
C equal to zero:
C
C CCUBIK*lambda**3 +CQUAD*lambda**2 +CLIN*lambda +CONST = 0  (12)
C
C Next, we set up the coefficients:
C
C CONST = constant term
C CLIN  = term linear in lambda
C CQUAD = term quadratic in lambda
C CCUBIK= term cubic in lambda
C
C of the cubic equation for lambda, the ring web buckling
C load factor (eigenvalue).
C
      CALL CUBICC(ASTFD(1,1),ASTFD(1,2),ASTFD(1,3),ASTFD(2,2),
     1            ASTFD(2,3),ASTFD(3,3),
     1            BSTFD(1,1),BSTFD(1,2),BSTFD(1,3),BSTFD(2,2),
     1            BSTFD(2,3),BSTFD(3,3),
     1            CONST,CLIN,CQUAD,CCUBIK)
C
C The cubic equation is solved for lambda in SUBROUTINE CUBIC.
C NOTE: SUBROUTINE CUBIC (in the util.src library) is also used
C for solving for web buckling in WEBBUK in the buckle.src
C library and for solving Arbocz' Eq.(361) in the bucpan1.src
C library. Here the output from SUBROUTINE CUBIC is the lowest
C positive eigenvalue, EIGVAL(NWAVE), in which NWAVE is the number
C of circumferential half-waves over the web length, FL .
C
      CALL CUBIC(CONST,CLIN,CQUAD,CCUBIK,EIGVAL(NWAVE),
     1           IMOD,ICUBIC,JCUBIC,1,1,0)
C
      IF (NPRT.GE.2) WRITE(IFILE,'(A,I3,1P,E12.4)')
     1 ' From "CUBIC": NWAVE, EIGVAL(NWAVE)=',NWAVE, EIGVAL(NWAVE)
C
      BUCKLE = MIN(EIGVAL(NWAVE),BUCKLE)
C
  (lines skipped to save space)

C Constraint condition...
      INUMTT = INUMTT + 1
      FSAFTY = 1.1
      CALL CONVRF(FSAFTY,CCN2)
      CALL CONVRT(NCRITC,CCN)
      IF (IMOD.EQ.0.AND.(BUCKLE/FSAFTY).LT.MAXCON) THEN
         ICAR = ICAR + 1
         PCWORD(ICAR) =
     1  'Cold-bending ring buckling, closed form soln'
         CPLOT(ICAR) = BUCKLE/FSAFTY - 1.
         IADDCC(ICAR) = 0
         FSAFEP(ICAR) = FSAFTY
      ENDIF
      IF (IMOD.EQ.0.AND.(BUCKLE/FSAFTY).GT.CONMAX) GO TO 1300
      IF (IMOD.EQ.1.AND.IPOINC(INUMTT).EQ.0) GO TO 1300
      ICONST = ICONST + 1
      IF (IMOD.EQ.0) IPOINC(INUMTT) = 1
      CONSTR(ICONST) = BUCKLE/FSAFTY
      WORDB(ICONST)=
     1'Cold-bending ring buckling, closed form soln; N='//CCN//
     1';FS='//CCN2
      IF (NPRT.GE.0) WRITE(IFILE,'(A,1P,E12.4,2X,A)')
     1 ' Margin=',CONSTR(ICONST)-1.,WORDB(ICONST)
C234567890123456789012345678901234567890123456789012345678901234567890012
      IF (NPRT.GE.2) WRITE(IFILE,'(A,/,A,/,A,I3,A,I2,A,I2)')
     1 ' *** THE FOLLOWING COLD-BENDING BUCKLING MARGIN JUST COMPUTED:',
```

```
     1   WORDB(ICONST),
     1 ' ******** CONSTRAINT NO.',ICONST,'; LOAD SET NO.',ILOADS,
     1 '; SUBCASE NO.',ICASE
 1300 CONTINUE
      IF (ITYPE.EQ.1.AND.NPRT.GE.2)
     1 WRITE(IFILE,*)' AFTER 4440 C: IMOD,INUMTT,ICONST=',
     1                               IMOD,INUMTT,ICONST
C
      IF (NPRT.GE.0) WRITE(IFILE,'(A,/,A,/,A,/,/)')
     1' End of computation of cold-bending ring buckling load factor',
     1' in SUBROUTINE COLDBD.',
     1' *******************************************************'
C
C   Next, find out if the sub-ring buckles under cold bending
C
C   ISUB = 0 means either that there is no sub-ring or the
C            sub-ring is external and therefore experiences no
C            destabilizing hoop compression during cold bending.
C
      IF (ISUB.EQ.0) GO TO 3000
C
  (lines skipped to save space)

 3000 CONTINUE
C234567890123456789012345678901234567890123456789012345678901234567890
C
      RETURN
      END
C
C
C
C=DECK      SMOOTH
      SUBROUTINE SMOOTH(NP,EBAR,JJ,ETOT,SIG,EPS,ET)
C
C     PURPOSE IS TO SMOOTH THE TANGENT MODULUS IN THE NEIGHBORHOOD OF A
C     CORNER IN THE STRESS-STRAIN CURVE...
C
      DIMENSION ETOT(20),SIG(20),EPS(20)
C
   (lines skipped to save space)
C
      RETURN
      END
C
C
C
C=DECK      CUBICC
      SUBROUTINE CUBICC(a11,a12,a13,a22,a23,a33,
     1                  b11,b12,b13,b22,b23,b33,
     1                  CONST,CLIN,CQUAD,CCUBIK)
C
C  Purpose is to get the coefficients,
C  CONST,CLIN,CQUAD,CCUBIK
C  of the cubic equation for the eigenvalues
C  of the cold-bending ring buckling problem.
C  The cubic equation is:
C   determinant = 0
C
C  Input:
C   a11,a12,a13,a22,a23,a33 = strain energy coefficients
C   b11,b12,b13,b22,b23,b33 = "work done" coefficients
C
C  Output:
C   CONST,CLIN,CQUAD,CCUBIK = coefficients of cubic equation
C
      DOUBLE PRECISION a11,a12,a13,a22,a23,a33
      DOUBLE PRECISION b11,b12,b13,b22,b23,b33
      DOUBLE PRECISION CONST,CLIN,CQUAD,CCUBIK
C
      CONST = a33*(a11*a22 -a12**2) +a23*(a12*a13 -a11*a23)
     1                             +a13*(a12*a23 -a13*a22)
C
      CLIN  = a33*(b11*a22 +b22*a11 -2.*a12*b12)
     1        +b33*(a11*a22 -a12**2)
     1        +a23*(b12*a13 +b13*a12 -b11*a23 -b23*a11)
     1        +b23*(a12*a13 -a11*a23)
     1        +a13*(b12*a23 +b23*a12 -a13*b22 -a22*b13)
     1        +b13*(a12*a23 -a13*a22)
```

```
C
      CQUAD = a33*(b11*b22 -b12**2)
     1        +b33*(a11*b22 +a22*b11 -2.*a12*b12)
     1        +a23*(b12*b13 -b11*b23)
     1        +b23*(b12*a13 +a12*b13 -b11*a23 -a11*b23)
     1        +a13*(b12*b23 -b13*b22)
     1        +b13*(b12*a23 +a12*b23 -b13*a22 -a13*b22)
C
      CCUBIK= b33*(b11*b22 -b12**2) +b23*(b12*b13 -b11*b23)
     1                               +b13*(b12*b23 -b13*b22)
C
      RETURN
      END
-----------------------------------------------------------------
```

What is going on in the new coding is described there.
(For the complete list, see the file ...panda2/doc/panda2.news.)

Typical new output in the *.OPM file from SUBROUTINE COLDBD
and from SUBROUTINE STRUCT is listed below. This output is
obtained with the print index, NPRINT = 2 in the *.OPT file:

```
-----------------------------------------------------------------
  LABEL NO. IN STRUCT= 9270

 ************************************************************
 ************************************************************
 ************************************************************
 ************         CHAPTER 26(b)         ****************
 ************************************************************
 ************************************************************
 ************************************************************
 **** CHAPTER 26b: DESIGN PERTURBATION INDEX, IMOD=  0 ****

 ************************************************************
 CHAPTER 26b Compute the ring web buckling load factor and
             circumferential wavelength from cold-bending a
             flat "hogged out" plate into a cylindrical panel
             with cold-bending radius RCOLD from iterations.
             This analysis is performed only for cylindrical
             shells with INTERNAL rings with rectangular or
             Tee-shaped cross sections. The entire shell must
             be fabricated of the same isotropic material.
             See Item No.790 in ...panda2/doc/panda2.news .

*** BEGIN SUBROUTINE COLDBD (COLD-BENDING RING BUCKLING) ****
 See Item No. 790 of the file, ...panda2/doc/panda2.news
 Buckling from COLDBD ("closed-form" solution) is Model no. 1
 Location of neutral axis for elastic material, DELAST=  9.3628E-02

 IBEND=   2
 Iteration=  1 Location of neutral axis, d=  6.0412E-02
 Iteration=  2 Location of neutral axis, d=  5.8127E-02
 Iteration=  3 Location of neutral axis, d=  5.7979E-02
 KOUNT,RCOLD,RADEND,ARCYL,DIFF=  1  3.2000E+01  6.6653E+01  4.8000E+01  2.7985E-01

 IBEND=   2
 Iteration=  1 Location of neutral axis, d=  5.2824E-02
 Iteration=  2 Location of neutral axis, d=  5.2521E-02
 KOUNT,RCOLD,RADEND,ARCYL,DIFF=  2  2.7522E+01  5.0708E+01  4.8000E+01  5.3403E-02

 IBEND=   2
 Iteration=  1 Location of neutral axis, d=  5.1601E-02
 Iteration=  2 Location of neutral axis, d=  5.1545E-02
 KOUNT,RCOLD,RADEND,ARCYL,DIFF=  3  2.6787E+01  4.8382E+01  4.8000E+01  7.8914E-03

 IBEND=   2
 Iteration=  1 Location of neutral axis, d=  7.4343E-02
 Iteration=  2 Location of neutral axis, d=  7.5316E-02
 Iteration=  3 Location of neutral axis, d=  7.5357E-02

 IBEND=   3
 Iteration=  1 Location of neutral axis, d=  5.2983E-02
 Iteration=  2 Location of neutral axis, d=  5.2302E-02
 Iteration=  3 Location of neutral axis, d=  5.2282E-02
 KOUNT,RCOLD,RADEND,ARCYL,DIFF=  4  2.6787E+01  4.9094E+01  4.8000E+01  2.2293E-02
```

Table a2 (p, 24 of 33)

```
Number of points on stress-strain curve, NSS =  5
   STRAIN        STRESS
 0.0000E+00  0.0000E+00
 6.3636E-03  7.0000E+04
 1.2727E-02  1.0000E+05
 1.9091E-02  1.1000E+05
 1.9091E+01  1.2100E+05

ring spacing,            B(RNG)=                      1.3974E+01
skin thickness,           TSKIN=                      5.8191E-02
ring web height,         H(RNG)=                      9.7173E-01
ring web thickness,        TWEB=                      1.8576E-01
ring flange width,       W(RNG)=                      0.0000E+00
ring flange thickness, TFLANG=                        0.0000E+00
cold-bending radius,      RCOLD=                      2.6787E+01
radius after springback,RADEND=                       4.9094E+01
design radius of cylinder,RCYL=                       4.8000E+01
At R =RCOLD: location d of the ring neutral axis=     5.2282E-02

ring web hoop force,       FWEB=                     -1.5634E+04
skin hoop force, SIGMA(1)*TSKIN*B=                    2.1307E+04
flange hoop force, SIGMA(NX)*TFLANG*W(RNG)=           0.0000E+00

force  integrated over the ring cross section=        5.6728E+03
moment integrated over the ring cross section=        9.8416E+03

x-coordinates for  11 radial locations along the ring web:
 0.0000E+00  1.0008E-01  2.0017E-01  3.0025E-01  4.0033E-01
 5.0042E-01  6.0050E-01  7.0058E-01  8.0066E-01  9.0075E-01
 1.0008E+00

hoop strain for  11 radial locations along the ring web:
 2.3820E-03 -1.3541E-03 -5.0903E-03 -8.8265E-03 -1.2563E-02
-1.6299E-02 -2.0035E-02 -2.3771E-02 -2.7507E-02 -3.1244E-02
-3.4980E-02

hoop stress for  11 radial locations along the ring web:
 2.6203E+04 -1.4896E+04 -5.5994E+04 -8.1611E+04 -9.9224E+04
-1.0561E+05 -1.1000E+05 -1.1000E+05 -1.1000E+05 -1.1001E+05
-1.1001E+05

hoop resultant for  11 radial locations along the ring web:
 4.8674E+03 -2.7670E+03 -1.0401E+04 -1.5160E+04 -1.8432E+04
-1.9619E+04 -2.0434E+04 -2.0434E+04 -2.0435E+04 -2.0435E+04
-2.0435E+04

uniform hoop resultant in the shell skin=  1.5248E+03
uniform hoop resultant in the outstanding flange=  0.0000E+00

E11LIN, E12LIN, E22LIN=  1.2088E+07  3.6264E+06  1.2088E+07
Ring Web: IX,DIFF=  1  0.0000E+00
Ring Web: IX,DIFF=  2  0.0000E+00
Ring Web: IX,DIFF=  3  0.0000E+00
Ring Web: IX,DIFF=  4  2.7726E-01
Ring Web: IX,DIFF=  5  6.8951E-01
Ring Web: IX,DIFF=  6  7.3218E-01
Ring Web: IX,DIFF=  7  8.6633E-01
Ring Web: IX,DIFF=  8  8.8521E-01
Ring Web: IX,DIFF=  9  8.9942E-01
Ring Web: IX,DIFF= 10  9.1051E-01
Ring Web: IX,DIFF= 11  9.1937E-01
Shell skin: DIFF=  0.0000E+00
From "CUBIC": NWAVE, EIGVAL(NWAVE)=  1  3.9232E+01
From "CUBIC": NWAVE, EIGVAL(NWAVE)=  2  1.0792E+01
From "CUBIC": NWAVE, EIGVAL(NWAVE)=  3  5.5201E+00
From "CUBIC": NWAVE, EIGVAL(NWAVE)=  4  3.6823E+00
From "CUBIC": NWAVE, EIGVAL(NWAVE)=  5  2.8401E+00
From "CUBIC": NWAVE, EIGVAL(NWAVE)=  6  2.3936E+00
From "CUBIC": NWAVE, EIGVAL(NWAVE)=  7  2.1381E+00
From "CUBIC": NWAVE, EIGVAL(NWAVE)=  8  1.9900E+00
From "CUBIC": NWAVE, EIGVAL(NWAVE)=  9  1.9087E+00
From "CUBIC": NWAVE, EIGVAL(NWAVE)= 10  1.8758E+00
From "CUBIC": NWAVE, EIGVAL(NWAVE)= 11  1.8761E+00

BUCKLE=  1.8758E+00 WAVLEN=  9.7288E-01 NCRIT3=   10
circumferential length of web used for buckling analysis, FL=  9.7288E+00
number of circumferential halfwaves over the length CIRC=  155
```

Table a2 (p.25-133)

