Table 4.6 Input file for WAVYCYL system "BEGIN" processor: testnew6.BEG.
These input data correspond to the starting design shown in Fig. 1. The
name that the WAVYCYL user has assigned to this specific case is "testnew6".

```
===========================================================================
      N           $ Do you want a tutorial session and tutorial output?
    180           $ length of cylindrical shell: AXIAL
      9           $ Average nominal radius of cylindrical shell: RADIUS
  0.1000000       $ Total wall thickness: THICK
      1           $ Location of T-ring: -1=internal, 0=none, 1=external: IRING
     20           $ ring spacing (use zero if no rings): BRINGS
  0.1000000       $ thickness of web of T-ring: TWEB
   2.000000       $ height of web of T-ring: HWEB
  0.1000000       $ thickness of outstanding flange of T-ring: TFLANG
   2.000000       $ width of outstanding flange of T-ring: HFLANG
  0.1000000E+08   $ Average modulus of ring material: ERING
  0.3000000       $ Average Poisson ratio of ring material: FNURNG
  0.2500000E-03   $ Average mass density of ring material: DENRNG
      5           $ Number of nodal points in each ring segment: NMESHR
   386.4000       $ Acceleration of gravity (e.g. 386.4 in/sec**2): GRAVTY
    800           $ Length of tube unrestrained by axial hanger: LGAXL
     34           $ Number (EVEN) of axial halfwaves in wavy part of cyl.: NWAVES
   3.000000       $ Axial halfwavelength of the waviness: WAVLEN
  0.5000000       $ Amplitude of waviness: AMPLIT
      2           $ Type of waviness (IWAVE=2 or 3): IWAVE
      0           $ Local meridional radius of curvature: RADSML
      0           $ Number of nodal points in STRAIGHT segment: NMESHS
     21           $ Number of nodal pts. in each curved segment: NMESHC
     97           $ Number of nodal pts. in "smeared" segment: NMESH1
  15000           $ Maximum number of d.o.f. of buckling problem: MAXDOF
      1           $ Boundary condition index: 1 = s.s.; 2=clamped: IBOUND
      1           $ Type of shell wall (1=isotropic, 2=laminated): IWALL
  0.1000000E+08   $ Youngs modulus: ESTIFF
  0.3000000       $ Poisson ratio: FNU
  0.2500000E-03   $ Material mass density (e.g. alum.=0.00025lb-sec**2/in: DENS
      0           $ Number of layers in the wall: NLAYER
      0           $ Number ILTYPE of rows in the array  LTYPE: ILTYPE
      0           $ Number ITLAYE of rows in the array  TLAYER: ITLAYE
      0           $ Number IE1    of rows in the array  E1: IE1
      0           $ control (0 or 1) for smeared stiffeners: NRS
      4           $ number of entries in table of damping factor v freq.: NDAMP
      4           $ Number IBDAMP of rows in the array  BDAMP: IBDAMP
  0.1000000E-01   $ damping factor: BDAMP( 1)
  0.1000000E-01   $ damping factor: BDAMP( 2)
  0.1000000E-01   $ damping factor: BDAMP( 3)
  0.5000000E-01   $ damping factor: BDAMP( 4)
      5           $ frequency (hertz) corresponding to damping factor: BFREQ( 1)
     10           $ frequency (hertz) corresponding to damping factor: BFREQ( 2)
     30           $ frequency (hertz) corresponding to damping factor: BFREQ( 3)
    500           $ frequency (hertz) corresponding to damping factor: BFREQ( 4)
      5           $ number of entries in table of spectral response v freq:NSPECT
      5           $ Number ISPTDE of rows in the array  SPTDEN: ISPTDE
  0.3000000       $ spectral density: SPTDEN( 1)
  0.5000000       $ spectral density: SPTDEN( 2)
   1.000000       $ spectral density: SPTDEN( 3)
   2.000000       $ spectral density: SPTDEN( 4)
   1.000000       $ spectral density: SPTDEN( 5)
      5           $ frequency (hertz) corresponding to spectral density: SFREQ(1)
      8           $ frequency (hertz) corresponding to spectral density: SFREQ(2)
     12           $ frequency (hertz) corresponding to spectral density: SFREQ(3)
    100           $ frequency (hertz) corresponding to spectral density: SFREQ(4)
    500           $ frequency (hertz) corresponding to spectral density: SFREQ(5)
      0           $ starting number of circumferential waves, buckling: N0B
```

```
       10       $ ending number of circumferential waves: NMAXB
        1       $ Increment in number of circumferential waves: INCRB
        0       $ starting no. of circ. waves for vibration: N0V
        3       $ ending no. of circ. waves for vibration: NMAXV
        1       $ increment in no. circ. waves for vibration: INCRV
        1       $ Number of eigenvalues for each circ. wavenumber: NVEC
        1       $ Number NCASES of load cases (environments): NCASES
      -53       $ Axial resultant (neg. for compression),Load Set A: FNX( 1)
        0       $ Axial resultant (neg. for compression), Load Set B: FNXB( 1)
  1.500000      $ number of g's acceleration along cylinder axis: GAXIAL( 1)
  3.000000      $ Number of g's perpendicular to axis of cylinder: GLATRL( 1)
 -11.80000      $ pressure (negative for external), Load Set A: PRESS( 1)
        0       $ pressure (negative for external), Load Set B: PRESSB( 1)
  50000.00      $ maximum allowable vonMises stress, nonlinear theory:STRALW(1)
        1       $ factor of safety for vonMises stress, nonl. theory: STRFS(1)
        1       $ allowable for buckling factor (use 1.0),nonl.theory:BUCALW(1)
  1.250000      $ factor of safety for buckling, nonlinear theory: BUCFS( 1)
        1       $ allowable for hi-wave buckling factor, nonl. theory:BUCHIA(1)
  1.250000      $ factor of safety for hi-wave buckling: BUCHIF( 1)
  50000.00      $ max. allowable vonMises stress, linear theory: STR0A( 1)
        1       $ factor of safety for vonMises stress, linear theory: STR0F(1)
  50000.00      $ max. allowable vonMises stress, linear theory: ST180A( 1)
        1       $ factor of safety for vonMises stress, linear theory:ST180F(1)
        1       $ allowable for buckling factor (use 1), linear theory:BUC0A(1)
  1.250000      $ factor of safety for buckling factor, linear theory: BUC0F(1)
        1       $ allowable (use 1) for antisymmetric buckling,0 deg.:B0ANTA(1)
  1.250000      $ factor of safety for antisymmetric buckling, 0 deg: B0ANTF(1)
        1       $ allowable (use 1) for mid-wave-range buckling,0 deg:BUC0MA(1)
  1.250000      $ factor of safety for mid-wave-range buckling, 0 deg:BUC0MF(1)
        1       $ allowable for hi-wave buckling (use 1) at 0 deg.: BUC0HA(1)
  1.250000      $ factor of safety for hi-wave buckling, lin. theory: BUC0HF(1)
        1       $ allowable buckling factor at 180 deg., lin. theory: BU180A(1)
  1.250000      $ factor of safety for buckling, 180 deg, lin. theory:BU180F(1)
        1       $ allowable (use 1) hi-wave buckling at 180 deg: B180HA(1)
  1.250000      $ factor of safety for hi-wave buckling at 180 deg.: B180HF(1)
 0.8000000      $ maximum allowable normal displacement, lin. theory: WWW0A(1)
        1       $ factor of safety for max. normal displacement: WWW0F(1)
 0.8000000      $ max. allowable normal displacment, linear theory: WW180A(1)
        1       $ factor of safety for normal displacment: WW180F(1)
  10.00000      $ minimum allowable modal frequency: VIBALW(1)
        1       $ factor of safety for modal frequency: VIBFS(1)
  50000.00      $ max. allowable stress from random excitation: STRRNA(1)
        1       $ factor of safety for stress from random excitation: STRRNF(1)
        1       $ allowable buckling load factor, random excitation:  BUCRNA(1)
  1.250000      $ factor of safety, buckling from random excitation:  BUCRNF(1)
        1       $ allowable for buckling factor, random excitation:   BRANHA(1)
  1.250000      $ factor of safety,hi-wave buckling,random excitation:BRANHF(1)
 0.8000000      $ max. allowable normal displ., random excitation:    WWWRNA(1)
        1       $ factor of safety, max. normal displ.,random excit.: WWWRNF(1)
================================================================================
```

Table 4.7 Input file for WAVYCYL system processor "DECIDE", testnew6.DEC

```
==============================================================================
      N          $ Do you want a tutorial session and tutorial output?
         1       $ Choose a decision variable (1,2,3,...) (skin thickness)
  0.3000000E-01 $ Lower bound of variable no.( 1)
  0.5000000      $ Upper bound of variable no.( 1)
      Y          $ Any more decision variables (Y or N) ?
         2       $ Choose a decision variable (1,2,3,...) (ring spacing)
        10       $ Lower bound of variable no.( 2)
       110       $ Upper bound of variable no.( 2)
      Y          $ Any more decision variables (Y or N) ?
         3       $ Choose a decision variable (1,2,3,...) (ring web thickness)
  0.5000000E-01 $ Lower bound of variable no.( 3)
  0.1000000      $ Upper bound of variable no.( 3)
      Y          $ Any more decision variables (Y or N) ?
         4       $ Choose a decision variable (1,2,3,...) (ring web height)
  0.2000000      $ Lower bound of variable no.( 4)
         4       $ Upper bound of variable no.( 4)
      Y          $ Any more decision variables (Y or N) ?
         5       $ Choose a decision variable (1,2,3,...) (ring flange thick.)
  0.5000000E-01 $ Lower bound of variable no.( 5)
  0.1000000      $ Upper bound of variable no.( 5)
      Y          $ Any more decision variables (Y or N) ?
         6       $ Choose a decision variable (1,2,3,...) (ring flange width)
  0.2000000      $ Lower bound of variable no.( 6)
   4.000000      $ Upper bound of variable no.( 6)
      Y          $ Any more decision variables (Y or N) ?
         7       $ Choose a decision variable (1,2,3,...) (axial halfwavelngth)
  0.5000000      $ Lower bound of variable no.( 7)
         5       $ Upper bound of variable no.( 7)
      Y          $ Any more decision variables (Y or N) ?
         8       $ Choose a decision variable (1,2,3,...) (waviness amplitude)
  0.1000000E-01 $ Lower bound of variable no.( 8)
  0.8000000      $ Upper bound of variable no.( 8)
      N          $ Any more decision variables (Y or N) ?
      N          $ Any linked variables (Y or N) ?
      N          $ Any inequality relations among variables? (type H)
      Y          $ Any escape variables (Y or N) ?
      Y          $ Want to have escape variables chosen by default? (thicknesses)
==============================================================================
```

Table 4.8 Input file for WAVYCYL system processors, "MAINSETUP" and "OPTIMIZE", testnew6.OPT. (See Table 6.1 for a list of what the 18 "behaviors" are.

```
=========================================================================
     N          $ Do you want a tutorial session and tutorial output?
        1       $ Choose an analysis you DON'T want (1, 2,..), IBEHAV
     Y          $ Any more analysis types NOT wanted (Y or N) ?
        2       $ Choose an analysis you DON'T want (1, 2,..), IBEHAV
     Y          $ Any more analysis types NOT wanted (Y or N) ?
        3       $ Choose an analysis you DON'T want (1, 2,..), IBEHAV
     Y          $ Any more analysis types NOT wanted (Y or N) ?
        9       $ Choose an analysis you DON'T want (1, 2,..), IBEHAV
     Y          $ Any more analysis types NOT wanted (Y or N) ?
       10       $ Choose an analysis you DON'T want (1, 2,..), IBEHAV
     Y          $ Any more analysis types NOT wanted (Y or N) ?
       11       $ Choose an analysis you DON'T want (1, 2,..), IBEHAV
     Y          $ Any more analysis types NOT wanted (Y or N) ?
       12       $ Choose an analysis you DON'T want (1, 2,..), IBEHAV
     Y          $ Any more analysis types NOT wanted (Y or N) ?
       13       $ Choose an analysis you DON'T want (1, 2,..), IBEHAV
     Y          $ Any more analysis types NOT wanted (Y or N) ?
       15       $ Choose an analysis you DON'T want (1, 2,..), IBEHAV
     Y          $ Any more analysis types NOT wanted (Y or N) ?
       16       $ Choose an analysis you DON'T want (1, 2,..), IBEHAV
     Y          $ Any more analysis types NOT wanted (Y or N) ?
       17       $ Choose an analysis you DON'T want (1, 2,..), IBEHAV
     Y          $ Any more analysis types NOT wanted (Y or N) ?
       18       $ Choose an analysis you DON'T want (1, 2,..), IBEHAV
     N          $ Any more analysis types NOT wanted (Y or N) ?
        0       $ NPRINT= output index (0=GOOD, 1=ok, 2=debug, 3=too much)
        1       $ Choose type of analysis (1=opt., 2=fixed, 3=sensit.) ITYPE
        5       $ How many design iterations in this run (3 to 25)?
        1       $ Choose (1="conservative"), (2="liberal") move limits, IMOVE
     Y          $ Do you want default (RATIO=10) for initial move limit jump?
     Y          $ Do you want the default perturbation (dx/x = 0.05)?
     N          $ Do you want to reset total iterations to zero (Type H)?
=========================================================================
```

Table 5.1 FORTRAN coding from SUBROUTINE STRUCT that computes the effective 6 x 6 integrated constitutive matrix, Ceff, for the shell segment of BOSOR4 MODEL 2 in which the waviness is "smeared out" .

```
=====================================================================
FL4 = WAVLEN/2.           (WAVLEN=axial halfwavelength of waviness)
ARCRAT = 1.0
IF (IWAVE.EQ.2) THEN      (IWAVE=2 means wavy section consists only
                            of little toroidal segments joined
                            together with alternating positive
                            and negative Gaussian curvature and
                            slope continuity at all junctions.)

   RMERID = AMPLIT/(1.-(FL4**2-AMPLIT**2)/(FL4**2+AMPLIT**2))
   SPHI = FL4/RMERID
   PHI = ASIN(SPHI)       (RMERID is the absolute value of the local
                           meridional radius of curvature.)
   ARCRAT = RMERID*PHI/FL4
ELSE                      (IWAVE.NE.2 means wavy section consists of
                           little toroidal segments joined to little
                           conical segments with slope continuity at
                           all junctions)
   ARCRAT = ARCLEN/(FLOAT(NWAVEX(1))*WAVLEN/2.)
ENDIF
                          (ARCLEN is the total arc length of the wavy
                                  portion of the BOSOR4 model.)
                          (NWAVEX(1) is the number of axial halfwaves
                                     in BOSOR4 MODEL 1.)
                          (ARCRAT is the ratio of axial length of the
                                  wavy "generator" to straight generator
                                  of the cylinder.)

EPSX = 1./(CW11-CW12**2/CW22) (EPSX is the axial compliance of the
                               "nominal" cylindrical shell. CW11, CW12,
                               CW22 are the membrane constitutive
                               matrix terms, C11, C12, C22 for the
                               "nominal" cylindrical shell, computed
                               in Item 5.)

ENDNOM = EPSX*FLOAT(NWAVEX(1))*WAVLEN/2.  (ENDNOM = uniform end
                                           shortening of nominal (nonwavy)
                                            cylindrical shell)
C11RAT = ABS(ENDNOM/ENDUV)  (C11RAT is "knockdown" factor for axial
                                    stiffness of the equivalent cylin-
                                    drical shell with "smeared out" waviness.)
                            (ENDUV  is the end shortening of the wavy
                                    cyl. shell determined in Item 8.)
C11EFF = C11RAT*CW11
C12EFF = C11RAT*CW12        (CijEFF = effective stiffnesses of the
C14EFF = 0.                         equivalent cyl. with "smeared
C15EFF = 0.                         out" waviness.)
C22EFF = ARCRAT*CW22        (CWij   = integrated constitutive
C24EFF = 0.                         coefficients for the actual
C25EFF = 0.                         wall of the wavy cyl. shell.)
C44EFF = CW44/ARCRAT
C45EFF = 0.                 (NOTE: in this "smeared" model the
                                   effective Poisson ratio is
                                   assumed to be zero.

C
C  Next, derive the effective hoop bending stiffness, C55EFF, for the
C  segment of BOSOR4 MODEL 2 in which the waviness is "smeared out".
C  The formula for in-plane modal vibration of a ring, vibrating with
C  n = 2 circumferential waves around the circumference (ovalization) is:
```

```
C
C         omega**2 = C55EFF*(36/5)(1/R**4)(1/m)
C
C  in which omega = frequency in rad/sec, R = nominal radius of ring, and
C  m = mass/(projected area) of wall, and C55EFF = effective hoop
C  bending stiffness of the straight wall with "smeared" waviness. We
C  use the modal vibration frequency found in Item 9, omega = 2*pi*FREQ2:
C
C55EFF = ARCRAT*SMPAW*(5./36.)*RADIUS**4*(2.*3.141593*FREQ2)**2
C33EFF = CW33/ARCRAT
C36EFF = 0.
C66EFF = CW66/ARCRAT
SMAEFF = ARCRAT*SMPAW       (SMPAW = actual shell wall mass/area,
                                     computed in Item 5.))
C55RAT = C55EFF/CW55

AREAR  = TWEB*HWEB + TFLANG*HFLANG  (In one of the BOSOR4 models
AREAS  = THICK*BRNGSV                for modal vibration with n=0
DENSHL = SMPAW/THICK                 circ. waves (axisymmetric axial
RHOEFF = DENSHL                      modal vibration) the rings are
IF (IRINGS.NE.0.AND.BRNGSV.NE.0.)    "smeared out" and their mass
                                     added to that of the shell wall.)
RHOEFF = DENSHL + DENRNG*AREAR/AREAS
=========================================================================
```

Table 6.1 The 18 "behaviors" (responses) that are possibly evaluated for each "current" design and design perturbation by the WAVYCYL computer program

PARAMETERS WHICH DESCRIBE BEHAVIOR (e.g. stress, buckling load, frequency)

BEH. NO.	CURRENT VALUE	DEFINITION
1	2.085E+04	maximum stress in wall from nonlinear theory: STRMAX(1)
2	1.000E+10	buckling load factor from nonlinear theory: BUCFAC(1)
3	1.000E+10	hi-wave buckling load factor, nonlinear theory: BUCHIW(1)
4	3.178E+04	max. stress at 0 deg., linear theory: STR0(1)
5	2.825E+04	max. stress at 180 deg., linear theory: STR180(1)
6	1.285E+00	buckling load factor at 0 deg., linear theory: BUC0(1)
7	1.267E+00	load factor for antisymmetric buckling at 0 deg: B0ANTI(1)
8	1.946E+00	load factor for mid-wave-range buckling at 0 deg: BUC0MD(1)
9	8.876E+00	hi-wave buckling load factor, 0 deg,linear theory:BUC0HI(1)
10	1.332E+00	buckling load factor at 180 deg, linear theory: BUC180(1)
11	1.031E+01	hi-wave buckling load factor 180 deg, lin.theory: B180HI(1)
12	3.007E-01	maximum normal displacement, 0 deg., linear theory: WWW0(1)
13	2.949E-01	maximum normal displacement, 180 deg., lin.theory:WWW180(1)
14	1.001E+01	modal frequency (hertz): FREQ(1)
15	1.000E-10	maximum stress from random excitation: STRRAN(1)
16	1.000E+10	buckling load factor from random excitation: BUCRAN(1)
17	1.000E+10	hi-wave buckling factor from random excitation: BRANHI(1)
18	1.000E-10	max. normal displacement from random excitation: WWWRAN(1)

Table 6.2 Margins corresponding to the "behaviors" listed in the previous table. NOTE: The "MARGIN NOs" do NOT correspond to the "Behavior" numbers in the previous table.

MARGINS CORRESPONDING TO CURRENT DESIGN (F.S.= FACTOR OF SAFETY)

MARGIN NO.	CURRENT VALUE	DEFINITION
1	5.831E-01	1-(STRMAX(1)/STRALW(1)) X STRFS(1); F.S.= 1.00
2	3.644E-01	1-(STR0(1)/STR0A(1)) X STR0F(1); F.S.= 1.00
3	4.351E-01	1-(STR180(1)/ST180A(1)) X ST180F(1); F.S.= 1.00
4	2.830E-02	(BUC0(1)/BUC0A(1)) / BUC0F(1)-1; F.S.= 1.25
5	1.366E-02	(B0ANTI(1)/B0ANTA(1)) / B0ANTF(1)-1; F.S.= 1.25
6	5.568E-01	(BUC0MD(1)/BUC0MA(1)) / BUC0MF(1)-1; F.S.= 1.25
7	6.101E+00	(BUC0HI(1)/BUC0HA(1)) / BUC0HF(1)-1; F.S.= 1.25
8	6.556E-02	(BUC180(1)/BU180A(1)) / BU180F(1)-1; F.S.= 1.25
9	7.249E+00	(B180HI(1)/B180HA(1)) / B180HF(1)-1; F.S.= 1.25
10	6.241E-01	1-(WWW0(1)/WWW0A(1)) X WWW0F(1); F.S.= 1.00
11	6.314E-01	1-(WWW180(1)/WW180A(1)) X WW180F(1); F.S.= 1.00
12	1.208E-03	(FREQ(1)/VIBALW(1)) / VIBFS(1)-1; F.S.= 1.00
13	1.000E+00	1-(STRRAN(1)/STRRNA(1)) X STRRNF(1); F.S.= 1.00
14	1.000E+00	1-(WWWRAN(1)/WWWRNA(1)) X WWWRNF(1); F.S.= 1.00

Table 6.3 Modal vibration frequencies, generalized masses, and participation factors for the optimized wavy cylindrical shell with external rings.

```
VIBRATION MODES FOLLOW
CIRCUMFERENTIAL WAVE NUMBER, N =      1
EIGENVALUES =
  1.001E+01   8.703E+01   2.216E+02   3.903E+02   5.751E+02
GENERALIZED MASS =
  2.341E-02   2.457E-02   2.634E-02   2.321E-02   1.333E-02
PARTICIPATION FACTORS=
  6.303E-01   1.947E-01   1.034E-01   7.113E-02   6.589E-02
```

Table 6.4 Input file, testnew6.RES for RESTART mode of BOSOR4 when response to base excitation is wanted. This file is generated by SUBROUTINE RESET, called in SUBROUTINE BEHX15

```
=======================================================================
  Y  $ Do you want response at resonance to base excitation?
  1  $ ISTRES=(0=resultants, 1=sigma, 2=epsilon)
 0  $ NLAST = plot options  (-1=none, 0=geometry, 1=u,v,w)
  N   $ no expanded regions for plots.
  Y  $ Want more information?
  Y  $ Want more information?
  Y  $ Want more information?
  2  $ Type of response analysis (2=random excitation)
  3.864000E+02 $ Acceleration of gravity in units of this case
  Y  $ Does B (damping factor) vary with f (frequency)?
  1.000000E-02 $ damping factor,   B(i)
  5.000000E+00 $ frequency,        F(i)
  Y  $  any more values?
  1.000000E-02 $ damping factor,   B(i)
  1.000000E+01 $ frequency,        F(i)
  Y  $  any more values?
  1.000000E-02 $ damping factor,   B(i)
  3.000000E+01 $ frequency,        F(i)
  Y  $  any more values?
  5.000000E-02 $ damping factor,   B(i)
  5.000000E+02 $ frequency,        F(i)
  N  $  any more values?
  Y  $ Does W (spectral density) vary with f (frequency)?
  3.000000E-01 $ spectral density, W(i)
  5.000000E+00 $ frequency,        F(i)
  Y  $  any more values?
  5.000000E-01 $ spectral density, W(i)
  8.000000E+00 $ frequency,        F(i)
  Y  $  any more values?
  1.000000E+00 $ spectral density, W(i)
  1.200000E+01 $ frequency,        F(i)
  Y  $  any more values?
  2.000000E+00 $ spectral density, W(i)
  1.000000E+02 $ frequency,        F(i)
  Y  $  any more values?
  1.000000E+00 $ spectral density, W(i)
  5.000000E+02 $ frequency,        F(i)
  N  $  any more values?
  Y  $ Do you want to find buckling load factors?
      0        $ Starting number of circumferential waves, N0B
      0        $ minimum number of circumferential waves, N0B
     10        $  Ending  number of circumferential waves, NMAXB
      1        $ Increment in number of circumferl. waves, INCRB
      1        $ No. eigenvalues for each circ. wavenumber, NVEC
  N  $ Want to suppress listing prebuckling resultants?
  N  $ Want to suppress listing the buckling modes?
  1  $ NDIST = number of circ. stations for meridional output
  1.800000E+02 $ THETA = circ. station (in deg.) meridional state
  0  $ NCIRC=number of meridional stations for circ. state
=======================================================================
```

Table 6.5 Summary of factors (right-most column) needed to compute the response, w(response), to random lateral excitation of the lateral supports of the wavy, ring-stiffened cylindrical tube.

```
=======================================================================
 RESTART IN MAINPROCESSOR...
 DYNAMIC RESPONSE ANALYSIS...
     g = ACCELERATION OF GRAVITY
 OMEGA = NATURAL FREQUENCY IN RADIANS/SEC
  BETA = DAMPING COEFFICIENT
 PARTICIPATION FACTOR:
   P/2 = integral(mass*mode*(base motion)/[2*(generalized mass)]

 RESPONSE TO  RANDOM EXCITATION
 FORMULA FOR MULTIPLIER,m(i) =  SQRT[OMEGA*specd/(2*beta)]g/OMEGA**2
```

FREQUENCY (HERTZ)	PARTICIPATION FACTOR, P/2	DAMPING COEFFICIENT beta	SPECTRAL DENSITY specd	MULTIPLIER (m) m(i)	AMPLITUDE FACTOR=m*P/2
1.0007E+01	6.3025E-01	1.0000E-02	7.3310E-01	4.6922E+00	2.9572E+00
8.7029E+01	1.9474E-01	1.4854E-02	1.9112E+00	2.4238E-01	4.7201E-02
2.2162E+02	1.0345E-01	2.6308E-02	1.4197E+00	3.8627E-02	3.9958E-03
3.9031E+02	7.1132E-02	4.0664E-02	1.1126E+00	1.1768E-02	8.3707E-04
5.7511E+02	6.5888E-02	5.0000E-02	1.0000E+00	5.6253E-03	3.7064E-04

Table 6.6 Results from SUBROUTINE BEHX15 (response to random lateral excitation of the lateral supports) for the optimized wavy cylindrical shell with external rings

```
====================================================================
 BEGIN SUB. BEHX15 (LINEAR NONSYM.STRESS, RANDOM EXCITATION).

 Modal frequencies for n = 1 circ. wave=
  1.0007E+01  8.7029E+01  2.2162E+02  3.9031E+02  5.7511E+02

 ***** BUCKLING LOAD FACTORS, RANDOM EXCITATION *****
 LINEAR BUCKLING LOAD FACTOR, MODEL 2 (CIRC. WAVES)
    eigenvalue(circ. waves)
        3.0095E-01(   2)
        6.4753E-01(   3)
        2.0317E-01(   4)
        2.6782E-01(   5)
        4.2743E-01(   6)
        5.0819E-01(   7)
        5.1695E-01(   8)
        6.1020E-01(   9)
        8.7106E-01(  10)
 =======================================
 Critical buckling load factor, BUCRAN=  2.0317E-01
 Critical number of circumferential waves, NWVCRT=    4              location
                                                                     seg node
 Maximum stress, random excitatn, load set A, STRNON(1)=  3.6776E+04,  114 013
 Maximum stress, random excitatn, load set B, STRNON(2)=  0.0000E+00,     0
 Maximum stress, nonlinear axisymmtrc analysis, STRMXX =  2.1988E+04
 Max. w-displacmnt,random excite, load set A, WWWNON(1)=  2.9038E+00,  117 007
 Max. w-displacmnt,random excite, load set B, WWWNON(2)=  0.0000E+00,     0

 Maximum stress from random excitation,
                  STRRAN(ILOADX)= STRNON(1) + STRMXX =  5.8764E+04
==========================================================================
```

Table 7.1 Input file for PANDA2 system processor "BEGIN", cyl.BEG

```
================================================================================
     n         $ Do you want a tutorial session and tutorial output?
      180      $ Panel length normal to the plane of the screen, L1
   28.27400    $ Panel length in the plane of the screen, L2  (pi*R = 28.274)
     n         $ Type of stiffener along L1 (N, T, J, Z, R, A, C, G)
     n         $ Is the next group of layers to be a "default group"?
        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?
  0.3000000E-01 $ thickness for layer index no.( 1)    (thickness of cyl skin)
        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)
     r         $ Identify type of stiffener along L2  (N, T, J, Z, R, A)
   10.08000    $ stiffener spacing, b                    (ring spacing)
        0      $ width of ring base, b2 (zero is allowed)
  0.7506000    $ height of stiffener (type H for sketch), h     (ring height)
     n         $ Are the rings cocured with the skin?
     n         $ Is the next group of layers to be a "default group"?
        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?
  0.5000000E-01 $ thickness for layer index no.( 2)         (ring thickness)
        0      $ winding angle (deg.) for layer index no.( 2)
        1      $ material index (1,2,...) for layer index no.( 2)
     n         $ Any more layers or groups of layers in Segment no.( 3)
        0      $ choose external (0) or internal (1) rings
     y         $ Is the panel curved in the plane of the screen (Y for cyls.)?
   9.000000    $ 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)?
  0.1000000E+08 $ Young's modulus,                  E( 1)
  0.3000000    $ Poisson's ratio,                  NU( 1)
   3846000.    $ transverse shear modulus,       G13( 1)
        0      $ Thermal expansion coeff.,    ALPHA( 1)
        0      $ residual stress temperature (positive),TEMPTUR( 1)
     n         $ Want to supply a stress-strain "curve" for this mat'l? (N)
     y         $ Want to specify  maximum effective stress ?
   50000.00    $ Maximum allowable effective stress in material type( 1)
     n         $ Do you want to take advantage of "bending overshoot"?
  0.1000000    $ weight density (greater than 0!) of material type( 1)
     n         $ Is lamina cracking permitted along fibers (type H(elp))?
        0      $ Prebuckling phase: choose 0=simple support or 1=clamping
        0      $ Buckling: choose 0=simple support or 1=clamping
================================================================================
```

