20 April, 2009
From the file, ...panda2/doc/panda2.news :

790. April, 2009

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

in which N is the number of circumferential halfwaves in the critical buckling mode. 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 undeformed 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,
      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
  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 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)

```
C BEG APR 2009
      COMMON/CIJCLD/CXCOLD(6,6,5),CYCOLD(6,6,5),CY3CLD(6,6,11),
     1              CXCLD0(6,6,5),CXCLD1(6,6,5)
      COMMON/CNVARX/CNXVAR(23,8),CNYVAR(23,8)
      COMMON/NCRITX/NCRIT1,NCRIT2,NCRIT3,NCRITA,NCRITB,NCRITC
      COMMON/NCRITY/NCRIT4,NCRITD,NCRIT5,NCRITE
      COMMON/LOCATR/ILOCPR,ILOCBR,IRWCPR(98),IRWCBR(98),IIWPR,IIWBR
      COMMON/NCONDX/NCONDR
      COMMON/RING3R/D1R(98),D2R(98)
      COMMON/JUNCTR/IFIXBR(588),IFXBR(588),ITYPER(98)
      COMMON/FREEDG/IFREE
      COMMON/ORTA/IFLGG,KTM,KROOTS
      COMMON/COLBND/FLGCLD,FN1WEB,RCOLD
      COMMON/YCOLDX/YCOLD1(400),YCOLD2(400)
      DIMENSION DUMMYA(1000),DIAGR(*),EIGCLD(50),YCOLD(400),YCOLDS(400)
      DIMENSION WDDD9(23,8),WFLANG(2),WFLNG0(2),B2COLD(2),B2CLD0(2)
      DIMENSION WDDD10(23,8),WDDD11(23,8),BCOLD(2),BCOLD0(2)
      COMMON/MODL11/WW9(23,8),WD9(23,8),WDD9(23,8),
     1 UU9(23,8),VV9(23,8),VP9(23,8)
      COMMON/MODL12/WW10(23,8),WD10(23,8),WDD10(23,8),
     1 UU10(23,8),VV10(23,8),VP10(23,8)
      COMMON/MODL13/WW11(23,8),WD11(23,8),WDD11(23,8),
     1 UU11(23,8),VV11(23,8),VP11(23,8)
      COMMON/IFCTXX/IFCT13,IFCT14,IFCT15
      CHARACTER*3 CCN
      CHARACTER*7 CCN2
C23456789012345678901234567890123456789012345678901234567890123456789012
C END APR 2009

(lines skipped to save space)

C BEG APR 2009
        WRITE(IFILE,'(A,/,A,/,A,/,A,/,A,/,A,/,A)')
     1 ' CHAPTER 26 Compute local, inter-ring, general buckling load',
     1 '            factors from PANDA-type models [1B] and from',
     1 '            "alternative" (double-trigonometric series',
     1 '            expansion) models, Ref.[1G]. Also compute',
     1 '            sandwich wall behavior [1F], if applicable.',
     1 '            Also, compute buckling load factors appropriate',
     1 '            when substiffeners are present.'
C
        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
        WRITE(IFILE,'(A,/,A,/,A)')
     1 ' CHAPTER 27 Compute the objective function (e.g. WEIGHT).',
     1 ' CHAPTER 28 Present design, loading, and margins for the',
     1 '            current load set and subcase. (See Table 6 in [18])'
C END APR 2009

(lines skipped to save space)

C**********************************************************************
C END CALCULATION OF VARIOUS KINDS OF BUCKLING FROM PANDA-TYPE
C (CLOSED FORM) ANALYSIS
C**********************************************************************
         IF (ITYPE.EQ.1.AND.NPRT.GE.2)
     1    WRITE(IFILE,*)' AFTER BUCPAN: IMOD,INUMTT,ICONST=',
     1                                  IMOD,INUMTT,ICONST
C BEG APR 2009
C234567890123456789012345678901234567890123456789012345678901234567890123456789012
      EIGCLM = 10.E+16
      IF ((ISTIF(2).EQ.1.OR.ISTIF(2).EQ.3).AND.RCOLD.LT.10.E+16
     1 .AND.INSRNG.EQ.1.AND.ILOADS.EQ.1.AND.ICASE.EQ.1) THEN
 9270   CONTINUE
        ILABEL=9270
        IF (NPRT.GE.1) WRITE(IFILE,*)' LABEL NO. IN STRUCT=',ILABEL
        IF (NPRT.GE.1)
     1      WRITE(IFILE,'(/,/,/,/,A,/,A,/,A,/,A,/,A,/,A,/,A)')
     1' **************************************************************',
     1' **************************************************************',
     1' **************************************************************',
     1' ************          CHAPTER 26(b)           *****************',
     1' **************************************************************',
     1' **************************************************************',
     1' **************************************************************'
        IF (NPRT.GE.0) WRITE(IFILE,'(A,I3,A)')
     1' **** CHAPTER 26b: DESIGN PERTURBATION INDEX, IMOD=',IMOD,' ****'
        IF (NPRT.GE.1)
     1  WRITE(IFILE,'(/,A,/,A,/,A,/,A,/,A,/,A,/,A,/,A,/,A,/,A)')
     1 ' *************************************************************',
     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
        CALL COLDBD(IFILE,NPRT,IMOD,ILABEL,ILOADS,ICASE,INUMTT,ICAR,
     1   PCWORD,CPLOT,IADDCC,FSAFEP,CONMAX,IPOINC,ICONST,CONSTR,WORDB,
     1   MAXCON,ITYPE,CXCOLD,CYCOLD,CY3CLD,CXCLD0,CXCLD1,
     1   CNXVAR,CNYVAR,WAVCLD,KLAYER(1,1),ISBCLD)
C
        WFLANG(1) = W(1)
        WFLANG(2) = W(2)
        WFLNG0(1) = WW0(1)
        WFLNG0(2) = WW0(2)
        BCOLD(1)  = B(1)
        BCOLD(2)  = B(2)
        B2COLD(1) = B2(1)
        B2COLD(2) = B2(2)
        B2CLD0(1) = B20(1)
        B2CLD0(2) = B20(2)
        IF (FLGCLD.LT.0.1) WFLANG(2) = 0.01*W(2)
        IF (FLGCLD.LT.0.1) WFLNG0(2) = 0.01*WW0(2)
C
        CIRCLD = MIN(CIRC,5.0*WAVCLD)
        EIGCLM = 10.E+16
        IF (NPRT.GE.0) WRITE(IFILE,'(/,A,/,A,/,A)')
     1' ***** BEGIN DISCRETIZED "SKIN"-RING MODULE MODEL OF    *****',
     1' *** COLD-BENDING BUCKLING OF RING (smeared stringers)    ***',
     1' ***** This is Model No. 2 of cold-bending ring buckling *****'
C
        IF (IMOD.EQ.0) THEN
C
          DO 9272 NWAVE = 1,10
C
          DUMMY = 0.
          CALL MOVER(0.,0,DUMMYA,1,1000)
          IPRINT = 0
C
          CALL ARRYS2(IFILE,IWR,ILOCR,DSR,NWAVE,ASR,BSR,R,CIRCLD,
     1       DUMMYA,0,0,0,DUMMYA,DUMMYA,DUMMYA,DUMMYA,
     1       DUMMYA,DUMMYA,DUMMY,DUMMY,DUMMY,IPRINT,1,IMOD,
     1       DUMMY,ILABEL,
     1       B,B2,B0,B20,H,H0,WFLANG,WFLNG0,W2,W20,IZSTIF,ISTIF,
     1       NSEGR,I5R,M3R,NCONDR,D1R,D2R,IFIXBR,
     1       IFXBR,ITYPER,IMAXBR,KMAXBR,ILOCBR,
     1       IRWCBR,IIWBR,IDRWR,NBLKR,NGBKR,NKFR,
     1       DUMMYA,DUMMYA,DUMMYA,DUMMYA,DUMMYA,DUMMYA,
     1       CXCOLD,1,WFOUND,ISANDW,NLAYER,IFREE,
     1       KROOTS,TX0,DUMMYA,
```

```
     1       CY3CLD,INSRNG,IFAY,TY0,CYCOLD,NPRT,DUMMY,DUMMY,
     1       0,DUMMY,DUMMY,DUMMY,DUMMY,0,PEDG,
     1       CNXVAR,CNYVAR,DUMMYA,DUMMYA,DUMMYA,DUMMYA,DUMMYA)
C
          CALL EBAND2(IFILE,0,NWAVE,ILOCR,DIAGR,ASR,BSR,CRX,DRX,DIR,
     1     XR,YR,ZR,0,M3R,NBLKR,IDRWR,NGBKR,NKFR,IMAXBR,KMAXBR,1,
     1     IPV2R,IBVCR,1000,2,1,0,-1.E-16,DUMMY,IFLGG,KTM,KROOTS)
C
C234567890123456789012345678901234567890123456789012345678901234567890123456789012
          EIGCLD(NWAVE) = ROOTX(1)
C
          IF (NPRT.GE.0) WRITE(IFILE,'(A,1P,E12.4,A,I3,/,A,1P,E12.4,A)')
     1  ' circumferential waves over the circ.length,',CIRCLD,'=',NWAVE,
     1  ' ring cold buckling load factor from a discretized module=',
     1    EIGCLD(NWAVE),' (smeared stringers)'
C
          EIGCLM = MIN(EIGCLM,ABS(EIGCLD(NWAVE)))
C
          IF (NWAVE.GT.1) CALL TRANS3(M3R,YCOLD,YCOLDS)
          CALL TRANS1(M3R,YR,YCOLD)
          NWAVE1 = NWAVE - 1
          IF (NWAVE.GT.1.AND.EIGCLD(NWAVE).GT.EIGCLD(NWAVE1)) GO TO 9273
 9272     CONTINUE
 9273     CONTINUE
          EIGCLM = ABS(EIGCLD(NWAVE1))
          NCRITA = NWAVE1*CIRC/CIRCLD
          NCRIT1 = NWAVE1
          WAVLEN = CIRC/FLOAT(NCRITA)
          CALL TRANS3(M3R,YCOLDS,YCOLD1)
C
          IF (ISTIF(1).NE.0.AND.IMOD.EQ.0.AND.NPRT.GE.0) THEN
            WRITE(IFILE,'(/,A,1P,E12.4,/,A,1P,E12.4)')
     1' circumferential spacing of the stringers=                    ',
     1  B(1),
     1' circumferential half-wavelength of the critical buckling mode=',
     1  WAVLEN
          ENDIF
C
          CALL TRANS2(M3R,YCOLDS,YR)
          IF (NPRT.GE.0) WRITE(IFILE,'(/,A)')
     1' **** BEGIN SUB. MODE ("SKIN"-RING MODULE COLD BENDING 1) ****'
          CALL MODE(IFILE,NPRT,NSEGR,I5R,IWR,DSR,M3R,YR,ISKN13,1,
     1             2, ZPARTY,0.,CYCOLD,1,WPRES,EIGCLM,
     1             RMAX,ITIPPL,ICWBRG,IMOD,
     1             WW9,WD9,WDD9,UU9,VV9,VP9,ZREFRG,NWAVE1,FKNSRG(1),
     1             FKNDUM,ICRNRG,P,IFCT13,WDDD9,14,0,TY,2,1,
     1    INTSNG,RAD2,TY,IZSTIF,B,B2,H,WFLANG,W2,
     1    B0,B20,H0,WFLNG0,W20,ISTIF,INTEXT,IFAY,IBEAM,IONEST,
```

```
     1    AXIAL,CIRC,ICRIP,ISEGC,WRATIO,WTIPWS,WRATTP,
     1    WRATWB,WRATCN,WRWIDE,WIDLMM,PEDG,ISOGRD,RESULT,IFLGPP)
C
          IF (IFCT13.NE.0) THEN
             WRITE(IFILE,'(/,A,/,A,/,A,/,A,/,A,/)')
     1     ' ******* NOTE ******* NOTE ******* NOTE ******',
     1     ' Since the mode is FICTITIOUS, the discretized',
     1     ' "skin"-ring module cold-bending buckling model',
     1     ' will not be used.',
     1     ' ***** END NOTE *** END NOTE **** END NOTE ***'
          ENDIF
C
        ELSE
C      End of (IMOD.EQ.0) condition
C
          DUMMY = 0.
          CALL MOVER(0.,0,DUMMYA,1,1000)
          IPRINT = 0
C
          CALL ARRYS2(IFILE,IWR,ILOCR,DSR,NCRIT1,ASR,BSR,R,CIRCLD,
     1       DUMMYA,0,0,0,DUMMYA,DUMMYA,DUMMYA,DUMMYA,
     1       DUMMYA,DUMMYA,DUMMY,DUMMY,DUMMY,IPRINT,1,IMOD,
     1       DUMMY,ILABEL,
     1       B,B2,B0,B20,H,H0,WFLANG,WFLNG0,W2,W20,IZSTIF,ISTIF,
     1       NSEGR,I5R,M3R,NCONDR,D1R,D2R,IFIXBR,
     1       IFXBR,ITYPER,IMAXBR,KMAXBR,ILOCBR,
     1       IRWCBR,IIWBR,IDRWR,NBLKR,NGBKR,NKFR,
     1       DUMMYA,DUMMYA,DUMMYA,DUMMYA,DUMMYA,DUMMYA,
     1       CXCOLD,1,WFOUND,ISANDW,NLAYER,IFREE,
     1       KROOTS,TX0,DUMMYA,
     1       CY3CLD,INSRNG,IFAY,TY0,CYCOLD,NPRT,DUMMY,DUMMY,
     1       0,DUMMY,DUMMY,DUMMY,DUMMY,0,PEDG,