```
 circumferential spacing of the stringers=                      2.2773E+00
 circumferential half-wavelength of the critical buckling mode=  9.7288E-01
 Margin=  7.0525E-01  Cold-bending ring buckling, closed form soln; N=155;FS=1.1
 *** THE FOLLOWING COLD-BENDING BUCKLING MARGIN JUST COMPUTED:
Cold-bending ring buckling, closed form soln; N=155;FS=1.1
 ******** CONSTRAINT NO. 17; LOAD SET NO. 1; SUBCASE NO. 1
 End of computation of cold-bending ring buckling load factor
 in SUBROUTINE COLDBD.
 ************************************************************

 ***** BEGIN DISCRETIZED "SKIN"-RING MODULE MODEL OF    *****
 *** COLD-BENDING BUCKLING OF RING (smeared stringers)    ***
 ***** This is Model No. 2 of cold-bending ring buckling *****
 circumferential waves over the circ.length,  4.8644E+00=  1
 ring cold buckling load factor from a discretized module=  6.4476E+00 (smeared stringers)
 circumferential waves over the circ.length,  4.8644E+00=  2
 ring cold buckling load factor from a discretized module=  2.4048E+00 (smeared stringers)
 circumferential waves over the circ.length,  4.8644E+00=  3
 ring cold buckling load factor from a discretized module=  1.8210E+00 (smeared stringers)
 circumferential waves over the circ.length,  4.8644E+00=  4
 ring cold buckling load factor from a discretized module=  1.8404E+00 (smeared stringers)

 circumferential spacing of the stringers=                      2.2773E+00
 circumferential half-wavelength of the critical buckling mode=  1.6215E+00

 **** BEGIN SUB. MODE ("SKIN"-RING MODULE COLD BENDING 1) ****

(lines skipped to save space)

 Margin=  6.5544E-01  Cold-bending ring buckling, "skin"-ring module; N=93 ;FS=1.1
 *** THE FOLLOWING COLD-BENDING BUCKLING MARGIN JUST COMPUTED:
Cold-bending ring buckling, "skin"-ring module; N=93 ;FS=1.1
 ******** CONSTRAINT NO. 18; LOAD SET NO. 1; SUBCASE NO. 1
 End of computation of cold-bending ring buckling load factor
 in SUBROUTINE STRUCT from "skin"-ring discretized module.
 ************************************************************


 ***** BEGIN DISCRETIZED  SKIN-RING  MODULE MODEL OF    *****
 ***    COLD-BENDING BUCKLING OF RING (no stringers)     ***
 ***** This is Model No. 3 of cold-bending ring buckling *****
 circumferential waves over the circ.length,  2.2773E+00=  1
 ring cold buckling load factor from a discretized module=  1.1032E+00 (no stringers)
 circumferential waves over the circ.length,  2.2773E+00=  2
 ring cold buckling load factor from a discretized module=  1.6198E+00 (no stringers)

 circumferential spacing of the stringers=                      2.2773E+00
 circumferential half-wavelength of the critical buckling mode=  2.2848E+00

 **** BEGIN SUB. MODE (SKIN-RING MODULE COLD BENDING 2) ****

(lines skipped to save space)

 *********** LOAD SET NO. 1  **************
 ICASE =  1  (ICASE=1 MEANS PANEL MIDLENGTH)
             (ICASE=2 MEANS AT RINGS                        )

   APPLIED LOADS IN LOAD SET A ("eigenvalue" loads):
         Applied     axial        stress resultant, Nx= -2.2190E+03
         Applied circumferential stress resultant, Ny= -2.2190E-03
         Applied    in-plane      shear  resultant,Nxy=  1.1095E+01
         Applied     axial        moment resultant, Mx=  0.0000E+00
         Applied circumferential moment resultant, My=  0.0000E+00
         Applied pressure (positive for upward),   p =  4.6229E-05

   APPLIED LOADS IN LOAD SET B ( fixed uniform loads):
         Applied     axial        stress resultant,Nx0=  0.0000E+00
         Applied circumferential stress resultant,Ny0=  0.0000E+00
         Applied    in-plane     shear  resultant,Nxy0=  0.0000E+00

 NOTE: "F.S." means "Factor of Safety";
 "DONL" means "Donnell shell theory used.";
 "SAND" means "Sanders shell theory used." panda2.news ITEM 128
 "Dseg" means "Segment numbering used in discretized model"
 "Iseg" means "Segment numbering used for input data." ITEM 272

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

```
 MAR. MARGIN
 NO.  VALUE                  DEFINITION
 1  1.45E-01 Local buckling from discrete model-1.,M=5   axial halfwaves;FS=0.99
 2  1.45E-01 Bending-torsion buckling; M=5  ;FS=0.999
 3  1.22E-01 Bending-torsion buckling: Koiter theory,M=5   axial halfwav;FS=0.99
 4  2.43E+00 eff.stress:matl=1,SKN,Dseg=2,node=6,layer=1,z=-0.0291; MID.;FS=1.
 5  5.75E-01 eff.stress:matl=2,STR,Dseg=3,node=11,layer=1,z=0.0432; MID.;FS=1.
 6  2.90E-01 (m=5   lateral-torsional buckling load factor)/(FS)-1;FS=0.999
 7  7.91E-01 Inter-ring bucklng, discrete model, n=15  circ.halfwaves;FS=0.999
 8  1.54E+00 eff.stress:matl=1,SKN,Iseg=1,at:n=1,layer=1,z=-0.0291;-MID.;FS=1.
 9  6.02E-01 eff.stress:matl=2,STR,Iseg=3,at:TIP,layer=1,z=0.;-MID.;FS=1.
10  2.48E-01 eff.stress:matl=3,RNG,Iseg=3,at:TIP,layer=1,z=0.;-MID.;FS=1.
11  8.07E-02 buckling margin stringer Iseg.3 . Local halfwaves=5  .MID.;FS=1.
12  7.47E-02 buckling margin stringer Iseg.3 . Local halfwaves=5  .NOPO;FS=1.
13  1.98E-01 buck.(SAND);simp-support general buck;M=2;N=7;slope=0.;FS=0.999
14  7.94E+00 buck.(SAND);rolling with smear rings; M=101;N=1;slope=0.;FS=0.999
15  8.95E-01 buck.(SAND);rolling only of stringers;M=40;N=0;slope=0.;FS=1.4
16  3.38E+02 buck.(SAND);rolling only axisym.rings;M=0;N=0;slope=0.;FS=1.4
17  7.05E-01 Cold-bending ring buckling, closed form soln; N=155;FS=1.1
18  6.55E-01 Cold-bending ring buckling, "skin"-ring module; N=93 ;FS=1.1
19  2.94E-03 Cold-bending ring buckling, skin-ring module; N=66 ;FS=1.1
20  5.85E+02 (Max.allowable ave.axial strain)/(ave.axial strain) -1; FS=1.
----------------------------------------------------------------------
```

The new "cold-bending buckling" margins appear near the end of the list of margins for Load Set 1, Subcase 1, as follows:

```
---------------------------------------------------------------------
 MARGINS FOR CURRENT DESIGN: LOAD CASE NO. 1, SUBCASE NO. 1
 MAR. MARGIN
 NO.  VALUE                  DEFINITION
17  7.05E-01 Cold-bending ring buckling, closed form soln; N=155;FS=1.1
18  6.55E-01 Cold-bending ring buckling, "skin"-ring module; N=93 ;FS=1.1
19  2.94E-03 Cold-bending ring buckling, skin-ring module; N=66 ;FS=1.1
-------------------------------------------------------------------------
```

```
*********************************
SOME COMMENTS ABOUT THE RESULTS:
*********************************
```

$\boxed{\text{COMMENTS 1}}$

The case to which the results listed above correspond is the "nasaortho" case described in the report:

"Optimum designs from PANDA2 of a uniformly axially compressed cylindrical shell with internal stringers and internal rings both with rectangular cross sections, and verification of the designs by BIGBOSOR4 and STAGS", David Bushnell, 31 March, 2009

In that report the internally stiffened shell was optimized before the cold-bending simulation capability existed. The shell (with imperfection amplitude, Wimp = plus and minus 0.125 inch) was re-optimized (2 SUPEROPTs) with the cold-bending simulation included. The results listed above correspond to the re-optimized "nasaortho" design.

The new optimum design is as follows:

```
--------------------------------------------------------------------------
 DIMENSIONS OF  CURRENT  DESIGN...
 VARIABLE   CURRENT
  NUMBER     VALUE              DEFINITION
    1     2.2773E+00       B(STR):stiffener spacing, b: STR seg=NA, layer=NA
    2     7.5902E-01      B2(STR):width of stringer base, b2 (must be > 0, see
    3     9.8977E-01       H(STR):height of stiffener (type H for sketch), h: S
    4     5.8191E-02    T(1 )(SKN):thickness for layer index no.(1 ): SKN seg=1
    5     8.6462E-02    T(2 )(STR):thickness for layer index no.(2 ): STR seg=3
    6     1.3974E+01       B(RNG):stiffener spacing, b: RNG seg=NA, layer=NA
    7     0.0000E+00      B2(RNG):width of ring base, b2 (zero is allowed): RNG
    8     9.7173E-01       H(RNG):height of stiffener (type H for sketch), h: R
    9     1.8576E-01    T(3 )(RNG):thickness for layer index no.(3 ): RNG seg=3

 ******************* DESIGN OBJECTIVE ******************
   CURRENT VALUE OF THE OBJECTIVE FUNCTION:
 VAR. STR/ SEG. LAYER   CURRENT
```

```
NO.  RNG  NO.   NO.    VALUE            DEFINITION
           0     0   1.070E+02   WEIGHT OF THE ENTIRE PANEL
  TOTAL WEIGHT OF SKIN                               =   5.7311E+01
  TOTAL WEIGHT OF SUBSTIFFENERS                      =   0.0000E+00
  TOTAL WEIGHT OF STRINGERS                          =   3.7011E+01
  TOTAL WEIGHT OF RINGS                              =   1.2722E+01
  SPECIFIC WEIGHT (WEIGHT/AREA) OF STIFFENED PANEL=   1.0325E-02
------------------------------------------------------------------------------
```

The old optimum design (before cold-bending simulation) is as follows:

```
------------------------------------------------------------------------------
 DIMENSIONS OF  CURRENT  DESIGN...
 VARIABLE   CURRENT
  NUMBER     VALUE            DEFINITION
    1     1.8594E+00       B(STR):stiffener spacing, b: STR seg=NA, layer=NA
    2     6.1973E-01      B2(STR):width of stringer base, b2 (must be > 0, see
    3     8.8811E-01       H(STR):height of stiffener (type H for sketch), h: S
    4     4.9565E-02    T(1 )(SKN):thickness for layer index no.(1 ): SKN seg=1
    5     8.0641E-02    T(2 )(STR):thickness for layer index no.(2 ): STR seg=3
    6     1.1772E+01       B(RNG):stiffener spacing, b: RNG seg=NA, layer=NA
    7     0.0000E+00      B2(RNG):width of ring base, b2 (zero is allowed): RNG
    8     1.7544E+00       H(RNG):height of stiffener (type H for sketch), h: R
    9     8.9081E-02    T(3 )(RNG):thickness for layer index no.(3 ): RNG seg=3

 ******************** DESIGN OBJECTIVE *******************
   CURRENT VALUE OF THE OBJECTIVE FUNCTION:
 VAR. STR/ SEG. LAYER   CURRENT
 NO.  RNG  NO.   NO.     VALUE            DEFINITION
           0     0   9.983E+01   WEIGHT OF THE ENTIRE PANEL
  TOTAL WEIGHT OF SKIN                               =   4.8816E+01
  TOTAL WEIGHT OF SUBSTIFFENERS                      =   0.0000E+00
  TOTAL WEIGHT OF STRINGERS                          =   3.7935E+01
  TOTAL WEIGHT OF RINGS                              =   1.3075E+01
  SPECIFIC WEIGHT (WEIGHT/AREA) OF STIFFENED PANEL=   9.6290E-03
--------------------------------------------------------------------------------
```

The new optimum design is heavier, of course, WEIGHT = 107.0 lb vs 99.83 lb.
The ring is much "stockier" in the new design than in the old design:

new design:

```
    8     9.7173E-01       H(RNG):height of stiffener (type H for sketch), h: R
    9     1.8576E-01    T(3 )(RNG):thickness for layer index no.(3 ): RNG seg=3
```

old design:

```
    8     1.7544E+00       H(RNG):height of stiffener (type H for sketch), h: R
    9     8.9081E-02    T(3 )(RNG):thickness for layer index no.(3 ): RNG seg=3
```

.

COMMENTS 2

Comparing the cold-bending ring buckling modes from the two discretized single module models is of interest:

Segment 2 is the base under the ring and Segment 3 is the ring web.

buckling mode in Segments 2 & 3 from the cold-bending "skin"-ring module model (includes smeared stringers):

```
-------------------------------------------------------------------------
     NORMAL MODAL DISPLACEMENTS IN THE PANEL MODULE SHOWN ABOVE
            "SKIN"-RING PANEL MODULE HAS 4 SEGMENTS
         NUMBER OF HALF-WAVES IN THE CIRC. DIRECTION, n=  3
 NODE    Z         W        WD       WDD        U         V        WDDD
                  MODAL DISPLACEMENTS FOR SEGMENT NO. 2
  1  0.00E+00  4.92E-02 -7.05E-03 -1.89E-02 -4.54E-03 -3.57E-04 -1.03E-02
  2  0.00E+00  4.57E-02 -1.40E-02 -2.25E-02 -5.96E-03 -1.02E-03 -1.03E-02
  3  0.00E+00  3.95E-02 -2.25E-02 -2.61E-02 -7.70E-03 -1.55E-03 -1.03E-02
  4  0.00E+00  3.00E-02 -3.21E-02 -2.93E-02 -1.01E-02 -2.00E-03 -9.21E-03
  5  0.00E+00  1.70E-02 -4.30E-02 -3.28E-02 -1.34E-02 -1.63E-03 -9.92E-03
  6  0.00E+00  5.33E-18 -4.87E-02 -8.74E-17 -1.53E-02  0.00E+00  9.38E-02
  7  0.00E+00 -1.70E-02 -4.30E-02  3.28E-02 -1.34E-02  1.63E-03  9.38E-02
  8  0.00E+00 -3.00E-02 -3.21E-02  2.93E-02 -1.01E-02  2.00E-03 -9.92E-03
  9  0.00E+00 -3.95E-02 -2.25E-02  2.61E-02 -7.70E-03  1.55E-03 -9.21E-03
 10  0.00E+00 -4.57E-02 -1.40E-02  2.25E-02 -5.96E-03  1.02E-03 -1.03E-02
 11  0.00E+00 -4.92E-02 -7.05E-03  1.89E-02 -4.54E-03  3.57E-04 -1.03E-02

                  MODAL DISPLACEMENTS FOR SEGMENT NO. 3
```

