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January 14, 1982

National Aeronautics and Space Administration
George C. Marshall Space Flight Center
Huntsville, AL 35812

Attention: Mr. L. A. Kiefling, ED23

Subject: NAS8-32664 Final Report

Gentlemen:

This letter, together with the three enclosed reports, comprise the final report for the subject contract.

The enclosed reports, which were transmitted individually to MSFC in 3/80, 2/81, and 12/81, describe in detail the software developed under the contract and delivered to MSFC.

Sincerely,
Engineering Information Systems, Inc.

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W. D. Whetstone
President

Enclosures:

1- SPAR Reference Manual Update, Revision 4 to EISI/A2200, 3/80

2- Procedures for Cyclically Symmetrical Structures, EISI TR 4012.80-1, 2/81

3- Macroelement Procedures, EISI TR 4012.60-1, 12/81

N82-17520 #

MARCH 1980

Revision 4 to:
EISI/A2200

SPAR Reference Manual Update

SPAR Level 15

Prepared Under

NASA/MSFC Contract NAS8-32664

by

W. D. Whetstone

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PREFACE

This document was prepared by Engineering Information Systems, Inc., for the George C. Marshall Space Flight Center of the National Aeronautics and Space Administration, under contract NAS8-32664. The Contracting Officer's Technical Representative was Mr. L. A. Kiefling.

The enclosed subsections and individual pages replace the corresponding portions of the preceeding version of the SPAR Reference Manual.

Submitted by:

Engineering Information Systems, Inc.

W. D. Whetstone
President

CONTENTS

Section

TABLE 1-1: SPAR Element Repertoire.

Name	Description	See Volume 1 Sections:
E21	General straight or curved beam elements, e.g. channels, wide-flanges, angles, tubes, zees.	3.1.7 - 9
E22	Beams for which the intrinsic stiffness matrix is given.	3.1.10
E23	Bar - Axial stiffness only.	3.1.11
E24	Plane beam.	3.1.12
E25	Zero-length element used to elastically connect geometrically coincident joints.	3.1.10
	Two-dimensional (area) elements:	3.1.13
E31	Triangular membrane.	
E32	Triangular plate.	
E33	Triangular combined membrane and bending element.	
E41	Quadrilateral membrane.	
E42	Quadrilateral plate.	
E43	Quadrilateral combined membrane and bending element.	
E44	Quadrilateral shear panel.	3.1.14
	Three-dimensional solids:	3.2.2.3
S41	Tetrahedron (pyramid).	
S61	Pentahedron (wedge).	
S81	Hexahedron (brick).	
	Compressible fluid elements:	12., 3.2.2.3
F41	Tetrahedron (pyramid).	
F61	Pentahedron (wedge).	
F81	Hexahedron (brick).	

Notes:

- See Section 7.2 for examples of stress output.
- See Volume 2 (Theory) for element formulation details.
- Aeolotropic constitutive relations permitted, all area elements.
- Laminated cross sections permitted for E33, E43.
- Membrane/bending coupling permitted for E33, E43.
- E41, E42, E43, E44 may be warped.
- Aeolotropic constitutive relations permitted for 3-D solids.
- Non-structural mass permitted for line and area elements.

3.1.9 E21 SECTION PROPERTIES (BA)

Element type E21 is a general family of either straight or curved beam elements. E21 element formulation details are discussed in Section A of Volume 2.

BA is used to create tables of E21 section properties. When E21 elements are defined using processor ELD, references to entries in this table are made using the NSECT table pointer.

Nine different types of cross-section input are provided. The first word in each input record identifies the cross-section type, e.g. TUBE. A single input record defines one section, except for section type DSY, which requires two records. Data sequences for individual types of cross-sections are indicated below.

BOX	$k,\ b_1, t_1,\ b_2, t_2$	
TEE	$k,\ b_1, t_1,\ b_2, t_2$	
ANG	$k,\ b_1, t_1,\ b_2, t_2$	
WFL	$k,\ b_1, t_1,\ b_2, t_2,\ b_3, t_3$	
CHN	$k,\ b_1, t_1,\ b_2, t_2,\ b_3, t_3$	
ZEE	$k,\ b_1, t_1,\ b_2, t_2,\ b_3, t_3$	
TUBE	k, inner radius, outer radius	
GIVN	$k,\ I_1,\ \alpha_1,\ I_2,\ \alpha_2,\ a_c,\ f,\ f_1,\ z_1,\ z_2,\ \theta$	
DSY	$k,\ I_1,\ \alpha_1,\ I_2,\ \alpha_2,\ a_c,\ f,\ f_1$	(card 1)
	$q_1,\ q_2,\ q_3,\ y_{11},\ y_{12},\ - - -\ y_{41},\ y_{42}$	(card 2)

In the above, k identifies the table entry number. The b's and t's are cross-section dimensions defined on Figure BA-1. In all cases the origin and terminus of the beam (see discussions of MREF, BRL, and ELD) coincide with the section centroid. For GIVN and DSY sections,

I_1, I_2	Principal moments of inertia. For DSY sections, principal axes must coincide with the element reference frame axes.
α_1, α_2	Transverse shear deflection constants associated with I_1 and I_2, respectively. For no shear deflection, set α_i equal to zero.
a_c	Cross-sectional area.

Circled numbers identify locations where bending stresses are evaluated.

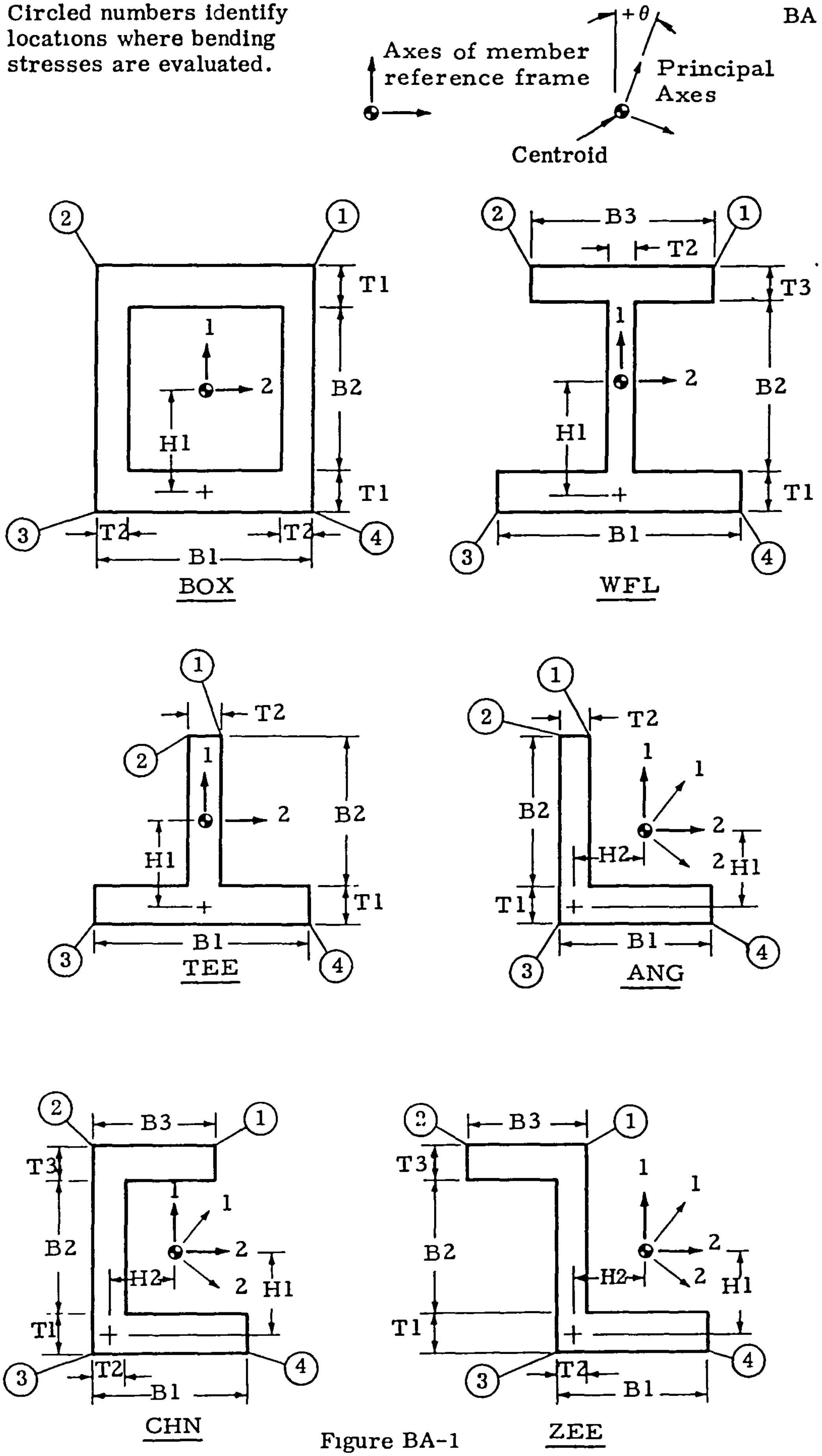


Figure BA-1

f	Uniform torsion constant.* For uniform torsion, torque = Gf x (twist angle/unit length), where G is the shear modulus.
f_1	Nonuniform torsion constant,* accounting for flange-bending effects on torsional stiffness, etc.
z_1, z_2	Shear center - centroid offsets.
θ	Inclination of principal axes relative to the element reference frame (see Figure BA-1). θ is in radians.

Use of section properties in computing element stiffness matrices is discussed in Volume 2. Items on the second card defining DSY sections are used by the program to compute stresses, as indicated below:

S1= $V_1 q_1$ = Transverse shear stress, direction 1.

S2= $V_2 q_2$ = Transverse shear stress, direction 2.

TWIST= $T\ q_3$ = Twisting shear stress.

Combined axial+ bending stress at point i= $P/a_c + M_2\ Y_{i1}/I_2 - M_1\ Y_{i2}/I_1$

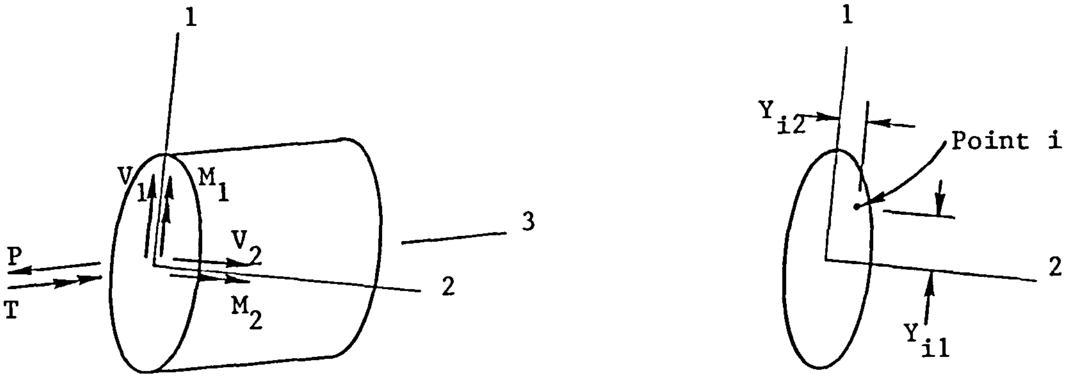


Figure BA-2

Combined stresses for curved beams may be computed by an alternate method which is discussed subsequently.

---

*In the notation of Volume 2, Section A,
$C = Gf$, and
$C_1 = Ef_1$

Curved Beams. E21 elements having DSY type cross-sections may be circularly curved, as shown on Figure BA-3. Ordinary curved beam theory[1], extended to include transverse shear deformation and torsion, is used to construct the elastic stiffness matrices of curved beams. The centerline of a curved E21 element lies in the element 1/3 plane, as shown on Figure BA-3, so that I_2 and α_2 establish flexural stiffness characteristics for bending in the plane of initial curvature. The input convention for curved beams is intended to give the user the opportunity to choose the basis of (1) reducing effective moments of inertia, and (2) stress recovery coefficients. The user must make any adjustments to I_2 necessary to account for reduced bending stiffness due to cross-section flattening.

The following commands are used to define curved beam attributes:

Command	Default Value	Meaning
R= r$	none	Radius - see Figure BA-3.
E= e$	.0	Centroid-neutral axis eccentricity[1]. Also see the subsequent discussion of stresses.
C= c$	1.0	See subsequent discussion of stresses.

When any of the above commands is given, the indicated attribute will apply to all DSY sections subsequently defined, until the attribute is redefined by another command. To indicate that subsequent sections are for straight beams, give the command STRAIGHT.

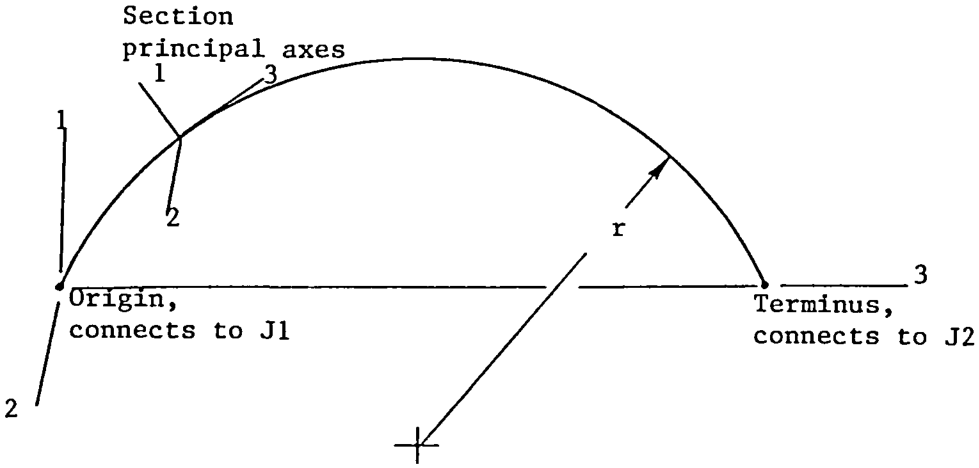


Figure BA-3

---

[1] Timoshenko, S. P., "Strength of Materials, Part 1", Ch. 12, pp 362-416. See the discussion at the end of this section concerning M and KG matrices.

Computation of flexural stresses in curved beams is based on the input values of r, e, and c, and the y_{ij}'s given on the second card defining the DSY section properties, as follows:

For point i, the combined direct + flexural stress, s_i, is:

$$s_i = \frac{P}{a_c} + c\,\frac{M_2}{a_c e}\,\frac{(Y_{i1} + e)}{(Y_{i1} + r)} - \frac{M_1\ Y_{i2}}{I_1} ,$$

unless e = .0, in which case

$$s_i = \frac{P}{a_c} + \frac{M_2\ Y_{i1}}{I_2} - \frac{M_1\ Y_{i2}}{I_1} .$$

M and KG terms associated with curved beams are handled as follows:

- In computing both consistent and diagonal system mass matrices, contributions of curved beams consist of two equal masses lumped at the connected joints.
- In KG, geometric stiffness matrix terms are computed as though the beam were straight.

6.1.6.1 Temperatures. The content of each entry (data column) within a TEMP Eij iset icase data set is described in this section.

- For E21, E22, E23, and E24 elements, each entry contains the following three words:

  $$T_a,\ T'_1,\ T'_2$$

  T_a is the average temperature of the element, and T'_1 and T'_2 are temperature gradients in directions 1 and 2, respectively, of the element reference frame.

  In the following, T_{j1} and T_{j2} are the nodal temperatures of joints j1 and j2 from block icase of NODAL TEMP iset, if present.

  The system assumes that the temperature along the element centerline is a constant, T, where

  $$T = T_a + \tfrac{1}{2}(T_{j1} + T_{j2}).$$

  If a rigid link connects joint j1 to the element origin, the temperature of the link is assumed to be a constant, T_{r1}, where

  $$T_{r1} = T_{j1} + T_a$$

  If a rigid link connects joint j2 to the terminus, the temperature of the link is assumed to be a constant, T_{r2}, where

  $$T_{r2} = T_{j2} + T_a$$

  The gradients, T'_1 and T'_2 apply only to the elastic part of the element, not to the rigid links. The rigid links are assumed to have the same thermal expansion coefficient as the elastic part of the element.

Example. Case 5 and 7 of set 48, type E21 elements.

```
@XQT AUS
-
-
ELDATA: TEMP E21 48
CASE 5
   G=4: E= 10, 20$               Elements 10 through 20 of group 4.
   100., 10., 20.$               T_a = 100., T_1' = 10., T_2' = 20.
CASE 7
   G=4: E=50$                    Element 50 of group 4.
   22., 1.5, 2.7$                T_a = 22., T_1' = 1.5, T_2' = 2.7.
   I=1$                          Following data records contain T_a only.
   G=4: E= 1, 5$
   1.2, 1.3, 1.4, 1.5, 1.6$      T_a's for elements 1-5 of group 4.
```

6.1.6.2 Dislocations (initial strains). Dislocational loading, which is similar to thermal loading, is used to describe situations in which element strains are not zero in the null structure. The term "null structure" indicates the state in which all joints are held motionless. Dislocations are the deformations an element would undergo if disconnected from the null structure, allowing it to assume a strain-free state.

The content of each entry (data column) within a DISL Eij <u>iset</u> <u>icase</u> data set is described below.

- For E21, E22, E23, E24, and E25 elements, each entry contains six words:

  $$d_1, d_2, d_3, r_1, r_2, r_3$$

  These quantities have the following interpretation. the d's and r's are displacements and rotations of the origin, relative to a reference frame, parallel to the member reference frame, embedded in the terminus.

  For example, thermal (TEMP) loading defined for a straight E21 element of length ℓ could also be modeled as dislocational (DISL) loading if the following values of the d's and r's were used:

  $$d_1 = -\alpha T_1' \frac{\ell^2}{2} \quad , \quad d_2 = -\alpha T_2' \frac{\ell^2}{2} \quad , \quad d_3 = -\alpha T_a \ell$$

  $$r_1 = -\alpha T_2' \ell \quad , \quad r_2 = \alpha T_1' \ell \quad , \quad r_3 = 0 .$$

<u>Example Input.</u> Case 7 of set 4, E21 elements:

```
@XQT AUS
      ELDATA: DISL  E21  4


      CASE 7
```

`G= 3 : E= 7$`	Element 7 of group 3.
`1.2, 1.5, 1.1, .01, .017, .18$`	$d_1, d_2, d_3, r_1, r_2, r_3$
`I= 1, 3, 6$`	Identify d_1, d_3, r_3
`G= 4:  E= 2,3$`	
`1.1, 4.2, .00817$`	Element 2, group 4.
`3.2, 6.7, .00903$`	Element 3, group 4.

Section 10

GRAPHICS

There are three graphics processors: PLTA, PLTB, and PXY. PLTA (Section 10.1) is a pre-processor for PLTB (Section 10.2) as shown on Figure 10-1. PXY, which is used independently, is described in Section 10.4. It is suggested that the new user examine the examples shown in Section 10.3 before reading 10.1 and 10.2.

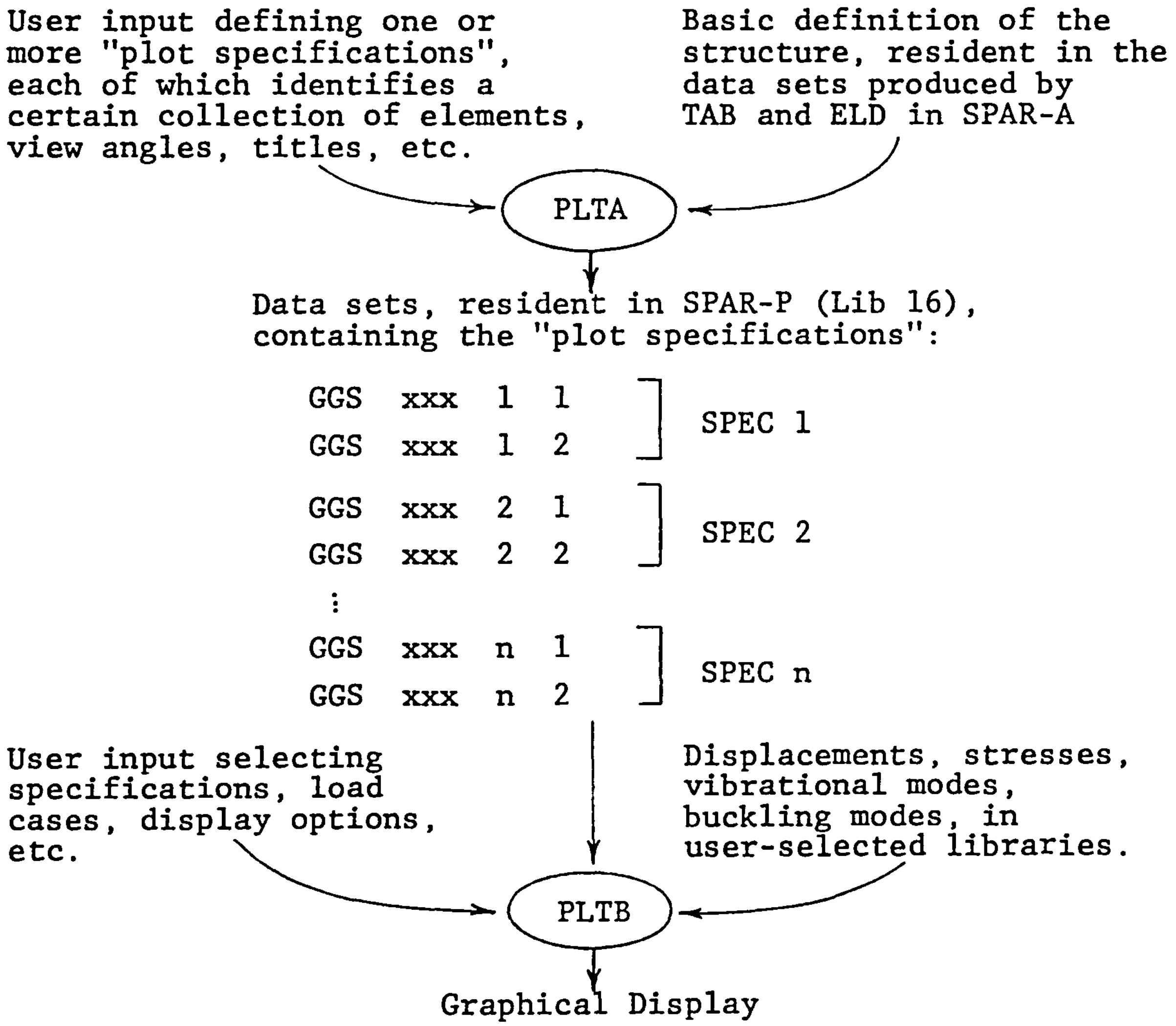


Fig. 10-1 PLTA - PLTB Data Exchange

10.3 EXAMPLES OF PLTA - PLTB EXECUTIONS

The examples on the following pages illustrate PLTA and PLTB command sequences used to produce typical kinds of graphical displays.

10.4 PXY - GENERAL PURPOSE GRAPHIC DISPLAY GENERATOR

10.4.1 Introduction and Command Summary. PXY is a general purpose processor for producing graphical displays. The user may compose very general forms of display of data which has previously been stored in data sets. One application is the production of x-y plots of transient response data. PXY commands fall in three categories:

Category 1: Through these preliminary commands, the user establishes the values of control parameters which determine the configuration and attributes of graphical displays which are subsequently produced as a result of Category 3 commands. Typical Category 1 commands establish the position of the plot on the screen, establish whether or not axes will be drawn, control axis tic-mark spacing, tic-mark numerals, and labelling, optionally establish manual or automatic scaling, select fonts, etc.

Category 2: These commands identify source data sets containing information to be displayed as a result of subsequent Category 3 commands.

Category 3: These commands cause curves, symbols, and/or alphanumeric text to be plotted.

The following is a summary of all the PXY commands, including alternate forms. Details are given in Section 10.4.2.

Section Reference	Figure Reference	Category 1, Preliminary Commands:
10.4.2.1	10.4-1	BOUNDARIES= h1, h2, v1, v2
10.4.2.2	10.4-1	XAXIS= NONE
"	"	XAXIS= ndigits, dxtic, mintics, maxtics
"	"	XAXIS= ndigits, mintics, maxtics
"	"	YAXIS= NONE
"	"	YAXIS= ndigits, dytic, mintics, maxtics
"	"	YAXIS= ndigits, mintics, maxtics
10.4.2.3	"	XLABEL' alphanumeric X axis label
"	"	YLABEL' alphanumeric Y axis label
"		
10.4.2.4		XLIMITS= NONE
"		XLIMITS= xleft, xright
"		YLIMITS= NONE
"		YLIMITS= ybottom, ytop

Section Reference	Category 1, Preliminary Commands (continued):
10.4.2.5	XYSCALE= AUTOMATIC
"	XYSCALE= rxy
10.4.2.6	FONT XNUMBERS= nfont
"	FONT YNUMBERS= nfont
"	FONT XLABEL= nfont
"	FONT YLABEL= nfont
"	FONT TEXT= nfont
"	FONT SYMBOL= nfont
10.4.2.9	RETAIN
10.4.2.12	TPOSITION

Section Reference	Category 2, Commands Which Identify Source Data Sets:
10.4.2.7	X= Lib N1 N2 n3 n4
"	Y= Lib N1 N2 n3 n4
"	TEXT= Lib N1 N2 n3 n4

Section Reference	Figure Reference	Category 3, Commands Which Cause Plots to be Displayed:
10.4.2.8		FLUSH
"		ADVANCE or CLEAR
10.4.2.9	10.4-1	INITIALIZE
10.4.2.10	10.4-2	PLOT CURVE
"	"	PLOT CURVE # n
10.4.2.11		PLOT CONSTANT X= x1, x2, x3, - - -
"		PLOT CONSTANT Y= y1, y2, y3, - - -
10.4.2.12	10.4-3	PLOT TEXT

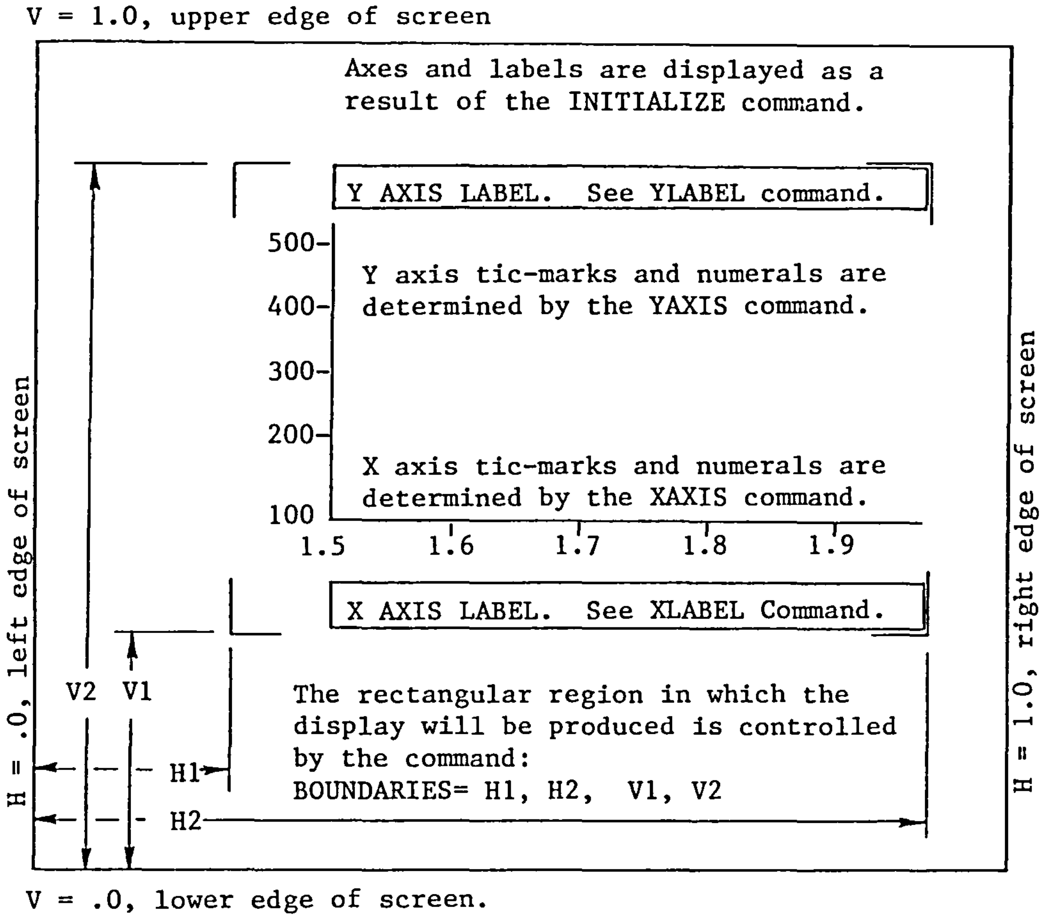


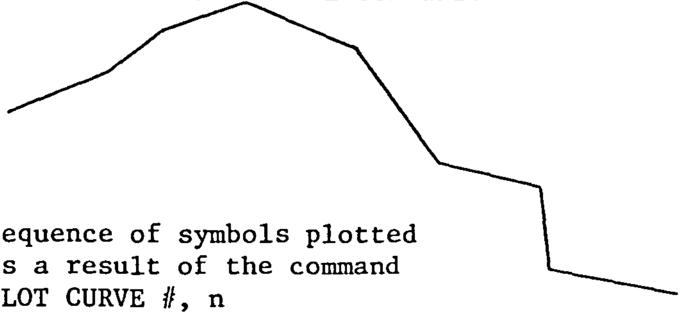
Figure 10.4-1: POSITIONING OF DISPLAYS, AND GRID CONFIGURATION.

The BOUNDARIES command may be used repeatedly to reposition the rectangular region within which curves and/or alphanumeric text are to be plotted using the PLOT commands illustrated on Figures 10.4-2 and 10.4-3. The axes and labels shown on Figure 10.4-1 need not be displayed unless required.

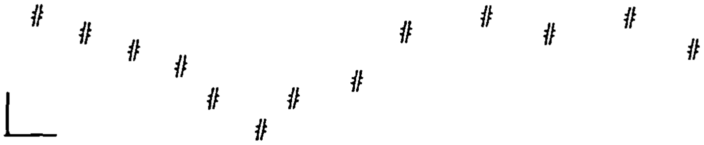
Scaling may be controlled directly through the XLIMIT, YLIMIT and XYSCALE commands, or the program will automatically determine scales based on the content of the arrays to be plotted.

An example is given in Section 10.4.6.

Sequence of line segments displayed as a result of a PLOT CURVE command:



Sequence of symbols plotted as a result of the command PLOT CURVE #, n



Alphanumeric text displayed as a result of a PLOT TEXT command.

10.4.2 Command Rules.

Details of all PXY commands are explained in the following subsections.

10.4.2.1 BOUNDARIES.

The form of this command is:

```
BOUNDARIES= h1, h2,  v1, v2
```

As illustrated on Figure 10.4-1, this command establishes the boundaries of a rectangular region on the screen within which curves, symbols, or alphanumeric text will be plotted as a result of subsequent commands. It is mandatory that

$$.0 \leq h1 < h2 \leq 1.0, \text{ and}$$
$$.0 \leq v1 < v2 \leq 1.0 \quad .$$

The default is a full screen display, BOUNDARIES= .0, 1., .0, 1.

10.4.2.2 XAXIS and YAXIS.

The XAXIS command controls the following (see Figure 10.4-2):

- whether or not the X axis will be displayed,
- X axis tic-mark spacing, if any, and
- the number of digits in the X axis tic-mark numerals, if any.

Three forms of the XAXIS command are permitted. If you do not want the X axis and associated tic-marks and tic-mark numerals to be displayed, the command XAXIS=NONE must be given.

In the following two forms of the XAXIS command, ndigits is the number of digits in the tic-mark numerals, mintics is the minimum number of tic-marks, and maxtics is the maximum number of tic-marks. To eliminate the numerals, set ndigits=0. To eliminate the tic-marks, set mintics=0 and maxtics=0.

If you want tic-marks to appear at equal intervals of dxtic, give the following command:

```
XAXIS= ndigits, dxtics, mintics, maxtics
```

If you wish to have tic-mark spacing determined automatically, give the following command:

```
XAXIS= ndigits, mintics, maxtics
```

The default is XAXIS= 2, 2, 5 (i.e. ndigits=2, mintics=2, and maxtics=5).

For the Y axis, the YAXIS command serves the same function as described above for the X axis.

10.4.2.3 XLABEL and YLABEL. Through these commands the user furnishes alphanumeric labels for the X and Y axes, to be positioned as shown on Figure 10.4-1. The commands are:

```
XLABEL' Text of alphanumeric label for the X axis.
YLABEL' Text of alphanumeric label for the Y axis.
```

If either command is omitted, the corresponding label will be omitted. If the label is too long to fit in the available space, it will be truncated.

The axis labels will not be displayed until the INITIALIZE command is given. See Section 10.4.2.9.

10.4.2.4 XLIMITS and YLIMITS. These commands control the values of x and y at the edges of the plot. By the "edges" of the plot, we mean the edges of the subspace remaining within the rectangular region defined by the BOUNDARIES command, reduced as necessary to accomodate the axes, tic-mark numerals, and labels, if present.

In the following, xleft and xright are the values of x at the edges of the plot, and ybottom and ytop are the edge values of y. To directly define the edge values of x and y, use the following commands:

```
XLIMITS= xleft, xright
YLIMITS= ybottom, ytop
```

To permit PXY to automatically determine the edge values based on the content of the X and Y arrays to be plotted, use the following commands:

```
XLIMITS= NONE
YLIMITS= NONE
```

The defaults are XLIMITS= NONE and YLIMITS= NONE.

10.4.2.5 XYSCALE. To cause the ratio of x scale to y scale to be rxy, give the following command:

```
XYSCALE= rxy
```

The XYSCALE command may cause adjustment to the plot edge coordinates as specified by XLIMIT and YLIMIT commands, if given, in order to keep the display within the available screen space. To revert to the default mode of operation of automatically determined x and y scaling, give the following command:

```
XYSCALE= AUTOMATIC
```

10.4.2.6 FONT. Depending upon the type of plotting device being used, and the host system graphics library, a variety of character fonts (size and shape) may be available. In the following commands, nfont is an integer designating a particular font. The default for all fonts is nfont= 1 (integer one). On systems where more than one font is available, successive values of nfont, i.e. 2, 3, - - - usually will indicate progressively larger character sizes. The commands are:

Command	Character Display Affected
FONT XNUMBERS=nfont	X axis tic-mark numbers
FONT YNUMBERS=nfont	Y axis tic-mark numbers
FONT XLABEL= nfont	X axis label
FONT YLABEL= nfont	Y axis label
FONT TEXT= nfont	Text plotted via PLOT TEXT
FONT SYMBOL= nfont	Characters plotted via PLOT CURVE # n

10.4.2.7 X, Y, and TEXT. In the following commands, default values of Lib, N2, n3, and n4 are 1, MASK, MASK, and MASK.

To identify a data set containing alphanumeric text to be displayed as a result of a subsequent PLOT TEXT command, give the following command:

TEXT= Lib N1 N2 n3 n4

To identify data sets containing x and y values to be plotted by subsequent PLOT CURVE commands, give the following commands:

X= Lib N1 N2 n3 n4
Y= Lib N1 N2 n3 n4

It is mandatory that the TOC parameter NI=1 for both X and Y. It is permissible for X and Y to have different NJ's, in which case the smaller NJ will determine the number of points to be plotted.

10.4.2.8 FLUSH, and ADVANCE or CLEAR. If plotting on a CRT device for which the host system is buffering the output, the command FLUSH will cause the buffer to be flushed, completing the screen display.

Either of the synonymous commands, ADVANCE or CLEAR, will cause the screen to be cleared (or frame advanced).

10.4.2.9 INITIALIZE, and RETAIN. The command INITIALIZE must be given before any PLOT CURVE commands are given. In the default mode the INITIALIZE command causes two actions:

1- Scaling will be established, based on (a) the current values of all of the Category 1 commands, and (b) the contents of the currently defined X and Y arrays.

2- The X and Y axes, tic-marks, tic-mark numerals, and X and Y axis labels will be displayed, if requested through prior Category 1 commands.

To inhibit redefinition of scale factors upon execution of subsequent INITIALIZE commands, give the command RETAIN=ON . To resume the default mode in which each INITIALIZE command results in scale factor determination, give the command RETAIN=OFF .

10.4.2.10 PLOT CURVE. The command,

```
PLOT CURVE
```

causes a sequence of straight line segments to be drawn, as illustrated on Figure 10.4-2, connecting successive (x,y) points established by the contents of the data sets identified by the last X= and Y= commands.

To cause the character #, or any other designated character, to be plotted on every n-th (x,y) point pair, give the following command:

```
PLOT CURVE #, n
```

10.4.2.11 PLOT CONSTANT. To cause vertical lines to be drawn at x1, x2, - - -, give the following command:

```
PLOT CONSTANT X= x1, x2, - - -
```

To cause horizontal lines to be drawn at y1, y2, - - -, give the following command:

```
PLOT CONSTANT Y= y1, y2, - - -
```

10.4.2.12 PLOT TEXT and TPOSITION. To cause the alphanumeric text contained in the data set identified by the last TEXT command to be displayed as indicated on Figure 10.4-3, give the command:

```
PLOT TEXT
```

The position of the text within the space designated by the preceding BOUNDARIES command may be controlled by preceding the PLOT TEXT command with the command:

```
TPOSITION= plateral, pvertical
```

Plateral values of -1, 0, and +1 indicate left, center, and right positioning, in that order.

Pvertical values of -1, 0, amd +1 indicate lower, center, and upper positioning, in that order.

The default is TPOSITION= 0, 0$.

10.4.3 Error Messages.

The following is a summary of the error messages produced by PXY.

NERR	NIND	Command, Error
EXPX	301	BOUNDARY, parameters not floating point number.
EXPX	302	" h2.LT.h1
EXPX	303	" v2.LT.v1
EXPX	621	XAXIS or YAXIS, ndigits not integer.
EXPX	622	" dxtic not floating point.
EXPX	631	" ndigits not integer.
EXPX	632	" mintics " "
EXPX	633	" maxtics " "
EXPX	801	XLIMITS or YLIMITS, syntax error.
EXPX	811	" xleft or ybottom not floating point.
EXPX	812	" xbottom or ytop " " "
EXPX	1101	XYSCALE, illegal syntax or rxy value.
EXPX	1201	TEXT, source data set unavailable.
EXPX	1301	TPOSITION, plateral not integer.
EXPX	1302	" pvertical " "
EXPX	1401	X or Y, source data set not available.
EXPX	1601	FONT, unknown font identifier.
EXPX	3004	INITIALIZE, FONT, illegal font code.
EXPX	3101	PLOT, Command syntax error.
EXPX	3201	PLOT CURVE, either X or Y not defined.
EXPX	3202	" " not preceded by INITIALIZE.
EXPX	3204	PLOT TEXT, FONT, illegal font code.
EXPX	3205	PLOT TEXT, POSITION, illegal plateral.
EXPX	3206	" " " pvertical.
EXPX	3241	PLOT CURVE # n, illegal font.

NERR	NIND	Command, Error (continued)
EXPX	3301	PLOT CONSTANT X or Y, no xi's or yi's.
EXPX	3302	" " illegal syntax.
EXPX	3303	" " some xi or yi not floating point.
EXPX	10000	Unrecognizable command.

10.4.4 Reset Controls.

No special RESET controls are provided.

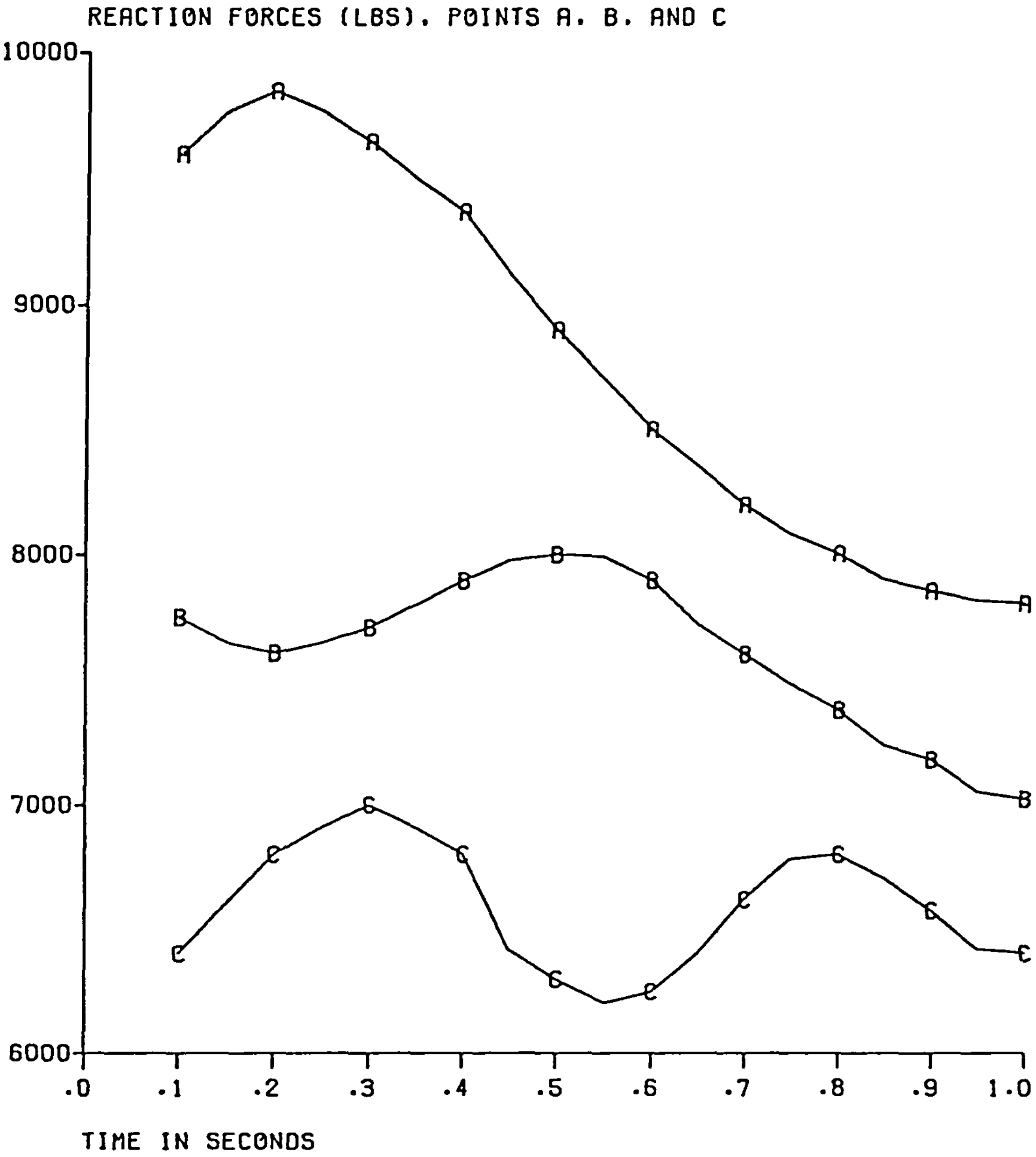
10.4.5 Central Memory Requirements.

PXY requires data space sufficient to simultaneously contain one block of each source data set currently being plotted, plus 1000 words.

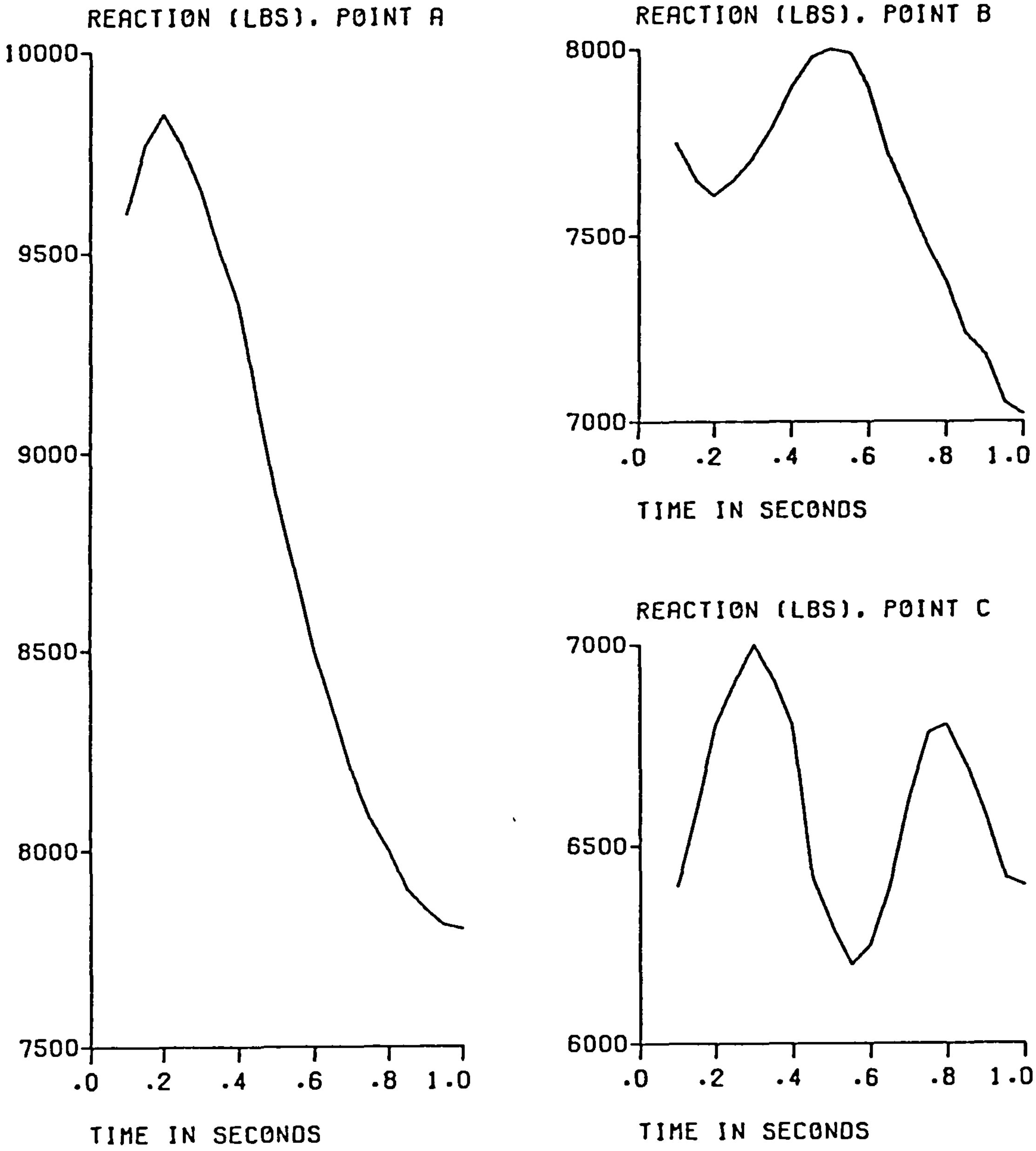
10.4.6 Example.

The following runstream was used to produce the plots shown on the next two pages.

```
@XQT AUS
$
$ CREATE DATA SETS NAMED TITLE, X, A, B, AND C TO BE USED AS
$ SOURCE DATA FOR THE EXAMPLE PXY DISPLAY:
$
 ALPHA: TITLE: 1'  RESPONSE TO BASE EXCITATION, CASE 407A
 TABLE(NI=1,NJ=19): X: DDATA=.05: J=1,19: .1
 TABLE(NI=1,NJ=19): A: J=1,19
  9600. 9770. 9850. 9770. 9650. 9500. 9370. 9120. 8900. 8700.
  8500. 8350. 8200. 8080. 8000. 7900. 7850. 7810. 7800.
 TABLE(NI=1,NJ=19): B: J=1,19
  7750. 7650. 7610. 7650. 7710. 7800. 7900. 7980. 8000. 7990.
  7900. 7720. 7600. 7480. 7380. 7240. 7180. 7050. 7020.
 TABLE(NI=1,NJ=19): C: J=1,19
  6400. 6600. 6800. 6910. 7000. 6910. 6800. 6420. 6300. 6200.
  6250. 6400. 6620. 6780. 6800. 6700. 6570. 6420. 6400.
$
@XQT PXY
$
$ CREATE A SINGLE FULL-PAGE PLOT WITH THREE CURVES ON ONE GRAPH:
$
 ADVANCE
 BOUNDARIES=.01 .99 .01 .2: TEXT=TITLE: PLOT TEXT
 BOUNDARIES=.01 .99 .2 .99: XAXIS=1 .1 11 11: YAXIS=5 1000. 5 5
 XLIMITS=0. 1.: YLIMITS=6000. 10000.
 XLABEL='TIME IN SECONDS
 YLABEL='REACTION FORCES (LBS), POINTS A, B, AND C
 X=X: Y=A: INITIALIZE: PLOT CURVE: PLOT CURVE A 2
      Y=B:             PLOT CURVE: PLOT CURVE B 2
      Y=C:             PLOT CURVE: PLOT CURVE C 2
$ FIRST PLOT FRAME COMPLETED
$
$ BEGIN SECOND PLOT, WHICH WILL CONTAIN THREE SEPARATE GRAPHS:
$
 ADVANCE
 XLIMITS=0. 1.: YLIMITS=NONE: X=X: XLABEL='TIME IN SECONDS
 BOUNDARIES=.01 .99 .01 .2: PLOT TEXT
 BOUNDARIES=.01 .48 .2 .99: XAXIS=1 .2 2 6: YAXIS=5 500. 2 10
    YLABEL='REACTION (LBS), POINT A
    Y=A: INITIALIZE: PLOT CURVE
 BOUNDARIES=.52 .99 .63 .99: YAXIS=4 500. 2 10
    YLABEL='REACTION (LBS), POINT B
    Y=B: INITIALIZE: PLOT CURVE
 BOUNDARIES=.52 .99 .2 .58
    YLABEL='REACTION (LBS), POINT C
    Y=C: INITIALIZE: PLOT CURVE
$ SECOND PLOT FRAME COMPLETED
```



RESPONSE TO BASE EXCITATION, CASE 407A



RESPONSE TO BASE EXCITATION, CASE 407A

EISI TR 4012.80-1

PROCEDURES FOR
CYCLICALLY SYMMETRICAL STRUCTURES

by

C. E. Jones

February 1981

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PREFACE

This report was prepared by Engineering Information Systems, Inc., for the George C. Marshall Space Flight Center of the National Aeronautics and Space Administration under contract NAS8-32664. The Contracting Officer's Technical Representative was Mr. L. A. Kiefling.

The cyclic symmetry procedures were designed jointly by W. D. Whetstone and C. E. Jones, and were prepared and tested by Dr. Jones.

Submitted by:

Engineering Information Systems, Inc.

W. D. Whetstone
President

TABLE OF CONTENTS

1. INTRODUCTION

EAL command runstream elements are presented for analyzing structural systems that are composed of a number of cyclically symmetrical sectors. Provisions are included for systems in which each cyclically symmetrical sector also possesses a plane of reflective symmetry.

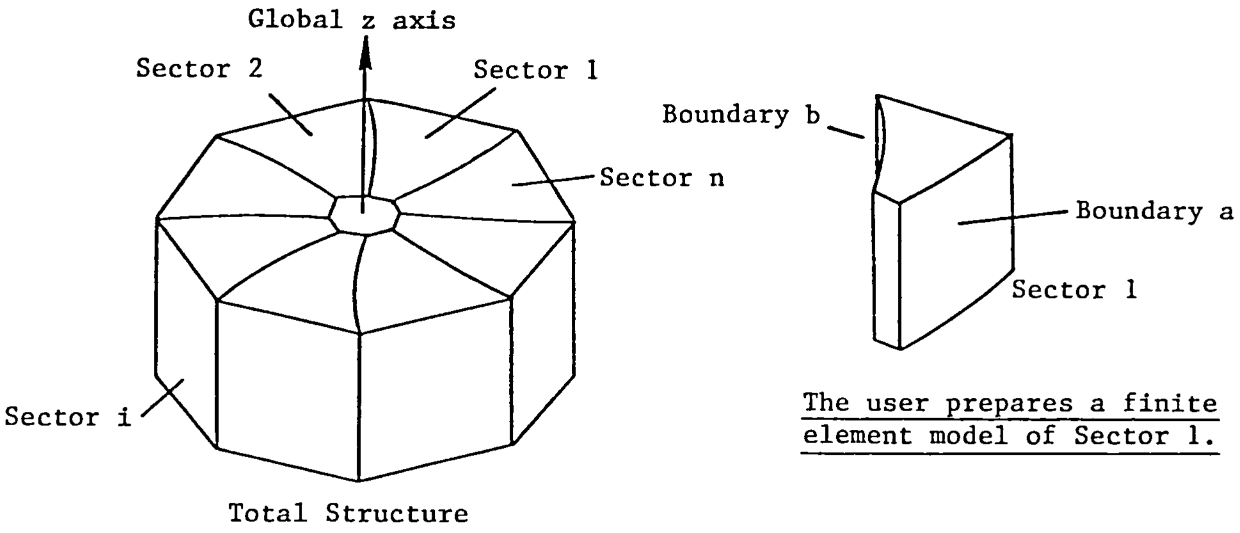
The following types of analysis may be performed:

- static analysis with and without preload,
- vibrational analysis with and without preload, and
- buckling analysis with and without preload.

The EAL procedure for cyclically symmetrical structures without reflective symmetry is named CS. The procedure for cyclically symmetrical structures including reflective symmetry is named CSR. Throughout this report, the acronyms CS and CSR refer to cyclic symmetry without and with reflective symmetry, respectively.

1.1 CYCLICALLY SYMMETRICAL STRUCTURES

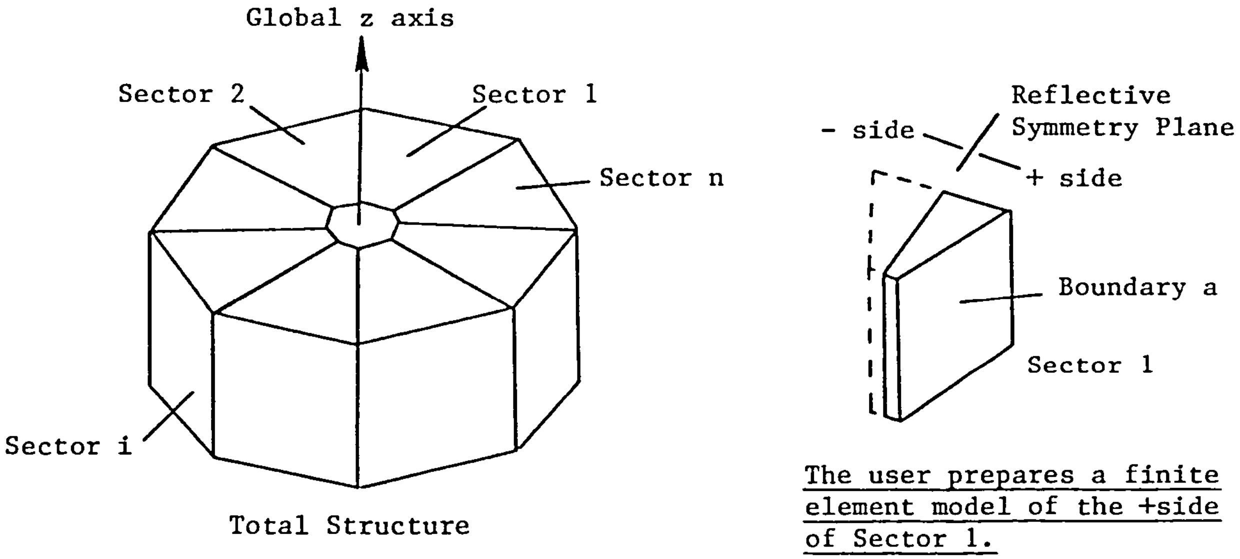
As illustrated in Fig. 1, a cyclically symmetrical structure consists of n identical sectors symmetrically arranged with respect to a central axis. The sectors are numbered consecutively from 1 to n.