     1       CNXVAR,CNYVAR,DUMMYA,DUMMYA,DUMMYA,DUMMYA,DUMMYA)
C
          CALL TRANS2(M3R,YCOLD1,YR)
          CALL EBAND2(IFILE,0,NCRIT1,ILOCR,DIAGR,ASR,BSR,CRX,DRX,DIR,
     1     XR,YR,ZR,1,M3R,NBLKR,IDRWR,NGBKR,NKFR,IMAXBR,KMAXBR,1,
     1     IPV2R,IBVCR,1000,2,1,0,-1.E-16,DUMMY,IFLGG,KTM,KROOTS)
C
C23456789012345678901234567890123456789012345678901234567890123456789012
          EIGCLM = ROOTX(1)
C
          IF (NPRT.GE.2) WRITE(IFILE,'(A,1P,E12.4,A,I3,/,A,1P,E12.4,A)')
     1 ' circumferential waves over the circ.length,',CIRCLD,'=',NCRIT1,
     1  ' ring cold buckling load factor from a discretized module=',
     1    EIGCLM,' (smeared stringers)'
C
        ENDIF
```

```
C     End of IMOD condtion
C
C Constraint condition for ring cold-bending buckling (yes stringers):
        IF (IFCT13.NE.0) GO TO 9276
        INUMTT = INUMTT + 1
        FSAFTY = 1.1
        CALL CONVRF(FSAFTY,CCN2)
        CALL CONVRT(NCRITA,CCN)
        IF (IMOD.EQ.0.AND.(EIGCLM/FSAFTY).LT.MAXCON) THEN
          ICAR = ICAR + 1
          PCWORD(ICAR) =
     1   'Cold-bending ring buckling, "skin"-ring module'
          CPLOT(ICAR) = EIGCLM/FSAFTY - 1.
          IADDCC(ICAR) = 0
          FSAFEP(ICAR) = FSAFTY
        ENDIF
        IF (IMOD.EQ.0.AND.(EIGCLM/FSAFTY).GT.CONMAX) GO TO 9276
        IF (IMOD.EQ.1.AND.IPOINC(INUMTT).EQ.0) GO TO 9276
        ICONST = ICONST + 1
        IF (IMOD.EQ.0) IPOINC(INUMTT) = 1
        CONSTR(ICONST) = EIGCLM/FSAFTY
        WORDB(ICONST)=
     1   'Cold-bending ring buckling, "skin"-ring module; N='//CCN//
     1   ';FS='//CCN2
        IF (NPRT.GE.0) WRITE(IFILE,'(A,1P,E12.4,2X,A)')
     1 ' Margin=',CONSTR(ICONST)-1.,WORDB(ICONST)
C2345678901234567890123456789012345678901234567890123456789012345678901
        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
 9276 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 STRUCT from "skin"-ring discretized module.',
     1' *********************************************************'
C
        IF (ISTIF(1).EQ.0) GO TO 9284
C
        CIRCLD = MIN(CIRC,10.0*WAVCLD)
        CIRCLD = MIN(CIRCLD,B(1))
        EIGCLM = 10.E+16
        IF (NPRT.GE.0) WRITE(IFILE,'(/,A,/,A,/,A)')
```

```
     1' ***** BEGIN DISCRETIZED  SKIN-RING  MODULE MODEL OF    *****',
     1' ***   COLD-BENDING BUCKLING OF RING (no stringers)     ***',
     1' ***** This is Model No. 3 of cold-bending ring buckling *****'
C
        IF (IMOD.EQ.0) THEN
C
          DO 9277 NWAVE = 1,10
C
          DUMMY = 0.
          CALL MOVER(0.,0,DUMMYA,1,1000)
          IPRINT = 0
C
          CALL ARRYS2(IFILE,IWR,ILOCR,DSR,NWAVE,ASR,BSR,R,CIRCLD,
     1       DUMMYA,0,0,0,DUMMYA,DUMMYA,DUMMYA,DUMMYA,
     1       DUMMYA,DUMMYA,DUMMY,DUMMY,DUMMY,IPRINT,1,IMOD,
     1       DUMMY,ILABEL,
     1       B,B2,B0,B20,H,H0,WFLANG,WFLNG0,W2,W20,IZSTIF,ISTIF,
     1       NSEGR,I5R,M3R,NCONDR,D1R,D2R,IFIXBR,
     1       IFXBR,ITYPER,IMAXBR,KMAXBR,ILOCBR,
     1       IRWCBR,IIWBR,IDRWR,NBLKR,NGBKR,NKFR,
     1       DUMMYA,DUMMYA,DUMMYA,DUMMYA,DUMMYA,DUMMYA,
     1       CXCLD1,1,WFOUND,ISANDW,NLAYER,IFREE,
     1       KROOTS,TX0,DUMMYA,
     1       CY3CLD,INSRNG,IFAY,TY0,CYCOLD,NPRT,DUMMY,DUMMY,
     1       0,DUMMY,DUMMY,DUMMY,DUMMY,0,PEDG,
     1       CNXVAR,CNYVAR,DUMMYA,DUMMYA,DUMMYA,DUMMYA,DUMMYA)
C
          CALL EBAND2(IFILE,0,NWAVE,ILOCR,DIAGR,ASR,BSR,CRX,DRX,DIR,
     1     XR,YR,ZR,0,M3R,NBLKR,IDRWR,NGBKR,NKFR,IMAXBR,KMAXBR,1,
     1     IPV2R,IBVCR,1000,2,1,0,-1.E-16,DUMMY,IFLGG,KTM,KROOTS)
C
C234567890123456789012345678901234567890123456789012345678901234567890123456789012
          EIGCLD(NWAVE) = ROOTX(1)
C
          IF (NPRT.GE.0) WRITE(IFILE,'(A,1P,E12.4,A,I3,/,A,1P,E12.4,A)')
     1  ' circumferential waves over the circ.length,',CIRCLD,'=',NWAVE,
     1  ' ring cold buckling load factor from a discretized module=',
     1    EIGCLD(NWAVE),' (no stringers)'
C
          EIGCLM = MIN(EIGCLM,ABS(EIGCLD(NWAVE)))
C
          IF (NWAVE.GT.1) CALL TRANS3(M3R,YCOLD,YCOLDS)
          CALL TRANS1(M3R,YR,YCOLD)
          NWAVE1 = NWAVE - 1
          IF (NWAVE.GT.1.AND.EIGCLD(NWAVE).GT.EIGCLD(NWAVE1)) GO TO 9278
 9277     CONTINUE
 9278     CONTINUE
          EIGCLM = ABS(EIGCLD(NWAVE1))
```

```
         NCRITB = NWAVE1*CIRC/CIRCLD
         NCRIT2 = NWAVE1
         WAVLEN = CIRC/FLOAT(NCRITB)
         CALL TRANS3(M3R,YCOLDS,YCOLD2)
C
         IF (ISTIF(1).NE.0.AND.IMOD.EQ.0.AND.NPRT.GE.0) THEN
           WRITE(IFILE,'(/,A,1P,E12.4,/,A,1P,E12.4)')
     1' circumferential spacing of the stringers=                     ',
     1  B(1),
     1' circumferential half-wavelength of the critical buckling mode=',
     1  WAVLEN
         ENDIF
C
         CALL TRANS2(M3R,YCOLDS,YR)
         IF (NPRT.GE.0) WRITE(IFILE,'(/,A)')
     1' **** BEGIN SUB. MODE (SKIN-RING MODULE COLD BENDING 2) ****'
         CALL MODE(IFILE,NPRT,NSEGR,I5R,IWR,DSR,M3R,YR,ISKN14,1,
     1         2, ZPARTY,0.,CYCOLD,1,WPRES,EIGCLM,
     1         RMAX,ITIPPL,ICWBRG,IMOD,
     1         WW10,WD10,WDD10,UU10,VV10,VP10,ZREFRG,NWAVE1,FKNSRG(1),
     1         FKNDUM,ICRNRG,P,IFCT14,WDDD10,15,0,TY,2,1,
     1    INTSNG,RAD2,TY,IZSTIF,B,B2,H,WFLANG,W2,
     1    B0,B20,H0,WFLNG0,W20,ISTIF,INTEXT,IFAY,IBEAM,IONEST,
     1    AXIAL,CIRC,ICRIP,ISEGC,WRATIO,WTIPWS,WRATTP,
     1    WRATWB,WRATCN,WRWIDE,WIDLMM,PEDG,ISOGRD,RESULT,IFLGPP)
C
         IF (IFCT14.NE.0) THEN
            WRITE(IFILE,'(/,A,/,A,/,A,/,A,/,A,/)')
     1      ' ******* NOTE ******* NOTE ******* NOTE ******',
     1      ' Since the mode is FICTITIOUS, the discretized',
     1      ' skin-ring module cold-bending buckling model',
     1      ' will not be used.',
     1      ' ***** END NOTE *** END NOTE **** END NOTE ***'
         ENDIF
C
        ELSE
C      End of (IMOD.EQ.0) condition
C
         DUMMY = 0.
         CALL MOVER(0.,0,DUMMYA,1,1000)
         IPRINT = 0
C
         CALL ARRYS2(IFILE,IWR,ILOCR,DSR,NCRIT2,ASR,BSR,R,CIRCLD,
     1        DUMMYA,0,0,0,DUMMYA,DUMMYA,DUMMYA,DUMMYA,
     1        DUMMYA,DUMMYA,DUMMY,DUMMY,DUMMY,IPRINT,1,IMOD,
     1        DUMMY,ILABEL,
     1        B,B2,B0,B20,H,H0,WFLANG,WFLNG0,W2,W20,IZSTIF,ISTIF,
     1        NSEGR,I5R,M3R,NCONDR,D1R,D2R,IFIXBR,
```

```
     1        IFXBR,ITYPER,IMAXBR,KMAXBR,ILOCBR,
     1        IRWCBR,IIWBR,IDRWR,NBLKR,NGBKR,NKFR,
     1        DUMMYA,DUMMYA,DUMMYA,DUMMYA,DUMMYA,DUMMYA,
     1        CXCLD1,1,WFOUND,ISANDW,NLAYER,IFREE,
     1        KROOTS,TX0,DUMMYA,
     1        CY3CLD,INSRNG,IFAY,TY0,CYCOLD,NPRT,DUMMY,DUMMY,
     1        0,DUMMY,DUMMY,DUMMY,DUMMY,0,PEDG,
     1        CNXVAR,CNYVAR,DUMMYA,DUMMYA,DUMMYA,DUMMYA,DUMMYA)
C
          CALL TRANS2(M3R,YCOLD2,YR)
          CALL EBAND2(IFILE,0,NCRIT2,ILOCR,DIAGR,ASR,BSR,CRX,DRX,DIR,
     1      XR,YR,ZR,1,M3R,NBLKR,IDRWR,NGBKR,NKFR,IMAXBR,KMAXBR,1,
     1      IPV2R,IBVCR,1000,2,1,0,-1.E-16,DUMMY,IFLGG,KTM,KROOTS)
C
          IF (NPRT.GE.0) WRITE(IFILE,'(/,A)')
     1' **** BEGIN SUB. MODE (SKIN-RING MODULE COLD BENDING 2) ****'
          CALL MODE(IFILE,NPRT,NSEGR,I5R,IWR,DSR,M3R,YR,ISKN14,1,
     1         2, ZPARTY,0.,CYCOLD,1,WPRES,EIGCLM,
     1         RMAX,ITIPPL,ICWBRG,IMOD,
     1         WW10,WD10,WDD10,UU10,VV10,VP10,ZREFRG,NWAVE1,FKNSRG(1),
     1         FKNDUM,ICRNRG,P,IFCT14,WDDD10,15,0,TY,2,1,
     1    INTSNG,RAD2,TY,IZSTIF,B,B2,H,WFLANG,W2,
     1    B0,B20,H0,WFLNG0,W20,ISTIF,INTEXT,IFAY,IBEAM,IONEST,
     1    AXIAL,CIRC,ICRIP,ISEGC,WRATIO,WTIPWS,WRATTP,
     1    WRATWB,WRATCN,WRWIDE,WIDLMM,PEDG,ISOGRD,RESULT,IFLGPP)
C
C23456789012345678901234567890123456789012345678901234567890123456789012
          EIGCLM = ROOTX(1)
C
          IF (NPRT.GE.2) WRITE(IFILE,'(A,1P,E12.4,A,I3,/,A,1P,E12.4,A)')
     1 ' circumferential waves over the circ.length,',CIRCLD,'=',NCRIT2,
     1  ' ring cold buckling load factor from a discretized module=',
     1    EIGCLM,' (no stringers)'
C
        ENDIF
C     End of IMOD condition
C
C Constraint condition for ring cold-bending buckling (no stringers):
        IF (IFCT14.NE.0) GO TO 9282
        INUMTT = INUMTT + 1
        FSAFTY = 1.1
        CALL CONVRF(FSAFTY,CCN2)
        CALL CONVRT(NCRITB,CCN)
        IF (IMOD.EQ.0.AND.(EIGCLM/FSAFTY).LT.MAXCON) THEN
          ICAR = ICAR + 1
          PCWORD(ICAR) =
     1   'Cold-bending ring buckling, skin-ring module'
          CPLOT(ICAR) = EIGCLM/FSAFTY - 1.
```

```
            IADDCC(ICAR) = 0
            FSAFEP(ICAR) = FSAFTY
          ENDIF
          IF (IMOD.EQ.0.AND.(EIGCLM/FSAFTY).GT.CONMAX) GO TO 9282
          IF (IMOD.EQ.1.AND.IPOINC(INUMTT).EQ.0) GO TO 9282
          ICONST = ICONST + 1
          IF (IMOD.EQ.0) IPOINC(INUMTT) = 1
          CONSTR(ICONST) = EIGCLM/FSAFTY
          WORDB(ICONST)=
     1     'Cold-bending ring buckling, skin-ring module; N='//CCN//
     1     ';FS='//CCN2
          IF (NPRT.GE.0) WRITE(IFILE,'(A,1P,E12.4,2X,A)')
     1 ' Margin=',CONSTR(ICONST)-1.,WORDB(ICONST)
C23456789012345678901234567890123456789012345678901234567890123456789012
          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
 9282     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 STRUCT from skin-ring discretized module.',
     1' ***********************************************************'
C
 9284     CONTINUE
C
        ENDIF
C  End of "IF ((ISTIF(2).EQ.1.OR.ISTIF(2).EQ.3).AND.RCOLD.LT.10.E+16
C      1   .AND.ILOADS.EQ.1.AND.ICASE.EQ.1)" condition
C
C END APR 2009
C      IF (FNX.GE.0.0.AND.FNY.GE.0.0) GO TO 87
----------------------------------------------------------------------
```