1	-2.91E-02	-1.67E-02	-4.87E-02	-2.23E+00	-2.71E-18	-6.11E-20	4.42E+00
2	-1.26E-01	-3.26E-02	-2.52E-01	-1.80E+00	-2.68E-18	2.45E-19	4.42E+00
3	-2.23E-01	-6.56E-02	-4.06E-01	-1.37E+00	-2.64E-18	5.65E-19	4.42E+00
4	-3.21E-01	-1.12E-01	-5.42E-01	-1.42E+00	-2.59E-18	9.08E-19	-4.77E-01
5	-4.18E-01	-1.71E-01	-7.29E-01	-2.44E+00	-2.42E-18	1.27E-18	-1.04E+01
6	-5.15E-01	-2.53E-01	-9.41E-01	-1.93E+00	-2.13E-18	1.65E-18	5.23E+00
7	-6.12E-01	-3.54E-01	-1.16E+00	-2.66E+00	-1.60E-18	2.01E-18	-7.50E+00
8	-7.09E-01	-4.79E-01	-1.40E+00	-2.20E+00	-7.95E-19	2.27E-18	4.72E+00
9	-8.06E-01	-6.26E-01	-1.62E+00	-2.37E+00	9.07E-20	2.36E-18	-1.78E+00
10	-9.04E-01	-7.95E-01	-1.92E+00	-3.86E+00	9.88E-19	2.28E-18	-1.53E+01
11	-1.00E+00	-1.00E+00	-2.40E+00	-5.35E+00	1.82E-18	2.01E-18	-1.53E+01

Segment 2 is the base under the ring and Segment 3 is the ring web.

buckling mode in Segments 2 & 3 from the cold-bending skin-ring module model (stringers not present):

NORMAL MODAL DISPLACEMENTS IN THE PANEL MODULE SHOWN ABOVE
"SKIN"-RING PANEL MODULE HAS 4 SEGMENTS
NUMBER OF HALF-WAVES IN THE CIRC. DIRECTION, n= 3

NODE	Z	W	WD	WDD	U	V	WDDD
			MODAL DISPLACEMENTS FOR SEGMENT NO. 2				
1	0.00E+00	-4.32E-02	-9.43E-02	-3.29E-01	2.92E-03	3.95E-04	4.24E-01
2	0.00E+00	-8.96E-02	-1.64E-01	-1.80E-01	4.10E-03	3.64E-04	4.24E-01
3	0.00E+00	-1.58E-01	-2.01E-01	-3.22E-02	5.66E-03	2.23E-04	4.24E-01
4	0.00E+00	-2.30E-01	-1.14E-01	5.34E-01	7.82E-03	1.85E-04	1.62E+00
5	0.00E+00	-2.37E-01	3.30E-01	2.00E+00	1.07E-02	1.72E-04	4.21E+00
6	0.00E+00	-2.80E-17	6.80E-01	6.08E-06	1.24E-02	0.00E+00	-5.74E+00
7	0.00E+00	2.37E-01	3.30E-01	-2.00E+00	1.07E-02	-1.72E-04	-5.74E+00
8	0.00E+00	2.30E-01	-1.14E-01	-5.34E-01	7.82E-03	-1.85E-04	4.21E+00
9	0.00E+00	1.58E-01	-2.01E-01	3.22E-02	5.66E-03	-2.23E-04	1.62E+00
10	0.00E+00	8.96E-02	-1.64E-01	1.80E-01	4.10E-03	-3.64E-04	4.24E-01
11	0.00E+00	4.32E-02	-9.43E-02	3.29E-01	2.92E-03	-3.95E-04	4.24E-01
			MODAL DISPLACEMENTS FOR SEGMENT NO. 3				
1	-2.91E-02	3.21E-02	6.80E-01	2.39E-01	1.13E-17	4.82E-19	5.75E-02
2	-1.26E-01	9.97E-02	7.08E-01	2.44E-01	-4.14E-14	1.89E-12	5.75E-02
3	-2.23E-01	1.70E-01	7.32E-01	2.50E-01	6.43E-14	3.85E-12	5.75E-02
4	-3.21E-01	2.42E-01	7.61E-01	3.51E-01	4.34E-13	6.16E-12	1.04E+00
5	-4.18E-01	3.18E-01	8.18E-01	8.31E-01	1.76E-12	8.96E-12	4.94E+00
6	-5.15E-01	4.01E-01	8.97E-01	7.89E-01	4.31E-12	1.21E-11	-4.40E-01
7	-6.12E-01	4.92E-01	1.00E+00	1.37E+00	9.29E-12	1.51E-11	5.99E+00
8	-7.09E-01	5.96E-01	1.14E+00	1.38E+00	1.68E-11	1.69E-11	9.01E-02
9	-8.06E-01	7.13E-01	1.28E+00	1.64E+00	2.47E-11	1.69E-11	2.71E+00
10	-9.04E-01	8.45E-01	1.48E+00	2.41E+00	3.16E-11	1.48E-11	7.85E+00
11	-1.00E+00	1.00E+00	1.75E+00	3.17E+00	3.69E-11	1.09E-11	7.85E+00

Notice that in the mode shape for the discretized skin-ring module model (stringers neglected) the critical buckling mode is characterized mostly by the ring web cross section rotating at its root, producing significant antisymmetric normal deflections W in the ring base (Segment 2). The mode shape for the discretized "skin"-ring module model (smeared stringers included) exhibits much less deformation of Segment 2 and much more deformation of the ring web (Segment 3). From the list of margins above we see that the model in which the stringers are neglected produces the critical margin, which is to be expected.

COMMENTS 3

These comments pertain to the output from SUBROUTINE COLDBD.

a. The following output from SUBROUTINE COLDBD:

```
 Location of neutral axis for elastic material, DELAST=  9.3628E-02

 IBEND=    2
 Iteration=  1 Location of neutral axis, d=  6.0412E-02
 Iteration=  2 Location of neutral axis, d=  5.8127E-02
 Iteration=  3 Location of neutral axis, d=  5.7979E-02
 KOUNT,RCOLD,RADEND,ARCYL,DIFF=  1   3.2000E+01  6.6653E+01  4.8000E+01  2.7985E-01

 IBEND=    2
 Iteration=  1 Location of neutral axis, d=  5.2824E-02
```

```
 Iteration=  2 Location of neutral axis, d=  5.2521E-02
 KOUNT,RCOLD,RADEND,ARCYL,DIFF=  2  2.7522E+01  5.0708E+01  4.8000E+01  5.3403E-02

 IBEND=   2
 Iteration=  1 Location of neutral axis, d=  5.1601E-02
 Iteration=  2 Location of neutral axis, d=  5.1545E-02
 KOUNT,RCOLD,RADEND,ARCYL,DIFF=  3  2.6787E+01  4.8382E+01  4.8000E+01  7.8914E-03

 IBEND=   2
 Iteration=  1 Location of neutral axis, d=  7.4343E-02
 Iteration=  2 Location of neutral axis, d=  7.5316E-02
 Iteration=  3 Location of neutral axis, d=  7.5357E-02

 IBEND=   3
 Iteration=  1 Location of neutral axis, d=  5.2983E-02
 Iteration=  2 Location of neutral axis, d=  5.2302E-02
 Iteration=  3 Location of neutral axis, d=  5.2282E-02
 KOUNT,RCOLD,RADEND,ARCYL,DIFF=  4  2.6787E+01  4.9094E+01  4.8000E+01  2.2293E-02
-------------------------------------------------------------------------------
```

demonstrates the nested iteration loops for the determination of RCOLD in the outer iteration loop and d in the inner iteration loop. In particular, we want RCOLD to have a value such that, upon elastic spring-back, RADEND is close to ARCYL (ARCYL = ABS(RCYL), with ABS(RCYL) being an input datum provided by the PANDA2 user: RCYL = the radius of the fabricated cylindrical shell.

b. The following input from SUBROUTINE COLDBD:

```
----------------------------------------------------------
 E11LIN, E12LIN, E22LIN=  1.2088E+07  3.6264E+06  1.2088E+07
 Ring Web: IX,DIFF=  1  0.0000E+00
 Ring Web: IX,DIFF=  2  0.0000E+00
 Ring Web: IX,DIFF=  3  0.0000E+00
 Ring Web: IX,DIFF=  4  2.7726E-01
 Ring Web: IX,DIFF=  5  6.8951E-01
 Ring Web: IX,DIFF=  6  7.3218E-01
 Ring Web: IX,DIFF=  7  8.6633E-01
 Ring Web: IX,DIFF=  8  8.8521E-01
 Ring Web: IX,DIFF=  9  8.9942E-01
 Ring Web: IX,DIFF= 10  9.1051E-01
 Ring Web: IX,DIFF= 11  9.1937E-01
 Shell skin: DIFF=  0.0000E+00
----------------------------------------------------------
```

lists the ring web nodal point number, IX, and a quantity called "DIFF". "DIFF" is a measure of how far we are into the nonlinear (plastic) portion of the PANDA2-user-supplied stress-strain curve. DIFF = 0 signifies loading below the proportional limit of the material. IX increases from the panel skin (IX = 1) to the tip of the ring web (IX = NX = 11). The tip of the ring web coincides with the middle surface of the outstanding flange, if any.

c. The following output from SUBROUTINE COLDBD:

```
------------------------------------------------------------
 From "CUBIC": NWAVE, EIGVAL(NWAVE)=  1  3.9232E+01
 From "CUBIC": NWAVE, EIGVAL(NWAVE)=  2  1.0792E+01
 From "CUBIC": NWAVE, EIGVAL(NWAVE)=  3  5.5201E+00
 From "CUBIC": NWAVE, EIGVAL(NWAVE)=  4  3.6823E+00
 From "CUBIC": NWAVE, EIGVAL(NWAVE)=  5  2.8401E+00
 From "CUBIC": NWAVE, EIGVAL(NWAVE)=  6  2.3936E+00
 From "CUBIC": NWAVE, EIGVAL(NWAVE)=  7  2.1381E+00
 From "CUBIC": NWAVE, EIGVAL(NWAVE)=  8  1.9900E+00
 From "CUBIC": NWAVE, EIGVAL(NWAVE)=  9  1.9087E+00
 From "CUBIC": NWAVE, EIGVAL(NWAVE)= 10  1.8758E+00 <--critical value
 From "CUBIC": NWAVE, EIGVAL(NWAVE)= 11  1.8761E+00
-------------------------------------------------------
```

lists the eigenvalue for each circumferential wave number, NWAVE, generated by SUBROUTINE CUBIC.

d. The following output from SUBROUTINE COLDBD:

```
-----------------------------------------------------------
 BUCKLE=  1.8758E+00 WAVLEN=  9.7288E-01 NCRIT3=   10
 circumferential length of web used for buckling analysis, FL=  9.7288E+00
 number of circumferential halfwaves over the length CIRC=  155
```

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```
 circumferential spacing of the stringers=                        2.2773E+00
 circumferential half-wavelength of the critical buckling mode=  9.7288E-01
 Margin=  7.0525E-01  Cold-bending ring buckling, closed form soln; N=155;FS=1.1
 *** THE FOLLOWING COLD-BENDING BUCKLING MARGIN JUST COMPUTED:
Cold-bending ring buckling, closed form soln; N=155;FS=1.1
 ******** CONSTRAINT NO. 17; LOAD SET NO. 1; SUBCASE NO. 1
 End of computation of cold-bending ring buckling load factor
 in SUBROUTINE COLDBD.
-----------------------------------------------------------------
```

lists the critcal buckling load factor, BUCKLE, and the number of circumferential half-waves over the circumferential length, CIRC.

With NPRINT = 0 in the *.OPT file, the output from the new cold-bending buckling part of PANDA2 is as follows:

```
--------------------------------------------------------------------
 **** CHAPTER 26b: DESIGN PERTURBATION INDEX, IMOD=  0 ****

*** BEGIN SUBROUTINE COLDBD (COLD-BENDING RING BUCKLING) ****
 See Item No. 790 of the file, ...panda2/doc/panda2.news
 Buckling from COLDBD ("closed-form" solution) is Model no. 1

 BUCKLE=  1.8758E+00 WAVLEN=  9.7288E-01 NCRIT3=   10

 circumferential spacing of the stringers=                        2.2773E+00
 circumferential half-wavelength of the critical buckling mode=  9.7288E-01
 Margin=  7.0525E-01  Cold-bending ring buckling, closed form soln; N=155;FS=1.1
 End of computation of cold-bending ring buckling load factor
 in SUBROUTINE COLDBD.
 ***********************************************************



 ***** BEGIN DISCRETIZED "SKIN"-RING MODULE MODEL OF    *****
 *** COLD-BENDING BUCKLING OF RING (smeared stringers)    ***
 ***** This is Model No. 2 of cold-bending ring buckling *****
 circumferential waves over the circ.length,  4.8644E+00=  1
 ring cold buckling load factor from a discretized module=  6.4476E+00 (smeared stringers)
 circumferential waves over the circ.length,  4.8644E+00=  2
 ring cold buckling load factor from a discretized module=  2.4048E+00 (smeared stringers)
 circumferential waves over the circ.length,  4.8644E+00=  3
 ring cold buckling load factor from a discretized module=  1.8210E+00 (smeared stringers)
 circumferential waves over the circ.length,  4.8644E+00=  4
 ring cold buckling load factor from a discretized module=  1.8404E+00 (smeared stringers)

 circumferential spacing of the stringers=                        2.2773E+00
 circumferential half-wavelength of the critical buckling mode=  1.6215E+00


 **** BEGIN SUB. MODE ("SKIN"-RING MODULE COLD BENDING 1) ****
 Margin=  6.5544E-01  Cold-bending ring buckling, "skin"-ring module; N=93 ;FS=1.1
 End of computation of cold-bending ring buckling load factor
 in SUBROUTINE STRUCT from "skin"-ring discretized module.
 ***********************************************************

 ***** BEGIN DISCRETIZED  SKIN-RING  MODULE MODEL OF    *****
 ***   COLD-BENDING BUCKLING OF RING (no stringers)      ***
 ***** This is Model No. 3 of cold-bending ring buckling *****
 circumferential waves over the circ.length,  2.2773E+00=  1
 ring cold buckling load factor from a discretized module=  1.1032E+00 (no stringers)
 circumferential waves over the circ.length,  2.2773E+00=  2
 ring cold buckling load factor from a discretized module=  1.6198E+00 (no stringers)

 circumferential spacing of the stringers=                        2.2773E+00
 circumferential half-wavelength of the critical buckling mode=  2.2848E+00

 **** BEGIN SUB. MODE (SKIN-RING MODULE COLD BENDING 2) ****
 Margin=  2.9428E-03  Cold-bending ring buckling, skin-ring module; N=66 ;FS=1.1
 End of computation of cold-bending ring buckling load factor
 in SUBROUTINE STRUCT from skin-ring discretized module.
 ***********************************************************
--------------------------------------------------------------------
```

There is a new sample case directory: ...panda2/case/nasacoldbend .
This directory contains the file, nasacoldbend.tar, which is the case

described in this PANDA2.news item.

Table a2 (p. 31 of 33)

791. April, 2009

The "PANEL" processor, bospan.src, was modified. This processor creates BIGBOSOR4 "huge torus" models of a panel previously optimized by PANDA2. Before this modification bospan.src would generate "huge torus" models only for the portion of the shell or panel between adjacent rings. Now bospan.src permits a general buckling model in which the entire axial length of the shell is included in the model and the rings are smeared out. The choice of model has always been identified by an index called "ILOCAL". Previously ILOCAL could only have the values 0 and 1. Now a third value is permitted, ILOCAL = -1. The prompting file, ...panda2/execute/PROMPT.DAT was modified as follows:

```
---------------------------------------------------------------------
825.1 Enter ILOCAL=0 or 1 or -1 or -2(Type (H)elp), ILOCAL
825.2
      ILOCAL=0  (panel buckling) means that tangent stiffnesses will
      be used for the wall stiffnesses.  The Nx, Ny, Nxy distributions
      over the panel module cross section are those calculated in the
      Koiter branch of PANDA2, that is, Nx, Ny, Nxy are for the locally
      postbuckled panel. You will generally select NWAVE=1 axial
      halfwaves when you are asked to supply a value for NWAVE. The
      axial length of the shell is the length between adjacent rings.