The user prepares a finite element model of Sector 1.

Figure 1. Cyclically Symmetrical Structure, No Reflective Symmetry Plane

If the individual sectors also possess a plane of reflective symmetry, as shown in Fig. 2, a finite element model of a symmetric half of one sector is required for the analysis.



The user prepares a finite element model of the +side of Sector 1.

Figure 2. Cyclically Symmetrical Structure with Reflective Symmetry

Note that for models with reflective symmetry, the intersector boundaries must be planar.

As shown in Fig. 2, the modeled side (adjacent to boundary a) of sector 1 is called the +side, and the reflected side is called the -side.

In the following discussion, F_i and U_i are defined as follows:

F_i = the vector of applied nodal forces in sector i,
U_i = the vector of nodal motions in sector i.

As shown in detail in Section 6, the following relations are characteristic of cyclically symmetrical structures:

$$F_i = \sum_{k=0}^{m} P_{kc} \cos(i-1) \frac{2\pi k}{n} + P_{ks} \sin(i-1) \frac{2\pi k}{n} \tag{1}$$

$$U_i = \sum_{k=0}^{m} Q_{kc} \cos(i-1) \frac{2\pi k}{n} + Q_{ks} \sin(i-1) \frac{2\pi k}{n} \tag{2}$$

n = number of sectors in the total structure, and
m = n/2 if n is even,
= (n-1)/2 if n is odd.

P_{kc} and P_{ks} are called symmetrical components of applied load. Q_{kc} and are called symmetrical components of motion. k is called the circumferential harmonic number.

For cyclically symmetrical structures with a plane of reflective symmetry, the following definitions are used:

F_i^+ = the vector of applied nodal forces in sector i, +side,
F_i^- = the vector of applied nodal forces in secton i, -side,
U_i^+ = the vector of nodal motions in sector i, +side,
U_i^- = the vector of nodal motions in sector i, -side.

The following relations are characteristic of structures with a plane of reflective symmetry:

$$F_i^+ = \tfrac{1}{2}(F_i^s + F_i^a), \quad F_i^- = \tfrac{1}{2}(F_i^s - F_i^a) \tag{3}$$

$$U_i^+ = \tfrac{1}{2}(U_i^s + U_i^a), \quad U_i^- = \tfrac{1}{2}(U_i^s - U_i^a), \tag{4}$$

where

F_i^s = the symmetric reflective component of applied nodal forces in sector i,
F_i^a = the anti-symmetric reflective component of applied nodal forces in sector i,
U_i^s = the symmetric reflective component of nodal motions in sector i,
U_i^a = the anti-symmetric reflective component of nodal motions in sector i.

Solving Eqs. 3 and 4 for the symmetric and anti-symmetric reflective components of force and motion yields:

$$F_i^s = (F_i^+ + F_i^-), \qquad F_i^a = (F_i^+ - F_i^-) \tag{5}$$

$$U_i^s = (U_i^+ + U_i^-), \qquad U_i^a = (U_i^+ - U_i^-) \tag{6}$$

As shown in detail in Section 6, the following relations are characteristic of cyclically symmetrical structures with a plane of reflective symmetry.

$$F_i^a = \sum_{k=0}^{m} P_{kc}^a \cos(i-1)\frac{2\pi k}{n} + P_{ks}^a \sin(i-1)\frac{2\pi k}{n} \tag{7}$$

$$F_i^s = \sum_{k=0}^{m} P_{kc}^s \cos(i-1)\frac{2\pi k}{n} + P_{ks}^s \sin(i-1)\frac{2\pi k}{n} \tag{8}$$

$$U_i^a = \sum_{k=0}^{m} Q_{kc}^a \cos(i-1)\frac{2\pi k}{n} + Q_{ks}^a \sin(i-1)\frac{2\pi k}{n} \tag{9}$$

$$U_i^s = \sum_{k=0}^{m} Q_{kc}^s \cos(i-1)\frac{2\pi k}{n} + Q_{ks}^s \sin(i-1)\frac{2\pi k}{n} \tag{10}$$

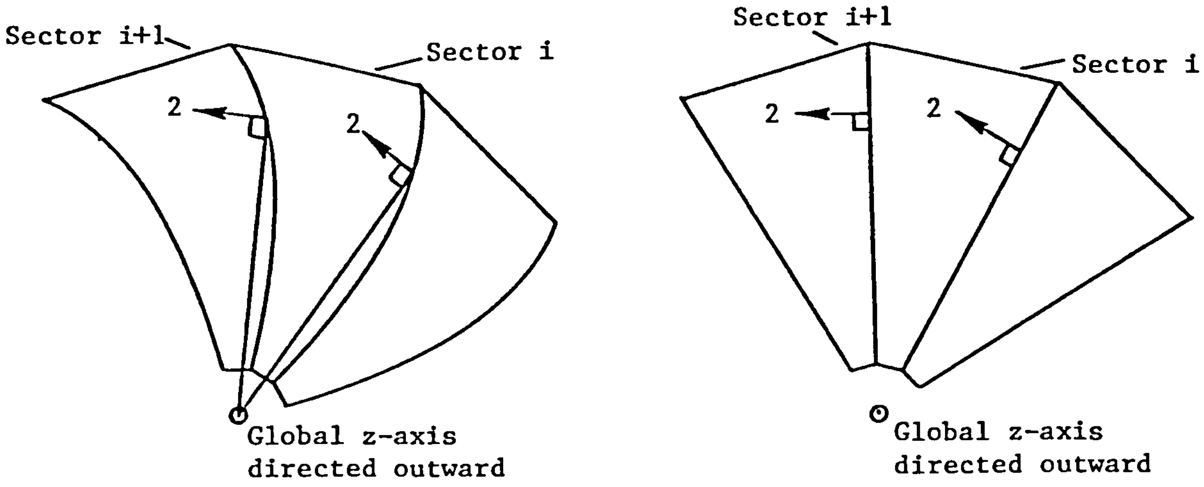
n = number of whole sectors in the total structure (a whole sector includes both the +side and -side),
m = n/2, if n is even,
= (n-1)/2, if n is odd.

P_{kc}^a, P_{ks}^a, P_{kc}^s, and P_{ks}^s are called symmetrical-reflective components of applied load. Q_{kc}^a, Q_{ks}^a, Q_{kc}^s, and Q_{ks}^s are called symmetrical-reflective components of motion.

As shown in Fig. 1, the two bounding surfaces of a sector are called boundary a and boundary b. Where U_{ai} is the boundary-a motion of sector i and U_{bi} is the motion of boundary b, the equation of constraint between adjacent sectors is

$$U_{a,i+1} = U_{bi}, \text{ for } i = 1, n, \tag{11}$$

where $U_{a,n+1} = U_{a1}$. To enforce Eq. 11, the finite element grid points on boundary a must coincide with the corresponding grid points on boundary b. As shown on Fig. 3, the joint reference frame associated with each boundary joint must be oriented so that the joint reference frame 2-axis is perpendicular to the plane that contains both the global z-axis and the boundary joint. Cylindrical joint reference frames are usually used to satisfy this requirement.



3a. Without Reflective Symmetry

3b. With Reflective Symmetry

Figure 3. Boundary Joint Reference Frames

For reflective symmetry, Fig. 2, the equation of constraint between adjacent sectors is

$$U^{+}_{a,i+1} = \overline{T}\cdot U^{-}_{ai}, \text{ for } i = 1, n. \tag{12}$$

where $U^{+}_{a,n+1} = U^{+}_{a1}$

In Eq. 12, $\overline{T}$ is a diagonal transformation matrix. To enforce Eq. 12, the joint reference frame associated with each joint on boundary a must be oriented as shown on Fig. 3. The joint reference frame 2-axis is perpendicular to the plane that contains both the global z-axis and the boundary joint. Cylindrical joint reference frames satisfy this requirement.

For vibrational and buckling analysis, eigensolutions are computed for user-designated values of the circumferential harmonic, k. For static analysis of an arbitrarily applied loading, the complete summations of Eq. 1 or Eqs. 9 and 10 are required for an exact solution. However, provisions are included for truncating the summation to user-selected values of k.

1.2 CAPABILITIES AND REQUIREMENTS OF THE EAL PROCEDURES

The EAL procedures for cyclically symmetrical structures include provisions for the following types of analyses:

- static analysis with and without preload,
- vibrational analysis with and without preload, and
- buckling analysis with and without preload.

All of the above types of analyses can be performed for structures with or without planes of reflective symmetry.

The procedures are based on the following requirements:

- The global Z axis of the sector 1 model is coincident with the central axis of the total structure,
- All joints lying on the central axis are fully constrained,
- The plane of reflective symmetry is either the XZ or YZ global plane of the sector 1 +side model,
- For each boundary joint, joint reference frames are defined for which the 2-axis is perpendicular to the plane that contains both the global z-axis and the boundary joint. See Figure 3. Cylindrical joint reference frames are usually used to satisfy this requirement.
- Joint motion constraints defined for the sector 1 model are symmetrically applied to sectors 2 through n,
- Preloads and active buckling loads must possess the same cyclic and reflective symmetry characteristics as the total structure.

Constraints, preloads, active buckling loads, and active static loads may be applied to boundary joints.

2. EXECUTION OF THE CYCLIC SYMMETRY PROCEDURES

The acronym CS is used to identify the sub-sections of section 2 that pertain to cyclically symmetrical structures with no plane of reflective symmetry. CSR is used to identify the sub-sections that pertain to cyclically symmetrical structures that do include planes of reflective symmetry.

Before executing the procedures described subsequently, the user must attach as EAL library 28 the file containing the cyclic symmetry command runstreams.

2.1 CS: CYCLIC SYMMETRY MODELS WITHOUT REFLECTIVE SYMMETRY

The following subsections, 2.1.1 through 2.1.4, present step-by-step instructions for using the cyclic symmetry procedures to compute static, vibrational, and buckling analyses for models with no plane of reflective symmetry.

2.1.1 CS: STATIC ANALYSIS PROCEDURE

To compute the static deformation of a cyclic symmetry model with no plane of reflective symmetry, proceed as follows:

```
*XQT TAB
 START jts
 - - -
```

All TAB data for the sector 1 model.

```
 JREF: NREF=nref
   ja1—: jb1—–
```

All joints on boundaries a and b have joint reference frames oriented as those shown on Fig. 3. Cylindrical joint reference frames, nref=-1, satisfy this requirement.

```
*XQT ELD
 Eij: - - -
```

Element definitions for sector 1.

```
*XQT AUS
 TABLE(NJ=nb,TYPE=0):
    JA: J=1,nb: ja1: ja2:---
 TABLE(NF=nb,TYPE=0):
```

JA contains a list of the sector 1 joints that lie on boundary a. JB contains a list of the sector 1 joints on boundary b. These lists must be ordered so that joint jak in sector i+1 coincides with joint jbk in sector i.

```
 OUTLIB=5
```

Loads and solution control data sets reside in Lib 5.

```
 TABLE(NI=18,NJ=1,TYPE=4):
    TITLE FORCE: J=1: 'Title
```

Title used for labeling displacements and stress printout.

```
 TABLE(NJ=nls,TYPE=0):
    SECT FORC
    J=1,nls: sf1: sf2:---
 SYSVEC: APPL FORC
    BLOCK 1: Sector sf1 loads
    BLOCK 2: Sector sf2 loads
    - - -
    BLOCK nls:---
```

The loads defined in the ith block of APPL FORC are applied to sector sfi, the ith entry in SECT FORC.

```
 TABLE(NJ=nk,TYPE=0):
    HARMONICS
    J=1,nb: k1: k2:---
```

The computed static solution summation (see Eq. 2, section 1.1), is to be truncated to include only those terms corresponding to harmonics k1, k2,---. If HARMONICS is not present in Lib 5, all harmonics are included in the summation.

```
 TABLE(NJ=nbsc,TYPE=0):
    BACK SECTORS
    J=1,nbsc: sb1: sb2:---
```

Solution joint displacement vectors are to be computed for sectors sb1, sb2,---. If BACK SECTORS is not present in Lib 5, solution vectors will be produced for all sectors.

```
*XQT U1
*(CONSTRAINTS)                 TAB/CON input defining the constraints of
  ZERO - - -                   sector 1, see section 1.2.

*(LOADS PRE)
  SYSVEC: APPL FORC: - - -     Preload definition, if any, see section
  ALPHA: CASE TITLE: - - -     2.3.

*(CONSTRAINTS PRE)             Preload constraints, if different from
  SYMMETRY PLANE= - - -        CONSTRAINTS, see section 2.3.

*(OPTIONS)
 !PROB='STAT                   The problem type is static analysis.

 !NSECTORS=n                   The total structure consists of n sectors.

 !VPRT=0: - - -                See Section 2.1.4 for a complete
                               list of the available options.

*(- - - -)                     Optional runstream elements described
                               in Section 2.8, Special Controls.

*PERFORM(CS)                   Compute the static solution.
```

2.1.2 CS: VIBRATIONAL ANALYSIS PROCEDURE

To compute the vibrational modes and frequencies for a cyclic symmetry model with no plane of reflective symmetry, proceed as follows:

*XQT TAB START jts - - -	All TAB data for the sector 1 model.
JREF: NREF=nref ja1—: jb1---	All joints on boundaries a and b have joint reference frames oriented as those shown on Fig. 3. Cylindrical joint reference frames, nref=-1, satisfy this requirement.
*XQT ELD Eij: - - -	Element definitions for sector 1.
*XQT AUS TABLE(NJ=nb,TYPE=0): JA: J=1,nb: ja1: j2:--- TABLE(NF=nb,TYPE=0): JB: J=1,nb: jb1: jb2:---	JA contains a list of the sector 1 joints that lie on boundary a. JB contains a list of the sector 1 joints on boundary b. These lists must be ordered so that joint jak in sector i+1 coincides with joint jbk in sector i.
OUTLIB=5	Control data sets reside in Lib 5.
TABLE(NJ=nk,TYPE=0): HARMONICS J=1,nb: k1: k2:---	Compute modal solutions for harmonics k1, k2,---. If HARMONICS is omitted, <u>all</u> harmonic solutions are computed.
TABLE(NJ=nbsc,TYPE=0): BACK SECTORS J-1,nbsc: sb1: sb2:---	Compute eigenvectors for sectors sb1, sb2,---. If BACK SECTORS is omitted, vectors are produced for <u>all</u> sectors.
*XQT U1	
*(CONSTRAINTS) ZERO - - -	TAB/CON input defining the constraints of sector 1, see section 1.2.
*(LOADS PRE) SYSVEC: APPL FORC: - - - ALPHA: CASE TITLE: - - -	Preloads, if any, see section 2.3.
*(CONSTRAINTS PRE) SYMMETRY PLANE= - - -	Preload constraints, if different from CONSTRAINTS, see section 2.3.

*(OPTIONS)	
!NSECTORS=n !MNAME='CEM !G=386:---	The total structure consists of n sectors. See Section 2.1.4 for a complete list of the available options.
*(- - - -)	Optional runstream elements described in Section 2., Special Controls.
*PERFORM(CS)	Compute the vibrational solution.

2.1.3 CS: BUCKLING ANALYSIS PROCEDURE

To compute the buckling modes and eigenvalues for a cyclic symmetry model with no plane of reflective symmetry, proceed as follows:

*XQT TAB START jts - - -	All TAB data for the sector 1 model.
JREF: NREF=nref ja1--: jb1---	All joints on boundaries a and b have joint reference frames oriented as those shown on Fig. 3. Cylindrical joint reference frames, nref=-1, satisfy this requirement.
*XQT ELD EXX: - - -	Element definitions for sector 1.
*XQT AUS TABLE(NJ=nb,TYPE=0): JA: J=1,nb: ja1: ja2:--- TABLE(NF=nb,TYPE=0):	JA contains a list of the sector 1 joints that lie on boundary a. JB contains a list of the sector 1 joints on boundary b. These lists must be ordered so that joint jak in sector i+1 coincides with joint jbk in sector i.
OUTLIB=5	Control data sets reside in Lib 5.
TABLE(NJ=nk,TYPE=0): HARMONICS J1,nb: k1: k2:---	Compute buckling solutions for harmonics k1, k2,---. If HARMONICS is omitted, all harmonic solutions are computed.
TABLE(NJ=nbsc,TYPE=0): BACK SECTORS J=1,nbsc: sb1: sb2:---	Compute eigenvectors for sectors sb1, sb2,---. If BACK SECTORS is omitted, vectors are produced for all sectors.
*XQT U1 *(CONSTRAINTS) ZERO - - -	TAB/CON input defining the constraints of sector 1, see section 2.4.
*(LOADS) SYSVEC: APPL FORC:--- ALPHA: CASE TITLE:---	Loads for which buckling solutions are to be computed, see section 2.4 for details.
*(LOADS PRE) SYSVEC: APPL FORC:--- ALPHA: CASE TITLE:---	Preloads, if any, see section 2.3.
*(CONSTRAINTS PRE) SYMMETRY PLANE=---	Preload constraints, if different from CONSTRAINTS, see section 2.3.

*(OPTIONS) !PROB='BUCK	The problem type is buckling analysis.
!NSECTORS=n !INIT=4: !NREQ=1:---	The total structure consists of n sectors. See Section 2.1.4 for a complete list of the available options.
*(- - - -)	Optional runstream elements described in Section 2.8, Special Controls.
*PERFORM(CS)	Compute the buckling solution.

2.1.4 OPTIONAL REGISTERS

As discussed in Sections 2.1.1, 2.1.2, and 2.1.3, values for the registers tabulated below can be changed through use of the data runstream element OPTIONS.

The following registers pertain to static, vibrational and buckling analysis.

Register	Default Value	Meaning
!PROB	'VIBR	Problem Type: 'VIBR, 'BUCK, or 'STAT.
!MNAME	'DEM	Mass matrix name, usually DEM or CEM. As described in Section 2.5, MNAME is automatically added to the rigid mass data set, RMASS, to form the total mass matrix.
!G	1	Mass = weight/"G".
!SPDP	2	=1, Single Precision Stiffness Matrix. =2, Double Precision Stiffness Matrix.
!NBSC	1	If NBSC=0, no solution vectors are produced for the sectors. This overrides the runstream element BACK SECTORS. If NBSC=1, BACK SECTORS directs the computation of solution vectors as discussed in Sections 2.1.1 - 2.1.3.
!ZERO	1.E-4	Floating Point Zero Test Value. If the absolute value of sin θ is less than ZERO, $\theta = 0$.
!KSAV	1	=1, Harmonic Libs are saved, see Section 2.10. =0, Harmonic Libs are not saved.
!QSAV	0	=1, Harmonic Solution Libs, LIB 6, are saved, as discussed in Section 2.10. =0, Harmonic Solution Libs are not saved.
!VPRT	1	=1, Sector Solution Vectors are printed. =0, Sector Solution Vectors are not printed.
!LIB1	1	Library Assignment, see Section 2.10.
!LIB2	2	Library Assignment, see Section 2.10.
!LIB3	3	Library Assignment, see Section 2.10.
!LIB4	4	Library Assignment, see Section 2.10.
!LIB5	5	Library Assignment, see Section 2.10.
!LIB6	6	Library Assignment, see Section 2.10.
!JROT	1	Sector is rotated about joint JROT for ACCL loads, see Sections 2.3 and 2.4.
!ERCK	1	=1, Data errors result in execution termination =0, Data errors are printed, but execution continues.

The following registers pertain only to static analysis.

Register	Default Value	Meaning
!SET	1	3rd word of the input data sets defining the applied loads: TITLE FORCE "SET", SECT FORC "SET", and APPL FORC "SET".
!ES	1	=1, Sector stresses are printed via ES. =0, Sector stresses are not printed.

The following registers pertain only to vibrational and buckling analyses.

Register	Default Value	Meaning
!INIT	8	EIG RESET
!SHIFT	0	EIG RESET
!NDYN	8	EIG RESET
!NREQ	4	EIG RESET
!V1	0	EIG RESET
!V2	0	EIG RESET
!NVECTORS	"INIT"	Number of eigenvectors to compute for each of the sectors named in BACK SECTORS, see sections 2.1.2 and 2.1.3.
!NEVALS	"INIT"	Number of eigenvalues to be stored in the solution library, Lib 5, see Section 3.1.1.

2.2 CSR: CYCLIC SYMMETRY MODELS WITH REFLECTIVE SYMMETRY

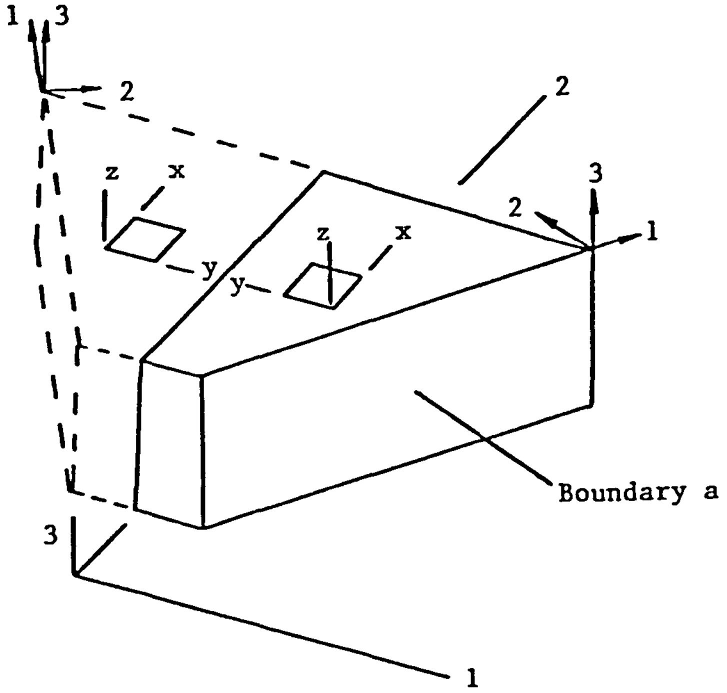


Figure 4. CSR: Joint Reference Frames and Element Reference Frames

Figure 4 illustrates a sector from a cyclically symmetrical structure. The 2-3 plane is a reflective symmetry plane. That half of the sector, outlined in solid lines, is called the +side of the sector and represents the finite element model that must be prepared by the user. The reflected half of the sector, outlined in dashed lines, is called the -side of the sector. Typical joint reference frames and element reference frames are shown on Figure 4. Note that the -side reference frames are left handed. Applied force vectors and joint motion vectors for the -side of all sectors are defined relative to left hand reference frames. Similarly, element stresses for the -side of all sectors are relative to left hand element reference frames. The following subsections, 2.2.1 through 2.2.4, present step-by-step instructions for using the cyclic symmetry procedure to compute static, vibrational, and buckling analyses for models with a plane of reflective symmetry.

2.2.1 CSR: STATIC ANALYSIS PROCEDURE

To compute the static deformation of a cyclic symmetry model with reflective symmetry, proceed as follows:

```
*XQT TAB
 START jts
 - - -
```

All TAB data for the sector 1 +side model.

```
 JREF:  NREF=nref
   ja1--
```

All joints on boundary a have joint reference frames oriented as those shown on Fig. 3. Cylindrical joint reference frames, nref=-1, satisfy this requirement.

```
*XQT ELD
 Eij: - - -
```

Element definitions for sector 1, +side.

```
*XQT AUS
 TABLE(NJ=nb,TYPE=0):
    JA: J=1,nb: ja1: ja2:---
```

JA contains a list of the sector 1 joints that lie on boundary a.

```
 OUTLIB=5
```

Loads and solution control data sets reside in Lib 5.

```
 TABLE(NI=18,NJ=1,TYPE=4):
    TITLE FORCE: J=1: 'Title
```

Title used for labeling displacements and stress printout.

```
 TABLE(NJ=nls,TYPE=0):
    SECT FORC
    J=1,nls: sf1: sf2:---
 SYSVEC: F+ FORC
    BLOCK 1: Loads on sf1,
             +side
    BLOCK 2: Loads on sf2,
             +side
    ---
    BLOCK nls:---
 SYSVEC: F- FORC
    BLOCK 1: Loads on sf1,
             -side
    BLOCK 2: Loads on sf2,
             -side
    ---
    BLOCK nls:---
```

The loads defined in the ith block of F+ FORC are applied to the +side of sector sfi, the ith entry in SECT FORC. The loads defined in the ith block of F- FORC are aplied to the -side of sector sfi. Note that all -side forces are defined relative to left-handed joint reference frames, see Fig. 4. All three of the above data sets must be present in Lib 5.

```
 TABLE(NJ=nk,TYPE=0):
    HARMONICS
    J=1,nb: k1: k2:---
```

The computed static solution summations (see Eq. 9 & 10, Section 1.1), are to be truncated to include only those terms corresponding to harmonics k1, k2,---. If HARMONICS is not present in Lib 5, <u>all</u> harmonics are included in the summation.

TABLE(NJ=nbsc,TYPE=0): BACK SECTORS J=1,nbsc: sb1: sb2:---	Solution joint displacement vectors are to be computed for both sides of sectors sb1, sb2,---. If BACK SECTORS is not present in Lib 5, solution vectors will be produced for <u>all</u> sectors.
*XQT U1	
*(CONSTRAINTS) ZERO---	TAB/CON input defining the constraints for the +side of sector 1, see section 1.2.
*(LOADS PRE) SYSVEC: APPL FORC: - - - ALPHA: CASE TITLE: - - -	Preloads, if any, see section 2.3.
*(CONSTRAINTS PRE) SYMMETRY PLANE= - - -	Preload constraints, if different from CONSTRAINTS, see section 2.3.
*(OPTIONS)	
!PROB='STAT	The problem type is static analysis.
!NSECTORS=n	The total structure consists of n whole sectors. A whole sector includes both the +side and -side.
!VPRT=0: - - -	See Section 2.2.4 for a discussion of the available options.
*(- - - -)	Optional runstream elements described in Section 2.8, Special Controls.
*PERFORM(CSR)	Compute the static solution.

2.2.2 CSR: VIBRATIONAL ANALYSIS PROCEDURE

To compute the vibrational modes and frequencies for a cyclic symmetry model with reflective symmetry, proceed as follows:

*XQT TAB START jts - - -	All TAB data for the sector 1 +side model.
JREF: NREF=nref ja1--	All joints on boundary a have joint reference frames oriented as those shown on Fig. 3. Cylindrical joint reference frames, nref=-1, satisfy this requirement.
*XQT ELD Eij: - - -	Element definitions for sector 1, +side.
*XQT AUS TABLE(NJ=nb,TYPE=0): JA: J=1,nb: ja1: ja2:---	JA contains a list of the sector 1 joints that lie on boundary a.
OUTLIB=5	Control data sets reside in Lib 5.
TABLE(NJ=nk,TYPE=0): HARMONICS J=1,nb: k1: k2:---	Compute modal solutions for harmonics k1, k2,---. If HARMONICS is omitted. all harmonic solutions are computed.
TABLE(NJ=nbsc,TYPE=0): BACK SECTORS J=1,nbsc: sb1: sb2:---	Compute eigenvectors for both sides of sectors sb1, sb2---. If BACK SECTORS is omitted, vectors are produced for all sectors.
*XQT U1 *(CONSTRAINTS) ZERO - - -	TAB/CON input defining constraints for the +side of sector 1, see section 1.2.
*(LOADS PRE) SYSVEC: APPL FORC: - - - ALPHA: CASE TITLE: - - -	Preloads, if any, see section 2.3.
*(CONSTRAINTS PRE) SYMMETRY PLANE= - - -	Preload constraints, if different from CONSTRAINTS, see section 2.3.
*(OPTIONS) !NSECTORS=n	The total structure consists of n whole sectors. A whole sector includes both the +side and -side.
!MNAME='CEM !G=386:---	See Section 2.2.4 for a discussion of the available options.
*(- - - -)	Optional runstream elements described in Section 2.8, Special Controls.
*PERFORM(CSR)	Compute the vibrational solution.

2.2.3 CSR: BUCKLING ANALYSIS PROCEDURE

To compute the buckling modes and eigenvalues for a cyclic symmetry model wih reflective symmetry, proceed as follows:

```
*XQT TAB
 START jts
 - - -
```

All TAB data for the sector 1 +side model.

```
 JREF:  NREF=nref
   ja1--
```

All joints on boundary a have joint reference frames oriented as those shown on Fig. 3. Cylindrical joint reference frames, nref=-1, satisfy this requirement.

```
*XQT ELD
 Eij: - - -
```

Element definitions for sector 1, +side.

```
*XQT AUS
 TABLE(NJ=nb,TYPE=0):
    JA: J=1,nb: ja1: ja2:---
```

JA contains a list of the sector 1 joints that lie on boundary a.

```
 OUTLIB=5
```

Control data sets reside in Lib 5.

```
 TABLE(NJ=nk,TYPE=0):
    HARMONICS
    J1,nb: k1: k2:---
```

Compute buckling solutions for harmonics k1, k2,---. If HARMONICS is omitted, all harmonic solutions are computed.

```
 TABLE(NJ=nbsc,TYPE=0):
    BACK SECTORS
    J=1,nbsc: sb1: sb2:---
```

Compute eigenvectors for both sides of sectors sb1, sb2,---. If BACK SECTORS is omitted, vectors are produced for all sectors.

```
*XQT U1
*(CONSTRAINTS)
  ZERO
```

TAB/CON input defining constraints for the +side of sector 1, see section 2.4.

```
*(LOADS)
  SYSVEC: APPL FORC:---
  ALPHA: CASE TITLE:---
```

Loads for which buckling solutions are to be computed, see section 2.4 for details.

```
*(LOADS PRE)
  SYSVEC: APPL FORC:---
  ALPHA: CASE TITLE:---
```

Preloads, if any, see section 2.3.

```
*(CONSTRAINTS PRE)
  SYMMETRY PLANE=---
```

Preload constraints, if different from CONSTRAINTS, see section 2.3.

*(OPTIONS)	
!PROB='BUCK	The problem type is buckling analysis.
!NSECTORS=n	The total structure consists of n whole sectors. A whole sector includes both the +side and -side.
!INIT=4: !NREQ=1:---	See Section 2.2.4 for a discussion of the available options.
*(- - - -)	Optional runstream elements described in Section 2.8, Special Controls.
*PERFORM(CSR)	Compute the buckling solution.

2.2.4 CSR: OPTIONAL REGISTERS

As discussed in Sections 2.2.1, 2.2.2 and 2.2.3, values for the registers tabulated below can be changed through use of the data runstream element OPTIONS.

The following registers pertain to static, vibrational, and buckling analysis.

Register	Default Value	Meaning
!PROB	'VIBR	Problem Type: 'VIBR, 'BUCK, or 'STAT.
!MNAME	'DEM	Mass matrix name, usually DEM or CEM. As described in Section 2.5, MNAME is automatically added to the rigid mass data set, RMASS, to form the total mass matrix.
!G	1	Mass= weight/"G".
!SPDP	2	=1, Single Precision Stiffness Matrix. =2, Double Precision Stiffness Matrix.
!CONS	10	The number of the constraint condition made up of the runstream element CONSTRAINTS or CONSTRAINTS PRE plus symmetry plane constraints on the reflective plane.
!CONA	20	The number of the constraint condition made up of the runstream element CONSTRAINTS or CONSTRAINTS PRE plus anti-symmetry plane contraints on the reflective plane.
!RFLP	1	Global axis that is normal to the reflective symmetry plane.
!NBSC	1	If NBSC=0, no solution vectors are produced for the sectors. This overrides the runstream element BACK SECTORS . If NBSC=1, BACK SECTORS direct the computation of solution vectors as discussed in sections 2.2.1 - 2.2.3.
!Zero	1.E-4	Floating Point Zero Test Value. If the absolute value of sin θ is less than ZERO, θ = 0.
!KSAV	1	=1, Harmonic Libs are saved, see Section 2.10. =0, Harmonic Libs are not saved.
!QSAV	0	=1, Harmonic Solution Libs, Lib 6, are saved as discussed in section 2.10. =0, Harmonic Solution Libs are not saved.
!VPRT	1	=1, Sector Solution Vectors are printed. =0, Sector Solution Vectors are not printed.
!LIB1	1	Library Assignment, see Section 2.10.
!LIB2	2	Library Assignment, see Section 2.10.
!LIB3	3	Library Assignment, see Section 2.10.
!LIB4	4	Library Assignment, see Section 2.10.
!LIB5	5	Library Assignment, see Section 2.10.
!LIB6	6	Library Assignment, see Section 2.10.
!JROT	1	Sector is rotated about joint JROT for ACCL loads, see sections 2.3 and 2.4.
!ERCK	1	=1, Data errors result in execution termination =0, Data errors are printed, but execution continues.

The following registers pertain only to static analysis.

Register	Default Value	Meaning
!SET	1	Static solution set number.
!ES	1	=1, Sector stresses are printed via ES. =0, Sector stresses are not printed.

The following registers pertain only to vibrational and buckling analyses.

Register	Default Value	Meaning
!INIT	8	EIG RESET
!SHIFT	0	EIG RESET
!NDYN	8	EIG RESET
!NREQ	4	EIG RESET
!V1	0	EIG RESET
!V2	0	EIG RESET
!NVECTORS	"INIT"	Number of eigenvectors to compute for both sides of each of the sectors named in BACK SECTORS, see sections 2.2.2 and 2.2.3.
!NEVALS	"INIT"	Number of eigenvalues to be stored in the solution library, Lib 5, see section 2.10.

2.3 PRELOAD AND PRELOAD CONSTRAINTS

As discussed in Sections 2.1 and 2.2, cyclically symmetrical preloads are defined through the data runstream element, LOADS PRE. In addition to LOADS PRE, the preload definition may also include the runstream elements ACCL PRE and/or CF PRE. The preload runstream elements are constructed as follows:

```
*XQT U1
*(LOADS PRE) $ See Section 6, Vol 1, EAL Reference Manual
  ALPHA:       CASE TITLE: 1'Preload Title
  SYSVEC:      APPLIED FORCES:    - - -
  TABLE:       NODAL TEMPERATURES:- - -
  TABLE:       NODAL PRESSURES:   - - -
  ELDATA:      TEMPERATURES Eij:  - - -
  ELDATA:      PRESSURES Eij:     - - -
  ELDATA:      DISLOCATIONS Eij:  - - -
*(ACCL PRE) $  Acceleration Component of the Preload
     ax ay az rx ry rz $          See below
*(CF PRE) $    Centrifugal Component of the Preload
     m k wx wy wz xo yo zo$       See below
```

ACCL Input:

Items defined via ACCL PRE are:

ax, ay, az = linear acceleration in the global x, y, and z directions.

rx, ry, rz = rotational accelerations about axes parallel to the global x, y, and z axes, passing through the joint identified by register JROT.
Default: !JROT= 1.

As an example, suppose that the global 3 axis points vertically downward, and that acceleration due to gravity is 386. The following would define 1 G gravitational preload:

```
*(ACCL PRE)
    0.  0.  386.  0.  0.  0.
```

CF Input:

m = name of mass matrix to be used (e.g. DEM) in computing centrifugal forces. As discussed in Section 2.5, MTOT is the name assigned to the total mass matrix, if rigid masses are included.
k = name of the sector k matrix.
wx, wy, wz = angular velocity components relative to the global reference frame.
xo, yo, zo = position coordinates of the spin center relative to the global frame.

The runstream element LOADS PRE is mandatory for preloads to be included. ACCL PRE and CF PRE are optional.

As outlined in sections 2.1 and 2.2, the data runstream element CONSTAINTS PRE contains the TAB/CON data defining the preload constraint condition. If CONSTRAINTS PRE is not present, the constraints defined via the runstream element CONSTRAINTS are used for the preload computations.

Preloads and preload constraints may be applied to any sector joints, boundary or interior. Preloads and preload constraints defined for sector 1 are assumed to possess the same cyclic and reflective symmetry characteristics as the total structure.

2.4 BUCKLING ACTIVE LOADS AND CONSTRAINTS

As discussed in sections 2.1.3 and 2.2.3, cyclically symmetrical buckling loads are defined through the data runstream element, LOADS. In the following, n3bl is the 3rd word of all buckling load data sets. If preloads are present, n3bl must be set equal to 2. If preloads are absent, n3bl=1. If omitted, n3bl defaults to 1. In addition to LOADS, the active buckling load definition may also include the runstream elements ACCL and/or CF. The buckling load runstream elements are constructed as follows:

```
*XQT U1
*(LOADS) $ See Section 6, Vol. 1, EAL Reference Manual
  ALPHA:   CASE  TITLE n3bl:  1' Buckling Load Title
  SYSVEC:  APPL  FORCE n3bl: - - -
  TABLE:   NODAL PRESS n3bl: - - -
  TABLE:   NODAL TEMPS n3bl: - - -
  ELDATA:  TEMPS EXX   n3bl: - - -
  ELDATA:  PRESS EXX   n3bl: - - -
  ELDATA:  DISLO EXX   n3bl: - - -
*(ACCL) $  Acceleration Component of the Buckling Load
     ax  ay  az  rx  ry  rz
*(CF) $    Centrifugal Component of the Buckling Load
     m  k  wx  wy  wz  xo  yo zo
```

ACCL and CF input are the same as ACCL PRE and CF PRE which are discussed in Section 2.3.

The runstream element LOADS is mandatory for buckling analysis. ACCL and CF are optional.

The constraint condition defined via the runstream element CONSTRAINTS PRE, if it is present in Lib 29, is used to compute the geometric stiffness matrix, KG, for the buckling eigensolution. If CONSTRAINTS PRE is not present in Lib 29, KG is computed using CONSTRAINTS. The buckling eigensolution is computed using the constraint condition defined in CONSTRAINTS.

Note that for preloaded buckling problems, both the preload KG and the buckling KG are computed using the same constraint condition.

Active buckling loads and buckling constraints defined for sector 1 are assumed to possess the same cyclic and reflective symmetry characteristics as the total structure.

2.5 MASS MATRICES and RIGID MASS DATA

To include rigid masses in the sector model, insert in LIB1 the SYSVEC format data set RMASS. RMASS can be created with either TAB/RMASS or AUS/SYSVEC. RMASS is automatically added to the sector mass matrix (defined by the register MNAME as discussed in Sections 2.1.4 and 2.2.4.) to form the total mass, MTOT. MTOT is then used by the cyclic symmetry procedures as the sector mass matrix.

2.6 SPECTRAL SHIFTS

Spectral shifting is included in a vibrational or buckling analysis by inputting a non-zero value for the register SHIFT through the data runstream element OPTIONS, see sections 2.1.4 and 2.2.4. The shifted stiffness matrix KSHF is then used by the cyclic symmetry procedures as the sector stiffness matrix. Spectral shifts may be used with either preloaded or non-preloaded models.

2.7 RESTART PROCEDURE

Restarted cyclic symmetry executions may be initiated through either of the following commands:

```
*CALL (CS RESTART)  $ No Reflective Symmetry Plane, or
*CALL (CSR RESTART) $ Including Reflective Symmetry
```

Provisions are included for the following kinds of restarted executions:

- Computing additional harmonic solutions. For vibrational or buckling analyses, additional solutions are computed for specified harmonic values. For static analysis, this kind of restart is used to compute additional terms for a previously truncated solution summation (see Eq. 2, Section 1.1). Consequently, newly computed harmonic components are added to the existing solution data sets.

- Performing additional types of analyses, or computing static solutions for additional loads. For this kind of restart, the stiffness matrices and factored stiffness matrices used for previously computed harmonic solutions may be retrieved and used directly. See section 2.10 for instructions on storage and retrieval of the harmonic matrices.

Before restarting a cyclic symmetry execution, attach the files that correspond to EAL Libraries LIB1, LIB4, and LIB5 (see section 2.10 for library descriptions). For restarting, proceed as follows:

```
*XQT AUS

 OUTLIB=5                           Control data sets reside in Lib 5.

 TABLE(NJ=nb,TYPE=0)                Solutions are to be computed for harmonics
 HARMONICS                          k1, k2,---.
    J=1,nk: k1: k2:---

 TABLE(NJ=nbsc,TYPE=0)              Solution vectors are to be computed for
 BACK SECTORS                       sectors sb1, sb2,---.
    J=1,NK: k1: k2:---

*XQT U1
*(OPTIONS)
 !PROB= 'VIBR                       Vibrational analysis
      = 'BUCK                       Buckling analysis
      = 'STAT                       Static analysis

 !VPRT= 0: ---                      See Sections 2.1.4 and 2.2.4 for a
                                    discussion of the available options.

*(- - - -)                          Optional runstream elements described in
                                    Section 2.8, Special Controls.

*PERFORM (CS RESTART), or           Initiate the restarted analysis
*PERFORM (CSR RESTART)
```

2.8 SPECIAL CONTROLS

In the cyclic symmetry procedures, many *XQT commands are followed by optional DCALL commands, such as:

```
*XQT SEQ
*DCALL, ROPT (SEQ OPTIONS)
```

This gives the user a means of inputting special processor resets or options. Optional runstream elements that are recognized by the cyclic symmetry procedures, are:

```
*(SEQ  OPTIONS)
*(TAN  OPTIONS)
*(LSU  OPTIONS)
*(RSI  OPTIONS), for either RSI or DRSI
*(EIG  OPTIONS)
*(SSOL OPTIONS)
*(ES   OPTIONS)
*(GSF  OPTIONS), for the EMBED operation
*(KG   OPTIONS)
```

Note that calls to other procedures may be initiated through an optional runstream element. For example, static accuracy improvement or eigensolution check procedures may be called by SSOL OPTIONS or EIG OPTIONS.

ES OPTIONS can be used to control the quantity and nature of stress print. If a subset of elements is chosen through ES OPTIONS, also include the register action command, !JUMP=1, for example:

```
*XQT U1
*(ES OPTIONS)       END
  E21 1:  E43 4  10,20:  !JUMP=1
*                   END
```

JUMP = 0 (the default value) causes the ES command ALL to be executed.

Optional data runstream elements may be supplied for each harmonic solution that is computed during an execution. For example, at the beginning of execution for harmonic k1, the following *DCALL is performed:

```
*DCALL, ROPT (OPTIONS K k1)
```

Consequently, the user may provide optional registers that differ for each harmonic solution.

2.9 ERROR MESSAGES

Before any actual computations are performed by the cyclic symmetry procedures, the input data sets are diagnosed for apparent errors.

The following list of error messages pertain to the cyclic symmetry models with no reflective symmetry plane.

1. The number of sectors must exceed 0. Check the runstream element (OPTIONS).
2. JA data set is not present in Lib 1.
3. JB data set is not present in Lib 1.
4. The dimensions of JA and JB data sets are not equal.
5. The number of defined boundary joints exceeds the total number of joints in the sector model.
6. Joint numbers in the JA data set exceed the total number of joints in the sector model.
7. Joint numbers in the JA data set are less than 1.
8. Joint numbers in the JB data set exceed the total number of joints in the sector model.

9. Joint numbers in the JB data set are less than 1.

10. Duplicate joint numbers are present in the JA and JB data sets.

11. Cylindrical joint reference frames have not been specified for all boundary joints appearing in the JA and JB data sets. If joint reference frames other than cylindrical are defined for the boundary joints, set register ERCK=0 in the runstream element OPTIONS, see Section 2.1.4. These joint reference frames must satisfy the requirements of Section 1.2, or the resulting solution will be in error.

12. Specified harmonic values exceed the maximum. Check the data set (HARMONICS) in Lib 5.

13. Specified harmonic value is less than zero. Check the data set (HARMONICS) in Lib 5.

14. All sectors specified by the data set (BACK SECTORS) are not within the bounds of 1 and "NSECTORS".

    The following error messages pertain to static load input:

15. Data set not present in Lib 5: SECT FORC "SET".

16. Data set not present in Lib 5: APPL FORC "SET".

17. The number of blocks in (APPL FORC "SET") does not equal NJ of (SECT FORC "SET").

18. All sectors specified by the data set (SECT FORC "SET") are not within the bounds of 1 and "NSECTORS".

The following list of error messages pertain to cyclic symmetry models with a reflective symmetry plane:

1. The number of sectors must exceed 0. Check the runstream element (OPTIONS).

2. JA data set is not present in Lib. 1.

3. Too many boundary joints defined.

4. Joint numbers in the JA data set exceed the total number of joints in the sector model.

5. Joint numbers in the JA data set are less than 1.

6. Duplicate joint numbers are present in the JA.

7. Cylindrical joint reference frames have not been specified for all boundary joints appearing in the JA data set. If joint reference frames other than cylindrical are defined for the boundary joints, set egister ERCK=0 in the runstream element OPTIONS, see Section 2.2.4. These joint reference frames must satisfy the requirements of Section 1.2, or the resulting solution will be in error.

8. Specified harmonic values exceed the maximum. Check the data set (HARMONICS) in Lib 5.

9. Specified harmonic value is less than zero. Check the data set (HARMONICS) in Lib 5.

10. All sectors specified by the data set (BACK SECTORS) are not within the bounds of 1 and "NSECTORS".

    The following error messages pertain to static load input:

11. Data set not present in Lib 5: SECT FORC "SET".

12. Data set not present in Lib 5: F+ FORC "SET".

13. Data set not present in Lib 5: F- FORC "SET".

14. The number of blocks in data set (F+ FORC "SET") does not equal the number of blocks in (F- FORC "SET").

15. The number of blocks in (F+ FORC "SET") does not equal NJ of (SECT FORC "SET").

16. All sectors specified by the data set (SECT FORC "SET") are not within the bounds of 1 and "NSECTORS".

If any of the above errors are encountered, execution is terminated in the default mode. However, if the register !ERCK=0 (see sections 2.1.4 and 2.2.4), error messages are printed, but the execution continues.

2.10 LIBRARY CONFIGURATION

The following EAL libraries are used by the cyclic symmetry procedures. Register notation is used to identify each library. As discussed in sections 2.1.4 and 2.2.4, LIB1 through LIB6 default to 1 through 6, respectively.

Library	Configuration
LIB1	Sector library containing the user supplied finite element model of sector 1.
LIB2	For each circumferential harmonic solution that is computed, LIB2 contains the harmonic stiffness matrix, factored stiffness matrix, mass matrix, etc. Subject to user control, LIB2 is stored as a LIBLIB data set in LIB4 upon completion of each harmonic solution.
LIB3	Contains temporary data sets.
LIB4	Contains LIBLIB data sets for each circumferential harmonic model. The data set stored for harmonic k is named: KLIB HARM k.
LIB5	For static analysis problems, LIB5 contains the input applied load data sets and the corresponding sector static displacement vectors. For vibrational and buckling analysis problems, LIB5 contains the solution eigenvalue and sector eigenvector data sets.
LIB6	For each circumferential harmonic solution that is computed, LIB6 is a temporary library. For static analysis, it contains the harmonic force vectors and the corresponding static displacements. For eigenvalue analysis, it contains the harmonic eigenvectors and eigenvalues. These vectors correspond to the symmetrical components of applied load and motion that are defined in section 1.1. Subject to user control, LIB6 may be stored as a LIBLIB data set in LIB5. See sections 2.1.4 and 2.2.4 for the appropriate options.

As discussed above, the library LIB2 is created for each harmonic solution. LIB2 contains the harmonic stiffness matrix, factored stiffness matrix, mass matrix, etc. For the k-th harmonic solution, the data set KLIB HARM k, if present in LIB4, is retrieved via DCU/RETRIEVE as LIB2, and the contained matrices are used. If KLIB HARM k is not present in LIB4, the required matrices are constructed and stored in LIB2. Subsequently, if the optional register KSAV =1, LIB2 is stored via DCU/STORE as KLIB HARM k in LIB4. In default, KSAV =1, see sections 2.1.4 and 2.2.4.

If the optional register QSAV =1, the data set QLIB HARM k is stored in LIB5 via the DCU/STORE command. k is a circumferential harmonic number. For static solutions, QLIB HARM k contains the symmetrical components of applied loads and motion. For vibrational and buckling analysis, QLIB HARM k contains the eigenvalues and the symmetrical components of the eigenvectors. In default QLIB HARM k is not stored, see sections 2.1.4 and 2.2.4.

3.1.1 CS: OUTPUT DATA SETS

In the following, nbsc is the number of sectors for which solution vectors are computed, as specified via the data set BACK SECTORS. The value assigned to the register SET is represented by "set" in the following. See Sections 2.1.1, 2.1.2, and 2.1.3.

STATIC ANALYSIS

For cyclic symmetry models with no plane of reflective symmetry, the following data sets are output to LIB5. If preload is present, ncon=2. With no preload, ncon=1. Registers LIB5, LIB6, SET, and QSAV are discussed in Section 2.1.4.

Data Set Name	Contents
SECT BACK set 1	(S1,S2,—Si—Snbsc),NJ=nbsc. Sector Numbers.
STAT DISP set ncon	NBLOCKS= nbsc Block i is the displacement vector for sector Si, the i-th entry in SECT BACK set.
CASE TITL set 1	Blocked case title data set for use by ES.
QLIB HARM set k1 QLIB HARM set k2	LIBLIB data sets created from LIB6 for each harmonic solution. These data sets are stored only if the register QSAV=1. k1, k2, etc., are harmonic numbers. The content of these data sets is discussed below.

If the data set STAT DISP set ncon is present in LIB5 at the beginning of the static analysis, the newly computed harmonic componenets are added to the existing data set.

For each harmonic solution, the library LIB6 is used for storage of harmonic force and displacement arrays. For the k-th harmonic solution, LIB6 will contain the following data sets:

Data Set Name	Contents
APPL FORC set 1	The harmonic force vector, Eq. 8, Section. 6.
STAT DISP set ncon	The harmonic displacement vector, Eq. 8, Section 6.
UC AUS set ncon	The cosine component of STAT DISP set ncon. Q_{kc} of Eq. 2, Section 1.1
US AUS set ncon	The sine component of STAT DISP set ncon. Q_{ks} or Eq. 2, Section 1.1. This data set is not present for k=0 or k=n/2, where n is the total number of sectors in the complete structure.

VIBRATIONAL AND BUCKLING ANALYSES

For vibrational and buckling analysis of cyclic symmetry models with no plane of reflective symmetry, the data sets tabulated below are output to LIB5.

REGISTERS:

NCON=ncon = 1, if preload is not present.
= 2, if preload is present.
LIB5 = Solution Library, see section 2.10.
LIB6 = Harmonic working Library, see section 2.10.
QSAV = Control register, see section 2.1.4.
PROB = 'VIBR, for vibrational analysis.
= 'BUCK, for buckling analysis.
k = Specific circumferential harmonic value.
NVECTORS = Number of sector eigenvectors, see section 2.1.4.
NEVALS = Number of retained eigenvalues, see section 2.1.4.

Data Set Name	Contents
EVAL HARM 1 1	(K1, K2,--- Kn), Circumferential Harmonic Values.
EVAL MATR 1 1	$\begin{bmatrix} W11 & W12\text{---} & W1n \\ W21 & W22\text{---} & W2n \\ Wm1 & Wm2\text{---} & Wmn \end{bmatrix}$ Wij= Eigenvalue corresponding to the ith mode of harmonic Kj. NI= "NEVALS".
PREV MATR 1 1	Matrix of eigenvalues from the next-to-last EIG iteration. Same format as (EVAL MATR 1 1).
CONV MATR 1 1	Eigenvalue convergence matrix = (EVAL-PREV)/EVAL.
HZ MATR 1 1	EVAL MATR 1 1 converted to HZ units. Present only if PROB = 'VIBR.

The following data sets are produced for each circumferential harmonic k=k1, k2,---kn.

"PROB"	EVAL	k	ncon	(W1, W2,---), Eigenvalues, NJ= NEVALS.
"PROB"	PREV	k	ncon	(W1, W2,---), Eigenvalues from the next-to-last EIG iteration, NJ= NEVALS.
SECT	BACK	k	0	(S1, S2,--- Snbsc), NJ= nbsc. Sector numbers,see below.
"PROB"	MODE	k	S1	Eigenvectors for sector S1, NBLOCKS= NVECTORS.
"PROB"	MODE	k	S2	Eigenvectors for sector S2.
- - -				
"PROB"	MODE	k	Snbsc	Eigenvectors for sector Snbsc.
QLIB	HARM	k	k	LIBLIB data set created from LIB6. This data set is produced only if register QSAV =1, see section 2.1.4.

For the k-th harmonic solution, LIB6 contains the following data sets:

Data Set Name				Contents
"PROB"	EVAL	k	ncon	Eigenvalues
"PROB"	PREV	k	ncon	Eigenvalues of the next-to-last EIG iteration.
"PROB"	MODE	k	ncon	Harmonic eigenvectors, see section 6.
UC	AUS	k	ncon	Cosine components of eigenvectors. Q_{kc} of Eq. 2, section 1.1.
US	AUS	k	ncon	Sine components of eigenvectors. Q_{ks} of Eq. 2, section 1.1. This data set is not present if k=0 or k= n/2; n= number of total sectors.

3.1.2 CS: PRINTED OUTPUT

As discussed in Section 2.1.4, the printed output for cyclic symmetry models with no plane of reflective symmetry is controlled by the user through the optional registers !VPRT and !ES. For static analysis, sector displacements and element stresses are printed. For vibrational and buckling analyses, the printout consists of eigenvectors and tables of eigenvalues, frequencies, and convergence characteristics. Printout is produced only for those sectors named in the input data set (BACK SECTORS), see Sections 2.1.1 through 2.1.3. All printout is appropriately labeled according to sector number and circumferential harmonic number.

Several examples of printout follow.