Table 7.2 Input file for PANDA2 processor "DECIDE", cyl.DEC

```
==============================================================================
     n          $ Do you want a tutorial session and tutorial output?
     n          $ Want to use default for thickness decision variables?
        1       $ Choose a decision variable (1,2,3,...)  (skin thickness)
 0.3000000E-01  $ Lower bound of variable no.( 1)
 0.2000000      $ Upper bound of variable no.( 1)
     y          $ Any more decision variables (Y or N) ?
        2       $ Choose a decision variable (1,2,3,...)  (ring spacing)
  10.00000      $ Lower bound of variable no.( 2)
  100.0000      $ Upper bound of variable no.( 2)
     y          $ Any more decision variables (Y or N) ?
        4       $ Choose a decision variable (1,2,3,...)  (ring height)
 0.1000000      $ Lower bound of variable no.( 4)
        5       $ Upper bound of variable no.( 4)
     y          $ Any more decision variables (Y or N) ?
        5       $ Choose a decision variable (1,2,3,...)  (ring thickness)
 0.1000000E-01  $ Lower bound of variable no.( 5)
 0.2000000      $ Upper bound of variable no.( 5)
     n          $ Any more decision variables (Y or N) ?
     n          $ Any linked variables (Y or N) ?
     y          $ Any inequality relations among variables?  TWEB > 0.1*HWEB
     y          $ Want to see an example of how to calculate C0, C1, D1,..?
        2       $ Identify the type of inequality expression (1 or 2)
  1.000000      $ Give a value to the constant, C0
     n          $ Are there any cross product terms in inequality expression?
        5       $ Choose a variable from the list above (1, 2, 3,...)
 -1.000000      $ Choose a value for the coefficient, C1
  1.000000      $ Choose a value for the power, D1
     y          $ Any more terms in expression: C0 +C1*v1**D1 +C2*v2**D2 +...
        4       $ Choose a variable from the list above (1, 2, 3,...)
 0.1000000      $ Choose a value for the coefficient, Cn
        1       $ Choose a value for the power, Dn
     n          $ Any more terms in expression: C0 +C1*v1**D1 +C2*v2**D2 +...
     n          $ Are there any more inequality expressions?
     y          $ Any escape variables (Y or N) ?
     y          $ Want to have escape variables chosen by default?
==============================================================================
```

Table 7.3 Input file for PANDA2 processors "MAINSETUP" and "PANDAOPT", cyl.OPT

```
==============================================================================
       n          $ Do you want a tutorial session and tutorial output?
  -57.00000       $ Resultant (e.g. lb/in) normal to the plane of screen, Nx( 1)
  -106.2000       $ Resultant (e.g. lb/in) in the plane of the screen,    Ny( 1)
          0       $ In-plane shear in load set A,                        Nxy( 1)
       n          $ Does the axial load vary in the L2 direction?
          0       $ Applied axial moment resultant (e.g. in-lb/in), Mx( 1)
          0       $ Applied hoop moment resultant (e.g. in-lb/in), My( 1)
       n          $ Want to include effect of transverse shear deformation?
          1       $ IQUICK = quick analysis indicator (0 or 1)
   1.250000       $ Factor of safety for general instability, FSGEN( 1)
   1.250000       $ Minimum load factor for local buckling, FSLOC( 1)
   1.000000       $ Minimum load factor for stiffener buckling, FSBSTR( 1)
          1       $ Factor of safety for stress, FSSTR( 1)
       n          $ Do you want wide-column buckling to constrain the design?
          0       $ Resultant (e.g. lb/in) normal to the plane of screen, Nx0( 1)
          0       $ Resultant (e.g. lb/in) in the plane of the screen,    Ny0( 1)
          0       $ Axial load applied along the (0=neutral plane),(1=panel skin)
  -11.80000       $ Uniform applied pressure [positive upward. See H(elp)], p( 1)
       y          $ Is the pressure part of Load Set A?
       y          $ Is the pressure hydrostatic (Type H for "HELP")?
          1       $ Choose in-plane immovable (IFREE=0) or movable (IFREE=1) b.c.
       n          $ Is there a maximum allowable deflection due to pressure?
          0       $ Out-of-roundness, Wimpg1=(Max.diameter-Min.diam)/4, Wimpg1(1)
 0.4500000E-01    $ Initial bucklng modal general imperfection amplit., Wimpg2(1)
          0       $ Initial local imperfection amplitude, Wloc( 1)
       n          $ Do you want PANDA2 to change imperfection amplitudes?
          1       $ Maximum allowable average axial strain (type H for HELP)
       n          $ Is there any thermal "loading" in this load set (Y/N)?
       y          $ Do you want a "complete" analysis (type H for "Help")?
       n          $ Want to provide another load set ?
       n          $ Do you want to impose minimum TOTAL thickness of any segment?
       n          $ Do you want to impose maximum TOTAL thickness of any segment?
       n          $ Do you want to impose minimum TOTAL thickness of any segment?
       n          $ Do you want to impose maximum TOTAL thickness of any segment?
       n          $ Use reduced effective stiffness in panel skin, Y or N)?
          0       $ NPRINT= output index (0=good, 1=ok, 2=more, 3=too much)
          1       $ Index for type of shell theory (0 or 1 or 2), ISAND
       Y          $ Does postbuckling axial wavelength of local buckles change?
       Y          $ Want to suppress general buckling mode with many axial waves?
       N          $ Do you want to double-check PANDA-type eigenvalues?
          1       $ Choose (0=transverse inextensional; 1=transverse extensional)
          1       $ Choose type of analysis (ITYPE = 1 or 2 or 3 or 4 or 5)
       Y          $ Do you want to prevent secondary buckling (mode jumping)?
       N          $ Do you want to use the "alternative" buckling solution?
          5       $ How many design iterations permitted in this run (5 to 25)?
   1.000000       $ MAXMAR. Plot only those margins less than MAXMAR (Type H)
       N          $ Do you want to reset total iterations to zero (Type H)?
          1       $ Index for objective (1=min. weight, 2=min. distortion)
   1.000000       $ FMARG (Skip load case with min. margin greater than FMARG)
==============================================================================
```

```
Table 7.4 Optimum design found from PANDA2 for IMPERFECT non-wavy
cylindrical shell with external blade rings. Ampltude of general buckling
modal initial imperfection = 0.045 in; No lateral or axial g-loading.
=======================================================================
 ANALYSIS: ITYPE=2;  IQUICK=1;  LOAD SET 1;  SUBCASE 1:
 LOADING: Nx, Ny, Nxy, Mx, My =  -5.70E+01 -1.06E+02  6.03E-01
                                  0.00E+00  0.00E+00
          Nxo, Nyo, pressure  =   0.00E+00  0.00E+00 -1.18E+01

          SUMMARY OF INFORMATION FROM OPTIMIZATION ANALYSIS
VAR.DEC.ESCAPE LOWER    CURRENT    UPPER       DEFINITION
NO. VAR. VAR.  BOUND     VALUE     BOUND
 1   Y    Y  3.00E-02 4.7032E-02  2.00E-01 T(1)(SKN):thickness of cyl. skin
 2   Y    N  1.00E+01 1.0000E+01  1.00E+02     B(RNG):ring spacing, b
 3   N    N  0.00E+00 0.0000E+00  0.00E+00    B2(RNG):width of ring base, b2
 4   Y    N  1.00E-01 6.7398E-01  5.00E+00     H(RNG):height of ring
 5   Y    Y  1.00E-02 6.7398E-02  2.00E-01 T(2)(RNG):thickness of ring

   CURRENT VALUE OF THE OBJECTIVE FUNCTION:
 VAR. STR/ SEG. LAYER   CURRENT
 NO.  RNG  NO.   NO.     VALUE            DEFINITION
            0     0    2.625E+01   WEIGHT OF THE ENTIRE PANEL

 MARGINS FOR CURRENT DESIGN: LOAD CASE 1, SUBCASE 1 (Midway between rings)
 MAR. MARGIN
 NO.  VALUE                 DEFINITION
 1  1.52E-01 Inter-ring bucklng, discrete model, n=9   circ.halfwaves;FS=1.25
 2  3.64E+00 eff.stress:matl=1,RNG,Iseg=3,at:TIP,layer=1,z=0.;-MID.;FS=1.
 3  1.13E-02 buck.(SAND);simp-support general buck;M=1;N=2;slope=0.;FS=1.25
 4  1.87E+04 (Max.allowable ave.axial strain)/(ave.axial strain) -1; FS=1.
 5  0.00E+00 1-[1.-V(5)^1+0.1V(4)^1]

 ****************************************
 ITERATION NO., LOAD SET NO., SUBCASE NO. =    0    1    2     AT RINGS
 ****************************************
 MARGINS FOR CURRENT DESIGN: LOAD CASE  1, SUBCASE  2   (At rings)
 MAR. MARGIN
 NO.  VALUE                 DEFINITION
 1 -9.52E-03 Inter-ring bucklng, discrete model, n=9   circ.halfwaves;FS=1.25
 2  3.64E+00 eff.stress:matl=1,RNG,Iseg=3,at:TIP,layer=1,z=0.;-RNGS;FS=1.
 3  4.12E+00 buckling margin   ring   Iseg.3 . Local halfwaves=9  .RNGS;FS=1.
 4  6.87E-03 buck.(SAND);rolling with local buck.; M=1;N=9;slope=0.;FS=1.25
 5  8.52E+00 buck.(SAND);rolling only of   rings;  M=0;N=26;slope=0.;FS=1.6
 6  1.75E+04 (Max.allowable ave.axial strain)/(ave.axial strain) -1; FS=1.

 ***********  ALL 1 LOAD SETS PROCESSED  ***********
=======================================================================
```

Table 7.5 Input data for WAVYCYL system processor "DECIDE" (testnew6.DEC)

```
==========================================================================
      N         $ Do you want a tutorial session and tutorial output?
        1       $ Choose a decision variable (1,2,3,...) (cyl thickness,THICK)
  0.3000000E-01 $ Lower bound of variable no.( 1)
  0.5000000     $ Upper bound of variable no.( 1)
      Y         $ Any more decision variables (Y or N) ?
        7       $ Choose a decision variable (1,2,3,...) (axial halfwavelngth)
  0.5000000     $ Lower bound of variable no.( 7)
     3.0        $ Upper bound of variable no.( 7)
      Y         $ Any more decision variables (Y or N) ?
        8       $ Choose a decision variable (1,2,3,...) (waviness amplitude)
  0.1000000E-01 $ Lower bound of variable no.( 8)
   0.800000     $ Upper bound of variable no.( 8)
      N         $ Any more decision variables (Y or N) ?
      N         $ Any linked variables (Y or N) ?
      N         $ Any inequality relations among variables? (type H)
      Y         $ Any escape variables (Y or N) ?
      Y         $ Want to have escape variables chosen by default?
==========================================================================
```

Table 7.6 Input data for MAINSETUP/OPTIMIZE for design sensitivity run with respect to the decision variable, WAVLEN (axial halfwavelength of waviness in the wall of the cylindrical shell)

```
==========================================================================
      N         $ Do you want a tutorial session and tutorial output?
        1       $ Choose an analysis you DON'T want (1, 2,..), IBEHAV
      Y         $ Any more analysis types NOT wanted (Y or N) ?
        2       $ Choose an analysis you DON'T want (1, 2,..), IBEHAV
      Y         $ Any more analysis types NOT wanted (Y or N) ?
        3       $ Choose an analysis you DON'T want (1, 2,..), IBEHAV
      Y         $ Any more analysis types NOT wanted (Y or N) ?
        9       $ Choose an analysis you DON'T want (1, 2,..), IBEHAV
      Y         $ Any more analysis types NOT wanted (Y or N) ?
       10       $ Choose an analysis you DON'T want (1, 2,..), IBEHAV
      Y         $ Any more analysis types NOT wanted (Y or N) ?
       11       $ Choose an analysis you DON'T want (1, 2,..), IBEHAV
      Y         $ Any more analysis types NOT wanted (Y or N) ?
       12       $ Choose an analysis you DON'T want (1, 2,..), IBEHAV
      Y         $ Any more analysis types NOT wanted (Y or N) ?
       13       $ Choose an analysis you DON'T want (1, 2,..), IBEHAV
      Y         $ Any more analysis types NOT wanted (Y or N) ?
       15       $ Choose an analysis you DON'T want (1, 2,..), IBEHAV
      Y         $ Any more analysis types NOT wanted (Y or N) ?
       16       $ Choose an analysis you DON'T want (1, 2,..), IBEHAV
      Y         $ Any more analysis types NOT wanted (Y or N) ?
       17       $ Choose an analysis you DON'T want (1, 2,..), IBEHAV
      Y         $ Any more analysis types NOT wanted (Y or N) ?
       18       $ Choose an analysis you DON'T want (1, 2,..), IBEHAV
      N         $ Any more analysis types NOT wanted (Y or N) ?
        0       $ NPRINT= output index (0=GOOD, 1=ok, 2=debug, 3=too much)
        3       $ Choose type of analysis (1=opt., 2=fixed, 3=sensit.) ITYPE
        7       $ Choose a design variable (1, 2, 3, ...), IBVAR  (WAVLEN)
  0.5450000     $ Starting value of the design parameter, VARBEG  (use tight
  0.5640000     $ Ending value of the design parameter, VAREND     limits)
      n         $ Do you want to use the default for the number of steps?
       27       $ Number of steps from VARBEG to VAREND. NSTEPS
==========================================================================
```

```
Table 7.7 Input data for WAVYCYL system processor "DECIDE" (testnew6.DEC)
=========================================================================
     N           $ Do you want a tutorial session and tutorial output?
        1        $ Choose a decision variable (1,2,3,...) (cyl. wall thickness)
  0.3000000E-01  $ Lower bound of variable no.( 1)
  0.5000000      $ Upper bound of variable no.( 1)
     Y           $ Any more decision variables (Y or N) ?
        8        $ Choose a decision variable (1,2,3,...) (waviness amplitude)
  0.1000000E-01  $ Lower bound of variable no.( 8)
   0.800000      $ Upper bound of variable no.( 8)
     N           $ Any more decision variables (Y or N) ?
     N           $ Any linked variables (Y or N) ?
     N           $ Any inequality relations among variables? (type H)
     Y           $ Any escape variables (Y or N) ?
     Y           $ Want to have escape variables chosen by default?
=========================================================================
```