      ILOCAL = 1 (local buckling) means that original stiffnesses will
      be used for the wall stiffnesses of the various segments in the
      panel module. The Nx, Ny, Nxy distributions over the panel module
      cross section are those calculated from SUBROUTINE FORCEX, that
      is, Nx, Ny, Nxy are for the panel with no local buckling. You
      will generally select NWAVE = number of axial halfwaves that
      corresponds to the minimum local buckling load factor, EIGOLD,
      computed by PANDA2. (See the *.OPM file). The axial length of the
      shell is the length between adjacent rings.

      ILOCAL = -1 (general buckling) The original stiffnesses are used
      for the panel skin with smeared rings [CY(i,j,5)]. The tangent
      stiffnesses are used for the stringer segments. The axial length
      of the shell model is the total length of the shell multiplied by
      the axial length modifyer, LENMOD. Rings are smeared in this model.

      ILOCAL = -2 (general buckling) The original stiffnesses are used
      for the shell skin with all stiffeners smeared [CS(i,j)]. The
      axial length of the shell model is the total length of the shell
      multiplied by the axial length modifier, LENMOD.
---------------------------------------------------------------------
```

The bospan.src library was modified as follows:

```
---------------------------------------------------------------------
      CALL DATUM(IFILE,825,1,2,ILOCAL,REALL,CHARAC,IOUT,0,1)
      IF (ILOCAL.EQ.1) THEN
         CALL MOVER(CX0,1,CX1,1,180)
         CALL MOVER(NXVAR0,1,NXVAR1,1,184)
         CALL MOVER(NYVAR0,1,NYVAR1,1,184)
         CALL MOVER(NXYVR0,1,NXYVR1,1,184)
      ELSE
         CALL MOVER(CX,1,CX1,1,180)
C BEG APR 2009
         IF (ILOCAL.EQ.-1) CALL MOVER(CY(1,1,5),1,CX1(1,1,1),1,36)
         IF (ILOCAL.EQ.-1) CALL MOVER(CY(1,1,5),1,CX1(1,1,2),1,36)
C END APR 2009
         CALL MOVER(NXVAR,1,NXVAR1,1,184)
         CALL MOVER(NYVAR,1,NYVAR1,1,184)
C BEG APR 2009
         IF (ILOCAL.EQ.-1) CALL MOVER(FNY,0,NYVAR1(1,1),1,23)
         IF (ILOCAL.EQ.-1) CALL MOVER(FNY,0,NYVAR1(1,2),1,23)
C END APR 2009
         CALL MOVER(NXYVAR,1,NXYVR1,1,184)
      ENDIF
```

(lines skipped to save space)

```
      RAVE =  100.*FLOAT(MULT)*AXIAL*FLONG/3.1415927
C BEG APR 2009
```

```
      IF (ISTIFF(2).NE.0.AND.ILOCAL.NE.-1)
     1       RAVE = 100.0*FLOAT(MULT)*B(2)/3.1415927
C END APR 2009
      RBEG = RAVE - CIRC/2. + B(1)/2.
---------------------------------------------------------------------
```

Table a2 (p.32 of 33)

792. April, 2009

A new PANDA2 processor called "bospn3" was created. This processor is executed via a new PANDA2 command, "panel3". The purpose of the new library, bospn3.src, is to set up a BIGBOSOR4 model of an optimized stiffened cylindrical shell with a weld land in it. bospn3.src was created starting from a copy of bospan.src. bospn3.src is similar to bospan.src. The new command, "panel3", corresponds to a new "*.com" file called "panel3.com", located in the directory, ...panda2/bin. Because there is a new command there is also a new version of the "*.com" file called "panda2.com", also located in the directory, ...panda2/bin. Because of the new library, "bospn3.src", there is a new version of makefile.linux and a new version of makefile.hp700. Also, new prompts were added to the file, ...panda2/execute/PROMPT.DAT.

The new prompts in the file, ...panda2/execute/PROMPT.DAT, are as follows:

```
-------------------------------------------------------------------
810.1 Enter control ILAND for weldland (0=none or 1=weldland)
810.2
      ILAND = 0 means this BOSOR4 model has no weldland segment.
      ILAND = 1 means this BOSOR4 model has one or more weldland
                segments.
-------------------------------------------------------------------
```

and

```
-------------------------------------------------------------------
781.0
      Next you will be asked to supply properties of the weld land:
      KLAND = number of BOSOR4-type segments in the weld land:
              If there is no extra stringer along the generator
              at the edges of the weld land, KLAND = 1
              If there is a Tee-shaped stringer, KLAND = 3
              If there is a rectangular stringer, KLAND = 2
      WLAND = width of the weld land in the circumferential direction.
      TLAND = thickness of the weld land (uniform)
      TWLAND= thickness of the web of the extra weld land stringer
      HWLAND= height of the web of the extra weld land stringer
      TFLAND= thickness of the outstanding flange of the weld land stringer
      WFLAND= width of the outstanding flange of the weld land stringer
      ECLAND= eccentricity of the weld land middle surface relative to
              the middle surface of the rest of the cylindrical shell

782.1 Number of BOSOR4-type segments in the weld land, KLAND
782.2
      KLAND = 1 if there are no "extra" stringers along its two
                generators (axially oriented edges)
      KLAND = 2 if there are extra edge stringers with rectangular
                cross sections
      KLAND = 3 if there are extra edge stringers with Tee-shaped
                cross sections

783.1 Width of the weld land, WLAND
783.2
      For NASA-type launch vehicles the width should be something
      like 4 inches.
      NOTE: in the BOSOR4-type model we assume no tapering of the
      weld land thickness. The weld land has uniform thickness.

784.1 Thickness of the weld land, TLAND
784.2
      We assume the thickness is uniform. No tapering accounted for
      in the BOSOR4-type model.

785.1 Thickness of "extra" weld land edge stringer web, TWLAND
785.2
      If KLAND > 1 there are "extra" stringers along the two
      axially oriented edges of the weld land, where the weld
      land is joined to the rest of the cylindrical shell. These
```

Table a2 (p. 33 of 33)

"extra" stringers may have either rectangular (KLAND = 2) or Tee-shaped (KLAND = 3) cross sections.

786.1 Height of "extra" weld land stringer web, HWLAND
786.2

If KLAND > 1 there are "extra" stringers along the two axially oriented edges of the weld land, where the weld land is joined to the rest of the cylindrical shell. These "extra" stringers may have either rectangular (KLAND = 2) or Tee-shaped (KLAND = 3) cross sections.

787.1 Thickness of outstanding flange of weld land stringer, TFLAND
787.2

If KLAND > 1 there are "extra" stringers along the two axially oriented edges of the weld land, where the weld land is joined to the rest of the cylindrical shell. These "extra" stringers may have either rectangular (KLAND = 2) or Tee-shaped (KLAND = 3) cross sections.

788.1 Width of outstanding flange of weld land stringer, WFLAND
788.2

If KLAND > 1 there are "extra" stringers along the two axially oriented edges of the weld land, where the weld land is joined to the rest of the cylindrical shell. These "extra" stringers may have either rectangular (KLAND = 2) or Tee-shaped (KLAND = 3) cross sections.

789.1 Eccentricity of the weld land outer surface, ECLAND
789.2

```
ECLAND = 0.0 means middle surface of weld land is flush with
             the middle surface of the rest of the cylindrical
             shell
ECLAND = positive means middle surface of the weld land lies
         inside the middle surface of the rest of the shell.
ECLAND = negative means middle surface of the weld lane lies
         outside the middle surface of the rest of the shell.
```

Units of ECLAND should be length (such as inches, for example).

End of Items 790-792 in PANDA2.NEWS (abridged here!)

Table a2(b)

RUN STREAM FOR OPTIMIZATION WITH COLD BENDING INCLUDED

```
The case is called "nasacoldbend"
==============================================================================
panda2log       (activate the PANDA2 commands)
begin           (supply starting design, material props, etc; nasacoldbend.BEG
                 Table a3)
setup           (PANDA2 gets matrix templates)
decide          (supply decision variables, bounds, etc.; nasacoldbend.DEC
                 Table a4)
mainsetup       (supply loading, strategy, analysis type, etc.; nasacoldbend.OPT
                 first part of Table a6, except ITYPE = 1 instead of 2)
superopt        (attempt to find "global" optimum design)
chooseplot      (choose what to plot vs design iterations)
diplot          (get postscript files, nasacoldbend.n.ps for plotting; Fig. a1)
superopt        (attempt to find "global" optimum design)
chooseplot      (choose what to plot vs design iterations)
diplot          (get postscript files, nasacoldbend.n.ps for plotting; Fig. a2)
change          (save the optimum design; nasacoldbend.CHG; Table a5)
(Edit the nasacoldbend.OPT file: Change NPRINT to -1, ITYPE to 1)
mainsetup       (supply loading, strategy, analysis type, etc.; nasacoldbend.OPT
                 first part of Table a6)
pandaopt        (obtain margins for the optimized design; nasacoldbend.OPM
                 Table a6)
(Edit the nasacoldbend.OPT file: Change ICONSV from 1 to -1)
mainsetup       (supply loading, strategy, analysis type, etc.; nasacoldbend.OPT
                 first part of Table a7)
pandaopt        (obtain margins for the optimized design; nasacoldbend.OPM
                 Table a7)
(Edit fhe nasacoldbend.OPT file: eliminate the second load set, change the
 amplitude of the initial general buckling modal imperfection to zero)
mainsetup       (supply loading, strategy, analysis type, etc.; nasacoldbend.OPT
                 first part of Table a8)
pandaopt        (obtain margins for the optimized design; nasacoldbend.OPM
                 Table a8
==============================================================================
```

Table a3 nasacoldbend.BEG (p.1 of 2)

```
       n        $ Do you want a tutorial session and tutorial output?
  68.75000      $ Panel length normal to the plane of the screen, L1
  150.7960      $ Panel length in the plane of the screen, L2
       r        $ Identify type of stiffener along L1 (N,T,J,Z,R,A,C,G)
  4.000000      $ stiffener spacing, b
  1.333000      $ width of stringer base, b2 (must be > 0, see Help)
 0.3000000      $ height of stiffener (type H for sketch), h
       n        $ Are the stringers cocured with the skin?
  1000000.      $ What force/(axial length) will cause web peel-off?
       n        $ Is the next group of layers to be a "default group" (12 layers!)?
         1      $ number of layers in the next group in Segment no.( 1)
       n        $ Can winding (layup) angles ever be decision variables?
         1      $ layer index (1,2,...), for layer no.( 1)
       y        $ Is this a new layer type?
 0.1000000      $ thickness for layer index no.( 1)
         0      $ winding angle (deg.) for layer index no.( 1)
         1      $ material index (1,2,...) for layer index no.( 1)
       n        $ Any more layers or groups of layers in Segment no.( 1)
       n        $ Is the next group of layers to be a "default group" (12 layers!)?
         1      $ number of layers in the next group in Segment no.( 2)
       n        $ Can winding (layup) angles ever be decision variables?
         1      $ layer index (1,2,...), for layer no.( 1)
       n        $ Is this a new layer type?
       n        $ Any more layers or groups of layers in Segment no.( 2)
       n        $ Is the next group of layers to be a "default group" (12 layers!)?
         1      $ number of layers in the next group in Segment no.( 3)
       n        $ Can winding (layup) angles ever be decision variables?
         2      $ layer index (1,2,...), for layer no.( 1)
       y        $ Is this a new layer type?
 0.1000000      $ thickness for layer index no.( 2)
         0      $ winding angle (deg.) for layer index no.( 2)
         2      $ material index (1,2,...) for layer index no.( 2)
       n        $ Any more layers or groups of layers in Segment no.( 3)
         1      $ choose external (0) or internal (1) stringers
       r        $ Identify type of stiffener along L2  (N, T, J, Z, R, A)
  4.000000      $ stiffener spacing, b
         0      $ width of ring base, b2 (zero is allowed)
 0.3000000      $ height of stiffener (type H for sketch), h
       n        $ Are the rings cocured with the skin?
       n        $ Is the next group of layers to be a "default group" (12 layers!)?
         1      $ number of layers in the next group in Segment no.( 3)
       n        $ Can winding (layup) angles ever be decision variables?
         3      $ layer index (1,2,...), for layer no.( 1)
       y        $ Is this a new layer type?
 0.1000000      $ thickness for layer index no.( 3)
         0      $ winding angle (deg.) for layer index no.( 3)
         3      $ material index (1,2,...) for layer index no.( 3)
       n        $ Any more layers or groups of layers in Segment no.( 3)
         1      $ choose external (0) or internal (1) rings
       y        $ Is the panel curved in the plane of the screen (Y for cyls.)?
  48.00000      $ Radius of curvature (cyl. rad.) in the plane of screen, R
       n        $ Is panel curved normal to plane of screen? (answer N)
       y        $ Is this material isotropic (Y or N)?
0.1100000E+08   $ Young's modulus,                  E( 1)
0.3000000       $ Poisson's ratio,                 NU( 1)
 4230769        $ transverse shear modulus,       G13( 1)
       0        $ Thermal expansion coeff.,     ALPHA( 1)
       0        $ residual stress temperature (positive),TEMPTUR( 1)
       y        $ Want to supply a stress-strain "curve" for this mat'l (H)?
 0.000000       $ strain coordinate for stress-strain "curve", strain( 1)
 0.000000       $ stress coordinate for stress-strain "curve", stress( 1)
       y        $ any more (strain, stress) pairs (Y or N)?
0.6363600E-02   $ strain coordinate for stress-strain "curve", strain( 2)
 70000.00       $ stress coordinate for stress-strain "curve", stress( 2)
       y        $ any more (strain, stress) pairs (Y or N)?
0.1272730E-01   $ strain coordinate for stress-strain "curve", strain( 3)
 100000.0       $ stress coordinate for stress-strain "curve", stress( 3)
       y        $ any more (strain, stress) pairs (Y or N)?
0.1909090E-01   $ strain coordinate for stress-strain "curve", strain( 4)
 110000.0       $ stress coordinate for stress-strain "curve", stress( 4)
       n        $ any more (strain, stress) pairs (Y or N)?
       n        $ Does cold bending include the outstanding ring flange?( 1)
 0.000000       $ ring web radial compression, FN1WEB( 1)
       y        $ Want to specify  maximum effective stress ?
 70000.00       $ Maximum allowable effective stress in material type( 1)
       n        $ Do you want to take advantage of "bending overshoot"?
0.9500000E-01   $ weight density (greater than 0!) of material type( 1)
       n        $ Is lamina cracking permitted along fibers (type H(elp))?
```

Table a3 (p.2 of 2)