Furthermore, three new subroutines were added to the struct.src library. A 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
C23456789012345678901234567890123456789012345678901234567890123456789012
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
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 |  | | |                                       | | |  |
C |  |   |                                       |   |  |
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 In the sketch above, "d" is the distance from the middle
C surface of the panel skin to the neutral axis.
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,
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 CXCLD1(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". (NOTE: The sub-stiffeners, if any, are ALWAYS
C smeared out in the cold-bending models.)
C
C23456789012345678901234567890123456789012345678901234567890123456789012
      DIMENSION XCOORD(100),FMPROD(100),RHIST(20)
      DIMENSION ETOTAL(100),EPLAST(100),FHOOP(100),SIGMA(100)
      DIMENSION EPROD(100),EIM(20),SIM(20),ETOTL2(100),EIGVAL(100)
      DIMENSION E11(100),E12(100),E22(100),G12(100),ASTF(3,3),BSTF(3,3)
      DIMENSION A11(100),A12(100),A13(100),A22(100),A23(100),A33(100)
      DIMENSION B11(100),B12(100),B13(100),B22(100),B23(100),B33(100)
      DIMENSION EIGALT(10),WORKSP(10),EVECT(50),ASTFD(3,3),BSTFD(3,3)
      DIMENSION PCWORD(*),CPLOT(*),IADDCC(*),IPOINC(*),CONSTR(*)
      DIMENSION WORDB(*),FSAFEP(*),ZCOORD(100),ETOTLZ(100)
      DIMENSION CXCOLD(6,6,5),CYCOLD(6,6,5),CY3CLD(6,6,11),CXCLD0(6,6,5)
      DIMENSION CNXVAR(23,8),CNYVAR(23,8),CXCLD1(6,6,5)
      DOUBLE PRECISION ASTFD,BSTFD,EIGALT,WORKSP,EVECT
      DOUBLE PRECISION CONST,CLIN,CQUAD,CCUBIK
      COMMON/GEOM1/AXIAL,CIRC,RCYL
      COMMON/GEOM2/BBB(2),B2(2),HH(2),WW(2),W2(2)
      COMMON/GEOM3/ISTIF(2),NLAYER(4,2),NSEG(2),INTEXT(2)
      COMMON/LAYER/MATL(90),LTYPE(99,5,2),TT(90),ANGLE(90)
      COMMON/MATER1/E1(20),E2(20),GGG(20),FFNU(20),DENS(20)
      COMMON/COLBND/FLGCLD,FN1WEB,RCOLD
      COMMON/RCLDSX/RCLDSV
      COMMON/NCRITX/NCRIT1,NCRIT2,NCRIT3,NCRITA,NCRITB,NCRITC
      COMMON/NCRITY/NCRIT4,NCRITD,NCRIT5,NCRITE
      COMMON/MATER2/STRAIN(20,20),STRESS(20,20)
      COMMON/THICK/TX(5),TY(5)
```