Table 7.8 Sample output (some editing) corresponding to optimized externally stiffened wavy cylindrical shell. This file is called testnew6.OPM. These results were arrived at via the runstream listed in Section 7.4.

```
================================================================================
      N         $ Do you want a tutorial session and tutorial output?
         2      $ Choose an analysis you DON'T want (1, 2,..), IBEHAV
      Y         $ Any more analysis types NOT wanted (Y or N) ?
         3      $ Choose an analysis you DON'T want (1, 2,..), IBEHAV
      Y         $ Any more analysis types NOT wanted (Y or N) ?
        15      $ Choose an analysis you DON'T want (1, 2,..), IBEHAV
      Y         $ Any more analysis types NOT wanted (Y or N) ?
        16      $ Choose an analysis you DON'T want (1, 2,..), IBEHAV
      Y         $ Any more analysis types NOT wanted (Y or N) ?
        17      $ Choose an analysis you DON'T want (1, 2,..), IBEHAV
      Y         $ Any more analysis types NOT wanted (Y or N) ?
        18      $ Choose an analysis you DON'T want (1, 2,..), IBEHAV
      N         $ Any more analysis types NOT wanted (Y or N) ?
         0      $ NPRINT= output index (0=GOOD, 1=ok, 2=debug, 3=too much)
         2      $ Choose type of analysis (1=opt., 2=fixed, 3=sensit.) ITYPE
         5      $ How many design iterations in this run (3 to 25)?
         1      $ Choose (1="conservative"), (2="liberal") move limits, IMOVE
      Y         $ Do you want default (RATIO=10) for initial move limit jump?
      Y         $ Do you want the default perturbation (dx/x = 0.05)?
      N         $ Do you want to reset total iterations to zero (Type H)?

 ************ END OF THE  testnew6.OPT  FILE ***********
 ************ OCTOBER, 1999 VERSION OF GENOPT ****************
 ******** BEGINNING OF THE  testnew6.OPM  FILE *********

 *********************** MAIN PROCESSOR **********************
 The purpose of the mainprocessor, OPTIMIZE, is to perform,
 in a batch mode, the work specified by MAINSETUP for the case
 called testnew6.  Results are stored in the file  testnew6.OPM.
 Please inspect testnew6.OPM before doing more design iterations.
 ************************************************************

 STRUCTURAL ANALYSIS FOR DESIGN ITERATION NO.    0: (fixed design analysis)
 This is the final optimum design arrived at via the runstream listed in
 Section 7.4.
  STRUCTURAL ANALYSIS WITH UNPERTURBED DECISION VARIABLES
 VAR. DEC. ESCAPE LINK. LINKED  LINKING   LOWER     CURRENT     UPPER
  NO. VAR.  VAR.  VAR.    TO   CONSTANT   BOUND      VALUE      BOUND
  Total wall thickness: THICK
   1   Y     Y     N      0    0.00E+00  3.00E-02 3.0605E-02  5.00E-01
  ring spacing (use zero if no rings): BRINGS
   2   N     N     N      0    0.00E+00  0.00E+00 1.0000E+01  0.00E+00
  thickness of web of T-ring: TWEB
   3   N     N     N      0    0.00E+00  0.00E+00 6.7398E-02  0.00E+00
  height of web of T-ring: HWEB
   4   N     N     N      0    0.00E+00  0.00E+00 6.7398E-01  0.00E+00
  thickness of outstanding flange of T-ring: TFLANG
   5   N     N     N      0    0.00E+00  0.00E+00 0.0000E+00  0.00E+00
  width of outstanding flange of T-ring: HFLANG
   6   N     N     N      0    0.00E+00  0.00E+00 0.0000E+00  0.00E+00
  Axial halfwavelength of the waviness: WAVLEN
   7   N     N     N      0    0.00E+00  0.00E+00 5.5555E-01  0.00E+00
  Amplitude of waviness: AMPLIT
   8   Y     N     N      0    0.00E+00  1.00E-02 6.6471E-02  8.00E-01
  Local meridional radius of curvature: RADSML
   9   N     N     N      0    0.00E+00  0.00E+00 0.0000E+00  0.00E+00

 *************** UNPERTURBED DESIGN: IMODX = 0 ***************
```

```
 BEGIN COMPUTATIONS FOR THE UNPERTURBED (CURRENT) DESIGN
  LOAD SET NO.  1

*** SYMMETRIC BUCKLING LOAD FACTORS AND MODE SHAPES ***
LINEAR BUCKLING LOAD FACTOR, 0 DEGREES, MODEL 2 (CIRC. WAVES)
The entire length (  9.0000E+01) of the cyl. has smeared        (See Item 12,
waviness and smeared rings. The purpose of this analysis is      Section 5.3)
to obtain a general buckling eigenvalue to be used in the
formula for FN2ADD(1) = added hoop compression from the
growth of the initial general buckling modal imperfection
during loading. FN2ADD(1) is used for inter-ring buckling.
   eigenvalue(circ. waves)
       1.9767E+01(   0)          (See Items 12a and 12b in Section 5.3
       2.0167E+01(   1)           for a discussion.)
       2.5841E+00(   2)  <--- critical value; compare with 1.3333 from the
       6.6902E+00(   3)                        model with discrete rings.
       1.1560E+01(   4)
       1.4550E+01(   5)
===== BUCKLING MODAL SYMMETRY AT SYMMETRY PLANE =====
Crit. buckling factor, BUCSMR(smeared waviness, SMEARED rings)=  2.5841E+00
Critical number of circumferential waves, NWVCRT=    2

*** SYMMETRIC BUCKLING LOAD FACTORS AND MODE SHAPES ***        (See Items
LINEAR BUCKLING LOAD FACTOR, 0 DEGREES, MODEL 2 (CIRC. WAVES)   12a,b in
The entire length (  9.0000E+01) of the cyl. has smeared        Section 5.3)
waviness and DISCRETE rings. The purpose of this analysis is
to obtain a general buckling eigenvalue to be used in the
formula for FN2ADD(2) = added hoop compression from the
growth of the initial general buckling modal imperfection
during loading. FN2ADD(2) is used in the stress analysis.
   eigenvalue(circ. waves)
       1.3333E+00(   2)    <--- compare with 2.5841 from smeared ring model.
===== BUCKLING MODAL SYMMETRY AT SYMMETRY PLANE =====
Crit. buckling factor, BUCDIS(smeared waviness, discrete rings)=  1.3333E+00
Critical number of circumferential waves, NWVCRT=    2

*** ANTISYMMETRIC BUCKLING LOAD FACTORS AND MODE SHAPES ***
BUCKLING LOAD FACTOR FROM INDIC=1, MODEL 2 (CIRC. WAVES).       (See Item 13,
The inter-ring length (  1.0000E+01) of the cyl. has smeared     Section 5.3)
waviness and discrete end rings. The purpose of this analysis
is to obtain inter-ring buckling eigenvalues to be used to
determine the minimum circ. wavnumber, NWAVLC, that corres-
ponds to inter-ring buckling in the larger models used later.
   eigenvalue(circ. waves)
       1.7298E+01(   2)
       7.7756E+00(   3)
       2.5047E+00(   4)
       2.0709E+00(   5) <--- critical value for local (inter-ring) buckling
       2.6127E+00(   6)      from simple model. See Item 13 in Section 5.3.
       3.5024E+00(   7)      The critical circumferential wavenumber,
       4.4283E+00(   8)      NWVCRT = 5
       5.4695E+00(   9)
       6.4417E+00(  10)
       7.4923E+00(  11)      (From these calculations and from Eq. 5.26,
       8.6456E+00(  12)       the WAVYCYL system sets the minimum circ.
       9.9042E+00(  13)       wavenumber corresponding to inter-ring
       1.1252E+01(  14)       buckling, NWAVLC = 0.7*HWVCRT +0.5 = 4 .
       1.2761E+01(  15)       NWAVLC is used later in SUBROUTINE STABIL to
       1.4410E+01(  16)       see if Ny(add) (see Eq. 5.22), that is,
       1.6214E+01(  17)       FN2ADD(1), should be added to the prebuckling
       1.8179E+01(  18)       hoop stress resultant for the perfect shell.)
       2.0304E+01(  19)
```

```
        2.2599E+01(  20)
 ===== BUCKLING MODAL ANTISYMMETRY AT SYMMETRY PLANE =====
 Crit. buckling factor, BUCLOC(smeared waviness, DISCRETE end rings)=2.0709E+00
 Critical number of circumferential waves, NWVCRT=     5
                                                                  Item, Eq.,
 Output from STRUCT (See Section 5.3 of paper):                   Table Nos.
                                                                Item Eq. Tab
 Maximum stress from nonlinear theory (no rings),STRMXX=  2.0847E+04  7  -   -
 End shortening under unit axial compression,     ENDUV=  8.0057E-04  8  -   -
 Modal frequency correspnding to 2 circ. waves,   FREQ2=  4.7935E+01  9  -   -
 Ratio of wavy arclength to straight length,     ARCRAT=  1.0377E+00 10  -  5.1
 Reduction factor for axial stiffness,           C11RAT=  3.8546E-02 10  -  5.1
 Hoop bending stiffness ratio,C55RAT=C55(eff)/C55(wall)=  2.5002E+01 10  -  5.1
 2nd ratio of wavy arclength to straight length, ARCRT2=  1.0377E+00  -  -   -
 Weight of the entire Model No. 2,               WEIGHT=  1.7817E+01 14  -   -
 Nx from axial g-loading and unsupported tube,   FNXADD= -2.1005E+00 15 5.27 -
 Effective mass density of shell wall material,  DENSHL=  2.5000E-04  -  -   -
 Mass density of ring material,                  DENRNG=  2.5000E-04  -  -   -
 Effective density of shell with smeared rings,  RHOEFF=  2.8711E-04  -  -  5.1
 Amplitude of initial general buckling imperfection, W0=  4.5000E-02 12b 5.25 -
(C22-C12**2/C11)*(C25/C22)*(n/R)**2*W0/(EIG1-1)=FN2ADD(1)=-1.9077E+01 12 5.22 -
(C22-C12**2/C11)*(C25/C22)*(n/R)**2*W0/(EIG2-1)=FN2ADD(2)=-3.4059E+02 12 5.22 -
in which
EIG1 = buckling load factor, smeared waviness and SMEARED  rings=2.5841E+00
and
EIG2 = buckling load factor, smeared waviness and DISCRETE rings=1.3333E+00
Smallest buckling circumferential wavenumber for which FN2ADD(1)= -1.9077E+01
is added to the hoop load from pressure in buckling analyses NWAVLC=4 (Item 13)

 Output from STRUCT for linear nonsymmetric stress analysis:          location
                                                                      seg node
 Max. critical stress,  theta=0, load set A,  STRNON(1)=  3.1778E+04, 156 023
 Max. critical stress,  theta=0, load set B,  STRNON(2)=  0.0000E+00,      0
 Max. normal displace., theta=0, load set A,  WWWNON(1)= -3.0072E-01, 157 007
 Max. normal displace., theta=0, load set B,  WWWNON(2)=  0.0000E+00,      0
 Max. critical stress,  theta=180,load set A, STRNON(1)=  2.8246E+04,  23 011
 Max. critical stress,  theta=180,load set B, STRNON(2)=  0.0000E+00,      0
 Max. normal displace., theta=180,load set A, WWWNON(1)=  2.9489E-01, 157 007
 Max. normal displace., theta=180,load set B, WWWNON(2)=  0.0000E+00,      0

 The 18 behaviors listed in Table 6.1, minus the behaviors, 2, 3, and 15-18,
 indicated in the testnew6.OPT file listed at the beginning of this table,
 are evaluated next. See Section 6.2 for discussions.

 ==============================================================
 BEGIN COMPUTATIONS IN SUBROUTINE BEHX1 (NONLINEAR STRESS).    (Behavior No. 1)
 IMODX= 0; LOAD SET NO.  1
 Maximum nonlinear effective stress, STRMAX=  2.0847E+04

 ==============================================================
 BEGIN SUBROUTINE BEHX4 (LINEAR NONAXISYMMETRIC STRESS, 0deg).(Behavior No. 4)
 IMODX= 0; LOAD SET NO.  1
 Maximum stress from linear theory at 0 deg, STR0(ILOADX)=    3.1778E+04

 ==============================================================
 BEGIN SUBROUTINE BEHX5 (LINEAR NONAXISYMMETRIC STRESS, 180d).(Behavior No. 5)
 IMODX= 0; LOAD SET NO.  1
 Maximum stress, linear theory at 180 deg, STR180(ILOADX)=    2.8246E+04

 ==============================================================
 BEGIN SUBROUTINE BEHX6 (LINEAR BUCKLING AT 0 DEGREES).       (Behavior No. 6)
 LOW-WAVE-RANGE, IMODX= 0; LOAD SET NO.  1
```

```
SYMMETRIC BUCKLING ABOUT MIDLENGTH SYMMETRY PLANE
***** SYMMETRIC BUCKLING LOAD FACTORS AND MODE SHAPES *****
LINEAR BUCKLING LOAD FACTOR, 0 DEGREES, MODEL 2 (CIRC. WAVES)
   eigenvalue(circ. waves)
      9.6037E+00(   0)                           (NOTE: the three ranges of
      9.2534E+00(   1)                            circ. wavenumber: low-n,
      1.2854E+00(   2)  <--- general buckling     mid-n, and high-n, were set
      2.4793E+00(   3)                            up to capture general bucklng,
      1.3122E+00(   4)  <--- local (inter-ring)   local buckling, and even more
      1.3657E+00(   5)       buckling             local buckling. In this case
===== BUCKLING MODAL SYMMETRY AT SYMMETRY PLANE   it turns out that both general
Critical buckling load factor, BUC0=  1.2854E+00  and local buckling are cap-
Critical number of circ. waves,NWVCRT=2           tured by the low-n range.
                                                  That's okay.)

*** SYMMETRIC BUCKLING LOAD FACTORS AND MODE SHAPES ***
LINEAR BUCKLING LOAD FACTOR, 0 DEGREES, MODEL 2 (CIRC. WAVES)
THE ENTIRE LENGTH (  9.0000E+01) OF THE CYL. HAS "SMEARED" WAVINESS.
   eigenvalue(circ. waves)
      1.7813E+01(   0)                           (The purpose of this "smeared"
      1.8377E+01(   1)                            model is to see how accurate
      1.3327E+00(   2)  <--- general buckling     smearing the waviness is.
      2.7517E+00(   3)                            The "smeared waviness" results
      2.1689E+00(   4)                            are not used for optimization.)
      1.7910E+00(   5)  <--- local (inter-ring) buckling
===== BUCKLING MODAL SYMMETRY AT SYMMETRY PLANE =====
Crit. buckling factor,  BUC0("smeared waviness")=  1.3327E+00
Critical number of circumferential waves, NWVCRT=    2

==============================================================
BEGIN SUBROUTINE BEHX7 (LINEAR BUCKLING AT 0 DEGREES).      (Behavior No. 7)
LOW-WAVE-RANGE, IMODX= 0; LOAD SET NO.  1
ANTI-SYMMETRIC BUCKLING ABOUT MIDLENGTH SYMMETRY PLANE
*** ANTISYMMETRIC BUCKLING LOAD FACTORS AND MODE SHAPES ***
LINEAR BUCKLING LOAD FACTOR, 0 DEGREES, MODEL 2 (CIRC. WAVES)
   eigenvalue(circ. waves)
      9.6037E+00(   0)
      9.2535E+00(   1)
      1.3204E+00(   2)  <--- general buckling
      2.4896E+00(   3)
      1.2671E+00(   4)  <--- local (inter-ring) buckling
      1.3505E+00(   5)
===== BUCKLING MODAL ANTISYMMETRY AT SYMMETRY PLANE =====
Critical buckling load factor, BUC0=  1.2671E+00
Critical number of circumferential waves, NWVCRT=    4

*** ANTISYMMETRIC BUCKLING LOAD FACTORS AND MODE SHAPES ***
LINEAR BUCKLING LOAD FACTOR, 0 DEGREES, MODEL 2 (CIRC. WAVES)
THE ENTIRE LENGTH (  9.0000E+01) OF THE CYL. HAS "SMEARED" WAVINESS.
   eigenvalue(circ. waves)
      1.7813E+01(   0)                         (See the note above in the
      1.8377E+01(   1)                          section for symmetric buckling
      1.3591E+00(   2)  <--- general            with "smeared waviness" along
      2.8315E+00(   3)       buckling           the entire length of the cyl.)
      2.0897E+00(   4)
      1.7626E+00(   5)  <--- local (inter-ring) buckling
===== BUCKLING MODAL ANTISYMMETRY AT SYMMETRY PLANE =====
Crit. buckling factor,  BUC0("smeared waviness")=  1.3591E+00
Critical number of circumferential waves, NWVCRT=    2

==============================================================
BEGIN SUBROUTINE BEHX8 (LINEAR BUCKLING AT 0 DEGREES).      (Behavior No. 8)
```

```
MID-WAVE-RANGE, IMODX= 0; LOAD SET NO.  1
***** SYMMETRIC BUCKLING LOAD FACTORS AND MODE SHAPES *****
LINEAR BUCKLING LOAD FACTOR, 0 DEGREES, MODEL 2 (CIRC. WAVES)
   eigenvalue(circ. waves)
       1.9602E+00(   6)
       2.3984E+00(   7)                          (Note: there is no further
       2.7866E+00(   8)                           minimum eigenvalue(n) in
       3.1569E+00(   9)                           this range of circ. waves.)
       3.9330E+00(  10)
===== BUCKLING MODAL SYMMETRY AT SYMMETRY PLANE =====
Critical buckling load factor, BUC0=  1.9602E+00
Critical number of circumferential waves, NWVCRT=    6

*** ANTISYMMETRIC BUCKLING LOAD FACTORS AND MODE SHAPES ***
LINEAR BUCKLING LOAD FACTOR, 0 DEGREES, MODEL 2 (CIRC. WAVES)
   eigenvalue(circ. waves)
       1.9460E+00(   6)
       2.3940E+00(   7)                          (Note: there is no further
       2.7795E+00(   8)                           minimum eigenvalue(n) in
       3.1568E+00(   9)                           this range of circ. waves.)
       3.9328E+00(  10)
===== BUCKLING MODAL ANTISYMMETRY AT SYMMETRY PLANE =====
Critical buckling load factor, BUC0=  1.9460E+00
Critical number of circumferential waves, NWVCRT=    6

======================================================================
BEGIN SUBROUTINE BEHX9(HI-WAVE LINEAR BUCKLING AT 0 DEGREES). (Behavior No. 9)
IMODX= 0; LOAD SET NO.  1                                      turned off for
*** ANTISYMMETRIC BUCKLING LOAD FACTORS AND MODE SHAPES ***    optimization
LINEAR HI-WAVE BUCKLING LOAD FACTOR, 0 DEGREES (CIRC. WAVES)   in this case.)
   eigenvalue(circ. waves)
       1.0608E+01(  16)
       1.3804E+01(  22)
       1.4299E+01(  28)
       1.5267E+01(  34)                          (Note: there is no further
       1.6641E+01(  40)                           minimum eigenvalue(n) in
       1.8286E+01(  46)                           this range of circ. waves.
       1.9902E+01(  52)                           Only buckling antisymmetric
       2.1461E+01(  58)                           with respect to the mid-
       2.3044E+01(  64)                           length symmetry plane is
       2.4655E+01(  70)                           explored for the high-n
       2.6279E+01(  76)                           range. This is because for
       2.7875E+01(  82)                           high-n buckling the ring
       2.9325E+01(  88)                           at the midlength symmetry
       3.0360E+01(  94)                           plane will surely prevent
       3.0955E+01( 100)                           radial displacement there)
===== BUCKLING MODAL ANTISYMMETRY AT SYMMETRY PLANE =====
Critical buckling load factor, BUC0HI=  1.0608E+01
Critical number of circumferential waves, NWVCRT=   16

======================================================================
BEGIN SUBROUTINE BEHX10 (LINEAR BUCKLING AT 180 DEGREES).   (Behavior No. 10
IMODX= 0; LOAD SET NO.  1                                    was turned off
***** SYMMETRIC BUCKLING LOAD FACTORS AND MODE SHAPES *****  during optimiza-
LINEAR BUCKLING LOAD FACTOR, 180 DEG., MODEL 2 (CIRC. WAVES) tion in this case)
   eigenvalue(circ. waves)
       1.1756E+01(   0)                          (NOTE: In WAVYCYL the buckling
       1.1769E+01(   1)                           load factors for the 180-deg
       1.3189E+00(   2)  <--- general buckling    meridian are computed over
       2.6115E+00(   3)                           both the low-n and mid-n
       1.4124E+00(   4)  <--- local (inter-ring)  ranges in one "behavior"
       1.4360E+00(   5)       buckling            subroutine, BEHX10. The n-
```

```
       2.1050E+00(   6)                        range is not divided up into
       2.5998E+00(   7)                        two sub-ranges. Also, the
       3.1652E+00(   8)                        "symmetric" and "antisymme-
       3.7065E+00(   9)                        tric buckling evaluations are
       4.6040E+00(  10)                        conducted in the same routine)
 ===== BUCKLING MODAL SYMMETRY AT SYMMETRY PLANE =====
 Critical buckling load factor, BUC180=  1.3189E+00
 Critical number of circumferential waves, NWVCRT=    2

 *** ANTISYMMETRIC BUCKLING LOAD FACTORS AND MODE SHAPES ***
 LINEAR BUCKLING LOAD FACTOR, 180 DEG., MODEL 2 (CIRC. WAVES)
    eigenvalue(circ. waves)
       1.1756E+01(   0)
       1.1769E+01(   1)                        (NOTE; We are still in
       1.3573E+00(   2)  <--- general buckling   SUBROUTINE BEHX10)
       2.6118E+00(   3)
       1.3854E+00(   4)  <--- local (inter-ring) buckling
       1.4317E+00(   5)
       2.1050E+00(   6)
       2.5998E+00(   7)
       3.1651E+00(   8)
       3.7065E+00(   9)
       4.6040E+00(  10)
 ===== BUCKLING MODAL ANTISYMMETRY AT SYMMETRY PLANE =====
 Critical buckling load factor, BUC180=  1.3573E+00
 Critical number of circumferential waves, NWVCRT=    2

 ==============================================================
 BEGIN SUBROUTINE BEHX11 (HI-WAVE LINEAR BUCKLNG 180 DEGREES).(Behavior No. 11
 IMODX= 0; LOAD SET NO.  1                                     turned off for
 *** ANTISYMMETRIC BUCKLING LOAD FACTORS AND MODE SHAPES ***   optimization)
 LINEAR HI-WAVE BUCKLING LOAD FACTOR, 180 DEG. (CIRC. WAVES)
    eigenvalue(circ. waves)
       1.1037E+01(  16)
       1.5923E+01(  22)
       1.6160E+01(  28)
       1.6962E+01(  34)                      (As with buckling along the
       1.8243E+01(  40)                       meridian at 0 degrees, only
       1.9847E+01(  46)                       antisymmetric buckling with
       2.1552E+01(  52)                       respect to the symmetry plane
       2.3258E+01(  58)                       at the midlength is explored
       2.4989E+01(  64)                       for the case of high-n
       2.6752E+01(  70)                       buckling.)
       2.8544E+01(  76)
       3.0347E+01(  82)
       3.2085E+01(  88)
       3.3340E+01(  94)
       3.3888E+01( 100)
 ===== BUCKLING MODAL ANTISYMMETRY AT SYMMETRY PLANE =====
 Critical buckling load factor, B180HI=  1.1037E+01
 Critical number of circumferential waves, NWVCRT=   16

 ==============================================================
 BEGIN SUBROUTINE BEHX12 (MAX. NORMAL DISPLACEMENT, 0 DEG.).  (Behavior No. 12
 IMODX= 0; LOAD SET NO.  1                                    turned off during
                                                              optimization.)
 Max. normal displacement, linear theory, 0 deg, WWW0(ILOADX)=3.0072E-01

 ==============================================================
 BEGIN SUBROUTINE BEHX13 (MAX. NORMAL DISPLACEMENT, 180 DEG.).(Behavior No. 13
 IMODX= 0; LOAD SET NO.  1                                    turned off during
                                                              optimization.)
```

```
Max. normal displac., linear theory, 180 deg, WWW180(ILOADX)=2.9489E-01

=============================================================
BEGIN SUBROUTINE BEHX14 (MODAL FREQUENCY, AXISYM. LOADING).  (Behavior No. 14)
IMODX= 0; LOAD SET NO.  1
***** FREQUENCIES AND MODE SHAPES *****
      FREQUENCY(CIRC. WAVES)
       9.2244E+01(   0)
       1.0012E+01(   1)  <--- critical value: "beam-type" vibration
       5.6759E+01(   2)       This is used during optimization cycles
       2.3223E+02(   3)
=======================================
Critical modal vibration frequency, FREQ=  1.0012E+01
Critical number of circumferential waves, NWVCRT=    1

***** FREQUENCIES AND MODE SHAPES: "SMEARED" WAVINESS *****
      FREQUENCY(CIRC. WAVES)
       1.0428E+02(   0)
       1.1439E+01(   1)  <--- critical value: "beam-type" vibration
       5.4769E+01(   2)       The "smeared waviness" model is not
       2.2424E+02(   3)       used during optimization cycles.
=======================================
Critical modal vibration frequency, FREQ=  1.1439E+01
Critical number of circumferential waves, NWVCRT=    1

Find natural frequency for axial length=  8.0000E+02   (Length between axial
                                                        motion restraints.)
***** FREQUENCY AND MODE SHAPE FOR 0 CIRC. WAVES *****
      FREQUENCY(CIRC. WAVES)
       2.2228E+01(   0)
=======================================
Critical modal vibration frequency, FREQ=  2.2228E+01
Critical number of circumferential waves, NWVCRT=    0


***** RESULTS FOR LOAD SET NO.  1  ******
PARAMETERS WHICH DESCRIBE BEHAVIOR (e.g. stress, buckling load)
BEH.   CURRENT
NO.     VALUE            DEFINITION
 1    2.085E+04    maximum stress in wall from nonlinear theory: STRMAX(1 )
 2    1.000E+10    buckling load factor from nonlinear theory: BUCFAC(1 )
 3    1.000E+10    hi-wave buckling load factor, nonlinear theory: BUCHIW(1 )
 4    3.178E+04    max. stress at 0 deg., linear theory: STR0(1 )
 5    2.825E+04    max. stress at 180 deg., linear theory: STR180(1 )
 6    1.285E+00    buckling load factor at 0 deg., linear theory: BUC0(1 )
 7    1.267E+00    load factor for antisymmetric buckling at 0 deg: B0ANTI(1)
 8    1.946E+00    load factor for mid-wave-range buckling at 0 deg: BUC0MD(1)
 9    8.876E+00    hi-wave buckling load factor, 0 deg,linear theory:BUC0HI(1)
10    1.332E+00    buckling load factor at 180 deg, linear theory: BUC180(1 )
11    1.031E+01    hi-wave buckling load factor 180 deg, lin.theory: B180HI(1)
12    3.007E-01    maximum normal displacement, 0 deg., linear theory: WWW0(1)
13    2.949E-01    maximum normal displacement, 180 deg., lin.theory:WWW180(1)
14    1.001E+01    modal frequency (hertz): FREQ(1 )
15    1.000E-10    maximum stress from random excitation: STRRAN(1 )
16    1.000E+10    buckling load factor from random excitation: BUCRAN(1 )
17    1.000E+10    hi-wave buckling factor from random excitation: BRANHI(1)
18    1.000E-10    max. normal displacement from random excitation: WWWRAN(1)

MARGINS CORRESPONDING TO CURRENT DESIGN (F.S.= FACTOR OF SAFETY)
MARGIN CURRENT                                                     BEHAVIOR
NO.     VALUE           DEFINITION                                  NUMBER
 1    5.831E-01  1-(STRMAX(1 )/STRALW(1 )) X STRFS(1 ); F.S.=  1.00     1
```

```
 2   3.644E-01  1-(STR0(1 )/STR0A(1 )) X STR0F(1 ); F.S.=  1.00          4
 3   4.351E-01  1-(STR180(1 )/ST180A(1 )) X ST180F(1 ); F.S.=  1.00      5
 4   2.830E-02  (BUC0(1 )/BUC0A(1 )) / BUC0F(1 )-1; F.S.=  1.25          6
 5   1.366E-02  (B0ANTI(1 )/B0ANTA(1 )) / B0ANTF(1 )-1; F.S.=  1.25      7
 6   5.568E-01  (BUC0MD(1 )/BUC0MA(1 )) / BUC0MF(1 )-1; F.S.=  1.25      8
 7   6.101E+00  (BUC0HI(1 )/BUC0HA(1 )) / BUC0HF(1 )-1; F.S.=  1.25      9
 8   6.556E-02  (BUC180(1 )/BU180A(1 )) / BU180F(1 )-1; F.S.=  1.25     10
 9   7.249E+00  (B180HI(1 )/B180HA(1 )) / B180HF(1 )-1; F.S.=  1.25     11
10   6.241E-01  1-(WWW0(1 )/WWW0A(1 )) X WWW0F(1 ); F.S.=  1.00         12
11   6.314E-01  1-(WWW180(1 )/WW180A(1 )) X WW180F(1 ); F.S.=  1.00     13
12   1.208E-03  (FREQ(1 )/VIBALW(1 )) / VIBFS(1 )-1; F.S.=  1.00        14
13   1.000E+00  1-(STRRAN(1 )/STRRNA(1 )) X STRRNF(1 ); F.S.=  1.00     15
14   1.000E+00  1-(WWWRAN(1 )/WWWRNA(1 )) X WWWRNF(1 ); F.S.=  1.00     18

******************** DESIGN OBJECTIVE *******************
   CURRENT VALUE OF THE OBJECTIVE FUNCTION:
VAR.   CURRENT
NO.     VALUE             DEFINITION
 1    1.782E+01  weight of the cylindrical shell: WEIGHT  (NOTE: This is the
******************** DESIGN OBJECTIVE *******************   weight of half the
***********  ALL 1 LOAD CASES PROCESSED ***********          length of the tube)

PARAMETERS WHICH ARE ALWAYS FIXED.  NONE CAN BE DECISION VARIAB.
VAR.   CURRENT
NO.     VALUE             DEFINITION
 1    1.800E+02  length of cylindrical shell: AXIAL
 2    9.000E+00  Average nominal radius of cylindrical shell: RADIUS
 3    1.000E+07  Average modulus of ring material: ERING
 4    3.000E-01  Average Poisson ratio of ring material: FNURNG
 5    2.500E-04  Average mass density of ring material: DENRNG
 6    3.864E+02  Acceleration of gravity (e.g. 386.4 in/sec**2): GRAVTY
 7    8.000E+02  Length of tube unrestrained by axial hanger: LGAXL
 8    1.000E+07  Youngs modulus: ESTIFF
 9    3.000E-01  Poisson ratio: FNU
10    2.500E-04  Material mass density (e.g. alum.=0.00025lb-sec**2/in: DENS
11    1.000E-02  damping factor: BDAMP(1 )
12    1.000E-02  damping factor: BDAMP(2 )
13    1.000E-02  damping factor: BDAMP(3 )
14    5.000E-02  damping factor: BDAMP(4 )
15    5.000E+00  frequency (hertz) corresponding to damping factor: BFREQ(1)
16    1.000E+01  frequency (hertz) corresponding to damping factor: BFREQ(2)
17    3.000E+01  frequency (hertz) corresponding to damping factor: BFREQ(3)
18    5.000E+02  frequency (hertz) corresponding to damping factor: BFREQ(4)
19    3.000E-01  spectral density: SPTDEN(1)
20    5.000E-01  spectral density: SPTDEN(2)
21    1.000E+00  spectral density: SPTDEN(3)
22    2.000E+00  spectral density: SPTDEN(4)
23    1.000E+00  spectral density: SPTDEN(5)
24    5.000E+00  frequency (hertz) corresponding to spectral density: SFREQ(1)
25    8.000E+00  frequency (hertz) corresponding to spectral density: SFREQ(2)
26    1.200E+01  frequency (hertz) corresponding to spectral density: SFREQ(3)
27    1.000E+02  frequency (hertz) corresponding to spectral density: SFREQ(4)
28    5.000E+02  frequency (hertz) corresponding to spectral density: SFREQ(5)

PARAMETERS WHICH ARE ENVIRONMENTAL FACTORS (e.g. loads, temps.)
VAR.   CURRENT
NO.     VALUE             DEFINITION
 1   -5.300E+01  Axial resultant (neg. for compression),Load Set A: FNX(1)
 2    0.000E+00  Axial resultant (neg. for compression), Load Set B: FNXB(1)
 3    1.500E+00  number of g's acceleration along cylinder axis: GAXIAL(1)
 4    3.000E+00  Number of g's perpendicular to axis of cylinder: GLATRL(1)
 5   -1.180E+01  pressure (negative for external), Load Set A: PRESS(1)
```

```
  6    0.000E+00  pressure (negative for external), Load Set B: PRESSB(1)

 PARAMETERS WHICH ARE CLASSIFIED AS ALLOWABLES (e.g. max. stress)
 VAR.   CURRENT
 NO.     VALUE             DEFINITION
  1    5.000E+04  maximum allowable stress, nonlinear theory: STRALW(1)
  2    1.000E+00  allowable buckling factor (use 1.0), nonlin.theory: BUCALW(1)
  3    1.000E+00  allowable hi-wave bucklng factor, nonlin.theory: BUCHIA(1)
  4    5.000E+04  max. allowable stress, linear theory: STR0A(1)
  5    5.000E+04  max. allowable stress, linear theory: ST180A(1)
  6    1.000E+00  allowable buckling factor (use 1), linear theory: BUC0A(1)
  7    1.000E+00  allowable (use 1), antisymmetric buckling, 0 deg.: B0ANTA(1)
  8    1.000E+00  allowable (use 1), mid-wave-range buckling, 0 deg: BUC0MA(1)
  9    1.000E+00  allowable for hi-wave buckling (use 1) at 0 deg.: BUC0HA(1)
 10    1.000E+00  allowable buckling factor,180 deg., linear theory: BU180A(1)
 11    1.000E+00  allowable (use 1), hi-wave buckling at 180 deg: B180HA(1)
 12    8.000E-01  maximum allowable normal displacemt, linear theory: WWW0A(1)
 13    8.000E-01  max. allowable normal displacment, linear theory: WW180A(1)
 14    1.000E+01  minimum allowable modal frequency: VIBALW(1)
 15    5.000E+04  max. allowable stress from random excitation: STRRNA(1)
 16    1.000E+00  allowable buckling load factor, random excit.: BUCRNA(1)
 17    1.000E+00  allowable (use 1), buckling factor, random excit.: BRANHA(1)
 18    8.000E-01  max. allowable normal displ., random excitation: WWWRNA(1)

 PARAMETERS WHICH ARE FACTORS OF SAFETY
 VAR.   CURRENT
 NO.     VALUE             DEFINITION
  1    1.000E+00  factor of safety stress, nonlinear theory: STRFS(1)
  2    1.250E+00  factor of safety buckling, nonlinear theory: BUCFS(1)
  3    1.250E+00  factor of safety hi-wave buckling: BUCHIF(1)
  4    1.000E+00  factor of safety stress, linear theory: STR0F(1)
  5    1.000E+00  factor of safety stress, linear theory: ST180F(1)
  6    1.250E+00  factor of safety buckling factor, linear theory: BUC0F(1)
  7    1.250E+00  factor of safety antisymmetric buckling, 0 deg: B0ANTF(1)
  8    1.250E+00  factor of safety mid-wave-range buckling, 0 deg: BUC0MF(1)
  9    1.250E+00  factor of safety hi-wave buckling, linear theory: BUC0HF(1)
 10    1.250E+00  factor of safety buckling at 180 deg, lin. theory: BU180F(1)
 11    1.250E+00  factor of safety hi-wave buckling at 180 deg.: B180HF(1)
 12    1.000E+00  factor of safety max. normal displacement: WWW0F(1)
 13    1.000E+00  factor of safety normal displacment: WW180F(1)
 14    1.000E+00  factor of safety modal frequency: VIBFS(1)
 15    1.000E+00  factor of safety stress from random excitation: STRRNF(1)
 16    1.250E+00  factor of safety, buckling from random excitation: BUCRNF(1)
 17    1.250E+00  factor of safety hi-wave buckling, random excit.: BRANHF(1)
 18    1.000E+00  factor of safety max. normal displ., random excit.: WWWRNF(1)

     0 INEQUALITY CONSTRAINTS WHICH MUST BE SATISFIED

 Menu of commands: CHOOSEPLOT, OPTIMIZE, MAINSETUP, CHANGE,
                   DECIDE, SUPEROPT

 IN ORDER TO AVOID FALSE CONVERGENCE OF THE DESIGN, BE SURE TO
 RUN  "OPTIMIZE"  MANY TIMES DURING AN OPTIMIZATION.
 ******************** END OF testnew6.OPM FILE ****************
================================================================
```

Table 7.9 Results from convergence study with respect to: 1. number of nodes in each little toroidal segment (NMESHC) 2. total number of degrees of freedom (d.o.f.) in BOSOR4 MODEL 2 Results for an optimized PERFECT shell with the following dimensions: wall thickness, THICK = 0.03 in.; Ring spacing, BRINGS=10 in.; ring thickness, TWEB = 0.06798 in., Ring height, HWEB=0.6815 in.; axial halfwavelength of waviness, WAVLEN=0.55556 in.; amplitude (0.5*peak-to-peak) of waviness, AMPLIT = 0.061541 in.

discretization (nodes,d.o.f.) (NMESHC,MAXDOF)	prebuckling state max.stress (psi)	prebuckling state max.displc. (in.)	linear buckling sym.buckling eigenv.(n)	linear buckling antisym.buck. eigenv.(n)	vibration frequency eigenv.(n)
(31, 15000)				1.2982(2)	
(21, 15000)	23095	-0.26400	1.2588(2)	1.2986(2)	10.579(1)
(21, 15000)			1.3448(5)	1.3255(5)	
(21, 9000)	23119	-0.26312	1.2354(2)	1.2617(2)	10.620(1)
(21, 9000)			1.3631(5)	1.3271(5)	
(11, 9000)	23266	-0.26844	1.2529(2)	1.2928(2)	10.471(1)
(11, 9000)			1.3231(5)	1.3039(5)	
(5, 9000)	24214	-0.29427	1.2160(2)	1.2604(2)	9.8546(1)
(5, 9000)			1.1971(5)	1.1792(5)	
(21, 6000)	23109	-0.25934	1.2609(2)	1.2288(2)	10.928(1)
(21, 6000)			1.3905(5)	1.3361(5)	
(21, 3000)	23097	-0.25415	1.2702(2)	1.2857(2)	11.436(1)
(21, 3000)			1.5109(5)	1.3674(5)	
smeared waviness for entire model		-0.25070	1.3148(2)	1.3434(2)	12.043(1)
smeared waviness for entire model			1.8200(5)	1.7851(5)	

NOTE: for buckling, n=2 corresponds to general instability;
n=5 corresponds to inter-ring (local) buckling