```
      y          $ Is this material isotropic (Y or N)?
 0.1100000E+08 $ Young's modulus,                  E( 2)
 0.3000000       $ Poisson's ratio,                 NU( 2)
  4230769.       $ transverse shear modulus,       G13( 2)
       0         $ Thermal expansion coeff.,     ALPHA( 2)
       0         $ residual stress temperature (positive),TEMPTUR( 2)
    n            $ Want to supply a stress-strain "curve" for this mat'l? (N)
    y            $ Want to specify  maximum effective stress ?
  70000.00       $ Maximum allowable effective stress in material type( 2)
    n            $ Do you want to take advantage of "bending overshoot"?
 0.9500000E-01 $ weight density (greater than 0!) of material type( 2)
    n            $ Is lamina cracking permitted along fibers (type H(elp))?
    y            $ Is this material isotropic (Y or N)?
 0.1100000E+08 $ Young's modulus,                  E( 3)
 0.3000000       $ Poisson's ratio,                 NU( 3)
  4230769.       $ transverse shear modulus,       G13( 3)
       0         $ Thermal expansion coeff.,     ALPHA( 3)
       0         $ residual stress temperature (positive),TEMPTUR( 3)
    n            $ Want to supply a stress-strain "curve" for this mat'l? (N)
    y            $ Want to specify  maximum effective stress ?
  70000.00       $ Maximum allowable effective stress in material type( 3)
    n            $ Do you want to take advantage of "bending overshoot"?
 0.9500000E-01 $ weight density (greater than 0!) of material type( 3)
    n            $ Is lamina cracking permitted along fibers (type H(elp))?
       0         $ Prebuckling: choose 0=bending included; 2=use membrane theory
       1         $ Buckling: choose 0=simple support or 1=clamping
```

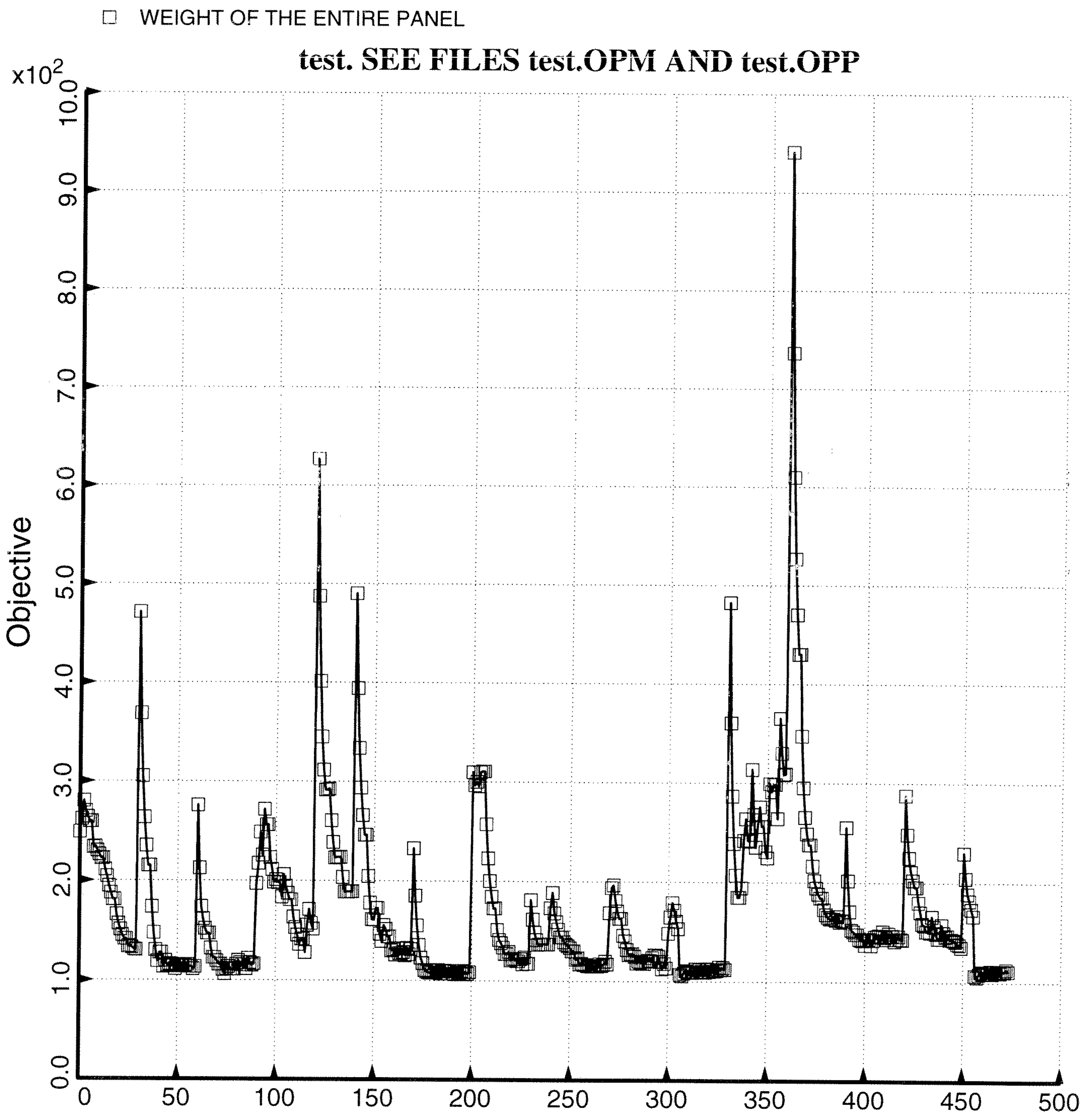
input for "BEGIN"

Table a4 nasacoldbend.DEC

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

input for "DECIDE"

(See the list at the end of Table a6 for the correspondance of decision variable number & what part of the structure that decision variable is.)



1st SUPEROPT

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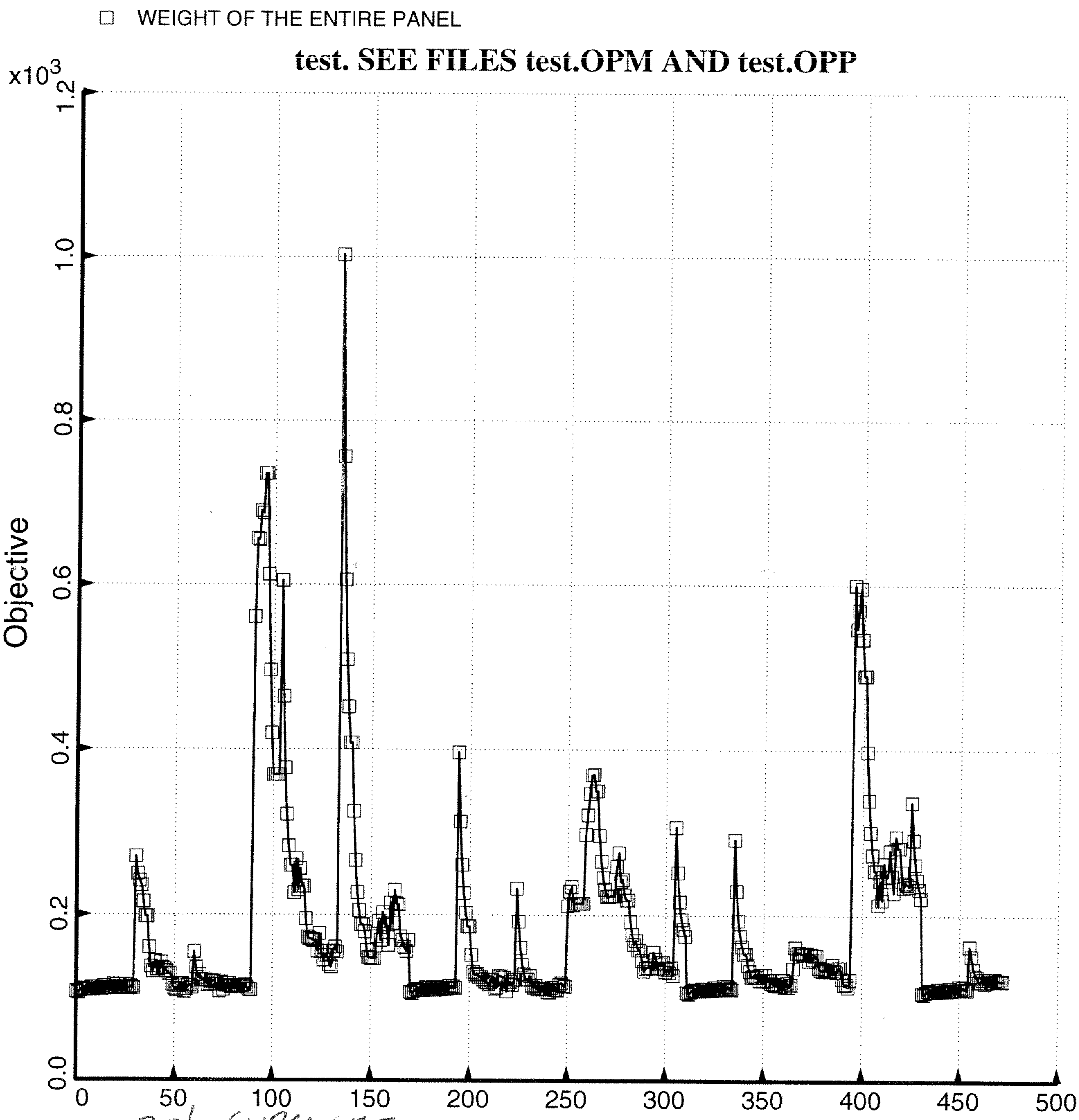
Fig a1.



2nd SUPEROPT

Fig. a2

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Table a5 nasacoldbend.CHG

```
    n           $ Do you want a tutorial session and tutorial output?
    y           $ Do you want to change any values in Parameter Set No. 1?
       1        $ Number of parameter to change (1, 2, 3, . .)
  2.277300      $ New value of the parameter
    y           $ Want to change any other parameters in this set?
       2        $ Number of parameter to change (1, 2, 3, . .)
 0.7590200      $ New value of the parameter
    y           $ Want to change any other parameters in this set?
       3        $ Number of parameter to change (1, 2, 3, . .)
 0.9897700      $ New value of the parameter
    y           $ Want to change any other parameters in this set?
       4        $ Number of parameter to change (1, 2, 3, . .)
 0.5819100E-01  $ New value of the parameter
    y           $ Want to change any other parameters in this set?
       5        $ Number of parameter to change (1, 2, 3, . .)
 0.8646200E-01  $ New value of the parameter
    y           $ Want to change any other parameters in this set?
       6        $ Number of parameter to change (1, 2, 3, . .)
 13.974000      $ New value of the parameter
    y           $ Want to change any other parameters in this set?
       8        $ Number of parameter to change (1, 2, 3, . .)
 0.9717300      $ New value of the parameter
    y           $ Want to change any other parameters in this set?
       9        $ Number of parameter to change (1, 2, 3, . .)
 0.1857600      $ New value of the parameter
    n           $ Want to change any other parameters in this set?
    n           $ Do you want to change values of "fixed" parameters?
    n           $ Do you want to change values of allowables?
```

input for "CHANGE"

Save the optimum design.

Table a6(1of4) nasacoldbend.OPM (imperfect ICONSV=1)

```
       n         $ Do you want a tutorial session and tutorial output?
-2219.000        $ Resultant (e.g. lb/in) normal to the plane of screen, Nx( 1)
       0         $ Resultant (e.g. lb/in) in the plane of the screen,    Ny( 1)
       0         $ In-plane shear in load set A,                       Nxy( 1)
       n         $ Does the axial load vary in the L2 direction?
       0         $ Applied axial moment resultant (e.g. in-lb/in), Mx( 1)
       0         $ Applied hoop moment resultant (e.g. in-lb/in), My( 1)
       y         $ Want to include effect of transverse shear deformation?
       0         $ IQUICK = quick analysis indicator (0 or 1)
       y         $ Do you want to vary M for minimum local buckling load?
       n         $ Do you want to choose a starting M for local buckling?
       y         $ Do you want to perform a "low-axial-wavenumber" search?
0.9990000        $ Factor of safety for general instability, FSGEN( 1)
0.9990000        $ Factor of safety for panel (between rings) instability, FSPAN( 1)
0.9990000        $ Minimum load factor for local buckling (Type H for HELP), FSLOC( 1)
 1.000000        $ Minimum load factor for stiffener buckling (Type H), FSBSTR( 1)
 1.000000        $ Factor of safety for stress, FSSTR( 1)
       y         $ Do you want "flat skin" discretized module for local buckling?
       n         $ Do you want wide-column buckling to constrain the design?
 0.000000        $ Resultant (e.g. lb/in) normal to the plane of screen, Nx0( 1)
 0.000000        $ Resultant (e.g. lb/in) in the plane of the screen,    Ny0( 1)
       0         $ Axial load applied along the (0=neutral plane), (1=panel skin)
 0.000000        $ Uniform applied pressure [positive upward. See H(elp)], p( 1)
 0.000000        $ Out-of-roundness, Wimpg1=(Max.diameter-Min.diam)/4, Wimpg1( 1)
 0.125000        $ Initial buckling modal general imperfection amplitude, Wimpg2( 1)
 0.000000        $ Initial buckling modal inter-ring imperfection amplitude,Wpan( 1)
0.1000000E-06    $ Initial local imperfection amplitude (must be positive), Wloc( 1)
       n         $ Do you want PANDA2 to change imperfection amplitudes (see H(elp))?( 1)
       y         $ Do you want PANDA2 to find the general imperfection shape?( 1)
 1.000000        $ Maximum allowable average axial strain (type H for HELP)( 1)
       N         $ Is there any thermal "loading" in this load set (Y/N)?
       Y         $ Do you want a "complete" analysis (type H for "Help")?
       Y         $ Want to provide another load set ?
-2219.000        $ Resultant (e.g. lb/in) normal to the plane of screen, Nx( 1)
       0         $ Resultant (e.g. lb/in) in the plane of the screen,    Ny( 1)
       0         $ In-plane shear in load set A,                       Nxy( 1)
       n         $ Does the axial load vary in the L2 direction?
       0         $ Applied axial moment resultant (e.g. in-lb/in), Mx( 1)
       0         $ Applied hoop moment resultant (e.g. in-lb/in), My( 1)
       y         $ Want to include effect of transverse shear deformation?
       0         $ IQUICK = quick analysis indicator (0 or 1)
       y         $ Do you want to vary M for minimum local buckling load?
       n         $ Do you want to choose a starting M for local buckling?
       y         $ Do you want to perform a "low-axial-wavenumber" search?
0.9990000        $ Factor of safety for general instability, FSGEN( 1)
0.9990000        $ Factor of safety for panel (between rings) instability, FSPAN( 1)
0.9990000        $ Minimum load factor for local buckling (Type H for HELP), FSLOC( 1)
 1.000000        $ Minimum load factor for stiffener buckling (Type H), FSBSTR( 1)
 1.000000        $ Factor of safety for stress, FSSTR( 1)
       y         $ Do you want "flat skin" discretized module for local buckling?
       n         $ Do you want wide-column buckling to constrain the design?
 0.000000        $ Resultant (e.g. lb/in) normal to the plane of screen, Nx0( 1)
 0.000000        $ Resultant (e.g. lb/in) in the plane of the screen,    Ny0( 1)
       0         $ Axial load applied along the (0=neutral plane), (1=panel skin)
 0.000000        $ Uniform applied pressure [positive upward. See H(elp)], p( 1)
 0.000000        $ Out-of-roundness, Wimpg1=(Max.diameter-Min.diam)/4, Wimpg1( 1)
-0.125000        $ Initial buckling modal general imperfection amplitude, Wimpg2( 1)
 0.000000        $ Initial buckling modal inter-ring imperfection amplitude,Wpan( 1)
0.1000000E-06    $ Initial local imperfection amplitude (must be positive), Wloc( 1)
       n         $ Do you want PANDA2 to change imperfection amplitudes (see H(elp))?( 1)
       y         $ Do you want PANDA2 to find the general imperfection shape?( 1)
 1.000000        $ Maximum allowable average axial strain (type H for HELP)( 1)
       N         $ Is there any thermal "loading" in this load set (Y/N)?
       Y         $ Do you want a "complete" analysis (type H for "Help")?
       N         $ Want to provide another load set ?
       N         $ Do you want to impose minimum TOTAL thickness of any segment?
       N         $ Do you want to impose maximum TOTAL thickness of any segment?
       N         $ Do you want to impose minimum TOTAL thickness of any segment?
       N         $ Do you want to impose maximum TOTAL thickness of any segment?
       N         $ Use reduced effective stiffness in panel skin (H(elp), Y or N)?
      -1         $ NPRINT= output index (-1=min. 0=good, 1=ok, 2=more, 3=too much)
       1         $ Index for type of shell theory (0 or 1 or 2), ISAND
       Y         $ Does the postbuckling axial wavelength of local buckles change?
       Y         $ Want to suppress general buckling mode with many axial waves?
       N         $ Do you want to double-check PANDA-type eigenvalues [type (H)elp]?
       1         $ Choose (0=transverse inextensional; 1=transverse extensional)
note →  1        $ Choose ICONSV = -1 or 0 or 1 or H(elp), ICONSV
       2         $ Choose type of analysis (ITYPE = 1 or 2 or 3 or 4 or 5)
```

nasacoldbend.OPT

Table ab (p. 294)

nasacoldbend.OPT

