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AUTOMATED INPUT DATA PREPARATION FOR NASTRAN

W. L. COOK

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AUTOMATED INPUT DATA PREPARATION FOR NASTRAN

Test and Evaluation Division
Systems Reliability Directorate

April 1969

GODDARD SPACE FLIGHT CENTER
Greenbelt, Maryland

AUTOMATED
INPUT DATA PREPARATION
FOR NASTRAN

Prepared by: William L Cook

William L. Cook
Structural Analysis Computer Group

Reviewed by: Thomas G. Butler

Thomas G. Butler
Head, Structural Analysis Computer Group

Approved by: John H Boeckel

John H. Boeckel
Deputy Chief, Test and Evaluation Division

PROJECT STATUS

This report describes five computer programs which aid the structural analyst in preparing input data for the NASTRAN program. The development of additional programs of this type will be documented as completed.

AUTHORIZATION

Test and Evaluation Division Charge Number 321-124-08-05-13

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FOR NASTRAN

William L. Cook

SUMMARY

A set of five computer programs are available to aid the structural engineer in preparing input data for the NASTRAN structural analysis program. The purpose of each program may be summarized briefly as follows:

AXIS – to generate data for shells described by the rotation of a plane curve about an axis.

SHELBY – to generate data for shells described by the translation of a plane curve along an arbitrary axis in space. The scale factor may vary along the length of the axis.

COONS – to generate data for free-form shell structures based on the description of four bounding curves.

BANDAID – to automatically resequence the grid points of a structural problem to achieve a reduced bandwidth in the stiffness matrix, given the NASTRAN data deck for the problem.

MOVE – to generate data for structures having a number of identical segments, given the NASTRAN bulk data for one of the segments.

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Goddard Space Flight Center

INTRODUCTION

In the analysis of complex three dimensional structures by means of structural analysis programs based on finite element techniques, it is necessary for the analyst to assemble the geometric, elastic and mass properties of his structural model in a more-or-less rigid format on punched cards which may be input to the program. For many practical applications the preparation of this input data may require a considerable expenditure of time and effort.

For those classes of structures possessing some form of symmetry, or for which at least some features may be described by analytical means, the burden of this data preparation may be taken over by the computer.

The programs described in this report have been written specifically to aid the analyst in using the NASTRAN Structural Analysis Program (reference 1).

AXIS, SHELBY and COONS were coded in FORTRAN IV for operation on the IBM/7094 and IBM/360 computers. BANDAID and MOVE were coded in PL1 for operation on the IBM/360 computer.

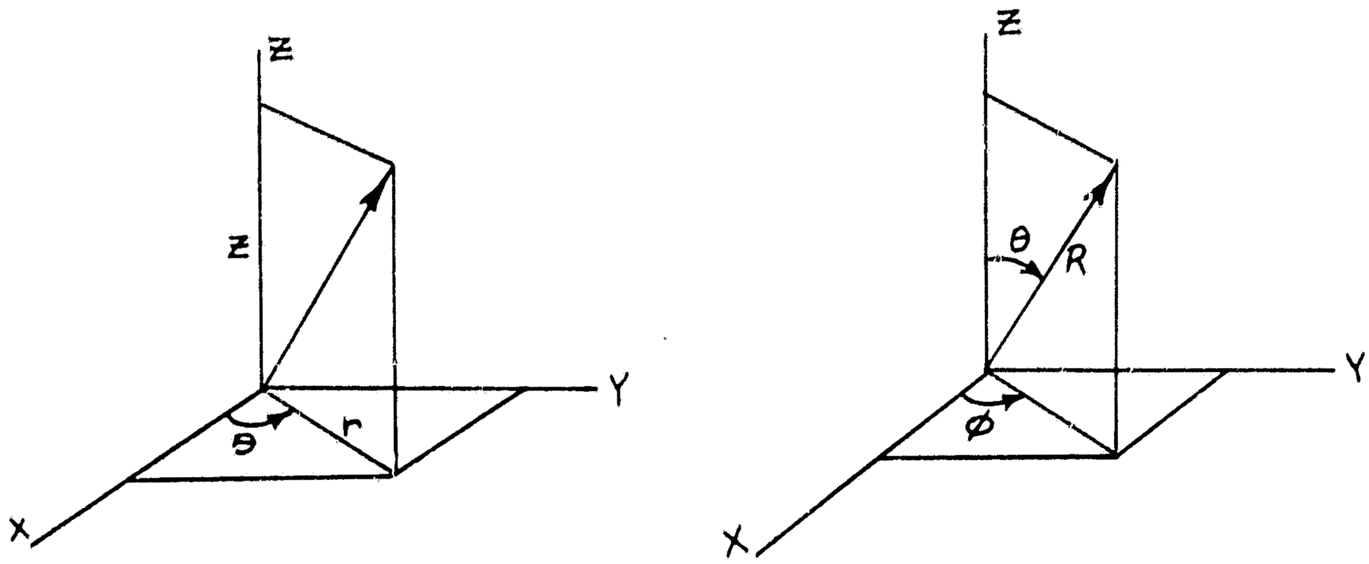
Listings and card decks may be obtained through the GSFC Computer Program Library by contacting Mrs. Pat Barnes, Code 543, and by referring to the following program numbers:

AXIS	- B00028
SHELBY	- B00043
COONS	- B00044
BANDAID	- B00045
MOVE	- B00046

This report describes the capabilities of each program and the format for data input. Sample problems are included to demonstrate the applicability of these programs to aerospace structures.