Table 8.1 Final optimum design of wavy cylindrical shell without rings. The name of the case is "testnew7". This design was obtained after four SUPEROPTs, in which the upper limit on the axial halfwavelength of waviness, WAVLEN, was set to 5.0, 3.0, 2.0, and 1.0 inches, during each successive SUPEROPT.

```
===========================================================================
     N          $ Do you want a tutorial session and tutorial output?
       2        $ Choose an analysis you DON'T want (1, 2,..), IBEHAV
     Y          $ Any more analysis types NOT wanted (Y or N) ?
       3        $ Choose an analysis you DON'T want (1, 2,..), IBEHAV
     Y          $ Any more analysis types NOT wanted (Y or N) ?
      15        $ Choose an analysis you DON'T want (1, 2,..), IBEHAV
     Y          $ Any more analysis types NOT wanted (Y or N) ?
      16        $ Choose an analysis you DON'T want (1, 2,..), IBEHAV
     Y          $ Any more analysis types NOT wanted (Y or N) ?
      17        $ Choose an analysis you DON'T want (1, 2,..), IBEHAV
     Y          $ Any more analysis types NOT wanted (Y or N) ?
      18        $ Choose an analysis you DON'T want (1, 2,..), IBEHAV
     N          $ Any more analysis types NOT wanted (Y or N) ?
       2        $ NPRINT= output index (0=GOOD, 1=ok, 2=debug, 3=too much)
       2        $ Choose type of analysis (1=opt., 2=fixed, 3=sensit.) ITYPE
       5        $ How many design iterations in this run (3 to 25)?
       1        $ Choose (1="conservative"), (2="liberal") move limits, IMOVE
     Y          $ Do you want default (RATIO=10) for initial move limit jump?
     Y          $ Do you want the default perturbation (dx/x = 0.05)?
     N          $ Do you want to reset total iterations to zero (Type H)?

 ************ END OF THE  testnew7.OPT  FILE ***********
 ************ OCTOBER, 1999 VERSION OF GENOPT ****************
 ******** BEGINNING OF THE  testnew7.OPM  FILE *********

 STRUCTURAL ANALYSIS FOR DESIGN ITERATION NO.    0:
  STRUCTURAL ANALYSIS WITH UNPERTURBED DECISION VARIABLES
 VAR. DEC. ESCAPE LINK. LINKED  LINKING   LOWER     CURRENT    UPPER       DEFIN»
ITION
  NO. VAR.  VAR.  VAR.    TO   CONSTANT   BOUND       VALUE     BOUND
  Total wall thickness: THICK
   1  Y     N     N       0    0.00E+00  3.00E-02 5.0248E-02  3.00E-01
  ring spacing (use zero if no rings): BRINGS
   2  N     N     N       0    0.00E+00  0.00E+00 0.0000E+00  0.00E+00
  thickness of web of T-ring: TWEB
   3  N     N     N       0    0.00E+00  0.00E+00 0.0000E+00  0.00E+00
  height of web of T-ring: HWEB
   4  N     N     N       0    0.00E+00  0.00E+00 0.0000E+00  0.00E+00
  thickness of outstanding flange of T-ring: TFLANG
   5  N     N     N       0    0.00E+00  0.00E+00 0.0000E+00  0.00E+00
  width of outstanding flange of T-ring: HFLANG
   6  N     N     N       0    0.00E+00  0.00E+00 0.0000E+00  0.00E+00
  Axial halfwavelength of the waviness: WAVLEN
   7  Y     N     N       0    0.00E+00  6.00E-01 7.6725E-01  1.00E+00
  Amplitude of waviness: AMPLIT
   8  Y     N     N       0    0.00E+00  4.00E-02 1.2856E-01  1.00E+00
  Local meridional radius of curvature: RADSML
   9  N     N     N       0    0.00E+00  0.00E+00 0.0000E+00  0.00E+00

 *************** UNPERTURBED DESIGN: IMODX = 0 ***************
  BEGIN COMPUTATIONS FOR THE UNPERTURBED (CURRENT) DESIGN
   LOAD SET NO.  1

 ============================================================
 BEGINNING OF COMPUTATIONS IN SUBROUTINE STRUCT.
 IMODX= 0; LOAD SET NO.  1
```

```
============================================================
Output from STRUCT:
Maximum stress from nonlinear theory (no rings),STRMXX=  1.4083E+04
End shortening under unit axial compression,     ENDUV=  8.0090E-04
Modal frequency correspnding to 2 circ. waves,   FREQ2=  8.9543E+01
Ratio of wavy arclength to straight length,     ARCRAT=  1.0733E+00
Reduction factor for axial stiffness,           C11RAT=  2.8598E-02
Hoop bending stiffness ratio,C55RAT=C55(eff)/C55(wall)=  3.3472E+01
2nd ratio of wavy arclength to straight length, ARCRT2=  1.0733E+00
Weight of the entire Model No. 2,               WEIGHT=  2.6183E+01
Nx from axial g-loading and unsupported tube,   FNXADD= -3.0868E+00
Effective mass density of shell wall material,  DENSHL=  2.5000E-04
Mass density of ring material,                  DENRNG=  2.5000E-04
Effective density of shell with smeared rings,  RHOEFF=  2.5000E-04
Amplitude of initial general buckling imperfection, W0=  0.0000E+00
(C22-C12**2/C11)*(C25/C22)*(n/R)**2*W0/(EIG1-1)=FN2ADD(1)=  0.0000E+00
(C22-C12**2/C11)*(C25/C22)*(n/R)**2*W0/(EIG2-1)=FN2ADD(2)=  0.0000E+00
in which
EIG1 = buckling load factor, smeared waviness and SMEARED  rings=  0.0000E+00
and
EIG2 = buckling load factor, smeared waviness and DISCRETE rings=  0.0000E+00
Smallest buckling circumferential wavenumber for which FN2ADD(1)=  0.0000E+00
is added to the hoop load from pressure in buckling analyses NWAVLC =10000000

Output from STRUCT for linear nonsymmetric stress analysis:          location
                                                                      seg node
Max. critical stress,  theta=0, load set A,  STRNON(1)=  1.8029E+04, 103 012
Max. critical stress,  theta=0, load set B,  STRNON(2)=  0.0000E+00,       0
Max. normal displace., theta=0, load set A,  WWWNON(1)= -3.6431E-01, 107 023
Max. normal displace., theta=0, load set B,  WWWNON(2)=  0.0000E+00,       0

In SUBROUTINE STRUCT: Use BOSOR4 MODEL 2 to compute max.stress at 180 degrees
Max. critical stress,  theta=180,load set A, STRNON(1)=  1.3763E+04,   4 012
Max. critical stress,  theta=180,load set B, STRNON(2)=  0.0000E+00,       0
Max. normal displace., theta=180,load set A, WWWNON(1)=  3.6804E-01, 107 023
Max. normal displace., theta=180,load set B, WWWNON(2)=  0.0000E+00,       0

============================================================
END OF COMPUTATIONS IN SUBROUTINE STRUCT.
IMODX= 0; LOAD SET NO.  1
============================================================

BEGIN SUBROUTINE BEHX4 (LINEAR NONAXISYMMETRIC STRESS, 0deg).
IMODX= 0; LOAD SET NO.  1
Maximum stress from linear theory at 0 deg, STR0(ILOADX)=    1.8029E+04
   4        18029.06      max. stress at 0 deg., linear theory: STR0(1 )

============================================================
BEGIN SUBROUTINE BEHX5 (LINEAR NONAXISYMMETRIC STRESS, 180d).
IMODX= 0; LOAD SET NO.  1
Maximum stress, linear theory at 180 deg, STR180(ILOADX)=    1.3763E+04
   5        13762.52      max. stress at 180 deg., linear theory: STR180(1 )

============================================================
BEGIN SUBROUTINE BEHX6 (LINEAR BUCKLING AT 0 DEGREES).
LOW-WAVE-RANGE, IMODX= 0; LOAD SET NO.  1
SYMMETRIC BUCKLING ABOUT MIDLENGTH SYMMETRY PLANE

Number axial halfwaves in discrete wavy part, NWAVEX(22) =210
d.o.f. in axisymmetric prestress problem,        NDOF2 = 5722
d.o.f. in nonsymmetric modal vibration problem, NDOF3 = 8475
Is "d.o.f." too big (IREDUC=1)?                 IREDUC = 0
```

```
***** SYMMETRIC BUCKLING LOAD FACTORS AND MODE SHAPES *****
LINEAR BUCKLING LOAD FACTOR, 0 DEGREES, MODEL 2 (CIRC. WAVES)
   eigenvalue(circ. waves)
       2.3362E+01(   0)
       1.2461E+01(   1)
       1.2792E+00(   2)  <--- critical value, explicit waviness (Fig. 55)
       2.9164E+00(   3)
       4.5599E+00(   4)
       5.8344E+00(   5)
===== BUCKLING MODAL SYMMETRY AT SYMMETRY PLANE =====
Critical buckling load factor, BUC0=  1.2792E+00
Critical number of circumferential waves, NWVCRT=    2

*** SYMMETRIC BUCKLING LOAD FACTORS AND MODE SHAPES ***
LINEAR BUCKLING LOAD FACTOR, 0 DEGREES, MODEL 2 (CIRC. WAVES)
THE ENTIRE LENGTH (  9.0000E+01) OF THE CYL. HAS "SMEARED" WAVINESS.
   eigenvalue(circ. waves)
       4.4110E+01(   0)
       1.8991E+01(   1)
       1.3515E+00(   2)  <--- critical value, "smeared" waviness
       3.5499E+00(   3)
       6.3914E+00(   4)
       9.5742E+00(   5)
===== BUCKLING MODAL SYMMETRY AT SYMMETRY PLANE =====
Crit. buckling factor,  BUC0("smeared waviness")=  1.3515E+00
Critical number of circumferential waves, NWVCRT=    2

==============================================================
BEGIN SUBROUTINE BEHX7 (LINEAR BUCKLING AT 0 DEGREES).
LOW-WAVE-RANGE, IMODX= 0; LOAD SET NO.  1
ANTI-SYMMETRIC BUCKLING ABOUT MIDLENGTH SYMMETRY PLANE
*** ANTISYMMETRIC BUCKLING LOAD FACTORS AND MODE SHAPES ***
LINEAR BUCKLING LOAD FACTOR, 0 DEGREES, MODEL 2 (CIRC. WAVES)
   eigenvalue(circ. waves)
       2.3362E+01(   0)
       1.2461E+01(   1)
       1.2453E+00(   2)  <--- critical value, explicit waviness (Fig. 56)
       2.9093E+00(   3)
       4.5595E+00(   4)
       5.8337E+00(   5)
===== BUCKLING MODAL ANTISYMMETRY AT SYMMETRY PLANE =====
Critical buckling load factor, BUC0=  1.2453E+00
Critical number of circumferential waves, NWVCRT=    2

*** ANTISYMMETRIC BUCKLING LOAD FACTORS AND MODE SHAPES ***
LINEAR BUCKLING LOAD FACTOR, 0 DEGREES, MODEL 2 (CIRC. WAVES)
THE ENTIRE LENGTH (  9.0000E+01) OF THE CYL. HAS "SMEARED" WAVINESS.
   eigenvalue(circ. waves)
       4.4110E+01(   0)
       1.8991E+01(   1)
       1.3631E+00(   2)  <--- critical value, "smeared" waviness
       3.5515E+00(   3)
       6.3895E+00(   4)
       9.5571E+00(   5)
===== BUCKLING MODAL ANTISYMMETRY AT SYMMETRY PLANE =====
Crit. buckling factor,  BUC0("smeared waviness")=  1.3631E+00
Critical number of circumferential waves, NWVCRT=    2

==============================================================
BEGIN SUBROUTINE BEHX8 (LINEAR BUCKLING AT 0 DEGREES).
MID-WAVE-RANGE, IMODX= 0; LOAD SET NO.  1
```

```
***** SYMMETRIC BUCKLING LOAD FACTORS AND MODE SHAPES *****
LINEAR BUCKLING LOAD FACTOR, 0 DEGREES, MODEL 2 (CIRC. WAVES)
   eigenvalue(circ. waves)
       6.2048E+00(   6)        (NOTE: There is no minimum buckling load
       8.3292E+00(   7)         factor in this range of circ. wavenumber
       1.2466E+01(   8)         n)
       1.5697E+01(   9)
       1.9122E+01(  10)
===== BUCKLING MODAL SYMMETRY AT SYMMETRY PLANE =====
Critical buckling load factor, BUC0=  6.2048E+00
Critical number of circumferential waves, NWVCRT=    6

=============================================================
BEGIN SUBROUTINE BEHX9(HI-WAVE LINEAR BUCKLING AT 0 DEGREES).
IMODX= 0; LOAD SET NO.  1

Number axial halfwaves in discrete wavy part, NWAVEX(30) = 30
d.o.f. in axisymmetric prestress problem,        NDOF2 = 1042
d.o.f. in nonsymmetric modal vibration problem, NDOF3 = 1545
Is "d.o.f." too big (IREDUC=1)?                  IREDUC = 0
*** ANTISYMMETRIC BUCKLING LOAD FACTORS AND MODE SHAPES ***
LINEAR HI-WAVE BUCKLING LOAD FACTOR, 0 DEGREES (CIRC. WAVES)
   eigenvalue(circ. waves)

       2.9707E+01(  14)
       3.0780E+01(  18)
       3.3038E+01(  22)
       3.6382E+01(  26)        (NOTE: There is no minimum buckling load
       4.0514E+01(  30)         factor in this range of circ. wavenumber
       4.5101E+01(  34)         n)
       4.9865E+01(  38)
       5.4611E+01(  42)
       5.9221E+01(  46)
       6.3643E+01(  50)
       6.7867E+01(  54)
       7.1910E+01(  58)
       7.5805E+01(  62)
===== BUCKLING MODAL ANTISYMMETRY AT SYMMETRY PLANE =====
Critical buckling load factor, BUC0HI=  2.9707E+01
Critical number of circumferential waves, NWVCRT=   14

=============================================================
BEGIN SUBROUTINE BEHX10 (LINEAR BUCKLING AT 180 DEGREES).
IMODX= 0; LOAD SET NO.  1
***** SYMMETRIC BUCKLING LOAD FACTORS AND MODE SHAPES *****
LINEAR BUCKLING LOAD FACTOR, 180 DEG., MODEL 2 (CIRC. WAVES)
   eigenvalue(circ. waves)
       3.1140E+01(   0)
       3.1180E+01(   1)
       1.3281E+00(   2)  <--- critical value, explicit waviness,
       3.2101E+00(   3)       but it is higher than that corresponding
       5.3730E+00(   4)       to the prebuckling conditions along the
       7.2285E+00(   5)       meridian at circumferential coordinate,
       7.9417E+00(   6)       theta = 0 degrees.
       1.0173E+01(   7)
       1.3332E+01(   8)
       1.6722E+01(   9)
       2.0327E+01(  10)
===== BUCKLING MODAL SYMMETRY AT SYMMETRY PLANE =====
Critical buckling load factor, BUC180=  1.3281E+00
Critical number of circumferential waves, NWVCRT=    2
```

```
 ==============================================================
 BEGIN SUBROUTINE BEHX11 (HI-WAVE LINEAR BUCKLNG 180 DEGREES).
 IMODX= 0; LOAD SET NO.  1
 *** ANTISYMMETRIC BUCKLING LOAD FACTORS AND MODE SHAPES ***
 LINEAR HI-WAVE BUCKLING LOAD FACTOR, 180 DEG. (CIRC. WAVES)
    eigenvalue(circ. waves)
         3.5065E+01(  14)
         3.7845E+01(  18)
         3.9741E+01(  22)            (NOTE: There is no minimum buckling
         4.2983E+01(  26)             load factor in this range of circ.
         4.7219E+01(  30)             wavenumber, n)
         5.2064E+01(  34)
         5.7201E+01(  38)
         6.2403E+01(  42)
         6.7527E+01(  46)
         7.2492E+01(  50)
         7.7254E+01(  54)
         8.1788E+01(  58)
         8.6039E+01(  62)
 ===== BUCKLING MODAL ANTISYMMETRY AT SYMMETRY PLANE =====
 Critical buckling load factor, B180HI=  3.5065E+01
 Critical number of circumferential waves, NWVCRT=   14

 ==============================================================
 BEGIN SUBROUTINE BEHX12 (MAX. NORMAL DISPLACEMENT, 0 DEG.).
 IMODX= 0; LOAD SET NO.  1
 Max. normal displacement, linear theory, 0 deg, WWW0(ILOADX)= 3.6431E-01

 ==============================================================
 BEGIN SUBROUTINE BEHX13 (MAX. NORMAL DISPLACEMENT, 180 DEG.).
 IMODX= 0; LOAD SET NO.  1
 Max. normal displac., linear theory, 180 deg, WWW180(ILOADX)= 3.6804E-01

 ==============================================================
 BEGIN SUBROUTINE BEHX14 (MODAL FREQUENCY, AXISYM. LOADING).
 IMODX= 0; LOAD SET NO.  1
 ***** FREQUENCIES AND MODE SHAPES *****
       FREQUENCY(CIRC. WAVES)
        8.7421E+01(   0)
        9.5541E+00(   1)  <--- critical value, explicit waviness
        4.8644E+01(   2)
        2.1827E+02(   3)
 =======================================
 Critical modal vibration frequency, FREQ=  9.5541E+00
 Critical number of circumferential waves, NWVCRT=    1

 ***** FREQUENCIES AND MODE SHAPES: "SMEARED" WAVINESS *****
       FREQUENCY(CIRC. WAVES)
        9.4777E+01(   0)
        1.0378E+01(   1)  <--- critical value, "smeared" waviness
        4.5776E+01(   2)
        2.1519E+02(   3)
 =======================================
 Critical modal vibration frequency, FREQ=  1.0378E+01
 Critical number of circumferential waves, NWVCRT=    1

 Find natural frequency for axial length=  8.0000E+02
 ***** FREQUENCY AND MODE SHAPE FOR 0 CIRC. WAVES *****
       FREQUENCY(CIRC. WAVES)
        2.0674E+01(   0)
 =======================================
 Critical modal vibration frequency, FREQ=  2.0674E+01
```

```
 Critical number of circumferential waves, NWVCRT=    0

 ***** RESULTS FOR LOAD SET NO.  1  ******
 PARAMETERS WHICH DESCRIBE BEHAVIOR (e.g. stress, buckling load)
 BEH.   CURRENT
 NO.     VALUE            DEFINITION
  1    1.408E+04    maximum stress in wall from nonlinear theory: STRMAX(1)
  2    1.000E+10    buckling load factor from nonlinear theory: BUCFAC(1)
  3    1.000E+10    hi-wave buckling load factor, nonlinear theory: BUCHIW(1)
  4    1.803E+04    max. stress at 0 deg., linear theory: STR0(1)
  5    1.376E+04    max. stress at 180 deg., linear theory: STR180(1)
  6    1.279E+00    buckling load factor at 0 deg., linear theory: BUC0(1)
  7    1.245E+00    load factor for antisymmetric buckling at 0 deg: B0ANTI(1)
  8    6.205E+00    load factor for mid-wave-range buckling at 0 deg: BUC0MD(1)
  9    2.950E+01    hi-wave buckling load factor, 0 deg, lin. theory: BUC0HI(1)
 10    1.383E+00    buckling load factor at 180 deg, linear theory: BUC180(1)
 11    3.891E+01    hi-wave buckling load factor 180 deg, lin.theory: B180HI(1)
 12    3.643E-01    maximum normal displacement, 0 deg., linear theory: WWW0(1)
 13    3.680E-01    maximum normal displacement, 180 deg., lin.theory:WWW180(1)
 14    9.554E+00    modal frequency (hertz): FREQ(1)
 15    1.000E-10    maximum stress from random excitation: STRRAN(1)
 16    1.000E+10    buckling load factor from random excitation: BUCRAN(1)
 17    1.000E+10    hi-wave buckling factor from random excitation: BRANHI(1)
 18    1.000E-10    max. normal displacement from random excitation: WWWRAN(1)

 MARGINS CORRESPONDING TO CURRENT DESIGN (F.S.= FACTOR OF SAFETY)
 MARGIN CURRENT
 NO.     VALUE            DEFINITION
  1    7.183E-01  1-(STRMAX(1 )/STRALW(1 )) X STRFS(1 ); F.S.=  1.00
  2    6.394E-01  1-(STR0(1 )/STR0A(1 )) X STR0F(1 ); F.S.=  1.00
  3    7.247E-01  1-(STR180(1 )/ST180A(1 )) X ST180F(1 ); F.S.=  1.00
  4    2.337E-02  (BUC0(1 )/BUC0A(1 )) / BUC0F(1 )-1; F.S.=  1.25
  5   -3.732E-03  (B0ANTI(1 )/B0ANTA(1 )) / B0ANTF(1 )-1; F.S.=  1.25
  6    3.964E+00  (BUC0MD(1 )/BUC0MA(1 )) / BUC0MF(1 )-1; F.S.=  1.25
  7    2.260E+01  (BUC0HI(1 )/BUC0HA(1 )) / BUC0HF(1 )-1; F.S.=  1.25
  8    1.065E-01  (BUC180(1 )/BU180A(1 )) / BU180F(1 )-1; F.S.=  1.25
  9    3.013E+01  (B180HI(1 )/B180HA(1 )) / B180HF(1 )-1; F.S.=  1.25
 10    5.446E-01  1-(WWW0(1 )/WWW0A(1 )) X WWW0F(1 ); F.S.=  1.00
 11    5.400E-01  1-(WWW180(1 )/WW180A(1 )) X WW180F(1 ); F.S.=  1.00
 12   -4.459E-02  (FREQ(1 )/VIBALW(1 )) / VIBFS(1 )-1; F.S.=  1.00
 13    1.000E+00  1-(STRRAN(1 )/STRRNA(1 )) X STRRNF(1 ); F.S.=  1.00
 14    1.000E+00  1-(WWWRAN(1 )/WWWRNA(1 )) X WWWRNF(1 ); F.S.=  1.00

 ******************** DESIGN OBJECTIVE *******************
   CURRENT VALUE OF THE OBJECTIVE FUNCTION:
 VAR.   CURRENT
 NO.     VALUE            DEFINITION
  1    2.618E+01  weight of the cylindrical shell: WEIGHT
 *****************************************************
 ***********  ALL 1 LOAD CASES PROCESSED ***********

 PARAMETERS WHICH ARE ALWAYS FIXED.  NONE CAN BE DECISION VARIAB.

 VAR.   CURRENT
 NO.     VALUE            DEFINITION
  1    1.800E+02  length of cylindrical shell: AXIAL
  2    9.000E+00  Average nominal radius of cylindrical shell: RADIUS
  3    1.000E+07  Average modulus of ring material: ERING
  4    3.000E-01  Average Poisson ratio of ring material: FNURNG
  5    2.500E-04  Average mass density of ring material: DENRNG
  6    3.864E+02  Acceleration of gravity (e.g. 386.4 in/sec**2): GRAVTY
  7    8.000E+02  Length of tube unrestrained by axial hanger: LGAXL
```

```
  8    1.000E+07  Youngs modulus: ESTIFF
  9    3.000E-01  Poisson ratio: FNU
 10    2.500E-04  Material mass density (e.g. alum.=0.00025lb-sec**2/in: DENS
 11    1.000E-02  damping factor: BDAMP(1 )
 12    1.000E-02  damping factor: BDAMP(2 )
 13    1.000E-02  damping factor: BDAMP(3 )
 14    5.000E-02  damping factor: BDAMP(4 )
 15    5.000E+00  frequency (hertz) corresponding to damping factor: BFREQ(1 )
 16    1.000E+01  frequency (hertz) corresponding to damping factor: BFREQ(2 )
 17    3.000E+01  frequency (hertz) corresponding to damping factor: BFREQ(3 )
 18    5.000E+02  frequency (hertz) corresponding to damping factor: BFREQ(4 )
 19    3.000E-01  spectral density: SPTDEN(1 )
 20    5.000E-01  spectral density: SPTDEN(2 )
 21    1.000E+00  spectral density: SPTDEN(3 )
 22    2.000E+00  spectral density: SPTDEN(4 )
 23    1.000E+00  spectral density: SPTDEN(5 )
 24    5.000E+00  frequency (hertz) corresponding to spectral density: SFREQ(1)
 25    8.000E+00  frequency (hertz) corresponding to spectral density: SFREQ(2)
 26    1.200E+01  frequency (hertz) corresponding to spectral density: SFREQ(3)
 27    1.000E+02  frequency (hertz) corresponding to spectral density: SFREQ(4)
 28    5.000E+02  frequency (hertz) corresponding to spectral density: SFREQ(5)

 PARAMETERS WHICH ARE ENVIRONMENTAL FACTORS (e.g. loads, temps.)
 VAR.   CURRENT
 NO.     VALUE              DEFINITION
  1   -5.300E+01  Axial resultant (neg. for compression),Load Set A: FNX(1 )
  2    0.000E+00  Axial resultant (neg. for compression), Load Set B: FNXB(1 )
  3    1.500E+00  number of g's acceleration along cylinder axis: GAXIAL(1 )
  4    3.000E+00  Number of g's perpendicular to axis of cylinder: GLATRL(1 )
  5   -1.180E+01  pressure (negative for external), Load Set A: PRESS(1 )
  6    0.000E+00  pressure (negative for external), Load Set B: PRESSB(1 )

 PARAMETERS WHICH ARE CLASSIFIED AS ALLOWABLES (e.g. max. stress)
 VAR.   CURRENT
 NO.     VALUE              DEFINITION
  1    5.000E+04  maximum allowable stress, nonlinear theory: STRALW(1)
  2    1.000E+00  allowable buckling factor (use 1.0), nonlin.theory: BUCALW(1)
  3    1.000E+00  allowable hi-wave bucklng factor, nonlin.theory: BUCHIA(1)
  4    5.000E+04  max. allowable stress, linear theory: STR0A(1)
  5    5.000E+04  max. allowable stress, linear theory: ST180A(1)
  6    1.000E+00  allowable buckling factor (use 1), linear theory: BUC0A(1)
  7    1.000E+00  allowable (use 1), antisymmetric buckling, 0 deg.: B0ANTA(1)
  8    1.000E+00  allowable (use 1), mid-wave-range buckling, 0 deg: BUC0MA(1)
  9    1.000E+00  allowable for hi-wave buckling (use 1) at 0 deg.: BUC0HA(1)
 10    1.000E+00  allowable buckling factor, 180 deg., linear theory: BU180A(1)
 11    1.000E+00  allowable (use 1), hi-wave buckling at 180 deg: B180HA(1)
 12    8.000E-01  maximum allowable normal displacement, lin. theory: WWW0A(1)
 13    8.000E-01  max. allowable normal displacment, linear theory: WW180A(1)
 14    1.000E+01  minimum allowable modal frequency: VIBALW(1)
 15    5.000E+04  max. allowable stress from random excitation: STRRNA(1)
 16    1.000E+00  allowable buckling load factor, random excit.: BUCRNA(1)
 17    1.000E+00  allowable (use 1), buckling factor, random excit.: BRANHA(1)
 18    8.000E-01  max. allowable normal displ., random excitation: WWWRNA(1)

 PARAMETERS WHICH ARE FACTORS OF SAFETY
 VAR.   CURRENT
 NO.     VALUE              DEFINITION
  1    1.000E+00  factor of safety stress, nonlinear theory: STRFS(1 )
  2    1.250E+00  factor of safety buckling, nonlinear theory: BUCFS(1 )
  3    1.250E+00  factor of safety hi-wave buckling: BUCHIF(1 )
  4    1.000E+00  factor of safety stress, linear theory: STR0F(1 )
  5    1.000E+00  factor of safety stress, linear theory: ST180F(1 )
```

```
  6    1.250E+00  factor of safety buckling factor, linear theory: BUC0F(1)
  7    1.250E+00  factor of safety antisymmetric buckling, 0 deg: B0ANTF(1)
  8    1.250E+00  factor of safety mid-wave-range buckling, 0 deg: BUC0MF(1)
  9    1.250E+00  factor of safety hi-wave buckling, linear theory: BUC0HF(1)
 10    1.250E+00  factor of safety buckling, 180 deg, linear theory: BU180F(1)
 11    1.250E+00  factor of safety hi-wave buckling at 180 deg.: B180HF(1)
 12    1.000E+00  factor of safety max. normal displacement: WWW0F(1)
 13    1.000E+00  factor of safety normal displacment: WW180F(1)
 14    1.000E+00  factor of safety modal frequency: VIBFS(1)
 15    1.000E+00  factor of safety stress from random excitation: STRRNF(1)
 16    1.250E+00  factor of safety, buckling from random excitation: BUCRNF(1)
 17    1.250E+00  factor of safety hi-wave buckling, random excit.: BRANHF(1)
 18    1.000E+00  factor of safety max. normal displ., random excit.: WWWRNF(1)

    0 INEQUALITY CONSTRAINTS WHICH MUST BE SATISFIED

 ********************* END OF testnew7.OPM FILE *****************
==============================================================================
```