CS: DISPLACEMENT VECTOR PRINTOUT

```
STATIC DISPLACEMENTS, SECTOR   1.                            ID=   1/ 1/ 1

EDGE LOADING, CONICAL SHELL, CYCLIC SYMMETRY MODEL

JOINT         1          2          3          4          5          6
   1    -.782-04   .142-08   .516-05  -.540-05   .600-04   .330-05
   2    -.772-04   .125-04   .510-05   .726-06   .593-04  -.518-06
   3    -.724-04   .128-08   .221-05  -.469-05   .738-04   .268-05
   4    -.715-04   .111-04   .219-05   .110-05   .729-04  -.151-05
   5    -.651-04   .116-08  -.961-06  -.342-05   .761-04   .200-05
   6    -.643-04   .986-05  -.949-06   .240-05   .751-04  -.173-05
   7    -.587-04   .103-08  -.320-05  -.249-05   .610-04   .144-05
   8    -.579-04   .874-05  -.316-05   .318-05   .602-04  -.202-05
   9    -.529-04   .908-09  -.474-05  -.201-05   .544-04   .116-05
  10    -.523-04   .773-05  -.468-05   .340-05   .537-04  -.212-05



VIBRATIONAL MODE.                                        ID=   5/ 1/ 1
SECTOR   1, HARMONIC   5.
EIGENVALUE=   .3428324+08,   FREQ=    931.8823 HZ

JOINT         1          2          3          4          5          6
   1    -.457+02  -.161+02   .000      .000      .000      .425+02
   2    -.929+02  -.531+01   .000      .000      .000      .140+02
   3    -.451+02  -.159+02  -.451+00  -.576+00   .231+01   .420+02
   4    -.917+02  -.524+01  -.916+00   .743-01   .479+01   .138+02
   5    -.435+02  -.153+02  -.891+00  -.133+01   .462+01   .404+02
   6    -.883+02  -.505+01  -.181+01  -.486-01   .947+01   .133+02
   7    -.407+02  -.143+02  -.131+01  -.212+01   .683+01   .379+02
   8    -.828+02  -.473+01  -.266+01  -.275+00   .139+02   .125+02
   9    -.370+02  -.130+02  -.169+01  -.287+01   .886+01   .344+02
  10    -.751+02  -.429+01  -.344+01  -.542+00   .180+02   .113+02



BUCKLING MODE.                                           ID=   6/ 1/ 1
SECTOR   1, HARMONIC   6.
EIGENVALUE=   .1933858+03

JOINT         1          2          3          4          5          6
   1     .271+00   .537-02   .000      .000      .000     -.205-01
   2     .187+00  -.310-01   .000      .000      .000      .119+00
   3     .268+00   .530-02   .234-02  -.542-03  -.143-01  -.203-01
   4     .185+00  -.306-01   .162-02  -.199-02  -.998-02   .117+00
   5     .258+00   .510-02   .463-02  -.577-03  -.282-01  -.195-01
   6     .178+00  -.294-01   .320-02  -.385-02  -.196-01   .113+00
   7     .241+00   .478-02   .680-02  -.354-03  -.415-01  -.183-01
   8     .167+00  -.276-01   .470-02  -.547-02  -.287-01   .106+00
   9     .219+00   .434-02   .881-02  -.233-04  -.537-01  -.166-01
  10     .151+00  -.251-01   .608-02  -.687-02  -.371-01   .960-01
```

CS: ELEMENT STRESS PRINTOUT

```
PAGE    1  CYCLIC SYMMETRY, ELEMENT STRESSES, SECTOR 4
S/C  1/  2 EDGE LOADING, CONICAL SHELL, CYCLIC SYMMETRY MODEL
E43

GRP-IND*/
  JOINTS            NX        NY       NXY  ANG    MAX PN    MIN PN   MAX SHR
  1-    1*     .545-01  .152+00 -.950+00 134.   .105+01 -.848+00  .951+00
  1-    2*    -.153-01  .386+00 -.791+00 128.   .100+01 -.631+00  .816+00
  1-    3*    -.175-02  .546+00 -.670+00 124.   .996+00 -.452+00  .724+00
  1-    4*    -.125-02  .656+00 -.574+00 120.   .989+00 -.334+00  .662+00
  1-    5*    -.219-02  .731+00 -.498+00 117.   .983+00 -.254+00  .618+00
  1-    6*    -.177-02  .782+00 -.436+00 114.   .976+00 -.196+00  .586+00
  1-    7*    -.162-02  .816+00 -.385+00 112.   .968+00 -.154+00  .561+00
  1-    8*    -.151-02  .837+00 -.342+00 110.   .959+00 -.123+00  .541+00
  1-    9*    -.138-02  .849+00 -.306+00 108.   .947+00 -.100+00  .524+00
  1-   10*    -.127-02  .854+00 -.275+00 106.   .935+00 -.823-01  .509+00
  1-   11*    -.118-02  .854+00 -.249+00 105.   .921+00 -.686-01  .495+00
  1-   12*    -.107-02  .850+00 -.227+00 104.   .907+00 -.577-01  .482+00
```

```
PAGE    1  CYCLIC SYMMETRY, ELEMENT STRESSES, SECTOR 1
S/C  1/  1 RAIL WHEEL EXAMPLE
S81

 STRESSES
GRP-IND* JOINT     ONS       OSS       SI      SYR
  1/    1*  MID    .402+03  .111+04  .257+04  .000
  1/    2*  MID  -.120+03  .453+03  .102+04  .000
  1/    3*  MID    .221+04  .160+04  .393+04  .000
  1/    4*  MID  -.974+03  .126+04  .301+04  .000
  1/    5*  MID    .930+03  .903+03  .200+04  .000
  1/    6*  MID    .837+02  .405+03  .991+03  .000
  1/    7*  MID    .597+03  .431+03  .931+03  .000
  1/    8*  MID    .840+02  .184+03  .446+03  .000
  1/    9*  MID    .954+02  .116+03  .281+03  .000
  1/   10*  MID    .115+03  .250+03  .600+03  .000
  1/   11*  MID  -.294+03  .306+03  .742+03  .000
  1/   12*  MID    .166+03  .322+03  .767+03  .000
```

CS: VIBRATIONAL EIGENVALUE PRINTOUT

```
CYCLIC SYMMETRY VIBRATIONAL EIGENVALUES FOLLOW:

      HARMONIC
MODE   NUMBER   EIGENVALUE         HZ
   1      1      .7508+07      436.11
   2      1      .7508+07      436.11
   3      2      .2289+08      761.52
   4      2      .2289+08      761.52
   5      0      .2386+08      777.35
   6      0      .4922+08     1116.57
   7      3      .1096+09     1666.33
   8      3      .1096+09     1666.33
   9      1      .1161+09     1714.57
  10      1      .1161+09     1714.57
  11      2      .1803+09     2137.32
  12      2      .1803+09     2137.32
  13      4      .2572+09     2552.20
  14      4      .2572+09     2552.30
  15      0      .3257+09     2872.42
  16      3      .3730+09     3073.97
  17      3      .3730+09     3073.97
  18      1      .4745+09     3466.83
  19      1      .4745+09     3466.88
  20      3      .4854+09     3506.62
  21      3      .4855+09     3506.72
  22      0      .6275+09     3986.69
  23      4      .8122+09     4535.66
  24      4      .8153+09     4544.35
  25      2      .8308+09     4587.40
  26      2      .8362+09     4602.38
  27      2      .8433+09     4621.87
  28      2      .8483+09     4635.51
  29      1      .8637+09     4677.27
  30      1      .8669+09     4685.97
  31      2      .1162+10     5424.33
  32      3      .1224+10     5568.93
  33      1      .1338+10     5821.83
  34      1      .1366+10     5883.15
  35      3      .1403+10     5962.37
  36      0      .1426+10     6010.39
  37      3      .1548+10     6261.61
  38      4      .1755+10     6668.14
  39      4      .1778+10     6710.19
  40      3      .1874+10     6889.51
  41      0      .2057+10     7218.62
  42      0      .2057+10     7218.84
  43      2      .2389+10     7778.75
  44      4      .2670+10     8223.40
  45      4      .2693+10     8258.71
  46      0      .3371+10     9240.64
  47      0      .3684+10     9659.75
  48      4      .4469+10    10639.18
```

CS: VIBRATIONAL EIGENVALUE PRINTOUT, (cont.)

```
VIBRATIONAL FREQUENCIES, HZ

          HARMONICS:
MODE        0        1        2        3        4
  1     .777+03  .436+03  .762+03  .167+04  .255+04
  2     .112+04  .436+03  .762+03  .167+04  .255+04
  3     .287+04  .171+04  .214+04  .307+04  .454+04
  4     .399+04  .171+04  .214+04  .307+04  .454+04
  5     .601+04  .347+04  .459+04  .351+04  .667+04
  6     .722+04  .347+04  .460+04  .351+04  .671+04
  7     .722+04  .468+04  .462+04  .557+04  .822+04
  8     .924+04  .469+04  .464+04  .596+04  .826+04
  9     .966+04  .582+04  .542+04  .626+04  .106+05
 10     .122+05  .588+04  .778+04  .689+04  .119+05


EIGENVALUES

          HARMONICS:
MODE        0        1        2        3        4
  1     .239+08  .751+07  .229+08  .110+09  .257+09
  2     .492+08  .751+07  .229+08  .110+09  .257+09
  3     .326+09  .116+09  .180+09  .373+09  .812+09
  4     .627+09  .116+09  .180+09  .373+09  .815+09
  5     .143+10  .474+09  .831+09  .485+09  .176+10
  6     .206+10  .474+09  .836+09  .485+09  .178+10
  7     .206+10  .864+09  .843+09  .122+10  .267+10
  8     .337+10  .867+09  .848+09  .140+10  .269+10
  9     .368+10  .134+10  .116+10  .155+10  .447+10
 10     .591+10  .137+10  .239+10  .187+10  .561+10


EIGENVALUE CONVERGENCE MATRIX

          HARMONICS:
MODE        0        1        2        3        4
  1     .000     .000     .000    -.912-08  .000
  2     .000     .000     .000    -.912-08  .000
  3    -.123-07  .000    -.111-07 -.429-07 -.493-07
  4    -.892-07  .000     .000    -.168-04 -.196-07
  5    -.238-04 -.814-05 -.150-04 -.659-05 -.506-03
  6    -.579-04 -.211-03 -.222-02 -.391-03 -.133-04
  7    -.391-03 -.317-03 -.815-04 -.425-02 -.355-02
  8    -.669-02 -.544-02 -.929-02 -.278-01 -.141-02
  9    -.404-01 -.175-02 -.353-02 -.257-01 -.169-02
 10    -.459-01 -.490-02 -.883-02 -.576-01 -.195+00
```

The EIGENVALUE CONVERGENCE MATRIX is computed as (E-P)/E, where

E= matrix of eigenvalues, and
P= matrix of eigenvalues from the next-to-last EIG iteration.

CS: BUCKLING EIGENVALUE PRINTOUT

```
 CYCLIC SYMMETRY BUCKLING EIGENVALUES FOLLOW:

      HARMONIC
 MODE  NUMBER   EIGENVALUE
    1    8       .1089+03
    2    8       .1089+03
    3    9       .1105+03
    4    9       .1105+03
    5    7       .1270+03
    6    7       .1270+03
    7    6       .1934+03
    8    6       .1934+03
    9    9       .7415+03
   10    9       .7426+03
   11    8       .9631+03
   12    8       .9682+03
   13    7       .1340+04
   14    7       .1372+04
   15    6       .2020+04
   16    6       .2130+04



 EIGENVALUES

        HARMONICS:
 MODE      6         7         8         9
    1   .193+03   .127+03   .109+03   .110+03
    2   .193+03   .127+03   .109+03   .110+03
    3   .202+04   .134+04   .963+03   .741+03
    4   .213+04   .137+04   .968+03   .743+03


 EIGENVALUE CONVERGENCE MATRIX

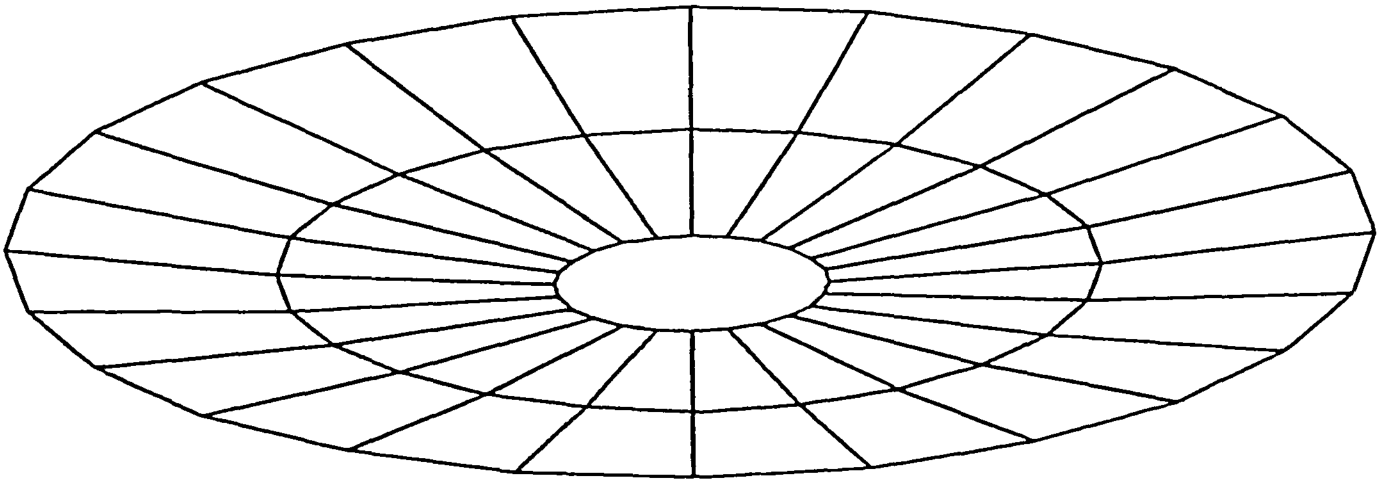
        HARMONICS:
 MODE      6         7         8         9
    1  -.397-05  -.841-06  -.709-06  -.123-05
    2  -.439-05  -.916-06  -.595-06  -.128-05
    3  -.298-01  -.227-01  -.104-01  -.540-02
    4  -.877-02  -.306-01  -.172-01  -.857-02
```

The EIGENVALUE CONVERGENCE MATRIX is computed as (E-P)/E, where

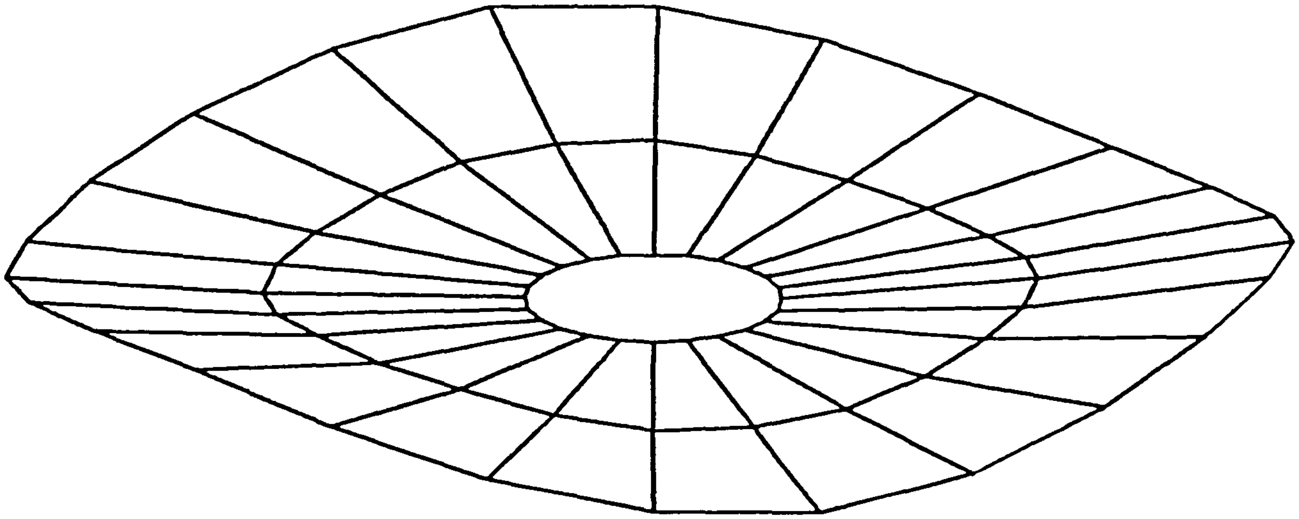
E= matrix of eigenvalues, and
P= matrix of eigenvalues from the next-to-last EIG iteration.

3.1.3. CS: PLOTTED OUTPUT

The plots shown below are examples of whole structure plots generated from a cyclic symmetry model of one sector. The runstream element CS PLOT was used to construct plots.



Undeformed Structure



Deformed Structure

Instructions for using CS PLOT are given on the following two pages.

The runstream element (CS PLOT) may be used to produce a pseudo model of the entire structure for purposes of generating undeformed and deformed plots of the entire assemblage of cyclically symmetrical sectors. For undeformed plots, it is necessary that "LIB1" from the (CS) execution be attached as Library 1. For deformed plots (static displacements, vibrational modes, or buckling modes), it is necessary that "LIB5" be attached as Library 5. See section 2.10 for descriptions of library contents. Data sets characterizing the pseudo model are inserted into EAL Library 2 by (CS PLOT).

Given a list of joint numbers which are a subset of the joints in the CS model, (CS PLOT) produces data sets containing joint locations and specified displacement vectors for the pseudo model. Plot specifications for the pseudo model are supplied by the user through LINES and/or CONNECT commands in PLTA. PLTB is then used to construct the required plots.

To plot the entire assemblage of cyclically symmetrical sectors, proceed as follows:

*XQT AUS	
OUTLIB=2	The following data set resides in Lib 2.
TABLE(NJ=njt, TYPE=0):JLIST J=1,njt: j1: j2:---	j1, j2,---is a list of joints from the CS model to include in the pseudo model. The total number of joints in the pseudo model will be (njt x NSECTORS). Joint 1 of the psuedo model is j1 of sector 1; joint 2 is j2 of sector 1; joint (njt+1) is j1 of sector 2; etc.
*XQT U1	
*(PLOT OPTIONS)	
!PROB = 'UNDEFORMED	For undeformed plots only, no displacement vectors.
= 'STAT	For static displacement vectors,
= 'VIBR	For vibrational modes,
= 'BUCK	For buckling modes, Default is !PROB='VIBR.
!SET = set !CON = con	If !PROB='STAT, set and con are the static solution set number and constraint condition. Default is set=1, con=1. For other !PROB values, SET and CON are not used.

```
*XQT AUS                          The following data set resides in Lib 2.
 OUTLIB=2

 TABLE(NJ=n, TYPE=0):HARMONICS    If !PROB='VIBR or 'BUCK, model vectors for
    J=1,n: k1: k2:---             the pseudo model are to be produced for
                                  harmonics k1, k2,---. For !PROB='UNDE or
                                  'STAT, this data set is not required.

*CALL (CS PLOT 1 1 )              Generate the pseudo model joint locations
                                  and the required displacement vectors.

*XQT PLTA

 SPEC 1

 LINES and/or CONNECT commands.   Pseudo model plot specifications are
                                  defined through these commands. Note that
                                  joint 1 of the pseudo model is j1 of the
                                  data set  JLIST; joint 2 is j2, etc.

 ---

*XQT PLTB

 ---

 Plot the required specs.

 ---
```

Note that no element definitions are generated for the pseudo model, only joint locations and displacement vectors. Consequently, all plot specifications consist of user supplied LINES and/or CONNECT commands. See the Volume 1 of the EAL Reference Manual for a discussion of these commands.

3.2.1 CSR: OUTPUT DATA SETS

The output data sets produced by CSR for cyclic symmetry models with a plane of reflective symmetry are summarized in this section. The registers LIB1, LIB5, LIB6, set, CONS, CONA, NVECTORS, NEVALS, and QSAV are discussed in section 2.2.4. Values assigned to registers CONS and CONA are represented by "cons" and "cona", respectively. The value assigned to SET is represented by "set".

The following data sets are output to LIB1.

Data Set Name			Contents
CON	cons	0	The active constraint plus symmetric constraint on the reflective plane.
CON	cona	0	The active constraint plus anti-symmetric constraint on the reflective plane.

If data set (CON "CONS" 0) and (CON "CONA" 0) reside in LIB1 at the beginning of the analysis, no new CON data sets will be produced.

In the following, nbsc is the number of sectors for which solution vectors are computed, as specified via the data set BACK SECTORS, See Sections 2.2.1, 2.2.2, and 2.2.3.

STATIC ANALYSIS

For static analysis, the following data sets are output to LIB5:

Data Set Name				Contents
SECT	BACK	set	1	(S1,S2--Si--Snbsc),NJ=nbsc
U+	DISP	set	1	NBLOCKS=nbsc. Block i is the displacement vector for the +side of sector Si, the ith entry in SECT BACK set 1.
U-	DISP	set	1	NBLOCKS=nbsc. Block i is the displacement vector for the -side of sector Si, the ith entry in SECT BACK set 1.
CASE	TITL	set	1	Blocked case title data set for use with ES.
QLIB	HARM	set	k1	LIBLIB data sets created from LIB6 for each harmonic solution. These data sets are stored only if the register QSAV =1. k1, k2, etc. are harmonic numbers. The contents of the data sets is discussed below.
QLIB	HARM	set	k2	
- - -				

Note that the -side displacement vectors stored in U- DISP set 1 are relative to left handed joint reference frames, see Fig. 4.

If U+ DISP set 1 and U- DISP set 1 reside in LIB5 at the beginning of the static analysis, the newly computed harmonic components are added to the existing data sets.

For each harmonic solution, the library LIB6 is used for storage of the harmonic force and displacement arrays. For the k-th harmonic solution, LIB6 will contain the following data sets:

Data Set Name				Contents
APPL	FORC	1	1	Force and displacement vectors, first harmonic solution, Eq. 28, section 6.
STAT	DISP	1	1	
APPL	FORC	2	1	Force and displacement vectors, second harmonic solution, Eq. 29, section 6.
STAT	DISP	2	2	
QCA	AUS	k	1	The anti-symmetric cosine component of the solution, Q^{a}_{kc} of Eq. 9, section 1.1.
QCS	AUS	k	1	The symmetric cosine component of the solution, Q^{s}_{kc} of Eq. 10, section 1.1.
QSA	AUS	k	1	The anti-symmetric sine component of the solution, Q^{a}_{ks} of Eq. 9, section 1.1.
QSS	AUS	k	1	The symmetric sine component of the solution, Q^{s}_{ks} of Eq. 10, section 1.1.

Data sets QSA AUS k 1 and QSS AUS k 1 are not present in LIB6 for k=0 or k=n/2, where n= number of sectors in the complete structure.

VIBRATIONAL AND BUCKLING ANALYSES

For vibrational and buckling analyses of cyclic symmetry models with a plane of reflective symmetry, the data sets tabulated below are output to LIB5.

Data Set Name	Contents
EVAL HARM 1 1	(k1, k2,---kn) , Circumferential Harmonic Values.
S-EV MATR 1 1	$\begin{bmatrix} W11 & W12---Win \\ W21 & W22---W2n \\ - - - & \\ Wm1 & Wm2---Wmn \end{bmatrix}$, Wij= eigenvalue corresponding to the ith mode of harmonic kj, with symmetric constraints on the reflective plane. NI= NEVALS.
S-PR MATR 1 1	Matrix of eigenvalues from the next-to-last EIG iteration. Same format as S-EV MATR 1 1.
S-CO MATR 1 1	Eigenvalue convergence matrix computed as ((S-EV)- (S-PR))/(S-EV).
S-HZ MATR 1 1	S-EV MATR 1 1 converted to HZ units. Present only if PROB= 'VIBR.
A-EV MATR 1 1	Eigenvalue matrices corresponding to anti-symmetric constraints on the reflective plane. Formats and content are the same as (S-EV), (S-PR), (S-CO), and (S-HZ).
A-PR MATR 1 1	
A-CO MATR 1 1	
A-HZ MATR 1 1	

The following data sets are output to LIB5 for each circumferential harmonic k=k1, k2,---kn. Data sets with a first word of SYM correspond to symmetric reflective eigensolutions. Data sets with a first word of ASYM correspond to anti-symmetric reflective eigensolutions.

Data Set Name	Contents
SECT BACK k 0	(S1, S2,--SnBsc),NJ=nbsc
SYM EVAL k cons	(W1, W2,---),Eigenvalues, NJ= NEVALS
SYM PREV k cons	(W1, W2,---),Eigenvalues, next-to-last EIG iteration.
SYM MODE k S1	Eigenvectors, Sector S1, Symmetric Motion, NBLOCKS= NVECTORS.
SYM MODE k S2	Eigenvectors, Sector S2, Symmetric motion.
- - -	
SYM MODE k Snbsc	Eigenvectors, Sector Snbsc, Symmetric motion.

Data Set Name	Contents
ASYM EVAL k cona	(W1, W1---),Eigenvalues, NJ= NVECTORS.
ASYM PRE k cona	(W1, W2---),Eigenvalues, next-to-last EIG iteration.
ASYM MODE k S1	Eigenvectors, Sector S1, Anti-Symmetric Motion, NBLOCKS= NVECTORS.
ASYM MODE k S2	Eigenvectors, Sector S2, Anti-Symmetric Motion.
ASYM MODE k Snbsc	Eigenvectors, Sector Snbsc, Anti-Symmetric Motion.
- - -	
QLIB HARM k k	LIBLIB data set created from LIB6. This data set is stored only if the register QSAV=1. The contents of this data set are discussed below.

For the k-th harmonic solution, LIB6 will contain the following data sets:

Data Set Name	Contents
"PROB" EVAL k 1	Eigenvalues and eigenvectors, first harmonic solution, see section 6.
"PROB" PREV k 1	
"PROB" MODE k 1	
"PROB" EVAL k 2	Eigenvalues and eigenvectors, second harmonic solution, see section 6.
"PROB" PREV k 2	
"PROB" MODE k 2	
QCA AUS k 1	The anti-symmetric cosine components of the eigenvectors. Q^{a}_{kc} of Eq. 9, section 1.1.
QCS AUS k 1	The symmetric cosine components of the eigenvectors. Q^{s}_{kc} of Eq. 10, section 1.1.
QSA AUS k 1	The anti-symmetric sine components of the eigenvectors. Q^{a}_{ks} of Eq. 9, section 1.1.
QSS AUS k 1	The symmetric sine components of the eigenvectors. Q^{s}_{ks} of Eq. 10, section 1.1.

Data sets QSA AUS k 1 and QSS AUS k 1 are not present on LIB6 for k=0, or k= n/2; n= number of sectors in the complete model.

3.2.2 CSR: PRINTED OUTPUT

As discussed in Section 2.2.4, the printed output for cyclic symmetry models with a plane of reflective symmetry is controlled by the user through optional registers !VPRT and !ES. For static analysis, sector displacements and element stresses are printed. For vibrational and buckling analyses, the printout consists of eigenvectors and tables of eigenvalues, frequencies, and convergence characteristics. Printout is produced only for those sectors named in the input data set (BACK SECTORS), see Sections 2.2.1 through 2.2.3. All printout is appropriately labeled according to sector number, sector side (+ or -), and circumferential harmonic number. Eigenvectors are labeled according to the boundary condition (symmetry of anti-symmetry) imposed on the reflective symmetry plane.

Several examples of printout follow.

CSR: DISPLACEMENT VECTOR PRINTOUT

```
SECTOR   6, +SIDE DISPLACEMENTS.                            ID=    1/ 1/ 4

EDGE LOADING, CONICAL SHELL, CYCLIC SYMMETRY MODEL

JOINT        1          2          3          4          5          6
    1    -.122-04    .783-04    .803-06    .400-04    .939-05   -.249-04
    2     .690-09    .793-04   -.455-10    .405-04   -.527-09   -.253-04
    3    -.113-04    .697-04    .344-06    .382-04    .115-04   -.273-04
    4     .640-09    .705-04   -.196-10    .389-04   -.652-09   -.278-04
    5    -.101-04    .619-04   -.149-06    .384-04    .118-04   -.245-04
    6     .575-09    .626-04    .849-11    .395-04   -.672-09   -.252-04


SECTOR   6, -SIDE DISPLACEMENTS.                            ID=    1/ 1/ 4

EDGE LOADING, CONICAL SHELL, CYCLIC SYMMETRY MODEL

JOINT        1          2          3          4          5          6
    1     .122-04   -.783-04   -.803-06   -.400-04   -.939-05    .249-04
    2     .690-09   -.793-04   -.455-10   -.405-04   -.527-09    .253-04
    3     .113-04   -.697-04   -.344-06   -.382-04   -.115-04    .273-04
    4     .640-09   -.705-04   -.196-10   -.389-04   -.652-09    .278-04
    5     .101-04   -.619-04    .149-06   -.384-04   -.118-04    .245-04
    6     .575-09   -.626-04    .849-11   -.395-04   -.672-09    .252-04


VIBRATIONAL MODE.                                        ID=    4/ 1/ 1
SECTOR   1, HARMONIC    4, SYMMETRIC MOTION.
EIGENVALUE=   .5629889+08,   FREQ=   1194.1807 HZ

JOINT        1          2          3          4          5          6
    1    -.779+02   -.128+02    .000       .000       .000       .226+02
    2    -.963+02    .000       .000       .000       .000       .000
    3    -.769+02   -.127+02   -.823+00   -.802+00    .394+01    .224+02
    4    -.951+02    .000      -.102+01    .000       .487+01    .000
    5    -.741+02   -.122+02   -.163+01   -.148+01    .778+01    .215+02
    6    -.916+02    .000      -.201+01    .000       .966+01    .000


BUCKLING MODE.                                           ID=    6/ 1/ 1
SECTOR   1, HARMONIC    6, ANTI-SYMMETRIC MOTION.
EIGENVALUE=   .1933798+03

JOINT        1          2          3          4          5          6
    1    -.221+00    .250-01    .000       .000       .000      -.959-01
    2     .000       .425-01    .000       .000       .000      -.162+00
    3    -.218+00    .247-01   -.191-02    .163-02    .117-01   -.947-01
    4     .000       .420-01    .000       .148-02    .000      -.160+00
    5    -.210+00    .238-01   -.377-02    .296-02    .230-01   -.912-01
    6     .000       .404-01    .000       .369-02    .000      -.155+00
```

CSR: ELEMENT STRESS PRINTOUT

```
PAGE     1  CYCLIC SYMMETRY, +SIDE ELEMENT STRESSES, SECTOR 2
S/C   1/  2 RAIL WHEEL EXAMPLE
S81

 STRESSES
GRP-IND* JOINT     ONS       OSS       SI      SYR
  1/   1*  MID   .220+03  .902+03  .215+04  .000
  1/   2*  MID  -.223+03  .552+03  .133+04  .000
  1/   3*  MID   .147+04  .110+04  .268+04  .000
  1/   4*  MID  -.823+03  .127+04  .297+04  .000
  1/   5*  MID   .738+03  .686+03  .157+04  .000
  1/   6*  MID   .139+03  .591+03  .143+04  .000
  1/   7*  MID   .502+03  .418+03  .102+04  .000
  1/   8*  MID  -.395+02  .648+03  .159+04  .000
  1/   9*  MID   .233+03  .342+03  .739+03  .000
  1/  10*  MID  -.180+03  .640+03  .155+04  .000
  1/  11*  MID   .326+02  .409+03  .100+04  .000
  1/  12*  MID  -.309+03  .640+03  .149+04  .000
```

```
PAGE     1  CYCLIC SYMMETRY, -SIDE ELEMENT STRESSES, SECTOR 2
S/C   1/  2 RAIL WHEEL EXAMPLE
S81

 STRESSES
GRP-IND* JOINT     ONS       OSS       SI      SYR
  1/   1*  MID   .212+03  .792+03  .183+04  .000
  1/   2*  MID   .102+03  .308+03  .755+03  .000
  1/   3*  MID   .156+04  .112+04  .273+04  .000
  1/   4*  MID  -.206+03  .109+04  .265+04  .000
  1/   5*  MID   .557+03  .592+03  .143+04  .000
  1/   6*  MID   .859+02  .831+03  .203+04  .000
  1/   7*  MID   .429+03  .387+03  .931+03  .000
  1/   8*  MID  -.706+02  .691+03  .169+04  .000
  1/   9*  MID   .206+03  .363+03  .797+03  .000
  1/  10*  MID  -.205+03  .630+03  .151+04  .000
  1/  11*  MID   .245+02  .383+03  .937+03  .000
  1/  12*  MID  -.323+03  .638+03  .148+04  .000
```

CSR: VIBRATIONAL EIGENVALUE PRINTOUT

```
CYCLIC SYMMETRY VIBRATIONAL EIGENVALUES FOLLOW:

     HARMONIC  REFLECTIVE
MODE  NUMBER   BND. COND.   EIGENVALUE          HZ
   1     7        ASYM       .2259+08       756.37
   2     7        SYMM       .2259+08       756.37
   3     6        ASYM       .2473+08       791.48
   4     6        SYMM       .2473+08       791.48
   5     8        SYMM       .2567+08       806.41
   6     8        ASYM       .2567+08       806.41
   7     9        ASYM       .3331+08       918.52
   8     9        SYMM       .3331+08       918.52
   9     5        SYMM       .3428+08       931.86
  10     5        ASYM       .3428+08       931.86
  11    10        SYMM       .4558+08      1074.46
  12    10        ASYM       .4559+08      1074.58
  13     4        ASYM       .5630+08      1194.18
  14     4        SYMM       .5630+08      1194.18
  15     9        ASYM       .6303+08      1263.58
  16     9        SYMM       .6303+08      1263.58
  17     8        ASYM       .8648+08      1480.05
  18     8        SYMM       .8648+08      1480.05
  19     7        ASYM       .1169+09      1721.11
  20     7        SYMM       .1169+09      1721.11
  21     6        SYMM       .1556+09      1985.35
  22     6        ASYM       .1556+09      1985.36
  23     5        ASYM       .2038+09      2271.98
  24     5        SYMM       .2038+09      2272.00


VIBRATIONAL FREQUENCIES, HZ
SYMMETRIC CONSTRAINT ON THE REFLECTIVE PLANE

       HARMONICS:
MODE     4        5        6        7        8        9        10
   1  .119+04  .932+03  .791+03  .756+03  .806+03  .919+03  .107+04
   2  .258+04  .227+04  .199+04  .172+04  .148+04  .126+04  .242+04
   3  .288+04  .275+04  .262+04  .251+04  .243+04  .240+04  .421+04
   4  .378+04  .344+04  .308+04  .282+04  .264+04  .251+04  .633+04


VIBRATIONAL FREQUENCIES, HZ
ANTI-SYMMETRIC CONSTRAINT ON THE REFLECTIVE PLANE

       HARMONICS:
MODE     4        5        6        7        8        9        10
   1  .119+04  .932+03  .791+03  .756+03  .806+03  .919+03  .107+04
   2  .258+04  .227+04  .199+04  .172+04  .148+04  .126+04  .242+04
   3  .288+04  .275+04  .262+04  .251+04  .243+04  .240+04  .420+04
   4  .360+04  .330+04  .304+04  .281+04  .263+04  .250+04  .631+04
```

CSR: VIBRATIONAL EIGENVALUE PRINTOUT (cont.)

```
EIGENVALUES
SYMMETRIC CONSTRAINT ON THE REFLECTIVE PLANE

        HARMONICS:
MODE      4        5        6        7        8        9        10
  1    .563+08  .343+08  .247+08  .226+08  .257+08  .333+08  .456+08
  2    .263+09  .204+09  .156+09  .117+09  .865+08  .630+08  .232+09
  3    .328+09  .298+09  .270+09  .248+09  .234+09  .228+09  .699+09
  4    .565+09  .467+09  .374+09  .314+09  .276+09  .248+09  .158+10


EIGENVALUE CONVERGENCE MATRIX
SYMMETRIC CONSTRAINT ON THE REFLECTIVE PLANE

        HARMONICS:
MODE      4        5        6        7        8        9        10
  1   -.888-08 -.146-07  .000     .000     .000    -.600-07 -.110-07
  2   -.322-03 -.128-03 -.322-04 -.545-05 -.379-04 -.612-05 -.139-04
  3   -.354-04 -.140-04 -.297-04 -.134-03 -.235-02 -.821-02 -.239-02
  4   -.936-02 -.486-01 -.440-01 -.216-01 -.549-01 -.541-01 -.178-01


EIGENVALUES
ANTI-SYMMETRIC CONSTRAINT ON THE REFLECTIVE PLANE

        HARMONICS:
MODE      4        5        6        7        8        9        10
  1    .563+08  .343+08  .247+08  .226+08  .257+08  .333+08  .456+08
  2    .263+09  .204+09  .156+09  .117+09  .865+08  .630+08  .232+09
  3    .328+09  .298+09  .270+09  .248+09  .233+09  .228+09  .698+09
  4    .513+09  .430+09  .364+09  .311+09  .273+09  .247+09  .157+10


EIGENVALUE CONVERGENCE MATRIX
ANTI-SYMMETRIC CONSTRAINT ON THE REFLECTIVE PLANE

        HARMONICS:
MODE      4        5        6        7        8        9        10
  1    .000     .000     .000     .000     .000    -.195-06  .000
  2   -.496-03 -.480-04 -.566-04 -.652-05 -.342-04 -.589-05 -.527-06
  3   -.770-04 -.225-04 -.869-04 -.134-03 -.371-02 -.767-02 -.296-03
  4   -.927-03 -.281-03 -.166-02 -.170-02 -.180-01 -.309-01 -.293-02
```

Each EIGENVALUE CONVERGENCE MATRIX is computed as (E-P)/E, where

E= matrix of eigenvalues, and
P= matrix of eigenvalues from the next-to-last EIG iteration.

CSR: BUCKLING EIGENVALUE PRINTOUT

```
 CYCLIC SYMMETRY BUCKLING EIGENVALUES FOLLOW:

      HARMONIC  REFLECTIVE
 MODE  NUMBER   BND. COND.   EIGENVALUE
    1     8        SYMM       .1089+03
    2     8        ASYM       .1089+03
    3     9        SYMM       .1105+03
    4     9        ASYM       .1105+03
    5     7        SYMM       .1270+03
    6     7        ASYM       .1270+03
    7     9        ASYM       .1381+03
    8     9        SYMM       .1381+03
    9     8        ASYM       .1584+03
   10     8        SYMM       .1584+03
   11     7        ASYM       .1817+03
   12     7        SYMM       .1817+03
   13     6        ASYM       .1934+03
   14     6        SYMM       .1934+03
   15     6        SYMM       .2076+03
   16     6        ASYM       .2076+03
   17     6        ASYM       .4763+03
   18     6        SYMM       .4764+03
   19     7        ASYM       .4769+03
   20     7        SYMM       .4774+03
   21     8        SYMM       .4943+03
   22     8        ASYM       .4947+03
   23     9        SYMM       .5377+03
   24     9        ASYM       .5439+03
   25     9        SYMM       .7476+03
   26     8        SYMM       .9663+03
   27     6        ASYM       .1175+04
   28     6        SYMM       .1250+04
   29     7        ASYM       .1270+04
   30     7        SYMM       .1344+04
   31     8        ASYM       .1394+04
   32     9        ASYM       .1476+04
```

CSR: BUCKLING EIGENVALUE PRINTOUT (cont.)

```
EIGENVALUES
SYMMETRIC CONSTRAINT ON THE REFLECTIVE PLANE

          HARMONICS:
MODE          6          7          8          9
   1     .193+03    .127+03    .109+03    .110+03
   2     .208+03    .182+03    .158+03    .138+03
   3     .476+03    .477+03    .494+03    .538+03
   4     .125+04    .134+04    .966+03    .748+03


EIGENVALUE CONVERGENCE MATRIX
SYMMETRIC CONSTRAINT ON THE REFLECTIVE PLANE

          HARMONICS:
MODE          6          7          8          9
   1   -.135-04   -.334-05   -.173-05   -.333-05
   2   -.388-03   -.183-03   -.624-04   -.422-04
   3   -.620-02   -.990-02   -.153-01   -.631-01
   4   -.861-01   -.253-01   -.154-01   -.541-01


EIGENVALUES
ANTI-SYMMETRIC CONSTRAINT ON THE REFLECTIVE PLANE

          HARMONICS:
MODE          6          7          8          9
   1     .193+03    .127+03    .109+03    .110+03
   2     .208+03    .182+03    .158+03    .138+03
   3     .476+03    .477+03    .495+03    .544+03
   4     .118+04    .127+04    .139+04    .148+04


EIGENVALUE CONVERGENCE MATRIX
ANTI-SYMMETRIC CONSTRAINT ON THE REFLECTIVE PLANE

          HARMONICS:
MODE          6          7          8          9
   1   -.679-05   -.223-05   -.360-05   -.103-04
   2   -.323-03   -.102-03   -.319-04   -.114-04
   3   -.465-02   -.508-02   -.108-01   -.199-01
   4   -.511-01   -.481-01   -.564-01   -.130+00
```

Each EIGENVALUE CONVERGENCE MATRIX is computed as (E-P)/E, where

E= matrix of eigenvalues, and
P= matrix of eigenvalues from the next-to-last EIG iteration.

4. EXAMPLES

Examples are presented in the following sections for static, buckling, and vibrational analyses of cyclically symmetrical structures with and without planes of reflective symmetry. The results computed with the cyclic symmetry models are compared with the results obtained with quarter or half models.

Generic model procedures were used to generate all finite element grids used in the following examples.

4.1 GENERIC MODELS USED TO COMPUTE EXAMPLE SOLUTIONS

The runstream elements MODEL BUILDER and RAIL WHEEL are used in the following examples to generate the required finite element grids. MODEL BUILDER is used for all cylindrical, conical, and spherical shell models. RAIL WHEEL is used for all rail wheel models.

In subsequent sections, the following symbols are used:

E= modulus of elasticity,
ν= poisson's ratio,
ρ= weight density,
α= thermal expansion coefficient, and
t= shell thickness.

MODEL BUILDER and RAIL WHEEL are located in the EAL procedure library for example problems (EAL027 at most installations). With EAL027 attached as EAL Library 27, proceed as follows:

- To obtain MODEL BUILDER

```
*XQT U1
*CALL(27 CS DEMO)
```

The above call causes MODEL BUILDER to be entered into LIB 29 along with runstream elements for each of the cylinder, cone, and sphere examples that follow in this section.

- To obtain RAIL WHEEL

```
*XQT U1
*CALL(27 RAIL MODELS)
```

The above call causes RAIL WHEEL to be entered into LIB 29 along with runstream elements for each of the rail wheel examples that follow in this section.

4.1.1 CYLINDRICAL, CONICAL, AND SPHERICAL SHELL MODELS

The runstream element MODEL BUILDER generates cyclic symmetry finite element models for cylindrical, conical, and spherical shells. MODEL BUILDER may be used for models including or excluding reflective symmetry. A finite element model produced by MODEL BUILDER is made up of a strip, one element wide, of n quadrilateral elements lying along a shell generator. Data sets containing the following information are automatically produced by MODEL BUILDER:

- Joint Locations
- Joint Reference Frame Orientations (Cylindrical),
- Material Constants,
- Shell Section Properties,
- E43 Element Definitions, and
- Cyclic Symmetry Boundary Joint Definitions

For models with reflective symmetry, the global y axis is normal to the reflective plane.

To conform with the requirement that all joints lying on the central axis must be fully constrained, spherical models are produced by MODEL BUILDER with a small hole at the apex. This modeling technique introduced no appreciable error in the computed solutions.

To use MODEL BUILDER proceed as shown below, see Examples 4.3.1, 4.2.1, and 4.3.4 for definitions of the symbols used:

- For a cylinder:

```
*XQT U1
*(CYLINDER DEFINITION)
  E    ν    ρ    α    t    radius    height    θ    n
*Call (MODEL BUILDER)
```

- For a cone:

```
*XQT U1
*(CONE DEFINITION)
  E    ν    ρ    α    t    rad1    rad2    height    θ    n
*Call (MODEL BUILDER)
```

- For a sphere:

```
*XQT U1
*(SPHERE DEFINITION)
  E    ν    ρ    α    t    radius    θ    γ    n
*Call (MODEL BUILDER)
```

To use (MODEL BUILDER) proceed as follows:

- o For a cylinder:

```
*XQT U1
*(CYLINDER DEFINITION)
  E    ν    ρ    α    t    radius    height    θ    n
*Call (MODEL BUILDER)
```

See Example 4.3.1 for definitions of the above items.

- o For a cone:

```
*XQT U1
*(CONE DEFINITION)
  E    ν    ρ    α    t    rad1    rad2    height    θ    n
*Call (MODEL BUILDER)
```

See Example 4.2.1 for definitions of the above items.

- o For a sphere:

```
*XQT U1
*(SPHERE DEFINITION)
  E    ν    ρ    α    t    radius    θ    γ    n
*Call (MODEL BUILDER)
```

See Example 4.3.4 for definitions of the above items.

4.1.2 RAIL WHEEL MODELS

The runstream element RAIL WHEEL generates finite element models for the rail wheel examples presented in subsequent sections (see Section 4.3.5). The number of circumferential subdivisions and the total central angle dimension of the desired rail wheel model is specified by the user. Consequently, RAIL WHEEL may be used to generate half models and quarter models in addition to cyclic symmetry models.

For cyclic symmetry + reflective symmetry models, the global y axis is normal to the reflective plane.

Data sets containing the following information are automatically produced by RAIL WHEEL:

- o Joint Locations,
- o Joint Reference Frame Orientations (Cylindrical),
- o Joint Elimination Sequence,
- o Material Constants
- o S81 Element Definitions.

Data sets containing the cyclic symmetry boundary joints must be specified by the user.

To use RAIL WHEEL proceed as follows:

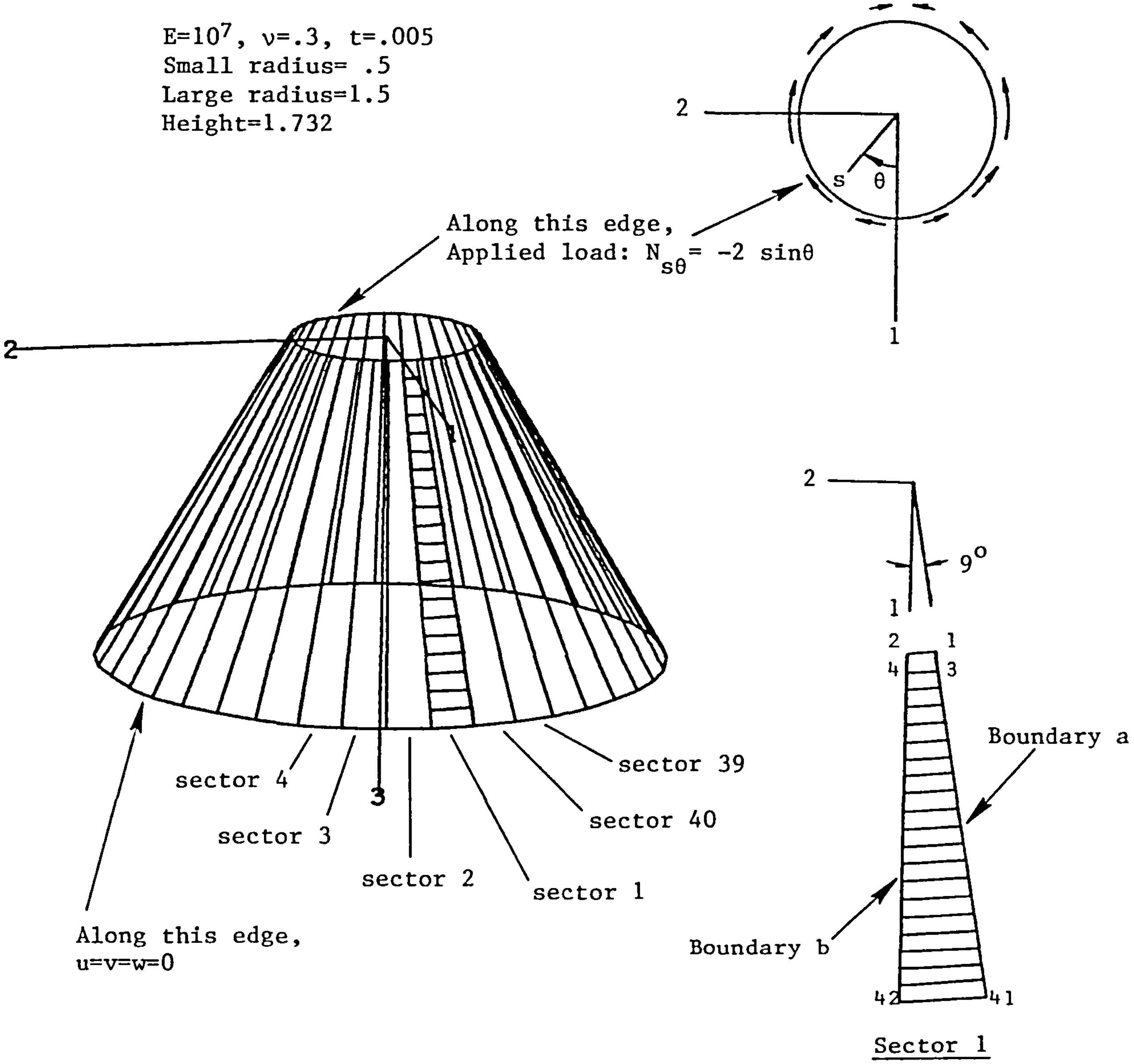
```
*XQT U1
*(RAIL OPTIONS)
     !NTHETA =  number of circumferential
                subdivisions
     ! THETA =  total central angle dimension
                of the model in degrees
*(ISOTROPIC SOLIDS)
  J=1:  E    ν    ρ    α    y_n   y_s
*CALL (RAIL WHEEL)
```

In the above, y_n and y_s are reference yield values for normal stress and yield stress. In the subsequent examples, $a=y_n=y_s=0$.

4.2.1 CS: CONICAL SHELL, EDGE LOADING

The runstream for the problem described below is shown on the next page. The computed results agree exactly with those obtained with the quarter model described in Volume 3 of the EAL Reference Manual. Sample stress printout from the cyclic cymmetry solution is shown on page 4.2.1-2.

$E=10^7$, $\nu=.3$, $t=.005$
Small radius= .5
Large radius=1.5
Height=1.732



```
*XQT U1
*(CONE DEFINITION)
  10.+6  .3  .1   1.-5  .005   .5   1.5   1.732    9.       20
$    E    NU  RHO  ALPHA    T   RAD1  RAD2  HEIGHT  THETA  ELEMENTS
*DCALL(MODEL BUILDER)
*XQT AUS
$
$ FORCE VECTOR COMPUTATION:
 OUTLIB=5: INLIB=5: SYSVEC: F1: I=2: J=1: .15707963
 TABLE(NJ=40): THETA: DDATA=9.: J=1,40: 0.
 SNT=SIN(.017453293 THETA): APPL FORC=CBR(F1,SNT)
 TABLE(NI=18,NJ=1,,TYPE=4): TITLE FORC: J=1
       'EDGE LOADING, CONICAL SHELL, CYCLIC SYMMETRY MODEL
 TABLE(NJ=40,TYPE=0): SECT FORC: DDATA=1: RJ=1,40: 1
$
$ SOLUTION CONTROL DATA SETS:
 TABLE(NJ=1,TYPE=0): HARMONICS: J=1: 1
 TABLE(NJ=4,TYPE=0): BACK SECTORS: J=1,4: 1: 4: 7: 10
*XQT U1
*(CONSTRAINTS)
  ZERO 1 2 3: 41,42
*(OPTIONS)
 !NSECTORS=40: !PROB='STAT
*(ES OPTIONS)
  NODES=0: DISPLAY=MSR
*CALL(CS)
```

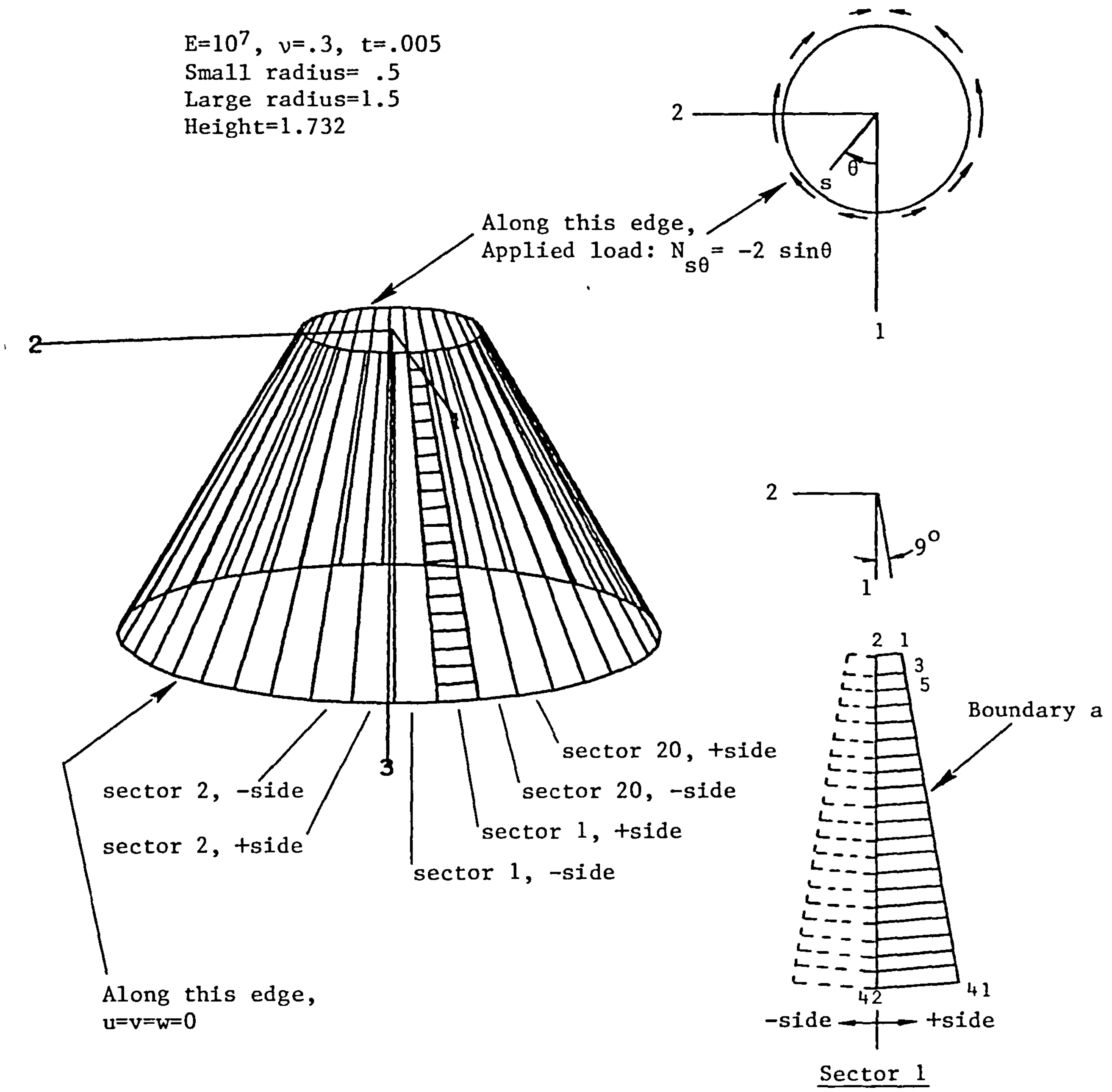
```
PAGE     1  CYCLIC SYMMETRY, ELEMENT STRESSES, SECTOR 1
S/C   1/   1 EDGE LOADING, CONICAL SHELL, CYCLIC SYMMETRY MODEL
E43

GRP-IND*/
  JOINTS              NX         NY        NXY   ANG     MAX PN     MIN PN    MAX SHR
  1-    1*      .637-01   .178+00 -.143+00  124.   .274+00  -.330-01   .154+00
  1-    2*     -.179-01   .452+00 -.119+00  103.   .480+00  -.463-01   .263+00
  1-    3*     -.205-02   .638+00 -.101+00   99.   .653+00  -.175-01   .335+00
  1-    4*     -.147-02   .767+00 -.863-01   96.   .776+00  -.110-01   .394+00
  1-    5*     -.257-02   .855+00 -.748-01   95.   .861+00  -.904-02   .435+00
  1-    6*     -.207-02   .915+00 -.655-01   94.   .919+00  -.672-02   .463+00
  1-    7*     -.189-02   .954+00 -.578-01   93.   .957+00  -.537-02   .481+00
  1-    8*     -.176-02   .978+00 -.514-01   93.   .981+00  -.445-02   .493+00
  1-    9*     -.162-02   .992+00 -.460-01   93.   .994+00  -.374-02   .499+00
  1-   10*     -.149-02   .998+00 -.414-01   92.   .100+01  -.320-02   .502+00
  1-   11*     -.137-02   .998+00 -.374-01   92.   .100+01  -.277-02   .501+00
  1-   12*     -.125-02   .994+00 -.340-01   92.   .995+00  -.241-02   .499+00
  1-   13*     -.115-02   .987+00 -.311-01   92.   .987+00  -.213-02   .495+00
  1-   14*     -.123-02   .977+00 -.285-01   92.   .977+00  -.206-02   .490+00
  1-   15*     -.113-02   .965+00 -.262-01   92.   .966+00  -.184-02   .484+00
  1-   16*      .626-03   .952+00 -.242-01   91.   .953+00   .108-04   .476+00
  1-   17*      .445-04   .939+00 -.224-01   91.   .939+00  -.490-03   .470+00
  1-   18*     -.160-01   .924+00 -.208-01   91.   .925+00  -.165-01   .471+00
  1-   19*     -.121-01   .909+00 -.195-01   91.   .910+00  -.125-01   .461+00
  1-   20*      .138+00   .896+00 -.180-01   91.   .896+00   .137+00   .380+00
```

4.2.2 CSR: CONICAL SHELL, EDGE LOADING

The runstream for the problem described below is shown on the next page. The computed results agree exactly with those obtained with the quarter model described in Volume 3 of the EAL Reference Manual. Sample stress printout for the cyclic symmetry + reflective symmetry solution is shown on page 4.2.2-2.