```
      COMMON/ALLCIJ/CX(6,6,5),CY(6,6,5),CS(6,6)
      COMMON/CSKINX/CSKIN(6,6),TSKINX(5),TSKINY(5)
      COMMON/GEOM2S/BSUBX(2),B2SUBX(2),HSUBX(2),WSUBX(2),W2SUBX(2)
      COMMON/SUBSTX/TSUB(2,4,2),HSUB(2,4,2),THSUB(2,4,2),BSUB(2,4,2)
      COMMON/GEOM3S/ISTFSB(2),NLAYSB(4,2),NSEGSB(2),INTXSB(2)
      COMMON/ALLSUB/CXXSUB(6,6,5)
      CHARACTER*3 CCN
      CHARACTER*7 CCN2
      CHARACTER*80 PCWORD,WORDB
      REAL MAXCON
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
      IF (ISTIF(2).NE.1.AND.ISTIF(2).NE.3) THEN
         WRITE(IFILE,'(A,/,A,/,A,/,A,I2)')
     1 ' The ring cross section is neither Tee-shaped nor rectangular.',
     1 ' You are allowed to simulate cold-bending only for "T" and "R"',
     1 ' ring cross sections. Therefore, ISTIF(2) must be either',
     1 ' 1 or 3. In your case, ISTIF(2) =',ISTIF(2)
         CALL ERREX
      ENDIF
      H = HH(2)
      WFLANG = 0.
      IF (ISTIF(2).EQ.1.AND.FLGCLD.GT.0.1) WFLANG = WW(2)
      B = BBB(2)
C
      NLAY = NLAYER(1,2)
      IF (NLAY.GT.1) THEN
         WRITE(IFILE,'(A,I2')
     1 ' Only one layer is allowed in the skin. NLAY=',NLAY
         CALL ERREX
      ENDIF
      K = LTYPE(1,1,1)
      TSKIN = TT(K)
      M = MATL(1)
C     WRITE(IFILE,'(A,/,2I6,1P,4E12.4)')
```