Table 9.1 Input data for the WAVYCYL system "BEGIN" processor (testcomp.BEG).
The following correspond to a laminated composite wavy cylindrical shell
with 8 layers in the wall, [90,45,-45,0]s, and without ring stiffeners.

```
==========================================================================
      N          $ Do you want a tutorial session and tutorial output?
    180          $ length of cylindrical shell: AXIAL
      9          $ Average nominal radius of cylindrical shell: RADIUS
  0.2000000      $ Total wall thickness: THICK
      0          $ Location of T-ring: -1=internal, 0=none, 1=external: IRING
      0          $ ring spacing (use zero if no rings): BRINGS
      0          $ thickness of web of T-ring: TWEB
      0          $ height of web of T-ring: HWEB
      0          $ thickness of outstanding flange of T-ring: TFLANG
      0          $ width of outstanding flange of T-ring: HFLANG
      0          $ Average modulus of ring material: ERING
      0          $ Average Poisson ratio of ring material: FNURNG
      0          $ Average mass density of ring material: DENRNG
      0          $ Number of nodal points in each ring segment: NMESHR
   386.4000      $ Acceleration of gravity (e.g. 386.4 in/sec**2): GRAVTY
    800          $ Length of tube unrestrained by axial hanger: LGAXL
     30          $ Number (EVEN) of axial halfwaves in wavy part of cyl.: NWAVES
      1          $ Axial halfwavelength of the waviness: WAVLEN
  0.1000000      $ Amplitude of waviness: AMPLIT
      2          $ Type of waviness (IWAVE=2 or 3): IWAVE
      0          $ Local meridional radius of curvature: RADSML
      0          $ Number of nodal points in STRAIGHT segment: NMESHS
     21          $ Number of nodal pts. in each curved segment: NMESHC
     97          $ Number of nodal pts. in "smeared" segment: NMESH1
   3000          $ Maximum number of d.o.f. of buckling problem: MAXDOF
      1          $ Boundary condition index: 1 = s.s.; 2=clamped: IBOUND
      2          $ Type of shell wall (1=isotropic, 2=laminated): IWALL
      0          $ Youngs modulus: ESTIFF
      0          $ Poisson ratio: FNU
      0          $ Material mass density (e.g. alum.=0.00025lb-sec**2/in: DENS
      8          $ Number of layers in the wall: NLAYER
      8          $ Number ILTYPE of rows in the array  LTYPE: ILTYPE
      1          $ Layer index: LTYPE( 1)
      2          $ Layer index: LTYPE( 2)
      3          $ Layer index: LTYPE( 3)
      4          $ Layer index: LTYPE( 4)
      4          $ Layer index: LTYPE( 5)
      3          $ Layer index: LTYPE( 6)
      2          $ Layer index: LTYPE( 7)
      1          $ Layer index: LTYPE( 8)
      1          $ NEWLAY: 0=not new layer type; 1=new layer type: NEWLAY( 1)
      1          $ NEWLAY: 0=not new layer type; 1=new layer type: NEWLAY( 2)
      1          $ NEWLAY: 0=not new layer type; 1=new layer type: NEWLAY( 3)
      1          $ NEWLAY: 0=not new layer type; 1=new layer type: NEWLAY( 4)
      0          $ NEWLAY: 0=not new layer type; 1=new layer type: NEWLAY( 5)
      0          $ NEWLAY: 0=not new layer type; 1=new layer type: NEWLAY( 6)
      0          $ NEWLAY: 0=not new layer type; 1=new layer type: NEWLAY( 7)
      0          $ NEWLAY: 0=not new layer type; 1=new layer type: NEWLAY( 8)
      4          $ Number ITLAYE of rows in the array  TLAYER: ITLAYE
  0.2500000E-01  $ thickness of layer type: TLAYER( 1)
  0.2500000E-01  $ thickness of layer type: TLAYER( 2)
  0.2500000E-01  $ thickness of layer type: TLAYER( 3)
  0.2500000E-01  $ thickness of layer type: TLAYER( 4)
     90          $ layup angle (deg.) for layer type: ANGLE( 1)
     45          $ layup angle (deg.) for layer type: ANGLE( 2)
    -45          $ layup angle (deg.) for layer type: ANGLE( 3)
      0          $ layup angle (deg.) for layer type: ANGLE( 4)
      1          $ Material index (1,2...) for layer type: MTYPE( 1)
```

```
          1       $ Material index (1,2...) for layer type: MTYPE( 2)
          1       $ Material index (1,2...) for layer type: MTYPE( 3)
          1       $ Material index (1,2...) for layer type: MTYPE( 4)
          1       $ NEWMAT: 0=not new matl; 1=new matl: NEWMAT( 1)
          0       $ NEWMAT: 0=not new matl; 1=new matl: NEWMAT( 2)
          0       $ NEWMAT: 0=not new matl; 1=new matl: NEWMAT( 3)
          0       $ NEWMAT: 0=not new matl; 1=new matl: NEWMAT( 4)
          1       $ Number IE1    of rows in the array  E1: IE1
  0.2000000E+08   $ modulus in the fiber direction: E1( 1)
   2000000.       $ modulus transverse to fibers: E2( 1)
   500000.0       $ in-plane shear modulus: G( 1)
  0.3000000E-01   $ small Poisson ratio: NU( 1)
          0       $ coeff. thermal expansion along fibers: A1( 1)
          0       $ coeff. thermal expansion transverse to fibers: A2( 1)
          0       $ residual stress temperature: CURETP( 1)
  0.1425000E-03   $ mass density (e.g. alum.=.00025 lb-sec**2/in): RHO( 1)
   100000.0       $ maximum tensile stress long fibers: S1TEN( 1)
   50000.00       $ max compressive stress along fibers: S1COMP( 1)
   20000.00       $ max tensile stress normal to fibers: S2TEN( 1)
   30000.00       $ max compressive stress normal to fibers: S2COMP( 1)
   10000.00       $ max shear stress: TAU12( 1)
          0       $ control (0 or 1) for smeared stiffeners: NRS
          4       $ number of entries in table of damping factor v frequency: NDAM»
P
          4       $ Number IBDAMP of rows in the array  BDAMP: IBDAMP
  0.1000000E-01   $ damping factor: BDAMP( 1)
  0.1000000E-01   $ damping factor: BDAMP( 2)
  0.1000000E-01   $ damping factor: BDAMP( 3)
  0.5000000E-01   $ damping factor: BDAMP( 4)
          5       $ frequency (hertz) corresponding to damping factor: BFREQ( 1)
         10       $ frequency (hertz) corresponding to damping factor: BFREQ( 2)
         30       $ frequency (hertz) corresponding to damping factor: BFREQ( 3)
        500       $ frequency (hertz) corresponding to damping factor: BFREQ( 4)
          5       $ number of entries in table of spectral response v frequency: N»
SPECT
          5       $ Number ISPTDE of rows in the array  SPTDEN: ISPTDE
  0.3000000       $ spectral density: SPTDEN( 1)
  0.5000000       $ spectral density: SPTDEN( 2)
   1.000000       $ spectral density: SPTDEN( 3)
   2.000000       $ spectral density: SPTDEN( 4)
   1.000000       $ spectral density: SPTDEN( 5)
          5       $ frequency (hertz) corresponding to spectral density: SFREQ( 1)
          8       $ frequency (hertz) corresponding to spectral density: SFREQ( 2)
         12       $ frequency (hertz) corresponding to spectral density: SFREQ( 3)
        100       $ frequency (hertz) corresponding to spectral density: SFREQ( 4)
        500       $ frequency (hertz) corresponding to spectral density: SFREQ( 5)
          0       $ starting number of circumferential waves, buckling: N0B
         10       $ ending number of circumferential waves: NMAXB
          1       $ Increment in number of circumferential waves: INCRB
          0       $ starting no. of circ. waves for vibration: N0V
          3       $ ending no. of circ. waves for vibration: NMAXV
          1       $ increment in no. circ. waves for vibration: INCRV
          1       $ Number of eigenvalues for each circ. wavenumber: NVEC
          1       $ Number NCASES of load cases (environments): NCASES
  -53.00000       $ Axial resultant (neg. for compression),Load Set A: FNX( 1)
          0       $ Axial resultant (neg. for compression), Load Set B: FNXB( 1)
   1.500000       $ number of g's acceleration along cylinder axis: GAXIAL( 1)
   3.000000       $ Number of g's perpendicular to axis of cylinder: GLATRL( 1)
  -11.80000       $ pressure (negative for external), Load Set A: PRESS( 1)
          0       $ pressure (negative for external), Load Set B: PRESSB( 1)
          0       $ maximum allowable stress, nonlinear theory: STRALW( 1)
          1       $ factor of safety stress, nonlinear theory: STRFS( 1)
```

```
        1       $ allowable buckling factor (use 1.0), nonlin.theory: BUCALW(1)
  1.250000      $ factor of safety buckling, nonlinear theory: BUCFS( 1)
        1       $ allowable hi-wave bucklng factor, nonlin.theory: BUCHIA(1)
  1.250000      $ factor of safety hi-wave buckling: BUCHIF( 1)
        0       $ max. allowable stress, linear theory: STR0A( 1)
        1       $ factor of safety stress, linear theory: STR0F( 1)
        0       $ max. allowable stress, linear theory: ST180A( 1)
        1       $ factor of safety stress, linear theory: ST180F( 1)
        1       $ allowable buckling factor (use 1), linear theory: BUC0A( 1)
  1.250000      $ factor of safety buckling factor, linear theory: BUC0F( 1)
        1       $ allowable (use 1), antisymmetric buckling, 0 deg.: B0ANTA(1)
  1.250000      $ factor of safety antisymmetric buckling, 0 deg: B0ANTF( 1)
        1       $ allowable (use 1), mid-wave-range buckling, 0 deg: BUC0MA(1)
  1.250000      $ factor of safety mid-wave-range buckling, 0 deg: BUC0MF( 1)
        1       $ allowable for hi-wave buckling (use 1) at 0 deg.: BUC0HA( 1)
  1.250000      $ factor of safety hi-wave buckling, linear theory: BUC0HF( 1)
        1       $ allowable buckling factor at 180 deg., lin. theory: BU180A(1)
  1.250000      $ factor of safety buckling at 180 deg, lin. theory: BU180F(1)
        1       $ allowable (use 1), hi-wave buckling at 180 deg: B180HA( 1)
  1.250000      $ factor of safety hi-wave buckling at 180 deg.: B180HF( 1)
 0.8000000      $ maximum allowable normal displacement, lin. theory: WWW0A(1)
  1.000000      $ factor of safety max. normal displacement: WWW0F( 1)
 0.8000000      $ max. allowable normal displacment, linear theory: WW180A(1)
  1.250000      $ factor of safety normal displacment: WW180F( 1)
  10.00000      $ minimum allowable modal frequency: VIBALW( 1)
  1.000000      $ factor of safety modal frequency: VIBFS( 1)
        0       $ max. allowable stress from random excitation: STRRNA(1)
        1       $ factor of safety stress from random excitation: STRRNF(1)
        1       $ allowable buckling load factor, random excit.: BUCRNA(1)
  1.250000      $ factor of safety, buckling from random excitation: BUCRNF(1)
        1       $ allowable (use 1), buckling factor, random excit.: BRANHA(1)
  1.250000      $ factor of safety hi-wave buckling, random excit.: BRANHF(1)
 0.8000000      $ max. allowable normal displ., random excitation: WWWRNA(1)
        1       $ factor of safety max. normal displ., random excit.: WWWRNF(1)
==========================================================================
```

```
Table 9.2 Input data for the WAVYCYL system processor "DECIDE" (testcomp.DEC)
The following correspond to an 8-layered wavy cylindrical shell without rings.
==============================================================================
     N           $ Do you want a tutorial session and tutorial output?
      7          $ Choose a decision variable (1,2,3,...)(halfwavelength,WAVLEN)
  0.5000000      $ Lower bound of variable no.( 7)
      1.0        $ Upper bound of variable no.( 7)
     Y           $ Any more decision variables (Y or N) ?
      8          $ Choose a decision variable (1,2,3,...)(amplitude, AMPLIT)
  0.1000000E-01  $ Lower bound of variable no.( 8)
     0.3         $ Upper bound of variable no.( 8)
     Y           $ Any more decision variables (Y or N) ?
     10          $ Choose a decision variable (1,2,3,...)(thick.of 90 deg layer)
  0.5000000E-02  $ Lower bound of variable no.(10)
  0.2500000E-01  $ Upper bound of variable no.(10)
     Y           $ Any more decision variables (Y or N) ?
     11          $ Choose a decision variable (1,2,3,...)(thick.of +45 deg layer)
  0.5000000E-02  $ Lower bound of variable no.(11)
  0.2500000E-01  $ Upper bound of variable no.(11)
     Y           $ Any more decision variables (Y or N) ?
     13          $ Choose a decision variable (1,2,3,...)(thick.of  0 deg layer)
  0.5000000E-02  $ Lower bound of variable no.(13)
  0.2500000E-01  $ Upper bound of variable no.(13)
     N           $ Any more decision variables (Y or N) ?
     Y           $ Any linked variables (Y or N) ?
     12          $ Choose a linked variable (1,2,3,...)(thick.of -45 deg layer)
      1          $ Choose type of linking (1=polynomial; 2=user-defined)
     11          $ To which variable is this variable linked?
   1.000000      $ Assign a value to the linking coefficient, C(j)
      1          $ To what power is the decision variable raised?
     n           $ Any other decision variables in the linking expression?
     n           $ Any constant C0 in the linking expression?
     n           $ Any more linked variables (Y or N) ?
     n           $ Any inequality relations among variables? (type H)
     y           $ Any escape variables (Y or N) ?
     y           $ Want to have escape variables chosen by default?
==============================================================================
```

Table 9.3 Input data for WAVYCYL processor, "CHANGE" (testcomp.CHG). Values of decision and linked variables are changed to those that correspond to the optimum design determined during the 90-iteration SUPEROPT run of the wavy composite cylindrical shell with layup [90, 45, -45, 0]s.

```
==========================================================================
      n          $ Do you want a tutorial session and tutorial output?
      y          $ Do you want to change any values in Parameter Set No. 1?
         7       $ Number of parameter to change (1, 2, 3, . .)      (WAVLEN)
  1,0000000      $ New value of the parameter
      y          $ Want to change any other parameters in this set?
         8       $ Number of parameter to change (1, 2, 3, . .)      (AMPLIT)
  0.1612000      $ New value of the parameter
      y          $ Want to change any other parameters in this set?
        10       $ Number of parameter to change (1, 2, 3, . .)(90-deg layer)
  0.5000000E-02  $ New value of the parameter
      y          $ Want to change any other parameters in this set?
        11       $ Number of parameter to change (1, 2, 3, . .)(45-deg layer)
  0.5000000E-02  $ New value of the parameter
      y          $ Want to change any other parameters in this set?
        12       $ Number of parameter to change (1, 2, 3, . .)(-45-deg layer)
  0.5000000E-02  $ New value of the parameter
      y          $ Want to change any other parameters in this set?
        13       $ Number of parameter to change (1, 2, 3, . .)(0-deg layer)
  0.1503300E-01  $ New value of the parameter
      n          $ Want to change any other parameters in this set?
      n          $ Do you want to change values of any "fixed" parameters?
      n          $ Do you want to change any loads?
      n          $ Do you want to change values of allowables?
      n          $ Do you want to change any factors of safety?
=================================================================
```

Table 9.4 Input data for WAVYCYL processors, MAINSETUP and OPTIMIZE, (testcomp.OPT file) and output from OPTIMIZE (testcomp.OPM file) for optimized wavy composite cylindrical shell. The following results correspond to user-selected maximum number of degrees of freedom, MAXDOF = 3000 and the optimum design found during a SUPEROPT run of duration 90 iterations.

```
=============================================================================
     N         $ Do you want a tutorial session and tutorial output?
        1      $ Choose an analysis you DON'T want (1, 2,..), IBEHAV
     Y         $ Any more analysis types NOT wanted (Y or N) ?
        2      $ Choose an analysis you DON'T want (1, 2,..), IBEHAV
     Y         $ Any more analysis types NOT wanted (Y or N) ?
        3      $ Choose an analysis you DON'T want (1, 2,..), IBEHAV
     Y         $ Any more analysis types NOT wanted (Y or N) ?
        9      $ Choose an analysis you DON'T want (1, 2,..), IBEHAV
     Y         $ Any more analysis types NOT wanted (Y or N) ?
       10      $ Choose an analysis you DON'T want (1, 2,..), IBEHAV
     Y         $ Any more analysis types NOT wanted (Y or N) ?
       11      $ Choose an analysis you DON'T want (1, 2,..), IBEHAV
     Y         $ Any more analysis types NOT wanted (Y or N) ?
       12      $ Choose an analysis you DON'T want (1, 2,..), IBEHAV
     Y         $ Any more analysis types NOT wanted (Y or N) ?
       13      $ Choose an analysis you DON'T want (1, 2,..), IBEHAV
     Y         $ Any more analysis types NOT wanted (Y or N) ?
       15      $ Choose an analysis you DON'T want (1, 2,..), IBEHAV
     Y         $ Any more analysis types NOT wanted (Y or N) ?
       16      $ Choose an analysis you DON'T want (1, 2,..), IBEHAV
     Y         $ Any more analysis types NOT wanted (Y or N) ?
       17      $ Choose an analysis you DON'T want (1, 2,..), IBEHAV
     Y         $ Any more analysis types NOT wanted (Y or N) ?
       18      $ Choose an analysis you DON'T want (1, 2,..), IBEHAV
     N         $ Any more analysis types NOT wanted (Y or N) ?
        0      $ NPRINT= output index (0=GOOD, 1=ok, 2=debug, 3=too much)
        2      $ Choose type of analysis (1=opt., 2=fixed, 3=sensit.) ITYPE
        5      $ How many design iterations in this run (3 to 25)?
        1      $ Choose (1="conservative"), (2="liberal") move limits, IMOVE
     Y         $ Do you want default (RATIO=10) for initial move limit jump?
     Y         $ Do you want the default perturbation (dx/x = 0.05)?
     n         $ Do you want to reset total iterations to zero (Type H)?
 ************ END OF THE  testcomp.OPT  FILE ***********
 ************ OCTOBER, 1999 VERSION OF GENOPT ****************
 ******** BEGINNING OF THE  testcomp.OPM  FILE *********
 *********************** MAIN PROCESSOR *********************
 The purpose of the mainprocessor, OPTIMIZE, is to perform,
 in a batch mode, the work specified by MAINSETUP for the case
 called testcomp.  Results are stored in the file  testcomp.OPM.
 Please inspect testcomp.OPM before doing more design iterations.
 ***********************************************************


 STRUCTURAL ANALYSIS FOR DESIGN ITERATION NO.    0:
  STRUCTURAL ANALYSIS WITH UNPERTURBED DECISION VARIABLES (This is the optim-
 VAR. DEC. ESCAPE LINK. LINKED  LINKING    LOWER     CURRENT    UPPER
  NO. VAR.  VAR.  VAR.    TO   CONSTANT   BOUND      VALUE      BOUND
  Total wall thickness: THICK
   1   N     N     N      0    0.00E+00  0.00E+00 2.0000E-01  0.00E+00
  ring spacing (use zero if no rings): BRINGS
   2   N     N     N      0    0.00E+00  0.00E+00 0.0000E+00  0.00E+00
  thickness of web of T-ring: TWEB
   3   N     N     N      0    0.00E+00  0.00E+00 0.0000E+00  0.00E+00
  height of web of T-ring: HWEB
   4   N     N     N      0    0.00E+00  0.00E+00 0.0000E+00  0.00E+00
  thickness of outstanding flange of T-ring: TFLANG
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 5  N     N     N      0    0.00E+00  0.00E+00 0.0000E+00  0.00E+00
width of outstanding flange of T-ring: HFLANG
 6  N     N     N      0    0.00E+00  0.00E+00 0.0000E+00  0.00E+00
Axial halfwavelength of the waviness: WAVLEN
 7  Y     N     N      0    0.00E+00  5.00E-01 1.0000E+00  1.00E+00
Amplitude of waviness: AMPLIT
 8  Y     N     N      0    0.00E+00  1.00E-02 1.6120E-01  3.00E-01
Local meridional radius of curvature: RADSML
 9  N     N     N      0    0.00E+00  0.00E+00 0.0000E+00  0.00E+00
thickness of layer type: TLAYER(1 )
10  Y     Y     N      0    0.00E+00  5.00E-03 5.0000E-03  2.50E-02
thickness of layer type: TLAYER(2 )
11  Y     Y     N      0    0.00E+00  5.00E-03 5.0000E-03  2.50E-02
thickness of layer type: TLAYER(3 )
12  N     N     Y     11    1.00E+00  0.00E+00 5.0000E-03  0.00E+00
thickness of layer type: TLAYER(4 )
13  Y     Y     N      0    0.00E+00  5.00E-03 1.5033E-02  2.50E-02
layup angle (deg.) for layer type: ANGLE(1 )
14  N     N     N      0    0.00E+00  0.00E+00 9.0000E+01  0.00E+00
layup angle (deg.) for layer type: ANGLE(2 )
15  N     N     N      0    0.00E+00  0.00E+00 4.5000E+01  0.00E+00
layup angle (deg.) for layer type: ANGLE(3 )
16  N     N     N      0    0.00E+00  0.00E+00-4.5000E+01  0.00E+00
layup angle (deg.) for layer type: ANGLE(4 )
17  N     N     N      0    0.00E+00  0.00E+00 0.0000E+00  0.00E+00

*************** UNPERTURBED DESIGN: IMODX = 0 ***************
 BEGIN COMPUTATIONS FOR THE UNPERTURBED (CURRENT) DESIGN
  LOAD SET NO.  1
****** (ALLOWABLE STRESS)/(ACTUAL STRESS) ******** (For the laminated wall
                                                   branch the actual stress
                                                   is not printed out, only
                                                   the ratio,
                                                   allowable/actual stress.)

Nonlinear BOSOR4 MODEL 1: Only wavy section, no rings
 1  5.4979E+00 fiber tension : matl=1 ,  A , seg=15, node=12, layer=4 ,z=-0
 2  2.1491E+00 fiber compres.: matl=1 ,  A , seg=5 , node=12, layer=7 ,z=0.
 3  6.0016E+00 transv tension: matl=1 ,  A , seg=6 , node=12, layer=8 ,z=0.
 4  7.9752E+00 transv compres: matl=1 ,  A , seg=15, node=12, layer=8 ,z=0.
 5  8.2632E+00 in-plane shear: matl=1 ,  A , seg=5 , node=12, layer=2 ,z=-0
****************************************************

Composite matl: Most critical stress ratio, allowable/actual, and definition
 2.1491E+00 fiber compres.: matl=1 ,  A , seg=5 , node=12, layer=7 ,z=0.

Output from STRUCT:
Maximum stress from nonlinear theory (no rings),STRMXX=  4.6531E-01
End shortening under unit axial compression,      ENDUV=  1.3898E-03
Modal frequency correspnding to 2 circ. waves,    FREQ2=  1.0862E+02
Ratio of wavy arclength to straight length,      ARCRAT=  1.0679E+00
Reduction factor for axial stiffness,            C11RAT=  1.5206E-02
Hoop bending stiffness ratio,C55RAT=C55(eff)/C55(wall)=  1.8472E+01
2nd ratio of wavy arclength to straight length,  ARCRT2=  1.0679E+00
Weight of the entire Model No. 2,                WEIGHT=  1.7707E+01
Nx from axial g-loading and unsupported tube,    FNXADD= -2.0876E+00
Effective mass density of shell wall material,   DENSHL=  1.4250E-04
Mass density of ring material,                   DENRNG=  0.0000E+00
Effective density of shell with smeared rings,   RHOEFF=  1.4250E-04
Amplitude of initial general buckling imperfection, W0=  0.0000E+00
(C22-C12**2/C11)*(C25/C22)*(n/R)**2*W0/(EIG1-1)=FN2ADD(1)=   0.0000E+00
(C22-C12**2/C11)*(C25/C22)*(n/R)**2*W0/(EIG2-1)=FN2ADD(2)=   0.0000E+00
in which
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EIG1 = buckling load factor, smeared waviness and SMEARED  rings=  0.0000E+00
and
EIG2 = buckling load factor, smeared waviness and DISCRETE rings=  0.0000E+00
Smallest buckling circumferential wavenumber for which FN2ADD(1)=  0.0000E+00
is added to the hoop load from pressure in buckling analyses NWAVLC =10000000

****** (ALLOWABLE STRESS)/(ACTUAL STRESS) ********
Linear BOSOR4 MODEL 2: Entire length + rings; theta=0 deg.
 1  4.7956E+00 fiber tension : matl=1 ,  A , seg=32, node=12, layer=4 ,z=-0
 2  1.8785E+00 fiber compres.: matl=1 ,  A , seg=30, node=12, layer=7 ,z=0.
 3  5.2090E+00 transv tension: matl=1 ,  A , seg=29, node=12, layer=8 ,z=0.
 4  6.8964E+00 transv compres: matl=1 ,  A , seg=32, node=12, layer=8 ,z=0.
 5  7.2745E+00 in-plane shear: matl=1 ,  A , seg=30, node=12, layer=2 ,z=-0
****************************************************

Composite matl: Most critical stress ratio, allowable/actual, and definition
 1.8785E+00 fiber compres.: matl=1 ,  A , seg=30, node=12, layer=7 ,z=0.

Output from STRUCT for linear nonsymmetric stress analysis:(NOTE: STRNON(1)=
                                                            1/1.8785=
                                                          actual/allowable)
Max. critical stress,  theta=0, load set A,  STRNON(1)=  5.3234E-01,
Max. critical stress,  theta=0, load set B,  STRNON(2)=  0.0000E+00, seg. node
Max. normal displace., theta=0, load set A,  WWWNON(1)= -3.2235E-01,  33  023
Max. normal displace., theta=0, load set B,  WWWNON(2)=  0.0000E+00,

****** (ALLOWABLE STRESS)/(ACTUAL STRESS) ********
Linear BOSOR4 MODEL 2: Entire length +rings; theta=180 deg.
 1  6.4544E+00 fiber tension : matl=1 ,  A , seg=4 , node=12, layer=4 ,z=-0
 2  2.4836E+00 fiber compres.: matl=1 ,  A , seg=4 , node=12, layer=7 ,z=0.
 3  7.1431E+00 transv tension: matl=1 ,  A , seg=5 , node=12, layer=8 ,z=0.
 4  9.3809E+00 transv compres: matl=1 ,  A , seg=4 , node=12, layer=8 ,z=0.
 5  9.4995E+00 in-plane shear: matl=1 ,  A , seg=4 , node=12, layer=2 ,z=-0
****************************************************

Composite matl: Most critical stress ratio, allowable/actual, and definition
 2.4836E+00 fiber compres.: matl=1 ,  A , seg=4 , node=12, layer=7 ,z=0.
Max. critical stress,  theta=180,load set A, STRNON(1)=  4.0264E-01,
Max. critical stress,  theta=180,load set B, STRNON(2)=  0.0000E+00, seg. node
Max. normal displace., theta=180,load set A, WWWNON(1)=  3.3010E-01,  33  023
Max. normal displace., theta=180,load set B, WWWNON(2)=  0.0000E+00,

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BEGIN SUBROUTINE BEHX4 (LINEAR NONAXISYMMETRIC STRESS, 0deg).(NOTE: With
IMODX= 0; LOAD SET NO.  1                              composite mat'l STR0 is
                                                       actual/allowable stress)
Maximum stress from linear theory at 0 deg, STR0(ILOADX)= 5.3234E-01

=============================================================
BEGIN SUBROUTINE BEHX5 (LINEAR NONAXISYMMETRIC STRESS, 180d).
IMODX= 0; LOAD SET NO.  1
Maximum stress, linear theory at 180 deg, STR180(ILOADX)= 4.0264E-01

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BEGIN SUBROUTINE BEHX6 (LINEAR BUCKLING AT 0 DEGREES).
LOW-WAVE-RANGE, IMODX= 0; LOAD SET NO.  1
SYMMETRIC BUCKLING ABOUT MIDLENGTH SYMMETRY PLANE
***** SYMMETRIC BUCKLING LOAD FACTORS AND MODE SHAPES *****
LINEAR BUCKLING LOAD FACTOR, 0 DEGREES, MODEL 2 (CIRC. WAVES)
   eigenvalue(circ. waves)
       2.0872E+01(   0)
       1.0170E+01(   1)
```

```
       1.3155E+00(   2) <--- critical value, explicit waviness
       2.5626E+00(   3)
       3.5695E+00(   4)
       3.9260E+00(   5)
 ===== BUCKLING MODAL SYMMETRY AT SYMMETRY PLANE =====
 Critical buckling load factor, BUC0=  1.3155E+00
 Critical number of circumferential waves, NWVCRT=    2

 *** SYMMETRIC BUCKLING LOAD FACTORS AND MODE SHAPES ***
 LINEAR BUCKLING LOAD FACTOR, 0 DEGREES, MODEL 2 (CIRC. WAVES)
 THE ENTIRE LENGTH (  9.0000E+01) OF THE CYL. HAS "SMEARED" WAVINESS.
    eigenvalue(circ. waves)
       3.7606E+01(   0)
       2.0127E+01(   1)
       1.3487E+00(   2) <--- critical value, "smeared" waviness
       3.5334E+00(   3)
       6.3383E+00(   4)
       9.4588E+00(   5)
 ===== BUCKLING MODAL SYMMETRY AT SYMMETRY PLANE =====
 Crit. buckling factor,  BUC0("smeared waviness")=  1.3487E+00
 Critical number of circumferential waves, NWVCRT=    2

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 BEGIN SUBROUTINE BEHX7 (LINEAR BUCKLING AT 0 DEGREES).
 LOW-WAVE-RANGE, IMODX= 0; LOAD SET NO.  1
 ANTI-SYMMETRIC BUCKLING ABOUT MIDLENGTH SYMMETRY PLANE
 *** ANTISYMMETRIC BUCKLING LOAD FACTORS AND MODE SHAPES ***
 LINEAR BUCKLING LOAD FACTOR, 0 DEGREES, MODEL 2 (CIRC. WAVES)
    eigenvalue(circ. waves)
       2.0872E+01(   0)
       1.0170E+01(   1)
       1.2483E+00(   2)  <--- critical value, explicit waviness
       2.6219E+00(   3)
       3.5584E+00(   4)
       3.9262E+00(   5)
 ===== BUCKLING MODAL ANTISYMMETRY AT SYMMETRY PLANE =====
 Critical buckling load factor, BUC0=  1.2483E+00
 Critical number of circumferential waves, NWVCRT=    2

 *** ANTISYMMETRIC BUCKLING LOAD FACTORS AND MODE SHAPES ***
 LINEAR BUCKLING LOAD FACTOR, 0 DEGREES, MODEL 2 (CIRC. WAVES)
 THE ENTIRE LENGTH (  9.0000E+01) OF THE CYL. HAS "SMEARED" WAVINESS.
    eigenvalue(circ. waves)
       3.7606E+01(   0)
       2.0127E+01(   1)
       1.3545E+00(   2)  <--- critical value, "smeared" waviness
       3.5385E+00(   3)
       6.3355E+00(   4)
       9.4408E+00(   5)
 ===== BUCKLING MODAL ANTISYMMETRY AT SYMMETRY PLANE =====
 Crit. buckling factor,  BUC0("smeared waviness")=  1.3545E+00
 Critical number of circumferential waves, NWVCRT=    2

 ==============================================================
 BEGIN SUBROUTINE BEHX8 (LINEAR BUCKLING AT 0 DEGREES).
 MID-WAVE-RANGE, IMODX= 0; LOAD SET NO.  1
 ***** SYMMETRIC BUCKLING LOAD FACTORS AND MODE SHAPES *****
 LINEAR BUCKLING LOAD FACTOR, 0 DEGREES, MODEL 2 (CIRC. WAVES)
    eigenvalue(circ. waves)
       5.1902E+00(   6)       (No minimum buckling load factor with
       8.2393E+00(   7)        respect to circ. wavenumber n in this
       1.0600E+01(   8)        range)
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```
        1.3011E+01(   9)
        1.5465E+01(  10)
===== BUCKLING MODAL SYMMETRY AT SYMMETRY PLANE =====
Critical buckling load factor, BUC0=  5.1902E+00
Critical number of circumferential waves, NWVCRT=    6

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BEGIN SUBROUTINE BEHX14 (MODAL FREQUENCY, AXISYM. LOADING).
IMODX= 0; LOAD SET NO.  1
***** FREQUENCIES AND MODE SHAPES *****
      FREQUENCY(CIRC. WAVES)
       9.3395E+01(   0)
       9.9962E+00(   1)  <--- critical value, explicit waviness
       5.9072E+01(   2)
       2.6055E+02(   3)
=======================================
Critical modal vibration frequency, FREQ=  9.9962E+00
Critical number of circumferential waves, NWVCRT=    1

***** FREQUENCIES AND MODE SHAPES: "SMEARED" WAVINESS *****
      FREQUENCY(CIRC. WAVES)
       9.8099E+01(   0)
       1.0750E+01(   1)  <--- critical value, "smeared" waviness
       5.5311E+01(   2)
       2.6079E+02(   3)
=======================================
Critical modal vibration frequency, FREQ=  1.0750E+01
Critical number of circumferential waves, NWVCRT=    1

Find natural frequency for axial length=  8.0000E+02
***** FREQUENCY AND MODE SHAPE FOR 0 CIRC. WAVES *****
      FREQUENCY(CIRC. WAVES)
       2.1801E+01(   0)
=======================================
Critical modal vibration frequency, FREQ=  2.1801E+01
Critical number of circumferential waves, NWVCRT=    0

***** RESULTS FOR LOAD SET NO.  1  ******
PARAMETERS WHICH DESCRIBE BEHAVIOR (e.g. stress, buckling load)

BEH.   CURRENT
NO.     VALUE            DEFINITION
 1    1.000E-10    maximum stress in wall from nonlinear theory: STRMAX(1)
 2    1.000E+10    buckling load factor from nonlinear theory: BUCFAC(1)
 3    1.000E+10    hi-wave buckling load factor, nonlinear theory: BUCHIW(1)
 4    5.323E-01    max. stress at 0 deg., linear theory: STR0(1)
 5    4.026E-01    max. stress at 180 deg., linear theory: STR180(1)
 6    1.316E+00    buckling load factor at 0 deg., linear theory: BUC0(1)
 7    1.248E+00    load factor for antisymmetric buckling at 0 deg: B0ANTI(1)
 8    5.190E+00    load factor for mid-wave-range buckling at 0 deg: BUC0MD(1)
 9    1.000E+10    hi-wave buckling load factor, 0 deg,lin. theory: BUC0HI(1)
10    1.000E+10    buckling load factor at 180 deg, linear theory: BUC180(1)
11    1.000E+10    hi-wave buckling load factor 180 deg, lin.theory: B180HI(1)
12    1.000E-10    maximum normal displacement, 0 deg., linear theory: WWW0(1)
13    1.000E-10    maximum normal displacement, 180 deg.,lin.theory: WWW180(1)
14    9.996E+00    modal frequency (hertz): FREQ(1)
15    1.000E-10    maximum stress from random excitation: STRRAN(1)
16    1.000E+10    buckling load factor from random excitation: BUCRAN(1)
17    1.000E+10    hi-wave buckling factor from random excitation: BRANHI(1)
18    1.000E-10    max. normal displacement from random excitation: WWWRAN(1)
MARGINS CORRESPONDING TO CURRENT DESIGN (F.S.= FACTOR OF SAFETY)
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MARGIN CURRENT
NO.     VALUE              DEFINITION
 1    1.000E+00  1-(STRMAX(1 )/STRALW(1 )) X STRFS(1 ); F.S.=1.
 2    4.677E-01  1-(STR0(1 )/STR0A(1 )) X STR0F(1 ); F.S.=1.
 3    5.974E-01  1-(STR180(1 )/ST180A(1 )) X ST180F(1 ); F.S.=1.
 4    5.244E-02  (BUC0(1 )/BUC0A(1 )) / BUC0F(1 )-1; F.S.=1.25
 5   -1.356E-03  (B0ANTI(1 )/B0ANTA(1 )) / B0ANTF(1 )-1; F.S.=1.25
 6    3.152E+00  (BUC0MD(1 )/BUC0MA(1 )) / BUC0MF(1 )-1; F.S.=1.25
 7    1.000E+00  1-(WWW0(1 )/WWW0A(1 )) X WWW0F(1 ); F.S.=1.
 8    1.000E+00  1-(WWW180(1 )/WW180A(1 )) X WW180F(1 ); F.S.=1.25
 9   -3.788E-04  (FREQ(1 )/VIBALW(1 )) / VIBFS(1 )-1; F.S.=1.
10    1.000E+00  1-(STRRAN(1 )/STRRNA(1 )) X STRRNF(1 ); F.S.=1.
11    1.000E+00  1-(WWWRAN(1 )/WWWRNA(1 )) X WWWRNF(1 ); F.S.=1.

******************** DESIGN OBJECTIVE *******************
   CURRENT VALUE OF THE OBJECTIVE FUNCTION:
VAR.    CURRENT
NO.      VALUE              DEFINITION
 1     1.771E+01  weight of the cylindrical shell: WEIGHT
******************** DESIGN OBJECTIVE *******************
***********  ALL 1 LOAD CASES PROCESSED ***********

PARAMETERS WHICH ARE ALWAYS FIXED.  NONE CAN BE DECISION VARIAB.
VAR.    CURRENT
NO.      VALUE              DEFINITION
 1     1.800E+02  length of cylindrical shell: AXIAL
 2     9.000E+00  Average nominal radius of cylindrical shell: RADIUS
 3     0.000E+00  Average modulus of ring material: ERING
 4     0.000E+00  Average Poisson ratio of ring material: FNURNG
 5     0.000E+00  Average mass density of ring material: DENRNG
 6     3.864E+02  Acceleration of gravity (e.g. 386.4 in/sec**2): GRAVTY
 7     8.000E+02  Length of tube unrestrained by axial hanger: LGAXL
 8     0.000E+00  Youngs modulus: ESTIFF
 9     0.000E+00  Poisson ratio: FNU
10     0.000E+00  Material mass density (e.g. alum.=0.00025lb-sec**2/in: DENS
11     2.000E+07  modulus in the fiber direction: E1(1 )
12     2.000E+06  modulus transverse to fibers: E2(1 )
13     5.000E+05  in-plane shear modulus: G(1 )
14     3.000E-02  small Poisson ratio: NU(1 )
15     0.000E+00  coeff. thermal expansion along fibers: A1(1 )
16     0.000E+00  coeff. thermal expansion transverse to fibers: A2(1 )
17     0.000E+00  residual stress temperature: CURETP(1 )
18     1.425E-04  mass density (e.g. alum.=.00025 lb-sec**2/in): RHO(1 )
19     1.000E+05  maximum tensile stress long fibers: S1TEN(1 )
20     5.000E+04  max compressive stress along fibers: S1COMP(1 )
21     2.000E+04  max tensile stress normal to fibers: S2TEN(1 )
22     3.000E+04  max compressive stress normal to fibers: S2COMP(1 )
23     1.000E+04  max shear stress: TAU12(1 )
24     1.000E-02  damping factor: BDAMP(1 )
25     1.000E-02  damping factor: BDAMP(2 )
26     1.000E-02  damping factor: BDAMP(3 )
27     5.000E-02  damping factor: BDAMP(4 )
28     5.000E+00  frequency (hertz) corresponding to damping factor: BFREQ(1)
29     1.000E+01  frequency (hertz) corresponding to damping factor: BFREQ(2)
30     3.000E+01  frequency (hertz) corresponding to damping factor: BFREQ(3)
31     5.000E+02  frequency (hertz) corresponding to damping factor: BFREQ(4)
32     3.000E-01  spectral density: SPTDEN(1 )
33     5.000E-01  spectral density: SPTDEN(2 )
34     1.000E+00  spectral density: SPTDEN(3 )
35     2.000E+00  spectral density: SPTDEN(4 )
36     1.000E+00  spectral density: SPTDEN(5 )
37     5.000E+00  frequency (hertz) corresponding to spectral density: SFREQ(1)
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38    8.000E+00  frequency (hertz) corresponding to spectral density: SFREQ(2)
39    1.200E+01  frequency (hertz) corresponding to spectral density: SFREQ(3)
40    1.000E+02  frequency (hertz) corresponding to spectral density: SFREQ(4)
41    5.000E+02  frequency (hertz) corresponding to spectral density: SFREQ(5)

PARAMETERS WHICH ARE ENVIRONMENTAL FACTORS (e.g. loads, temps.)
VAR.  CURRENT
NO.    VALUE            DEFINITION
 1   -5.300E+01  Axial resultant (neg. for compression),Load Set A: FNX(1)
 2    0.000E+00  Axial resultant (neg. for compression), Load Set B: FNXB(1)
 3    1.500E+00  number of g's acceleration along cylinder axis: GAXIAL(1)
 4    3.000E+00  Number of g's perpendicular to axis of cylinder: GLATRL(1)
 5   -1.180E+01  pressure (negative for external), Load Set A: PRESS(1)
 6    0.000E+00  pressure (negative for external), Load Set B: PRESSB(1)

PARAMETERS WHICH ARE CLASSIFIED AS ALLOWABLES (e.g. max. stress)
VAR.  CURRENT
NO.    VALUE            DEFINITION
 1    0.000E+00  maximum allowable stress, nonlinear theory: STRALW(1)
 2    1.000E+00  allowable buckling factor (use 1.0), nonlin.theory: BUCALW(1)
 3    1.000E+00  allowable hi-wave bucklng factor, nonlin.theory: BUCHIA(1)
 4    0.000E+00  max. allowable stress, linear theory: STR0A(1)
 5    0.000E+00  max. allowable stress, linear theory: ST180A(1)
 6    1.000E+00  allowable buckling factor (use 1), linear theory: BUC0A(1)
 7    1.000E+00  allowable (use 1), antisymmetric buckling, 0 deg.: B0ANTA(1)
 8    1.000E+00  allowable (use 1), mid-wave-range buckling, 0 deg: BUC0MA(1)
 9    1.000E+00  allowable for hi-wave buckling (use 1) at 0 deg.: BUC0HA(1)
10    1.000E+00  allowable buckling factor at 180 deg., lin theory: BU180A(1)
11    1.000E+00  allowable (use 1), hi-wave buckling at 180 deg: B180HA(1)
12    8.000E-01  maximum allowable normal displacement, lin. theory: WWW0A(1)
13    8.000E-01  max. allowable normal displacment, linear theory: WW180A(1)
14    1.000E+01  minimum allowable modal frequency: VIBALW(1)
15    0.000E+00  max. allowable stress from random excitation: STRRNA(1)
16    1.000E+00  allowable buckling load factor, random excit.: BUCRNA(1)
17    1.000E+00  allowable (use 1), buckling factor, random excit.: BRANHA(1)
18    8.000E-01  max. allowable normal displ., random excitation: WWWRNA(1)

PARAMETERS WHICH ARE FACTORS OF SAFETY
VAR.  CURRENT
NO.    VALUE            DEFINITION
 1    1.000E+00  factor of safety stress, nonlinear theory: STRFS(1 )
 2    1.250E+00  factor of safety buckling, nonlinear theory: BUCFS(1 )
 3    1.250E+00  factor of safety hi-wave buckling: BUCHIF(1 )
 4    1.000E+00  factor of safety stress, linear theory: STR0F(1 )
 5    1.000E+00  factor of safety stress, linear theory: ST180F(1 )
 6    1.250E+00  factor of safety buckling factor, linear theory: BUC0F(1)
 7    1.250E+00  factor of safety antisymmetric buckling, 0 deg: B0ANTF(1)
 8    1.250E+00  factor of safety mid-wave-range buckling, 0 deg: BUC0MF(1)
 9    1.250E+00  factor of safety hi-wave buckling, linear theory: BUC0HF(1)
10    1.250E+00  factor of safety buckling at 180 deg, lin. theory: BU180F(1)
11    1.250E+00  factor of safety hi-wave buckling at 180 deg.: B180HF(1)
12    1.000E+00  factor of safety max. normal displacement: WWW0F(1)
13    1.250E+00  factor of safety normal displacment: WW180F(1)
14    1.000E+00  factor of safety modal frequency: VIBFS(1)
15    1.000E+00  factor of safety stress from random excitation: STRRNF(1)
16    1.250E+00  factor of safety, buckling from random excitation: BUCRNF(1)
17    1.250E+00  factor of safety hi-wave buckling, random excit.: BRANHF(1)
18    1.000E+00  factor of safety max. normal displ., random excit.: WWWRNF(1)

    0 INEQUALITY CONSTRAINTS WHICH MUST BE SATISFIED
===========================================================================
```

```
Table 9.5 Same optimized wavy composite cylindrical shell as for
the previous table. The following results are for MAXDOF = 15000.
 ============================================================
 BEGIN SUBROUTINE BEHX4 (LINEAR NONAXISYMMETRIC STRESS, 0deg).
 IMODX= 0; LOAD SET NO.  1
 Maximum stress from linear theory at 0 deg, STR0(ILOADX)= 5.3298E-01

 ============================================================
 BEGIN SUBROUTINE BEHX5 (LINEAR NONAXISYMMETRIC STRESS, 180d).
 IMODX= 0; LOAD SET NO.  1
 Maximum stress, linear theory at 180 deg, STR180(ILOADX)= 4.5222E-01

 ============================================================
 BEGIN SUBROUTINE BEHX6 (LINEAR BUCKLING AT 0 DEGREES).
 LOW-WAVE-RANGE, IMODX= 0; LOAD SET NO.  1
 SYMMETRIC BUCKLING ABOUT MIDLENGTH SYMMETRY PLANE
 ***** SYMMETRIC BUCKLING LOAD FACTORS AND MODE SHAPES *****
 LINEAR BUCKLING LOAD FACTOR, 0 DEGREES, MODEL 2 (CIRC. WAVES)
    eigenvalue(circ. waves)
        2.0845E+01(   0)
        1.0716E+01(   1)
        1.1662E+00(   2)  <--- critical value, explicit waviness
        2.5053E+00(   3)
        3.5347E+00(   4)
        3.9215E+00(   5)
 ===== BUCKLING MODAL SYMMETRY AT SYMMETRY PLANE =====
 Critical buckling load factor, BUC0=  1.1662E+00
 Critical number of circumferential waves, NWVCRT=    2

 *** SYMMETRIC BUCKLING LOAD FACTORS AND MODE SHAPES ***
 LINEAR BUCKLING LOAD FACTOR, 0 DEGREES, MODEL 2 (CIRC. WAVES)
 THE ENTIRE LENGTH (  9.0000E+01) OF THE CYL. HAS "SMEARED" WAVINESS.
    eigenvalue(circ. waves)
        3.7605E+01(   0)
        2.0126E+01(   1)
        1.3487E+00(   2)  <--- critical value, "smeared" waviness
        3.5335E+00(   3)
        6.3383E+00(   4)
        9.4589E+00(   5)
 ===== BUCKLING MODAL SYMMETRY AT SYMMETRY PLANE =====
 Crit. buckling factor,  BUC0("smeared waviness")=  1.3487E+00
 Critical number of circumferential waves, NWVCRT=    2

 ============================================================
 BEGIN SUBROUTINE BEHX7 (LINEAR BUCKLING AT 0 DEGREES).
 LOW-WAVE-RANGE, IMODX= 0; LOAD SET NO.  1
 ANTI-SYMMETRIC BUCKLING ABOUT MIDLENGTH SYMMETRY PLANE
 *** ANTISYMMETRIC BUCKLING LOAD FACTORS AND MODE SHAPES ***
 LINEAR BUCKLING LOAD FACTOR, 0 DEGREES, MODEL 2 (CIRC. WAVES)
    eigenvalue(circ. waves)
        2.0845E+01(   0)
        1.0716E+01(   1)
        1.2138E+00(   2)  <--- critical value, explicit waviness
        2.5050E+00(   3)
        3.5343E+00(   4)
        3.9217E+00(   5)
 ===== BUCKLING MODAL ANTISYMMETRY AT SYMMETRY PLANE =====
 Critical buckling load factor, BUC0=  1.2138E+00
 Critical number of circumferential waves, NWVCRT=    2

 *** ANTISYMMETRIC BUCKLING LOAD FACTORS AND MODE SHAPES ***
 LINEAR BUCKLING LOAD FACTOR, 0 DEGREES, MODEL 2 (CIRC. WAVES)
```

```
THE ENTIRE LENGTH (  9.0000E+01) OF THE CYL. HAS "SMEARED" WAVINESS.
   eigenvalue(circ. waves)
       3.7605E+01(   0)
       2.0126E+01(   1)
       1.3545E+00(   2)  <--- critical value, "smeared" waviness
       3.5385E+00(   3)
       6.3355E+00(   4)
       9.4409E+00(   5)
===== BUCKLING MODAL ANTISYMMETRY AT SYMMETRY PLANE =====
Crit. buckling factor,  BUC0("smeared waviness")=  1.3545E+00
Critical number of circumferential waves, NWVCRT=    2

============================================================
BEGIN SUBROUTINE BEHX14 (MODAL FREQUENCY, AXISYM. LOADING).
IMODX= 0; LOAD SET NO.  1
***** FREQUENCIES AND MODE SHAPES *****
      FREQUENCY(CIRC. WAVES)
       9.0237E+01(   0)
       9.8130E+00(   1)  <--- critical value, explicit waviness
       5.1901E+01(   2)
       2.5947E+02(   3)
======================================
Critical modal vibration frequency, FREQ=  9.8130E+00
Critical number of circumferential waves, NWVCRT=    1

***** FREQUENCIES AND MODE SHAPES: "SMEARED" WAVINESS *****
      FREQUENCY(CIRC. WAVES)
       9.8096E+01(   0)
       1.0750E+01(   1)  <--- critical value, "smeared" waviness
       5.5313E+01(   2)
       2.6080E+02(   3)
======================================
Critical modal vibration frequency, FREQ=  1.0750E+01
Critical number of circumferential waves, NWVCRT=    1

MARGIN CURRENT
NO.     VALUE            DEFINITION
 1    1.000E+00  1-(STRMAX(1 )/STRALW(1 )) X STRFS(1 ); F.S.=1.
 2    4.670E-01  1-(STR0(1 )/STR0A(1 )) X STR0F(1 ); F.S.=1.
 3    5.478E-01  1-(STR180(1 )/ST180A(1 )) X ST180F(1 ); F.S.=1.
 4   -6.708E-02  (BUC0(1 )/BUC0A(1 )) / BUC0F(1 )-1; F.S.=1.25
 5   -2.895E-02  (B0ANTI(1 )/B0ANTA(1 )) / B0ANTF(1 )-1; F.S.=1.25
 6    3.145E+00  (BUC0MD(1 )/BUC0MA(1 )) / BUC0MF(1 )-1; F.S.=1.25
 7    1.000E+00  1-(WWW0(1 )/WWW0A(1 )) X WWW0F(1 ); F.S.=1.
 8    1.000E+00  1-(WWW180(1 )/WW180A(1 )) X WW180F(1 ); F.S.=1.25
 9   -1.870E-02  (FREQ(1 )/VIBALW(1 )) / VIBFS(1 )-1; F.S.=1.
10    1.000E+00  1-(STRRAN(1 )/STRRNA(1 )) X STRRNF(1 ); F.S.=1.
11    1.000E+00  1-(WWWRAN(1 )/WWWRNA(1 )) X WWWRNF(1 ); F.S.=1.
=====================================================================
```