$E=10^7$, $\nu=.3$, $t=.005$
Small radius= .5
Large radius=1.5
Height=1.732



```
*XQT U1
*(CONE DEFINITION)
  10.+6  .3  .1   1.-5  .005   .5   1.5   1.732    9.       20
$    E   NU  RHO  ALPHA   T   RAD1  RAD2  HEIGHT  THETA  ELEMENTS
*DCALL(MODEL BUILDER)
*XQT AUS
$ APPLIED FORCE COMPUTATION:
 OUTLIB=5: INLIB=5: SYSVEC: F1: I=2: J=1,2: .15707963 .15514572
 SYSVEC: F2: I=2: J=2: -.02457267
 TABLE(NJ=20): THETA: DDATA=18.:J=1,20:0.: CST=COS(.017453293 THETA)
 SNT=SIN(.017453293 THETA): F+ FORC=CBR(F1,SNT): F- FORC=CBR(F2,CST)
 TABLE(NI=18,NJ=1,,TYPE=4): TITLE FORC: J=1
       'EDGE LOADING, CONICAL SHELL, CYCLIC SYMMETRY MODEL
 TABLE(NJ=20,TYPE=0): SECT FORC: DDATA=1: RJ=1,20: 1
$ SOLUTION CONTROL DATA SETS:
 TABLE(NJ=1,TYPE=0): HARMONICS: J=1: 1
 TABLE(NJ=4,TYPE=0): BACK SECTORS: J=1,4: 1: 3: 4: 6
*XQT U1
*(CONSTRAINTS)
  ZERO 1 2 3: 41,42
*(OPTIONS)
 !NSECTORS=20: !RFLP=2: !PROB='STAT
*(ES OPTIONS)
  NODES=0: DISPLAY=MSR
*CALL(CSR)
```

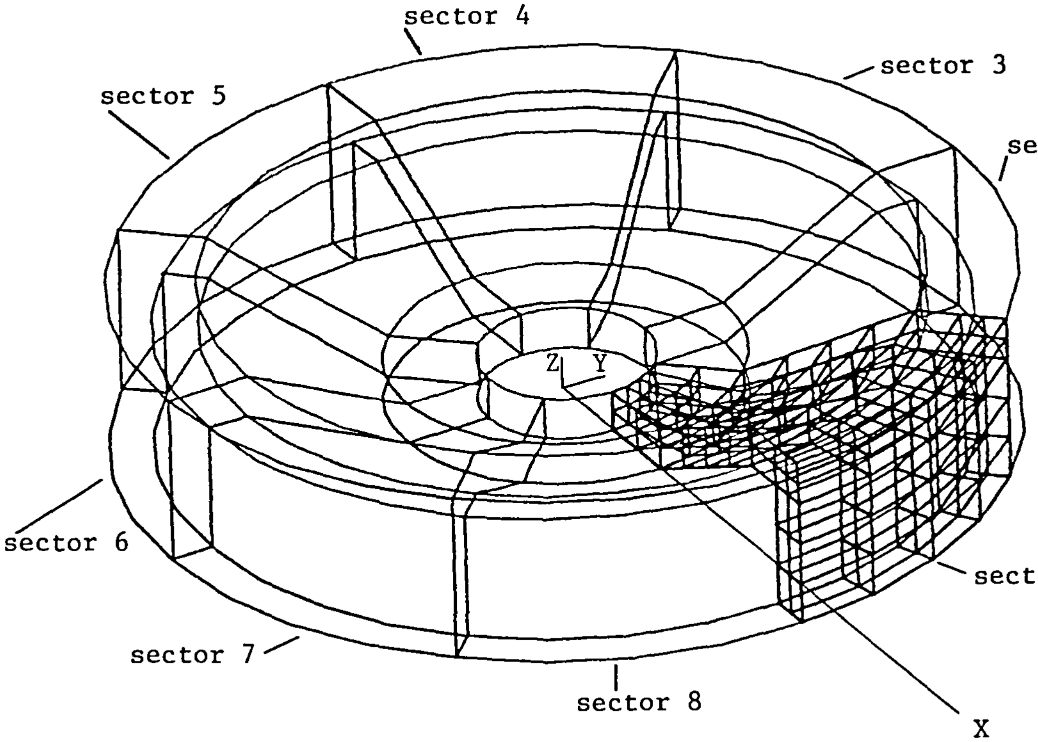
```
PAGE     1  CYCLIC SYMMETRY, +SIDE ELEMENT STRESSES, SECTOR 1
S/C  1/  1 EDGE LOADING, CONICAL SHELL, CYCLIC SYMMETRY MODEL
E43

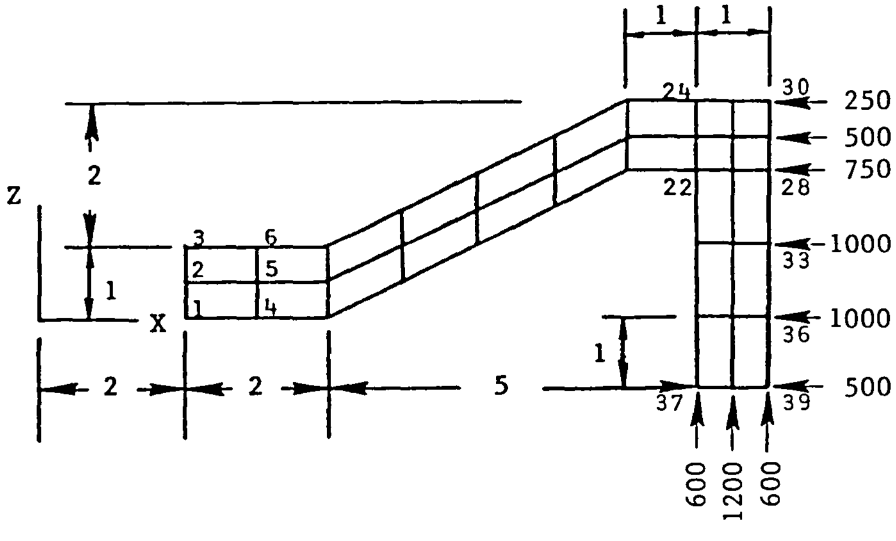
GRP-IND*/
  JOINTS            NX        NY        NXY   ANG    MAX PN    MIN PN   MAX SHR
  1-   1*     .637-01  .178+00 -.143+00  124.  .274+00 -.330-01  .154+00
  1-   2*    -.179-01  .452+00 -.119+00  103.  .480+00 -.463-01  .263+00
  1-   3*    -.206-02  .638+00 -.101+00   99.  .653+00 -.175-01  .335+00
  1-   4*    -.147-02  .767+00 -.863-01   96.  .776+00 -.110-01  .394+00
  1-   5*    -.257-02  .855+00 -.748-01   95.  .861+00 -.904-02  .435+00
  1-   6*    -.207-02  .915+00 -.655-01   94.  .919+00 -.672-02  .463+00
  1-   7*    -.189-02  .954+00 -.578-01   93.  .957+00 -.537-02  .481+00
  1-   8*    -.176-02  .978+00 -.514-01   93.  .981+00 -.445-02  .493+00
  1-   9*    -.161-02  .992+00 -.460-01   93.  .994+00 -.373-02  .499+00
  1-  10*    -.148-02  .998+00 -.414-01   92.  .100+01 -.319-02  .502+00
  1-  11*    -.137-02  .998+00 -.374-01   92.  .100+01 -.277-02  .501+00
  1-  12*    -.125-02  .994+00 -.340-01   92.  .995+00 -.241-02  .499+00
  1-  13*    -.115-02  .987+00 -.311-01   92.  .987+00 -.213-02  .495+00
  1-  14*    -.124-02  .977+00 -.285-01   92.  .977+00 -.207-02  .490+00
  1-  15*    -.113-02  .965+00 -.262-01   92.  .966+00 -.184-02  .484+00
  1-  16*     .612-03  .952+00 -.242-01   91.  .953+00 -.428-05  .476+00
  1-  17*     .267-04  .939+00 -.224-01   91.  .939+00 -.509-03  .470+00
  1-  18*    -.160-01  .924+00 -.209-01   91.  .925+00 -.164-01  .471+00
  1-  19*    -.120-01  .909+00 -.194-01   91.  .910+00 -.125-01  .461+00
  1-  20*     .138+00  .896+00 -.181-01   91.  .896+00  .137+00  .380+00
```

4.2.3 CS: RAIL WHEEL, POINT LOADS

The runstream for the problem described below is shown on the next page. The computed results agree exactly with those obtained with a half model of the wheel. Sample stress printout from the cyclic symmetry solution is shown on page 4.2.3-3.

$E=29 \times 10^6$
$\nu=.3$





Point loads are applied as shown.

Constraint conditions: at joints 4, 5, 6, 160, 161, and 162, u=v=w=0.

```
*XQT U1
*(RAIL OPTIONS)
 !NTHETA=4: !THETA=45.
*(ISOTROPIC SOLIDS)$    E       NU       RHO      OTHERS
  J=1:                  29.+6  .3       .28      0. 0. 0.
*DCALL(RAIL WHEEL)
*XQT AUS
 TABLE(NJ=39,TYPE=0): JA: DDATA=1: RJ=1,39: 1
 TABLE(NJ=39,TYPE=0): JB: DDATA=1: RJ=1,39: 157
 TABLE(NI=18,NJ=1,TYPE=4): 5 TITLE FORC: J=1
   'RAIL WHEEL, POINT LOADS APPLIED AT STATION 1
 TABLE(NJ=1,TYPE=0): 5 SECT FORC: J=1: 1
 SYSVEC: 5 APPL FORC
     I=1: J=   28:     29:     30:     33:     36:     39
             -750.: -500.: -250.:-1000.:-1000.: -500.
     I=3: J=   37:     38:     39
              600.: 1200.:  600.
*XQT U1
*(CONSTRAINTS)
  ZERO 1 2 3: 4,6: 160,162: "JTS"
*(OPTIONS)
 !NSECTORS=8: !PROB='STAT
*(ES OPTIONS)
  NODES=0: D3D=3
*CALL(CS)
```

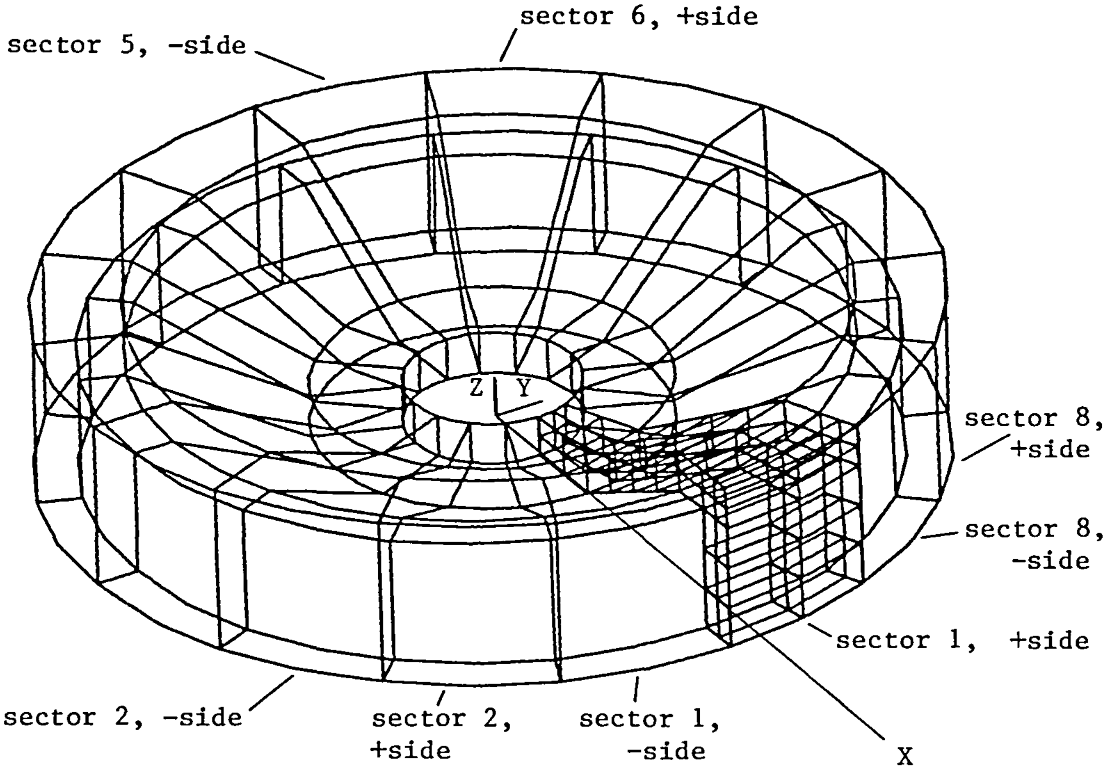
```
PAGE    1  CYCLIC SYMMETRY, ELEMENT STRESSES, SECTOR 4
S/C  1/  4 RAIL WHEEL, POINT LOADS APPLIED AT STATION 1
S81

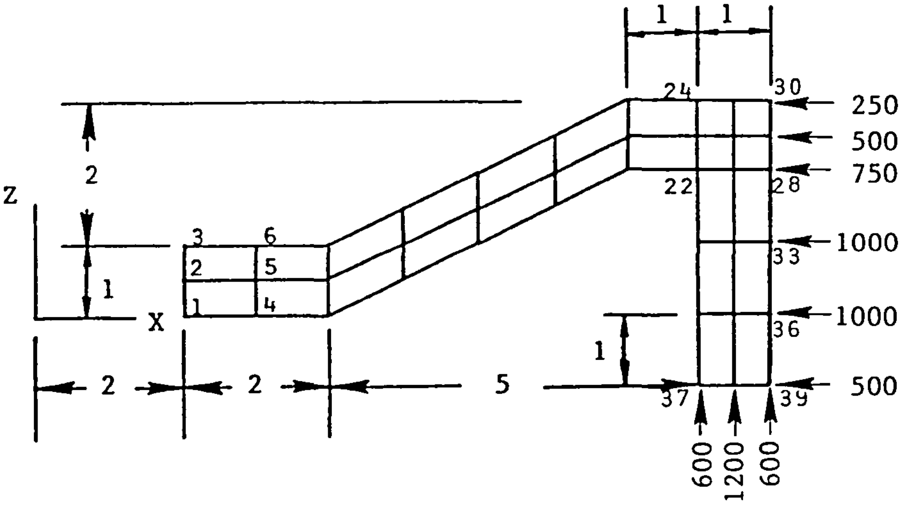
 STRESSES
GRP-IND* JOINT     ONS       OSS       SI      SYR
  1/   1*  MID  -.113+03  .453+03  .106+04  .000
  1/   2*  MID   .161+03  .378+03  .888+03  .000
  1/   3*  MID  -.786+03  .573+03  .137+04  .000
  1/   4*  MID   .674+03  .855+03  .196+04  .000
  1/   5*  MID  -.451+03  .451+03  .109+04  .000
  1/   6*  MID  -.282+02  .389+03  .952+03  .000
  1/   7*  MID  -.280+03  .284+03  .677+03  .000
  1/   8*  MID  -.205+02  .292+03  .714+03  .000
  1/   9*  MID  -.923+02  .129+03  .281+03  .000
  1/  10*  MID  -.209+02  .198+03  .480+03  .000
  1/  11*  MID   .137+02  .514+02  .125+03  .000
  1/  12*  MID   .750+01  .122+03  .300+03  .000
  1/  13*  MID   .923+02  .423+02  .103+03  .000
  1/  14*  MID   .138+02  .110+03  .268+03  .000
  1/  15*  MID   .579+02  .564+02  .137+03  .000
  1/  16*  MID   .203+02  .106+03  .259+03  .000
  1/  17*  MID  -.258+01  .105+03  .254+03  .000
  1/  18*  MID   .275+02  .847+02  .204+03  .000
  1/  19*  MID  -.423+02  .769+02  .176+03  .000
  1/  20*  MID  -.844+01  .488+02  .119+03  .000
  1/  21*  MID  -.430+02  .981+02  .227+03  .000
  1/  22*  MID  -.367+02  .132+03  .318+03  .000
  1/  23*  MID   .695+02  .604+02  .133+03  .000
  1/  24*  MID  -.325+02  .129+03  .310+03  .000
  1/  25*  MID  -.362+03  .320+03  .783+03  .000
  1/  26*  MID   .214+03  .266+03  .639+03  .000
  1/  27*  MID  -.456+03  .377+03  .920+03  .000
  1/  28*  MID   .156+03  .380+03  .890+03  .000
  1/  29*  MID  -.521+03  .464+03  .113+04  .000
  1/  30*  MID   .914+02  .381+03  .932+03  .000
  1/  31*  MID  -.320+03  .290+03  .711+03  .000
  1/  32*  MID  -.127+02  .213+03  .522+03  .000
  1/  33*  MID  -.876+02  .106+03  .236+03  .000
  1/  34*  MID   .600+00  .175+03  .426+03  .000
  1/  35*  MID   .539+02  .590+02  .144+03  .000
  1/  36*  MID   .302+02  .185+03  .451+03  .000
  1/  37*  MID   .164+03  .722+02  .164+03  .000
  1/  38*  MID   .337+02  .181+03  .442+03  .000
  1/  39*  MID   .963+02  .693+02  .169+03  .000
  1/  40*  MID   .390+02  .160+03  .392+03  .000
  1/  41*  MID  -.309+01  .122+03  .291+03  .000
  1/  42*  MID   .469+02  .125+03  .299+03  .000
  1/  43*  MID  -.842+02  .133+03  .298+03  .000
  1/  44*  MID  -.238+02  .867+02  .212+03  .000
  1/  45*  MID  -.735+02  .117+03  .254+03  .000
  1/  46*  MID  -.602+02  .120+03  .282+03  .000
  1/  47*  MID   .110+03  .771+02  .170+03  .000
  1/  48*  MID  -.522+02  .121+03  .278+03  .000
```

4.2.4 CSR: RAIL WHEEL, POINT LOADS

The runstream for the problem described below is shown on the next page. The computed results agree exactly with those obtained with a half model of the wheel. Sample stress printout from the cyclic symmetry + reflective symmetry solution is shown on page 4.2.4-3.

$E=29x10^6$
$\nu=.3$





Point loads are applied as shown.

Constraint conditions: at joints 4, 5, 6, u=v=w=0.

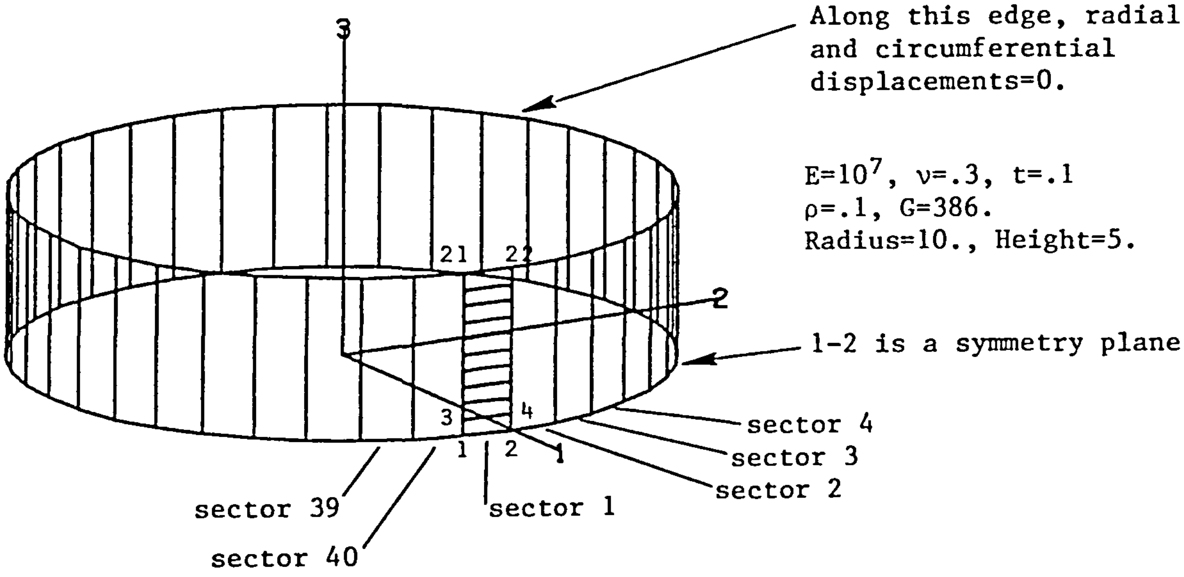
```
*XQT U1
*(RAIL OPTIONS)
 !NTHETA=2: !THETA=22.5
*(ISOTROPIC SOLIDS)$   E      NU      RHO      OTHERS
  J=1:                 29.+6  .3      .28      0. 0. 0.
*DCALL(RAIL WHEEL)
*XQT AUS
 TABLE(NJ=39,TYPE=0): JA: DDATA=1: RJ=1,39: 79
 TABLE(NI=18,NJ=1,TYPE=4): 5 TITLE FORC: J=1
   'RAIL WHEEL, POINT LOADS APPLIED AT STATION 1
 TABLE(NJ=1,TYPE=0): 5 SECT FORC: J=1: 1
 SYSVEC: 5 F+ FORC
     I=1: J=   28:    29:    30:    33:    36:    39
            -750.: -500.: -250.:-1000.:-1000.: -500.
     I=3: J=   37:    38:    39
             600.: 1200.:  600.
 OUTLIB=5: INLIB=5: F- FORC= UNION(0. F+)
*XQT U1
*(CONSTRAINTS)
  ZERO 1 2 3: 4,6: "JTS"
*(OPTIONS)
 !NSECTORS=8: !PROB='STAT
*(ES OPTIONS)
  NODES=0: D3D=3
*CALL(CSR)
```

```
PAGE    1  CYCLIC SYMMETRY, +SIDE ELEMENT STRESSES, SECTOR 6
S/C  1/  6 RAIL WHEEL, POINT LOADS APPLIED AT STATION 1
S81

 STRESSES
GRP-IND* JOINT      ONS       OSS       SI      SYR
  1/   1*  MID  -.113+03  .453+03  .106+04  .000
  1/   2*  MID   .161+03  .378+03  .888+03  .000
  1/   3*  MID  -.786+03  .573+03  .137+04  .000
  1/   4*  MID   .674+03  .855+03  .196+04  .000
  1/   5*  MID  -.451+03  .451+03  .109+04  .000
  1/   6*  MID  -.282+02  .388+03  .952+03  .000
  1/   7*  MID  -.280+03  .284+03  .677+03  .000
  1/   8*  MID  -.205+02  .292+03  .714+03  .000
  1/   9*  MID  -.923+02  .129+03  .281+03  .000
  1/  10*  MID  -.209+02  .198+03  .480+03  .000
  1/  11*  MID   .137+02  .514+02  .125+03  .000
  1/  12*  MID   .750+01  .122+03  .300+03  .000
  1/  13*  MID   .923+02  .423+02  .103+03  .000
  1/  14*  MID   .138+02  .110+03  .268+03  .000
  1/  15*  MID   .579+02  .564+02  .137+03  .000
  1/  16*  MID   .203+02  .106+03  .259+03  .000
  1/  17*  MID  -.258+01  .105+03  .254+03  .000
  1/  18*  MID   .275+02  .848+02  .204+03  .000
  1/  19*  MID  -.423+02  .769+02  .176+03  .000
  1/  20*  MID  -.844+01  .488+02  .119+03  .000
  1/  21*  MID  -.430+02  .981+02  .227+03  .000
  1/  22*  MID  -.367+02  .132+03  .318+03  .000
  1/  23*  MID   .695+02  .604+02  .133+03  .000
  1/  24*  MID  -.325+02  .129+03  .310+03  .000
  1/  25*  MID  -.362+03  .320+03  .783+03  .000
  1/  26*  MID   .214+03  .266+03  .639+03  .000
  1/  27*  MID  -.456+03  .377+03  .920+03  .000
  1/  28*  MID   .156+03  .380+03  .890+03  .000
  1/  29*  MID  -.521+03  .464+03  .113+04  .000
  1/  30*  MID   .914+02  .381+03  .932+03  .000
  1/  31*  MID  -.320+03  .290+03  .711+03  .000
  1/  32*  MID  -.127+02  .213+03  .522+03  .000
  1/  33*  MID  -.876+02  .106+03  .236+03  .000
  1/  34*  MID   .599+00  .175+03  .426+03  .000
  1/  35*  MID   .539+02  .590+02  .144+03  .000
  1/  36*  MID   .302+02  .185+03  .451+03  .000
  1/  37*  MID   .164+03  .721+02  .164+03  .000
  1/  38*  MID   .337+02  .181+03  .442+03  .000
  1/  39*  MID   .963+02  .693+02  .169+03  .000
  1/  40*  MID   .390+02  .160+03  .392+03  .000
  1/  41*  MID  -.309+01  .122+03  .291+03  .000
  1/  42*  MID   .469+02  .125+03  .299+03  .000
  1/  43*  MID  -.842+02  .133+03  .298+03  .000
  1/  44*  MID  -.238+02  .867+02  .212+03  .000
  1/  45*  MID  -.735+02  .117+03  .254+03  .000
  1/  46*  MID  -.602+02  .120+03  .282+03  .000
  1/  47*  MID   .110+03  .771+02  .170+03  .000
  1/  48*  MID  -.522+02  .121+03  .278+03  .000
```

4.3.1 CS: VIBRATIONAL MODES OF A CYLINDRICAL SHELL

The runstream for the problem described below is shown at the bottom of the page. The computed results agree exactly with those obtained with the quarter model described in Volume 3 of the EAL Reference Manual. Sample printout from the cyclic symmetry solution is shown on pages 4.3.1-2 and 4.3.1-3.



Along this edge, radial and circumferential displacements=0.

$E=10^7$, $\nu=.3$, $t=.1$
$\rho=.1$, $G=386.$
Radius=10., Height=5.

1-2 is a symmetry plane

```
*XQT U1
*(CYLINDER DEFINITION)
   10.+6 .3  .1   1.-5  .1   10.     5.     9.      10
$    E   NU  RHO  ALPHA  T  RADIUS  HEIGHT  THETA  ELEMENTS
*DCALL(MODEL BUILDER)
*XQT AUS
 TABLE(NJ=8,TYPE=0): 5 HARMONICS: DDATA=1: RJ=1,8: 4
 TABLE(NJ=1,TYPE=0): 5 BACK SECTORS: J=1: 1
*XQT U1
*(CONSTRAINTS)
    SYMM PLANE=3: ZERO 1 2: 21,22
*(OPTIONS)
 !NSECTORS=40: !G=386.: !MNAME='CEM
 !INIT=6: !NREQ=4: !NVECTORS=4: !NEVALS=4
*CALL(CS)
```

```
CYCLIC SYMMETRY VIBRATIONAL EIGENVALUES FOLLOW:

     HARMONIC
MODE  NUMBER   EIGENVALUE        HZ
   1     7      .2259+08      756.38
   2     7      .2259+08      756.38
   3     6      .2473+08      791.50
   4     6      .2473+08      791.50
   5     8      .2567+08      806.41
   6     8      .2567+08      806.41
   7     9      .3331+08      918.51
   8     9      .3331+08      918.51
   9     5      .3428+08      931.88
  10     5      .3428+08      931.88
  11    10      .4558+08     1074.50
  12    10      .4558+08     1074.50
  13     4      .5630+08     1194.21
  14     4      .5630+08     1194.21
  15    11      .6303+08     1263.55
  16    11      .6303+08     1263.55
  17     9      .2276+09     2401.31
  18     9      .2276+09     2401.31
  19    10      .2317+09     2422.47
  20    10      .2317+09     2422.47
  21     8      .2335+09     2431.80
  22     8      .2335+09     2431.80
  23    11      .2464+09     2498.18
  24    11      .2464+09     2498.18
  25     7      .2482+09     2507.14
  26     7      .2482+09     2507.14
  27     6      .2704+09     2616.91
  28     6      .2704+09     2616.91
  29     5      .2981+09     2747.97
  30     5      .2981+09     2747.97
  31     4      .3287+09     2885.61
  32     4      .3287+09     2885.62


VIBRATIONAL FREQUENCIES, HZ

       HARMONICS:
MODE      4         5         6         7         8         9        10
   1   .119+04   .932+03   .791+03   .756+03   .806+03   .919+03   .107+04
   2   .119+04   .932+03   .791+03   .756+03   .806+03   .919+03   .107+04
   3   .289+04   .275+04   .262+04   .251+04   .243+04   .240+04   .242+04
   4   .289+04   .275+04   .262+04   .251+04   .243+04   .240+04   .242+04

       HARMONICS:
MODE      11
   1   .126+04
   2   .126+04
   3   .250+04
   4   .250+04
```

```
EIGENVALUES

       HARMONICS:
MODE      4        5        6        7        8        9        10
   1   .563+08  .343+08  .247+08  .226+08  .257+08  .333+08  .456+08
   2   .563+08  .343+08  .247+08  .226+08  .257+08  .333+08  .456+08
   3   .329+09  .298+09  .270+09  .248+09  .233+09  .228+09  .232+09
   4   .329+09  .298+09  .270+09  .248+09  .233+09  .228+09  .232+09

       HARMONICS:
MODE     11
   1   .630+08
   2   .630+08
   3   .246+09
   4   .246+09

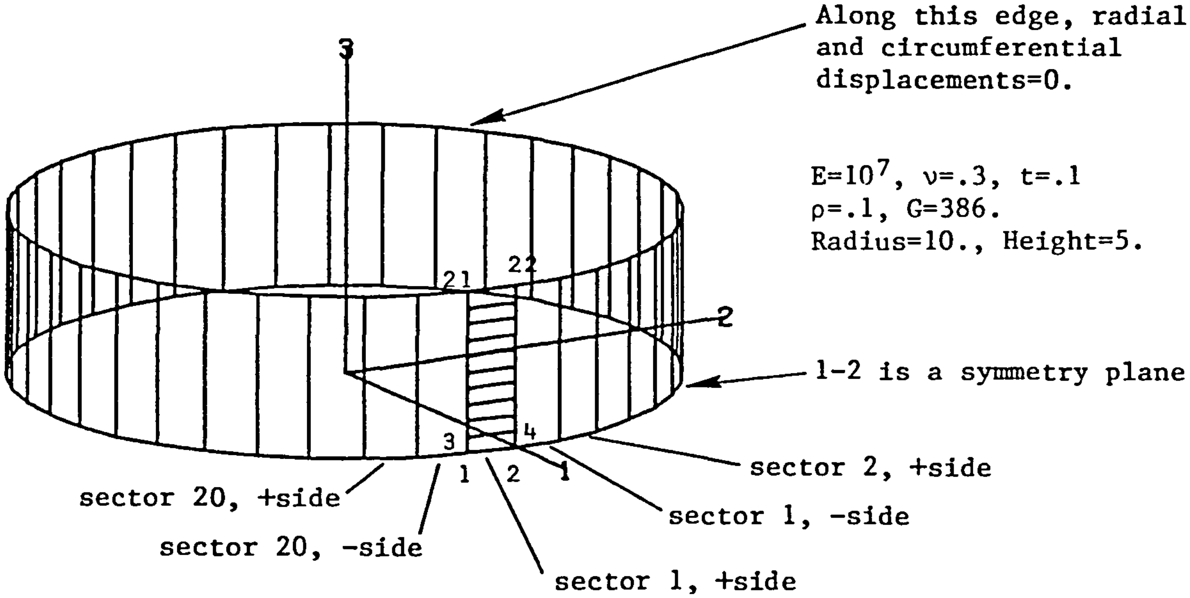

EIGENVALUE CONVERGENCE MATRIX

       HARMONICS:
MODE      4        5        6        7        8        9        10
   1   .000     .000     .000     .000     .000     .000     .000
   2  -.888-08  .000     .000     .000     .000     .000     .000
   3  -.243-07 -.134-07  .000    -.806-08 -.257-07 -.351-07 -.345-07
   4  -.845-04 -.414-04 -.192-04 -.908-05 -.479-05 -.304-05 -.253-05

       HARMONICS:
MODE     11
   1   .000
   2   .000
   3  -.114-06
   4  -.263-05
```

4.3.2 CSR: VIBRATIONAL MODES OF A CYLINDRICAL SHELL

The runstream for the problem described below is shown at the bottom of the page. The computed results agree exactly with those obtained with the quarter model described in Volume 3 of the EAL Reference Manual. Sample printout from the cyclic symmetry + reflective symmetry solution is shown on pages 4.3.2-2 through 4.3.2-4.



Along this edge, radial and circumferential displacements=0.

$E=10^7$, $\nu=.3$, $t=.1$
$\rho=.1$, $G=386.$
Radius=10., Height=5.

1-2 is a symmetry plane

sector 2, +side

sector 1, -side

sector 1, +side

sector 20, +side

sector 20, -side

```
*XQT U1
*(CYLINDER DEFINITION)
   10.+6 .3  .1   1.-5  .1   10.     5.     9.      10
$    E   NU  RHO  ALPHA  T  RADIUS  HEIGHT  THETA  ELEMENTS
*DCALL(MODEL BUILDER)
*XQT AUS
 TABLE(NJ=8,TYPE=0): 5 HARMONICS: DDATA=1: RJ=1,8: 3
 TABLE(NJ=1,TYPE=0): 5 BACK SECTORS: J=1: 1
*XQT U1
*(CONSTRAINTS)
    SYMM PLANE=3: ZERO 1 2: 21,22
*(OPTIONS)
 !NSECTORS=20: !RFLP=2:  !G=386.: !MNAME='CEM
 !NDYN=12: !INIT=4: !NREQ=4: !NVECTORS=2: !NEVALS=2
*CALL(CSR)
```

```
CYCLIC SYMMETRY VIBRATIONAL EIGENVALUES FOLLOW:

      HARMONIC  REFLECTIVE
MODE   NUMBER   BND. COND.   EIGENVALUE        HZ
   1      7        ASYM       .2259+08      756.37
   2      7        SYMM       .2259+08      756.37
   3      6        SYMM       .2473+08      791.48
   4      6        ASYM       .2473+08      791.48
   5      8        SYMM       .2567+08      806.41
   6      8        ASYM       .2567+08      806.41
   7      9        ASYM       .3331+08      918.51
   8      9        SYMM       .3331+08      918.52
   9      5        SYMM       .3428+08      931.86
  10      5        ASYM       .3428+08      931.86
  11     10        SYMM       .4558+08     1074.46
  12     10        ASYM       .4559+08     1074.58
  13      4        ASYM       .5630+08     1194.18
  14      4        SYMM       .5630+08     1194.18
  15      9        ASYM       .6303+08     1263.58
  16      9        SYMM       .6303+08     1263.58
  17      8        SYMM       .8648+08     1480.04
  18      8        ASYM       .8648+08     1480.04
  19      3        ASYM       .1009+09     1598.50
  20      3        SYMM       .1009+09     1598.50
  21      7        SYMM       .1169+09     1721.11
  22      7        ASYM       .1169+09     1721.11
  23      6        SYMM       .1556+09     1985.35
  24      6        ASYM       .1556+09     1985.35
  25      5        SYMM       .2038+09     2271.97
  26      5        ASYM       .2038+09     2271.98
  27     10        ASYM       .2316+09     2422.19
  28     10        SYMM       .2317+09     2422.76
  29      4        SYMM       .2629+09     2580.48
  30      4        ASYM       .2629+09     2580.49
  31      3        ASYM       .3344+09     2910.23
  32      3        SYMM       .3344+09     2910.23
```

```
VIBRATIONAL FREQUENCIES, HZ
SYMMETRIC CONSTRAINT ON THE REFLECTIVE PLANE

       HARMONICS:
MODE      3         4         5         6         7         8         9
  1    .160+04  .119+04  .932+03  .791+03  .756+03  .806+03  .919+03
  2    .291+04  .258+04  .227+04  .199+04  .172+04  .148+04  .126+04

       HARMONICS:
MODE     10
  1    .107+04
  2    .242+04


VIBRATIONAL FREQUENCIES, HZ
ANTI-SYMMETRIC CONSTRAINT ON THE REFLECTIVE PLANE

       HARMONICS:
MODE      3         4         5         6         7         8         9
  1    .160+04  .119+04  .932+03  .791+03  .756+03  .806+03  .919+03
  2    .291+04  .258+04  .227+04  .199+04  .172+04  .148+04  .126+04

       HARMONICS:
MODE     10
  1    .107+04
  2    .242+04


EIGENVALUES
SYMMETRIC CONSTRAINT ON THE REFLECTIVE PLANE

       HARMONICS:
MODE      3         4         5         6         7         8         9
  1    .101+09  .563+08  .343+08  .247+08  .226+08  .257+08  .333+08
  2    .334+09  .263+09  .204+09  .156+09  .117+09  .865+08  .630+08

       HARMONICS:
MODE     10
  1    .456+08
  2    .232+09
```

```
EIGENVALUE CONVERGENCE MATRIX
SYMMETRIC CONSTRAINT ON THE REFLECTIVE PLANE

       HARMONICS:
MODE     3        4        5        6        7        8        9
   1  .000    -.888-08  .000     .000     .000     .000     .000
   2 -.120-07 -.115-05 -.785-07 -.129-07  .000    -.116-07  .000

       HARMONICS:
MODE    10
   1  .000
   2  .000


EIGENVALUES
ANTI-SYMMETRIC CONSTRAINT ON THE REFLECTIVE PLANE

       HARMONICS:
MODE     3        4        5        6        7        8        9
   1  .101+09  .563+08  .343+08  .247+08  .226+08  .257+08  .333+08
   2  .334+09  .263+09  .204+09  .156+09  .117+09  .865+08  .630+08

       HARMONICS:
MODE    10
   1  .456+08
   2  .232+09

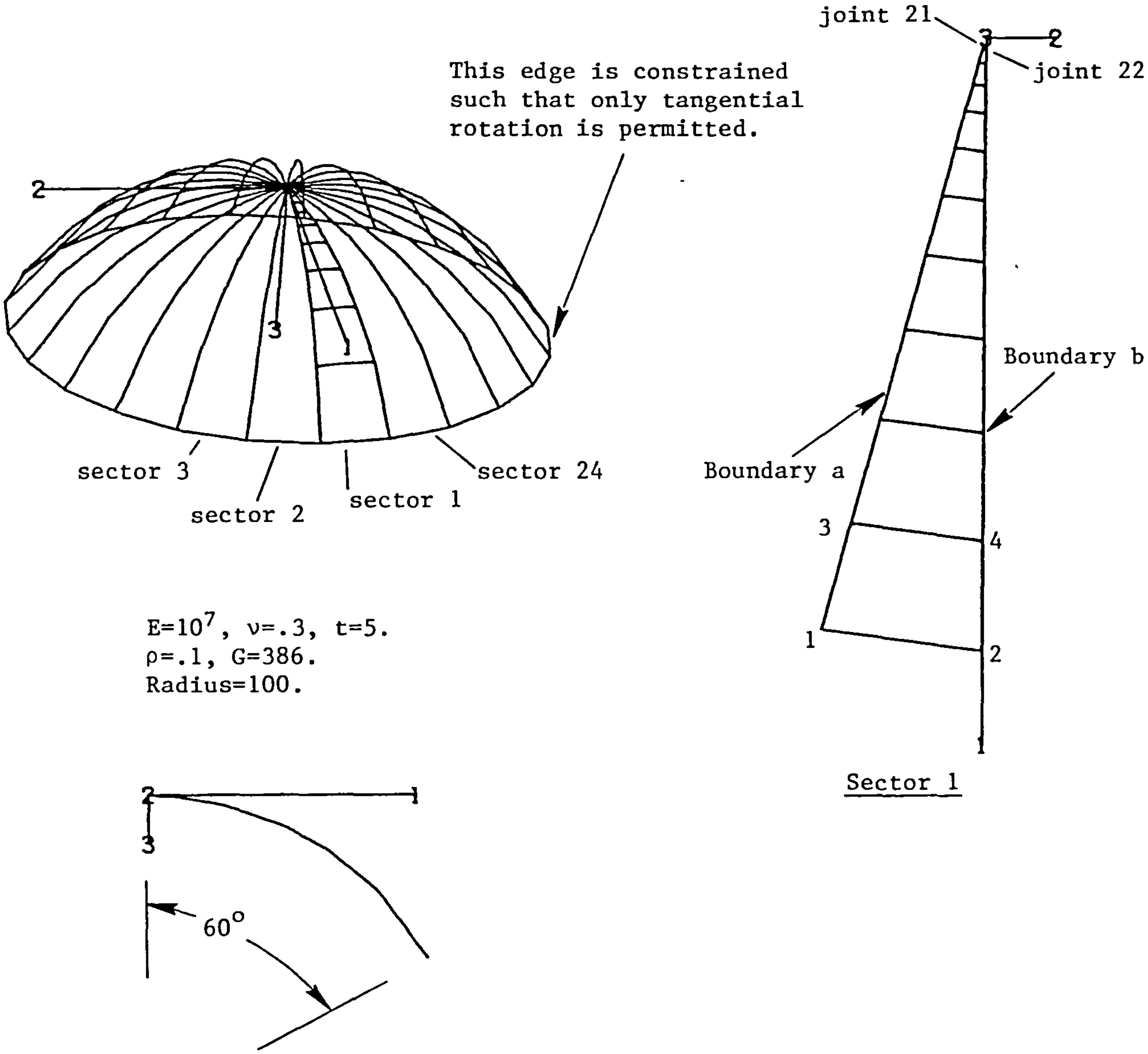

EIGENVALUE CONVERGENCE MATRIX
ANTI-SYMMETRIC CONSTRAINT ON THE REFLECTIVE PLANE

       HARMONICS:
MODE     3        4        5        6        7        8        9
   1  .000     .000     .000     .000     .000     .000     .000
   2 -.239-07 -.152-07  .000     .000     .000     .000     .000

       HARMONICS:
MODE    10
   1  .000
   2  .000
```

4.3.3 CS: VIBRATIONAL MODES OF A 60 DEGREE SECTOR OF A SPHERICAL SHELL

The runstream for the problem described below is shown on the next page. For the zeroth harmonic, the lowest two computed frequencies were 298 Hz and 414 Hz. The corresponding frequencies obtained with the quarter model described in Volume 3 of the EAL Reference Manual were 300 Hz and 412 Hz. The solution discrepancies are attributable to differences between the two finite element grids. Sample printout from the cyclic symmetry solution is shown on pages 4.3.3-2 and 4.3.3-3.



$E=10^7$, $\nu=.3$, $t=5.$
$\rho=.1$, $G=386.$
Radius=100.

```
*XQT U1
*(SPHERE DEFINITION)
 1.E+7  .3  .1   .1E-4  5.  100.    15.    60.      10
$  E    NU  RHO  ALPHA  T  RADIUS  THETA  GAMMA  ELEMENTS
*DCALL(MODEL BUILDER)
*XQT AUS
 TABLE(NJ=4,TYPE=0): 5 HARMONICS: DDATA=1: RJ=1,4: 0
 TABLE(NJ=1,TYPE=0): 5 BACK SECTORS: J=1: 1
*XQT U1
*(CONSTRAINTS)
 ZERO 1 2 3 4 6: 1,2
*(OPTIONS)
 !NSECTORS=24: !G=386.: !MNAME='CEM
 !INIT=6: !NREQ=4: !NVECTORS=4: !NEVALS=4: !ERCK=0
*CALL(CS)
```

```
CYCLIC SYMMETRY VIBRATIONAL EIGENVALUES FOLLOW:

      HARMONIC
MODE   NUMBER    EIGENVALUE        HZ
   1      1       .2969+07      274.22
   2      1       .2969+07      274.22
   3      0       .3494+07      297.52
   4      2       .4335+07      331.39
   5      2       .4335+07      331.39
   6      1       .4785+07      348.13
   7      1       .4785+07      348.13
   8      3       .5248+07      364.61
   9      3       .5248+07      364.61
  10      0       .6754+07      413.62
  11      2       .6988+07      420.73
  12      2       .6988+07      420.73
  13      0       .9455+07      489.37
  14      3       .1051+08      515.87
  15      3       .1051+08      515.87
  16      0       .1685+08      653.35
```

```
VIBRATIONAL FREQUENCIES, HZ

        HARMONICS:
MODE       0         1         2         3
   1    .298+03   .274+03   .331+03   .365+03
   2    .414+03   .274+03   .331+03   .365+03
   3    .489+03   .348+03   .421+03   .516+03
   4    .653+03   .348+03   .421+03   .516+03


EIGENVALUES

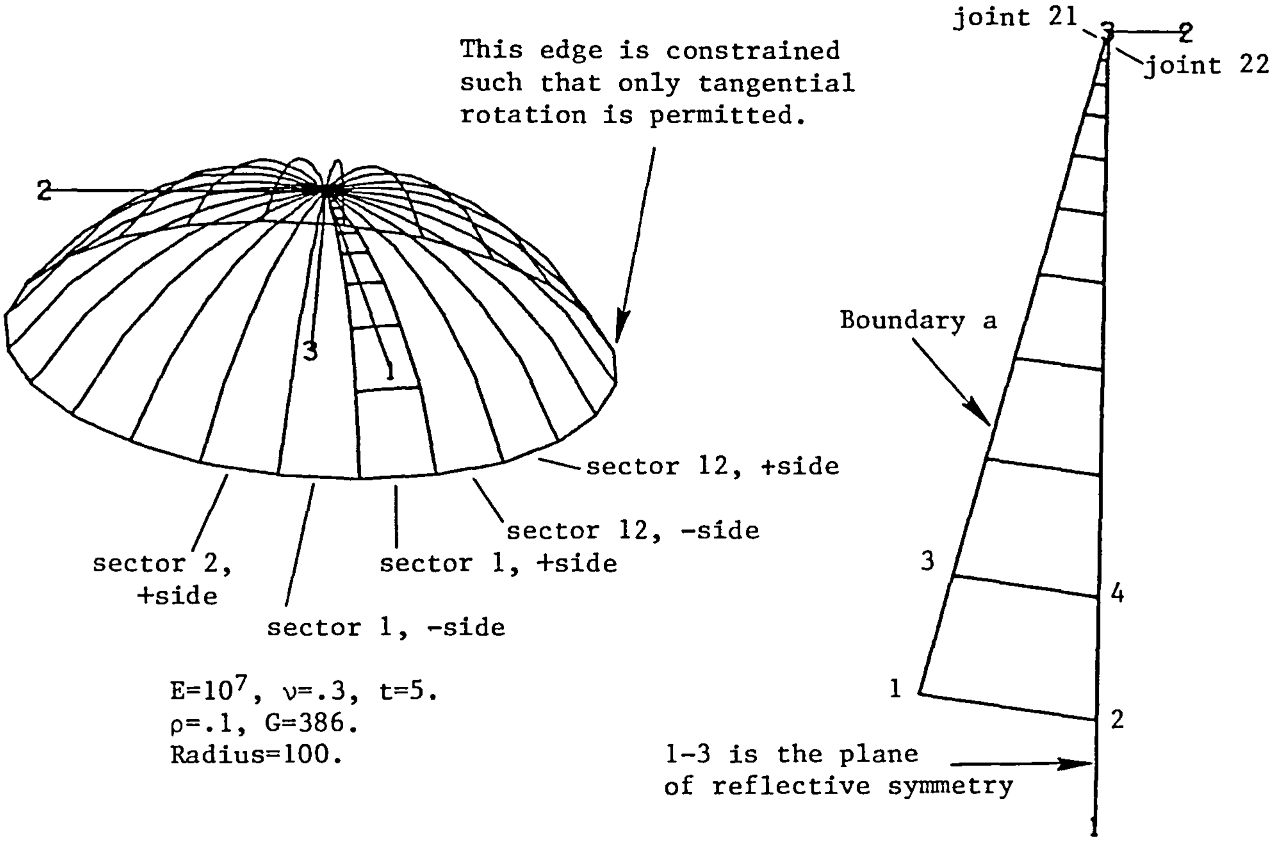
        HARMONICS:
MODE       0         1         2         3
   1    .349+07   .297+07   .434+07   .525+07
   2    .675+07   .297+07   .434+07   .525+07
   3    .945+07   .478+07   .699+07   .105+08
   4    .169+08   .478+07   .699+07   .105+08


EIGENVALUE CONVERGENCE MATRIX

        HARMONICS:
MODE       0         1         2         3
   1    .000     -.211-07 -.144-07 -.119-07
   2  -.833-07 -.105-07 -.721-07 -.167-06
   3    .000     -.101-04 -.485-04  .000
   4  -.278-04 -.350-04 -.686-04 -.234-04
```

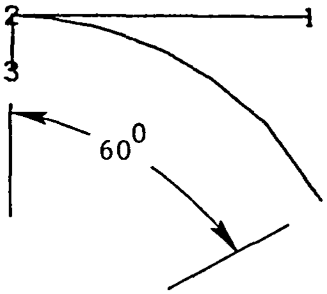
4.3.4 CSR: VIBRATIONAL MODES OF A 60 DEGREE SECTOR OF A SPHERICAL SHELL

The runstream for the problem described below is shown on the next page. For the zeroth harmonic, the lowest two computed frequencies were 298 Hz and 414 Hz. The corresponding frequencies obtained with the quarter model described in Volume 3 of the EAL Reference Manual were 300 Hz and 412 Hz. The solution discrepancies are attributable to the differences between the two finite elemnt grids. Sample printout from the cyclic symmetry + reflective symmetry solution is shown on pages 4.3.4-2 and 4.3.4-3.



$E=10^7$, $\nu=.3$, $t=5.$
$\rho=.1$, $G=386.$
Radius=100.

Sector 1, +side



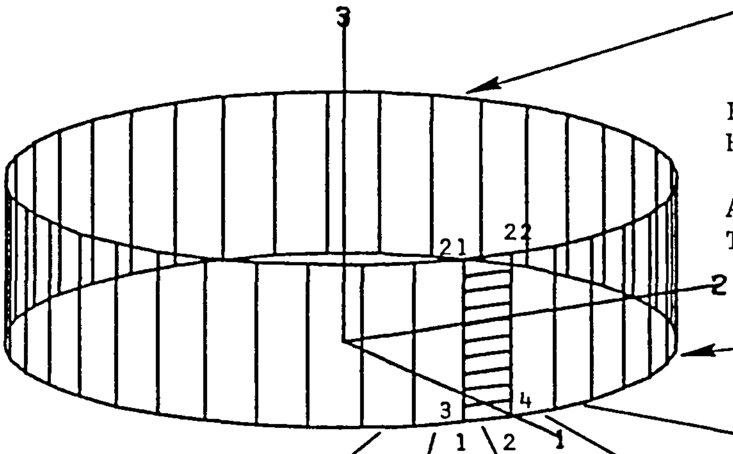
```
*XQT U1
*(SPHERE DEFINITION)
 1.E+7  .3   .1   .1E-4  5.  100.    15.    60.      10
$  E    NU  RHO  ALPHA  T  RADIUS  THETA  GAMMA  ELEMENTS
*DCALL(MODEL BUILDER)
*XQT AUS
 TABLE(NJ=4,TYPE=0): 5 HARMONICS: DDATA=1: RJ=1,4: 0
 TABLE(NJ=1,TYPE=0): 5 BACK SECTORS: J=1: 1
*XQT U1
*(CONSTRAINTS)
 ZERO 1 2 3 4 6: 1,2
*(OPTIONS)
 !NSECTORS=12: !RFLP=2: !G=386.: !MNAME='CEM
 !INIT=4: !NREQ=2: !NVECTORS=2: !NEVALS=2: !ERCK=0
*CALL(CSR)
```

```
CYCLIC SYMMETRY VIBRATIONAL EIGENVALUES FOLLOW:

     HARMONIC   REFLECTIVE
MODE  NUMBER    BND. COND.    EIGENVALUE        HZ
   1     1         ASYM        .2969+07       274.25
   2     1         SYMM        .2969+07       274.25
   3     0         SYMM        .3505+07       297.96
   4     2         ASYM        .4329+07       331.14
   5     2         SYMM        .4329+07       331.14
   6     1         SYMM        .4789+07       348.28
   7     1         ASYM        .4789+07       348.28
   8     3         ASYM        .5234+07       364.10
   9     3         SYMM        .5234+07       364.10
  10     0         SYMM        .6780+07       414.42
  11     2         SYMM        .6984+07       420.59
  12     2         ASYM        .6984+07       420.59
  13     3         ASYM        .1049+08       515.44
  14     3         SYMM        .1049+08       515.44
  15     0         ASYM        .1725+08       661.07
  16     0         ASYM        .7012+08      1332.73
```

4.4.6 CSR: BUCKLING OF A PRE-TENSIONED CYLINDRICAL SHELL DUE TO PRESSURE LOADING

The runstream for the problem described below is shown at the bottom of the page. The computed buckling pressure of 162.3 agrees exactly with the solution obtained with the quarter model described in Volume 3 of the EAL Reference Manual. Sample printout from the cyclic symmetry + reflective symmetry solution is shown on page 4.4.6-2.



Along this edge, radial and circumferential displacements=0.

E=10^7, ν=.3, t=.10954
Height=5.236, Radius=10.