```
C    1' K,M,TSKIN,E1(M),E2(M),GGG(M)=',K,M,TSKIN,E1(M),E2(M),GGG(M)
      FN1 = FN1WEB
      EAXIAL = E1(M)
      EINPUT = E2(M)
      GELAST = GGG(M)
C
      CALL MOVER(STRAIN(1,M),1,EIM,1,20)
      CALL MOVER(STRESS(1,M),1,SIM,1,20)
C     WRITE(IFILE,'(A,/,1P,6E12.4)')
C    1' EIM(1),SIM(1),EIM(2),SIM(2),EIM(3),SIM(3)=',
C    1  EIM(1),SIM(1),EIM(2),SIM(2),EIM(3),SIM(3)
      NSS = 20
      DO 10 I = 2,20
         IF (SIM(I).LT.0.000001) THEN
            NSS = I - 1
            GO TO 11
         ENDIF
   10 CONTINUE
   11 CONTINUE
C
      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.'
C23456789012345678901234567890123456789012345678901234567890123456789012
         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
C234567890123456789012345678901234567890123456789012345678901234567890112
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
            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
C234567890123456789012345678901234567890123456789012345678901234567890l2
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
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
C234567890123456789012345678901234567890123456789012345678901234567890I2
      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
      IF (NPRT.GE.2) THEN
       WRITE(IFILE,'(/,A,I3,/,A)')
     1' Number of points on stress-strain curve, NSS =',NSS,
     1'   STRAIN       STRESS'
       DO 610 I = 1,NSS
         WRITE(IFILE,'(1P,2E12.4)') EIM(I),SIM(I)
  610  CONTINUE
       WRITE(IFILE,'(/,A,1P,E12.4,/,A,1P,E12.4)')
     1' ring spacing,          B(RNG)=                   ',B,
     1' skin thickness,         TSKIN=                   ',TSKIN
       WRITE(IFILE,'(A,1P,E12.4,/,A,1P,E12.4)')
     1' ring web height,       H(RNG)=                   ',H,
     1' ring web thickness,      TWEB=                   ',TWEB
       WRITE(IFILE,'(A,1P,E12.4,/,A,1P,E12.4)')
     1' ring flange width,     W(RNG)=                   ',WFLANG,
     1' ring flange thickness, TFLANG=                   ',TFLANG
       WRITE(IFILE,'(A,1P,E12.4,/,A,1P,E12.4)')
     1' cold-bending radius,    RCOLD=                   ',RCOLD,
     1' radius after springback,RADEND=                  ',RADEND
       WRITE(IFILE,'(A,1P,E12.4,/,A,1P,E12.4)')
     1' design radius of cylinder,RCYL=                  ',ABS(RCYL),
     1' At R =RCOLD: location d of the ring neutral axis=',D
       WRITE(IFILE,'(/,A,1P,E12.4,/,A,1P,E12.4,/,A,1P,E12.4)')
     1' ring web hoop force,     FWEB=                   ',FWEB,
     1' skin hoop force, SIGMA(1)*TSKIN*B=               ',FCESKN,
     1' flange hoop force, SIGMA(NX)*TFLANG*W(RNG)=      ',FCEFLG
```