Table 9.6 Composite cylindrical shell without rings: 0-degree layer on the outside ([0, 45, -45, 90]s). Input data for the WAVYCYL processor "CHANGE" (testcomp.CHG). The values below represent the optimum design found with MAXDOF=15000 before accounting for plies of thickness only equal to multiples of 0.005 inches.

```
================================================================================
     n          $ Do you want a tutorial session and tutorial output?
     y          $ Do you want to change any values in Parameter Set No. 1?
        7       $ Number of parameter to change (1, 2, 3, . .)      (WAVLEN)
  0.9687000     $ New value of the parameter
     y          $ Want to change any other parameters in this set?
        8       $ Number of parameter to change (1, 2, 3, . .)      (AMPLIT)
  0.1693000     $ New value of the parameter
     y          $ Want to change any other parameters in this set?
       10       $ Number of parameter to change (1, 2, 3, . .)(0-deg layer)
  0.5000000E-02 $ New value of the parameter
     y          $ Want to change any other parameters in this set?
       11       $ Number of parameter to change (1, 2, 3, . .)(45-deg layer)
  0.5000000E-02 $ New value of the parameter
     y          $ Want to change any other parameters in this set?
       12       $ Number of parameter to change (1, 2, 3, . .)(-45-deg layer)
  0.5000000E-02 $ New value of the parameter
     y          $ Want to change any other parameters in this set?
       13       $ Number of parameter to change (1, 2, 3, . .)(90-deg layer)
  0.6320000E-02 $ New value of the parameter
     n          $ Want to change any other parameters in this set?
     n          $ Do you want to change values of any "fixed" parameters?
     n          $ Do you want to change any loads?
     n          $ Do you want to change values of allowables?
     n          $ Do you want to change any factors of safety?
======================================================================
```

Table 9.7 Composite wavy cylindrical shell without rings; [0,45,-45,90]s Another input file for "CHANGE" (testcomp.CHG); The values below represent the optimum design found with MAXDOF=15000 after accounting for plies of thickness only equal to multiples of 0.005 inches.

```
================================================================================
     n          $ Do you want a tutorial session and tutorial output?
     y          $ Do you want to change any values in Parameter Set No. 1?
        7       $ Number of parameter to change (1, 2, 3, . .)      (WAVLEN)
   1.000000     $ New value of the parameter
     y          $ Want to change any other parameters in this set?
        8       $ Number of parameter to change (1, 2, 3, . .)      (AMPLIT)
  0.1760000     $ New value of the parameter
     y          $ Want to change any other parameters in this set?
       10       $ Number of parameter to change (1, 2, 3, . .)(0-deg layer)
  0.5000000E-02 $ New value of the parameter
     y          $ Want to change any other parameters in this set?
       11       $ Number of parameter to change (1, 2, 3, . .)(45-deg layer)
  0.5000000E-02 $ New value of the parameter
     y          $ Want to change any other parameters in this set?
       12       $ Number of parameter to change (1, 2, 3, . .)(-45-deg layer)
  0.5000000E-02 $ New value of the parameter
     y          $ Want to change any other parameters in this set?
       13       $ Number of parameter to change (1, 2, 3, . .)(90-deg layer)
  0.7500000E-02 $ New value of the parameter
     n          $ Want to change any other parameters in this set?
     n          $ Do you want to change values of any "fixed" parameters?
     n          $ Do you want to change any loads?
     n          $ Do you want to change values of allowables?
     n          $ Do you want to change any factors of safety?
======================================================================
```

```
Table 9.8 Composite wavy cylindrical shell without rings; [0,45,-45,90]s
Another input file for "DECIDE" (testcomp.DEC); Decision variables and
bounds used for final execution of SUPEROPT. The thicknesses are no
longer decision variables because they represent the optimum accounting
for the fact that plies must be of thickness equal to a multiple of
0.005 inch.
==============================================================
     n            $ Do you want a tutorial session and tutorial output?
        7         $ Choose a decision variable (1,2,3,...)      (WAVLEN)
  0.5000000       $ Lower bound of variable no.( 7)
   2.000000       $ Upper bound of variable no.( 7)
     y            $ Any more decision variables (Y or N) ?
        8         $ Choose a decision variable (1,2,3,...)      (AMPLIT)
  0.1000000E-01   $ Lower bound of variable no.( 8)
  0.4000000       $ Upper bound of variable no.( 8)
     n            $ Any more decision variables (Y or N) ?
     n            $ Any linked variables (Y or N) ?
     n            $ Any inequality relations among variables? (type H)
     n            $ Any escape variables (Y or N) ?
==============================================================
```