Active load=external pressure, P
Tensile preload=2200/unit length

1-2 is a symmetry plane

sector 2, +side

sector 1, -side

sector 1, +side

sector 20, +side

sector 20, -side

```
*XQT U1
*(CYLINDER DEFINITION)
   10.+6 .3  .1   1.-5  .10954   10.    5.236    9.      10
$     E   NU  RHO  ALPHA    T    RADIUS  HEIGHT  THETA  ELEMENTS
*DCALL(MODEL BUILDER)
*XQT U1
*(LOADS PRE)
  ALPHA: CASE TITLE: 1'PRETENSION
  SYSVEC: APPL FORC: I=3: J=21,22: 1727.9
*(CONSTRAINTS PRE)
  SYMMETRY PLANE=3: ZERO 2 4 6: 1,22
*(LOADS)
  ALPHA: CASE TITLE 2: 1'UNIT EXTERNAL PRESSURE
  TABLE: NODAL PRESSURES 2: J=1,22: -1.
*(CONSTRAINTS)
  SYMMETRY PLANE=3: ZERO 1 2 6: 21,22
*XQT AUS
 TABLE(NJ=3,TYPE=0): 5 HARMONICS: J=1,3: 7: 8: 9
 TABLE(NJ=1,TYPE=0): 5 BACK SECTORS: J=1: 1
*XQT U1
*(OPTIONS)
 !RFLP=2
 !NSECTORS=20: !INIT=4: !NREQ=1: !NVECT=1: !NEVAL=1: !PROB='BUCK
*CALL(CSR)
```

```
VIBRATIONAL FREQUENCIES, HZ
SYMMETRIC CONSTRAINT ON THE REFLECTIVE PLANE
       HARMONICS:
MODE      0        1        2        3
   1   .298+03  .274+03  .331+03  .364+03
   2   .414+03  .348+03  .421+03  .515+03


VIBRATIONAL FREQUENCIES, HZ
ANTI-SYMMETRIC CONSTRAINT ON THE REFLECTIVE PLANE
       HARMONICS:
MODE      0        1        2        3
   1   .661+03  .274+03  .331+03  .364+03
   2   .133+04  .348+03  .421+03  .515+03


EIGENVALUES
SYMMETRIC CONSTRAINT ON THE REFLECTIVE PLANE
       HARMONICS:
MODE      0        1        2        3
   1   .351+07  .297+07  .433+07  .523+07
   2   .678+07  .479+07  .698+07  .105+08


EIGENVALUE CONVERGENCE MATRIX
SYMMETRIC CONSTRAINT ON THE REFLECTIVE PLANE
       HARMONICS:
MODE      0        1        2        3
   1  -.892-08  .000     .000     .000
   2  -.251-04 -.312-04 -.233-04 -.445-04

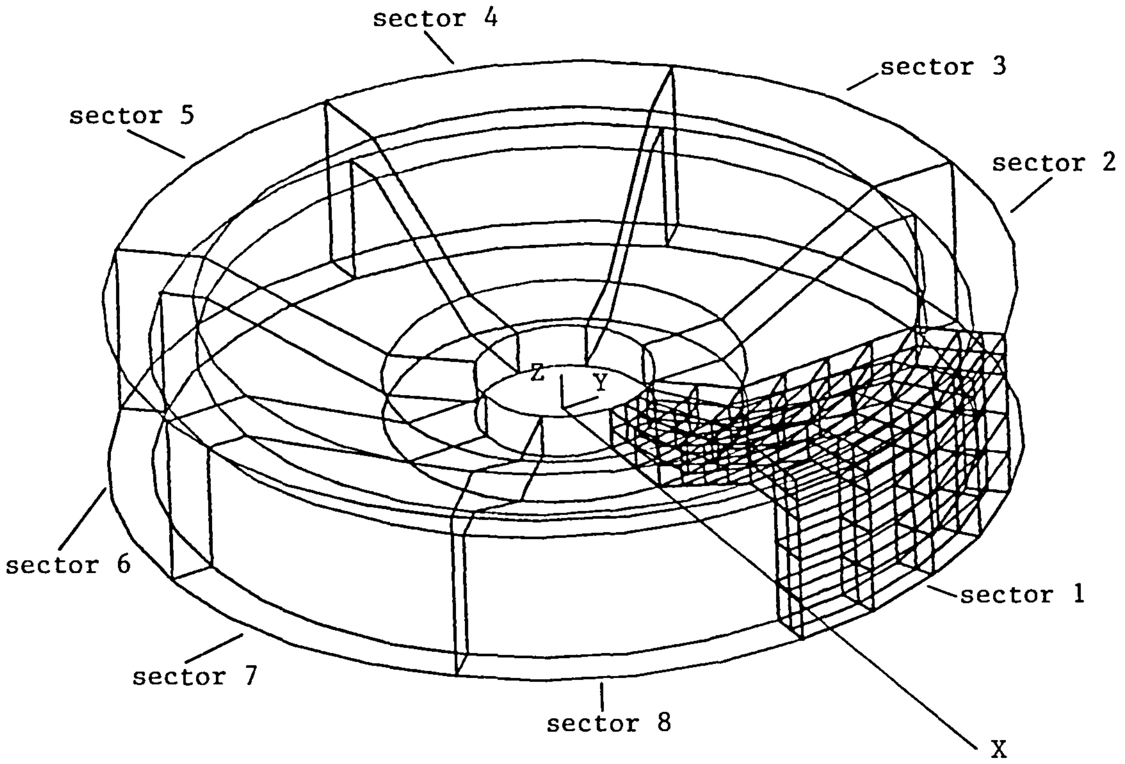

EIGENVALUES
ANTI-SYMMETRIC CONSTRAINT ON THE REFLECTIVE PLANE
       HARMONICS:
MODE      0        1        2        3
   1   .173+08  .297+07  .433+07  .523+07
   2   .701+08  .479+07  .698+07  .105+08

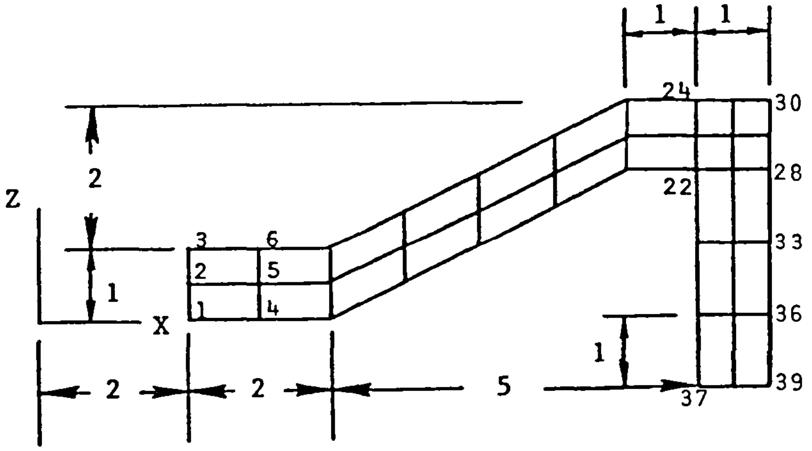

EIGENVALUE CONVERGENCE MATRIX
ANTI-SYMMETRIC CONSTRAINT ON THE REFLECTIVE PLANE
       HARMONICS:
MODE      0        1        2        3
   1   .000    -.358-05 -.228-05  .000
   2  -.414-04 -.193-04 -.383-04 -.375-05
```

4.3.5 CS: VIBRATIONAL MODES OF A RAIL WHEEL

The runstream for the problem described below is shown on the next page. The computed results agree exactly with those obtained with a half model of the wheel. Sample printout from the cyclic symmetry solution is shown on pages 4.3.5-2 and 4.3.5-3.

$E=29\times10^6$
$\nu=.3$
$\rho=.28$
$G=386.$





Constraint conditions:
at joints 4, 5, 6,
160, 161, and 162,
u=v=w=0.

```
*XQT U1
*(RAIL OPTIONS)
 !NTHETA=4: !THETA=45.
*(ISOTROPIC SOLIDS)$   E      NU      RHO      OTHERS
  J=1:                29.+6  .3      .28      0. 0. 0.
*DCALL(RAIL WHEEL)
*XQT AUS
 TABLE(NJ=39,TYPE=0): JA: DDATA=1: RJ=1,39: 1
 TABLE(NJ=39,TYPE=0): JB: DDATA=1: RJ=1,39: 157
*XQT U1
*(CONSTRAINTS)
  ZERO 1 2 3: 4,6: 160,162: "JTS"
*(OPTIONS)
 !NSECTORS=8: !G=386.
 !INIT=10: !NREQ=8: !NVECTORS=6: !NEVALS=6: !NDYN=20: !VPRT=0
*CALL(CS)
```

```
CYCLIC SYMMETRY VIBRATIONAL EIGENVALUES FOLLOW:

     HARMONIC
MODE  NUMBER   EIGENVALUE        HZ
   1     1      .7525+07     436.58
   2     1      .7525+07     436.58
   3     2      .2303+08     763.70
   4     2      .2303+08     763.70
   5     0      .2385+08     777.25
   6     0      .4940+08    1118.58
   7     3      .1109+09    1676.15
   8     3      .1109+09    1676.15
   9     1      .1158+09    1712.61
  10     1      .1158+09    1712.61
  11     2      .1803+09    2136.98
  12     2      .1803+09    2136.98
  13     4      .2615+09    2573.52
  14     4      .2615+09    2573.62
  15     0      .3246+09    2867.29
  16     3      .3725+09    3071.65
  17     3      .3725+09    3071.66
  18     1      .4745+09    3466.87
  19     1      .4745+09    3466.87
  20     3      .4950+09    3541.03
  21     3      .4950+09    3541.04
  22     0      .6263+09    3982.87
  23     4      .8097+09    4528.86
  24     4      .8128+09    4537.57
  25     2      .8424+09    4619.35
  26     2      .8424+09    4619.37
  27     0      .1424+10    6005.42
  28     4      .1754+10    6664.88
  29     4      .1776+10    6707.20
  30     0      .2110+10    7311.22
```

```
VIBRATIONAL FREQUENCIES, HZ

       HARMONICS:
MODE      0        1        2        3        4
  1    .777+03  .437+03  .764+03  .168+04  .257+04
  2    .112+04  .437+03  .764+03  .168+04  .257+04
  3    .287+04  .171+04  .214+04  .307+04  .453+04
  4    .398+04  .171+04  .214+04  .307+04  .454+04
  5    .601+04  .347+04  .462+04  .354+04  .666+04
  6    .731+04  .347+04  .462+04  .354+04  .671+04


EIGENVALUES

       HARMONICS:
MODE      0        1        2        3        4
  1    .238+08  .752+07  .230+08  .111+09  .261+09
  2    .494+08  .752+07  .230+08  .111+09  .261+09
  3    .325+09  .116+09  .180+09  .372+09  .810+09
  4    .626+09  .116+09  .180+09  .372+09  .813+09
  5    .142+10  .474+09  .842+09  .495+09  .175+10
  6    .211+10  .474+09  .842+09  .495+09  .178+10

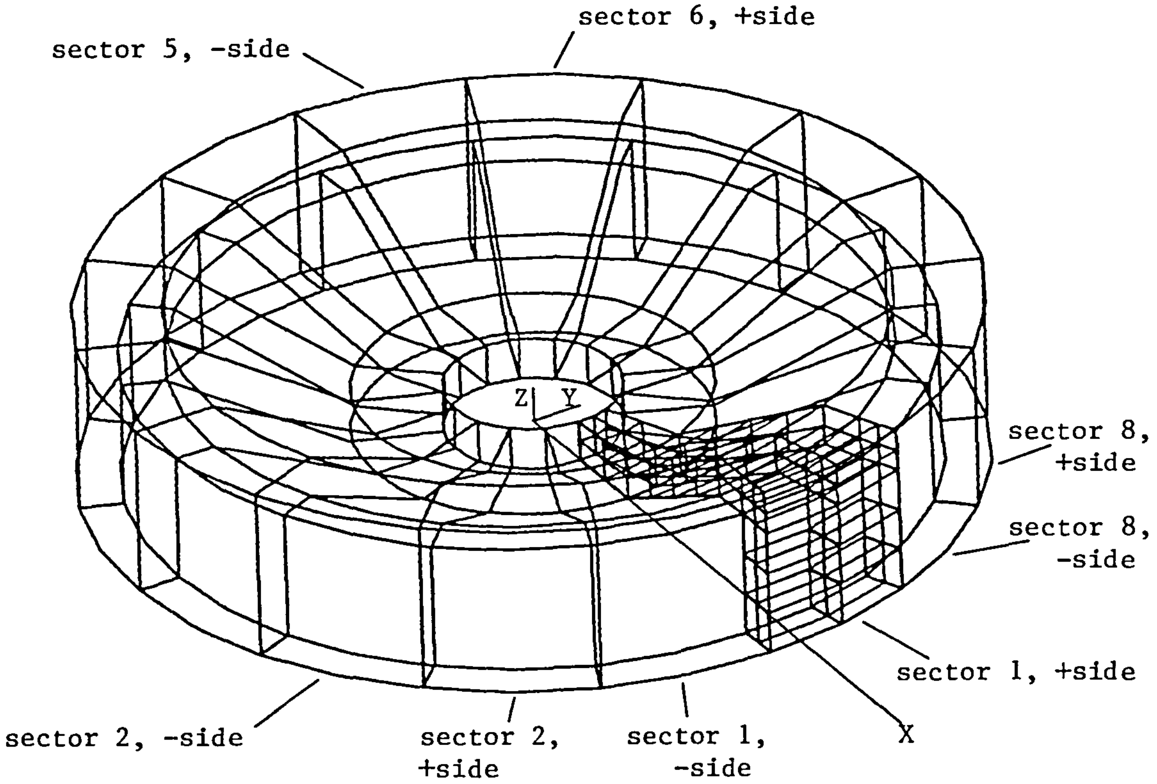

EIGENVALUE CONVERGENCE MATRIX

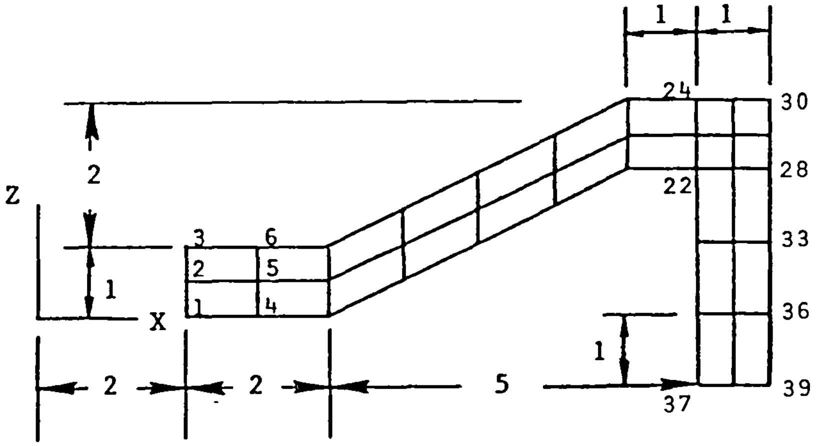
       HARMONICS:
MODE      0        1        2        3        4
  1    .000     .000     .000     .000     .000
  2    .000     .000     .000     .000     .000
  3    .000     .000    -.111-07  .000    -.198-07
  4    .000     .000     .000    -.215-07 -.197-07
  5   -.450-07 -.843-08 -.824-05 -.808-08 -.173-05
  6   -.690-06  .000    -.137-04 -.921-06 -.270-06
```

4.3.6 CSR: VIBRATIONAL MODES OF A RAIL WHEEL

The runstream for the problem described below is shown on the next page. The computed results agree exactly with those obtained with a half model of the wheel. Sample printout from the cyclic symmetry solution is shown on pages 4.3.6-2 and 4.3.6-3.

$E=29\times10^6$
$\nu=.3$
$\rho=.28$
$G=386.$





Constraint conditions:
at joints 4, 5, 6,
u=v=w=0.

```
*XQT U1
*(RAIL OPTIONS)
 !NTHETA=2: !THETA=22.5
*(ISOTROPIC SOLIDS)$   E      NU      RHO      OTHERS
  J=1:                 29.+6  .3      .28      0. 0. 0.
*DCALL(RAIL WHEEL)
*XQT AUS
 TABLE(NJ=39,TYPE=0): JA: DDATA=1: RJ=1,39: 79
*XQT U1
*(CONSTRAINTS)
  ZERO 1 2 3: 4,6: "JTS"
*(OPTIONS)
 !NSECTORS=8: !G=386.: !RFLP=2
 !INIT=6: !NREQ=4: !NVECTORS=3: !NEVALS=3: !NDYN=20: !VPRT=0
*CALL(CSR)
```

```
CYCLIC SYMMETRY VIBRATIONAL EIGENVALUES FOLLOW:

     HARMONIC  REFLECTIVE
MODE  NUMBER   BND. COND.   EIGENVALUE        HZ
   1     1        ASYM       .7525+07      436.58
   2     1        SYMM       .7525+07      436.58
   3     2        SYMM       .2303+08      763.70
   4     2        ASYM       .2303+08      763.71
   5     0        SYMM       .2385+08      777.25
   6     0        ASYM       .4940+08     1118.59
   7     3        ASYM       .1109+09     1676.15
   8     3        SYMM       .1109+09     1676.15
   9     1        SYMM       .1158+09     1712.61
  10     1        ASYM       .1158+09     1712.61
  11     2        SYMM       .1803+09     2136.98
  12     2        ASYM       .1803+09     2136.98
  13     4        ASYM       .2615+09     2573.52
  14     4        SYMM       .2615+09     2573.61
  15     0        SYMM       .3246+09     2867.29
  16     3        ASYM       .3725+09     3071.65
  17     3        SYMM       .3725+09     3071.65
  18     1        ASYM       .4745+09     3466.87
  19     1        SYMM       .4745+09     3466.87
  20     3        ASYM       .4950+09     3541.03
  21     3        SYMM       .4950+09     3541.03
  22     0        SYMM       .6263+09     3982.87
  23     4        ASYM       .8097+09     4528.86
  24     4        SYMM       .8128+09     4537.57
  25     2        SYMM       .8424+09     4619.35
  26     2        ASYM       .8424+09     4619.36
  27     4        ASYM       .1754+10     6664.88
  28     4        SYMM       .1776+10     6707.20
  29     0        ASYM       .2110+10     7311.21
  30     0        ASYM       .3578+10     9520.07
```

```
VIBRATIONAL FREQUENCIES, HZ
SYMMETRIC CONSTRAINT ON THE REFLECTIVE PLANE
       HARMONICS:
MODE      0        1        2        3        4
   1   .777+03  .437+03  .764+03  .168+04  .257+04
   2   .287+04  .171+04  .214+04  .307+04  .454+04
   3   .398+04  .347+04  .462+04  .354+04  .671+04


VIBRATIONAL FREQUENCIES, HZ
ANTI-SYMMETRIC CONSTRAINT ON THE REFLECTIVE PLANE
       HARMONICS:
MODE      0        1        2        3        4
   1   .112+04  .437+03  .764+03  .168+04  .257+04
   2   .731+04  .171+04  .214+04  .307+04  .453+04
   3   .952+04  .347+04  .462+04  .354+04  .666+04


EIGENVALUES
SYMMETRIC CONSTRAINT ON THE REFLECTIVE PLANE
       HARMONICS:
MODE      0        1        2        3        4
   1   .238+08  .752+07  .230+08  .111+09  .261+09
   2   .325+09  .116+09  .180+09  .372+09  .813+09
   3   .626+09  .474+09  .842+09  .495+09  .178+10

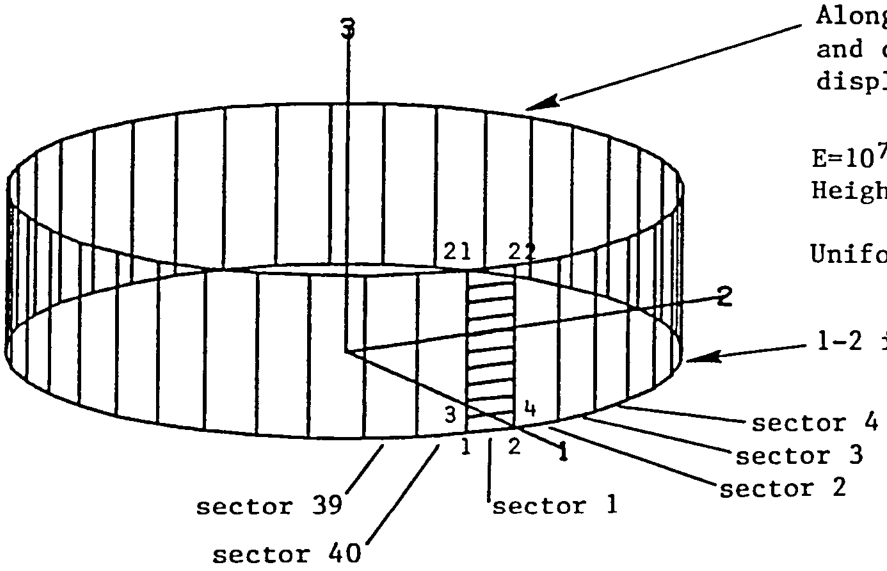

EIGENVALUE CONVERGENCE MATRIX
SYMMETRIC CONSTRAINT ON THE REFLECTIVE PLANE
       HARMONICS:
MODE      0        1        2        3        4
   1   .000     .000     .000     .000     .000
   2   .000     .000    -.111-07  .000    -.984-08
   3   .000     .000    -.463-04 -.808-08 -.991-07


EIGENVALUES
ANTI-SYMMETRIC CONSTRAINT ON THE REFLECTIVE PLANE
       HARMONICS:
MODE      0        1        2        3        4
   1   .494+08  .752+07  .230+08  .111+09  .261+09
   2   .211+10  .116+09  .180+09  .372+09  .810+09
   3   .358+10  .474+09  .842+09  .495+09  .175+10


EIGENVALUE CONVERGENCE MATRIX
ANTI-SYMMETRIC CONSTRAINT ON THE REFLECTIVE PLANE
       HARMONICS:
MODE      0        1        2        3        4
   1   .000     .000     .000     .000     .000
   2  -.607-07  .000     .000     .000    -.988-08
   3  -.349-06  .000    -.684-04 -.242-07 -.391-04
```

4.4.1 CS: BUCKLING OF A CYLINDRICAL SHELL DUE TO PRESSURE LOADING

The runstream for the problem described below is shown at the bottom of the page. The computed buckling loads agree exactly with those obtained with the quarter model described in Volume 3 of the EAL Reference Manual. Sample printout from the cyclic symmetry solution is shown on page 4.4.1-2.



Along this edge, radial and circumferential displacements=0.

$E=10^7$, $\nu=.3$, $t=.1$
Height=5., Radius=10.

Uniform external pressure=P

1-2 is a symmetry plane

```
*XQT U1
*(CYLINDER DEFINITION)
   10.+6 .3  .1   1.-5  .1   10.     5.    9.      10
$    E   NU  RHO  ALPHA  T  RADIUS  HEIGHT  THETA  ELEMENTS
*DCALL(MODEL BUILDER)
*XQT U1
*(CONSTRAINTS PRE)
  SYMMETRY PLANE=3: ZERO 2 4 6: 1,22
*(CONSTRAINTS)
  SYMMETRY PLANE=3: ZERO 1 2: 21,22
*(LOADS)
  ALPHA: CASE TITLE: 1'UNIT EXTERNAL PRESSURE
  TABLE: NODAL PRESSURES: J=1,22: -1.
*XQT AUS
 TABLE(NJ=4,TYPE=0): 5 HARMONICS: J=1,4: 6: 7: 8: 9
 TABLE(NJ=1,TYPE=0): 5 BACK SECTORS: J=1: 1
*XQT U1
*(OPTIONS)
 !NSECTORS=40: !INIT=4: !NREQ=2: !NVECT=2: !NEVAL=2: !PROB='BUCK
*CALL(CS)
```

```
CYCLIC SYMMETRY BUCKLING EIGENVALUES FOLLOW:

     HARMONIC
MODE  NUMBER   EIGENVALUE
   1     8      .1089+03
   2     8      .1089+03
   3     9      .1105+03
   4     9      .1105+03
   5     7      .1270+03
   6     7      .1270+03
   7     6      .1934+03
   8     6      .1934+03


EIGENVALUES

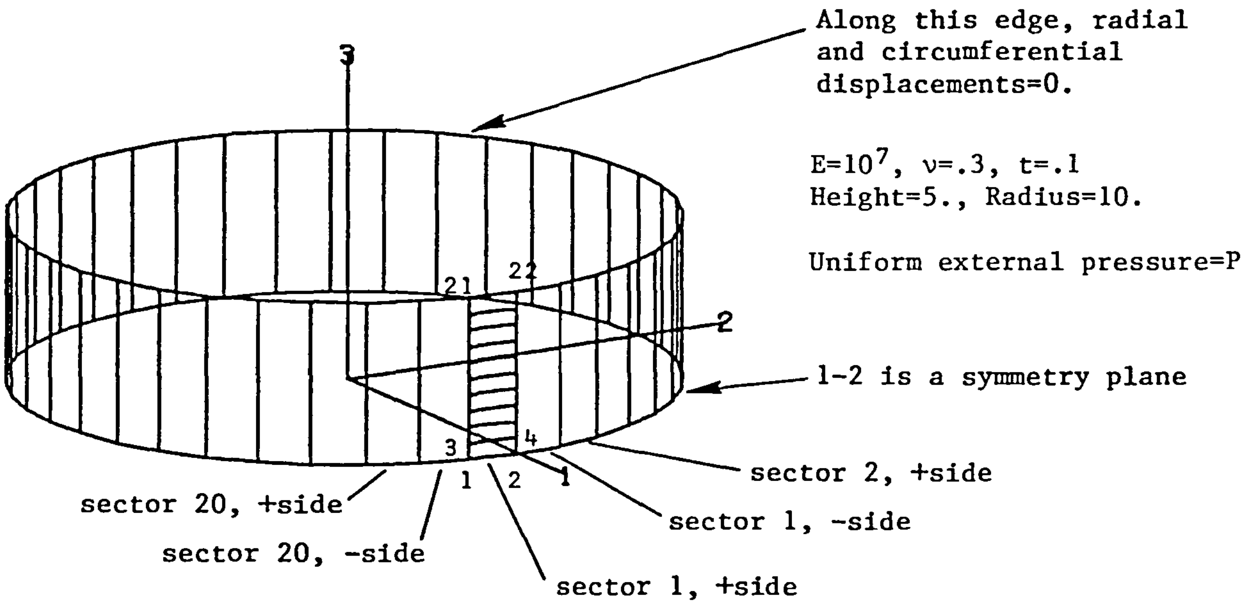
       HARMONICS:
MODE      6        7        8        9
   1   .193+03  .127+03  .109+03  .110+03
   2   .193+03  .127+03  .109+03  .110+03


EIGENVALUE CONVERGENCE MATRIX

       HARMONICS:
MODE      6        7        8        9
   1  -.393-05 -.871-06 -.709-06 -.107-05
   2  -.438-05 -.931-06 -.692-06 -.122-05
```

4.4.2 CSR: BUCKLING OF A CYLINDRICAL SHELL DUE TO PRESSURE LOADING

The runstream for the problem described below is shown at the bottom of the page. The computed buckling loads agree exactly with those obtained with the quarter model described in Volume 3 of the EAL Reference Manual. Sample printout from the cyclic symmetry + reflective symmetry solution is shown of page 4.4.2-2.



```
*XQT U1
*(CYLINDER DEFINITION)
   10.+6 .3  .1   1.-5  .1   10.      5.     9.      10
$    E   NU  RHO  ALPHA  T  RADIUS  HEIGHT  THETA  ELEMENTS
*DCALL(MODEL BUILDER)
*XQT U1
*(CONSTRAINTS PRE)
  SYMMETRY PLANE=3: ZERO 2 4 6: 1,22
*(CONSTRAINTS)
  SYMMETRY PLANE=3: ZERO 1 2: 21,22
*(LOADS)
  ALPHA: CASE TITLE: 1'UNIT EXTERNAL PRESSURE
  TABLE: NODAL PRESSURES: J=1,22: -1.
*XQT AUS
 TABLE(NJ=4,TYPE=0): 5 HARMONICS: J=1,4: 6: 7: 8: 9
 TABLE(NJ=1,TYPE=0): 5 BACK SECTORS: J=1: 1
*XQT U1
*(OPTIONS)
 !RFLP=2
 !NSECTORS=20: !INIT=4: !NREQ=1: !NVECT=1: !NEVAL=1: !PROB='BUCK
*CALL(CSR)
```

```
CYCLIC SYMMETRY BUCKLING EIGENVALUES FOLLOW:

      HARMONIC  REFLECTIVE
MODE  NUMBER    BND. COND.   EIGENVALUE
   1     8         SYMM       .1089+03
   2     8         ASYM       .1089+03
   3     9         ASYM       .1105+03
   4     9         SYMM       .1105+03
   5     7         ASYM       .1270+03
   6     7         SYMM       .1270+03
   7     6         SYMM       .1934+03
   8     6         ASYM       .1934+03


EIGENVALUES
SYMMETRIC CONSTRAINT ON THE REFLECTIVE PLANE

       HARMONICS:
MODE       6         7         8         9
   1    .193+03   .127+03   .109+03   .110+03


EIGENVALUE CONVERGENCE MATRIX
SYMMETRIC CONSTRAINT ON THE REFLECTIVE PLANE

       HARMONICS:
MODE       6         7         8         9
   1   -.135-04 -.325-05 -.175-05 -.328-05


EIGENVALUES
ANTI-SYMMETRIC CONSTRAINT ON THE REFLECTIVE PLANE

       HARMONICS:
MODE       6         7         8         9
   1    .193+03   .127+03   .109+03   .110+03

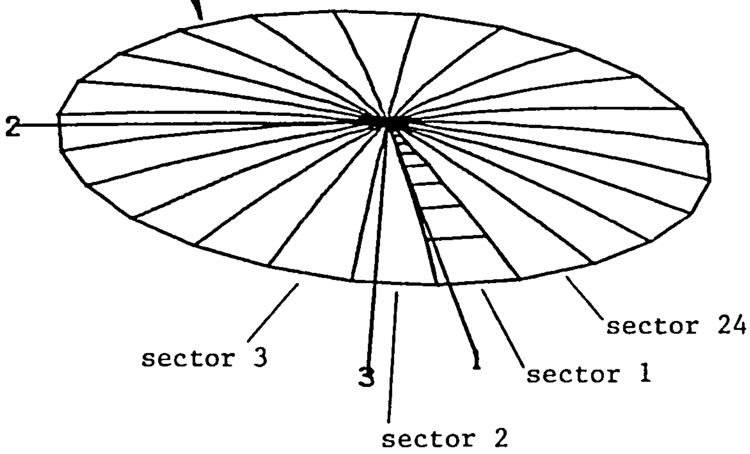

EIGENVALUE CONVERGENCE MATRIX
ANTI-SYMMETRIC CONSTRAINT ON THE REFLECTIVE PLANE

       HARMONICS:
MODE       6         7         8         9
   1   -.678-05 -.222-05 -.362-05 -.103-04
```

4.4.3 CS: BUCKLING OF A 10 DEGREE SECTOR OF A SPHERICAL SHELL DUE TO PRESSURE LOADING

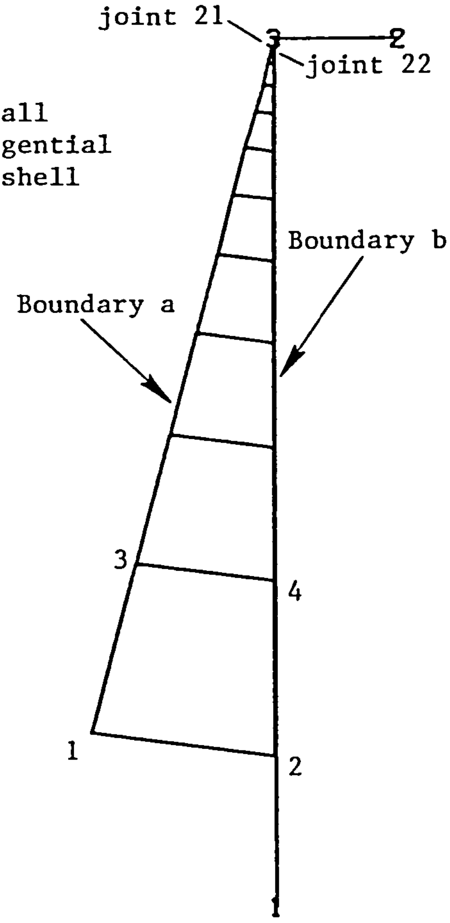
The runstream for the problem described below is shown on the following page. The computed results agree exactly with those obtained with the quarter model described in Volume 3 of the EAL Reference Manual. Sample printout for the cyclic symmetry solution is shown on pages 4.4.3-2 and 4.4.3-3.

Along the edge:
- For computing the buckling solution, all joints are fully fixed.
- For computing the pre-buckling solution, all joints are constrained such that only tangential rotation and displacements normal to the shell surface are permitted.

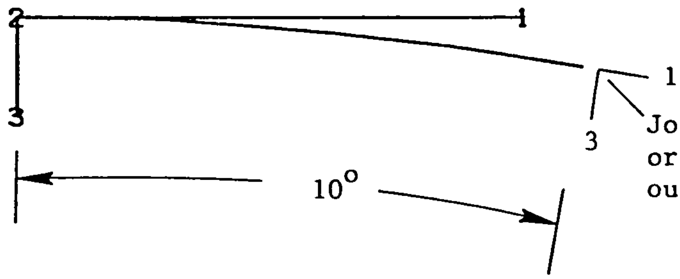


E=10^7, ν=.3333, t=.396
Radius=100.

Uniform external pressure=P



Sector 1



Joint reference frame orientations at the outer edge

```
*XQT U1
*(29 SPHERE DEFINITION)
 1.+7  .3333 .1   .1-4  .396  100.      15.    10.     10
$  E     NU  RHO  ALPHA   T  RADIUS   THETA  GAMMA  ELEMENTS
*DCALL(MODEL BUILDER)
*XQT U1
*(CONSTRAINTS PRE)
  ZERO 2 4 6: 1,22: ZERO 1: 1,2
*(CONSTRAINTS)
  ZERO 1 2 3 4 5 6: 1,2
*(LOADS)
  ALPHA: CASE TITLE: 1'UNIT EXTERNAL PRESSURE
  TABLE: NODAL PRESSURE: J=1,22: 1.
*XQT AUS
 TABLE(NJ=4,TYPE=0): 5 HARMONICS: DDATA=1: RJ=1,4: 0
 TABLE(NJ=1,TYPE=0): 5 BACK SECTORS: J=1: 1
*XQT U1
*(OPTIONS)
 !NSECTORS=24: !INIT=6: !NREQ=4: !NVECTORS=4: !ERCK=0: !PROB='BUCK
 !NEVALS=4
*CALL(CS)
```

```
CYCLIC SYMMETRY BUCKLING EIGENVALUES FOLLOW:

     HARMONIC
MODE  NUMBER   EIGENVALUE
   1     0       .2383+03
   2     1       .2473+03
   3     1       .2473+03
   4     2       .2488+03
   5     2       .2488+03
   6     3       .2850+03
   7     3       .2850+03
   8     1       .3533+03
   9     1       .3533+03
  10     0       .4012+03
  11     2       .4184+03
  12     2       .4184+03
  13     3       .5159+03
  14     3       .5159+03
  15     0       .6595+03
  16     0       .9940+03
```

```
EIGENVALUES

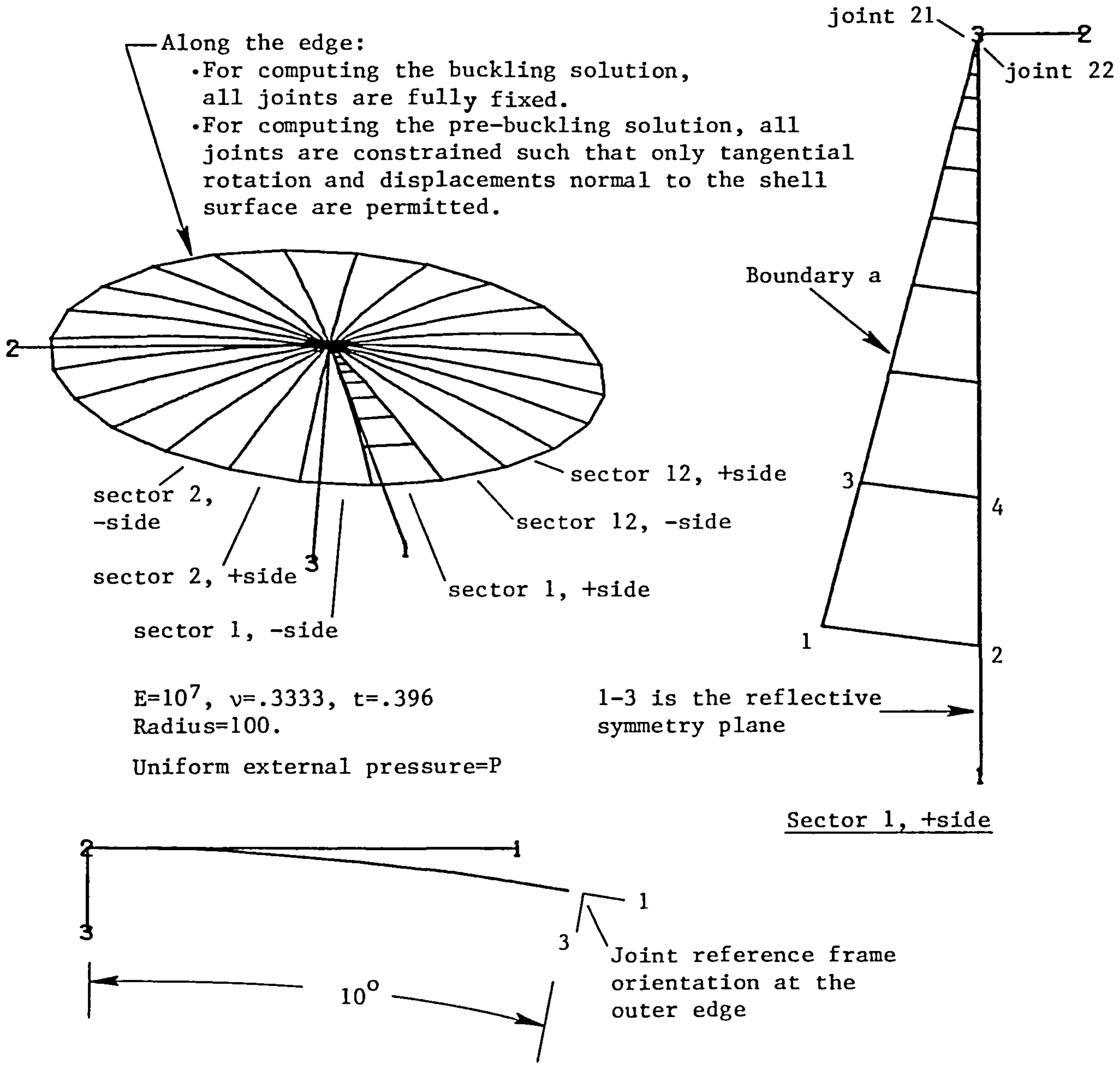
           HARMONICS:
MODE         0          1         2         3
   1       .238+03   .247+03   .249+03   .285+03
   2       .401+03   .247+03   .249+03   .285+03
   3       .660+03   .353+03   .418+03   .516+03
   4       .994+03   .353+03   .418+03   .516+03


EIGENVALUE CONVERGENCE MATRIX

           HARMONICS:
MODE         0          1         2         3
   1       .000     -.154-07   .000      .000
   2       .000     -.154-06 -.307-07   .000
   3     -.116-07 -.756-07 -.912-08 -.166-05
   4     -.967-04 -.311-04 -.908-04 -.422-04
```

4.4.4 CSR: BUCKLING OF A 10 DEGREE SECTOR OF A SPHERICAL SHELL DUE TO PRESSURE LOADING

The runstream for the problem described below is shown on the following page. The computed results agree exactly with those obtained with the quarter model described in Volume 3 of the EAL Reference Manual. Sample printout from the cyclic symmetry + reflective symmetry solution is shown on pages 4.4.4-2 and 4.4.4-3.


Along the edge:
- For computing the buckling solution, all joints are fully fixed.
- For computing the pre-buckling solution, all joints are constrained such that only tangential rotation and displacements normal to the shell surface are permitted.

$E=10^7$, $\nu=.3333$, $t=.396$
Radius=100.

Uniform external pressure=P

1-3 is the reflective symmetry plane

Sector 1, +side

Joint reference frame orientation at the outer edge

```
*XQT U1
*(29 SPHERE DEFINITION)
 1.+7  .3333 .1   .1-4  .396  100.      15.    10.     10
$  E     NU  RHO  ALPHA   T  RADIUS   THETA  GAMMA  ELEMENTS
*DCALL(MODEL BUILDER)
*XQT U1
*(CONSTRAINTS PRE)
  ZERO 2 4 6: 1,22: ZERO 1: 1,2
*(CONSTRAINTS)
  ZERO 1 2 3 4 5 6: 1,2
*(LOADS)
  ALPHA: CASE TITLE: 1'UNIT EXTERNAL PRESSURE
  TABLE: NODAL PRESSURE: J=1,22: 1.
*XQT AUS
 TABLE(NJ=4,TYPE=0): 5 HARMONICS: DDATA=1: RJ=1,4: 0
 TABLE(NJ=1,TYPE=0): 5 BACK SECTORS: J=1: 1
*XQT U1
*(OPTIONS)
 !NSECTORS=12: !RFLP=2: !PROB='BUCK
 !INIT=4: !NREQ=2: !NVECTORS=2: !NEVALS=2: !ERCK=0
*CALL(CSR)
```

```
CYCLIC SYMMETRY BUCKLING EIGENVALUES FOLLOW:

     HARMONIC  REFLECTIVE
MODE  NUMBER   BND. COND.   EIGENVALUE
   1     0        SYMM       .2379+03
   2     1        SYMM       .2471+03
   3     1        ASYM       .2471+03
   4     2        SYMM       .2488+03
   5     2        ASYM       .2488+03
   6     3        SYMM       .2853+03
   7     3        ASYM       .2853+03
   8     1        SYMM       .3517+03
   9     1        ASYM       .3517+03
  10     0        SYMM       .3996+03
  11     2        SYMM       .4172+03
  12     2        ASYM       .4172+03
  13     3        ASYM       .5160+03
  14     3        SYMM       .5160+03
  15     0        ASYM       .1483+04
  16     0        ASYM       .2744+04
```

```
EIGENVALUES
SYMMETRIC CONSTRAINT ON THE REFLECTIVE PLANE

       HARMONICS:
MODE      0        1        2        3
   1   .238+03  .247+03  .249+03  .285+03
   2   .400+03  .352+03  .417+03  .516+03


EIGENVALUE CONVERGENCE MATRIX
SYMMETRIC CONSTRAINT ON THE REFLECTIVE PLANE

       HARMONICS:
MODE      0        1        2        3
   1   .000    -.347-06  .000     .000
   2  -.537-04 -.151-04 -.420-04 -.161-04


EIGENVALUES
ANTI-SYMMETRIC CONSTRAINT ON THE REFLECTIVE PLANE

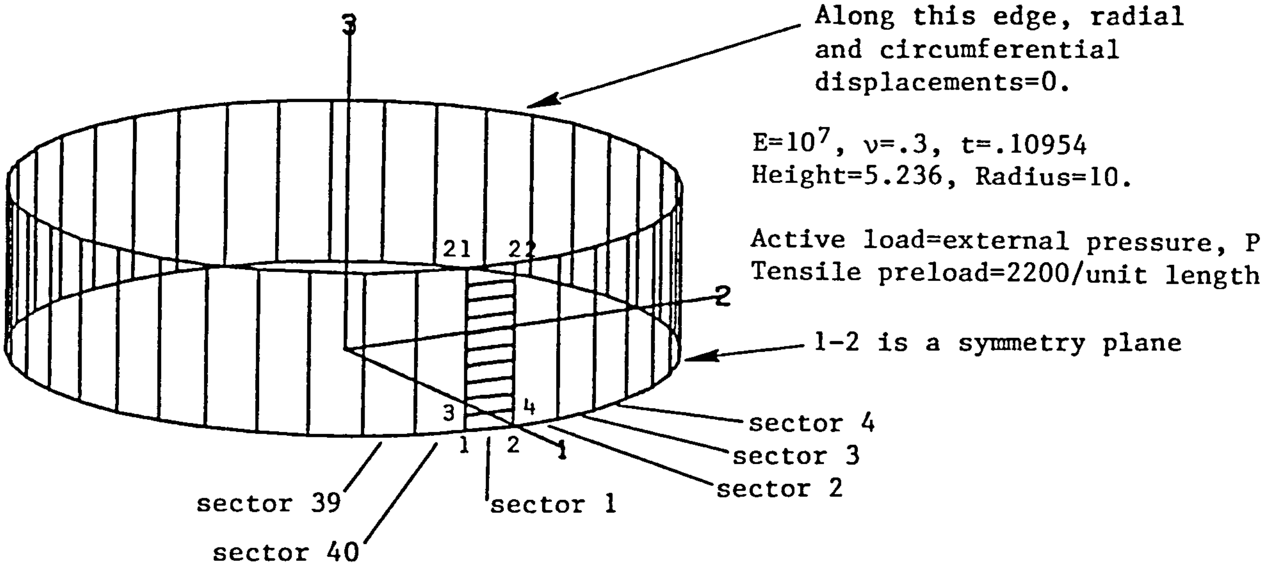
       HARMONICS:
MODE      0        1        2        3
   1   .148+04  .247+03  .249+03  .285+03
   2   .274+04  .352+03  .417+03  .516+03


EIGENVALUE CONVERGENCE MATRIX
ANTI-SYMMETRIC CONSTRAINT ON THE REFLECTIVE PLANE

       HARMONICS:
MODE      0        1        2        3
   1   .000    -.136-04 -.153-07 -.134-07
   2  -.688-04  .000    -.789-04 -.172-04
```

4.4.5 CS: BUCKLING OF A PRE-TENSIONED CYLINDRICAL SHELL DUE TO PRESSURE LOADING

The runstream for the problem described below is shown at the bottom of the page. The computed buckling pressure of 162.3 agrees exactly with the solution obtained with the quarter model described in Volume 3 of the EAL Reference Manual. Sample printout from the cyclic symmetry solution is shown on page 4.4.5-2.



$E=10^7$, $\nu=.3$, $t=.10954$
Height=5.236, Radius=10.

Active load=external pressure, P
Tensile preload=2200/unit length

```
*XQT U1
*(CYLINDER DEFINITION)
   10.+6 .3  .1   1.-5  .10954   10.    5.236    9.      10
$    E   NU  RHO  ALPHA    T    RADIUS  HEIGHT  THETA  ELEMENTS
*DCALL(MODEL BUILDER)
*XQT U1
*(LOADS PRE)
  ALPHA: CASE TITLE: 1'PRETENSION
  SYSVEC: APPL FORC: I=3: J=21,22: 1727.9
*(CONSTRAINTS PRE)
  SYMMETRY PLANE=3: ZERO 2 4 6: 1,22
*(LOADS)
  ALPHA: CASE TITLE 2: 1'UNIT EXTERNAL PRESSURE
  TABLE: NODAL PRESSURES 2: J=1,22: -1.
*(CONSTRAINTS)
  SYMMETRY PLANE=3: ZERO 1 2 6: 21,22
*XQT AUS
 TABLE(NJ=3,TYPE=0): 5 HARMONICS: J=1,3: 7: 8: 9
 TABLE(NJ=1,TYPE=0): 5 BACK SECTORS: J=1: 1
*XQT U1
*(OPTIONS)
 !NSECTORS=40: !INIT=4: !NREQ=2: !NVECT=2: !NEVAL=2: !PROB='BUCK
*CALL(CS)
```

```
CYCLIC SYMMETRY BUCKLING EIGENVALUES FOLLOW:

     HARMONIC
MODE  NUMBER   EIGENVALUE
   1     8       .1623+03
   2     8       .1623+03
   3     9       .1631+03
   4     9       .1631+03
   5     7       .1845+03
   6     7       .1845+03


EIGENVALUES

       HARMONICS:
MODE      7        8        9
   1   .184+03  .162+03  .163+03
   2   .184+03  .162+03  .163+03


EIGENVALUE CONVERGENCE MATRIX

       HARMONICS:
MODE      7        8        9
   1  -.124-05 -.119-05 -.191-05
   2  -.121-05 -.112-05 -.200-05
```

```
CYCLIC SYMMETRY BUCKLING EIGENVALUES FOLLOW:

     HARMONIC  REFLECTIVE
MODE  NUMBER   BND. COND.   EIGENVALUE
   1     8        ASYM       .1623+03
   2     8        SYMM       .1623+03
   3     9        ASYM       .1631+03
   4     9        SYMM       .1631+03
   5     7        ASYM       .1845+03
   6     7        SYMM       .1845+03


EIGENVALUES
SYMMETRIC CONSTRAINT ON THE REFLECTIVE PLANE

       HARMONICS:
MODE      7        8        9
   1    .184+03  .162+03  .163+03


EIGENVALUE CONVERGENCE MATRIX
SYMMETRIC CONSTRAINT ON THE REFLECTIVE PLANE

       HARMONICS:
MODE      7        8        9
   1  -.511-05 -.300-05 -.526-05


EIGENVALUES
ANTI-SYMMETRIC CONSTRAINT ON THE REFLECTIVE PLANE

       HARMONICS:
MODE      7        8        9
   1    .184+03  .162+03  .163+03


EIGENVALUE CONVERGENCE MATRIX
ANTI-SYMMETRIC CONSTRAINT ON THE REFLECTIVE PLANE

       HARMONICS:
MODE      7        8        9
   1  -.371-05 -.601-05 -.137-04
```

4.5.1 CS: RESTARTED ANALYSIS, RAIL WHEEL EXAMPLE, STATIC ANALYSIS, VIBRATIONAL MODES

The runstream is shown below for computing in a single execution both the static analysis and the vibrational analysis described in Sections 4.2.3 and 4.3.5. The static solution computations utilize the harmonic stiffness matrices and factored harmonic stiffness matrices created during the vibrational solution. See Section 2.7 for instructions for restarted executions.

```
*XQT U1
*(RAIL OPTIONS)
 !NTHETA=4: !THETA=45.
*(ISOTROPIC SOLIDS)$   E       NU       RHO      OTHERS
  J=1:                 29.+6   .3       .28      0. 0. 0.
*DCALL(RAIL WHEEL)
*XQT AUS
 TABLE(NJ=39,TYPE=0): JA: DDATA=1: RJ=1,39: 1
 TABLE(NJ=39,TYPE=0): JB: DDATA=1: RJ=1,39: 157
$
$ COMPUTE VIBRATIONAL MODES:
*XQT U1
*(CONSTRAINTS)
  ZERO 1 2 3: 4,6: 160,162: "JTS"
*(OPTIONS)
 !NSECTORS=8: !G=386.
 !INIT=10: !NREQ=8: !NVECTORS=6: !NEVALS=6: !NDYN=20: !VPRT=0
*CALL(CS)
$
$ COMPUTE STATIC SOLUTION:
*XQT AUS
 TABLE(NI=18,NJ=1,TYPE=4): 5 TITLE FORC: J=1
   'RAIL WHEEL, POINT LOADS APPLIED AT STATION 1
 TABLE(NJ=1,TYPE=0): 5 SECT FORC: J=1: 1
 SYSVEC: 5 APPL FORC
     I=1: J=   28:     29:     30:     33:     36:    39
             -750.: -500.: -250.:-1000.:-1000.: -500.
     I=3: J=   37:     38:     39
              600.: 1200.:  600.
*XQT U1
*(OPTIONS)
 !PROB='STAT
*(ES OPTIONS)
  NODES=0: D3D=3
*CALL(CS RESTART)
```

4.5.2 CSR: RESTARTED ANALYSIS, RAIL WHEEL EXAMPLE, STATIC ANALYSIS, VIBRATIONAL MODES

The runstream is shown below for computing in a single execution both the static analysis and the vibrational analysis described in Sections 4.2.4 and 4.3.6. The static solution computations utilize the harmonic stiffness matrices and factored harmonic stiffness matrices created during the vibrational solution. See Section 2.7 for instructions for restarted executions.

```
*XQT U1
*(RAIL OPTIONS)
 !NTHETA=2: !THETA=22.5
*(ISOTROPIC SOLIDS)$   E      NU      RHO      OTHERS
  J=1:                 29.+6  .3      .28      0. 0. 0.
*DCALL(RAIL WHEEL)
*XQT AUS
 TABLE(NJ=39,TYPE=0): JA: DDATA=1: RJ=1,39: 79
$
$ COMPUTE VIBRATIONAL MODES:
*XQT U1
*(CONSTRAINTS)
  ZERO 1 2 3: 4,6: "JTS"
*(OPTIONS)
 !NSECTORS=8: !G=386.: !RFLP=2
 !INIT=6: !NREQ=4: !NVECTORS=3: !NEVALS=3: !NDYN=20: !VPRT=0
*CALL(CSR)
$
$ COMPUTE STATIC ANALYSIS:
*XQT AUS
 TABLE(NI=18,NJ=1,TYPE=4): 5 TITLE FORC: J=1
   'RAIL WHEEL, POINT LOADS APPLIED AT STATION 1
 TABLE(NJ=1,TYPE=0): 5 SECT FORC: J=1: 1
 SYSVEC: 5 F+ FORC
     I=1: J=   28:    29:    30:    33:    36:    39
             -750.: -500.: -250.:-1000.:-1000.: -500.
     I=3: J=   37:    38:    39
              600.: 1200.:  600.
 OUTLIB=5: INLIB=5: F- FORC= UNION(0. F+)
*XQT U1
*(OPTIONS)
 !PROB='STAT
*(ES OPTIONS)
  NODES=0: D3D=3
*CALL(CSR RESTART)
```

5. SUMMARY OF CYCLIC SYMMETRY COMMAND RUNSTREAMS

Command runstream element names and functions are tabulated below. Elements with a first word of CS in their name pertain to cyclically symmetrical structures with no plane of reflective symmetry. A first word of CSR in the element name pertains to cyclically symmetrical structures with a plane of reflective symmetry.

Element Name	Function
CS XXXX 1 1 CSR XXXX 1 1	Driver procedures for the initial execution for a model. Directs the analysis by calling the appropriate sub-procedures.
CS RESTART 1 1 CSR RESTART 1 1	Directs the analysis for a restarted execution.
CS K+KG 1 1	For both CS and CSR models, this procedure computes the main sector stiffness matrix, K+KG, for preload.
CS DEFAULT 1 1 CSR DEFAULT 1 1	Creates default register values,
CS STORE 1 1 CSR STORE 1 1	Stores registers in Lib.1 that are required for a restarted execution.
CS FETCH 1 1 CSR FETCH 1 1	Fetches registers stored by (CS STORE) and (CSR STORE)
CS STEP 1 1 CSR STEP 1 1	(1) Creates data sets containing lists of boundary and interior joints. (2) Directs computation of sector stiffness, mass, and geometric stiffness matrices. Spectral shifts and the adding of rigid masses are included.
CSR CONS 1 1	Creates symmetric and anti-symmetric constraint conditions.
CS JSEQ 1 1 CSR JSEQ 1 1	Computes the single sector joint sequencing array to insure that the sector matrices are properly formatted for subsequent procedures.
CS DCK 1 1 CS DCK 2 1 CSR DCK 1 1 CSR DCK 2 1	Checks for errors in the input data runstream elements and data sets.

Element Name				Function
CS	LPREP	1	1	Creates applied force related data sets for subsequent static analysis.
CSR	LPREP			
CS	MAIN	1	1	Directs the computation of each harmonic solution.
CSR	MAIN	1	1	
CS	INIT	1	1	Creates registers and data sets that do not change with the harmonic number, k.
CS	PLOT	1	1	Controls production of the pseudo model for plotting the entire structure.
CS	JPLT	1	1	Creates joint locations for the pseudo plot model.
CS	JPLT	1	1	Creates displacement vectors for the pseudo plot model.