```
    Y          $ Do you want to prevent secondary buckling (mode jumping)?
    N          $ Do you want to use the "alternative" buckling solution?
      5        $ How many design iterations permitted in this run (5 to 25)?
 1.000000      $ MAXMAR. Plot only those margins less than MAXMAR (Type H)
    N          $ Do you want to reset total iterations to zero (Type H)?
      1        $ Index for objective (1=min. weight, 2=min. distortion)
 1.000000      $ FMARG (Skip load case with min. margin greater than FMARG)

************ END OF THE  nasacoldbend.OPT  FILE ***********
************ APRIL, 2009 VERSION OF PANDA2   ************
******** BEGINNING OF THE  nasacoldbend.OPM  FILE *********


****************************************
ITERATION NO., LOAD SET NO., SUBCASE NO. =    0    1    1     PANEL MIDLENGTH
****************************************
 ******************************************
 **** LOCAL MODE HAS STRINGER SIDESWAY ****
 ******************************************
0
MARGINS FOR CURRENT DESIGN: LOAD CASE NO. 1, SUBCASE NO. 1
MAR. MARGIN
NO.  VALUE                  DEFINITION
 1  1.45E-01 Local buckling from discrete model-1.,M=5   axial halfwaves;FS=0.99
 2  1.45E-01 Bending-torsion buckling; M=5  ;FS=0.999
 3  1.22E-01 Bending-torsion buckling: Koiter theory,M=5   axial halfwav;FS=0.99
 4  2.43E+00 eff.stress:matl=1,SKN,Dseg=2,node=6,layer=1,z=-0.0291; MID.;FS=1.
 5  5.75E-01 eff.stress:matl=2,STR,Dseg=3,node=11,layer=1,z=0.0432; MID.;FS=1.
 6  2.90E-01 (m=5   lateral-torsional buckling load factor)/(FS)-1;FS=0.999
 7  7.91E-01 Inter-ring bucklng, discrete model, n=15  circ.halfwaves;FS=0.999
 8  1.54E+00 eff.stress:matl=1,SKN,Iseg=1,at:n=1,layer=1,z=-0.0291;-MID.;FS=1.
 9  6.02E-01 eff.stress:matl=2,STR,Iseg=3,at:TIP,layer=1,z=0.;-MID.;FS=1.
10  2.48E-01 eff.stress:matl=3,RNG,Iseg=3,at:TIP,layer=1,z=0.;-MID.;FS=1.
11  8.07E-02 buckling margin stringer Iseg.3 . Local halfwaves=5  .MID.;FS=1.
12  7.47E-02 buckling margin stringer Iseg.3 . Local halfwaves=5  .NOPO;FS=1.
13  1.98E-01 buck.(SAND);simp-support general buck;M=2;N=7;slope=0.;FS=0.999
14  7.94E+00 buck.(SAND);rolling with smear rings; M=101;N=1;slope=0.;FS=0.999
15  8.95E-01 buck.(SAND);rolling only of stringers;M=40;N=0;slope=0.;FS=1.4
16  3.38E+02 buck.(SAND);rolling only axisym.rings;M=0;N=0;slope=0.;FS=1.4
17  7.05E-01 Cold-bending ring buckling, closed form soln; N=155;FS=1.1
18  6.55E-01 Cold-bending ring buckling, "skin"-ring module; N=93 ;FS=1.1
19  2.95E-03 Cold-bending ring buckling, skin-ring module; N=66 ;FS=1.1
20  5.85E+02 (Max.allowable ave.axial strain)/(ave.axial strain) -1; FS=1.


****************************************
ITERATION NO., LOAD SET NO., SUBCASE NO. =    0    1    2     AT RINGS
****************************************
 ******************************************
 **** LOCAL MODE HAS STRINGER SIDESWAY ****
 ******************************************
0
MARGINS FOR CURRENT DESIGN: LOAD CASE NO. 1, SUBCASE NO. 2
MAR. MARGIN
NO.  VALUE                  DEFINITION
 1  1.82E-01 Local buckling from discrete model-1.,M=5   axial halfwaves;FS=0.99
 2  1.81E-01 Bending-torsion buckling; M=5  ;FS=1.
 3  1.46E-01 Bending-torsion buckling: Koiter theory,M=5   axial halfwav;FS=0.99
 4  2.36E+00 eff.stress:matl=1,SKN,Dseg=2,node=11,layer=1,z=0.0291; RNGS;FS=1.
 5  6.91E-01 eff.stress:matl=2,STR,Dseg=3,node=11,layer=1,z=-0.0432; RNGS;FS=1.
 6  3.36E-01 (m=5   lateral-torsional buckling load factor)/(FS)-1;FS=0.999
 7  9.52E-02 Inter-ring bucklng, discrete model, n=43  circ.halfwaves;FS=0.999
 8  1.54E+00 eff.stress:matl=1,SKN,Iseg=1,at:n=1,layer=1,z=-0.0291;-RNGS;FS=1.
 9  7.43E-01 eff.stress:matl=2,STR,Iseg=3,at:TIP,layer=1,z=0.;-RNGS;FS=1.
10  2.44E-01 eff.stress:matl=3,RNG,Iseg=3,at:TIP,layer=1,z=0.;-RNGS;FS=1.
11  1.44E-01 buckling margin stringer Iseg.3 . Local halfwaves=5  .RNGS;FS=1.
12  1.28E+00 buck.(SAND);rolling with smear string;M=1;N=12;slope=0.;FS=0.999
13  7.91E+00 buck.(SAND);rolling with smear rings; M=101;N=1;slope=0.;FS=0.999
14  9.99E-01 buck.(SAND);rolling only of stringers;M=40;N=0;slope=0.;FS=1.4
15  9.33E+00 buck.(SAND);rolling only of   rings;  M=0;N=93;slope=0.;FS=1.4
16  3.38E+02 buck.(SAND);rolling only axisym.rings;M=0;N=0;slope=0.;FS=1.4
17  5.62E+02 (Max.allowable ave.axial strain)/(ave.axial strain) -1; FS=1.


****************************************
ITERATION NO., LOAD SET NO., SUBCASE NO. =    0    2    1     PANEL MIDLENGTH
****************************************
```

ICONSV = 1 (IMPERFECT)

Table a6 (p.3-14)

```
 ******************************************
 **** LOCAL MODE HAS STRINGER SIDESWAY ****
 ******************************************
0
 MARGINS FOR CURRENT DESIGN: LOAD CASE NO. 2, SUBCASE NO. 1
 MAR. MARGIN
 NO.  VALUE                 DEFINITION
 1  7.24E-02 Local buckling from discrete model-1.,M=3   axial halfwaves;FS=0.99
 2  7.23E-02 Bending-torsion buckling; M=3  ;FS=0.999
 3  7.45E-02 Bending-torsion buckling: Koiter theory,M=3   axial halfwav;FS=0.99
 4  1.62E+00 eff.stress:matl=1,SKN,Dseg=2,node=6,layer=1,z=0.0291; MID.;FS=1.
 5  5.52E+06 stringer popoff margin:(allowable/actual)-1, web 1  MID.;FS=1.
 6  1.69E+00 eff.stress:matl=2,STR,Dseg=3,node=1,layer=1,z=0.0432; MID.;FS=1.
 7 -1.07E-02 (m=1   lateral-torsional buckling load factor)/(FS)-1;FS=0.999
 8  1.18E-01 Inter-ring bucklng, discrete model, n=43  circ.halfwaves;FS=0.999
 9  1.56E+00 eff.stress:matl=1,SKN,Iseg=1,at:n=1,layer=1,z=0.0291;-MID.;FS=1.
10  6.02E-01 eff.stress:matl=2,STR,Iseg=3,at:TIP,layer=1,z=0.;-MID.;FS=1.
11  2.48E-01 eff.stress:matl=3,RNG,Iseg=3,at:TIP,layer=1,z=0.;-MID.;FS=1.
12  3.38E+00 buckling margin stringer Iseg.3 . Local halfwaves=5  .MID.;FS=1.
13  7.47E-02 buckling margin stringer Iseg.3 . Local halfwaves=5  .NOPO;FS=1.
14  1.98E-01 buck.(SAND);simp-support general buck;M=2;N=7;slope=0.;FS=0.999
15 -3.14E-02 buck.(SAND);rolling with smear string;M=1;N=46;slope=0.;FS=0.999
16  5.54E+00 buck.(SAND);rolling with smear rings; M=103;N=1;slope=0.;FS=0.999
17  8.95E-01 buck.(SAND);rolling only of stringers;M=40;N=0;slope=0.;FS=1.4
18  9.33E+00 buck.(SAND);rolling only of   rings;  M=0;N=93;slope=0.;FS=1.4
19  3.38E+02 buck.(SAND);rolling only axisym.rings;M=0;N=0;slope=0.;FS=1.4
20  4.12E+02 (Max.allowable ave.axial strain)/(ave.axial strain) -1; FS=1.

 ****************************************
 ITERATION NO., LOAD SET NO., SUBCASE NO. =    0    2    2     AT RINGS
 ****************************************
  ******************************************
  **** LOCAL MODE HAS STRINGER SIDESWAY ****
  ******************************************
0
 MARGINS FOR CURRENT DESIGN: LOAD CASE NO. 2, SUBCASE NO. 2
 MAR. MARGIN
 NO.  VALUE                 DEFINITION
 1  4.91E-02 Local buckling from discrete model-1.,M=1   axial halfwaves;FS=0.99
 2  4.80E-02 Bending-torsion buckling; M=1  ;FS=1.
 3  8.33E-02 Bending-torsion buckling: Koiter theory,M=1   axial halfwav;FS=0.99
 4  1.55E+00 eff.stress:matl=1,STR,Dseg=4,node=11,layer=1,z=0.0291; RNGS;FS=1.
 5  1.63E+00 eff.stress:matl=2,STR,Dseg=3,node=1,layer=1,z=0.0432; RNGS;FS=1.
 6 -2.10E-02 (m=1   lateral-torsional buckling load factor)/(FS)-1;FS=0.999
 7  7.92E-01 Inter-ring bucklng, discrete model, n=15  circ.halfwaves;FS=0.999
 8  1.52E+00 eff.stress:matl=1,SKN,Iseg=1,at:n=1,layer=1,z=0.0291;-RNGS;FS=1.
 9  7.43E-01 eff.stress:matl=2,STR,Iseg=3,at:TIP,layer=1,z=0.;-RNGS;FS=1.
10  2.44E-01 eff.stress:matl=3,RNG,Iseg=3,at:TIP,layer=1,z=0.;-RNGS;FS=1.
11  4.64E+00 buckling margin stringer Iseg.3 . Local halfwaves=5  .RNGS;FS=1.
12  5.52E+00 buck.(SAND);rolling with smear rings; M=103;N=1;slope=0.;FS=0.999
13  9.99E-01 buck.(SAND);rolling only of stringers;M=40;N=0;slope=0.;FS=1.4
14  3.38E+02 buck.(SAND);rolling only axisym.rings;M=0;N=0;slope=0.;FS=1.4
15  4.01E+02 (Max.allowable ave.axial strain)/(ave.axial strain) -1; FS=1.
 ***********  ALL 2 LOAD SETS PROCESSED  ***********
 **************************************************
```

ICONSV=1 (IMPERFECT)

optimum design

```
0
        SUMMARY OF INFORMATION FROM OPTIMIZATION ANALYSIS
 VAR. DEC. ESCAPE LINK. LINKED  LINKING    LOWER    CURRENT     UPPER        DEFINITION
  NO. VAR.  VAR.  VAR.    TO   CONSTANT    BOUND     VALUE      BOUND
   1   Y     N     N      0    0.00E+00  1.00E+00 2.2773E+00  1.00E+01        B(STR):stiffener s»
pacing, b: STR seg=NA, layer=NA
   2   N     N     Y      1    3.33E-01  0.00E+00 7.5902E-01  0.00E+00       B2(STR):width of st»
ringer base, b2 (must be > 0, see
   3   Y     N     N      0    0.00E+00  1.00E-02 9.8977E-01  2.00E+00        H(STR):height of s»
tiffener (type H for sketch), h:
   4   Y     Y     N      0    0.00E+00  1.00E-02 5.8191E-02  1.00E+00     T(1 )(SKN):thickness f»
or layer index no.(1 ): SKN seg=1
   5   Y     Y     N      0    0.00E+00  1.00E-02 8.6462E-02  1.00E+00     T(2 )(STR):thickness f»
or layer index no.(2 ): STR seg=3
   6   Y     N     N      0    0.00E+00  1.00E+00 1.3974E+01  3.00E+01        B(RNG):stiffener s»
pacing, b: RNG seg=NA, layer=NA
   7   N     N     N      0    0.00E+00  0.00E+00 0.0000E+00  0.00E+00       B2(RNG):width of ri»
ng base, b2 (zero is allowed): RN
   8   Y     N     N      0    0.00E+00  1.00E-02 9.7173E-01  2.00E+00        H(RNG):height of s»
tiffener (type H for sketch), h:
```

Table a6 (p.4 of 4)

```
    9   Y     Y     N      0    0.00E+00  1.00E-02 1.8576E-01  1.00E+00    T(3 )(RNG):thickness f»
or layer index no.(3 ): RNG seg=3
0
   CURRENT VALUE OF THE OBJECTIVE FUNCTION:
 VAR. STR/ SEG. LAYER    CURRENT
 NO.  RNG  NO.   NO.      VALUE            DEFINITION
            0      0    1.070E+02   WEIGHT OF THE ENTIRE PANEL

  TOTAL WEIGHT OF SKIN                                =   5.7312E+01
  TOTAL WEIGHT OF SUBSTIFFENERS                       =   0.0000E+00
  TOTAL WEIGHT OF STRINGERS                           =   3.7011E+01
  TOTAL WEIGHT OF RINGS                               =   1.2722E+01
  SPECIFIC WEIGHT (WEIGHT/AREA) OF STIFFENED PANEL=   1.0325E-02
 IN ORDER TO AVOID FALSE CONVERGENCE OF THE DESIGN, BE SURE TO
 RUN  PANDAOPT  MANY TIMES DURING AN OPTIMIZATION. INSPECT THE
 nasacoldbend.OPP  FILE AFTER EACH OPTIMIZATION RUN. OR BETTER YET,
 RUN SUPEROPT.
 ********************* END OF nasacoldbend.OPM FILE *****************
```

optimum design after 2 executions of SUPEROPT

Table a7 (1 of 3) nasacoldbend.OPM (imperfect - ICONSV = -1)