```
        WRITE(IFILE,'(/,A,1P,E12.4,/,A,1P,E12.4)')
     1' force  integrated over the ring cross section=   ',FORCE,
     1' moment integrated over the ring cross section=   ',FMOMNT
C234567890123456789012345678901234567890123456789012345678901234567890
C
C Print out stress and strain distribution over the ring module cross
C section and compute the bending moment that creates this distribution.
C
        WRITE(IFILE,'(/,A,I3,A,/(1P,5E12.4))')
     1' x-coordinates for ',NX,' radial locations along the ring web:',
     1 (XCOORD(I), I=1,NX)
        WRITE(IFILE,'(/,A,I3,A,/(1P,5E12.4))')
     1' hoop strain for ',NX,' radial locations along the ring web:',
     1 (ETOTAL(I), I=1,NX)
        WRITE(IFILE,'(/,A,I3,A,/(1P,5E12.4))')
     1' hoop stress for ',NX,' radial locations along the ring web:',
     1 (SIGMA(I), I=1,NX)
        WRITE(IFILE,'(/,A,I3,A,/(1P,5E12.4))')
     1' hoop resultant for ',NX,' radial locations along the ring web:',
     1 (FHOOP(I), I=1,NX)
        WRITE(IFILE,'(/,A,1P,E12.4,/,A,1P,E12.4)')
     1' uniform hoop resultant in the shell skin=',SIGMA(1)*TSKIN,
     1' uniform hoop resultant in the outstanding flange=',
     1  SIGMA(NX)*TFLANG
       ENDIF
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
C FLGCLD (an input datum provided by the PANDA2 user) is zero
C if the ring outstanding flange is not present during the
C cold-bending process.
         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
      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
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.)
         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)
C  G   in-plane shear modulus
C
C  First, find the instantaneous moduli for the flange:
C
         SIG12 = 0.
         SIG1 =  0.
         DO 750 I = 2,NSS
            IF (ABS(ETOTAL(NX)).LT.EIM(I)) THEN
               II = I
               II1 = II - 1
               GO TO 751
            ENDIF
  750    CONTINUE
  751    CONTINUE
         SIDIFF = SIM(II) - SIM(II1)
         EIDIFF = EIM(II) - EIM(II1)
         SIG2 =SIM(II1) +SIDIFF*(ABS(ETOTAL(NX)) -EIM(II1))/EIDIFF
         FMULT = 1.0
         IF (ETOTAL(NX).LT.0.) FMULT = -1.0
         FN2F = FMULT*SIG2*TFLANG
         ES = SIG2/ABS(ETOTAL(NX))
         ETT = SIDIFF/EIDIFF
         CALL SMOOTH(NSS,ETOTAL(NX),II,EIM,SIM,EIM,ETT)
         ET = ETT
         SBAR = SQRT(SIG1*SIG1 + SIG2*SIG2 - SIG1*SIG2 + 3.*SIG12**2)
         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
          E22(NX) = cc/del
          EI  = E22(NX)*TFLANG*WFLANG**3/12.
C
C  Frequently used quantities:
C
          WF   = WFLANG
          RWEB = RCOLD
          S3   = -C**2*H**3*2.
          S26  = -C**2*H**3*H*5.
          S36  = -H**2*3.
          S212 = -H**2*H*8.
          S310 = -C**2*H**3*H**2*9.
          S320 = -H**2*H**2*15.
C
          ASTF(1,1) = ASTF(1,1) + S3*S3*EI +S36*S36*EI/RWEB**2
          ASTF(1,2) = ASTF(1,2) + S3*S26*EI + S36*S212*EI/RWEB**2
          ASTF(1,3) = ASTF(1,3) + S3*S310*EI + S36*S320*EI/RWEB**2
C
          ASTF(2,2) = ASTF(2,2) + S26*S26*EI + S212*S212*EI/RWEB**2
          ASTF(2,3) = ASTF(2,3) + S26*S310*EI + S212*S320*EI/RWEB**2
C
          ASTF(3,3) = ASTF(3,3) + S310*S310*EI + S320*S320*EI/RWEB**2
C
          BSTF(1,1) = BSTF(1,1)
     1      + S3*S3*FN2F*WF/C**2 + C**2*S36*S36*FN2F*WF**3/12.
          BSTF(1,2) = BSTF(1,2)
     1      + S3*S26*FN2F*WF/C**2 + C**2*S36*S212*FN2F*WF**3/12.
          BSTF(1,3) = BSTF(1,3)
     1      + S3*S310*FN2F*WF/C**2 + C**2*S36*S320*FN2F*WF**3/12.
C
          BSTF(2,2) = BSTF(2,2)
     1      + S26*S26*FN2F*WF/C**2 + C**2*S212*S212*FN2F*WF**3/12.
          BSTF(2,3) = BSTF(2,3)
     1      + S26*S310*FN2F*WF/C**2 + C**2*S212*S320*FN2F*WF**3/12.
C
          BSTF(3,3) = BSTF(3,3)
     1      + S310*S310*FN2F*WF/C**2 + C**2*S320*S320*FN2F*WF**3/12.
       ENDIF
C
       ASTFD(1,1) = ASTF(1,1)
       ASTFD(1,2) = ASTF(1,2)
       ASTFD(1,3) = ASTF(1,3)
       ASTFD(2,2) = ASTF(2,2)
       ASTFD(2,3) = ASTF(2,3)
       ASTFD(3,3) = ASTF(3,3)
C
       BSTFD(1,1) = BSTF(1,1)
```

```
      BSTFD(1,2) = BSTF(1,2)
      BSTFD(1,3) = BSTF(1,3)
      BSTFD(2,2) = BSTF(2,2)
      BSTFD(2,3) = BSTF(2,3)
      BSTFD(3,3) = BSTF(3,3)
C
      ASTFD(2,1) = ASTFD(1,2)
      ASTFD(3,1) = ASTFD(1,3)
      ASTFD(3,2) = ASTFD(2,3)

      BSTFD(2,1) = BSTFD(1,2)
      BSTFD(3,1) = BSTFD(1,3)
      BSTFD(3,2) = BSTFD(2,3)
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 determinant 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
C23456789012345678901234567890123456789012345678901234567890123456789012
C
C  Here's what we tried before we decided to use SUBROUTINE CUBIC:
C
C  Next, solve for the three eigenvalues. Use SUBROUTINE GSEIG,
C  which is also used for extracting eigenvalues for the alternative
C  (double trig. series) buckling solution in PANDA2. This eigensystem
C  is much, much smaller than that for the alternative buckling
C  solution in PANDA2. Here we have only three roots (system
C  rank = 3, that is, MNTOT = 3).
C
C  Use generalized Jacobi iteration for current design computations...
C
C     MNTOT = 3
C     CALL GSEIG (MNTOT, ASTFD, BSTFD, EIGALT, EVECT, WORKSP, IPRINT)
C     IF (MNTOT.LT.0) THEN
C        WRITE(IFILE,'(A,/,A,I4,/,A)')
C    1 ' ***** WARNING ********** WARNING ********* WARNING *****',
C    1 ' SUB. GSEIG FAILED TO OBTAIN EIGENVALUE: MNTOT=',MNTOT,
C    1 ' ***** WARNING ********** WARNING ********* WARNING *****'
C
C     The lowest positive eigenvalue from SUBROUTINE GSEIG always
C     agreed with that from SUBROUTINE CUBIC, that is, when GSEIG
C     did not fail because of complex eigenvalues. The failure of
C     GSEIG caused run abortion during SUPEROPT runs, which is
C     annoying to the PANDA2 user. That is why we decide to use
C     SUBROUTINE CUBIC instead of SUBROUTINE GSEIG.
C
      BUCKLE = MIN(EIGVAL(NWAVE),BUCKLE)
C
      NWAVE1 = NWAVE-1
      IF (NWAVE.GT.1.AND.EIGVAL(NWAVE).GT.EIGVAL(NWAVE1)) GO TO 1050
C
 1000 CONTINUE
C End of the loop over the number of circumferential halfwaves,
C NWAVE
 1050 CONTINUE
C
      IF (IMOD.EQ.0) THEN
         DO 1100 NWAVE = NBEG,NEND
```