The following command runstream elements perform functions for a given circumferential harmonic, k:

Element Name				Function
CS	TAB	1	1	Sets up initial TAB data sets, including JDF1, JREF, JSEQ, and CON.
CSR	TAB	1	1	
CS	MAPS	1	1	(1) Constructs list of joints used for subsequent data transfers, and (2) Constructs the harmonic constraint arrays.
CSR	MAPS	1	1	
CS	MKKG	1	1	Directs computation of harmonic mass, stiffness, and geometric stiffness matrices.
CSR	MKKG	1	1	
CS	TDEM	1	1	Constructs the harmonic diagonal mass matrix.
CSR	TDEM	1	1	
CS	TK	1	1	Constructs a harmonic system matrix in labeled element format.
CSR	TK	1	1	
CSR	CT	1	1	Constructs data sets used in the CSR solution.
CS	EIG	1	1	Computes the harmonic eigensolution.
CSR	EIG	1	1	
CS	STAT	1	1	Computes the harmonic static solution.
CSR	STAT	1	1	

Element Name				Function
CS	FOUR	1	1	Constructs the Fourier symmetrical components of motion corresponding to the harmonic solution.
CSR	FOUR	1	1	
CS	SECT	1	1	Constructs sector eigenvectors.
CSR	SECT	1	1	
CS	SECT	2	1	Constructs sector static displacement vectors.
CSR	SECT	2	1	
CS	EVMX	1	1	Constructs eigenvalue solution matrices. NI = harmonics, NJ = modes.
CSR	EVMX	1	1	
CS	EVPR	1	1	Directs printing of solution eigenvalues.
CSR	EVPR	1	1	
CS	EVPR	2	1	Prints a single eigenvalue matrix.
CS	VPRT	1	1	Prints solution eigenvectors.
CSR	VPRT	1	1	
CS	VPRT	2	1	Prints static displacement solution vectors.
CSR	VPRT	2	1	

6. THEORY

Section 6.1 presents the theoretical background for cyclically symmetrical structures with no plane of reflective symmetry. Section 6.2 presents the theoretical background for cyclically symmetrical structures with a plane of reflective symmetry.

Equation numbering in this section begins with Eq.(1). All equation references pertain to equations that are contained in Section 6.

6.1 THEORETICAL BASIS OF CS

The following notation will be used:

n = number of sectors

K = stiffness matrix of a single sector (same for all sectors)

U_{ai} = motion vector, boundary a, sector i

U_{bi} = motion vector, boundary b, sector i

U_{oi} = motion vector, non-boundary portion of sector i

$U_i = \begin{bmatrix} U_{ai} \\ U_{bi} \\ U_{oi} \end{bmatrix}$ = motion vector, sector i

F_{ai} = applied force vector, boundary a, sector i

F_{bi} = applied force vector, boundary b, sector i

F_{oi} = applied force vector, non-boundary portion of sector i

$F_i = \begin{bmatrix} F_{ai} \\ F_{bi} \\ F_{oi} \end{bmatrix}$ = applied force vector, sector i

λ = system eigenvalue

System equations for static analysis may be written in the following form:

$$\begin{bmatrix} K & & & \\ & K & & \\ & & \cdot & \\ & & & \cdot \\ & & & & K \end{bmatrix} \begin{bmatrix} U_1 \\ U_2 \\ \cdot \\ \cdot \\ U_n \end{bmatrix} = \begin{bmatrix} F_1 \\ F_2 \\ \cdot \\ \cdot \\ F_n \end{bmatrix} \text{, or } \bar{K}\, U = F, \qquad (1)$$

subject to the inter-sector compatibility requirements,

$$U_{bi} = U_{a,i-1}, \text{ for } i = 1 \text{ through } n-1, \text{ and} \qquad (2)$$

$$U_{bn} = U_{a1}$$

As discussed in Reference 1, the following transformation of coordinates may be used to reformulate Eqs.(1) and (2) as a sequence of uncoupled static analysis problems of much lower order:

$$U_i = \sum_{k=0}^{m} Q_{kc} \cos(i-1) \frac{2\pi k}{n} + Q_{ks} \sin(i-1) \frac{2\pi k}{n}, \qquad (3)$$

$$m = n/2 \text{ if } n \text{ is even,}$$

$$= (n-1)2 \text{ if } n \text{ is odd.}$$

---

[1] Mac Neal, R. H., R. L. Harder, and J. B. Mason, NASTRAN Cyclic Symmetry Capability, NASTRAN Users Experiences 3rd Colloq., Langley Research Center, Hampton, Virginia, 395-421 (1973), NASA TEch. Memo, NASA TM X-2893.

Performing the transformation of coordinates indicated by Eq.(3) and Eq.(1) yields the following system equations:

$$\bar{K}\, Q = P, \tag{4}$$

where

$$Q = \left[Q_{0c} \quad Q_{0s} \quad Q_{1c} \quad Q_{1s} \cdot \cdot \cdot Q_{mc} \quad Q_{ms} \right]^t \text{, and}$$

$$P = \left[P_{0c} \quad P_{0s} \quad P_{1c} \quad P_{1s} \cdot \cdot \cdot P_{mc} \quad P_{ms} \right]^t .$$

Expressions for P_{kc} and P_{ks} are,

$$P_{kc} = \begin{bmatrix} P_{akc} \\ P_{bkc} \\ P_{okc} \end{bmatrix} = A_k \sum_{i=1}^{n} \begin{bmatrix} F_{ai} \\ F_{bi} \\ F_{oi} \end{bmatrix} \cos(i-1) \frac{2\pi k}{n}, \text{ and}$$

$$P_{ks} = \begin{bmatrix} P_{aks} \\ P_{bks} \\ P_{oks} \end{bmatrix} = A_k \sum_{i=1}^{n} \begin{bmatrix} F_{ai} \\ F_{bi} \\ F_{oi} \end{bmatrix} \sin(i-1) \frac{2\pi k}{n}, \tag{5}$$

where A_k = 1/n for k=0 and k-n/2, and A_k = 2/n for all other values of k.

Note that the stiffness matrix of Eq.(4) is the same as the stiffness matrix of Eq.(1).

Inter-sector compatibility requirements must now be imposed on Eq.(4).

In the following,

$$Q_{kc} = \begin{bmatrix} Q_{akc} \\ Q_{bkc} \\ Q_{okc} \end{bmatrix} , \quad Q_{ks} = \begin{bmatrix} Q_{aks} \\ Q_{bks} \\ Q_{oks} \end{bmatrix} , \tag{6}$$

where a, b, and o subscripts have the same meaning as in U_{ai}, U_{bi}, and U_{oi}.

For inter-sector compatibility, we substitute Eqs.(6) and (3) into Eq.(2) to obtain

$$\begin{bmatrix} C_k & S_k \\ -S_k & C_k \end{bmatrix} \begin{bmatrix} Q_{akc} \\ Q_{aks} \end{bmatrix} = \begin{bmatrix} Q_{bkc} \\ Q_{bks} \end{bmatrix} , \tag{7}$$

where $C_k = \cos(2\pi k/n)$, $S_k = \sin(2\pi k/n)$, and $k = 0$ through m.

Eq.(7) indicates that coupling exists only for symmetrical components of the same circumferential harmonic.

Writing the sector stiffness matrix in partitions as

$$K = \begin{bmatrix} K_{aa} & K_{ab} & K_{ao} \\ & K_{bb} & K_{bo} \\ \text{Symmetric} & & K_{oo} \end{bmatrix} ,$$

and imposing the compatibility requirements of Eq.(7) onto Eq.(4) yields m uncoupled equations of the form:

$$\bar{K}_k \begin{bmatrix} Q_{okc} \\ Q_{akc} \\ Q_{oks} \\ Q_{aks} \end{bmatrix} = \begin{bmatrix} P_{okc} \\ P_{akc} + C_k \cdot P_{bkc} - S_k \cdot P_{bks} \\ P_{oks} \\ P_{aks} + S_k \cdot P_{bkc} + C_k \cdot P_{bks} \end{bmatrix} , \quad \text{where} \tag{8}$$

$$\bar{K}_k = \begin{bmatrix} K_{oo} & K_{oa}+C_k\cdot K_{ob} & 0 & S_k\cdot K_{ob} \\ & K_{aa}+K_{bb}+C_k(K_{ab}+K_{ba}) & -S_k\cdot K_{ab} & S_k(K_{ab}-K_{ba}) \\ & & K_{oo} & K_{oa}+C_k\cdot K_{ob} \\ \text{Symmetric} & & & K_{aa}+K_{bb}+C_k(K_{ab}+K_{ba}) \end{bmatrix} \quad (9)$$

$\bar{K}_k$ is called the $k^{\underline{th}}$ harmonic stiffness matrix. Note that for k=0 or k=n/2, $S_k=0$, and $\bar{K}_k$ reduces two equal decoupled partitions each of which is half the order of $\bar{K}_k$.

In the cyclic symmetry procedures, CS, static solutions are computed as follows:

1. For each value of k,
   - The applied loads are factored into their harmonic components according to Eqs.(5),
   - The harmonic stiffness matrix is formed according to Eq.(9),
   - Eq.(8) is used to compute Q_{okc}, Q_{akc}, Q_{oks}, and Q_{aks}, and
   - Eq.(7) is used to compute Q_{bkc} and Q_{bks}, and Q_{kc} and Q_{ks} are formed according to Eq.(6).
2. Individual sector displacement vectors are computed by substituting Q_{kc} and Q_{ks} into Eq.(3).

For a general applied loading, all possible values of k (0 through m) are required for an exact solution. However, provisions are included in CS for truncating the solution to a specified subset of harmonics.

For cyclic symmetry eigenvalue problems, system equations are written as:

$$\lambda \bar{M} U - \bar{K} U = 0, \text{ for undamped vibration, and} \qquad (10)$$

$$\lambda \overline{KG} U + \bar{K} U = 0, \text{ for buckling.}$$

The system mass matrix $\bar{M}$ and geometric stiffness matrix $\overline{KG}$ have the same form as $\bar{K}$ in Eq.(1). Performing the transformation of coordinates indicated by Eq.(3) and imposing the compatibility requirements of Eq.(7) on Eqs.(10) yields M uncoupled eigenvalue problems of the following form:

$$\lambda \; \bar{M}_k \; \bar{Q}_k - \bar{K}_k \; \bar{Q}_k = 0, \text{ for vibration, and} \tag{11}$$

$$\lambda \; \overline{KG}_k \; \bar{Q}_k + \bar{K}_k \; \bar{Q}_k = 0, \text{ for buckling}$$

where

$$\bar{Q}_k = \begin{bmatrix} Q_{okc} \\ Q_{akc} \\ Q_{oks} \\ Q_{aks} \end{bmatrix}$$

$\overline{KG}_k$ has the same form as $\bar{K}_k$ in Eq.(9). For a consistent mass matrix formulation, $\bar{M}_k$ has the same form as $\bar{K}_k$. For a diagonal mass matrix

$$\bar{M}_k = \begin{bmatrix} M_{oo} & & & \\ & (M_{aa} + M_{bb}) & & \\ & & M_{oo} & \\ & & & (M_{aa} + M_{bb}) \end{bmatrix} \tag{12}$$

The CS procedures compute eigenvalue solutions according to Eqs.(11) for user specified values of k (0 through m). Back transformation for the corresponding sector eignevectors is performed by successive use of Eqs.(7), (6), and (3).

6.2 THEORETICAL BASIS OF CSR

For cylically symmetrical structures in which each sector possesses a reflective plane of symmetry, a finite element model of a symmetric half of one sector is used to compute static, vibrational, and buckling solutions for the complete structure.

The following terminology will be used:

+side = that half of a sector for which the finite model is supplied.

-side = the reflective half of a sector,

sector = the +side and -side together make up 1 sector.

The following notation will be used:

n = number of sectors in the complete structure,

K = stiffness matrix of the +side of a sector (same for both sides of all sectors)

U^{+}_{ai} = motion vector, boundary a, +side of sector i,

U^{+}_{oi} = motion vector, non-boundary portion of the +side of sector i,

$U^{+}_{i} = \begin{bmatrix} U^{+}_{oi} \\ U^{+}_{ai} \end{bmatrix}$ = motion vector, +side of sector i

F^{+}_{ai} = applied force vector, boundary a, +side of sector i

F^{+}_{oi} = applied force vector, non-boundary portion of the +side of sector i,

$F^{+}_{i} = \begin{bmatrix} F^{+}_{oi} \\ F^{+}_{ai} \end{bmatrix}$ = applied force vector, +side of sector i

$U^{-}_{ai}, U^{-}_{oi}, U^{-}_{i}, F^{-}_{ai}, F^{-}_{oi}, F^{-}_{i},$ = motion and applied force vectors, -side of sector i. These vectors are defined relative to left-handed joint reference frames, see Fig.3, Section 2.2,

λ = system eigenvalue

System equations for static analysis may be written in the following form:

$$\begin{bmatrix} K & & & & & \\ & K & & & & \\ & & \cdot & & & \\ & & & \cdot & & \\ & & & & K & \\ & & & & & K \end{bmatrix} \begin{bmatrix} U_1^+ \\ U_1^- \\ \cdot \\ \cdot \\ U_n^+ \\ U_n^- \end{bmatrix} = \begin{bmatrix} F_1^+ \\ F_1^- \\ \cdot \\ \cdot \\ F_n^+ \\ F_n^- \end{bmatrix} \quad \text{, or } \bar{K}\,U = F, \qquad (13)$$

Subject to the inter-sector compatibility requirements

$$U^+_{a,i+1} = \bar{T}\cdot U^-_{ai}, \text{ for i=1 through n-1, and} \qquad (14)$$

$$U^+_{a,1} = \bar{T}\cdot U^-_{an}.$$

Using cylindrical joint reference frames for a structure in which the global 3 axis is the axis of cyclic symmetry, $\bar{T}$ of Eq.(14) takes the following form:

$$\bar{T} = \begin{bmatrix} 1 & & & & & \\ & -1 & & & & \\ & & 1 & & & \\ & & & -1 & & \\ & & & & 1 & \\ & & & & & -1 \end{bmatrix}$$

Transformations for reflective symmetry may be written as

$$U_i^+ = U_i^s + U_i^a, \text{ and} \qquad (15)$$

$$U_i^- = U_i^s - U_i^a,$$

where

U_i^s = motion vector, symmetric deformation, sector i, and

U_i^a = motion vector, anti-symmetric deformation, sector i.

Performing the transformation indicated by Eq.(15) on Eq.(13), yields

$$\begin{bmatrix} K & & & & \\ & K & & & \\ & & \cdot & & \\ & & & \cdot & \\ & & & & K & \\ & & & & & K \end{bmatrix} \begin{bmatrix} U_1^s \\ U_1^a \\ \cdot \\ \cdot \\ U_n^s \\ U_n^a \end{bmatrix} = \begin{bmatrix} F_1^s \\ F_1^a \\ \cdot \\ \cdot \\ F_n^s \\ F_n^a \end{bmatrix} , \qquad (16)$$

where

$$F_i^s = \tfrac{1}{2}(F_i^+ + F_i^-), \text{ and} \qquad (17)$$

$$F_i^a = \tfrac{1}{2}(F_i^+ - F_i^-).$$

As discussed in Reference 1, the following transformation of coordinates may be used to reformulate Eq.(16) as a sequence of uncoupled static analysis problems of much lower order:

$$U_i^s = \sum_{k=0}^{m} Q_{kc}^s \cos(i-1) \frac{2\pi k}{n} + Q_{ks}^s \sin(i-1) \frac{2\pi k}{n}, \text{ and} \qquad (18)$$

$$U_i^a = \sum_{k=0}^{m} Q_{kc}^a \cos(i-1) \frac{2\pi k}{n} + Q_{ks}^a \sin(i-1) \frac{2\pi k}{n},$$

$$m = n/2 \text{ if } n \text{ is even,}$$

$$= (n-1)/2 \text{ if } n \text{ is odd.}$$

Expressions for Q_{kc}^s, Q_{ks}^s, Q_{kc}^a, Q_{ks}^a are

$$Q_{kc}^s = \begin{bmatrix} Q_{okc}^s \\ Q_{akc}^s \end{bmatrix}, \qquad Q_{ks}^s = \begin{bmatrix} Q_{oks}^s \\ Q_{aks}^s \end{bmatrix},$$

$$Q_{kc}^a = \begin{bmatrix} Q_{okc}^a \\ Q_{akc}^a \end{bmatrix}, \qquad Q_{ks}^a = \begin{bmatrix} Q_{oks}^a \\ Q_{aks}^a \end{bmatrix}, \qquad (19)$$

where o and a subscripts have the same meaning as in U_{ai}^+ and U_{oi}^+ .

Performing the transformation of coordinates indicated by Eqs.(18) and Eq.(16), yields the following system equations:

$$\bar{K}\, Q = P, \tag{20}$$

where

$$Q = \begin{bmatrix} Q^s_{0c} & Q^s_{0s} & Q^a_{0c} & Q^a_{0s} & \cdots & Q^s_{mc} & Q^s_{ms} & Q^a_{mc} & Q^a_{ms} \end{bmatrix}^t , \quad \text{and} \tag{21}$$

$$P = \begin{bmatrix} P^s_{0c} & P^s_{0s} & P^a_{0c} & P^a_{0s} & \cdots & P^s_{mc} & P^s_{ms} & P^a_{mc} & P^a_{ms} \end{bmatrix}^t .$$

Expressions for P^s_{kc}, P^s_{ks}, P^a_{kc}, and P^a_{ks} are,

$$\begin{aligned}
P^s_{kc} &= \begin{bmatrix} P^s_{okc} \\ P^s_{akc} \end{bmatrix} = A_k \sum_{i=1}^{n} \begin{bmatrix} F^s_{oi} \\ F^s_{ai} \end{bmatrix} \cos(i-1)\,\frac{2\pi k}{n} \;, \\
P^s_{ks} &= \begin{bmatrix} P^s_{oks} \\ P^s_{aks} \end{bmatrix} = A_k \sum_{i=1}^{n} \begin{bmatrix} F^s_{oi} \\ F^s_{ai} \end{bmatrix} \sin(i-1)\,\frac{2\pi k}{n} \;, \\
P^a_{kc} &= \begin{bmatrix} P^a_{okc} \\ P^a_{akc} \end{bmatrix} = A_k \sum_{i=1}^{n} \begin{bmatrix} F^a_{oi} \\ F^a_{ai} \end{bmatrix} \cos(i-1)\,\frac{2\pi k}{n} \;, \quad \text{and} \\
P^a_{ks} &= \begin{bmatrix} P^a_{oks} \\ P^a_{aks} \end{bmatrix} = A_k \sum_{i=1}^{n} \begin{bmatrix} F^a_{oi} \\ F^a_{ai} \end{bmatrix} \sin(i-1)\,\frac{2\pi k}{n} \;,
\end{aligned} \tag{22}$$

where $A_k = 1/n$ for $k = 0$ and $k = n/2$, and $A_k = 2/n$ for all other values of k. Note that the stiffness matrix of Eq.(20) is the same as the stiffness matrix of Eq.(13).

Inter-sector compatibility requirements must now be imposed on Eq.(20).

Substituting Eqs.(15) into Eqs.(14) yields,

$$U^s_{a,i+1} + U^a_{a,i-1} = \bar{T}\,(U^s_{ai} - U^a_{ai}) \quad . \tag{23}$$

By substituting Eqs.(19) and (18) into Eqs.(23), we obtain the following inter-sector compatibility equations, for systems in which $\bar{T}$ is a diagonal matrix with terms of +1 or -1.

$$S_k\, Q^a_{akc} - (C_k - \bar{T})\, Q^s_{aks} = 0, \text{ and} \tag{24}$$

$$-S_k\, Q^s_{akc} + (C_k + \bar{T})\, Q^a_{aks} = 0, \tag{25}$$

where

$S_k = \sin \frac{2\pi k}{n}$,

$C_k = \cos \frac{2\pi k}{n}$. (6x6 identity matrix), and

$k =$ 0 through m.

Eqs.(24) and (25) are imposed on the system by introducing new coordinates, and such that:

$$Q^s_{aks} = S_k\, Q_x, \quad Q^a_{akc} = (C_k - \bar{T})\, Q_x \, , \tag{26}$$

$$Q^a_{aks} = S_k\, Q_y, \quad Q^s_{akc} = (C_k + \bar{T})\, Q_y \, . \tag{27}$$

Writing a sector +side stiffness matrix as,

$$K = \begin{bmatrix} K_{oo} & K_{oa} \\ \text{Sym} & K_{aa} \end{bmatrix} ,$$

and imposing the compatibility requirements of Eq.(26) onto Eq.(20) yields m uncoupled equations of the form:

$$\begin{bmatrix} K_{oo} & 0 & K_{oa} \cdot S_k \\ & K_{oo} & K_{oa} \cdot (C_k - \bar{T}) \\ \text{Sym} & & K_{aa} \cdot S_k^2 + (C_k - \bar{T}) K_{aa} (C_k - \bar{T}) \end{bmatrix} \begin{bmatrix} Q^s_{oks} \\ Q^a_{okc} \\ Q_x \end{bmatrix} = \begin{bmatrix} P^s_{oks} \\ P^a_{okc} \\ S_k \cdot P^s_{aks} + (C_k - \bar{T}) P^a_{akc} \end{bmatrix} , \tag{28}$$

or $\bar{K}_{kx}\, \bar{Q}_{kx} = \bar{P}_{kx}$.

In Eq.(28), pre-and post-multiples of K_{oa} and K_{aa} by $(C_k - \bar{T})$ indicate that each (6x6) submatrix of K_{oa} and K_{aa} are operated on by $(C_k - \bar{T})$.

Imposing the compatibility requirements of Eq.(27) onto Eq.(20) yields a second set of m uncoupled equations of the form:

$$\begin{bmatrix} K_{oo} & 0 & K_{oa}\cdot(C_k+\bar{T}) \\ & K_{oo} & K_{oa}\cdot S_k \\ \text{Sym} & & K_{aa}\cdot S_k^2+(C_k+\bar{T})K_{aa}(C_k+\bar{T}) \end{bmatrix} \begin{bmatrix} Q^s_{okc} \\ Q^a_{oks} \\ Q_y \end{bmatrix} = \begin{bmatrix} P^s_{okc} \\ P^a_{oks} \\ S_k\cdot P^a_{aks}+(C_k+\bar{T})P^s_{akc} \end{bmatrix}, \tag{29}$$

$$\text{or} \qquad \bar{K}_{ky}\ \bar{Q}_{ky} = \bar{P}_{ky} .$$

For $S_k=0$, k=0 and k=n/2, Eqs. (28) and (29) reduce to the following:

$$\begin{bmatrix} K_{oo} & K_{oa}\cdot(C_k-\bar{T}) \\ \text{Sym} & (C_k-\bar{T})K_{aa}(C_k-\bar{T}) \end{bmatrix} \begin{bmatrix} Q^s_{oks} \\ Q_x \end{bmatrix} = \begin{bmatrix} P^a_{okc} \\ (C_k-\bar{T})P^a_{akc} \end{bmatrix}, \text{ and} \tag{30}$$

$$\begin{bmatrix} K_{oo} & K_{oa}\cdot(C_k+\bar{T}) \\ \text{Sym} & (C_k+\bar{T})K_{aa}(C_k+\bar{T}) \end{bmatrix} \begin{bmatrix} Q^s_{okc} \\ Q_y \end{bmatrix} = \begin{bmatrix} P^s_{okc} \\ (C_k+\bar{T})P^s_{akc} \end{bmatrix}. \tag{31}$$

In the reflective cyclic symmetry procedures, CSR, static solutions are computed as follows:

1. For each value of k,
    - o The applied loads are factored into their harmonic components according to Eqs.(22).
    - o Eq.(28) (or Eq.(30) if $S_k=0$) is used to compute Q^s_{oks}, Q^a_{okc}, and Q_x.
    - o Eq.(29) (or Eq.(31) if $S_k=0$) is used to compute Q^s_{okc}, Q^a_{oks}, and Q_y.
    - o Eqs.(26) and (27) are used to compute Q^s_{aks}, Q^a_{akc}, Q^a_{aks}, and Q^s_{akc}.
2. Individual sector displacement vectors are computed by successive application of Eqs.(19), (18), and (15).

For a general applied loading, all possible values of k are required for an exact solution. However, provisions are inluded in CSR for truncating the solution to a specified subset of harmonics.

Eigenvalue problems for cyclically symmetrical structures with reflective symmetry are written as:

$$\lambda\ \bar{M}\, U - \bar{K}\, U = 0\ , \tag{32}$$

$$\lambda\ \overline{KG}\, U + \bar{K}\, U = 0\ ,$$

The system mass matrix M and geometric stiffness matrix KG have the same form as K in Eq.(13). Performing the transformation of coordinates and imposing the inter-sector compatibility requirements on M and KG as was done with K, results in m uncoupled eigenvalue problems of the following form:

$$\lambda\ \bar{M}_{kx}\, \bar{Q}_{kx} - \bar{K}_{kx}\, \bar{Q}_{kx} = 0\ , \tag{33a}$$

For undamped vibration

$$\lambda\ \bar{M}_{ky}\, \bar{Q}_{ky} - \bar{K}_{ky}\, \bar{Q}_{ky} = 0\ , \tag{33b}$$

$$\lambda\ \overline{KG}_{kx}\bar{Q}_{kx} - \bar{K}_{kx}\, \bar{Q}_{kx} = 0\ , \tag{34a}$$

For buckling

$$\lambda\ \overline{KG}_{ky}\bar{Q}_{ky} - \bar{K}_{ky}\, \bar{Q}_{ky} = 0\ . \tag{34b}$$

$\overline{M}_{kx}$ and $\overline{KG}_{kx}$ have the same form as $\bar{K}_{kx}$ of Eq.(28) or Eq.(30) depending on the value of S_k. $\bar{M}_{ky}$ and $\overline{KG}_{ky}$ have the same form as $\bar{K}_{ky}$ of Eq.(29) or Eq.(31).

The eigenvalues of Eqs.(33a) are identical to the eigenvalues of Eqs.(33b). Eigenvalues of Eqs.(34a) are identical to those of Eqs.(34b). However, solutions to both sets of equations are required for computing complete eigenvectors.

The CSR procedures compute eigenvalue solutions according to Eqs.(33) or (34) for user specified values of k (a through m). Back transformation for the corresponding sector eigenvectors is performed by successive use of Eqs.(20), (27), (19), and (18) to obtain U_i^s and U_i^a. Except for harmonics k=0 and k=n/2, all system eigenvalues occur in pairs, corresponding to U_i^s and U_i^a, respectively. For k=0 and k=n/2, the eigenvalues associated with U_i^s and U_i^a are unique.

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MACROELEMENT PROCEDURES

by

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PREFACE

This report was prepared by Engineering Information Systems, Inc., for the George C. Marshall Space Flight Center of the National Aeronautics and Space Administration, under contract NAS8-32664. The Contracting Officer's Technical Representative was Mr. L. A. Kiefling.

The macroelement procedures were designed jointly by W. D. Whetstone and C. E. Jones, and were prepared and tested by Dr. Jones.

Submitted by:

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I. INTRODUCTION

The EAL macro element procedures may be used to model structural systems incorporating macro elements. Each macro element is an independent finite element model. Macro elements are commonly used in modeling situations such as the following:

- Modeling a structure that is made up of a number of identical substructures. In this case, a single macro element model is used to represent all occurrences of a repeated substructure.
- Modeling specific structural parts such as irregular beams, tapered beams, beams with thin-walled open cross sections, curved beams with non-symmetrical sections, sectors of curved shells, etc. For this type of modeling, the macro element model usually has a finer mesh density than the overall structural model.

Provisions are included in the procedures for back transformation and printing of individual macro element displacements, reactions, and stresses.

The macro element procedures rely heavily on the EAL processors used for substructure analysis. Those processors are AUS/(SSPREP, SSM, SSK), SYN, and SSBT.

In subsequent sections of this report, MEi is used to denote a macro element name. MEi is any four character named specified by the user to define a basic macro element.

1.1 TERMINOLOGY

The terminology used in subsequent sections of this report is very similar to the terminology used in Vol. 1 of the EAL Reference Manual in those sections that pertain to substructure analysis.

As illustrated on Figure 1-1. a system consists of system joints interconnected by any number of macro elements and finite elements. Each macro element has one or more boundary nodes, each of which is connected to a system joint. If a boundary node does not coincide with the system joint to which it is connected, the connection is made through a rigid link.

In Figure 1-1, MEi represents a macro element which is repeated three times. MEj and MEk denote macro elements that occur once in the system model.

Each macro element has an associated macro element reference frame, relative to which are defined (1) the locations of the boundary nodes, and (2) the orientation of boundary node reference frames. Each macro element reference frame coincides with one of the system alternate reference frames, each of which is defined by specifying (1) the location of its origin, and (2) the orientation of its axes, relative to the system global frame.

The degrees of freedom that represent the state of the assembled system are the system joint motions. The motion of a system joint is a six component vector relative to a system joint reference frame uniquely associated with the system joint.

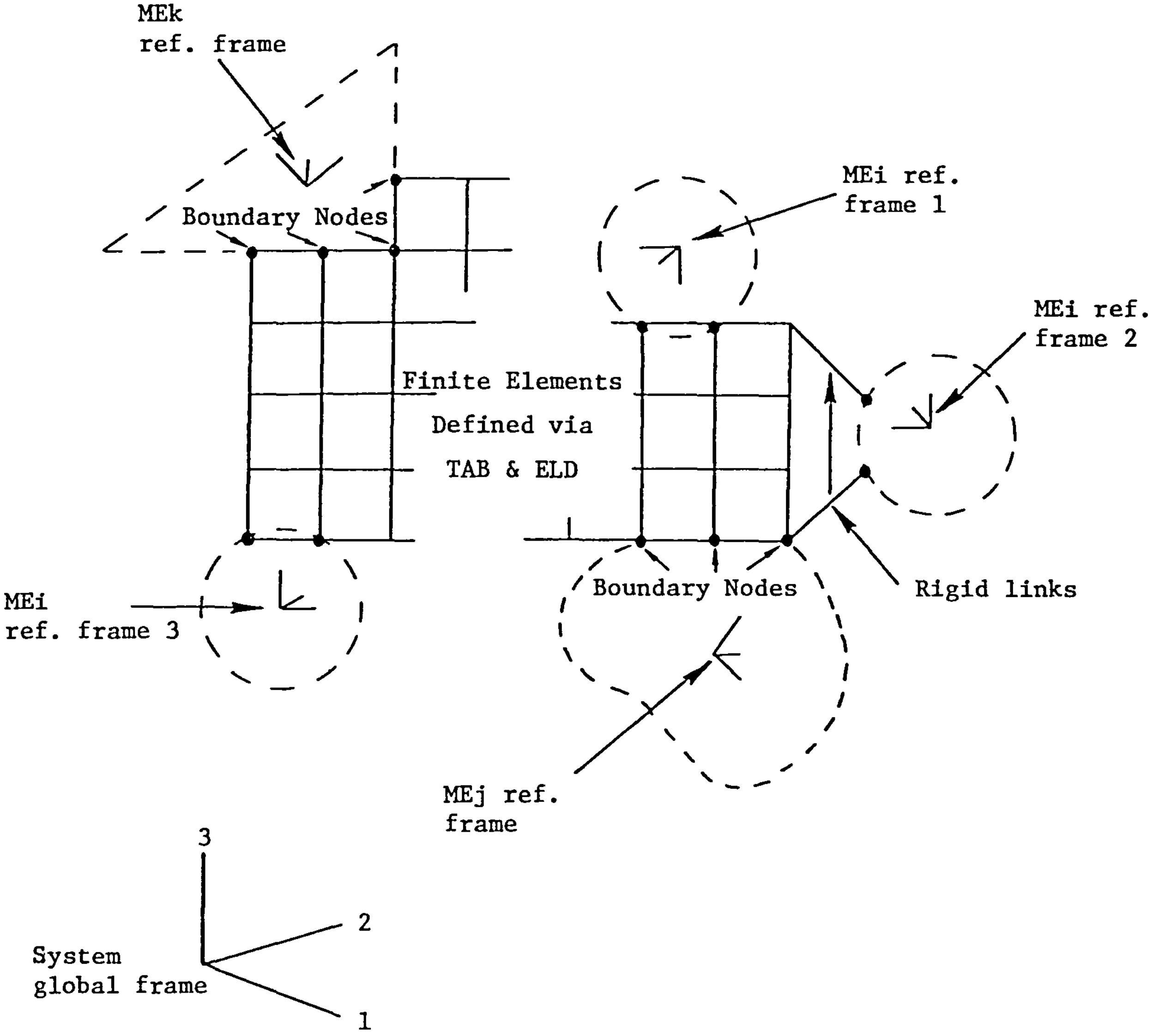


Figure 1-1 Assembled System

1.2 ANALYSIS PROCEDURE

A typical analysis procedure for a macro element assembly is outlined below:

1. Define the finite element model for each unique macro element, as described in Section 2. Each macro element may be repeated any number of times in the system.
2. Define the system, as discussed in Section 2. In addition to macro elements, the system may also contain ordinary finite elements, e.g. E21, E43, --. It is also permissible for the system to contain only macro elements.
3. Assemble the system mass and stiffness matrices. As produced by the procedure ME SYS, these matrices are named MSYS and KSYS.
4. Perform the system analysis using MSYS and KSYS. The user may compute system vibrational modes, static displacement solutions, dynamic response solutions, etc.
5. As described in Section 3, back transform for the individual macro element displacement vectors associated with the system solution vectors computed in step 4.
6. Print the macro element stresses, reactions, and joint motions as described in Section 4.

Except for step 4, all of the steps are performed automatically by the EAL macro element procedures. Step 4 must be performed by the user.

2. CONSTRUCTING THE ASSEMBLED SYSTEM MASS AND STIFFNESS MATRICES

The primary procedure for constructing system mass and stiffness matrices is ME SYS. Utility procedures that are called by ME SYS are:

ME MACRO 1
ME RMRK, and
ME ASSEMBLE.

An information flow diagram for ME SYS is shown on Figure 2-1.

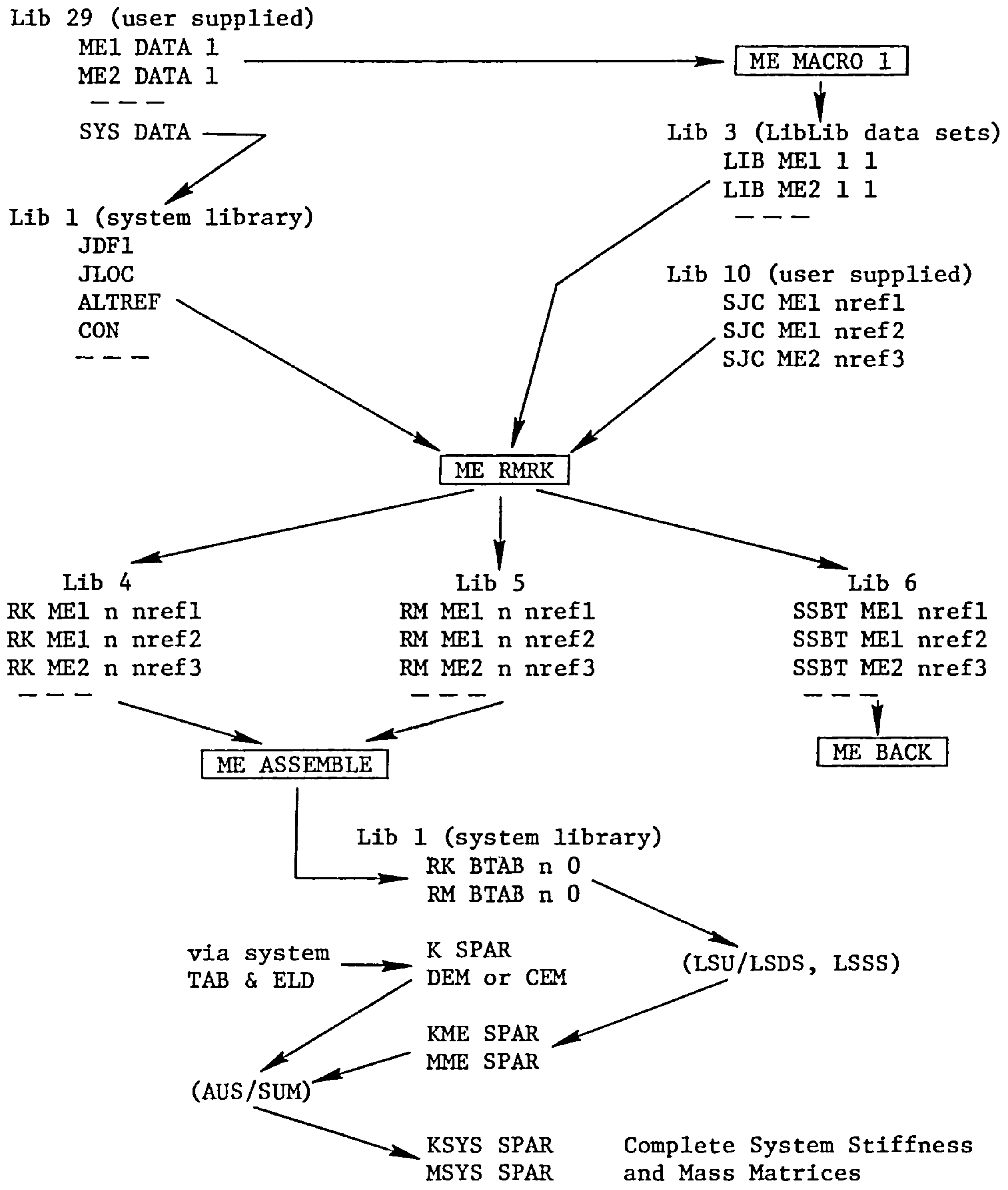
System matrices are constructed by ME SYS in three phases, as follows:

Phase 1: For each runstream element in library 29 named MEi DATA 1, the procedure ME MACRO 1 computes and stores into library 3 a data set named LIB MEi 1 1. LIB MEi 1 1 is a liblib data set that contains the mass and stiffness matrices for the basic macro element MEi. The stored M and K are computed relative to the macro element reference frame.

Phase 2: For each runstream element in library 10 maned SJC MEi nref, the procedure ME RMRK computes the corresponding contributions to the system mass and stiffness matrices, RM MEi nref and RK MEi nref. These data sets are stored in libraries 4 and 5 in labeled submatrix format. SSBT MEi nref is stored in library 6 for subsequent use in back transformation.

Phase 3: Using the contents of libraries 4 and 5 and the system finite elements defined via TAB and ELD, the system mass and stiffness matrices, MSYS and KSYS, are computed and stored in library 1.

As discussed in Section 2.1.3, the parameter ASSEM is provided to control the execution of Phase 3. The user may elect not to execute Phase 3 during the model preparation phase of an analysis.



Normal flow of information for constructing the complete system mass and stiffness matrices. This process is carried out by the procedure ME SYS.

Figure 2-1 Information Flow Diagram for ME SYS

2.1.1 INPUT SCHEMATIC, SYSTEM DEFINITION

To construct the system mass and stiffness matrices representing an assemblage of macro elements, proceed as follows:

```
*XQT U1

*(29 ME1 DATA 1)  ENDME1        . Data for macro element ME1
$ ME1 PARAMETER SPECIFICATIONS:
   G=386.,  MNAM = CEM          . Optional parameters; see Sect. 2.1.2.
*(TAB)                          . ME1 TAB data
   START jtme1                  . 6 DOF per joint
   JLOC
   SA
   ---
*(ELD)                          . ME1 ELD data
   Exx
   ---
*(BN)                           . ME1 boundary nodes
   j1: j2: j3,j4: ---           . Loop limit format permitted.  j1<j2<j3...
*(----)                         . Optional Runstream Elements, Sect. 2.1.5.
*                 ENDME1

*(29 ME2 DATA 1)  ENDME2        . Data for macro element ME2
  ---
*                 ENDME2

  ---                           . Data for any number of macro elements

*(SYS DATA)       ENDSYS        . Data for system model
$ SYSTEM PARAMETER SPECIFICATIONS:
   G=386.                       . Optional parameters; see Sect. 2.1.3.
*(TAB)
   START jtsys                  . 6 DOF per joint
   JLOC                         . System joint locations
   ALTREF                       . Alternate ref. frames are used to define
                                  the position and orientation of macro
                                  element ref. frames.
   CON = 1                      . System Constraint
   ---
*(ELD)                          . Optional system elements defined via ELD
  Exx
  ---
*(----)                         . Optional Runstream Elements, Sect. 2.1.5.
*                 ENDSYS
```

*(10 SJC ME1 nref1) a1: a2: — — —	. An ME1 macro element is positioned and oriented according to the system alternate ref. frame nref1. ME1 boundary node j1 is attached to system joint a1; j2 is attached to a2; etc. Loop format is not permitted.
*(10 SJC ME1 nref2) b1: b2: — — —	. Another ME1 macro element is positioned and oriented according to the system alternate ref. frame nref2.
*(10 SJC ME2 nref3) c1: c2: — — —	. An ME2 macro element is positioned and oriented according to the system alternate ref. frame nref3.
— — —	. Any number of SJC data sets may be entered into Lib 10.

*CALL (ME SYS)

As illustrated by the flow diagram, Figure 2-1, the procedure ME SYS constructs complete system mass and stiffness matrices named MSYS and KSYS.

For each runstream element in Lib 29 named MEi DATA 1, a Liblib data set is entered into Lib 3 as shown on Figure 2-1. For each SJC MEi nref data set in Lib 10, a data set is entered into Libs 4, 5, and 6, as shown on Figure 2-1.

2.1.2 MEi DATA OPTIONAL PARAMETERS

As shown in Section 2.1.1, optional parameter specifications may be included at the beginning of MEi DATA 1 to change the values of the parameters listed below:

Parameter Name	Default Value	Meaning
G	1	Acceleration of gravity.
SEQ	1	If nonzero, SEQ is executed for the macro element.
MNAME	DEM	Mass matrix name. DEM for diagonal, CEM for consistent.
MWARP	.05	E Reset
KFAC	1	K Reset
SPDP	2	K Reset

Parameter specifications must be the first executable commands in a MEi DATA 1 runstream element.

2.1.3 SYS DATA OPTIONAL PARAMETERS

As shown in Section 2.1.1, optional parameter specifications may be included at the beginning of SYS DATA to change the values of the parameters listed below:

Parameter Name	Default Value	Meaning	
G	1	Acceleration of gravity.	
SEQ	1	If nonzero, SEQ is executed for the system.	
MNAME	DEM	Mass matrix name associated with system ELD elements. DEM for diagonal, CEM for consistent.	
MWARP	.05	E Reset	Used only if system elements are defined via ELD.
KFAC	1	K Reset	
SPDP	2	K Reset	
ASSM	1	=1, System matrices, KSYS and MSYS, are assembled during this execution. =0, Macro element matrices are entered into libraries 4, 5, and 6, but the system matrices are not assembled. See the information flow diagram, Figure 2-1.	

Parameter specifications must be the first executable commands in the SYS DATA runstream element.

2.1.4 MASS MATRICES AND RIGID MASSES

To include rigid mass in macro elements or in the system, insert TAB/RMASS input into the appropriate *(TAB) runstream element. See Section 2.1.1. RMASS is automatically added to the corresponding mass matrix (defined by the register MNAME as discussed in Sections 2.1.2 and 2.1.3) to form the total mass, MTOT. MTOT is then used by the macro element procedures as the mass matrix.

2.1.5 OPTIONAL RUNSTREAM ELEMENTS

In the ME procedures, many *XQT commands are followed by optional DCALL commands, such as:

```
*XQT SEQ
*DCALL, OPT (SEQ OPTIONS)
```

These optional runstream elements are input as described in Section 2.1.1 for each macro element and for the system. Optional runstream elements that are recognized by the ME procedures are:

```
*(E       OPTIONS)
*(EKS     OPTIONS)
*(SEQ     OPTIONS)
*(TAN     OPTIONS)
*(K       OPTIONS)
*(M       OPTIONS)
*(RSI     OPTIONS)
*(SYN     OPTIONS)         See ME RMRK
*(LELS    OPTIONS)         See ME RMRK
*(SSBT    OPTIONS)         See ME BACK
*(LSU     OPTIONS)         For LSDS and LSSS
```

Note that calls to other procedures may be initiated through an optional runstream element.

2.2 ADDING OR REPLACING MACRO ELEMENTS IN AN EXISTING MODEL

New macro elements may be added to an existing system model, or macro elements may be replaced in an existing system model by executing the following steps:

1. Attach to the run libraries 1, 3, 4, 5, and 6.
2. Prepare and execute a runstream like the input schematic in Section 2.1.1.

All macro elements processed during the run will cause new data sets to be added to the system libraries, or old data sets to be replaced in the system libraries. Be sure that runstream elements are entered into Libs 29 and 10 only for those macro elements that are to be processed during the execution.

2.3 RIGID CONNECTION BETWEEN SYSTEM JOINTS AND MACRO ELEMENT BOUNDARY NODES

If a macro element boundary node does not geometrically coincide with the system joint to which it is attached, a transformation is performed by the processor SYN that assumes a rigid connection between the two.

3. BACK TRANSFORMATION FROM SYSTEM DISPLACEMENT VECTORS TO INDIVIDUAL MACRO ELEMENT DISPLACEMENT VECTORS

The procedure ME BACK is used to back transform displacement vectors in system SYSVEC format to displacement vectors for the individual macro elements. The macro element displacement vectors are in SYSVEC format in accordance with the characteristics of their respective macro elements.

An information flow diagram for ME BACK is shown on Figure 3-1. Provisions are included for back transformation of static displacement vectors and vibrational modes.

For each runstream element in Lib 10 named SJC MEi nref, ME BACK computes and inserts into Lib 7 a data set named USB MEi nset nref. USB MEi nset nref is the displacement vector for macro element MEi oriented and positioned according to nref.

To execute ME BACK:

1. Attach libraries 1, 3, 6, 7, 10, and "QLIB". The contents of these libraries are shown on Fig. 3-1.
2.
```
*XQT U1
*(BACK PARAMETERS)
  VECT = 'VIBR      . Optional Parameters; see the table below.
*CALL (ME BACK)
```

The optional runstream element BACK PARAMETERS may be used to change the values of the parameters tabulated below:

Parameter Name	Default Value	Meaning
VECT	'STAT	= 'STAT For static displacements = 'VIBR For vibrational modes
SET	1	Set number nset; see Fig. 3-1.
CON	1	Constraint number ncon; see Fig. 3-1.
QLIB	1	Solution library; see Fig. 3-1.

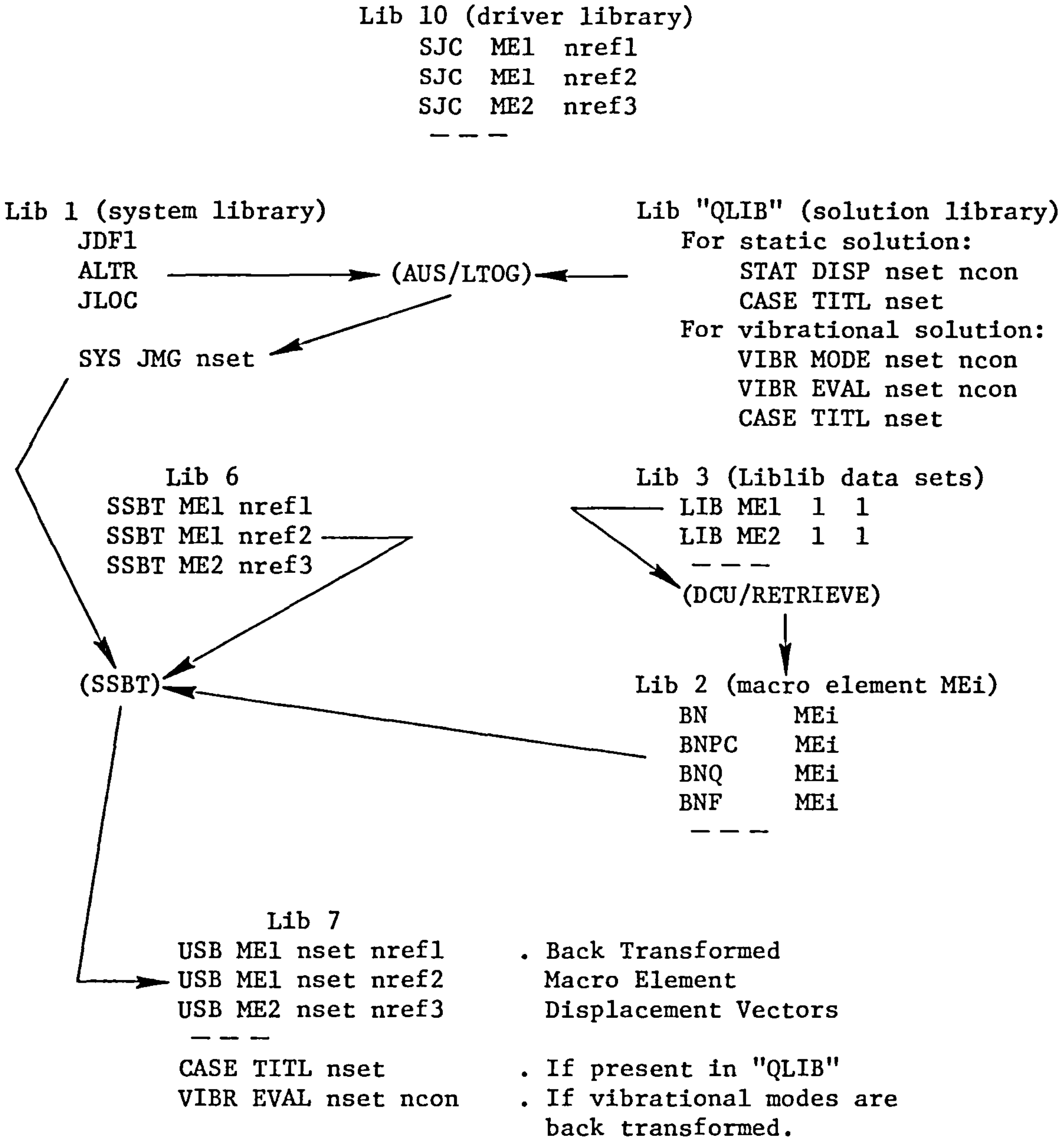


Figure 3-1 Information Flow Diagram for ME BACK

4. PRINTING RESULTS

Procedures are provided for printing stresses, displacements, and reactions for individual macro elements. Stresses are printed using the EAL processor ES. Displacement and reaction vectors are printed using U3/RP2.

For printing stresses, displacements, or reactions, the following EAL libraries must be attached:

Lib 3.	Basic macro element liblib data sets; see Fig. 3-1.
Lib 7.	Back transformed macro element displacement vectors; see Fig. 3-1.
Lib 10.	Driver library containing the SJC MEi nref data sets; see Fig. 3-1.

4.1 STRESS PRINTING

Stresses are printed for each macro element for which a data set named SJC MEi nref resides in Lib 10.

To print macro element stresses:

```
*XQT U1
*(ES PARAMETERS)
    SET = nset   . Default nset = 1
*(ES ALL)
    ES commands that pertain to all macro elements
*(ES MEi)
    ES commands that pertain to all MEi macro elements
*(ES MEi nref)
    ES commands that pertain to the single macro element MEi
    oriented and positioned according to nref.
— — —
*CALL (ME ES)
```

All of the above input runstream elements are optional.

The runstream elements ES ALL, ES MEi, and ES MEi nref are used to issue any of the ES commands described in Vol. 1 of the EAL Ref. Manual.

To prevent the ES command ALL from being executed, include the register action command !ALL=0 in any of the ES XXXX YYYY runstream elements.

4.2 DISPLACEMENTS AND REACTIONS PRINTING

Displacements or reactions are printed for each macro element for which a data set named SJC MEi nref resides in Lib 10.

To print macro element displacements or reactions:

```
       *XQT U1
       *(VPRT PARAMETERS)
          SET = nset:  CON = ncon       . Optional parameters; see the
       *CALL (ME VPRT)                    table below.
```

The optional runstream element VPRT PARAMETERS may be used to change the values of the parameters tabulated below:

Parameter Name	Default Value	Meaning
SET	1	Set number, nset; see Fig. 3-1.
CON	1	Constraint condition, ncon; see Fig. 3-1.
EVAL	0	= 0, no eigenvalues displayed. = 'XXXX, eigenvalues in the data set named (XXXX EVAL "SET") are displayed with the appropriate vectors. = 'VIBR, eigenvalues and frequencies in HZ are displayed with the vectors.
N1	'USB	= 'USB, displacements are printed. = 'REAC, reactions corresponding to the matrix product of the macro element stiffness matrix and USB MEi nset nref are computed and printed.

The output of ME VPRT is similar to the output of the processor VPRT. Fixed DOF's are marked with a *. Boundary node DOF's are marked with a B.

5.1 DESCRIPTION OF PROCEDURE FUNCTIONS

ME SYS

This procedure directs construction of the system mass and stiffness matrices by calling the procedures ME MACRO 1, ME RMRK, and ME ASSEMBLE. The total system M and K are named MSYS and KSYS, and are stored in Lib 1.

ME MACRO 1

For each data set in Lib 29 named MEi DATA 1, this procedure stores a Liblib data set in Lib 3 named LIB MEi 1 1. ME MACRO 1 uses the AUS processors SSPREP, SSM, and SSK to compute the data sets BN MEi, BNPC MEi, BNQ MEi, BNF MEi, SSMK MEi 1 1, and SSMK MEi 2 1. These data sets are used by ME RMRK to construct MEi contributions to the system M and K.

ME RMRK

For each data set in Lib 10 named SJC MEi nref, this procedure stores in Lib 4, 5, and 6 data sets named RK MEi n nref, RM MEi n nref, and SSBT MEi nref, respectively. ME RMRK uses the Liblib data set named LIB MEi 1 1 in Lib 3 and the system alternate reference frame nref from Lib 1 to construct the output data sets. RK MEi n nref is that part of the system stiffness matrix associated with the macro element MEi oriented and positioned according to nref and attached through its boundary nodes to the system joints defined in SJC MEi nref. RM MEi n nref is the MEi contribution to the system mass matrix. RK and RM are in labeled submatrix format.

ME ASSEMBLE

This procedure converts the RK MEi n nref data sets in Lib 4 into a single data set named RK BTAB 6 0 in Lib 1. RK BTAB 6 0 is that part of the system stiffness matrix representing the assemblage of all macro elements. The corresponding system mass matrix RM BTAB 6 0 is computed from Lib 5. All data sets involved are in labeled submatrix format.

ME BACK

For each data set in Lib 10 named SJC MEi nref, this procedure stores in Lib 7 a data set named USB MEi nset nref. USB MEi nset nref is the back transformed displacement vector for macro element MEi oriented and positioned according to nref. nset is the set number of the input system displacement vector.

ME ES

For each data set in Lib 10 named SJC MEi nref, this procedure prints element stresses associated with the displacement vector USB MEi nset nref stored in Lib 7.

ME VPRT

For each data set in Lib 10 named SJC MEi nref, this procedure prints in VPRT format the displacement vector USB MEi nset nref stored in Lib 7. ME VPRT optionally prints as reactions the matrix product of the macro element stiffness matrix and USB MEi nset nref.