```
          n           $ Do you want a tutorial session and tutorial output?
  -2219.000           $ Resultant (e.g. lb/in) normal to the plane of screen, Nx( 1)
          0           $ Resultant (e.g. lb/in) in the plane of the screen,    Ny( 1)
          0           $ In-plane shear in load set A,                       Nxy( 1)
          n           $ Does the axial load vary in the L2 direction?
          0           $ Applied axial moment resultant (e.g. in-lb/in), Mx( 1)
          0           $ Applied hoop moment resultant (e.g. in-lb/in), My( 1)
          y           $ Want to include effect of transverse shear deformation?
          0           $ IQUICK = quick analysis indicator (0 or 1)
          y           $ Do you want to vary M for minimum local buckling load?
          n           $ Do you want to choose a starting M for local buckling?
          y           $ Do you want to perform a "low-axial-wavenumber" search?
  0.9990000           $ Factor of safety for general instability, FSGEN( 1)
  0.9990000           $ Factor of safety for panel (between rings) instability, FSPAN( 1)
  0.9990000           $ Minimum load factor for local buckling (Type H for HELP), FSLOC( 1)
   1.000000           $ Minimum load factor for stiffener buckling (Type H), FSBSTR( 1)
   1.000000           $ Factor of safety for stress, FSSTR( 1)
          y           $ Do you want "flat skin" discretized module for local buckling?
          n           $ Do you want wide-column buckling to constrain the design?
   0.000000           $ Resultant (e.g. lb/in) normal to the plane of screen, Nx0( 1)
   0.000000           $ Resultant (e.g. lb/in) in the plane of the screen,    Ny0( 1)
          0           $ Axial load applied along the (0=neutral plane), (1=panel skin)
   0.000000           $ Uniform applied pressure [positive upward. See H(elp)], p( 1)
   0.000000           $ Out-of-roundness, Wimpg1=(Max.diameter-Min.diam)/4, Wimpg1( 1)
   0.125000           $ Initial buckling modal general imperfection amplitude, Wimpg2( 1)
   0.000000           $ Initial buckling modal inter-ring imperfection amplitude,Wpan( 1)
 0.1000000E-06        $ Initial local imperfection amplitude (must be positive), Wloc( 1)
          n           $ Do you want PANDA2 to change imperfection amplitudes (see H(elp))?( 1)
          y           $ Do you want PANDA2 to find the general imperfection shape?( 1)
   1.000000           $ Maximum allowable average axial strain (type H for HELP)( 1)
          N           $ Is there any thermal "loading" in this load set (Y/N)?
          Y           $ Do you want a "complete" analysis (type H for "Help")?
          Y           $ Want to provide another load set ?
  -2219.000           $ Resultant (e.g. lb/in) normal to the plane of screen, Nx( 1)
          0           $ Resultant (e.g. lb/in) in the plane of the screen,    Ny( 1)
          0           $ In-plane shear in load set A,                       Nxy( 1)
          n           $ Does the axial load vary in the L2 direction?
          0           $ Applied axial moment resultant (e.g. in-lb/in), Mx( 1)
          0           $ Applied hoop moment resultant (e.g. in-lb/in), My( 1)
          y           $ Want to include effect of transverse shear deformation?
          0           $ IQUICK = quick analysis indicator (0 or 1)
          y           $ Do you want to vary M for minimum local buckling load?
          n           $ Do you want to choose a starting M for local buckling?
          y           $ Do you want to perform a "low-axial-wavenumber" search?
  0.9990000           $ Factor of safety for general instability, FSGEN( 1)
  0.9990000           $ Factor of safety for panel (between rings) instability, FSPAN( 1)
  0.9990000           $ Minimum load factor for local buckling (Type H for HELP), FSLOC( 1)
   1.000000           $ Minimum load factor for stiffener buckling (Type H), FSBSTR( 1)
   1.000000           $ Factor of safety for stress, FSSTR( 1)
          y           $ Do you want "flat skin" discretized module for local buckling?
          n           $ Do you want wide-column buckling to constrain the design?
   0.000000           $ Resultant (e.g. lb/in) normal to the plane of screen, Nx0( 1)
   0.000000           $ Resultant (e.g. lb/in) in the plane of the screen,    Ny0( 1)
          0           $ Axial load applied along the (0=neutral plane), (1=panel skin)
   0.000000           $ Uniform applied pressure [positive upward. See H(elp)], p( 1)
   0.000000           $ Out-of-roundness, Wimpg1=(Max.diameter-Min.diam)/4, Wimpg1( 1)
  -0.125000           $ Initial buckling modal general imperfection amplitude, Wimpg2( 1)
   0.000000           $ Initial buckling modal inter-ring imperfection amplitude,Wpan( 1)
 0.1000000E-06        $ Initial local imperfection amplitude (must be positive), Wloc( 1)
          n           $ Do you want PANDA2 to change imperfection amplitudes (see H(elp))?( 1)
          y           $ Do you want PANDA2 to find the general imperfection shape?( 1)
   1.000000           $ Maximum allowable average axial strain (type H for HELP)( 1)
          N           $ Is there any thermal "loading" in this load set (Y/N)?
          Y           $ Do you want a "complete" analysis (type H for "Help")?
          N           $ Want to provide another load set ?
          N           $ Do you want to impose minimum TOTAL thickness of any segment?
          N           $ Do you want to impose maximum TOTAL thickness of any segment?
          N           $ Do you want to impose minimum TOTAL thickness of any segment?
          N           $ Do you want to impose maximum TOTAL thickness of any segment?
          N           $ Use reduced effective stiffness in panel skin (H(elp), Y or N)?
         -1           $ NPRINT= output index (-1=min. 0=good, 1=ok, 2=more, 3=too much)
          1           $ Index for type of shell theory (0 or 1 or 2), ISAND
          Y           $ Does the postbuckling axial wavelength of local buckles change?
          Y           $ Want to suppress general buckling mode with many axial waves?
          N           $ Do you want to double-check PANDA-type eigenvalues [type (H)elp]?
          1           $ Choose (0=transverse inextensional; 1=transverse extensional)
note →   -1           $ Choose ICONSV = -1 or 0 or 1 or H(elp), ICONSV
          2           $ Choose type of analysis (ITYPE = 1 or 2 or 3 or 4 or 5)
```

nasacoldbend.OPT

Table a7 (p.2 of 3)

```
     Y          $ Do you want to prevent secondary buckling (mode jumping)?
     N          $ Do you want to use the "alternative" buckling solution?
        5       $ How many design iterations permitted in this run (5 to 25)?
  1.000000      $ MAXMAR. Plot only those margins less than MAXMAR (Type H)
     N          $ Do you want to reset total iterations to zero (Type H)?
        1       $ Index for objective (1=min. weight, 2=min. distortion)
  1.000000      $ FMARG (Skip load case with min. margin greater than FMARG)

 ************ END OF THE  nasacoldbend.OPT  FILE ***********
 ************ APRIL, 2009 VERSION OF PANDA2   ************
 ******** BEGINNING OF THE  nasacoldbend.OPM  FILE *********


 ****************************************
 ITERATION NO., LOAD SET NO., SUBCASE NO. =   0   1   1     PANEL MIDLENGTH
 ****************************************
  ******************************************
  **** LOCAL MODE HAS STRINGER SIDESWAY ****
  ******************************************
0
 MARGINS FOR CURRENT DESIGN: LOAD CASE NO. 1, SUBCASE NO. 1
 MAR. MARGIN
 NO.  VALUE                 DEFINITION
 1  2.37E-01 Local buckling from discrete model-1.,M=5   axial halfwaves;FS=0.99
 2  2.36E-01 Bending-torsion buckling; M=5  ;FS=0.999
 3  2.31E-01 Bending-torsion buckling: Koiter theory,M=5   axial halfwav;FS=0.99
 4  2.24E+00 eff.stress:matl=1,SKN,Dseg=2,node=6,layer=1,z=-0.0291; MID.;FS=1.
 5  1.12E+00 eff.stress:matl=2,STR,Dseg=3,node=11,layer=1,z=0.0432; MID.;FS=1.
 6  3.49E-01 (m=5   lateral-torsional buckling load factor)/(FS)-1;FS=0.999
 7  1.25E+00 Inter-ring bucklng, discrete model, n=15  circ.halfwaves;FS=0.999
 8  1.86E+00 eff.stress:matl=1,SKN,Iseg=2,at:n=1,layer=1,z=-0.0291;-MID.;FS=1.
 9  1.14E+00 eff.stress:matl=2,STR,Iseg=3,at:TIP,layer=1,z=0.;-MID.;FS=1.
10  1.50E+00 eff.stress:matl=3,RNG,Iseg=3,at:TIP,layer=1,z=0.;-MID.;FS=1.
11  7.27E-01 buck.(SAND);simp-support general buck;M=2;N=7;slope=0.;FS=0.999
12  7.81E+00 buck.(SAND);rolling with smear rings; M=103;N=1;slope=0.;FS=0.999
13  9.98E+02 buck.(SAND);rolling only axisym.rings;M=0;N=0;slope=0.;FS=1.4
14  7.05E-01 Cold-bending ring buckling, closed form soln; N=155;FS=1.1
15  6.55E-01 Cold-bending ring buckling, "skin"-ring module; N=93 ;FS=1.1
16  2.95E-03 Cold-bending ring buckling, skin-ring module; N=66 ;FS=1.1
17  5.23E+02 (Max.allowable ave.axial strain)/(ave.axial strain) -1; FS=1.


 ****************************************
 ITERATION NO., LOAD SET NO., SUBCASE NO. =   0   1   2     AT RINGS
 ****************************************
  ******************************************
  **** LOCAL MODE HAS STRINGER SIDESWAY ****
  ******************************************
0
 MARGINS FOR CURRENT DESIGN: LOAD CASE NO. 1, SUBCASE NO. 2
 MAR. MARGIN
 NO.  VALUE                 DEFINITION
 1  2.69E-01 Local buckling from discrete model-1.,M=5   axial halfwaves;FS=0.99
 2  2.67E-01 Bending-torsion buckling; M=5  ;FS=1.
 3  2.48E-01 Bending-torsion buckling: Koiter theory,M=5   axial halfwav;FS=0.99
 4  2.18E+00 eff.stress:matl=1,SKN,Dseg=1,node=1,layer=1,z=-0.0291; RNGS;FS=1.
 5  1.34E+00 eff.stress:matl=2,STR,Dseg=3,node=11,layer=1,z=0.0432; RNGS;FS=1.
 6  3.78E-01 (m=5   lateral-torsional buckling load factor)/(FS)-1;FS=0.999
 7  9.68E-01 Inter-ring bucklng, discrete model, n=32  circ.halfwaves;FS=0.999
 8  1.83E+00 eff.stress:matl=1,SKN,Iseg=2,at:n=1,layer=1,z=0.0291;-RNGS;FS=1.
 9  1.40E+00 eff.stress:matl=2,STR,Iseg=3,at:TIP,layer=1,z=0.;-RNGS;FS=1.
10  1.48E+00 eff.stress:matl=3,RNG,Iseg=3,at:TIP,layer=1,z=0.;-RNGS;FS=1.
11  1.49E+00 buck.(SAND);rolling with smear string;M=1;N=14;slope=0.;FS=0.999
12  7.78E+00 buck.(SAND);rolling with smear rings; M=103;N=1;slope=0.;FS=0.999
13  2.94E+01 buck.(SAND);rolling only of   rings;  M=0;N=93;slope=0.;FS=1.4
14  9.98E+02 buck.(SAND);rolling only axisym.rings;M=0;N=0;slope=0.;FS=1.4
15  5.05E+02 (Max.allowable ave.axial strain)/(ave.axial strain) -1; FS=1.


 ****************************************
 ITERATION NO., LOAD SET NO., SUBCASE NO. =   0   2   1     PANEL MIDLENGTH
 ****************************************
  ******************************************
  ******************************************
0
 MARGINS FOR CURRENT DESIGN: LOAD CASE NO. 2, SUBCASE NO. 1
 MAR. MARGIN
```

ICONSV = -1
(IMPERFECT)

Table a7 (p.3 of 3)

```
NO.  VALUE                 DEFINITION
 1  2.10E-01 Local buckling from discrete model-1.,M=5   axial halfwaves;FS=0.99
 2  2.15E-01 Local buckling from Koiter theory,M=5   axial halfwaves;FS=0.999
 3  1.90E+00 eff.stress:matl=1,STR,Dseg=4,node=11,layer=1,z=0.0291; MID.;FS=1.
 4  1.90E+00 eff.stress:matl=2,STR,Dseg=3,node=1,layer=1,z=-0.0432; MID.;FS=1.
 5  2.02E-01 (m=4   lateral-torsional buckling load factor)/(FS)-1;FS=0.999
 6  9.68E-01 Inter-ring bucklng, discrete model, n=30  circ.halfwaves;FS=0.999
 7  1.86E+00 eff.stress:matl=1,SKN,Iseg=2,at:n=1,layer=1,z=-0.0291;-MID.;FS=1.
 8  1.14E+00 eff.stress:matl=2,STR,Iseg=3,at:TIP,layer=1,z=0.;-MID.;FS=1.
 9  1.50E+00 eff.stress:matl=3,RNG,Iseg=3,at:TIP,layer=1,z=0.;-MID.;FS=1.
10  7.27E-01 buck.(SAND);simp-support general buck;M=2;N=7;slope=0.;FS=0.999
11  7.88E-01 buck.(SAND);rolling with smear string;M=1;N=36;slope=0.;FS=0.999
12  6.59E+00 buck.(SAND);rolling with smear rings; M=103;N=1;slope=0.;FS=0.999
13  2.94E+01 buck.(SAND);rolling only of   rings;  M=0;N=93;slope=0.;FS=1.4
14  9.98E+02 buck.(SAND);rolling only axisym.rings;M=0;N=0;slope=0.;FS=1.4
15  4.49E+02 (Max.allowable ave.axial strain)/(ave.axial strain) -1; FS=1.