AXIS PROGRAM DESCRIPTION

The AXIS program will generate NASTRAN input data for shells described by the rotation of a plane curve about an axis. The axis of rotation will be restricted (without loss of generality) to be the z-axis of a local coordinate system. The spherical and cylindrical coordinate systems used in the NASTRAN program are shown in Figure 1.



(a) Cylindrical Coordinate System

(b) Spherical Coordinate System

Figure 1–Cylindrical and Spherical Coordinate Systems in NASTRAN.

The shape of the plane curve is described by listing the coordinates of "n" grid points (in either cylindrical (r, z) or spherical (R, θ) coordinate systems) lying in the meridional plane, as indicated in Figure 2.

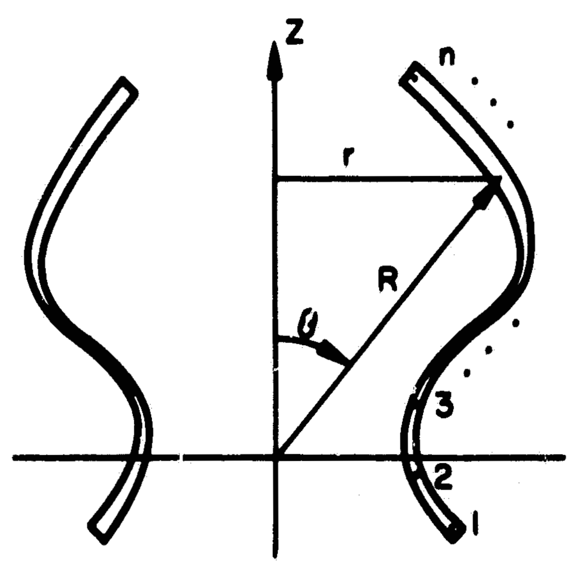


Figure 2–Coordinate System for AXIS

The grid points must be ordered in increasing value of z, and no point may lie on the z-axis except grid point "n" (i.e., the shell may be closed only at the top).

Notice that a flat circular plate will be developed in the special case where z = constant and $0 < R <$ constant.

The thickness of the shell must be indicated at each of the "n" grid points. The thickness of the elements between any two adjacent rows of grid points is calculated as the average of the two thicknesses.

A pressure loading of the shell may be generated for linearly varying pressures (as in uniform or hyrostatic pressures) which are of the form

$$P = P_0 + P_1 x + P_2 y + P_3 z, \tag{1}$$

where the x, y, and z coordinates are those defined in Figure 1, and where P_0, P_1, P_2 and P_3 are constants (positive, negative, or zero) specified by the analyst. A positive pressure on the shell is in the outward (positive r) direction.

The meridional grid point spacing in the resulting model will be the same as that used to define the plane curve. Circumferential grid points will be located at equal angular increments about the z-axis, and the number of such points is specified by the analyst. Quadrilateral plate elements are connected to the grid points thus generated to form the shell surface. When the shell is closed at the top (i.e. grid point "n" lies on the z-axis) the top row of quadrilaterals is replaced by triangular plate elements.

The pressure at each grid point is calculated from equation (1), and the pressure loading applied to each element is found by averaging the pressures at the four grid points defining the element.

Finally, whenever the number of circumferential grid points exceeds the number of meridional grid points, the grid points are automatically resequenced in order to reduce the bandwidth in the stiffness matrix.

The following NASTRAN data cards are generated by AXIS:

1. (TITLE =) card for the case control deck
2. (LOAD =) card for the case control deck
3. (BULK DATA) card
4. (CORDij) coordinate system definition card

5. (GRID) cards for all grid points
6. (CQUAD2) and (PQUAD2) cards
7. (CTRIA2) and (PTRIA2) cards for the top of a closed shell
8. (MAT1) material definition card
9. (SEQGP) cards to reorder grid points when necessary to reduce bandwidth
10. (PLOAD) cards defining the pressure loading
11. (ENDDATA) card

AXIS INPUT DATA

1. Title Card

The problem title may appear anywhere in columns 1-80 of this card.

2. Problem Parameter Card

Column

1-5	= 0 for cylindrical coordinate system = 1 for spherical coordinate system
6-10	= coordinate system identification number (may not be equal to zero)
11-15	= 1 for complete shell = 2 for half symmetry = n for nth symmetry
16-20	= number of meridional grid points desired for structural model (≤ 1000)
21-25	= number of circumferential grid points desired for the structural model
26-30	= number to be added to all grid points
31-35	= 0 for output in basic coordinate system = 1 for output in local coordinate system
36-40	= number to be added to all elements
41-45	= pressure load identification number (if no pressure load, leave blank)

All values on this card are integers and must be right-adjusted.