```
            DIFF = ABS(BUCKLE - EIGVAL(NWAVE))/ABS(BUCKLE)
            IF (DIFF.LT.0.0001) THEN
               NCRIT3 = NWAVE
               GO TO 1200
            ENDIF
 1100    CONTINUE
 1200    CONTINUE
      ENDIF
C
      WAVLEN = FL/FLOAT(NCRIT3)
      IF (NPRT.GE.0) WRITE(IFILE,'(/,A,1P,E12.4,A,1P,E12.4,A,I5)')
     1' BUCKLE=',BUCKLE, ' WAVLEN=',WAVLEN, ' NCRIT3=',NCRIT3
C234567890123456789012345678901234567890123456789012345678901234567890l2
      IF (IMOD.EQ.0) NCRITC = CIRC/WAVLEN
      IF (NPRT.GE.2) WRITE(IFILE,'(A,1P,E12.4,/,A,I5)')
     1' circumferential length of web used for buckling analysis, FL=',
     1 FL,
     1' number of circumferential halfwaves over the length CIRC=',
     1 NCRITC
C
      IF (ISTIF(1).NE.0.AND.IMOD.EQ.0.AND.NPRT.GE.0) THEN
        WRITE(IFILE,'(/,A,1P,E12.4,/,A,1P,E12.4)')
     1' circumferential spacing of the stringers=                      ',
     1  BBB(1),
     1' circumferential half-wavelength of the critical buckling mode=',
     1  WAVLEN
      ENDIF
C
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)
C23456789012345678901234567890123456789012345678901234567890123456789012
      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
      NZ = NX
      DZ = (HSUB(2,1,1) +TSKIN/2.)/FLOAT(NZ-1)
      Z = -DZ
      DO 1400 IZ = 1,NZ
         Z = Z + DZ
         DO 1350 I = 1,NX
            IF (Z.LT.XCOORD(I)) THEN
               II = I
               II1 = I - 1
               GO TO 1351
            ENDIF
            IF (Z.GE.XCOORD(NX)) ETOTLZ(IZ) = ETOTAL(I)
 1350    CONTINUE
         GO TO 1400
 1351    CONTINUE
         EDIFF = ETOTAL(II) - ETOTAL(II1)
         XDIFF = DX
         ETOTLZ(IZ) = ETOTAL(II1) +EDIFF*(Z - XCOORD(II1))/XDIFF
 1400 CONTINUE
C
C  First, find the instantaneous moduli for the web:
```

```
C
      SIG12 = 0.
      SIG1 =  0.
C
      DO 1600 IZ = 1,NZ
         ZCOORD(IZ) = DZ*FLOAT(IZ - 1)
         DO 1550 I = 2,NSS
            IF (ABS(ETOTLZ(IZ)).LT.EIM(I)) THEN
               II = I
               II1 = II - 1
               GO TO 1551
            ENDIF
 1550    CONTINUE
 1551    CONTINUE
         SIDIFF = SIM(II) - SIM(II1)
         EIDIFF = EIM(II) - EIM(II1)
         SIG2 =SIM(II1) +SIDIFF*(ABS(ETOTLZ(IZ)) -EIM(II1))/EIDIFF
         ES = SIG2/ABS(ETOTLZ(IZ))
         ETT = SIDIFF/EIDIFF
         CALL SMOOTH(NSS,ABS(ETOTLZ(IZ)),II,EIM,SIM,EIM,ETT)
         ET = ETT
         FMULT = 1.0
         IF (ETOTLZ(IZ).LT.0.) FMULT = -1.0
         SIG2 = FMULT*SIG2
         SIGMA(IZ) = SIG2
         FHOOP(IZ) = SIG2*TSUB(2,1,1)
         SBAR = SQRT(SIG1*SIG1 + SIG2*SIG2 - SIG1*SIG2 + 3.*SIG12**2)
         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(IZ) = aa/del
         E12(IZ) = bb/del
         E22(IZ) = cc/del
         G12(IZ) = GELAST*(1.+FNU)/(1.+FNU +g +2.*gprime*SIG12**2)
         FMPROD(IZ) = FHOOP(IZ)*(D-ZCOORD(IZ))
 1600 CONTINUE
C
      CALL SIMPSN(IFILE,NZ,DZ,FHOOP,FWEB)
      CALL SIMPSN(IFILE,NZ,DZ,FMPROD,FMWEB)
C
C234567890123456789012345678901234567890123456789012345678901234567890123456789012
      IF (NPRT.GE.2) THEN
       WRITE(IFILE,'(/,A,1P,E12.4,/,A,1P,E12.4)')
```

```
     1' sub-ring spacing,       BSUB=                        ',BSUB(2,1,1),
     1' skin thickness,         TSKIN=                       ',TSKIN
       WRITE(IFILE,'(A,1P,E12.4,/,A,1P,E12.4)')
     1' sub-ring web height,    HSUB(2,1,1)=                 ',HSUB(2,1,1),
     1' sub-ring web thickness, TSUB(2,1,1)=                 ',TSUB(2,1,1)
       WRITE(IFILE,'(A,1P,E12.4,/,A,1P,E12.4)')
     1' cold-bending radius,    RCOLD=                       ',RCOLD,
     1' radius after springback,RADEND=                      ',RADEND
       WRITE(IFILE,'(A,1P,E12.4,/,A,1P,E12.4)')
     1' design radius of cylinder,RCYL=                      ',ABS(RCYL),
     1' At R =RCOLD: location d of the ring neutral axis=',D
       WRITE(IFILE,'(/,A,1P,E12.4)')
     1' sub-ring web hoop force,  FWEB=                      ',FWEB
C234567890123456789012345678901234567890123456789012345678901234567890123456789012
C
C Print out stress and strain distribution over the ring module cross
C section and compute the bending moment that creates this distribution.
C
       WRITE(IFILE,'(/,A,I3,A,/(1P,5E12.4))')
     1' z-coords. for ',NZ,' radial locations along the subring web:',
     1 (ZCOORD(I), I=1,NZ)
       WRITE(IFILE,'(/,A,I3,A,/(1P,5E12.4))')
     1' hoop strain for ',NZ,' radial locations along the subring web:',
     1 (ETOTLZ(I), I=1,NZ)
       WRITE(IFILE,'(/,A,I3,A,/(1P,5E12.4))')
     1' hoop stress for ',NZ,' radial locations along the subring web:',
     1 (SIGMA(I), I=1,NZ)
       WRITE(IFILE,'(/,A,I3,A,A,/(1P,5E12.4))')
     1' hoop resultant for ',NZ,' radial locations along the subring',
     1' web:', (FHOOP(I), I=1,NZ)
      ENDIF
C
C STABILITY EQUATIONS FOR THE "CLOSED FORM" SOLUTION
C
      PI = 3.1415927
      FL = CIRC
      DS = 1./FLOAT(NZ-1)
      H  = HSUB(2,1,1)
      TWEB = TSUB(2,1,1)
      FN1 = 0.
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
         NBEG = NCRIT4
         NEND = NCRIT4
      ENDIF
C
      DO 2000 NWAVE = NBEG,NEND
C
       FN = NWAVE
       S = -DS
C
       DO 1800 IZ = 1,NZ
C
C Some frequently used combinations:
C
         C44 = E11(IZ)*TWEB**3/12.
         C45 = E12(IZ)*TWEB**3/12.
         C55 = E22(IZ)*TWEB**3/12.
         C66 = G12(IZ)*TWEB**3/12.
         FN2 = FHOOP(IZ)
         S = S + DS
         C  = FN*PI/FL
         S1 =  H*6.*(S - 1.)
         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(IZ) = S1*S1*C44 +S3*S1*C45 +S1*S3*C45 +S3*S3*C55
     1                                            +S36*S36*4.*C66
         A12(IZ) = S1*S21*C44 +S3*S21*C45 +S1*S26*C45 +S3*S26*C55
     1                                            +S36*S212*4.*C66
         A13(IZ) = S1*S31*C44 +S3*S31*C45 +S1*S310*C45 +S3*S310*C55
     1                                            +S36*S320*4.*C66
C
         A22(IZ) = S21*S21*C44 +S26*S21*C45 +S21*S26*C45 +S26*S26*C55
```