****************************************
ITERATION NO., LOAD SET NO., SUBCASE NO. =    0   2   2     AT RINGS
****************************************
 ******************************************
 ******************************************
0
MARGINS FOR CURRENT DESIGN: LOAD CASE NO. 2, SUBCASE NO. 2
MAR. MARGIN
NO.  VALUE                 DEFINITION
 1  2.18E-01 Local buckling from discrete model-1.,M=5   axial halfwaves;FS=0.99
 2  2.05E-01 Local buckling from Koiter theory,M=5   axial halfwaves;FS=0.999
 3  1.80E+00 eff.stress:matl=1,STR,Dseg=4,node=11,layer=1,z=0.0291; RNGS;FS=1.
 4  9.59E+06 stringer popoff margin:(allowable/actual)-1, web 1  RNGS;FS=1.
 5  1.82E+00 eff.stress:matl=2,STR,Dseg=3,node=1,layer=1,z=-0.0432; RNGS;FS=1.
 6  2.01E-01 (m=5   lateral-torsional buckling load factor)/(FS)-1;FS=0.999
 7  1.25E+00 Inter-ring bucklng, discrete model, n=15  circ.halfwaves;FS=0.999
 8  1.83E+00 eff.stress:matl=1,SKN,Iseg=1,at:n=1,layer=1,z=0.0291;-RNGS;FS=1.
 9  1.40E+00 eff.stress:matl=2,STR,Iseg=3,at:TIP,layer=1,z=0.;-RNGS;FS=1.
10  1.48E+00 eff.stress:matl=3,RNG,Iseg=3,at:TIP,layer=1,z=0.;-RNGS;FS=1.
11  6.57E+00 buck.(SAND);rolling with smear rings; M=103;N=1;slope=0.;FS=0.999
12  9.98E+02 buck.(SAND);rolling only axisym.rings;M=0;N=0;slope=0.;FS=1.4
13  4.36E+02 (Max.allowable ave.axial strain)/(ave.axial strain) -1; FS=1.
***********  ALL 2 LOAD SETS PROCESSED  ***********
**************************************************


0
        SUMMARY OF INFORMATION FROM OPTIMIZATION ANALYSIS
VAR. DEC. ESCAPE LINK. LINKED  LINKING    LOWER    CURRENT     UPPER          DEFINITION
 NO. VAR.  VAR.  VAR.    TO    CONSTANT   BOUND     VALUE      BOUND
  1   Y     N     N      0    0.00E+00  1.00E+00 2.2773E+00  1.00E+01        B(STR):stiffener s»
pacing, b: STR seg=NA, layer=NA
  2   N     N     Y      1    3.33E-01  0.00E+00 7.5902E-01  0.00E+00      B2(STR):width of st»
ringer base, b2 (must be > 0, see
  3   Y     N     N      0    0.00E+00  1.00E-02 9.8977E-01  2.00E+00       H(STR):height of s»
tiffener (type H for sketch), h:
  4   Y     Y     N      0    0.00E+00  1.00E-02 5.8191E-02  1.00E+00  T(1 )(SKN):thickness f»
or layer index no.(1 ): SKN seg=1
  5   Y     Y     N      0    0.00E+00  1.00E-02 8.6462E-02  1.00E+00  T(2 )(STR):thickness f»
or layer index no.(2 ): STR seg=3
  6   Y     N     N      0    0.00E+00  1.00E+00 1.3974E+01  3.00E+01        B(RNG):stiffener s»
pacing, b: RNG seg=NA, layer=NA
  7   N     N     N      0    0.00E+00  0.00E+00 0.0000E+00  0.00E+00      B2(RNG):width of ri»
ng base, b2 (zero is allowed): RN
  8   Y     N     N      0    0.00E+00  1.00E-02 9.7173E-01  2.00E+00       H(RNG):height of s»
tiffener (type H for sketch), h:
  9   Y     Y     N      0    0.00E+00  1.00E-02 1.8576E-01  1.00E+00  T(3 )(RNG):thickness f»
or layer index no.(3 ): RNG seg=3
0
  CURRENT VALUE OF THE OBJECTIVE FUNCTION:
VAR. STR/ SEG. LAYER   CURRENT
NO.  RNG   NO.  NO.     VALUE          DEFINITION
            0    0    1.070E+02   WEIGHT OF THE ENTIRE PANEL

 TOTAL WEIGHT OF SKIN                                =    5.7312E+01
 TOTAL WEIGHT OF SUBSTIFFENERS                       =    0.0000E+00
 TOTAL WEIGHT OF STRINGERS                           =    3.7011E+01
 TOTAL WEIGHT OF RINGS                               =    1.2722E+01
 SPECIFIC WEIGHT (WEIGHT/AREA) OF STIFFENED PANEL=        1.0325E-02
IN ORDER TO AVOID FALSE CONVERGENCE OF THE DESIGN, BE SURE TO
```

ICONSV = 1 (IMPERFECT)

Optimum design obtained with ICONSV=1 (same as in the previous table)

Table a8 (p.1 of 2) nasacoldbend.OPM (perfect)

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

 ************ END OF THE  nasacoldbend.OPT  FILE ***********
 ************ APRIL, 2009 VERSION OF PANDA2   ************
 ******** BEGINNING OF THE  nasacoldbend.OPM  FILE *********


 *****************************************
 ITERATION NO., LOAD SET NO., SUBCASE NO. =    0    1    1     PANEL MIDLENGTH
 *****************************************
  *****************************************
  **** LOCAL MODE HAS STRINGER SIDESWAY ****
  *****************************************
0
 MARGINS FOR CURRENT DESIGN: LOAD CASE NO. 1, SUBCASE NO. 1
 MAR. MARGIN
 NO.  VALUE               DEFINITION
 1  2.94E-01 Local buckling from discrete model-1.,M=5   axial halfwaves;FS=0.99
 2  2.93E-01 Bending-torsion buckling; M=5  ;FS=0.999
 3  3.04E-01 Bending-torsion buckling: Koiter theory,M=5   axial halfwav;FS=0.99
 4  2.08E+00 eff.stress:matl=1,SKN,Dseg=2,node=6,layer=1,z=-0.0291; MID.;FS=1.
 5  1.92E+00 eff.stress:matl=2,STR,Dseg=3,node=11,layer=1,z=0.0432; MID.;FS=1.
 6  3.09E-01 (m=5   lateral-torsional buckling load factor)/(FS)-1;FS=0.999
 7  1.26E+00 Inter-ring bucklng, discrete model, n=17  circ.halfwaves;FS=0.999
 8  2.08E+00 eff.stress:matl=1,SKN,Iseg=2,at:n=6,layer=1,z=-0.0291;-MID.;FS=1.
```

nasacoldbend.OPT

Table a8 (p. 2/2)

```
  9  1.92E+00 eff.stress:matl=2,STR,Iseg=3,at:TIP,layer=1,z=0.;-MID.;FS=1.
 10  1.15E+01 eff.stress:matl=3,RNG,Iseg=3,at:TIP,layer=1,z=0.;-MID.;FS=1.
 11  1.18E+00 buck.(SAND);simp-support general buck;M=2;N=7;slope=0.;FS=0.999
 12  7.70E+00 buck.(SAND);rolling with smear rings; M=103;N=1;slope=0.;FS=0.999
 13  7.05E-01 Cold-bending ring buckling, closed form soln; N=155;FS=1.1
 14  6.55E-01 Cold-bending ring buckling, "skin"-ring module; N=93 ;FS=1.1
 15  2.95E-03 Cold-bending ring buckling, skin-ring module; N=66 ;FS=1.1
 16  4.83E+02 (Max.allowable ave.axial strain)/(ave.axial strain) -1; FS=1.


 ****************************************
 ITERATION NO., LOAD SET NO., SUBCASE NO. =    0    1    2      AT RINGS
 ****************************************
  ******************************************
  **** LOCAL MODE HAS STRINGER SIDESWAY ****
  ******************************************
0
 MARGINS FOR CURRENT DESIGN: LOAD CASE NO. 1, SUBCASE NO. 2
 MAR. MARGIN
 NO.  VALUE                    DEFINITION
 1  3.17E-01 Local buckling from discrete model-1.,M=5   axial halfwaves;FS=0.99
 2  3.15E-01 Bending-torsion buckling; M=5  ;FS=1.
 3  3.10E-01 Bending-torsion buckling: Koiter theory,M=5   axial halfwav;FS=0.99
 4  2.00E+00 eff.stress:matl=1,STR,Dseg=4,node=11,layer=1,z=0.0291; RNGS;FS=1.
 5  1.99E+00 eff.stress:matl=2,STR,Dseg=3,node=1,layer=1,z=-0.0432; RNGS;FS=1.
 6  3.17E-01 (m=5   lateral-torsional buckling load factor)/(FS)-1;FS=0.999
 7  1.26E+00 Inter-ring bucklng, discrete model, n=17  circ.halfwaves;FS=0.999
 8  2.07E+00 eff.stress:matl=1,SKN,Iseg=2,at:n=6,layer=1,z=0.0291;-RNGS;FS=1.
 9  2.06E+00 eff.stress:matl=2,STR,Iseg=3,at:ROOT,layer=1,z=0.;-RNGS;FS=1.
10  1.12E+01 eff.stress:matl=3,RNG,Iseg=3,at:TIP,layer=1,z=0.;-RNGS;FS=1.
11  7.62E+00 buck.(SAND);rolling with smear rings; M=103;N=1;slope=0.;FS=0.999
12  4.68E+02 (Max.allowable ave.axial strain)/(ave.axial strain) -1; FS=1.
 ***********  ALL 1 LOAD SETS PROCESSED  ***********
 ****************************************************


0
          SUMMARY OF INFORMATION FROM OPTIMIZATION ANALYSIS
 VAR. DEC. ESCAPE LINK. LINKED  LINKING    LOWER     CURRENT     UPPER         DEFINITION
  NO. VAR.  VAR.   VAR.    TO   CONSTANT   BOUND      VALUE      BOUND
   1   Y     N      N      0    0.00E+00  1.00E+00  2.2773E+00  1.00E+01          B(STR):stiffener s»
pacing, b: STR seg=NA, layer=NA
   2   N     N      Y      1    3.33E-01  0.00E+00  7.5902E-01  0.00E+00         B2(STR):width of st»
ringer base, b2 (must be > 0, see
   3   Y     N      N      0    0.00E+00  1.00E-02  9.8977E-01  2.00E+00          H(STR):height of s»
tiffener (type H for sketch), h:
   4   Y     Y      N      0    0.00E+00  1.00E-02  5.8191E-02  1.00E+00     T(1 )(SKN):thickness f»
or layer index no.(1 ): SKN seg=1
   5   Y     Y      N      0    0.00E+00  1.00E-02  8.6462E-02  1.00E+00     T(2 )(STR):thickness f»
or layer index no.(2 ): STR seg=3
   6   Y     N      N      0    0.00E+00  1.00E+00  1.3974E+01  3.00E+01          B(RNG):stiffener s»
pacing, b: RNG seg=NA, layer=NA
   7   N     N      N      0    0.00E+00  0.00E+00  0.0000E+00  0.00E+00         B2(RNG):width of ri»
ng base, b2 (zero is allowed): RN
   8   Y     N      N      0    0.00E+00  1.00E-02  9.7173E-01  2.00E+00          H(RNG):height of s»
tiffener (type H for sketch), h:
   9   Y     Y      N      0    0.00E+00  1.00E-02  1.8576E-01  1.00E+00     T(3 )(RNG):thickness f»
or layer index no.(3 ): RNG seg=3
0
  CURRENT VALUE OF THE OBJECTIVE FUNCTION:
 VAR. STR/ SEG. LAYER   CURRENT
 NO.  RNG  NO.   NO.     VALUE            DEFINITION
            0     0    1.070E+02   WEIGHT OF THE ENTIRE PANEL

  TOTAL WEIGHT OF SKIN                                   =     5.7312E+01
  TOTAL WEIGHT OF SUBSTIFFENERS                          =     0.0000E+00
  TOTAL WEIGHT OF STRINGERS                              =     3.7011E+01
  TOTAL WEIGHT OF RINGS                                  =     1.2722E+01
  SPECIFIC WEIGHT (WEIGHT/AREA) OF STIFFENED PANEL=            1.0325E-02
 IN ORDER TO AVOID FALSE CONVERGENCE OF THE DESIGN, BE SURE TO
 RUN  PANDAOPT  MANY TIMES DURING AN OPTIMIZATION. INSPECT THE
 nasacoldbend.OPP  FILE AFTER EACH OPTIMIZATION RUN. OR BETTER YET,
 RUN SUPEROPT.
 ******************** END OF nasacoldbend.OPM FILE ****************
```

Optimum design after 2 executions of SUPEROPT.

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

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

Huge torus model (BIGBOSOR4)

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

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

PANEL3 is like PANEL
PANEL3 has welds added

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

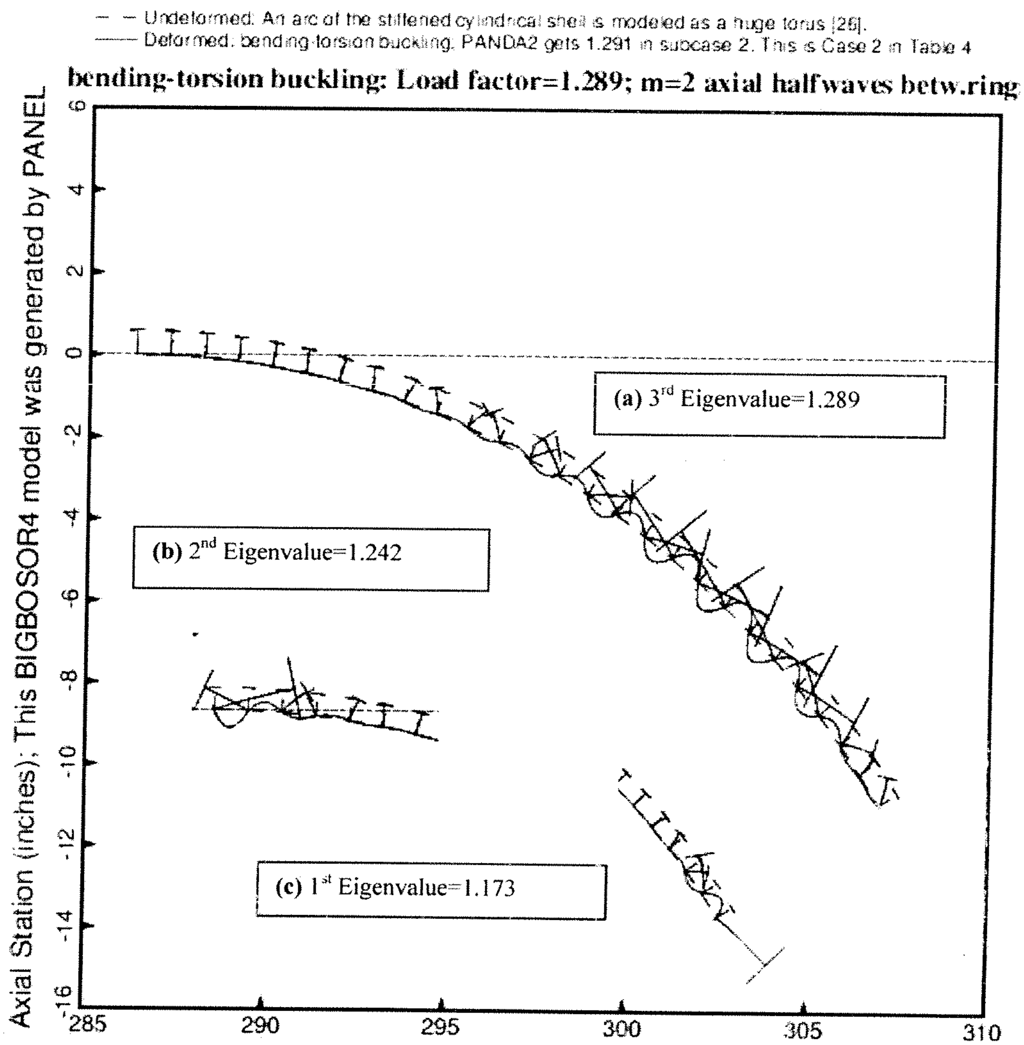

FIG. 20b BIGBOSOR4 [14] model of buckling between rings; Radius (inche

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