ME LOOP

This is a utility procedure for looping through all macro elements associated with the data sets in Lib 10 named SJC MEi nref. For each macro element, the following optional calls are made:

```
*DCALL,OPT(LOOP ALL)
*DCALL,OPT(LOOP "SSID")
*DCALL,OPT(LOOP "SSID" "NREF"),
```

where "SSID" and "NRFF" take on all values of MEi and nref.

5.2 PROCEDURE LISTINGS

The following pages are U1/PRT listings of the macro element procedures listed below:

1.	ME	SYS	0	0
2.	ME	MACRO	1	0
3.	ME	RMRK	0	0
4.	ME	ASSEMBLE	0	0
5.	ME	BACK	0	0
6.	ME	ES	0	0
7.	ME	VPRT	0	0
8.	ME	LOOP	0	0

```
$
$ THIS PROCEDURE DIRECTS THE CONSTRUCTION OF SYSTEM MASS AND
$ STIFFNESS MATRICES FOR ASSEMBLAGES OF MACRO ELEMENTS PLUS
$ ELEMENTS DEFINED VIA TAB AND ELD.
$
$ FORM THE BASIC MACRO ELEMENT LIBLIB DATA SETS:
*LIBS 2 1 3 4 5 6 7 8 9 10 11 12 13 14 15 16 17 18 19 20
*CALL(ME MACRO 1)
*LIBS 1 2 3 4 5 6 7 8 9 10 11 12 13 14 15 16 17 18 19 20
$
$ INPUT THE SYSTEM TAB AND ELD DATA:
*XQT U1
    !OPT=0
*DLIB=20
$
$ DEFAULT REGISTERS:
*RGI
     SEQ=      1$ =1, SEQ IS EXECUTED FOR THE SYSTEM
$                 =0, SEQ IS NOT EXECUTED FOR THE SYSTEM
     ASSM=     1$ =1, SYSTEM MATRICES ARE ASSEMBLED THIS EXECUTION
$                 =0, MACRO ELEMENT MATRICES ARE FORMED, BUT SYSTEM
$                     MATRICES ARE NOT ASSEMBLED.
     G=       1.$ ACCELERATION OF GRAVITY
     MNAM=   DEM
     MWARP=  .05$ E RESET
     KFAC=     1$ K RESET
     SPDP=     2$ K RESET
*DCALL,OPT(29 SYS DATA)
    !TAB=TOC,IERR(20 TAB MASK MASK MASK)
*                                                JNZ(TAB,800)
*XQT TAB
*DCALL(TAB)
*                                                LABEL 800
    !ELD=TOC,IERR(20 ELD MASK MASK MASK)
*                                                JNZ(ELD,100)
*XQT ELD
*DCALL(ELD)
*                                                LABEL 100
$
$ COMPUTE MACRO ELEMENT M AND K MATRICES:
*CALL(ME RMRK)
$
*                                                JZ(ASSM,200)
$ ASSEMBLE THE MACRO ELEMENT RM AND RK:
$
*CALL(ME ASSEMBLE)
$
$ ASSEMBLE THE M AND K DEFINED VIA TAB AND ELD:
    !ELD=TOC,IERR(1 ELTS NAME 0 0)
*                                                JNZ(ELD,300)
```

```
    !TNAM='DEM
    !TEST=EQUAL(MNAM,TNAM): !CEM=0
*                                                JNZ(TEST,1000)
    !CEM=1$ CONSISTENT MASS MATRIX
*                                                LABEL 1000
*CALL(SPREP)
*                                                JUMP 400
*                                                LABEL 300
*                                                JZ(SEQ,500)
*XQT SEQ
*DCALL,OPT(SEQ OPTIONS)
*                                                LABEL 500
*XQT TAN
*DCALL,OPT(TAN OPTIONS)
*                                                LABEL 400
$ REFORMAT THE MACRO ELEMENT M AND K:
$
*XQT LSU
*DCALL,OPT(LSU OPTIONS)
    !SPD1=SPDP-1: !LS='LSSS
*                                                JZ(SPD1,600)
    !LS='LSDS
*                                                LABEL 600
 KME="LS"(RK): MME=LSSS(RM)
*                                                JZ(ELD,700)
$ NO ELD ELEMENTS:
$
*XQT DCU
 TOCCHG 1 KME SPAR MASK MASK: N1=KSYS
 TOCCHG 1 MME SPAR MASK MASK: N1=MSYS
*                                                JUMP  900
*                                                LABEL 700
$ ELD ELEMENTS INCLUDED:
$
*XQT AUS
 KSYS=SUM(K,KME): MSYS=SUM("MNAM",MME)
*                                                LABEL 900
*                                                LABEL 200
*                                                RETURN
```

```
$
$ THIS PROCEDURE FORMS THE BASIC LIBLIB LIBRARY FOR MACRO ELEMENTS
$ DEFINED VIA (SSID DATA 1) DATA SETS IN LIB 29.
$
*XQT U1
*REGISTER EXCEPTIONS
*REGISTER STORE(29 REGI HOUSE 1 1)
*DLIB=20
    !ISEQ=0: !SYS='SYS
*                                               LABEL 1000
    !SSID=TOC,N1(29 MASK DATA 1 MASK),ISEQ
*                                               JLZ(ISEQ,2000)
    !TEST=EQUAL(SSID,SYS)$ =0, FOR NO EQUALITY
*                                               JNZ(TEST,1000)
*XQTC U1
*FREE 20
*FREE 1
    !OPT=0
$
$ DEFAULT REGISTERS:
*RGI
     G=        1.$ ACCELERATION OF GRAVITY
     SEQ=       1$ NON-ZERO VALUE SEQ IS EXECUTED FRO "SSID"
     MNAM=   DEM
     MWARP=  .05$ E RESET
     KFAC=      1$ K RESET
     SPDP=      2$ K RESET
*DCALL(29 "SSID" DATA 1)
$
    !BLANK='
    !TNAM='DEM
    !TEST=EQUAL(MNAM,TNAM): !CEM=0
*                                              JNZ(TEST,100)
    !CEM=1$  CONSISTENT MASS MATRIX
*                                               LABEL 100
*XQT AUS
 TABLE(NI=1,NJ=1): "SSID" ME
*XQT TAB
*DCALL(TAB)
 UPDATE=1: CON=1: NONZERO 1 2 3 4 5 6
*DCALL(BN)
 DC FLAG CON "BLANK",*,B
*XQT ELD
*DCALL(ELD)
$
$ FORM THE MACRO ELEMENT K AND M MATRICES:
*CALL(SPREP)
    !CONR=1: !KNAM='K
*CALL(FACTOR)
*XQT AUS
```

```
ME   MACR         1        0                        CREATED: 811210 123433
                                                    PRINTED: 811210 123700

      *DCALL,OPT(AUS OPTIONS)
       SSID="SSID": SSPREP("KNAM", "CONR")
       SSK("KNAM"): SSM("MNAM")
      *XQT DCU
       LIBLIB=3: STORE 1 LIB "SSID" 1 1
      *                                                  JUMP 1000
      *                                                  LABEL 2000
      *XQTC U1
      *DLIB=29
      *REGISTER RETRIEVE(29 REGI HOUSE 1 1)
      *FREE 1
      *FREE 20
      *                                                  RETURN
```

```
ME   RMRK        0       0                       CREATED: 811201 190309
                                                 PRINTED: 811201 190341

$
$ THIS PROCEDURE IS DRIVEN BY THE DATA SETS RESIDING IN LIBRARY 10.
$ MACRO ELEMENT LABELED SUBMATRIX M AND K MATRICES ARE ENTERED INTO
$ LIBS 4 AND 5, RESPECTIVELY, FOR EACH MACRO ELEMENT PROCESSED.
$
*XQTC U1
*REGISTER EXCEPTIONS
*REGISTER STORE( 29 REGI HOUSE 1 1)
$
$ SET UP CONSTRAINT 9999 IN LIB 1.  CON 9999 HAS ALL SYSTEM
$ DOF'S UNCONSTRAINED.
$
    !TEST=TOC,IERR(1 CON MASK 9999 0)
*                                                JZ(TEST,200)
*XQT TAB
 CON 9999
*                                                LABEL 200
    !ISEQ=0: !MEOL=0: !OPT=0
*                                                LABEL 1000
    !SSID=TOC,N2(10 SJC MASK MASK MASK),ISEQ: !JSEQ=ISEQ-1
*                                                JLZ(ISEQ,END)
    !TEST=EQUAL(SSID,MEOL)$  =0 FOR NO EQUALITY
*                                                JNZ(TEST,100)
$ NEW MACRO ELEMENT SSID:
$
*XQTC DCU
 LIBLIB=3: RETR 2 LIB "SSID" 1 1
    !MEOL=SSID: !NBN=TOC,NI(2 BN "SSID" MASK MASK)
*                                                LABEL 100
    !NREF=TOC,N3(10 SJC "SSID" MASK MASK),JSEQ
$ MACRO ELEMENT DEFINED BY SSID AND NREF:
$
*XQT SYN
*FREE 8
 RESET LIBC=8,LIBB=0,LIBA=6,CON=9999
*DCALL,OPT(SYN OPTIONS)
 "SSID" 2 "NREF"
*DCALL(10 SJC "SSID" "NREF" MASK)
*XQT LSU
*DCALL,OPT(LELS OPTIONS)
 4 RK "SSID" MASK "NREF"= LELS(8 SYN K 10000)
 5 RM "SSID" MASK "NREF"= LELS(8 SYN M 10000)
*                                                JUMP  1000
*                                                LABEL END
*XQT U1
*REGISTER RETRIEVE(29 REGI HOUSE 1 1)
*                                                RETURN
```

```
ME   ASSE        0       0                        CREATED: 811201 190309
                                                  PRINTED: 811201 190341

$
$ THIS PROCEDURE COMBINES RK AND RM DATA SETS IN LIBS 4 AND 5 INTO
$ SINGLE RK AND RM DATA SETS IN LIB 1.
$
*XQTC U1
*REGISTER EXCEPTIONS
*REGISTER STORE(29 REGI HOUSE 1 1)
    !NDO=2: !LIB=4: !RMRK='RK
    !SECT=28$$$ FUTURE REGISTER ACTION COMMAND $$$
*XQT AUS
 TABLE(NI=1,NJ=1): 4 END END 999 999: J=1: 1.
 TABLE(NI=1,NJ=1): 5 END END 999 999: J=1: 1.
*XQT DCU
*                                                LABEL 1000
*FREE 8
 COPY "LIB",8
    !ISEQ=0
    !RR1=TOC,RR(8 "RMRK" MASK MASK MASK),ISEQ
    !RR=TOC,RR(8 END END 999 999): !NWDS=RR-RR1*SECT
    !NJ=  TOC,NJ(  "LIB" "RMRK" MASK MASK MASK)
    !N3=  TOC,N3(  "LIB" "RMRK" MASK MASK MASK)
    !NINJ=TOC,NINJ("LIB" "RMRK" MASK MASK MASK)
    !NSEC=NINJ/SECT: !NSEC=NSEC*SECT: !NTST=NSEC-NINJ
*                                                JZ(NTST,200)
    !NSEC=NSEC+SECT
*                                                LABEL 200
    !NWDS=NWDS/NSEC: !NWDS=NWDS*NINJ
 REPOS 8,"RR1"
 XLOAD 8,1 "NWDS" "NJ" "NINJ" -1 "RMRK" BTAB "N3" 0
    !LIB=5: !RMRK='RM
*                                                JGZ,-1(NDO,1000)
*XQT U1
*REGISTER RETRIEVE(29 REGI HOUSE 1 1)
*                                                RETURN
```

```
ME   BACK        0       0                       CREATED: 811210 123433
                                                 PRINTED: 811210 123700

$
$ THIS PROCEDURE BACK TRANSFORMS FROM SYSTEM DISPLACEMENT
$ VECTORS (SYSVEC FORMAT) TO MACRO ELEMENT DISPLACEMENT
$ VECTORS.  EACH MACRO ELEMENT FOR WHICH A DATA SET NAMED
$ (SJC "SSID" "NREF") RESIDES IN LIB 10 IS PROCESSED.
$
*XQTC U1
*REGISTER EXCEPTIONS
*REGISTER STORE(29 REGI HOUSE 1 1)
$
$ DEFAULT REGISTERS:
    !OPT=0
*RGI
     VECT=   STAT  $ FOR STATIC DISPLACEMENTS
$        =   VIBR  $ FOR VIBRATIONAL MODES
$        =   BUCK  $ FOR BUCKLING MODES
     SET=       1  $ SET NUMBER
     CON=       1  $ CONSTRAINT CONDITION
     QLIB=      1  $ DISPLACEMENT VECTOR LIBRARY
*DCALL,OPT(BACK PARAMETERS)$ OPTIONAL REGISTERS
    !STAT='STAT
    !N2='DISP
    !VTST=EQUAL(VECT,STAT)$ =0 FOR NO EQUALITY
    !ISEQ=0
*                                                LABEL 400
    !IERR=TOC,IERR(1 SYS JMG MASK MASK),ISEQ
*                                                JLZ(ISEQ,300)
*XQTC DCU
 DISABLE 1 "ISEQ"
*                                                JUMP 400
*                                                LABEL 300
*XQTC DCU
    !IERR=TOC,IERR("QLIB" CASE TITL "SET" MASK)
*                                                JNZ(IERR,500)
 COPY "QLIB",7 CASE TITL "SET"
*                                                LABEL 500
*                                                JNZ(VTST,600)
 COPY "QLIB",7 "VECT" EVAL "SET" "CON": !N2='MODE
*                                                LABEL 600
$
$ TRANSFORM TO SYSTEM GLOBAL COORDINATES:
*XQT AUS
 DEFINE U= "QLIB" "VECT" "N2" "SET" "CON"
 SYS JMG "SET" "CON"= LTOG(U)
    !ISEQ=0: !MEOL=0
*                                                LABEL 1000
    !SSID=TOC,N2(10 SJC MASK MASK MASK),ISEQ: !JSEQ=ISEQ-1
*                                                JLZ(ISEQ,END)
    !TEST=EQUAL(SSID,MEOL)$ =0 FOR NO EQUALITY
*                                                JNZ(TEST,100)
```

```
$ NEW MACRO ELEMENT SSID:
$
*XQT DCU
 LIBLIB=3: RETR 2 LIB "SSID" 1 1
    !MEOL=SSID
*XQT SSBT
 RESET JMG=0
*DCALL,OPT(SSBT OPTIONS)
*                                             LABEL 100
    !NREF=TOC,N3(10 SJC "SSID" MASK MASK),JSEQ
$ MACRO ELEMENT DEFINED VIA SSID AND NREF:
$
 "SSID" 2 7 "NREF" 6
*                                             JUMP 1000
*                                             LABEL END
*XQT U1
*REGISTER RETRIEVE(29 REGI HOUSE 1 1)
*                                             RETURN
```

```
ME   ES          0       0                         CREATED: 811210 123433
                                                   PRINTED: 811210 123700
$
$ THIS PROCEDURE EXECUTES ES FOR EACH SJC DATA SET IN LIB 10.
$ HEADINGS ARE PRODUCED WITH THE ES PRINTOUT TO IDENTIFY THE
$ MACRO ELEMENT AND THE ASSOCIATED REFERENCE FRAME.
$
*XQT U1
*REGISTER EXCEPTIONS
*REGISTER STORE(29 REGI HOUSE 1 1)
$
$ DEFAULT REGISTERS:
    !OPT=0
*RGI
     SET=   1$ SET NUMBER
*DCALL,OPT(ES PARAMETERS)$ OPTIONAL REGISTERS
*LIBS 2 1 3 4 5 6 7 8 9 10 11 12 13 14 15 16 17 18 19 20
    !ISEQ=0: !MEOL=0: !OPT=0
*                                                 LABEL 1000
    !SSID=TOC,N2(10 SJC MASK MASK MASK),ISEQ: !JSEQ=ISEQ-1
*                                                 JLZ(ISEQ,END)
    !TEST=EQUAL(SSID,MEOL)$ =0 FOR NO EQUALITY
*                                                 JNZ(TEST,100)
$ NEW MACRO ELEMENT SSID:
$
*XQT DCU
 LIBLIB=3: RETRIEVE 1 LIB "SSID" 1 1
    !MEOL=SSID
*                                                 LABEL 100
!NREF=TOC,N3(10 SJC "SSID" MASK MASK),JSEQ
$ MARCO ELEMENT DEFINED VIA SSID AND NREF:
$
    !TEST=TOC,IERR(7 HEAD "SSID" "NREF" 0)
*                                                 JZ(TEST,200)
*XQT U3
 RP2
 OUTP=7 HEAD "SSID" "NREF" 0
 FORMAT 1'(37HPAGE 0'STRESS DATA FOR MACRO ELEMENT ,A4,7H, NREF=I3)
 PRINT(1) "SSID" "NREF"
*                                                 LABEL 200
*XQTC ES
    !ALL=1
 U=7 USB "SSID" "SET" "NREF"
*DCALL,OPT(7 HEAD "SSID" "NREF" 0)
*DCALL,OPT(ES ALL)
*DCALL,OPT(ES "SSID")
*DCALL,OPT(ES "SSID" "NREF")
*                                                 JZ(ALL,300)
 ALL
*                                                 LABEL 300
*                                                 JUMP 1000
*                                                 LABEL END
*XQT U1
*REGISTER RETRIEVE(29 REGI HOUSE 1 1)
*LIBS 1 2 3 4 5 6 7 8 9 10 11 12 13 14 15 16 17 18 19 20
*                                                 RETURN
```

```
ME   VPRT        0       0                       CREATED: 811210 123433
                                                 PRINTED: 811210 123700

         $
         $ THIS PROCEDURE SIMULATES VPRT PRINTOUT FOR EACH MACRO ELEMENT
         $ FOR WHICH  A DATA SET NAMED (SJC "SSID" "NREF") RESIDES IN
         $ LIB 10.
         $
         *XQT U1
         *REGISTER EXCEPTIONS
         *REGISTER STORE(29 REGI HOUSE 1 1)
         *LIBS 2 1 3 4 5 6 7 8 9 10 11 12 13 14 15 16 17 18 19 20
         $
         $ DEFAULT REGISTERS:
            !OPT=0
         *RGI
              SET=      1  $  SET NUMBER
              CON=      1  $  CONSTRAINT CONDITION
              EVAL=     0  $  NO EIGENVALUES ARE DISPLAYED
         $        =  VIBR  $  EIGENVALUES IN THE DATA SET (VIBR EVAL) ARE
         $                    DISPLAYED WITH THE APPROPRIATE VECTORS.
         $        =  BUCK  $  EIGENVALUES IN THE DATA SET (BUCK EVAL) ARE
         $                    DISPLAYED WITH THE APPROPRIATE VECTORS.
              N1=     USB  $  DISPLACEMENTS ARE PRINTED
         $      =    REAC  $  REACTIONS CORRESPONDING TO THE MATRIX PRODUCT
         $                    OF K AND USB ARE COMPUTED AND PRINTED.
         *DCALL,OPT(VPRT PARAMETERS)
             !REAC='REAC
             !BLANK='
             !VIBR='VIBR
             !CASE=TOC,IERR(7 CASE TITLE "SET" MASK)
             !RTST=EQUAL(N1,REAC): !ETST=EQUAL(EVAL,VIBR)$ =0 FOR NO EQUALITY
         *                                                JZ(EVAL,130)
         *                                                JZ(ETST,130)
         *XQTC AUS
          DEFINE E=7 "EVAL" EVAL "SET"
          7 "EVAL" HZ "SET"= SQRT(.0253303 E)
         *                                                LABEL 130
             !IFMT=1: !ISEQ=0: !MEOL=0
         *                                                JZ(RTST,1000)
             !IFMT=2
         *                                                LABEL 1000
             !SSID=TOC,N2(10 SJC MASK MASK MASK),ISEQ: !JSEQ=ISEQ-1
         *                                                JLZ(ISEQ,END)
             !TEST=EQUAL(SSID,MEOL)$ =0 FOR NO EQUALITY
         *                                                JNZ(TEST,100)
         $
         $ NEW MACRO ELEMENT SSID:
         *XQT DCU
          LIBLIB=3: RETRIEVE 1 LIB "SSID" 1 1: !MEOL=SSID
             !IERR=TOC,IERR(1 FLAG CON "CON" 0)
         *                                                JZ(IERR,100)
         *XQT TAB
```

```
 UPDATE=1: CON="CON": DC FLAG CON "BLANK",*,B
*                                                LABEL 100
    !NREF=TOC,N3(10 SJC "SSID" MASK MASK),JSEQ
*                                                JZ(RTST,200)
    !IERR=TOC,IERR(7 REAC "SSID" "SET" "NREF")
*                                                JZ(IERR,200)
*XQT AUS
 DEFINE X=7 USB "SSID" "SET" "NREF"
 7 REAC "SSID" "SET" "NREF"= PROD(K,X)
*                                                LABEL 200
*XQTC U3
 RP2
    !NLH=4
*                                                JZ(EVAL,500)
    !NLH=NLH+1
*                                                LABEL 500
*                                                JNZ(CASE,600)
    !NLH=NLH+1
*                                                LABEL 600
 NUMBER OF FORMATS=8
 FORMAT 1'(29H1DISPLACEMENTS, MACRO ELEMENT  1XA4, 7H, NREF= I4)
 FORMAT 2'(25H1REACTIONS, MACRO ELEMENT  1XA4, 7H, NREF= I4)
 FORMAT 3'(5H SET=I4,6H, CON=I4,9H, VECTOR=I4)
 FORMAT 4'(1X,19A4)
 FORMAT 5'(12H EIGENVALUE= E14.7, 9H,   FREQ= F12.4, 3H HZ)
 FORMAT 6'(12H EIGENVALUE=  E14.7)
 FORMAT 7'(/6H JOINT,7X1H1,10X1H2,10X1H3,10X1H4,10X1H5,10X1H6)
 FORMAT 8'(I6,6(E10.3,A1))
    !NVEC=TOC,NBLOCKS(7 "N1" "SSID" "SET" "NREF"): !IVEC=1
 DEFINE F=1 FLAG CON "CON"
*                                                LABEL 300
 DEFINE X=7 "N1" "SSID" "SET" "NREF" "IVEC"
*                                                JNZ(CASE,400)
 DEFINE C=7 CASE TITLE "SET" MASK "IVEC"
*                                                LABEL 400
*                                                JZ(EVAL,210)
    !E=DS,"IVEC",1,1(7 "EVAL" EVAL "SET" MASK)
*                                                JZ(ETST,210)
    !HZ=DS,"IVEC",1,1(7 "EVAL" HZ "SET" MASK)
*                                                LABEL 210
 NLH="NLH": NLH1="NLH"
 LAYOUT
   WRITE(ALL,"IFMT") "SSID", "NREF"
   WRITE(ALL,3) "SET","CON","IVEC"
*                                                JZ(EVAL,110)
*                                                JZ(ETST,120)
   WRITE(ALL,5) "E","HZ"
*                                                JUMP 110
*                                                LABEL 120
   WRITE(ALL,6) "E"
```

```
ME   VPRT        0       0                       CREATED: 811210 123433
                                                 PRINTED: 811210 123700

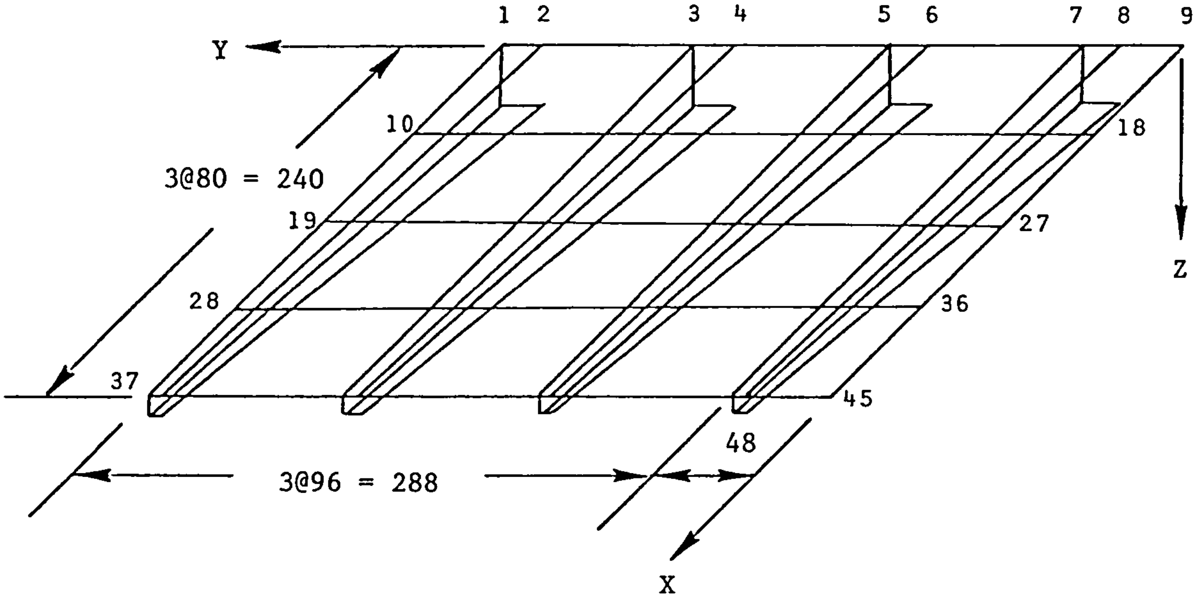
*                                                LABEL 110
*                                                JNZ(CASE,130)
   WRITE(ALL,4) C
*                                                LABEL 130
   WRITE(ALL,7)
   WRITE(MAIN,8) J,X(1),F(1),X(2),F(2),X(3),F(3),X(4),F(4),>
                   X(5),F(5),X(6),F(6)
 PRODUCE REPORT
    !IVEC=IVEC+1
*                                                JGZ,-1(NVEC,300)
*                                                JUMP 1000
*                                                LABEL END
*XQT U1
*REGISTER RETRIEVE(29 REGI HOUSE 1 1)
*LIBS 1 2 3 4 5 6 7 8 9 10 11 12 13 14 15 16 17 18 19 20
*                                                RETURN
```

```
ME   LOOP         0       0                         CREATED: 811201 190309
                                                    PRINTED: 811201 190341

$
$ THIS IS A MACRO ELEMENT UTILITY PROCEDURE.  THE FOLLOWING
$ OPTIONAL CALLS ARE MADE FOR EACH MACRO ELEMENT FOR WHICH A
$ DATA SET NAMED (SJC "SSID" "NREF") RESIDES IN LIB 10:
$          *DCALL,OPT(LOOP ALL)
$          *DCALL,OPT(LOOP "SSID")
$          *DCALL,OPT(LOOP "SSID" "NREF")
$ WHERE "SSID" AND "NREF" TAKE ON ALL VALUES AS DICTATED BY
$ BY THE CONTENTS OF LIB 10.  AT THE TIME OF THE OPTIONAL CALL
$ LIB 2 IS THE MAIN "SSID" LIBRARY.
$
*XQT U1
*REGISTER EXCEPTIONS
*REGISTER STORE(29 REGI HOUSE 1 1)
    !ISEQ=0: !MEOL=0: !OPT=0
*                                                LABEL 1000
    !SSID=TOC,N2(10 SJC MASK MASK MASK),ISEQ: !JSEQ=ISEQ-1
*                                                JLZ(ISEQ,END)
    !TEST=EQUAL(SSID,MEOL)$ =0 FOR NO EQUALITY
*                                                JNZ(TEST,100)
$ NEW MACRO ELEMENT SSID:
$
*XQT DCU
 LIBLIB=3: RETRIEVE 2 LIB "SSID" 1 1
    !MEOL=SSID
*                                                LABEL 100
!NREF=TOC,N3(10 SJC "SSID" MASK MASK),JSEQ
$
$ MARCO ELEMENT DEFINED VIA SSID AND NREF:
$
*DCALL,OPT(LOOP ALL)
*DCALL,OPT(LOOP "SSID")
*DCALL,OPT(LOOP "SSID" "NREF")
*                                                JUMP 1000
*                                                LABEL END
*XQT U1
*REGISTER RETRIEVE(29 REGI HOUSE 1 1)
*                                                RETURN
```

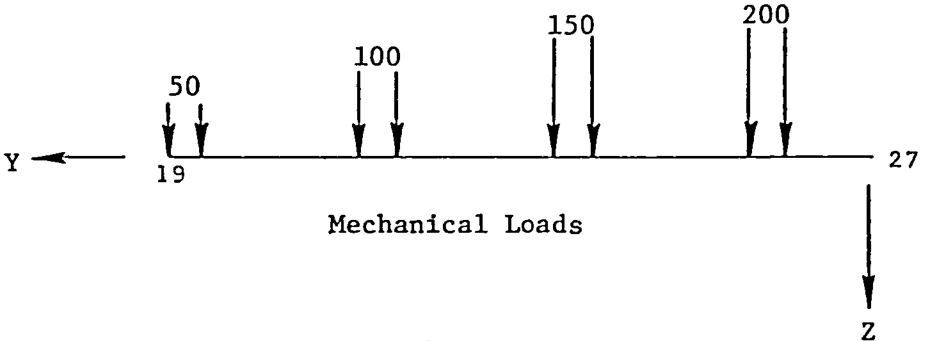
6.1 STATIC DISPLACEMENTS OF A FLAT ROOF SUPPORTED BY TAPERED CHANNELS

The EAL macro element procedures were used to compute the static solution for the system model described below. All tapered channels are identical and are represented by the single macro element model shown on page 6.1-2. The system model consists of the membrane finite elements lying in the XY plane plus four repeated macro elements representing the tapered channels. The input runstream for the problem is shown on pages 6.1-3 and 6.1-4. Sample printout of the computed results are shown on pages 6.1-5 through 6.1-9. Tables of contents for all pertinent EAL libraries are shown on pages 6.1-10 through 6.1-12.



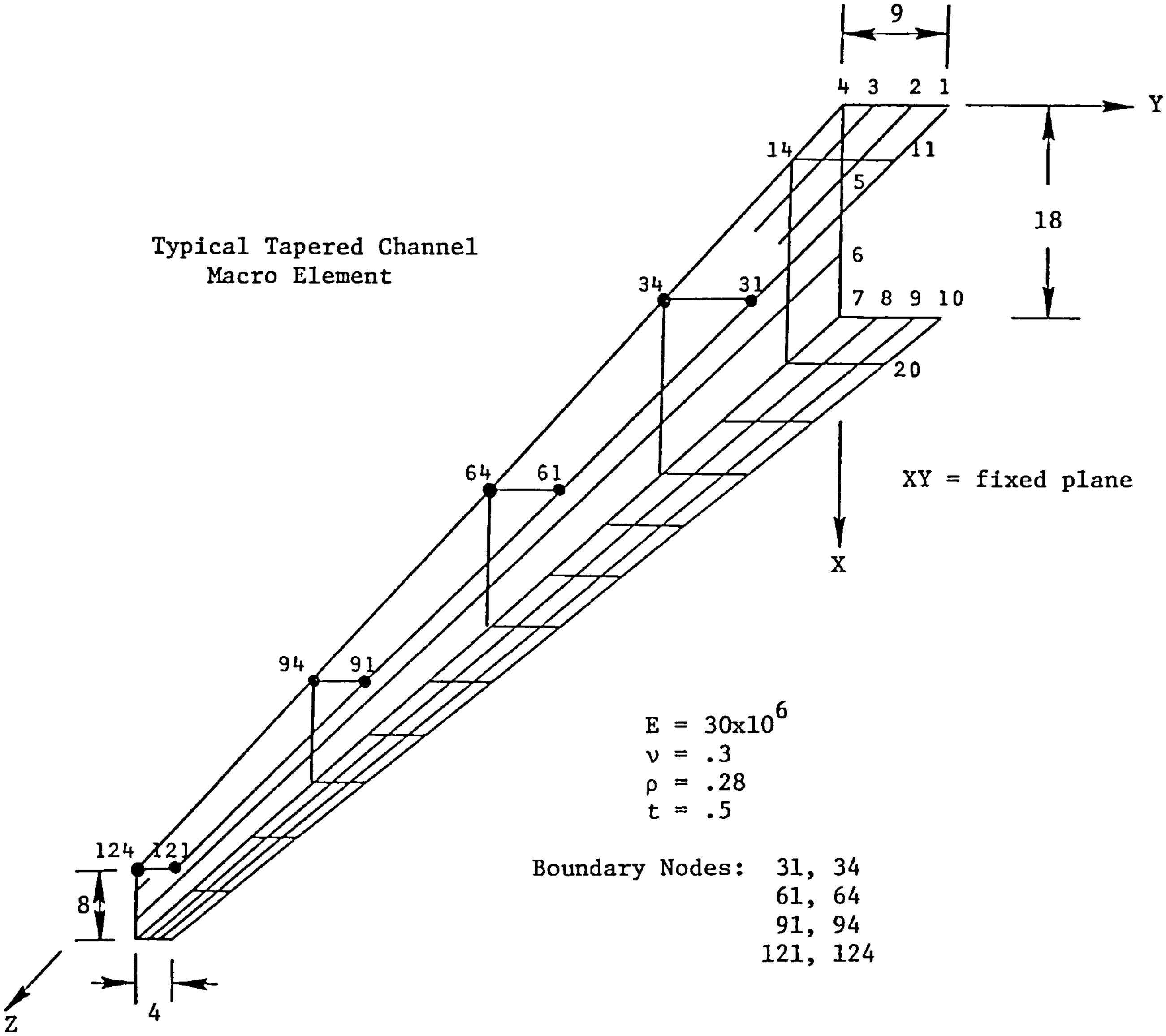
YZ = fixed plane
XZ = symmetry plane

XY plane: E = 30×10^6
$\nu = .3$
$t = .5$
membrane stiffness only



Mechanical Loads

Static Loading = Dead Weight
+ 20 Lbs. per Sq. Ft.
+ Mechanical Loads



Typical Tapered Channel
Macro Element

XY = fixed plane

$E = 30x10^6$
$\nu = .3$
$\rho = .28$
$t = .5$

Boundary Nodes: 31, 34
61, 64
91, 94
121, 124

```
*XQT U1
$ DEFINE THE TAPERED CHANNEL MACRO ELEMENT:
*(CHNL DATA 1)                                    END
$ MACRO ELEMENT PARAMETERS:
    G=386.$ ACCELERATION OF GRAVITY
*(TAB)
 START 130
 TEXT: 'TAPEDED CHANNEL, MACRO ELEMENT MODEL
 JLOC:  1   0.   9.   0.   0.   0.   0.  4 1 13
       10   0.   4. 240.   0.   0. 240.
        7  18.   0.   0.  18.   9.   0.  4 1 13
       10   8.   0. 240.   8.   4. 240.
        4   0.   0.   0.  18.   0.   0.  4 1 13
       10   0.   0. 240.   8.   0. 240.
 MATC: 1 30.+06 .3 .28 .1-4
 SA:   1 .5
 CON=1:FIXED PLANE=3
*(ELD)
 E43
 GROUP 1'TAPERED CHANNEL, TOP FLANGE
         1 2 12 11 1 3 12
 GROUP 2'TAPERED CHANNEL, BOTTOM FLANGE
         7 8 18 17 1 3 12
 GROUP 3'TAPERED CHANNEL, WEB
         4 5 15 14 1 3 12
*(BN)
 31:34:  61:64:  91:94:  121:124
*                                                END
$ DEFINE THE SYSTEM MODEL:
*(SYS DATA)                                      END
$ SYSTEM PARAMETERS:
    G=386.$  ACCELERATION OF GRAVITY
*(TAB)                  ENDTAB
 START 45
 JLOC: 1   0. 336.   0.   0.  48.   0.  4 2 5
       9 240. 336.   0. 240.  48.   0.
       2   0. 327.   0.   0.  39.   0.  4 2 5
       9 240. 332.   0. 240.  44.   0.
       9   0.   0.   0. 240.   0.   0.  5 9
 MATC: 1 30.+6 .3 .2 1.-4
 SA:   1 .5
 ALTR: !IALT=2: !YLOC=48.: !NDO=4
*                                                LABEL 100
       "IALT" 3 180. 2 -90. 1 0. 0. "YLOC" 0.
       !IALT=IALT+1: !YLOC=YLOC+96.
*                                                JGZ,-1(NDO,100)
 CON=1:FIXED PLANE=1: ZERO 2 3 4 5 6: 18,45,9
*                       ENDTAB
*(ELD)
 E41:  9 18 17 8 1 4 8
*                                                END
$
```

```
$ DEFINE THE MACRO ELEMENT CONNECTIVITIES:
*(10 SJC CHNL 2)
  17:16:  26:25:  35:34:  44:43
*(10 SJC CHNL 3)
  15:14:  24:23:  33:32:  42:41
*(10 SJC CHNL 4)
  13:12:  22:21:  31:30:  40:39
*(10 SJC CHNL 5)
  11:10:  20:19:  29:28:  38:37
$
$ FORM THE SYSTEM MASS AND STIFFNESS MATRICES:
*CALL(ME SYS)
$
$ COMPUTE THE STATIC SOLUTION:
*XQT AUS
 ALPHA: CASE TITLE: 1'DEAD WEIGHT + 20 LBS/SQ FT + MECHANICAL LOADS
 TABLE: NODAL PRESSURE: J=1,45: .1389
 R=RIGID(0. 0. 0.): DEFINE R3=R AUS 1 1 3,3
 APPL FORC= PROD(386. MSYS, R3)
 SYSVEC,U: APPL FORC: I=3: DDATA=50.: J=19,25,2: 50.
                           DDATA=50.: J=20,26,2: 50.
*XQT EQNF
*XQT DRSI
 RESET K=KSYS
*XQT SSOL
 RESET K=KSYS
*XQT VPRT
 PRINT STAT DISP: PRINT STAT REAC
$
$ BACK TRANSFORM FOR MACRO ELEMENT DISPLACEMENT VECTORS:
*CALL(ME BACK)
$
$ PRINT THE MACRO ELEMENT MEMBRANE STRESS RESULTANTS:
*XQT U1
*(ES ALL)
 NODES=0: DISPLAY=MSR
*CALL(ME ES)
$
$ PRINT THE MACRO ELEMENT DISPLACEMENT VECTORS:
*CALL(ME VPRT)
$
$ PRINT THE MACRO ELEMENT REACTION VECTORS:
*XQT U1
*(VPRT PARAMETERS)
    N1=REAC
*CALL(ME VPRT)
```

```
STATIC DISPLACEMENTS.                                          ID=   1/ 1/  1
JOINT      1          2          3          4          5          6
   1   .000    *  .000    *  .000    *  .000    *  .000    *  .000    *
   2   .000    *  .000    *  .000    *  .000    *  .000    *  .000    *
   3   .000    *  .000    *  .000    *  .000    *  .000    *  .000    *
   4   .000    *  .000    *  .000    *  .000    *  .000    *  .000    *
   5   .000    *  .000    *  .000    *  .000    *  .000    *  .000    *
   6   .000    *  .000    *  .000    *  .000    *  .000    *  .000    *
   7   .000    *  .000    *  .000    *  .000    *  .000    *  .000    *
   8   .000    *  .000    *  .000    *  .000    *  .000    *  .000    *
   9   .000    *  .000    *  .000    *  .000    *  .000    *  .000    *
  10   .215-02   -.100-02    .337-01   -.975-02   -.991-03   -.703-04
  11   .178-02   -.931-03    .122+00   -.128-01   -.267-02   -.957-04
  12   .169-02   -.404-03    .455-01   -.110-01   -.137-02   -.845-04
  13   .158-02   -.374-03    .143+00   -.140-01   -.334-02   -.118-03
  14   .166-02   -.187-03    .461-01   -.111-01   -.138-02   -.848-04
  15   .154-02   -.162-03    .145+00   -.141-01   -.339-02   -.118-03
  16   .147-02   -.196-04    .353-01   -.715-02   -.106-02   -.546-04
  17   .142-02    .562-06    .976-01   -.869-02   -.245-02   -.754-04
  18   .104-02    .000    *  .000    *  .000    *  .000    *  .000    *
  19   .279-02   -.104-02    .110+00   -.272-01   -.131-02   -.127-03
  20   .281-02   -.102-02    .294+00   -.296-01   -.364-02   -.126-03
  21   .268-02   -.666-03    .150+00   -.320-01   -.188-02   -.157-03
  22   .263-02   -.643-03    .367+00   -.346-01   -.467-02   -.157-03
  23   .254-02   -.335-03    .152+00   -.326-01   -.189-02   -.158-03
  24   .249-02   -.323-03    .374+00   -.354-01   -.472-02   -.157-03
  25   .224-02   -.122-03    .117+00   -.224-01   -.145-02   -.101-03
  26   .221-02   -.115-03    .268+00   -.242-01   -.338-02   -.986-04
  27   .186-02    .000    *  .000    *  .000    *  .000    *  .000    *
  28   .317-02   -.858-03    .198+00   -.504-01   -.135-02   -.135-03
  29   .308-02   -.855-03    .467+00   -.520-01   -.356-02   -.126-03
  30   .311-02   -.698-03    .277+00   -.598-01   -.199-02   -.167-03
  31   .308-02   -.689-03    .595+00   -.614-01   -.463-02   -.158-03
  32   .291-02   -.441-03    .279+00   -.606-01   -.199-02   -.167-03
  33   .287-02   -.431-03    .602+00   -.622-01   -.465-02   -.157-03
  34   .256-02   -.170-03    .214+00   -.408-01   -.154-02   -.104-03
  35   .253-02   -.158-03    .431+00   -.416-01   -.330-02   -.979-04
  36   .233-02    .000    *  .000    *  .000    *  .000    *  .000    *
  37   .307-02   -.678-03    .277+00   -.761-01   -.133-02   -.124-03
  38   .314-02   -.683-03    .584+00   -.762-01   -.431-02   -.125-03
  39   .319-02   -.669-03    .398+00   -.906-01   -.198-02   -.156-03
  40   .319-02   -.672-03    .762+00   -.906-01   -.495-02   -.156-03
  41   .300-02   -.549-03    .400+00   -.917-01   -.198-02   -.156-03
  42   .298-02   -.547-03    .768+00   -.917-01   -.495-02   -.156-03
  43   .266-02   -.251-03    .308+00   -.614-01   -.155-02   -.971-04
  44   .265-02   -.239-03    .553+00   -.613-01   -.301-02   -.969-04
  45   .253-02    .000    *  .000    *  .000    *  .000    *  .000    *
```

```
PAGE     1  STRESS DATA FOR MACRO ELEMENT CHNL, NREF=  2
S/C  1/  1  DEAD WEIGHT + 20 LBS/SQ FT + MECHANICAL LOADS
E43         TAPERED CHANNEL, TOP FLANGE

GRP-IND*/
  JOINTS          NX        NY       NXY  ANG    MAX PN    MIN PN   MAX SHR
  1-   1*     .114+03   .803+03   .137+03  79.   .829+03   .878+02   .371+03
  1-   2*     .154+03   .876+03   .973+02  82.   .889+03   .141+03   .374+03
  1-   3*     .131+03   .907+03   .490+02  86.   .910+03   .128+03   .391+03
  1-   4*    -.289+01   .466+03  -.673+02  98.   .475+03  -.124+02   .244+03
  1-   5*    -.299+02   .382+03   .952+02  78.   .403+03  -.508+02   .227+03
  1-   6*    -.693+01   .483+03   .280+03  66.   .610+03  -.134+03   .372+03
  1-   7*    -.655+02  -.111+03   .162+03  41.   .752+02  -.251+03   .163+03
  1-   8*    -.555+02   .110+02   .119+03  53.   .102+03  -.146+03   .124+03
  1-   9*    -.767+02  -.194+03   .646+02  24.  -.481+02  -.223+03   .873+02
  1-  10*     .952+02   .667+03   .201+03  72.   .731+03   .316+02   .349+03
  1-  11*     .935+02   .572+03   .818+02  81.   .586+03   .799+02   .253+03
  1-  12*     .119+03   .754+03  -.446+02  94.   .757+03   .116+03   .321+03
  1-  13*     .734+01   .225+03  -.123+03 114.   .281+03  -.480+02   .164+03
  1-  14*     .139+02   .236+03   .842+02  71.   .265+03  -.143+02   .139+03
  1-  15*    -.907+01   .180+03   .315+03  53.   .414+03  -.243+03   .328+03
  1-  16*    -.933+02  -.358+03   .188+03  27.   .445+01  -.455+03   .230+03
  1-  17*    -.102+03  -.321+03   .112+03  23.  -.552+02  -.369+03   .157+03
  1-  18*    -.882+02  -.396+03   .109+02   2.  -.878+02  -.396+03   .154+03
  1-  19*     .528+02   .401+03   .116+03  73.   .435+03   .179+02   .209+03
  1-  20*     .632+02   .358+03   .398+02  82.   .364+03   .580+02   .153+03
  1-  21*     .689+02   .443+03  -.191+02  93.   .444+03   .679+02   .188+03
  1-  22*     .109+02   .108+03  -.730+02 118.   .147+03  -.283+02   .876+02
  1-  23*     .927+01   .106+03   .550+02  66.   .131+03  -.157+02   .731+02
  1-  24*    -.127+01   .686+02   .175+03  51.   .212+03  -.144+03   .178+03
  1-  25*    -.755+02  -.297+03   .108+03  22.  -.318+02  -.340+03   .154+03
  1-  26*    -.745+02  -.276+03   .535+02  14.  -.612+02  -.289+03   .114+03
  1-  27*    -.656+02  -.301+03   .500+01   1.  -.655+02  -.302+03   .118+03
  1-  28*     .104+02   .157+03   .398+02  76.   .167+03   .271+00   .833+02
  1-  29*     .861+01   .119+03   .211+02  79.   .122+03   .470+01   .589+02
  1-  30*     .904+01   .140+03  -.261+01  91.   .140+03   .899+01   .656+02
  1-  31*     .484+01  -.631+00  -.221+02 139.   .244+02  -.202+02   .223+02
  1-  32*     .115+02   .351+02   .143+02  65.   .419+02   .480+01   .185+02
  1-  33*     .100+02   .334+02   .527+02  51.   .757+02  -.322+02   .540+02
  1-  34*    -.359+02  -.107+03   .265+02  18.  -.270+02  -.115+03   .442+02
  1-  35*    -.382+02  -.121+03   .107+02   7.  -.369+02  -.122+03   .425+02
  1-  36*    -.362+02  -.117+03  -.505+01 176.  -.358+02  -.117+03   .406+02
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PAGE     2  STRESS DATA FOR MACRO ELEMENT CHNL, NREF=  4
S/C   1/   1 DEAD WEIGHT + 20 LBS/SQ FT + MECHANICAL LOADS
E43         TAPERED CHANNEL, BOTTOM FLANGE

GRP-IND*/
  JOINTS            NX        NY        NXY   ANG    MAX PN    MIN PN    MAX SHR
  2-    1*     -.538+03 -.442+04 -.863+02 179. -.536+03 -.443+04  .195+04
  2-    2*     -.115+03 -.108+04 -.131+03 172. -.974+02 -.109+04  .499+03
  2-    3*      .301+03  .224+04 -.113+03  93.  .225+04  .294+03  .978+03
  2-    4*      .157+03 -.366+04 -.602+02 179.  .158+03 -.366+04  .191+04
  2-    5*      .385+02 -.117+04 -.147+03 173.  .562+02 -.119+04  .622+03
  2-    6*     -.739+02  .137+04 -.110+03  94.  .138+04 -.822+02  .729+03
  2-    7*     -.193+02 -.304+04 -.923+02 178. -.165+02 -.304+04  .151+04
  2-    8*      .738+01 -.127+04 -.110+03 175.  .169+02 -.128+04  .647+03
  2-    9*      .220+02  .480+03 -.714+02  99.  .491+03  .111+02  .240+03
  2-   10*      .182+02 -.262+04 -.437+02 179.  .189+02 -.262+04  .132+04
  2-   11*      .307+01 -.144+04 -.755+02 177.  .701+01 -.144+04  .724+03
  2-   12*     -.335+01 -.238+03 -.415+02 170.  .378+01 -.245+03  .124+03
  2-   13*     -.110+02 -.209+04 -.192+02 179. -.108+02 -.209+04  .104+04
  2-   14*      .260+01 -.149+04 -.611+02 178.  .510+01 -.149+04  .747+03
  2-   15*      .825+01 -.909+03 -.301+02 178.  .923+01 -.910+03  .459+03
  2-   16*      .314+02 -.136+04 -.991+01 180.  .314+02 -.136+04  .697+03
  2-   17*      .107+02 -.149+04 -.508+02 178.  .124+02 -.149+04  .752+03
  2-   18*     -.602+01 -.159+04 -.971+01 180. -.596+01 -.159+04  .793+03
  2-   19*      .776+01 -.105+04  .161+02   1.  .801+01 -.105+04  .529+03
  2-   20*      .279+01 -.150+04  .265+02   1.  .325+01 -.150+04  .753+03
  2-   21*     -.647+01 -.198+04  .372+02   1. -.577+01 -.198+04  .985+03
  2-   22*     -.171+02 -.730+03  .605+02   5. -.120+02 -.735+03  .362+03
  2-   23*     -.613+01 -.143+04  .193+02   1. -.587+01 -.143+04  .711+03
  2-   24*      .774+01 -.212+04  .313+02   1.  .820+01 -.212+04  .106+04
  2-   25*      .268+02 -.165+03  .473+02  13.  .378+02 -.176+03  .107+03
  2-   26*      .766+01 -.123+04  .288+02   1.  .833+01 -.123+04  .620+03
  2-   27*     -.140+02 -.230+04  .406+02   1. -.133+02 -.230+04  .114+04
  2-   28*      .496+01 -.336+02  .917+02  39.  .794+02 -.108+03  .937+02
  2-   29*     -.359+01 -.104+04  .966+02   5.  .534+01 -.105+04  .527+03
  2-   30*     -.113+02 -.205+04  .747+02   2. -.858+01 -.205+04  .102+04
  2-   31*     -.528+01 -.567+02  .110+03  38.  .818+02 -.144+03  .113+03
  2-   32*     -.103+02 -.715+03  .916+02   7.  .146+01 -.727+03  .364+03
  2-   33*     -.137+02 -.138+04  .570+02   2. -.114+02 -.138+04  .684+03
  2-   34*     -.152+02  .197+02  .113+03  49.  .117+03 -.112+03  .115+03
  2-   35*      .400+01 -.257+03  .987+02  19.  .371+02 -.290+03  .164+03
  2-   36*      .216+02 -.534+03  .496+02   5.  .260+02 -.538+03  .282+03
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```
DISPLACEMENTS, MACRO ELEMENT CHNL, NREF=   3
SET=   1, CON=   1, VECTOR=   1
DEAD WEIGHT + 20 LBS/SQ FT + MECHANICAL LOADS

JOINT      1           2           3           4           5           6
    1   .000    *   .000    *   .000    *   .000    *   .000    *   .000    *
    2   .000    *   .000    *   .000    *   .000    *   .000    *   .000    *
    3   .000    *   .000    *   .000    *   .000    *   .000    *   .000    *
    4   .000    *   .000    *   .000    *   .000    *   .000    *   .000    *
    5   .000    *   .000    *   .000    *   .000    *   .000    *   .000    *
    6   .000    *   .000    *   .000    *   .000    *   .000    *   .000    *
    7   .000    *   .000    *   .000    *   .000    *   .000    *   .000    *
    8   .000    *   .000    *   .000    *   .000    *   .000    *   .000    *
    9   .000    *   .000    *   .000    *   .000    *   .000    *   .000    *
   10   .000    *   .000    *   .000    *   .000    *   .000    *   .000    *
   11   .154-01    -.206-03     .116-02    -.559-04     .144-02    -.817-03
   12   .123-01    -.148-03     .129-02    -.398-04     .118-02    -.863-03
   13   .916-02    -.985-04     .138-02    -.306-04     .916-03    -.884-03
   14   .599-02    -.330-04     .142-02    -.157-04     .667-03    -.883-03
   15   .600-02    -.605-02    -.151-02     .496-03     .488-03    -.821-03
   16   .635-02    -.113-01    -.451-02     .803-03     .407-03    -.771-03
   17   .701-02    -.152-01    -.770-02     .642-03     .339-03    -.668-03
   18   .928-02    -.149-01    -.328-02     .439-03     .551-03    -.654-03
   19   .115-01    -.149-01     .104-02     .330-03     .751-03    -.625-03
   20   .135-01    -.150-01     .539-02     .218-03     .940-03    -.574-03
   21   .590-01     .116-03     .200-02    -.916-04     .318-02    -.411-02
   22   .467-01     .117-03     .187-02    -.773-04     .246-02    -.423-02
   23   .343-01     .129-03     .197-02    -.652-04     .176-02    -.422-02
   24   .222-01     .129-03     .233-02    -.546-04     .113-02    -.412-02
   25   .223-01    -.220-01    -.325-02     .989-03     .933-03    -.365-02
   26   .225-01    -.409-01    -.848-02     .152-02     .809-03    -.319-02
   27   .229-01    -.575-01    -.138-01     .115-02     .712-03    -.304-02
   28   .314-01    -.573-01    -.599-02     .934-03     .116-02    -.307-02
   29   .398-01    -.572-01     .181-02     .771-03     .161-02    -.307-02
   30   .483-01    -.573-01     .962-02     .623-03     .203-02    -.306-02
   31   .145+00B    .162-03B    .154-02B   -.118-03B    .339-02B   -.141-01B
   32   .110+00     .171-03     .187-02    -.107-03     .271-02    -.137-01
   33   .765-01     .182-03     .193-02    -.961-04     .204-02    -.127-01
   34   .461-01B    .187-03B    .166-02B   -.848-04B    .138-02B   -.111-01B
   35   .461-01    -.483-01    -.452-02     .104-02     .127-02    -.810-02
   36   .462-01    -.868-01    -.112-01     .180-02     .116-02    -.675-02
   37   .465-01    -.121+00    -.181-01     .157-02     .107-02    -.659-02
   38   .640-01    -.121+00    -.796-02     .140-02     .176-02    -.677-02
   39   .818-01    -.121+00     .215-02     .124-02     .243-02    -.683-02
   40   .996-01    -.121+00     .123-01     .109-02     .307-02    -.680-02
   41   .184+00     .314-03     .282-02    -.137-03     .348-02    -.143-01
   42   .148+00     .349-03     .274-02    -.130-03     .288-02    -.144-01
   43   .112+00     .369-03     .282-02    -.123-03     .226-02    -.144-01
   44   .762-01     .407-03     .309-02    -.112-03     .158-02    -.143-01
   45   .762-01    -.691-01    -.515-02     .109-02     .151-02    -.138-01
   46   .763-01    -.136+00    -.131-01     .206-02     .143-02    -.134-01
   47   .765-01    -.200+00    -.212-01     .204-02     .137-02    -.132-01
   48   .109+00    -.200+00    -.941-02     .189-02     .223-02    -.132-01
   49   .141+00    -.200+00     .240-02     .176-02     .306-02    -.132-01
   50   .173+00    -.200+00     .142-01     .163-02     .388-02    -.131-01
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REACTIONS, MACRO ELEMENT CHNL, NREF=   5
SET=   1, CON=   1, VECTOR=   1
DEAD WEIGHT + 20 LBS/SQ FT + MECHANICAL LOADS

JOINT      1          2          3          4          5          6
    1  -.372+03*   .168+04*  -.213+04*   .620+03*  -.904+03*  -.531+03*
    2  -.110+02*   .565+03*  -.223+04*   .648+03*  -.776+02*  -.938+03*
    3   .760+01*   .172+03*  -.252+04*   .433+03*  -.131+02*  -.942+03*
    4  -.343+03*  -.185+04*  -.380+04*   .385+03*  -.142+03*  -.701+03*
    5   .209+04*   .347+02*   .460+04*  -.182+03*  -.112+04*  -.428+03*
    6   .215+04*   .891+02*   .154+05*  -.469+03*  -.954+03*  -.151+03*
    7  -.699+04*   .559+04*   .181+05*  -.659+04*   .537+03*  -.665+03*
    8  -.234+03*  -.485+04*   .497+04*  -.654+04*  -.134+03*  -.103+04*
    9   .134+03*  -.479+04*  -.403+04*  -.457+04*  -.162+03*  -.873+03*
   10  -.455+02*   .508+04*  -.509+04*  -.882+03*  -.653+03*  -.407+03*
   11  -.164-02    .198-02    .946-03    .212-04   -.318-02   -.244-02
   12   .206-02   -.475-02   -.897-03    .573-04    .122-03   -.229-02
   13   .636-03    .788-03   -.672-03   -.246-04    .642-02    .208-02
   14  -.103-02    .130-02   -.244-02   -.180-03   -.341-02    .179-02
   15   .311-01    .320-03    .589-02   -.460-03    .230-04    .878-03
   16  -.202-01   -.181-03    .140-02    .951-03    .198-04    .100-02
   17  -.849-02    .108-01    .624-02   -.980-03   -.288-02    .289-02
   18   .293-02    .133-01    .419-02   -.398-03    .319-02   -.561-03
   19  -.443-02   -.114+00   -.504-03   -.417-03   -.606-02    .186-02
   20   .273-02    .890-01   -.204-02   -.354-03    .535-02    .352-02
   21  -.177-01   -.134-01    .472-03   -.554-04   -.184-01   -.221-01
   22   .779-02    .106-01    .559-02    .278-03    .133-01   -.353-01
   23   .152-01   -.674-02    .299-03    .157-03    .960-02   -.480-02
   24  -.464-01    .889-02   -.231-02   -.295-03   -.457-02    .580-02
   25  -.360-02    .820-03    .646-02   -.290-03   -.650-04    .298-02
   26  -.288-01   -.157-02   -.244-01   -.235-03   -.808-04   -.272-03
   27   .494-01    .202+00    .231-01   -.208-02   -.349-02    .584-02
   28   .844-02   -.118+00    .800-02   -.565-04    .957-05    .348-02
   29  -.655-02   -.217+00    .217-01   -.109-02    .155-01    .556-03
   30   .373-02    .133+00   -.140-01    .328-03   -.137-01    .372-02
   31   .736+03B  -.497+03B  -.344+04B   .403+00B   .163+03B   .108+03B
   32  -.130-01    .771-03   -.133-01    .987-04   -.259-01   -.197-01
   33   .121-01   -.125-01   -.331-03    .228-03   -.218-02   -.117-01
   34   .414+03B  -.184+03B  -.657+04B  -.518+01B  -.130+03B  -.115+03B
   35  -.428+00    .300-02    .147-01   -.226-02    .698-03    .926-03
   36  -.131-01   -.175-02   -.345-03   -.242-02    .328-03    .269-02
   37   .109+00   -.256+00    .251-01    .331-03   -.481-02    .890-02
   38   .420-02    .322+00   -.498-01    .363-02    .403-02    .595-02
   39   .273-01   -.921-01    .663-01   -.140-02    .282-01   -.252-01
   40  -.242-01    .394-01   -.535-01    .104-02   -.278-01   -.321-01
   41   .565-02   -.453-01    .139-01    .140-03    .174-01    .817-02
   42  -.351-01    .359-01   -.237-01    .735-03   -.525-01   -.321-01
   43   .379-01   -.279-01    .101-01    .260-03    .751-01   -.188-01
   44   .324-01    .327-01   -.158-02   -.754-03   -.294-01    .132-01
   45  -.154+00    .747-03   -.331-02    .717-02   -.584-03    .427-02
   46  -.111+00    .450-02   -.125-01   -.846-02    .725-03    .129-01
   47   .198+00   -.951+00    .311-01    .288-02   -.191-02    .258-01
   48   .205-01    .623+00   -.225-01   -.273-02    .445-02    .134-01
   49   .189-02    .397-01    .754-01   -.528-02   -.441-01   -.141-01
   50  -.640-02    .268+00   -.657-01    .469-02    .403-01   -.134-01
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TABLE OF CONTENTS, LIBRARY  1
                             E                         T   DATA SET NAME
SEQ        RR  DATE    TIME  R    WORDS     NJ  NI*NJ  Y  N1   N2     N3    N4
   1       17 811201 165240  0       18      1     18  0 JDF1 BTAB     1     8
   2       18 811201 165240  0       45     45     45  0 JREF BTAB     2     6
   3      -20 811201 165240  0       12      1     12 -1 ALTR BTAB     2     4
   4      -21 811201 165240  0       45      1     45  0 JSEQ BTAB     2    17
   5      -23 811201 165240  0       45      1     45  0 SEQ  BTAB     2   170
   6       25 811201 165240  0      135     45    135 -1 JLOC BTAB     2     5
   7       30 811201 165240  0       10      1     10 -1 MATC BTAB     2     2
   8       31 811201 165240  0       43      1     43 -1 SA   BTAB     2    13
   9       33 811201 165240  0       60      5     60 -1 ALTR BTAB     2     4
  10       36 811201 165240  0       45     45     45  0 CON            1     0
  11       38 811201 165240  0      405     45    405 -1 QJJT BTAB     2    19
  12       53 811201 165244  0      512     56    896  0 DEF  E41      9     4
  13       85 811201 165244  0        2      1      2  0 GD   E41      9     4
  14       86 811201 165244  0       15      1     15  4 GTIT E41      9     4
  15       87 811201 165244  0       20      1     20  0 DIR  E41      9     4
  16       88 811201 165244  0        1      1      1  4 ELTS NAME     0     0
  17       89 811201 165244  0        1      1      1  0 ELTS NNOD     0     0
  18       90 811201 165244  0        1      1      1  0 ELTS ISCT     0     0
  19       91 811201 165244  0       15      1     15  0 NS             0     0
  20       92 811201 165250  0       45     45     45  0 CON         9999     0
  21       94 811201 165416  0     7144     47   1786 -1 RK   BTAB     6     0
  22      350 811201 165416  0     7144     47   1786 -1 RM   BTAB     6     0
  23      606 811201 165431  0     5376     32    168  4 E41  EFIL     9     4
  24      798 811201 165427  0      270     45    270 -1 DEM  DIAG     0     0
  25      808 811201 165434  0       45     45     45  0 SEQ  BTAB     2   170
  26      810 811201 165434  0       45     45     45  0 JSEQ BTAB     2    17
  27      812 811201 165441  0     1792     45   1792  0 KMAP TOPO   233    23
  28      876 811201 165441  0      896      1    896  0 TAN  IMAP     0     0
  29      908 811201 165441  0        9      9      9  0 TAN  STAT     0     0
  30      909 811201 165441  0       21      7     21  0 TAN  TBCT     0     0
  31      910 811201 165441  0        8      8      8  0 TAN  PBCT     0     0
  32      911 811201 165447  0    11200     45   2240  2 K    SPAR    36     0
  33     1725 811201 165452  0    11200     45   2240  2 KME  SPAR    36     0
  34     2525 811201 165452  0    11200     45   2240  1 MME  SPAR    36     0
  35     2925 811201 165500  0    11200     45   2240  2 KSYS SPAR    36     0
  36     3725 811201 165500  0    11200     45   2240  1 MSYS SPAR    36     0
  37     4125 811201 165508  0       15      1     15  4 CASE TITL     1     1
  38     4126 811201 165508  0       45     45     45 -1 NODA PRES     1     1
  39     4128 811201 165508  0     1620     45    270 -1 R    AUS      1     1
  40     4188 811201 165508  0      270     45    270 -1 APPL FORC     1     1
  41     4198 811201 165514  0      270     45    270 -1 EQNF FORC     1     1
  42     4208 811201 165517  0    12740     45   1820  1 INV  KSYS     1     0
  43     4663 811201 165517  0        2      1      2  0 XINV KSYS     1     0
  44     4664 811201 165531  0      270     45    270 -1 STAT DISP     1     1
  45     4674 811201 165531  0      270     45    270 -1 STAT REAC     1     1
  46     4684 811201 165545  0      270     45    270 -1 SYS  JMG      1     1
```

```
TABLE OF CONTENTS, LIBRARY  3
                            E                       T  DATA SET NAME
SEQ        RR   DATE   TIME R   WORDS     NJ NI*NJ  Y N1   N2     N3   N4
  1        17 811201 165224 0  214536      1 19992  8 LIB  CHNL    1    1


TABLE OF CONTENTS, LIBRARY  4
                            E                       T  DATA SET NAME
SEQ        RR   DATE   TIME R   WORDS     NJ NI*NJ  Y N1   N2     N3   N4
  1        17 811201 165307 0    1786     47  1786 -1 RK   CHNL    6    2
  2        81 811201 165324 0    1786     47  1786 -1 RK   CHNL    6    3
  3       145 811201 165342 0    1786     47  1786 -1 RK   CHNL    6    4
  4       209 811201 165402 0    1786     47  1786 -1 RK   CHNL    6    5
  5       273 811201 165414 0       1      1     1 -1 END  END   999  999


TABLE OF CONTENTS, LIBRARY  5
                            E                       T  DATA SET NAME
SEQ        RR   DATE   TIME R   WORDS     NJ NI*NJ  Y N1   N2     N3   N4
  1        17 811201 165307 0    1786     47  1786 -1 RM   CHNL    6    2
  2        81 811201 165324 0    1786     47  1786 -1 RM   CHNL    6    3
  3       145 811201 165342 0    1786     47  1786 -1 RM   CHNL    6    4
  4       209 811201 165402 0    1786     47  1786 -1 RM   CHNL    6    5
  5       273 811201 165414 0       1      1     1 -1 END  END   999  999


TABLE OF CONTENTS, LIBRARY  6
                            E                       T  DATA SET NAME
SEQ        RR   DATE   TIME R   WORDS     NJ NI*NJ  Y N1   N2     N3   N4
  1        17 811201 165259 0      12      1    12  0 SSBT CHNL    2    0
  2        18 811201 165316 0      12      1    12  0 SSBT CHNL    3    0
  3        19 811201 165333 0      12      1    12  0 SSBT CHNL    4    0
  4        20 811201 165352 0      12      1    12  0 SSBT CHNL    5    0
```