```
     1                                                        +S212*S212*4.*C66
         A23(IZ) = S21*S31*C44 +S26*S31*C45 +S21*S310*C45 +S26*S310*C55
     1                                                        +S212*S320*4.*C66
C
         A33(IZ) = S31*S31*C44 +S310*S31*C45 + S31*S310*C45 +S310*S310*C55
     1                                                        +S320*S320*4.*C66
C
         B11(IZ) = S3*S3*FN2/C**2 + S36*S36*FN1/C**2
         B12(IZ) = S3*S26*FN2/C**2 +S36*S212*FN1/C**2
         B13(IZ) = S3*S310*FN2/C**2 +S36*S320*FN1/C**2
C
         B22(IZ) = S26*S26*FN2/C**2 +S212*S212*FN1/C**2
         B23(IZ) = S26*S310*FN2/C**2 +S212*S320*FN1/C**2
C
         B33(IZ) = S310*S310*FN2/C**2 +S320*S320*FN1/C**2
C
 1800 CONTINUE
C  end of the loop over IZ
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,NZ,DS,A11,ASTF(1,1))
      CALL SIMPSN(IFILE,NZ,DS,A12,ASTF(1,2))
      CALL SIMPSN(IFILE,NZ,DS,A13,ASTF(1,3))
      CALL SIMPSN(IFILE,NZ,DS,A22,ASTF(2,2))
      CALL SIMPSN(IFILE,NZ,DS,A23,ASTF(2,3))
      CALL SIMPSN(IFILE,NZ,DS,A33,ASTF(3,3))
C
      CALL SIMPSN(IFILE,NZ,DS,B11,BSTF(1,1))
      CALL SIMPSN(IFILE,NZ,DS,B12,BSTF(1,2))
      CALL SIMPSN(IFILE,NZ,DS,B13,BSTF(1,3))
      CALL SIMPSN(IFILE,NZ,DS,B22,BSTF(2,2))
      CALL SIMPSN(IFILE,NZ,DS,B23,BSTF(2,3))
      CALL SIMPSN(IFILE,NZ,DS,B33,BSTF(3,3))
C
      ASTFD(1,1) = ASTF(1,1)
      ASTFD(1,2) = ASTF(1,2)
      ASTFD(1,3) = ASTF(1,3)
      ASTFD(2,2) = ASTF(2,2)
      ASTFD(2,3) = ASTF(2,3)
      ASTFD(3,3) = ASTF(3,3)
C
      BSTFD(1,1) = BSTF(1,1)
      BSTFD(1,2) = BSTF(1,2)
      BSTFD(1,3) = BSTF(1,3)
      BSTFD(2,2) = BSTF(2,2)
```

```
      BSTFD(2,3) = BSTF(2,3)
      BSTFD(3,3) = BSTF(3,3)
C
      ASTFD(2,1) = ASTFD(1,2)
      ASTFD(3,1) = ASTFD(1,3)
      ASTFD(3,2) = ASTFD(2,3)

      BSTFD(2,1) = BSTFD(1,2)
      BSTFD(3,1) = BSTFD(1,3)
      BSTFD(3,2) = BSTFD(2,3)
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
      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
      NWAVE1 = NWAVE-1
      IF (NWAVE.GT.1.AND.EIGVAL(NWAVE).GT.EIGVAL(NWAVE1)) GO TO 2050
C
 2000 CONTINUE
C End of the loop over the number of circumferential waves, NWAVE
 2050 CONTINUE
C
      IF (IMOD.EQ.0) THEN
         DO 2100 NWAVE = NBEG,NEND
            DIFF = ABS(BUCKLE - EIGVAL(NWAVE))/ABS(BUCKLE)
            IF (DIFF.LT.0.0001) THEN
               NCRIT4 = NWAVE
               GO TO 2200
            ENDIF
 2100    CONTINUE
 2200    CONTINUE
      ENDIF
C
      WAVLN2 = FL/FLOAT(NCRIT4)
      IF (NPRT.GE.0) WRITE(IFILE,'(/,A,1P,E12.4,A,1P,E12.4,A,I5)')
     1' BUCKLE=',BUCKLE, ' WAVLN2=',WAVLN2, ' NCRIT4=',NCRIT4
C234567890123456789012345678901234567890123456789012345678901234567890
      IF (IMOD.EQ.0) NCRITD = CIRC/WAVLN2
```

```
      IF (NPRT.GE.2) WRITE(IFILE,'(A,1P,E12.4,/,A,I5)')
     1' circumferential length of web used for buckling analysis, FL=',
     1 FL,
     1' number of circumferential halfwaves over the length CIRC=',
     1 NCRITD
C
      IF (ISTIF(1).NE.0.AND.IMOD.EQ.0.AND.NPRT.GE.0) THEN
        WRITE(IFILE,'(/,A,1P,E12.4,/,A,1P,E12.4)')
     1' circumferential spacing of the stringers=                     ',
     1  BBB(1),
     1' circumferential half-wavelength of the critical buckling mode=',
     1  WAVLN2
      ENDIF
C
C Constraint condition for sub-ring cold-bending buckling...
      INUMTT = INUMTT + 1
      FSAFTY = 1.1
      CALL CONVRF(FSAFTY,CCN2)
      CALL CONVRT(NCRITD,CCN)
      IF (IMOD.EQ.0.AND.(BUCKLE/FSAFTY).LT.MAXCON) THEN
         ICAR = ICAR + 1
         PCWORD(ICAR) =
     1  'Cold-bending subring 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 2300
      IF (IMOD.EQ.1.AND.IPOINC(INUMTT).EQ.0) GO TO 2300
      ICONST = ICONST + 1
      IF (IMOD.EQ.0) IPOINC(INUMTT) = 1
      CONSTR(ICONST) = BUCKLE/FSAFTY
      WORDB(ICONST)=
     1'Cold-bending subring 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)
C23456789012345678901234567890123456789012345678901234567890123456789012
      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
 2300 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 subring bucklng load factor',
     1' in SUBROUTINE COLDBD.',
     1' ***********************************************************'
C
 3000 CONTINUE
C234567890123456789012345678901234567890123456789012345678901234567890112
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
      JJ1 = JJ - 1
      IF (JJ1.LE.1) RETURN
      IF (JJ.GE.(NP-1)) RETURN
      EJ = ETOT(JJ)
      EJ1 = ETOT(JJ1)
      DTOT = EJ - EJ1
      ELOC = EBAR - EJ1
      ETMID = ET
      JJM = JJ1 - 1
      ETM = (SIG(JJ1) -SIG(JJM))/(EPS(JJ1) -EPS(JJM))
C
      JJP = JJ + 1
      ETP = (SIG(JJP) -SIG(JJ))/(EPS(JJP) -EPS(JJ))
C
      EMINUS = (ETM + ETMID)/2.
      IF (JJ.EQ.3) EMINUS = ETM
      EPLUS = (ETP + ETMID)/2.
      IF (JJ.EQ.(NP-2)) EPLUS = ETP
C
      A1 = 1. -ELOC/DTOT
      A2 = ELOC/DTOT
      ET = A1*EMINUS + A2*EPLUS
C
 1000 CONTINUE
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.

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

 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

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:
****

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

 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.**