Table 9.9 Final optimum design of wavy composite cylindrical shell without rings. Layup=[0, 45, -45, 90]s. The following is a slightly edited version of the file called testcomp.OPM

```
=====================================================================
    N        $ Do you want a tutorial session and tutorial output?
      1      $ Choose an analysis you DON'T want (1, 2,..), IBEHAV
    Y        $ Any more analysis types NOT wanted (Y or N) ?
      2      $ Choose an analysis you DON'T want (1, 2,..), IBEHAV
    Y        $ Any more analysis types NOT wanted (Y or N) ?
      3      $ Choose an analysis you DON'T want (1, 2,..), IBEHAV
    Y        $ Any more analysis types NOT wanted (Y or N) ?
      9      $ Choose an analysis you DON'T want (1, 2,..), IBEHAV
    Y        $ Any more analysis types NOT wanted (Y or N) ?
     10      $ Choose an analysis you DON'T want (1, 2,..), IBEHAV
    Y        $ Any more analysis types NOT wanted (Y or N) ?
     11      $ Choose an analysis you DON'T want (1, 2,..), IBEHAV
    Y        $ Any more analysis types NOT wanted (Y or N) ?
     15      $ Choose an analysis you DON'T want (1, 2,..), IBEHAV
    Y        $ Any more analysis types NOT wanted (Y or N) ?
     16      $ Choose an analysis you DON'T want (1, 2,..), IBEHAV
    Y        $ Any more analysis types NOT wanted (Y or N) ?
     17      $ Choose an analysis you DON'T want (1, 2,..), IBEHAV
    Y        $ Any more analysis types NOT wanted (Y or N) ?
     18      $ Choose an analysis you DON'T want (1, 2,..), IBEHAV
    N        $ Any more analysis types NOT wanted (Y or N) ?
      0      $ NPRINT= output index (0=GOOD, 1=ok, 2=debug, 3=too much)
      2      $ Choose type of analysis (1=opt., 2=fixed, 3=sensit.) ITYPE
      5      $ How many design iterations in this run (3 to 25)?
      1      $ Choose (1="conservative"), (2="liberal") move limits, IMOVE
    y        $ Do you want default (RATIO=10) for initial move limit jump?
    y        $ Do you want the default perturbation (dx/x = 0.05)?
    n        $ Do you want to reset total iterations to zero (Type H)?

 ************ END OF THE  testcomp.OPT  FILE ***********
 ************ OCTOBER, 1999 VERSION OF GENOPT ****************
 ******** BEGINNING OF THE  testcomp.OPM  FILE *********

 *********************** MAIN PROCESSOR **********************
 The purpose of the mainprocessor, OPTIMIZE, is to perform,
 in a batch mode, the work specified by MAINSETUP for the case
 called testcomp.  Results are stored in the file  testcomp.OPM.
 Please inspect testcomp.OPM before doing more design iterations.
 ************************************************************

 STRUCTURAL ANALYSIS FOR DESIGN ITERATION NO.    0:0
  STRUCTURAL ANALYSIS WITH UNPERTURBED DECISION VARIABLES
 VAR. DEC. ESCAPE LINK. LINKED  LINKING    LOWER     CURRENT     UPPER
  NO. VAR.  VAR.  VAR.    TO   CONSTANT    BOUND      VALUE      BOUND
  Total wall thickness: THICK
   1  N     N     N      0    0.00E+00  0.00E+00 2.0000E-01  0.00E+00
  ring spacing (use zero if no rings): BRINGS
   2  N     N     N      0    0.00E+00  0.00E+00 0.0000E+00  0.00E+00
  thickness of web of T-ring: TWEB
   3  N     N     N      0    0.00E+00  0.00E+00 0.0000E+00  0.00E+00
  height of web of T-ring: HWEB
   4  N     N     N      0    0.00E+00  0.00E+00 0.0000E+00  0.00E+00
  thickness of outstanding flange of T-ring: TFLANG
   5  N     N     N      0    0.00E+00  0.00E+00 0.0000E+00  0.00E+00
  width of outstanding flange of T-ring: HFLANG
   6  N     N     N      0    0.00E+00  0.00E+00 0.0000E+00  0.00E+00
  Axial halfwavelength of the waviness: WAVLEN
   7  Y     N     N      0    0.00E+00  5.00E-01 1.0133E+00  2.00E+00
```

```
Amplitude of waviness: AMPLIT
  8   Y    N    N     0    0.00E+00  1.00E-02 1.7190E-01  4.00E-01
Local meridional radius of curvature: RADSML
  9   N    N    N     0    0.00E+00  0.00E+00 0.0000E+00  0.00E+00
thickness of layer type: TLAYER(1 )
 10   N    N    N     0    0.00E+00  0.00E+00 5.0000E-03  0.00E+00
thickness of layer type: TLAYER(2 )
 11   N    N    N     0    0.00E+00  0.00E+00 5.0000E-03  0.00E+00
thickness of layer type: TLAYER(3 )
 12   N    N    N     0    0.00E+00  0.00E+00 5.0000E-03  0.00E+00
thickness of layer type: TLAYER(4 )
 13   N    N    N     0    0.00E+00  0.00E+00 7.5000E-03  0.00E+00
layup angle (deg.) for layer type: ANGLE(1 )
 14   N    N    N     0    0.00E+00  0.00E+00 0.0000E+00  0.00E+00
layup angle (deg.) for layer type: ANGLE(2 )
 15   N    N    N     0    0.00E+00  0.00E+00 4.5000E+01  0.00E+00
layup angle (deg.) for layer type: ANGLE(3 )
 16   N    N    N     0    0.00E+00  0.00E+00-4.5000E+01  0.00E+00
layup angle (deg.) for layer type: ANGLE(4 )
 17   N    N    N     0    0.00E+00  0.00E+00 9.0000E+01  0.00E+00

*************** UNPERTURBED DESIGN: IMODX = 0 ***************
 BEGIN COMPUTATIONS FOR THE UNPERTURBED (CURRENT) DESIGN
  LOAD SET NO.  1

****** (ALLOWABLE STRESS)/(ACTUAL STRESS) ********
Nonlinear BOSOR4 MODEL 1: Only wavy section, no rings
 1  3.3109E+00 fiber tension : matl=1 ,  A , seg=15, node=12, layer=1 ,z=-0
 2  1.4741E+00 fiber compres.: matl=1 ,  A , seg=12, node=12, layer=1 ,z=-0
 3  1.1580E+01 transv tension: matl=1 ,  A , seg=4 , node=12, layer=8 ,z=0.
 4  1.1313E+01 transv compres: matl=1 ,  A , seg=5 , node=12, layer=8 ,z=0.
 5  9.1394E+00 in-plane shear: matl=1 ,  A , seg=5 , node=12, layer=2 ,z=-0
****************************************************

Composite matl: Most critical stress ratio, allowable/actual, and definition
 1.4741E+00 fiber compres.: matl=1 ,  A , seg=12, node=12, layer=1 ,z=-0

Output from STRUCT:
Maximum stress from nonlinear theory (no rings),STRMXX=  6.7836E-01
End shortening under unit axial compression,     ENDUV=  1.6523E-03
Modal frequency correspnding to 2 circ. waves,   FREQ2=  1.3075E+02
Ratio of wavy arclength to straight length,     ARCRAT=  1.0751E+00
Reduction factor for axial stiffness,           C11RAT=  2.8222E-02
Hoop bending stiffness ratio,C55RAT=C55(eff)/C55(wall)=  1.2218E+02
2nd ratio of wavy arclength to straight length, ARCRT2=  1.0751E+00
Weight of the entire Model No. 2,               WEIGHT=  1.3342E+01
Nx from axial g-loading and unsupported tube,   FNXADD= -1.5729E+00
Effective mass density of shell wall material,  DENSHL=  1.4250E-04
Mass density of ring material,                  DENRNG=  0.0000E+00
Effective density of shell with smeared rings,  RHOEFF=  1.4250E-04
Amplitude of initial general buckling imperfection, W0=  0.0000E+00
(C22-C12**2/C11)*(C25/C22)*(n/R)**2*W0/(EIG1-1)=FN2ADD(1)=  0.0000E+00
(C22-C12**2/C11)*(C25/C22)*(n/R)**2*W0/(EIG2-1)=FN2ADD(2)=  0.0000E+00
in which
EIG1 = buckling load factor, smeared waviness and SMEARED  rings=  0.0000E+00
and
EIG2 = buckling load factor, smeared waviness and DISCRETE rings=  0.0000E+00
Smallest buckling circumferential wavenumber for which FN2ADD(1)=  0.0000E+00
is added to the hoop load from pressure in buckling analyses NWAVLC =10000000

****** (ALLOWABLE STRESS)/(ACTUAL STRESS) ********
Linear BOSOR4 MODEL 2: Entire length + rings; theta=0 deg.
```

```
 1  3.0207E+00 fiber tension : matl=1 ,  A , seg=80, node=12, layer=1 ,z=-0
 2  1.3275E+00 fiber compres.: matl=1 ,  A , seg=77, node=12, layer=1 ,z=-0
 3  1.0255E+01 transv tension: matl=1 ,  A , seg=77, node=12, layer=8 ,z=0.
 4  1.0354E+01 transv compres: matl=1 ,  A , seg=78, node=12, layer=8 ,z=0.
 5  8.3971E+00 in-plane shear: matl=1 ,  A , seg=78, node=12, layer=2 ,z=-0
*********************************************************

Composite matl: Most critical stress ratio, allowable/actual, and definition
 1.3275E+00 fiber compres.: matl=1 ,  A , seg=77, node=12, layer=1 ,z=-0

Output from STRUCT for linear nonsymmetric stress analysis:
Max. critical stress,  theta=0, load set A,  STRNON(1)=  7.5330E-01,
Max. critical stress,  theta=0, load set B,  STRNON(2)=  0.0000E+00, seg. node
Max. normal displace., theta=0, load set A,  WWWNON(1)= -2.8733E-01,  81  023
Max. normal displace., theta=0, load set B,  WWWNON(2)=  0.0000E+00,

****** (ALLOWABLE STRESS)/(ACTUAL STRESS) ********
Linear BOSOR4 MODEL 2: Entire length +rings; theta=180 deg.
 1  3.4719E+00 fiber tension : matl=1 ,  A , seg=4 , node=12, layer=1 ,z=-0
 2  1.5449E+00 fiber compres.: matl=1 ,  A , seg=5 , node=12, layer=1 ,z=-0
 3  1.2184E+01 transv tension: matl=1 ,  A , seg=3 , node=12, layer=8 ,z=0.
 4  1.1652E+01 transv compres: matl=1 ,  A , seg=4 , node=12, layer=8 ,z=0.
 5  9.4720E+00 in-plane shear: matl=1 ,  A , seg=4 , node=12, layer=2 ,z=-0
*********************************************************

Composite matl: Most critical stress ratio, allowable/actual, and definition
 1.5449E+00 fiber compres.: matl=1 ,  A , seg=5 , node=12, layer=1 ,z=-0
Max. critical stress,  theta=180,load set A, STRNON(1)=  6.4731E-01,
Max. critical stress,  theta=180,load set B, STRNON(2)=  0.0000E+00, seg node
Max. normal displace., theta=180,load set A, WWWNON(1)=  2.9724E-01,  81  023
Max. normal displace., theta=180,load set B, WWWNON(2)=  0.0000E+00,

==============================================================
BEGIN SUBROUTINE BEHX4 (LINEAR NONAXISYMMETRIC STRESS, 0deg).
IMODX= 0; LOAD SET NO.  1
Maximum stress from linear theory at 0 deg, STR0(ILOADX)= 7.5330E-01

==============================================================
BEGIN SUBROUTINE BEHX5 (LINEAR NONAXISYMMETRIC STRESS, 180d).
IMODX= 0; LOAD SET NO.  1
Maximum stress, linear theory at 180 deg, STR180(ILOADX)= 6.4731E-01

==============================================================
BEGIN SUBROUTINE BEHX6 (LINEAR BUCKLING AT 0 DEGREES).
LOW-WAVE-RANGE, IMODX= 0; LOAD SET NO.  1
SYMMETRIC BUCKLING ABOUT MIDLENGTH SYMMETRY PLANE
***** SYMMETRIC BUCKLING LOAD FACTORS AND MODE SHAPES *****
LINEAR BUCKLING LOAD FACTOR, 0 DEGREES, MODEL 2 (CIRC. WAVES)
   eigenvalue(circ. waves)
        2.1421E+01(   0)
        1.0976E+01(   1)
        1.2462E+00(   2)
        2.4146E+00(   3)
        3.0618E+00(   4)
        2.9263E+00(   5)
===== BUCKLING MODAL SYMMETRY AT SYMMETRY PLANE =====
Critical buckling load factor, BUC0=  1.2462E+00
Critical number of circumferential waves, NWVCRT=    2

*** SYMMETRIC BUCKLING LOAD FACTORS AND MODE SHAPES ***
LINEAR BUCKLING LOAD FACTOR, 0 DEGREES, MODEL 2 (CIRC. WAVES)
THE ENTIRE LENGTH (  9.0000E+01) OF THE CYL. HAS "SMEARED" WAVINESS.
```

```
   eigenvalue(circ. waves)
       3.7745E+01(   0)
       2.3020E+01(   1)
       1.4738E+00(   2)
       3.8470E+00(   3)
       6.8258E+00(   4)
       1.0069E+01(   5)
===== BUCKLING MODAL SYMMETRY AT SYMMETRY PLANE =====
Crit. buckling factor,  BUC0("smeared waviness")=  1.4738E+00
Critical number of circumferential waves, NWVCRT=    2

============================================================
BEGIN SUBROUTINE BEHX7 (LINEAR BUCKLING AT 0 DEGREES).
LOW-WAVE-RANGE, IMODX= 0; LOAD SET NO.  1
ANTI-SYMMETRIC BUCKLING ABOUT MIDLENGTH SYMMETRY PLANE
*** ANTISYMMETRIC BUCKLING LOAD FACTORS AND MODE SHAPES ***
LINEAR BUCKLING LOAD FACTOR, 0 DEGREES, MODEL 2 (CIRC. WAVES)
   eigenvalue(circ. waves)
       2.1421E+01(   0)
       1.0976E+01(   1)
       1.2475E+00(   2)
       2.4114E+00(   3)
       3.0615E+00(   4)
       2.9201E+00(   5)
===== BUCKLING MODAL ANTISYMMETRY AT SYMMETRY PLANE =====
Critical buckling load factor, BUC0=  1.2475E+00
Critical number of circumferential waves, NWVCRT=    2

*** ANTISYMMETRIC BUCKLING LOAD FACTORS AND MODE SHAPES ***
LINEAR BUCKLING LOAD FACTOR, 0 DEGREES, MODEL 2 (CIRC. WAVES)
THE ENTIRE LENGTH (  9.0000E+01) OF THE CYL. HAS "SMEARED" WAVINESS.
   eigenvalue(circ. waves)
       3.7745E+01(   0)
       2.3020E+01(   1)
       1.4759E+00(   2)
       3.8426E+00(   3)
       6.8212E+00(   4)
       1.0042E+01(   5)
===== BUCKLING MODAL ANTISYMMETRY AT SYMMETRY PLANE =====
Crit. buckling factor,  BUC0("smeared waviness")=  1.4759E+00
Critical number of circumferential waves, NWVCRT=    2

============================================================
BEGIN SUBROUTINE BEHX8 (LINEAR BUCKLING AT 0 DEGREES).
MID-WAVE-RANGE, IMODX= 0; LOAD SET NO.  1
***** SYMMETRIC BUCKLING LOAD FACTORS AND MODE SHAPES *****
LINEAR BUCKLING LOAD FACTOR, 0 DEGREES, MODEL 2 (CIRC. WAVES)
   eigenvalue(circ. waves)
       4.8686E+00(   6)
       8.0760E+00(   7)
       1.0258E+01(   8)
       1.2436E+01(   9)
       1.4531E+01(  10)
===== BUCKLING MODAL SYMMETRY AT SYMMETRY PLANE =====
Critical buckling load factor, BUC0=  4.8686E+00
Critical number of circumferential waves, NWVCRT=    6

============================================================
BEGIN SUBROUTINE BEHX12 (MAX. NORMAL DISPLACEMENT, 0 DEG.).
IMODX= 0; LOAD SET NO.  1
Max. normal displacement, linear theory, 0 deg, WWW0(ILOADX)= 2.8733E-01
```

```
=======================================================================
BEGIN SUBROUTINE BEHX13 (MAX. NORMAL DISPLACEMENT, 180 DEG.).
IMODX= 0; LOAD SET NO.  1
Max. normal displac., linear theory, 180 deg, WWW180(ILOADX)= 2.9724E-01

=======================================================================
BEGIN SUBROUTINE BEHX14 (MODAL FREQUENCY, AXISYM. LOADING).
IMODX= 0; LOAD SET NO.  1
***** FREQUENCIES AND MODE SHAPES *****
      FREQUENCY(CIRC. WAVES)
       9.5715E+01(   0)
       1.0385E+01(   1)
       7.1867E+01(   2)
       3.0961E+02(   3)
========================================
Critical modal vibration frequency, FREQ=  1.0385E+01
Critical number of circumferential waves, NWVCRT=    1

***** FREQUENCIES AND MODE SHAPES: "SMEARED" WAVINESS *****
      FREQUENCY(CIRC. WAVES)
       1.0609E+02(   0)
       1.1640E+01(   1)
       7.4180E+01(   2)
       3.1883E+02(   3)
========================================
Critical modal vibration frequency, FREQ=  1.1640E+01
Critical number of circumferential waves, NWVCRT=    1

Find natural frequency for axial length=  8.0000E+02

***** FREQUENCY AND MODE SHAPE FOR 0 CIRC. WAVES *****
      FREQUENCY(CIRC. WAVES)
       2.2948E+01(   0)
========================================
Critical modal vibration frequency, FREQ=  2.2948E+01
Critical number of circumferential waves, NWVCRT=    0

***** RESULTS FOR LOAD SET NO.  1   ******

PARAMETERS WHICH DESCRIBE BEHAVIOR (e.g. stress, buckling load)
BEH.   CURRENT
NO.     VALUE            DEFINITION
 1    1.000E-10    maximum stress in wall from nonlinear theory: STRMAX(1 )
 2    1.000E+10    buckling load factor from nonlinear theory: BUCFAC(1 )
 3    1.000E+10    hi-wave buckling load factor, nonlinear theory: BUCHIW(1 )
 4    7.533E-01    max. stress at 0 deg., linear theory: STR0(1 )
 5    6.473E-01    max. stress at 180 deg., linear theory: STR180(1 )
 6    1.246E+00    buckling load factor at 0 deg., linear theory: BUC0(1 )
 7    1.248E+00    load factor for antisymmetric buckling at 0 deg: B0ANTI(1)
 8    4.869E+00    load factor for mid-wave-range buckling at 0 deg: BUC0MD(1)
 9    1.000E+10    hi-wave buckling load factor, 0 deg, lin. theory: BUC0HI(1)
10    1.000E+10    buckling load factor at 180 deg, linear theory: BUC180(1)
11    1.000E+10    hi-wave buckling load factor 180 deg, lin.theory: B180HI(1)
12    2.873E-01    maximum normal displacement, 0 deg., linear theory: WWW0(1)
13    2.972E-01    maximum normal displace., 180 deg., lin.theory: WWW180(1)
14    1.038E+01    modal frequency (hertz): FREQ(1 )
15    1.000E-10    maximum stress from random excitation: STRRAN(1 )
16    1.000E+10    buckling load factor from random excitation: BUCRAN(1)
17    1.000E+10    hi-wave buckling factor from random excitation: BRANHI(1)
18    1.000E-10    max. normal displacement from random excitation: WWWRAN(1)

MARGINS CORRESPONDING TO CURRENT DESIGN (F.S.= FACTOR OF SAFETY)
```

```
MARGIN CURRENT
NO.     VALUE             DEFINITION
 1     1.000E+00  1-(STRMAX(1 )/STRALW(1 )) X STRFS(1 ); F.S.=1.
 2     2.467E-01  1-(STR0(1 )/STR0A(1 )) X STR0F(1 ); F.S.=1.
 3     3.527E-01  1-(STR180(1 )/ST180A(1 )) X ST180F(1 ); F.S.=1.
 4    -3.055E-03  (BUC0(1 )/BUC0A(1 )) / BUC0F(1 )-1; F.S.=1.25
 5    -1.994E-03  (B0ANTI(1 )/B0ANTA(1 )) / B0ANTF(1 )-1; F.S.=1.25
 6     2.895E+00  (BUC0MD(1 )/BUC0MA(1 )) / BUC0MF(1 )-1; F.S.=1.25
 7     6.408E-01  1-(WWW0(1 )/WWW0A(1 )) X WWW0F(1 ); F.S.=1.
 8     5.356E-01  1-(WWW180(1 )/WW180A(1 )) X WW180F(1 ); F.S.=1.25
 9     3.850E-02  (FREQ(1 )/VIBALW(1 )) / VIBFS(1 )-1; F.S.=1.
10     1.000E+00  1-(STRRAN(1 )/STRRNA(1 )) X STRRNF(1 ); F.S.=1.
11     1.000E+00  1-(WWWRAN(1 )/WWWRNA(1 )) X WWWRNF(1 ); F.S.=1.

******************** DESIGN OBJECTIVE ********************
   CURRENT VALUE OF THE OBJECTIVE FUNCTION:
VAR.    CURRENT
NO.      VALUE             DEFINITION
 1     1.334E+01  weight of the cylindrical shell: WEIGHT
******************** DESIGN OBJECTIVE ********************
***********  ALL 1 LOAD CASES PROCESSED ***********
================================================================================
```

Appendix Tables

Table A.1 Input for GENTEXT (cylinder.INP) for monocoque cylindrical shell under combined axial loading and pressure loading. The shell is to be optimized subject to stress, buckling, and modal vibration constraints.

```
==========================================================================
      5  $ starting prompt index in the file cylinder.PRO
      5  $ increment for prompt index
      0  $ Type of prompt: 0="help" paragraph, 1=one-line prompt
 The following sample GENOPT case is a simple cylindrical shell.
 y       $ Are there more lines in the "help" paragraph?
 We wish to optimize with constraints on stress, buckling, and
 y       $ Are there more lines in the "help" paragraph?
 modal vibration.
 n       $ Are there more lines in the "help" paragraph?
      1  $ Type of prompt: 0="help" paragraph, 1=one-line prompt

 LENGTH  $ Name of a variable in the users program (defined below)
      2  $ Role of the variable in the users program
      2  $ type of variable:  1 =integer,  2 =floating point
 n       $ Is the variable  LENGTH  an array?
 Length of the cylindrical shell
 n       $ Do you want to include a "help" paragraph?
 y       $ Any more variables for role types  1  or  2   ?    $10
      1  $ Type of prompt: 0="help" paragraph, 1=one-line prompt
 RADIUS  $ Name of a variable in the users program (defined below)
      2  $ Role of the variable in the users program
      2  $ type of variable:  1 =integer,  2 =floating point
 n       $ Is the variable  RADIUS  an array?
 Radius of the cylindrical shell
 n       $ Do you want to include a "help" paragraph?
 y       $ Any more variables for role types  1  or  2   ?    $15
      1  $ Type of prompt: 0="help" paragraph, 1=one-line prompt
 THICK   $ Name of a variable in the users program (defined below)
      1  $ Role of the variable in the users program
 n       $ Is the variable  THICK  an array?
 Thickness of the cylindrical shell
 n       $ Do you want to include a "help" paragraph?
 y       $ Any more variables for role types  1  or  2   ?    $20
      1  $ Type of prompt: 0="help" paragraph, 1=one-line prompt
 ESTIFF  $ Name of a variable in the users program (defined below)
      2  $ Role of the variable in the users program
      2  $ type of variable:  1 =integer,  2 =floating point
 n       $ Is the variable  ESTIFF  an array?
 Youngs modulus of the shell wall
 n       $ Do you want to include a "help" paragraph?
 y       $ Any more variables for role types  1  or  2   ?    $25
      1  $ Type of prompt: 0="help" paragraph, 1=one-line prompt
 NU      $ Name of a variable in the users program (defined below)
      2  $ Role of the variable in the users program
      2  $ type of variable:  1 =integer,  2 =floating point
 n       $ Is the variable  NU  an array?
 Poisson ratio of the shell wall
 n       $ Do you want to include a "help" paragraph?
 y       $ Any more variables for role types  1  or  2   ?    $30
      1  $ Type of prompt: 0="help" paragraph, 1=one-line prompt
 DENS    $ Name of a variable in the users program (defined below)
      2  $ Role of the variable in the users program
      2  $ type of variable:  1 =integer,  2 =floating point
 n       $ Is the variable  DENS  an array?
 mass density (e.g. lb-sec^2/in^4)
 n       $ Do you want to include a "help" paragraph?
 y       $ Any more variables for role types  1  or  2   ?    $35
      1  $ Type of prompt: 0="help" paragraph, 1=one-line prompt
```

```
IBOUND    $ Name of a variable in the users program (defined below)
     2    $ Role of the variable in the users program
     1    $ type of variable:  1 =integer,  2 =floating point
n         $ Is the variable  IBOUND  an array?
IBOUND = 1 = simple support; 2 = clamped
n         $ Do you want to include a "help" paragraph?
n         $ Any more variables for role types  1  or  2   ?    $
     1    $ Type of prompt: 0="help" paragraph, 1=one-line prompt
NX        $ Name of a variable in the users program (defined below)
     3    $ Role of the variable in the users program
Axial resultant (e.g. lb/in)
n         $ Do you want to include a "help" paragraph?
y         $ Any more variables for role type  3 ?              $50
     1    $ Type of prompt: 0="help" paragraph, 1=one-line prompt
PRESS     $ Name of a variable in the users program (defined below)
     3    $ Role of the variable in the users program
Pressure, positive for internal
n         $ Do you want to include a "help" paragraph?
n         $ Any more variables for role type  3 ?              $
     1    $ Type of prompt: 0="help" paragraph, 1=one-line prompt
STRESS    $ Name of a variable in the users program (defined below)
     4    $ Role of the variable in the users program
n         $ Do you want to reset the number of columns in STRESS ?
Maximum effective stress in wall of shell
n         $ Do you want to include a "help" paragraph?
     1    $ Type of prompt: 0="help" paragraph, 1=one-line prompt
STRSSA    $ Name of a variable in the users program (defined below)
     5    $ Role of the variable in the users program
Maximum allowable stress
n         $ Do you want to include a "help" paragraph?
     1    $ Type of prompt: 0="help" paragraph, 1=one-line prompt
STRSSF    $ Name of a variable in the users program (defined below)
     6    $ Role of the variable in the users program
Factor of safety for stress
n         $ Do you want to include a "help" paragraph?
     1    $ Indicator (1 or 2) for type of constraint
y         $ Any more variables for role type  4 ?              $70
     1    $ Type of prompt: 0="help" paragraph, 1=one-line prompt
BSYM      $ Name of a variable in the users program (defined below)
     4    $ Role of the variable in the users program
n         $ Do you want to reset the number of columns in BSYM ?
Symmetric buckling load factor
n         $ Do you want to include a "help" paragraph?
     1    $ Type of prompt: 0="help" paragraph, 1=one-line prompt
BSYMA     $ Name of a variable in the users program (defined below)
     5    $ Role of the variable in the users program
Allowable for sym. buckling load factor
n         $ Do you want to include a "help" paragraph?
     1    $ Type of prompt: 0="help" paragraph, 1=one-line prompt
BSYMF     $ Name of a variable in the users program (defined below)
     6    $ Role of the variable in the users program
Factor of safety for sym. buckling load
n         $ Do you want to include a "help" paragraph?
     2    $ Indicator (1 or 2) for type of constraint
y         $ Any more variables for role type  4 ?              $85
     1    $ Type of prompt: 0="help" paragraph, 1=one-line prompt
BANTI     $ Name of a variable in the users program (defined below)
     4    $ Role of the variable in the users program
n         $ Do you want to reset the number of columns in BANTI ?
Antisymmetric buckling load factor
n         $ Do you want to include a "help" paragraph?
     1    $ Type of prompt: 0="help" paragraph, 1=one-line prompt
```

```
BANTIA   $ Name of a variable in the users program (defined below)
      5  $ Role of the variable in the users program
Allowable for antisym. buckling load factor
n        $ Do you want to include a "help" paragraph?
      1  $ Type of prompt: 0="help" paragraph, 1=one-line prompt
BANTIF   $ Name of a variable in the users program (defined below)
      6  $ Role of the variable in the users program
Factor of safety for antisym. buckling load
n        $ Do you want to include a "help" paragraph?
      2  $ Indicator (1 or 2) for type of constraint
y        $ Any more variables for role type  4 ?          $100
      1  $ Type of prompt: 0="help" paragraph, 1=one-line prompt
FREQ     $ Name of a variable in the users program (defined below)
      4  $ Role of the variable in the users program
n        $ Do you want to reset the number of columns in FREQ ?
Fundamental modal frequency (hertz)
n        $ Do you want to include a "help" paragraph?
      1  $ Type of prompt: 0="help" paragraph, 1=one-line prompt
FREQA    $ Name of a variable in the users program (defined below)
      5  $ Role of the variable in the users program
Allowable for modal frequency
n        $ Do you want to include a "help" paragraph?
      1  $ Type of prompt: 0="help" paragraph, 1=one-line prompt
FREQF    $ Name of a variable in the users program (defined below)
      6  $ Role of the variable in the users program
Factor of safety for modal frequency
n        $ Do you want to include a "help" paragraph?
      2  $ Indicator (1 or 2) for type of constraint
n        $ Any more variables for role type  4 ?          $
      1  $ Type of prompt: 0="help" paragraph, 1=one-line prompt
WEIGHT   $ Name of a variable in the users program (defined below)
      7  $ Role of the variable in the users program
weight of half of cyl. shell
n        $ Do you want to include a "help" paragraph?
==========================================================================
```

Table A.2 Prompting file (cylinder.PRO) automatically generated by GENOPT

```
==========================================================================
   5.0
        The following sample GENOPT case is a simple cylindrical shell.
        We wish to optimize with constraints on stress, buckling, and
        modal vibration.

  10.1 Length of the cylindrical shell: LENGTH
  15.1 Radius of the cylindrical shell: RADIUS
  20.1 Thickness of the cylindrical shell: THICK
  25.1 Youngs modulus of the shell wall: ESTIFF
  30.1 Poisson ratio of the shell wall: NU
  35.1 mass density (e.g. lb-sec^2/in^4): DENS
  40.1 IBOUND = 1 = simple support; 2 = clamped: IBOUND
  45.1 Number NCASES of load cases (environments): NCASES
  50.1 Axial resultant (e.g. lb/in): NX
  55.1 Pressure, positive for internal: PRESS
  60.0 Maximum effective stress in wall of shell: STRESS
  65.1 Maximum allowable stress: STRSSA
  70.1 Factor of safety for stress: STRSSF
  75.0 Symmetric buckling load factor: BSYM
  80.1 Allowable for sym. buckling load factor: BSYMA
  85.1 Factor of safety for sym. buckling load: BSYMF
  90.0 Antisymmetric buckling load factor: BANTI
  95.1 Allowable for antisym. buckling load factor: BANTIA
 100.1 Factor of safety for antisym. buckling load: BANTIF
 105.0 Fundamental modal frequency (hertz): FREQ
 110.1 Allowable for modal frequency: FREQA
 115.1 Factor of safety for modal frequency: FREQF
 120.0 weight of half of cyl. shell: WEIGHT
 999.0 DUMMY ENTRY TO MARK END OF FILE
==========================================================================
```

Table A.3 Glossary of variables automatically produced by GENOPT. This list represents part of the cylinder.DEF file.

```
=======================================================================
C  ARRAY  NUMBER OF        PROMPT                        DEFINITION OF VARIABLE
C    ?   (ROWS,COLS)  ROLE NUMBER    NAME
C                     (cylinder.PRO)
C=====================================================================
C    n   (  0,   0)    2     10    LENGTH  = Length of the cylindrical shell
C    n   (  0,   0)    2     15    RADIUS  = Radius of the cylindrical shell
C    n   (  0,   0)    1     20    THICK   = Thickness of the cylindrical shell
C    n   (  0,   0)    2     25    ESTIFF  = Youngs modulus of the shell wall
C    n   (  0,   0)    2     30    NU      = Poisson ratio of the shell wall
C    n   (  0,   0)    2     35    DENS    = mass density (e.g. lb-sec^2/in^4)
C    n   (  0,   0)    2     40    IBOUND  = IBOUND = 1 = s.s.; 2 = clamped
C    n   (  0,   0)    2     45    NCASES  = Number of load cases
C    n   (  0,   0)    2     50    NX      = Axial resultant (e.g. lb/in)
C    y   ( 20,   0)    3     55    PRESS   = Pressure, positive for internal
C    y   ( 20,   0)    3     60    STRESS  = Maximum effective stress in wall
C    y   ( 20,   0)    4     65    STRSSA  = Maximum allowable stress
C    y   ( 20,   0)    5     70    STRSSF  = Factor of safety for stress
C    y   ( 20,   0)    6     75    BSYM    = Symmetric buckling load factor
C    y   ( 20,   0)    4     80    BSYMA   = Allowable for sym. buckling load
C    y   ( 20,   0)    5     85    BSYMF   = Fact.safety for sym. bucklng load
C    y   ( 20,   0)    6     90    BANTI   = Antisymmetric buckling load factor
C    y   ( 20,   0)    4     95    BANTIA  = Allowable,antisym. bucklng load
C    y   ( 20,   0)    5    100    BANTIF  = Fact.safety for antisym.buckling
C    y   ( 20,   0)    6    105    FREQ    = Fundamental modal frequency
C    y   ( 20,   0)    4    110    FREQA   = Allowable for modal frequency
C    y   ( 20,   0)    5    115    FREQF   = Fact.safety for modal frequency
C    y   ( 20,   0)    6    120    WEIGHT  = weight of half of cyl. shell
C    n   (  0,   0)    7
=======================================================================
```

Table A.4 CYLINDER Labelled common blocks (cylinder.COM) generated by GENOPT

```
=======================================================================
      COMMON/FV07/NX(20)
      REAL NX
      COMMON/FV11/STRESS(20),STRSSA(20),STRSSF(20)
      REAL STRESS,STRSSA,STRSSF
      COMMON/FV14/BSYM(20),BSYMA(20),BSYMF(20)
      REAL BSYM,BSYMA,BSYMF
      COMMON/FV17/BANTI(20),BANTIA(20),BANTIF(20)
      REAL BANTI,BANTIA,BANTIF
      COMMON/FV20/FREQ(20),FREQA(20),FREQF(20)
      REAL FREQ,FREQA,FREQF
      COMMON/IV01/IBOUND
      INTEGER IBOUND
      COMMON/FV01/LENGTH,RADIUS,THICK,ESTIFF,NU,DENS,WEIGHT
      REAL LENGTH,RADIUS,THICK,ESTIFF,NU,DENS,WEIGHT
      COMMON/FV08/PRESS(20)
      REAL PRESS
=======================================================================
```