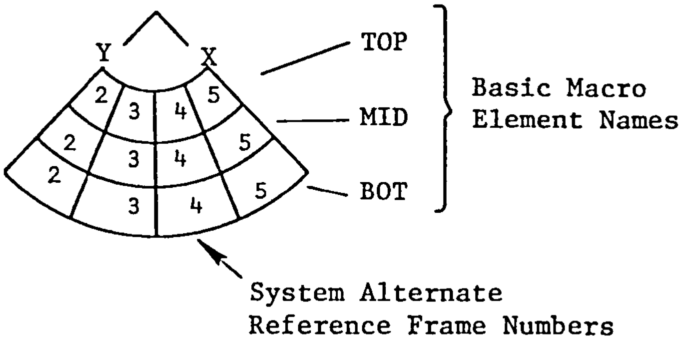
```
TABLE OF CONTENTS, LIBRARY  7
                            E                      T  DATA SET NAME
SEQ      RR   DATE   TIME   R  WORDS    NJ NI*NJ   Y   N1   N2   N3   N4
  1      17 811201 165508   0     15     1    15   4 CASE TITL    1    1
  2      18 811201 165553   0    780   130   780  -1 USB  CHNL    1    2
  3      46 811201 165553   0    780   130   780  -1 USB  CHNL    1    3
  4      74 811201 165553   0    780   130   780  -1 USB  CHNL    1    4
  5     102 811201 165553   0    780   130   780  -1 USB  CHNL    1    5
  6     130 811201 165634   0     14    32   448   6 HEAD CHNL    2    0
  7     146 811201 165642   0     14    32   448   6 HEAD CHNL    3    0
  8     162 811201 165651   0     14    32   448   6 HEAD CHNL    4    0
  9     178 811201 165659   0     14    32   448   6 HEAD CHNL    5    0
 10     194 811201 165742   0    780   130   780  -1 REAC CHNL    1    2
 11     222 811201 165750   0    780   130   780  -1 REAC CHNL    1    3
 12     250 811201 165757   0    780   130   780  -1 REAC CHNL    1    4
 13     278 811201 165804   0    780   130   780  -1 REAC CHNL    1    5


TABLE OF CONTENTS, LIBRARY 10
                            E                      T  DATA SET NAME
SEQ      RR   DATE   TIME   R  WORDS    NJ NI*NJ   Y   N1   N2   N3   N4
  1      17 811201 164925   0     14    32   448   6 SJC  CHNL    2    0
  2      33 811201 164925   0     14    32   448   6 SJC  CHNL    3    0
  3      49 811201 164925   0     14    32   448   6 SJC  CHNL    4    0
  4      65 811201 164925   0     42    32   448   6 SJC  CHNL    5    0


TABLE OF CONTENTS, LIBRARY 29
                            E                      T  DATA SET NAME
SEQ      RR   DATE   TIME   R  WORDS    NJ NI*NJ   Y   N1   N2   N3   N4
  1      17 811201 164922   0   1372    32   448   6 ME   DOC     1    0
  2      81 811201 164925   0    336    32   448   6 CHNL DATA    1    0
  3      97 811201 164925   0    280    32   448   6 SYS  DATA    0    0
  4     113 811201 165734   0    336     3   336   0 REGI HOUS    1    1
```

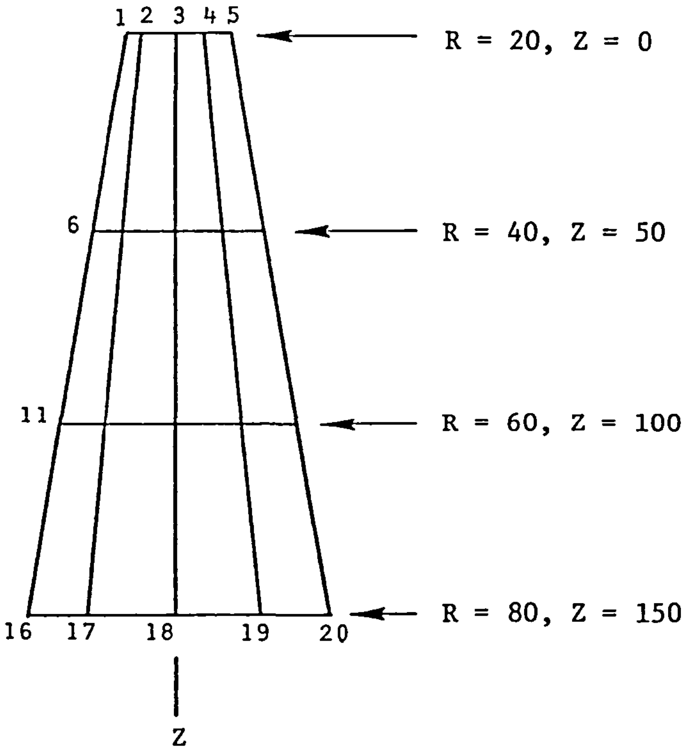
6.2 VIBRATIONAL MODES OF A STRINGER STIFFENED CONICAL SHELL

The EAL macro element procedures were used to compute the vibrational modes and frequencies of the stiffened conical shell shown below. As illustrated, the system model consists of 12 macro elements. Each of three unique macro elements is repeated four times. A generic model runstream element named GENERIC CONE was used to generate the finite element model for each of the three basic macro elements. The macro element generic model is illustrated on page 6.2-2. The input runstream for the problem and a listing of GENERIC CONE are shown on pages 6.2-3 through 6.2-6. Sample printout of the computed modes are shown on pages 6.2-7 through 6.2-11. Tables of contents for all pertinent EAL libraries are shown on pages 6.2-12 through 6.2-14.

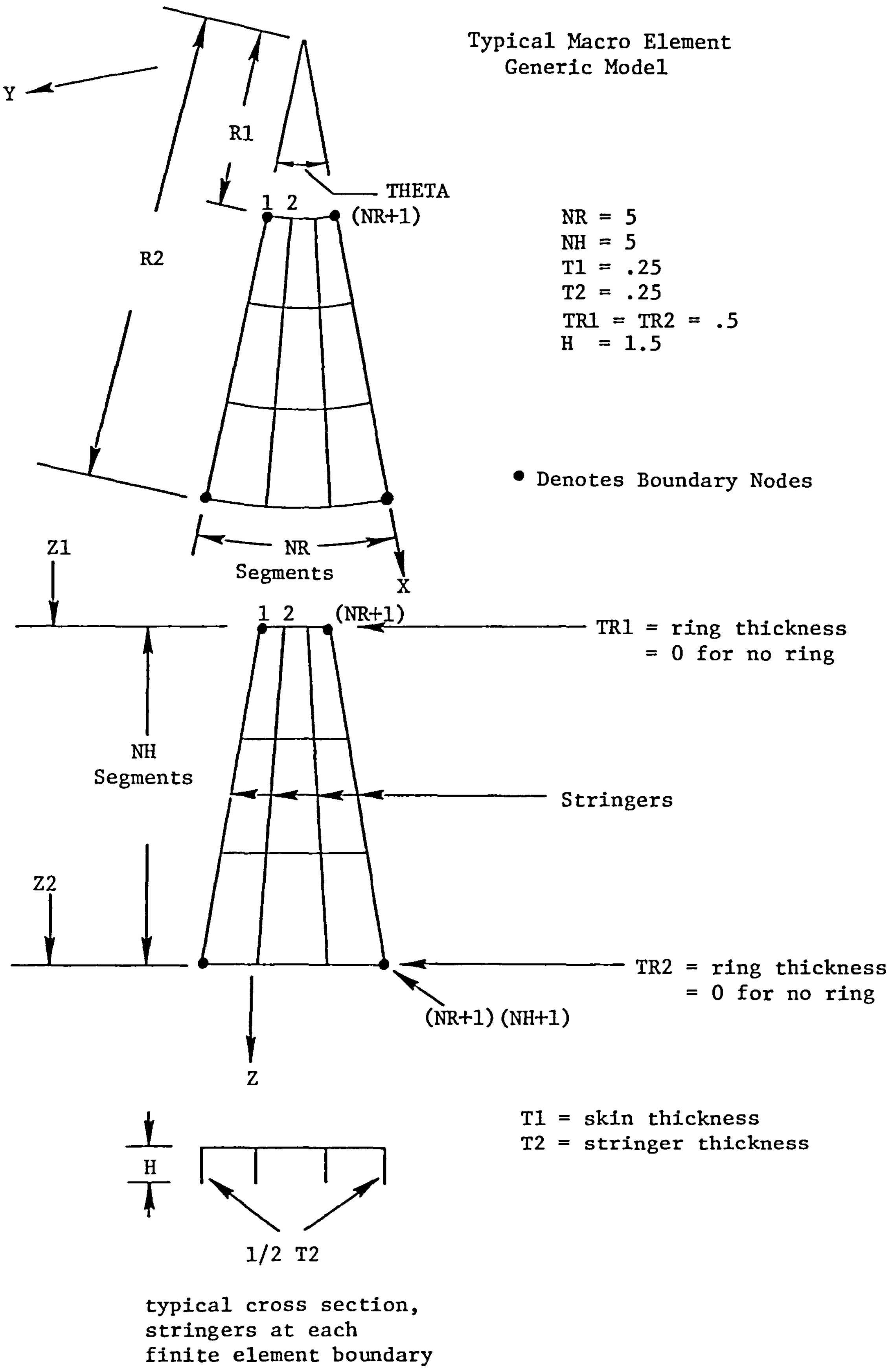


$E = 30x10^{6}$
$\nu = .3$
$\rho = .28$
skin t = .25
stringer t = .25
@4.5° increments
ring t = .5 @ large and
small circles
ring and stringer depth = 4

XZ = YZ = symmetry plane
Z-direction displacement
constrained at joints 16-20



Typical Macro Element Generic Model



```
ME   DOC          2       0                      CREATED: 811201 180633
                                                 PRINTED: 811201 180633

*XQT U1
$
$ MACRO ELEMENT, TOP CONICAL SEGMENT:
*(TOP DATA 1)                                    END
$ GRAVITY             GENERIC CONE PARAMETERS
  G=386.       R1=20., Z1=0., R2=40., Z2=50., TR1=.5
*DCALL(29 GENERIC CONE)
*                                                END
$
$ MACRO ELEMENT, MIDDLE CONICAL SEGMENT:
*(MID DATA 1)                                    END
$ GRAVITY          GENERIC CONE PARAMETERS
  G=386.       R1=40., Z1=50., R2=60., Z2=100.
*DCALL(29 GENERIC CONE)
*                                                END
$
$ MACRO ELEMENT, BOTTOM CONICAL SEGMENT:
*(BOT DATA 1)                                    END
$ GRAVITY              GENERIC CONE PARAMETERS
  G=386.       R1=60., Z1=100., R2=80., Z2=150., TR2=.5
*DCALL(29 GENERIC CONE)
*                                                END
$
$ SYSTEM DATA:
*(SYS DATA)                                      ENDSYS
*(TAB)                                           END
  START   20
  JLOC:   FORMAT=2: 1  20.  90.   0.  20.   0.   0.  5 1 4
                    5  80.  90. 150.  80.   0. 150.
  JREF:   NREF=-1: 1,20
  CON=1:  ZERO 3: 16, 20: SYMM PLANE=1: SYMM PLANE=2
  ALTR:   !NR=4: !T=67.5: !IAL=2
*                                                LABEL 100
  "IAL" 3 "T": !IAL=IAL+1: !T=T-22.5
*                                                JGZ,-1(NR,100)
*                                                END
*                                                ENDSYS
$ SET UP THE SJC DATA SETS IN LIB 10:
$
*XQT U3
    !NDO=3: !N=-1: !N2='TOP
*                                                LABEL 1000
    !MDO=4: !NREF=1: !N=N+1
*                                                LABEL 2000
    !NREF=NREF+1: !N=N+1: !N1=N+1: !N6=N+6: !N5=N+5
 RP2
 OUTP=10 SJC "N2" "NREF" 0: FORMAT 1'(3(I4,1H:),I4)
 PRINT(1) "N" "N1" "N5" "N6"
*                                                JGZ,-1(MDO,2000)
    !TST=NDO-3: !N2='MID
*                                                JZ(TST,200)
    !N2='BOT
```

```
*                                                LABEL 200
*                                                JGZ,-1(NDO,1000)
$ FORM THE SYSTEM MASS AND STIFFNESS MATRICES:
$
*CALL(ME SYS)
$ COMPUTE THE SYSTEM MODES AND FREQUENCIES:
$
*XQT E4
 RESET M=MSYS, K=KSYS, NMODES=3, ICA=1
*XQT VPRT
 PRINT VIBR MODE
$ BACK TRANSFORM FOR AND PRINT MACRO ELEMENT EIGENVECTORS:
$
*XQT U1
*(BACK PARAMETERS)
    VECT=VIBR
*(VPRT PARAMETERS)
    EVAL=VIBR
*CALL(ME BACK)
*CALL(ME VPRT)
```

```
GENE CONE        0       0                       CREATED: 811201 180633
                                                 PRINTED: 811201 180633

*XQT U1
*(TAB)                                           ENDTAB
$
$ REGISTERS THAT ARE COMMON TO ALL MACRO ELEMENTS:
    !THET=22.5: !NR=5: !NH=5: !T1=.25: !T2=.25: !H=1.5
$
$ CONICAL SEGMENT REGISTERS:
$   NR=   NUMBER OF RADIAL SUBDIVISIONS
$   NH=   NUMBER OF LONGITUDINAL SUBDIVISIONS
$   R1,Z1=RADIUS AND Z LOCATION OF END 1
$   R2,Z2=RADIUS AND Z LOCATION OF END 2
$   THET= ANGULAR DIMENSION IN DEGREES
$   H=    RING AND STRINGER DEPTH
$   T1=   SKIN THICKNESS
$   T2=   STRINGER THICKNESS
$   TR1=  RING 1 THICKNESS, OMIT THIS REGISTER FOR FOR NO RING 1
$   TR2=  RING 2 THICKNESS, OMIT THIS REGISTER FOR FOR NO RING 2
$
    !NR1=NR+1: !NH1=NH+1: !NR2=NR+2: !NR3=NR+3: !JT1=NR1*NH1
    !K1=JT1+1: !K2=JT1+2: !KNR1=JT1+NR1: !KNR2=JT1+NR2
    !KNR3=JT1+NR3: !NRM1=NR-1: !NRH1=NR+1*NH: !BN3=NRH1+1
    !JT=2*JT1: !R1S=R1-H: !R2S=R2-H: !T2H=.5*T2
    !LTR1=LOCA(TR1): !LTR2=LOCA(TR2)
 START "JT"
 JLOC: FORMAT=2
       1     "R1"  "THET"  "Z1"  "R1"  0.  "Z1"  "NR1"  1  "NR1"
       "NH1" "R2"  "THET"  "Z2"  "R2"  0.  "Z2"
       "K1"  "R1S" "THET"  "Z1"  "R1S" 0.  "Z1"  "NR1"  1  "NR1"
       "NH1" "R2S" "THET"  "Z2"  "R2S" A\  "Z2"
 JREF: NREF=-1: 1,"JT"
 CON=1
 MATC: 1 30.+6 .3 .28  .1-4
 SA:   1 "T1"  $ SKIN
       2 "T2"  $ INTERIOR STRINGERS
       3 "T2H" $ EXTERIOR STRINGERS
*                                                JZ(LTR1,100)
       4 "TR1" $ END RING 1
*                                                LABEL 100
*                                                JZ(LTR2,200)
       5 "TR2" $ END RING 2
*                                                LABEL 200
*                                                RETURN
*                                                ENDTAB
*(ELD)                                           ENDELD
 E43:  GROUP 1'CONICAL SEGMENT SKIN
          1 2 "NR3" "NR2" 1 "NR" "NH"
       GROUP 2'CONICAL SEGMENT STRINGERS
          NSECT=3: 1 "NR2" "KNR2" "K1" 1 "NH" 1 2 "NR"
          NSECT=2: 2 "NR3" "KNR3" "K2" 1 "NH" 1 "NRM1" 1
    !TEST=LTR1+LTR2
*                                                JZ(TEST,200)
       GROUP 3'CONICAL SEGMENT RINGS
```

```
*                                                JZ(LTR1,100)
          NSECT=4: 1 2 "K2" "K1" 1 "NR" 1
*                                                LABEL 100
*                                                JZ(LTR2,200)
          MOD JOINT="NRH1": NSECT=5: 1 2 "K2" "K1" 1 "NR" 1
*                                                LABEL 200
*                                                RETURN
*                                                ENDELD
*(BN)
  1: "NR1": "BN3": "JT1"
```

```
VIBRATIONAL MODE.                                                ID=   1/ 1/  1
EIGENVALUE=     .4030203+04,   FREQ=    10.1038 HZ
JOINT      1           2           3           4           5           6
    1   .105+01     .000   *  -.289+00     .000   *  -.579-02     .000   *
    2   .759+00     .359+00   -.211+00    -.203-01    -.517-02    -.528-01
    3   .129-01     .513+00   -.458-02    -.284-01    -.255-03    -.736-01
    4  -.751+00     .366+00    .208+00    -.199-01     .476-02    -.514-01
    5  -.109+01     .000   *   .304+00     .000   *   .821-02     .000   *
    6   .844+00     .000   *  -.208+00     .000   *  -.343-02     .000   *
    7   .610+00     .291+00   -.152+00    -.747-02    -.259-02    -.210-01
    8   .911-02     .415+00   -.316-02    -.106-01    -.891-04    -.292-01
    9  -.605+00     .296+00    .150+00    -.747-02     .256-02    -.203-01
   10  -.873+00     .000   *   .219+00     .000   *   .385-02     .000   *
   11   .600+00     .000   *  -.108+00     .000   *  -.454-02     .000   *
   12   .433+00     .208+00   -.795-01    -.268-02    -.335-02    -.993-02
   13   .510-02     .296+00   -.158-02    -.378-02    -.768-04    -.136-01
   14  -.429+00     .210+00    .779-01    -.267-02     .329-02    -.936-02
   15  -.619+00     .000   *   .114+00     .000   *   .483-02     .000   *
   16   .335+00     .000   *   .000   *    .000   *  -.583-02     .000   *
   17   .238+00     .119+00    .000   *   -.116-03    -.427-02    -.375-02
   18   .117-02     .169+00    .000   *   -.155-03    -.763-04    -.522-02
   19  -.238+00     .120+00    .000   *   -.106-03     .419-02    -.363-02
   20  -.338+00     .000   *   .000   *    .000   *   .612-02     .000   *
```

```
VIBRATIONAL MODE.                                                ID=   1/ 1/  2
EIGENVALUE=     .3667824+05,   FREQ=    30.4807 HZ
JOINT      1           2           3           4           5           6
    1   .148+00     .000   *  -.691-01     .000   *   .164-01     .000   *
    2   .116-01     .328-01   -.393-02    -.934-02     .313-03    -.179-01
    3  -.147+00     .486-02    .698-01     .104-03    -.165-01     .549-03
    4  -.114-01    -.277-01    .386-02     .937-02    -.295-03     .180-01
    5   .145+00     .000   *  -.703-01     .000   *   .167-01     .000   *
    6   .978+00     .000   *  -.380+00     .000   *   .138-01     .000   *
    7   .358-01     .213+00   -.135-01    -.299-01     .405-03    -.606-01
    8  -.102+01     .710-02    .397+00     .719-03    -.139-01     .535-02
    9  -.344-01    -.213+00    .129-01     .307-01    -.380-03     .632-01
   10   .105+01     .000   *  -.412+00     .000   *   .140-01     .000   *
   11   .101+01     .000   *  -.355+00     .000   *  -.632-02     .000   *
   12   .414-01     .224+00   -.150-01    -.215-01    -.355-03    -.399-01
   13  -.106+01     .720-02    .376+00    -.226-03     .684-02     .449-02
   14  -.396-01    -.226+00    .143-01     .222-01     .340-03     .424-01
   15   .111+01     .000   *  -.395+00     .000   *  -.732-02     .000   *
   16   .189+00     .000   *   .000   *    .000   *  -.231-01     .000   *
   17   .518-02     .575-01    .000   *   -.258-02    -.941-03    -.508-02
   18  -.191+00     .215-02    .000   *   -.241-03     .241-01     .110-03
   19  -.507-02    -.561-01    .000   *    .259-02     .897-03     .518-02
   20   .193+00     .000   *   .000   *    .000   *  -.251-01     .000   *
```

```
VIBRATIONAL MODE.                                                ID=   1/ 1/  3
EIGENVALUE=     .9131283+05,  FREQ=   48.0935 HZ
JOINT      1           2           3           4           5           6
    1  -.327-01     .000   *   .153-01     .000   *  -.111-01     .000   *
    2   .139-01   -.362-02   -.732-02     .198-02     .716-02     .327-02
    3   .133-01    .149-02   -.552-02    -.193-02     .118-02    -.266-02
    4  -.175-01    .103-02    .840-02     .690-03    -.818-02     .377-03
    5   .132-01     .000   *  -.729-02     .000   *   .107-01     .000   *
    6  -.561+00     .000   *   .237+00     .000   *  -.356-01     .000   *
    7   .360+00   -.449-01   -.153+00     .103-01     .237-01     .165-01
    8   .712-01    .514-01   -.286-01    -.143-01     .275-02    -.264-01
    9  -.422+00   -.281-01    .179+00     .985-02    -.280-01     .207-01
   10   .546+00     .000   *  -.234+00     .000   *   .376-01     .000   *
   11  -.154+01     .000   *   .593+00     .000   *   .213-03     .000   *
   12   .105+01   -.118+00   -.404+00     .231-01    -.224-03     .251-01
   13   .126+00    .157+00   -.479-01    -.330-01    -.442-03    -.499-01
   14  -.124+01   -.105+00    .478+00     .239-01     .587-03     .459-01
   15   .169+01     .000   *  -.654+00     .000   *  -.870-03     .000   *
   16  -.150+00     .000   *    .000   *    .000   *   .485-01     .000   *
   17   .100+00   -.215-01     .000   *    .340-02    -.326-01     .241-02
   18   .120-01    .275-01     .000   *   -.351-02    -.384-02    -.339-02
   19  -.113+00   -.176-01     .000   *    .163-02     .384-01     .235-02
   20   .152+00     .000   *    .000   *    .000   *  -.519-01     .000   *
```

```
DISPLACEMENTS, MACRO ELEMENT TOP , NREF=   2
SET=   1, CON=   1, VECTOR=   1
EIGENVALUE=   .4030203+04,   FREQ=     10.1038 HZ

JOINT      1          2          3          4          5          6
    1  .105+01B   .224-07B  -.289+00B   .116-09B  -.579-02B   .000   B
    2  .101+01    .805-01   -.279+00   -.102-01   -.167-02   -.193-01
    3  .961+00    .157+00   -.264+00   -.111-01   -.337-02   -.252-01
    4  .903+00    .229+00   -.248+00   -.109-01   -.333-02   -.288-01
    5  .835+00    .297+00   -.231+00   -.115-01   -.185-02   -.338-01
    6  .759+00B   .359+00B  -.211+00B  -.203-01B  -.517-02B  -.528-01B
    7  .103+01   -.372-02   -.284+00   -.121-01   -.478-03   -.281-01
    8  .977+00    .750-01   -.265+00   -.104-01   -.253-02   -.232-01
    9  .926+00    .150+00   -.249+00   -.999-02   -.379-02   -.224-01
   10  .868+00    .221+00   -.233+00   -.911-02   -.371-02   -.227-01
   11  .803+00    .287+00   -.217+00   -.821-02   -.254-02   -.231-01
   12  .734+00    .347+00   -.203+00   -.596-02   -.897-04   -.185-01
   13  .994+00   -.281-02   -.270+00   -.950-02   -.265-02   -.213-01
   14  .943+00    .733-01   -.252+00   -.927-02   -.281-02   -.211-01
   15  .889+00    .145+00   -.234+00   -.845-02   -.362-02   -.196-01
   16  .832+00    .213+00   -.218+00   -.772-02   -.354-02   -.190-01
   17  .771+00    .276+00   -.204+00   -.660-02   -.267-02   -.180-01
   18  .707+00    .334+00   -.190+00   -.615-02   -.203-02   -.182-01
   19  .950+00   -.211-02   -.253+00   -.763-02   -.314-02   -.171-01
   20  .903+00    .707-01   -.235+00   -.750-02   -.304-02   -.172-01
   21  .851+00    .140+00   -.219+00   -.704-02   -.363-02   -.167-01
   22  .796+00    .204+00   -.204+00   -.632-02   -.352-02   -.158-01
   23  .738+00    .265+00   -.190+00   -.569-02   -.280-02   -.153-01
   24  .675+00    .320+00   -.178+00   -.536-02   -.232-02   -.154-01
   25  .901+00   -.902-03   -.232+00   -.658-02   -.393-02   -.150-01
   26  .859+00    .683-01   -.217+00   -.572-02   -.313-02   -.133-01
   27  .812+00    .134+00   -.203+00   -.560-02   -.365-02   -.135-01
   28  .761+00    .196+00   -.190+00   -.517-02   -.353-02   -.132-01
   29  .704+00    .253+00   -.177+00   -.493-02   -.281-02   -.136-01
   30  .644+00    .306+00   -.165+00   -.404-02   -.296-02   -.120-01
   31  .844+00B   .186-07B  -.208+00B   .873-10B  -.343-02B   .000   B
   32  .817+00    .651-01   -.200+00   -.454-02   -.324-02   -.108-01
   33  .772+00    .127+00   -.187+00   -.471-02   -.375-02   -.116-01
   34  .725+00    .186+00   -.175+00   -.394-02   -.362-02   -.103-01
   35  .675+00    .241+00   -.165+00   -.374-02   -.292-02   -.106-01
   36  .610+00B   .291+00B  -.152+00B  -.747-02B  -.259-02B  -.210-01B
   37  .105+01    .342-01   -.293+00   -.387-02   -.308-02   -.984-02
   38  .101+01    .116+00   -.283+00   -.645-02   -.212-02   -.143-01
   39  .961+00    .196+00   -.269+00   -.934-02   -.379-02   -.225-01
   40  .903+00    .272+00   -.253+00   -.107-01   -.370-02   -.274-01
   41  .835+00    .343+00   -.236+00   -.116-01   -.235-02   -.315-01
   42  .759+00    .406+00   -.216+00   -.150-01   -.333-02   -.371-01
   43  .103+01    .327-01   -.286+00   -.178-01   -.294-02   -.249-01
   44  .977+00    .111+00   -.270+00   -.123-01   -.219-02   -.249-01
   45  .926+00    .185+00   -.255+00   -.103-01   -.363-02   -.236-01
```

```
DISPLACEMENTS, MACRO ELEMENT MID , NREF=   3
SET=   1, CON=   1, VECTOR=   2
EIGENVALUE=   .3667824+05,   FREQ=     30.4807 HZ

JOINT      1          2          3          4          5          6
    1   .358-01B   .213+00B  -.135-01B  -.299-01B   .405-03B  -.606-01B
    2  -.201+00    .206+00    .720-01   -.318-01    .261-02   -.607-01
    3  -.432+00    .181+00    .160+00   -.314-01    .220-02   -.567-01
    4  -.647+00    .139+00    .243+00   -.301-01    .108-02   -.489-01
    5  -.842+00    .809-01    .322+00   -.323-01   -.303-02   -.354-01
    6  -.102+01B   .710-02B   .397+00B   .719-03B  -.139-01B   .535-02B
    7   .567-01    .218+00   -.275-01   -.301-01    .238-02   -.636-01
    8  -.179+00    .213+00    .632-01   -.309-01    .231-02   -.630-01
    9  -.411+00    .190+00    .151+00   -.315-01    .194-02   -.620-01
   10  -.638+00    .149+00    .239+00   -.329-01    .102-02   -.619-01
   11  -.863+00    .900-01    .328+00   -.369-01   -.187-02   -.651-01
   12  -.109+01    .130-01    .419+00   -.429-01   -.171-01   -.780-01
   13   .750-01    .223+00   -.328-01   -.266-01    .107-02   -.575-01
   14  -.164+00    .220+00    .566-01   -.267-01    .185-02   -.566-01
   15  -.400+00    .197+00    .146+00   -.272-01    .153-02   -.561-01
   16  -.636+00    .156+00    .236+00   -.287-01    .556-03   -.574-01
   17  -.879+00    .964-01    .330+00   -.315-01   -.195-02   -.605-01
   18  -.113+01    .171-01    .430+00   -.333-01   -.693-02   -.606-01
   19   .768-01    .225+00   -.321-01   -.240-01    .518-03   -.524-01
   20  -.159+00    .222+00    .555-01   -.241-01    .152-02   -.527-01
   21  -.397+00    .200+00    .144+00   -.249-01    .122-02   -.539-01
   22  -.640+00    .160+00    .235+00   -.262-01    .261-03   -.559-01
   23  -.888+00    .990-01    .330+00   -.279-01   -.182-02   -.580-01
   24  -.114+01    .189-01    .426+00   -.291-01   -.308-02   -.578-01
   25   .652-01    .225+00   -.255-01   -.220-01   -.414-04   -.468-01
   26  -.165+00    .221+00    .588-01   -.220-01    .130-02   -.480-01
   27  -.404+00    .199+00    .147+00   -.231-01    .101-02   -.511-01
   28  -.654+00    .158+00    .239+00   -.240-01    .375-04   -.532-01
   29  -.900+00    .978-01    .330+00   -.229-01   -.201-02   -.498-01
   30  -.112+01    .180-01    .416+00   -.254-01    .222-02   -.537-01
   31   .414-01B   .224+00B  -.150-01B  -.215-01B  -.355-03B  -.399-01B
   32  -.177+00    .218+00    .641-01   -.207-01    .128-02   -.439-01
   33  -.419+00    .195+00    .153+00   -.224-01    .953-03   -.495-01
   34  -.677+00    .151+00    .248+00   -.230-01   -.194-04   -.514-01
   35  -.924+00    .867-01    .339+00   -.202-01   -.191-02   -.448-01
   36  -.106+01B   .720-02B   .376+00B  -.226-03B   .684-02B   .449-02B
   37   .355-01    .318+00   -.107-01   -.244-01    .781-03   -.613-01
   38  -.201+00    .310+00    .758-01   -.267-01    .276-02   -.613-01
   39  -.431+00    .281+00    .163+00   -.258-01    .244-02   -.587-01
   40  -.647+00    .232+00    .245+00   -.231-01    .147-02   -.526-01
   41  -.841+00    .165+00    .320+00   -.254-01   -.255-02   -.426-01
   42  -.102+01    .888-01    .383+00   -.582-02   -.105-01   -.285-01
   43   .571-01    .316+00   -.229-01   -.303-01    .131-02   -.646-01
   44  -.179+00    .311+00    .661-01   -.309-01    .245-02   -.641-01
   45  -.412+00    .287+00    .154+00   -.310-01    .207-02   -.626-01
```

```
DISPLACEMENTS, MACRO ELEMENT BOT , NREF=   5
SET=   1, CON=   1, VECTOR=   3
EIGENVALUE=   .9131283+05,   FREQ=     48.0935 HZ

JOINT      1          2          3          4          5          6
    1  -.124+01B  -.105+00B   .478+00B   .239-01B   .587-03B   .459-01B
    2  -.633+00   -.177+00    .240+00    .729-01    .803-02    .764-01
    3  -.198-01   -.202+00    .108-01    .652-01    .320-03    .831-01
    4   .584+00   -.180+00   -.213+00    .631-01   -.102-01    .771-01
    5   .115+01   -.113+00   -.431+00    .705-01   -.173-01    .575-01
    6   .169+01B  -.281-07B  -.654+00B  -.145-10B  -.870-03B   .000   B
    7  -.115+01   -.879-01    .426+00    .704-01    .407-02    .133+00
    8  -.556+00   -.156+00    .207+00    .692-01    .987-02    .114+00
    9  -.209-01   -.179+00    .108-01    .670-01    .589-03    .979-01
   10   .480+00   -.161+00   -.171+00    .664-01   -.104-01    .952-01
   11   .986+00   -.103+00   -.361+00    .756-01   -.194-01    .106+00
   12   .153+01   -.325-02   -.572+00    .864-01   -.563-02    .129+00
   13  -.951+00   -.702-01    .343+00    .447-01    .170-01    .829-01
   14  -.466+00   -.126+00    .165+00    .442-01    .111-01    .780-01
   15  -.226-01   -.146+00    .103-01    .420-01    .863-03    .671-01
   16   .381+00   -.132+00   -.130+00    .434-01   -.103-01    .645-01
   17   .806+00   -.848-01   -.283+00    .502-01   -.204-01    .711-01
   18   .126+01   -.268-02   -.459+00    .575-01   -.228-01    .717-01
   19  -.705+00   -.524-01    .240+00    .312-01    .237-01    .627-01
   20  -.343+00   -.940-01    .113+00    .289-01    .124-01    .575-01
   21  -.167-01   -.108+00    .640-02    .263-01    .126-02    .493-01
   22   .281+00   -.980-01   -.882-01    .272-01   -.105-01    .477-01
   23   .594+00   -.634-01   -.194+00    .330-01   -.216-01    .533-01
   24   .933+00   -.280-02   -.321+00    .414-01   -.317-01    .564-01
   25  -.422+00   -.349-01    .124+00    .190-01    .309-01    .385-01
   26  -.198+00   -.594-01    .532-01    .157-01    .136-01    .344-01
   27   .134-03   -.673-01   -.832-03    .135-01    .158-02    .293-01
   28   .179+00   -.603-01   -.470-01    .132-01   -.106-01    .273-01
   29   .360+00   -.392-01   -.979-01    .153-01   -.226-01    .296-01
   30   .560+00   -.316-02   -.168+00    .231-01   -.413-01    .330-01
   31  -.113+00B  -.176-01B  -.269-07B   .163-02B   .384-01B   .235-02B
   32  -.455-01   -.239-01   -.794-02    .242-02    .143-01    .247-02
   33   .202-01   -.250-01   -.910-02    .926-03    .187-02    .218-02
   34   .767-01   -.210-01   -.545-02    .597-03   -.107-01    .146-02
   35   .119+00   -.125-01   -.134-02    .181-02   -.231-01    .622-03
   36   .152+00B  -.253-08B  -.216-15B  -.863-09B  -.519-01B   .000   B
   37  -.124+01   -.294+00    .483+00    .758-02    .937-02    .611-01
   38  -.633+00   -.366+00    .252+00    .508-01    .722-02    .698-01
   39  -.201-01   -.391+00    .105-01    .436-01    .323-03    .821-01
   40   .583+00   -.363+00   -.229+00    .431-01   -.105-01    .820-01
   41   .115+01   -.284+00   -.458+00    .531-01   -.165-01    .701-01
   42   .169+01   -.168+00   -.667+00   -.335-02   -.120-01    .482-01
   43  -.114+01   -.281+00    .450+00    .855-01    .498-02    .130+00
   44  -.556+00   -.339+00    .218+00    .745-01    .891-02    .121+00
   45  -.208-01   -.340+00    .107-01    .690-01    .481-03    .103+00
```

```
TABLE OF CONTENTS, LIBRARY  1
                            E                             T   DATA SET NAME
SEQ      RR   DATE    TIME  R   WORDS      NJ NI*NJ  Y  N1   N2   N3    N4
  1      17 811201  181048  0      18       1     18  0 JDF1 BTAB    1    8
  2     -18 811201  181048  0      20      20     20  0 JREF BTAB    2    6
  3     -19 811201  181048  0      12       1     12 -1 ALTR BTAB    2    4
  4     -20 811201  181048  0      20       1     20  0 JSEQ BTAB    2   17
  5     -21 811201  181048  0      20       1     20  0 SEQ  BTAB    2  170
  6      22 811201  181048  0      60      20     60 -1 JLOC BTAB    2    5
  7      25 811201  181048  0      20      20     20  0 JREF BTAB    2    6
  8      26 811201  181048  0      20      20     20  0 CON          1    0
  9      27 811201  181048  0      60       5     60 -1 ALTR BTAB    2    4
 10      30 811201  181048  0     180      20    180 -1 QJJT BTAB    2   19
 11      37 811201  181055  0      20      20     20  0 CON       9999    0
 12      38 811201  181254  0   21432      47   1786 -1 RK   BTAB    6    0
 13     806 811201  181254  0   21432      47   1786 -1 RM   BTAB    6    0
 14    1574 811201  181302  0      20      20     20  0 SEQ  BTAB    2  170
 15    1575 811201  181302  0      20      20     20  0 JSEQ BTAB    2   17
 16    1576 811201  181306  0    1792      20   1792  0 KMAP TOPO   75   10
 17    1640 811201  181306  0     896       1    896  0 TAN  IMAP    0    0
 18    1672 811201  181306  0       9       9      9  0 TAN  STAT    0    0
 19    1673 811201  181306  0       6       3      6  0 TAN  TBCT    0    0
 20    1674 811201  181306  0       8       8      8  0 TAN  PBCT    0    0
 21    1675 811201  181310  0    4480      20   2240  2 KSYS SPAR   36    0
 22    1995 811201  181310  0    4480      20   2240  1 MSYS SPAR   36    0
 23    2155 811201  181315  0     360      20    120 -1 VIBR MODE    1    1
 24    2170 811201  181315  0     360      20    120 -1 VIBR MMOD    1    1
 25    2185 811201  181315  0       3       1      3 -1 VIBR EVAL    1    1
 26    2186 811201  181315  0      12       1     12  0 VIBR STAT    1    1
 27    2187 811201  181349  0     360      20    120 -1 SYS  JMG     1    1
```

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TABLE OF CONTENTS, LIBRARY  3
                            E                             T   DATA SET NAME
SEQ      RR   DATE    TIME  R   WORDS      NJ NI*NJ  Y  N1   N2   N3    N4
  1      17 811201  180759  0   97888       1  19992  8 LIB  TOP     1    1
  2    3513 811201  180926  0   97888       1  19992  8 LIB  MID     1    1
  3    7009 811201  181041  0  106204       1  19992  8 LIB  BOT     1    1
```

```
TABLE OF CONTENTS, LIBRARY  4
                          E                      T   DATA SET NAME
SEQ     RR   DATE   TIME  R   WORDS    NJ NI*NJ  Y N1    N2      N3    N4
  1     17 811201 181108  0    1786    47  1786 -1 RK    TOP      6     2
  2     81 811201 181119  0    1786    47  1786 -1 RK    TOP      6     3
  3    145 811201 181129  0    1786    47  1786 -1 RK    TOP      6     4
  4    209 811201 181137  0    1786    47  1786 -1 RK    TOP      6     5
  5    273 811201 181153  0    1786    47  1786 -1 RK    MID      6     2
  6    337 811201 181200  0    1786    47  1786 -1 RK    MID      6     3
  7    401 811201 181208  0    1786    47  1786 -1 RK    MID      6     4
  8    465 811201 181215  0    1786    47  1786 -1 RK    MID      6     5
  9    529 811201 181225  0    1786    47  1786 -1 RK    BOT      6     2
 10    593 811201 181233  0    1786    47  1786 -1 RK    BOT      6     3
 11    657 811201 181240  0    1786    47  1786 -1 RK    BOT      6     4
 12    721 811201 181247  0    1786    47  1786 -1 RK    BOT      6     5
 13    785 811201 181253  0       1     1     1 -1 END   END    999   999


TABLE OF CONTENTS, LIBRARY  5
                          E                      T   DATA SET NAME
SEQ     RR   DATE   TIME  R   WORDS    NJ NI*NJ  Y N1    N2      N3    N4
  1     17 811201 181108  0    1786    47  1786 -1 RM    TOP      6     2
  2     81 811201 181119  0    1786    47  1786 -1 RM    TOP      6     3
  3    145 811201 181129  0    1786    47  1786 -1 RM    TOP      6     4
  4    209 811201 181137  0    1786    47  1786 -1 RM    TOP      6     5
  5    273 811201 181153  0    1786    47  1786 -1 RM    MID      6     2
  6    337 811201 181200  0    1786    47  1786 -1 RM    MID      6     3
  7    401 811201 181208  0    1786    47  1786 -1 RM    MID      6     4
  8    465 811201 181215  0    1786    47  1786 -1 RM    MID      6     5
  9    529 811201 181225  0    1786    47  1786 -1 RM    BOT      6     2
 10    593 811201 181233  0    1786    47  1786 -1 RM    BOT      6     3
 11    657 811201 181240  0    1786    47  1786 -1 RM    BOT      6     4
 12    721 811201 181247  0    1786    47  1786 -1 RM    BOT      6     5
 13    785 811201 181253  0       1     1     1 -1 END   END    999   999


TABLE OF CONTENTS, LIBRARY  6
                          E                      T   DATA SET NAME
SEQ     RR   DATE   TIME  R   WORDS    NJ NI*NJ  Y N1    N2      N3    N4
  1     17 811201 181102  0       8     1     8  0 SSBT  TOP      2     0
  2     18 811201 181114  0       8     1     8  0 SSBT  TOP      3     0
  3     19 811201 181126  0       8     1     8  0 SSBT  TOP      4     0
  4     20 811201 181133  0       8     1     8  0 SSBT  TOP      5     0
  5     21 811201 181147  0       8     1     8  0 SSBT  MID      2     0
  6     22 811201 181157  0       8     1     8  0 SSBT  MID      3     0
  7     23 811201 181204  0       8     1     8  0 SSBT  MID      4     0
  8     24 811201 181212  0       8     1     8  0 SSBT  MID      5     0
  9     25 811201 181222  0       8     1     8  0 SSBT  BOT      2     0
 10     26 811201 181230  0       8     1     8  0 SSBT  BOT      3     0
 11     27 811201 181237  0       8     1     8  0 SSBT  BOT      4     0
 12     28 811201 181244  0       8     1     8  0 SSBT  BOT      5     0
```

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TABLE OF CONTENTS, LIBRARY  7
                            E                        T   DATA SET NAME
SEQ        RR   DATE   TIME R   WORDS     NJ NI*NJ  Y   N1   N2   N3   N4
  1        17 811201 181315 0       3      1     3 -1 VIBR EVAL    1    1
  2        18 811201 181353 0    1296     72   432 -1 USB  TOP     1    2
  3        66 811201 181353 0    1296     72   432 -1 USB  TOP     1    3
  4       114 811201 181353 0    1296     72   432 -1 USB  TOP     1    4
  5       162 811201 181353 0    1296     72   432 -1 USB  TOP     1    5
  6       210 811201 181415 0    1296     72   432 -1 USB  MID     1    2
  7       258 811201 181415 0    1296     72   432 -1 USB  MID     1    3
  8       306 811201 181415 0    1296     72   432 -1 USB  MID     1    4
  9       354 811201 181415 0    1296     72   432 -1 USB  MID     1    5
 10       402 811201 181433 0    1296     72   432 -1 USB  BOT     1    2
 11       450 811201 181433 0    1296     72   432 -1 USB  BOT     1    3
 12       498 811201 181433 0    1296     72   432 -1 USB  BOT     1    4
 13       546 811201 181433 0    1296     72   432 -1 USB  BOT     1    5
 14       594 811201 181452 0       3      1     3 -1 VIBR HZ      1    1
```

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TABLE OF CONTENTS, LIBRARY 10
                            E                        T   DATA SET NAME
SEQ        RR   DATE   TIME R   WORDS     NJ NI*NJ  Y   N1   N2   N3   N4
  1        17 811201 180638 0      14     32   448  6 SJC  TOP     2    0
  2        33 811201 180638 0      14     32   448  6 SJC  TOP     3    0
  3        49 811201 180638 0      14     32   448  6 SJC  TOP     4    0
  4        65 811201 180638 0      14     32   448  6 SJC  TOP     5    0
  5        81 811201 180638 0      14     32   448  6 SJC  MID     2    0
  6        97 811201 180638 0      14     32   448  6 SJC  MID     3    0
  7       113 811201 180638 0      14     32   448  6 SJC  MID     4    0
  8       129 811201 180638 0      14     32   448  6 SJC  MID     5    0
  9       145 811201 180638 0      14     32   448  6 SJC  BOT     2    0
 10       161 811201 180638 0      14     32   448  6 SJC  BOT     3    0
 11       177 811201 180638 0      14     32   448  6 SJC  BOT     4    0
 12       193 811201 180638 0      14     32   448  6 SJC  BOT     5    0
```

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TABLE OF CONTENTS, LIBRARY 29
                            E                        T   DATA SET NAME
SEQ        RR   DATE   TIME R   WORDS     NJ NI*NJ  Y   N1   N2   N3   N4
  1        17 811201 180633 0     868     32   448  6 GENE CONE    0    0
  2        49 811201 180633 0    1008     32   448  6 ME   DOC     2    0
  3        97 811201 180637 0      42     32   448  6 TOP  DATA    1    0
  4       113 811201 180637 0      42     32   448  6 MID  DATA    1    0
  5       129 811201 180637 0      42     32   448  6 BOT  DATA    1    0
  6       145 811201 180637 0     154     32   448  6 SYS  DATA    0    0
  7       161 811201 181451 0     336      3   336  0 REGI HOUS    1    1
```

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