Table A.5 SUBROUTINE STRUCT, mostly generated by GENOPT and modified by the GENOPT user. In this case the version of SUBROUTINE STRUCT (file STRUCT.NEW) generated by GENOPT was modified as indicated by the string, "<--- added by GENOPT user"

```
===============================================================================
C=DECK      STRUCT
      SUBROUTINE STRUCT(IMODX,CONSTX,OBJGEN,CONMAX,NCONSX,IPOINC,
     1                  PCWORD,CPLOTX,ILOADX,ISTARX,NUSERC,IBEHV)
C
C  PURPOSE IS TO PERFORM THE ANALYSIS FOR A GIVEN DESIGN AND LOADING.
C  CONSTRAINT CONDITIONS ARE ALSO GENERATED.

   (lines omitted to save space. See Ref. [2]).

C  Start of first part of STRUCT written by "GENTEXT"
C  INSERT ADDITIONAL COMMON BLOCKS HERE: (THESE ARE "GENTEXT" VARIABLES)
      COMMON/FV07/NX(20)
      REAL NX
      COMMON/FV11/STRESS(20),STRSSA(20),STRSSF(20)
      REAL STRESS,STRSSA,STRSSF
      COMMON/FV14/BSYM(20),BSYMA(20),BSYMF(20)
      REAL BSYM,BSYMA,BSYMF
      COMMON/FV17/BANTI(20),BANTIA(20),BANTIF(20)
      REAL BANTI,BANTIA,BANTIF
      COMMON/FV20/FREQ(20),FREQA(20),FREQF(20)
      REAL FREQ,FREQA,FREQF
      COMMON/IV01/IBOUND
      INTEGER IBOUND
      COMMON/FV01/LENGTH,RADIUS,THICK,ESTIFF,NU,DENS,WEIGHT
      REAL LENGTH,RADIUS,THICK,ESTIFF,NU,DENS,WEIGHT
      COMMON/FV08/PRESS(20)
      REAL PRESS
C  End of first part of STRUCT written by "GENTEXT"
C==========================================================================
C
C  INSERT ADDITIONAL DIMENSION AND/OR LABELLED COMMON BLOCKS HERE,
C  IF NECESSARY. THESE WOULD BE STATEMENTS THAT ARE CONSISTENT WITH
C  SUBROUTINES THAT YOU OR OTHERS MAY HAVE WRITTEN THAT ARE REQUIRED
C  FOR WHATEVER ANALYSIS YOU ARE PERSUING.  MAKE SURE THAT YOU DO NOT
C  INTRODUCE NAME CONFLICTS WITH THE "GENTEXT" LABELLED COMMON BLOCKS
C  LISTED ABOVE.

      (lines omitted to save space. See Ref. [2]).

C
      COMMON/TOTMAX/TOTMAS           <---- added by GENOPT user
C
C  THE FOLLOWING CODE WAS WRITTEN BY "GENTEXT":
C=================================================================
C  Start the second portion of STRUCT written by "GENTEXT":
C
      ICARX   = ISTARX
      INUMTT = 0
      ICONSX = 0
      KCONX   = 0
      IF (IMODX.EQ.0) THEN
         CALL MOVERX(0.,0,CONSTX,1,99)
         CALL MOVERX(0, 0,IPOINC,1,1500)
      ENDIF
C
      IF (ILOADX.EQ.1) THEN
C
```

```
C  ESTABLISH FIRST ANY CONSTRAINTS THAT ARE INEQUALITY RELATIONSHIPS
C  AMONG THE VARIABLES IN THE ARRAY VARX(*) (THAT IS, VARIABLES THAT
C  ARE EITHER DECISION VARIABLES, LINKED VARIABLES, ESCAPE VARIABLES,
C  OR CANDIDATES FOR ANY OF THESE TYPES OF VARIABLES.
C
         IF (NINEQX.GT.0)
     1        CALL VARCON(WORDIQ,WORDMX,CINEQX,DPWREQ,IDINEQ,
     1        NINEQX,JINEQX,IEQTYP,INUMTT,IMODX,CONMAX,IPOINC,
     1        ICONSX,CONSTX,VARX,PCWORD,CPLOTX,ICARX)
C
C  NEXT, ESTABLISH USER-WRITTEN CONSTRAINTS. AT PRESENT, THE PROGRAM
C  ALLOWS ONLY ONE USER-WRITTEN CONSTRAINT. HOWEVER, THE USER CAN
C  EASILY EXPAND THIS CAPABILITY SIMPLY BY ADDING SUBROUTINES THAT
C  ARE ANALOGOUS TO USRCON (WITH NAMES SUCH AS USRCN2, USRCN3, ETC.
C  TO THE  BEHAVIOR.NEW LIBRARY, AND ADD CALLS TO THESE ADDITIONAL
C  SUBROUTINES FOLLOWING THE CALL TO USRCON IMMEDIATELY BELOW.
C
         CALL USRCON(INUMTT,IMODX,CONMAX,ICONSX,IPOINC,CONSTX,WORDCX,
     1             WORDMX,PCWORD,CPLOTX,ICARX,IFILE8)
C
         NUSERC = ICARX - NINEQX
      ENDIF
C
      IF (NPRINX.GT.0) THEN
         WRITE(IFILE8,'(1X,A,I2,A)')
     1 ' BEHAVIOR FOR ',ILOADX,' ENVIRONMENT (LOAD SET)'
         WRITE(IFILE8,'(A)')'  '
         WRITE(IFILE8,'(A)')
     1 ' CONSTRAINT  BEHAVIOR                  DEFINITION'
         WRITE(IFILE8,'(A)')
     1 '   NUMBER      VALUE'
      ENDIF
C
      CALL CONVR2(ILOADX,CIX)
      IF (NPRINX.GT.0) THEN
         WRITE(IFILE8,'(1X,A)')'  '
         WRITE(IFILE8,'(1X,A,I2)')
     1 ' BEHAVIOR FOR LOAD SET NUMBER, ILOADX=',ILOADX
      ENDIF
C
C  End of the second portion of STRUCT written by "GENTEXT"
C======================================================================
C
C  USER: YOU MAY WANT TO INSERT SUBROUTINE CALLS FROM SOFTWARE DEVELOPED
C        ELSEWHERE FOR ANY CALCULATIONS PERTAINING TO THIS LOAD SET.
C
      CALL OPNGEN  <---- added by GENOPT user
      CALL RWDGEN  <---- added by GENOPT user
C
C     initialize behaviors:  <---- added by GENOPT user
      STRESS(ILOADX) = 0.    <---- added by GENOPT user
      BSYM(ILOADX) = 0.      <---- added by GENOPT user
      BANTI(ILOADX) = 0.     <---- added by GENOPT user
      FREQ(ILOADX)   = 0.    <---- added by GENOPT user
C
C  Find mass of cyl. shell from boundary to mid-length symmetry plane.
C  The mass is stored in TOTMAS, which is one of the BOSOR4 labelled
C  common blocks.
      INDIC = 0                        <---- added by GENOPT user
      CALL BOSDEC(5,ILOADX,INDIC)      <---- added by GENOPT user
      CALL B4READ                      <---- added by GENOPT user
      CALL GASP (DUM1,DUM2,-2,DUM3)    <---- added by GENOPT user
```

```
      GRAVTY = 386.4                    <---- added by GENOPT user
      WEIGHT = GRAVTY*TOTMAS            <---- added by GENOPT user
C
C=========================================================================
C  Start of the final portion of STRUCT written by "GENTEXT"
C
C  INSERT THE PROGRAM FILE HERE:
C
C  Behavior and constraints generated next for STRESS:
C  STRESS = Maximum effective stress in wall of shell
C
       PHRASE =
     1 'Maximum effective stress in wall of shell'
       CALL BLANKX(PHRASE,IENDP4)
       IF (IBEHV(1  ).EQ.0) CALL BEHX1  (IFILE8,NPRINX,IMODX, ILOADX  ,
     1 'Maximum effective stress in wall of shell')
       IF (STRESS(ILOADX  ).EQ.0.)  STRESS(ILOADX  ) = 1.E-10
       IF (STRSSA(ILOADX  ).EQ.0.)  STRSSA(ILOADX  ) = 1.0
       IF (STRSSF(ILOADX  ).EQ.0.)  STRSSF(ILOADX  ) = 1.0
       KCONX = KCONX + 1
       CARX(KCONX) =STRESS(ILOADX  )
       WORDCX= '(STRESS('//CIX//')/STRSSA('//CIX//
     1  ')) X STRSSF('//CIX//')'
       CALL CONX(STRESS(ILOADX  ),STRSSA(ILOADX  ),STRSSF(ILOADX  )
     1,'Maximum effective stress in wall of shell',
     1 'Maximum allowable stress',
     1 'Factor of safety for stress',
     1 1,INUMTT,IMODX,CONMAX,ICONSX,IPOINC,CONSTX,WORDCX,
     1 WORDMX,PCWORD,CPLOTX,ICARX)
       IF (IMODX.EQ.0) THEN
          CODPHR =
     1 '  Maximum effective stress in wall of shell: '
          IENDP4 =45
          CODNAM ='STRESS('//CIX//')'
          MLET4 =6 + 4
          WORDBX(KCONX)= CODPHR(1:IENDP4)//CODNAM(1:MLET4)
          IF (NPRINX.GT.0) WRITE(IFILE8,'(I5,6X,G14.7,A,A)')
     1     KCONX,CARX(KCONX),CODPHR(1:IENDP4),CODNAM(1:MLET4)
       ENDIF
   70 CONTINUE
   71 CONTINUE
C
C  Behavior and constraints generated next for BSYM:
C  BSYM = Symmetric buckling load factor
C
       PHRASE =
     1 'Symmetric buckling load factor'
       CALL BLANKX(PHRASE,IENDP4)
       IF (IBEHV(2  ).EQ.0) CALL BEHX2  (IFILE8,NPRINX,IMODX, ILOADX  ,
     1 'Symmetric buckling load factor')
       IF (BSYM(ILOADX  ).EQ.0.)  BSYM(ILOADX  ) = 1.E+10
       IF (BSYMA(ILOADX  ).EQ.0.)  BSYMA(ILOADX  ) = 1.0
       IF (BSYMF(ILOADX  ).EQ.0.)  BSYMF(ILOADX  ) = 1.0
       KCONX = KCONX + 1
       CARX(KCONX) =BSYM(ILOADX  )
       WORDCX= '(BSYM('//CIX//')/BSYMA('//CIX//
     1  ')) / BSYMF('//CIX//')'
       CALL CONX(BSYM(ILOADX  ),BSYMA(ILOADX  ),BSYMF(ILOADX  )
     1,'Symmetric buckling load factor',
     1 'Allowable for sym. buckling load factor',
     1 'Factor of safety for sym. buckling load',
     1 2,INUMTT,IMODX,CONMAX,ICONSX,IPOINC,CONSTX,WORDCX,
```

```
     1 WORDMX,PCWORD,CPLOTX,ICARX)
      IF (IMODX.EQ.0) THEN
         CODPHR =
     1 '  Symmetric buckling load factor: '
         IENDP4 =34
         CODNAM ='BSYM('//CIX//')'
         MLET4 =4 + 4
         WORDBX(KCONX)= CODPHR(1:IENDP4)//CODNAM(1:MLET4)
         IF (NPRINX.GT.0) WRITE(IFILE8,'(I5,6X,G14.7,A,A)')
     1    KCONX,CARX(KCONX),CODPHR(1:IENDP4),CODNAM(1:MLET4)
      ENDIF
   85 CONTINUE
   86 CONTINUE
C
C  Behavior and constraints generated next for BANTI:
C  BANTI = Antisymmetric buckling load factor
C
      PHRASE =
     1 'Antisymmetric buckling load factor'
      CALL BLANKX(PHRASE,IENDP4)
      IF (IBEHV(3  ).EQ.0) CALL BEHX3  (IFILE8,NPRINX,IMODX, ILOADX  ,
     1 'Antisymmetric buckling load factor')
      IF (BANTI(ILOADX  ).EQ.0.)  BANTI(ILOADX  ) = 1.E+10
      IF (BANTIA(ILOADX  ).EQ.0.)  BANTIA(ILOADX  ) = 1.0
      IF (BANTIF(ILOADX  ).EQ.0.)  BANTIF(ILOADX  ) = 1.0
      KCONX = KCONX + 1
      CARX(KCONX) =BANTI(ILOADX  )
      WORDCX= '(BANTI('//CIX//')/BANTIA('//CIX//
     1  ')) / BANTIF('//CIX//')'
      CALL CONX(BANTI(ILOADX  ),BANTIA(ILOADX  ),BANTIF(ILOADX  )
     1,'Antisymmetric buckling load factor',
     1 'Allowable for antisym. buckling load factor',
     1 'Factor of safety for antisym. buckling load',
     1 2,INUMTT,IMODX,CONMAX,ICONSX,IPOINC,CONSTX,WORDCX,
     1 WORDMX,PCWORD,CPLOTX,ICARX)
      IF (IMODX.EQ.0) THEN
         CODPHR =
     1 '  Antisymmetric buckling load factor: '
         IENDP4 =38
         CODNAM ='BANTI('//CIX//')'
         MLET4 =5 + 4
         WORDBX(KCONX)= CODPHR(1:IENDP4)//CODNAM(1:MLET4)
         IF (NPRINX.GT.0) WRITE(IFILE8,'(I5,6X,G14.7,A,A)')
     1    KCONX,CARX(KCONX),CODPHR(1:IENDP4),CODNAM(1:MLET4)
      ENDIF
  100 CONTINUE
  101 CONTINUE
C
C  Behavior and constraints generated next for FREQ:
C  FREQ = Fundamental modal frequency (hertz)
C
      PHRASE =
     1 'Fundamental modal frequency (hertz)'
      CALL BLANKX(PHRASE,IENDP4)
      IF (IBEHV(4  ).EQ.0) CALL BEHX4  (IFILE8,NPRINX,IMODX, ILOADX  ,
     1 'Fundamental modal frequency (hertz)')
      IF (FREQ(ILOADX  ).EQ.0.)  FREQ(ILOADX  ) = 1.E+10
      IF (FREQA(ILOADX  ).EQ.0.)  FREQA(ILOADX  ) = 1.0
      IF (FREQF(ILOADX  ).EQ.0.)  FREQF(ILOADX  ) = 1.0
      KCONX = KCONX + 1
      CARX(KCONX) =FREQ(ILOADX  )
      WORDCX= '(FREQ('//CIX//')/FREQA('//CIX//
```

```
     1  ')) / FREQF('//CIX//')'
      CALL CONX(FREQ(ILOADX  ),FREQA(ILOADX  ),FREQF(ILOADX  )
     1,'Fundamental modal frequency (hertz)',
     1 'Allowable for modal frequency',
     1 'Factor of safety for modal frequency',
     1 2,INUMTT,IMODX,CONMAX,ICONSX,IPOINC,CONSTX,WORDCX,
     1 WORDMX,PCWORD,CPLOTX,ICARX)
      IF (IMODX.EQ.0) THEN
         CODPHR =
     1 '  Fundamental modal frequency (hertz): '
         IENDP4 =39
         CODNAM ='FREQ('//CIX//')'
         MLET4 =4 + 4
         WORDBX(KCONX)= CODPHR(1:IENDP4)//CODNAM(1:MLET4)
         IF (NPRINX.GT.0) WRITE(IFILE8,'(I5,6X,G14.7,A,A)')
     1    KCONX,CARX(KCONX),CODPHR(1:IENDP4),CODNAM(1:MLET4)
      ENDIF
  115 CONTINUE
  116 CONTINUE
C
C  NEXT, EVALUATE THE OBJECTIVE, OBJGEN:
      IF (ILOADX.EQ.1) THEN
         PHRASE ='weight of half of cyl. shell'
         CALL BLANKX(PHRASE,IENDP4)
         CALL OBJECT(IFILE8,NPRINX,IMODX,OBJGEN,
     1    'weight of half of cyl. shell')
      ENDIF
      NCONSX = ICONSX
C
      CALL CLSGEN <---- Added by GENOPT user
C
      RETURN
      END
C
C  End of the final portion of STRUCT written by "GENTEXT"
C=========================================================================
```

Table A.6 BEHAVIOR.NEW. The "skeleton" routines are generated by GENOPT
and they are "fleshed out" by the GENOPT user

```
===================================================================
C=DECK      BEHAVIOR.NEW
C  This library contains the skeletons of
C  subroutines called SUBROUTINE BEHXn, n = 1,
C  2, 3, . . . that will yield predictions
C  of behavioral responses of various systems
C  to environments (loads).

  (lines omitted to save space. See Ref.[2]).

C=DECK      BEHX1
      SUBROUTINE BEHX1  (IFILE,NPRINX,IMODX,ILOADX,PHRASE)
C
C   PURPOSE: OBTAIN Maximum effective stress in wall of shell
C
C   YOU MUST WRITE CODE THAT, USING
C   THE VARIABLES IN THE LABELLED
C   COMMON BLOCKS AS INPUT, ULTIMATELY
C   YIELDS THE RESPONSE VARIABLE FOR
C   THE ith LOAD CASE, ILOADX:
C
C     STRESS(ILOADX)
C
C   AS OUTPUT. THE ith CASE REFERS
C   TO ith ENVIRONMENT (e.g. load com-
C   bination).
C
C   DEFINITIONS OF INPUT DATA:
C    IMODX  = DESIGN CONTROL INTEGER:
C     IMODX = 0 MEANS BASELINE DESIGN
C     IMODX = 1 MEANS PERTURBED DESIGN
C    IFILE = FILE FOR OUTPUT LIST:
C    NPRINX= OUTPUT CONTROL INTEGER:
C     NPRINX=0 MEANS SMALLEST AMOUNT
C     NPRINX=1 MEANS MEDIUM AMOUNT
C     NPRINX=2 MEANS LOTS OF OUTPUT
C
C     ILOADX = ith LOADING COMBINATION
C     PHRASE = Maximum effective stress in wall of shell
C
C   OUTPUT:
C
C     STRESS(ILOADX)
C
      CHARACTER*80 PHRASE
C  INSERT ADDITIONAL COMMON BLOCKS: (This is automatically done by GENOPT)
      COMMON/FV07/NX(20)
      REAL NX
      COMMON/FV11/STRESS(20),STRSSA(20),STRSSF(20)
      REAL STRESS,STRSSA,STRSSF
      COMMON/FV14/BSYM(20),BSYMA(20),BSYMF(20)
      REAL BSYM,BSYMA,BSYMF
      COMMON/FV17/BANTI(20),BANTIA(20),BANTIF(20)
      REAL BANTI,BANTIA,BANTIF
      COMMON/FV20/FREQ(20),FREQA(20),FREQF(20)
      REAL FREQ,FREQA,FREQF
      COMMON/IV01/IBOUND
      INTEGER IBOUND
      COMMON/FV01/LENGTH,RADIUS,THICK,ESTIFF,NU,DENS,WEIGHT
      REAL LENGTH,RADIUS,THICK,ESTIFF,NU,DENS,WEIGHT
```

```
      COMMON/FV08/PRESS(20)
      REAL PRESS
C
C
C  INSERT SUBROUTINE STATEMENTS HERE.   (The GENOPT user added the following)
C
      COMMON/INSTAB/INDIC
      COMMON/ENDUVX/ENDUV,STRMAX,ARCLEN (STRMAX is computed in B4POST)
C
      INDIC = 0
      CALL BOSDEC(1,ILOADX,INDIC)
      CALL B4READ
      CALL B4MAIN
      CALL B4POST
      CALL GASP(DUM1, DUM2, -2, DUM3)    (GENOPT user has to reset GASP)
      STRESS(ILOADX) = STRMAX            (STRMAX is computed in B4POST)
      WRITE(IFILE,'(A,1P,E12.4)')
     1' Maximum effective stress from BEHX1: STRESS=',STRMAX
                                   (End of the GENOPT user's statements)
C
C
      RETURN
      END
C
C
C
C
C=DECK      BEHX2
      SUBROUTINE BEHX2   (IFILE,NPRINX,IMODX,ILOADX,PHRASE)
C
C   PURPOSE: OBTAIN Symmetric buckling load factor
C
C   YOU MUST WRITE CODE THAT, USING
C   THE VARIABLES IN THE LABELLED
C   COMMON BLOCKS AS INPUT, ULTIMATELY
C   YIELDS THE RESPONSE VARIABLE FOR
C   THE ith LOAD CASE, ILOADX:
C
C     BSYM(ILOADX)
C
C   AS OUTPUT. THE ith CASE REFERS
C   TO ith ENVIRONMENT (e.g. load com-
C   bination).
C
C   DEFINITIONS OF INPUT DATA:
C    IMODX  = DESIGN CONTROL INTEGER:
C     IMODX = 0 MEANS BASELINE DESIGN
C     IMODX = 1 MEANS PERTURBED DESIGN
C    IFILE = FILE FOR OUTPUT LIST:
C    NPRINX= OUTPUT CONTROL INTEGER:
C     NPRINX=0 MEANS SMALLEST AMOUNT
C     NPRINX=1 MEANS MEDIUM AMOUNT
C     NPRINX=2 MEANS LOTS OF OUTPUT
C
C     ILOADX = ith LOADING COMBINATION
C     PHRASE = Symmetric buckling load factor
C
C   OUTPUT:
C
C     BSYM(ILOADX)
C
      CHARACTER*80 PHRASE
C  INSERT ADDITIONAL COMMON BLOCKS:(This is automatically done by GENOPT)
```

```
      COMMON/FV07/NX(20)
      REAL NX
      COMMON/FV11/STRESS(20),STRSSA(20),STRSSF(20)
      REAL STRESS,STRSSA,STRSSF
      COMMON/FV14/BSYM(20),BSYMA(20),BSYMF(20)
      REAL BSYM,BSYMA,BSYMF
      COMMON/FV17/BANTI(20),BANTIA(20),BANTIF(20)
      REAL BANTI,BANTIA,BANTIF
      COMMON/FV20/FREQ(20),FREQA(20),FREQF(20)
      REAL FREQ,FREQA,FREQF
      COMMON/IV01/IBOUND
      INTEGER IBOUND
      COMMON/FV01/LENGTH,RADIUS,THICK,ESTIFF,NU,DENS,WEIGHT
      REAL LENGTH,RADIUS,THICK,ESTIFF,NU,DENS,WEIGHT
      COMMON/FV08/PRESS(20)
      REAL PRESS
C
C
C   INSERT SUBROUTINE STATEMENTS HERE.   (The GENOPT user added the following)
C
      COMMON/INSTAB/INDIC
      COMMON/EIGB4M/EIGCOM(200),IWAVEB   (These are computed in B4MAIN)
      COMMON/WVEB4M/NWVCOM(200)          (This is computed in B4MAIN))
      COMMON/EIGBUK/EIGCRT               (This is computed in B4MAIN)
      COMMON/NWVBUK/NWVCRT               (This is computed in B4MAIN)
      COMMON/BUCKN/N0BX,NMINBX,NMAXBX,INCRBX  (These are used in B4MAIN)
      COMMON/PRMOUT/IFILE3,IFILE4,IFILE8,IFILE9,IFIL11
      COMMON/EIGALL/EIG2,EIG3,EIG4
      COMMON/WAVALL/NWAV2,NWAV3,NWAV4    (These must be saved for perturbation)
C
      INDIC = 1
      N0B = 2
      NMAXB = 10
      CALL BOSDEC(2,ILOADX,INDIC)
      CALL B4READ
      IF (IMODX.EQ.0) THEN          (IMODX = 0 means "current design")
         N0BX = N0B
         NMINBX = N0B
         NMAXBX = NMAXB
         INCRBX = 1
      ELSE                          (IMODX = 1 means "perturbed design")
         NOBX = NWAV2               (lots of computer time is saved by
         NMINBX = NWAV2              not searching over a range of circ.
         NMAXBX = NWAV2              waves for the perturbed design, which
         INCRBX = 1                  is very close to the current design.)
      ENDIF
      REWIND IFILE9
      CALL STOCM1(IFILE9)           (STOCM1, STOCM2 are called to get the
      CALL STOCM2(IFILE9)            correct values of N0BX,..in common)
      CALL B4MAIN
      CALL GASP(DUM1,DUM2,-2,DUM3)    (GENOPT user has to reset GASP)
      IF (IMODX.EQ.0) THEN          (IMODX = 0 means "current design")
         EIG2 = EIGCRT
         NWAV2= NWVCRT
      ENDIF
      WRITE(IFILE,'(/,A)')
     1 ' SYMMETRIC BUCKLING LOAD FACTORS AND MODES (BEHX2)'
      DO 10 I = 1,IWAVEB
         WRITE(IFILE,'(A,1P,E12.4,A,I4,A)')
     1  '       ',EIGCOM(I),'(',NWVCOM(I),')'
   10 CONTINUE
      WRITE(IFILE,'(A,1P,E12.4)')
```

```
     1' Critical buckling load factor, BSYM=',EIGCRT
      WRITE(IFILE,'(A,I5)')
     1' Critical number of circumferential waves, NWVCRT=',NWVCRT
      BSYM(ILOADX) = EIGCRT
                                       (End of the GENOPT user's statements)
C
C
      RETURN
      END
C
C
C
C
C=DECK      BEHX3
      SUBROUTINE BEHX3  (IFILE,NPRINX,IMODX,ILOADX,PHRASE)
C
C   PURPOSE: OBTAIN Antisymmetric buckling load factor
C
C   YOU MUST WRITE CODE THAT, USING
C   THE VARIABLES IN THE LABELLED
C   COMMON BLOCKS AS INPUT, ULTIMATELY
C   YIELDS THE RESPONSE VARIABLE FOR
C   THE ith LOAD CASE, ILOADX:
C
C     BANTI(ILOADX)
C
C   AS OUTPUT. THE ith CASE REFERS
C   TO ith ENVIRONMENT (e.g. load com-
C   bination).
C
C   DEFINITIONS OF INPUT DATA:
C    IMODX   = DESIGN CONTROL INTEGER:
C     IMODX = 0 MEANS BASELINE DESIGN
C     IMODX = 1 MEANS PERTURBED DESIGN
C    IFILE = FILE FOR OUTPUT LIST:
C    NPRINX= OUTPUT CONTROL INTEGER:
C     NPRINX=0 MEANS SMALLEST AMOUNT
C     NPRINX=1 MEANS MEDIUM AMOUNT
C     NPRINX=2 MEANS LOTS OF OUTPUT
C
C     ILOADX = ith LOADING COMBINATION
C     PHRASE = Antisymmetric buckling load factor
C
C   OUTPUT:
C
C     BANTI(ILOADX)
C
      CHARACTER*80 PHRASE
C  INSERT ADDITIONAL COMMON BLOCKS:(This is automatically done by GENOPT)
      COMMON/FV07/NX(20)
      REAL NX
      COMMON/FV11/STRESS(20),STRSSA(20),STRSSF(20)
      REAL STRESS,STRSSA,STRSSF
      COMMON/FV14/BSYM(20),BSYMA(20),BSYMF(20)
      REAL BSYM,BSYMA,BSYMF
      COMMON/FV17/BANTI(20),BANTIA(20),BANTIF(20)
      REAL BANTI,BANTIA,BANTIF
      COMMON/FV20/FREQ(20),FREQA(20),FREQF(20)
      REAL FREQ,FREQA,FREQF
      COMMON/IV01/IBOUND
      INTEGER IBOUND
      COMMON/FV01/LENGTH,RADIUS,THICK,ESTIFF,NU,DENS,WEIGHT
      REAL LENGTH,RADIUS,THICK,ESTIFF,NU,DENS,WEIGHT
```

```
      COMMON/FV08/PRESS(20)
      REAL PRESS
C
C
C  INSERT SUBROUTINE STATEMENTS HERE.    (The GENOPT user added the following)
C
      COMMON/INSTAB/INDIC
      COMMON/EIGB4M/EIGCOM(200),IWAVEB  (These are computed in B4MAIN)
      COMMON/WVEB4M/NWVCOM(200)         (This is computed in B4MAIN)
      COMMON/EIGBUK/EIGCRT              (This is computed in B4MAIN)
      COMMON/NWVBUK/NWVCRT              (This is computed in B4MAIN)
      COMMON/BUCKN/N0BX,NMINBX,NMAXBX,INCRBX  (These are used in B4MAIN)
      COMMON/PRMOUT/IFILE3,IFILE4,IFILE8,IFILE9,IFIL11
      COMMON/EIGALL/EIG2,EIG3,EIG4
      COMMON/WAVALL/NWAV2,NWAV3,NWAV4   (These must be saved for perturbation)
C
      INDIC = 1
      N0B = 2
      NMAXB = 15
      CALL BOSDEC(3,ILOADX,INDIC)
      CALL B4READ
      IF (IMODX.EQ.0) THEN          (IMODX = 0 means "current design")
         N0BX = N0B
         NMINBX = N0B
         NMAXBX = NMAXB
         INCRBX = 1
      ELSE                          (IMODX = 1 means "perturbed design")
         NOBX = NWAV3
         NMINBX = NWAV3
         NMAXBX = NWAV3
         INCRBX = 1
      ENDIF
      REWIND IFILE9
      CALL STOCM1(IFILE9)
      CALL STOCM2(IFILE9)
      CALL B4MAIN
      CALL GASP(DUM1,DUM2,-2,DUM3)   (GENOPT user has to reset GASP)
      IF (IMODX.EQ.0) THEN          (IMODX = 0 means "current design")
         EIG3 = EIGCRT
         NWAV3= NWVCRT
      ENDIF
      WRITE(IFILE,'(/,A)')
     1 ' ANTISYMMETRIC BUCKLING LOAD FACTORS AND MODES (BEHX3)'
      DO 10 I = 1,IWAVEB
         WRITE(IFILE,'(A,1P,E12.4,A,I4,A)')
     1  '        ',EIGCOM(I),'(',NWVCOM(I),')'
   10 CONTINUE
      WRITE(IFILE,'(A,1P,E12.4)')
     1' Critical buckling load factor, BANTI=',EIGCRT
      WRITE(IFILE,'(A,I5)')
     1' Critical number of circumferential waves, NWVCRT=',NWVCRT
      BANTI(ILOADX) = EIGCRT
C                                   (End of the GENOPT user's statements)
C
      RETURN
      END
C
C
C
C=DECK      BEHX4
      SUBROUTINE BEHX4   (IFILE,NPRINX,IMODX,ILOADX,PHRASE)
C
```