3. Material Property and Pressure Load Card (All values must be specified in consistent units.)

Column

1-10	= Young's modulus	
11-20	= Poisson's ratio	
21-30	= mass density	
31-40	= coefficient of thermal expansion	
41-50	= P_0	
51-60	= P_1	Where $P = P_0 + P_1 x + P_2 y + P_3 z$
61-70	= P_2	
71-80	= P_3	

4. Grid Point Coordinate Cards for Describing the Plane Curve (One card for each meridional grid point.)

Column	Cylindrical	Spherical
1-10 =	r	R
11-20 =	z	θ
21-30 =	thickness	thickness

Repeat cards 1-4 for additional cases.

SOUNDING ROCKET STAGE

The AXIS program has been used to generate the NASTRAN data for the first stage of a sounding rocket. The input to the AXIS program is listed below, and a computer plot of the generated structure is shown in Figure 3.

Input Listing:

```
SOUNDING ROCKET STAGE
       0       2       1      10      16       0       0       0
       1.0E07     0.3            0.1
  20.0        -210.0          0.05
  10.0        -190.0          0.05
  20.0        -180.0          0.05
  20.0        -140.0          0.05
  20.0        -100.0          0.05
  20.0        - 60.0          0.05
  20.0        - 50.0          0.05
  10.0        - 40.0          0.05
   5.0        - 20.0          0.05
   0.0        - 20.0          0.05
```

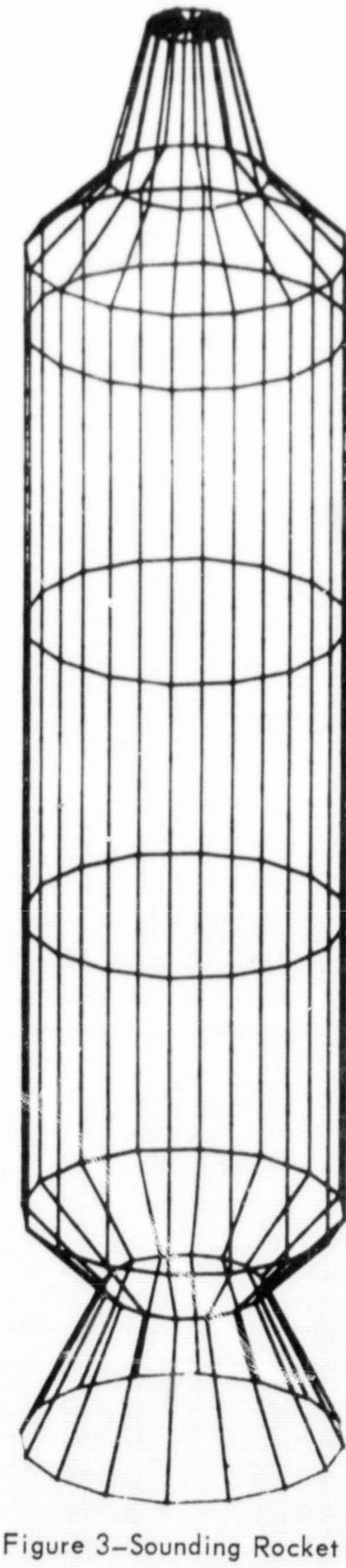


Figure 3–Sounding Rocket Stage

SHELBY PROGRAM DESCRIPTION

The SHELBY program will generate NASTRAN input data for shells described by the translation of a plane curve along an arbitrary axis in space. In addition, the linear scale factor of the curve may vary as a function of distance in that direction, thus allowing for the creation of conical shells as well as more exotic species.

The plane curve is specified in the x-y plane of a local Cartesian or basic coordinate system by listing the coordinates of "n" grid points (in either Cartesian (x, y) or polar (r, θ) coordinates) lying on this curve, (see Figure 4). The points may be listed in either clockwise or counterclockwise direction for the case of a closed curve (i.e., if an element exists between grid points 1 and "n".) The thickness of the shell is specified by the user at each of the "n" points.

The curve specified in the x-y plane is translated in a direction defined by the vector $\vec{s}$, which makes an angle α with the z-axis, and whose projection in the x-y plane makes an angle β with the x-axis.

The length of the shell along the z-axis and the number of grid points in that direction are specified by the user.

In addition a scale factor may be defined which will be multiplied by the x and y coordinates at each station along the z-axis. This scale factor is of the form

$$S.F. = 1.0 + A_1 z + A_2 z^2 + A_3 z^3 + A_4 z^4. \tag{1}$$

A pressure loading of the shell may be generated for linearly varying pressures which are of the form

$$P = P_0 + P_1 x + P_2 y + P_3 z. \tag{2}$$

A positive pressure on the shell is in the outward direction for a counterclockwise ordering of the grid points.

In equations (1) and (2) the x, y and z coordinates are those defined in Figure 4, and the constants A_i and P_i, which are specified by the analyst, may be either positive, negative or zero.

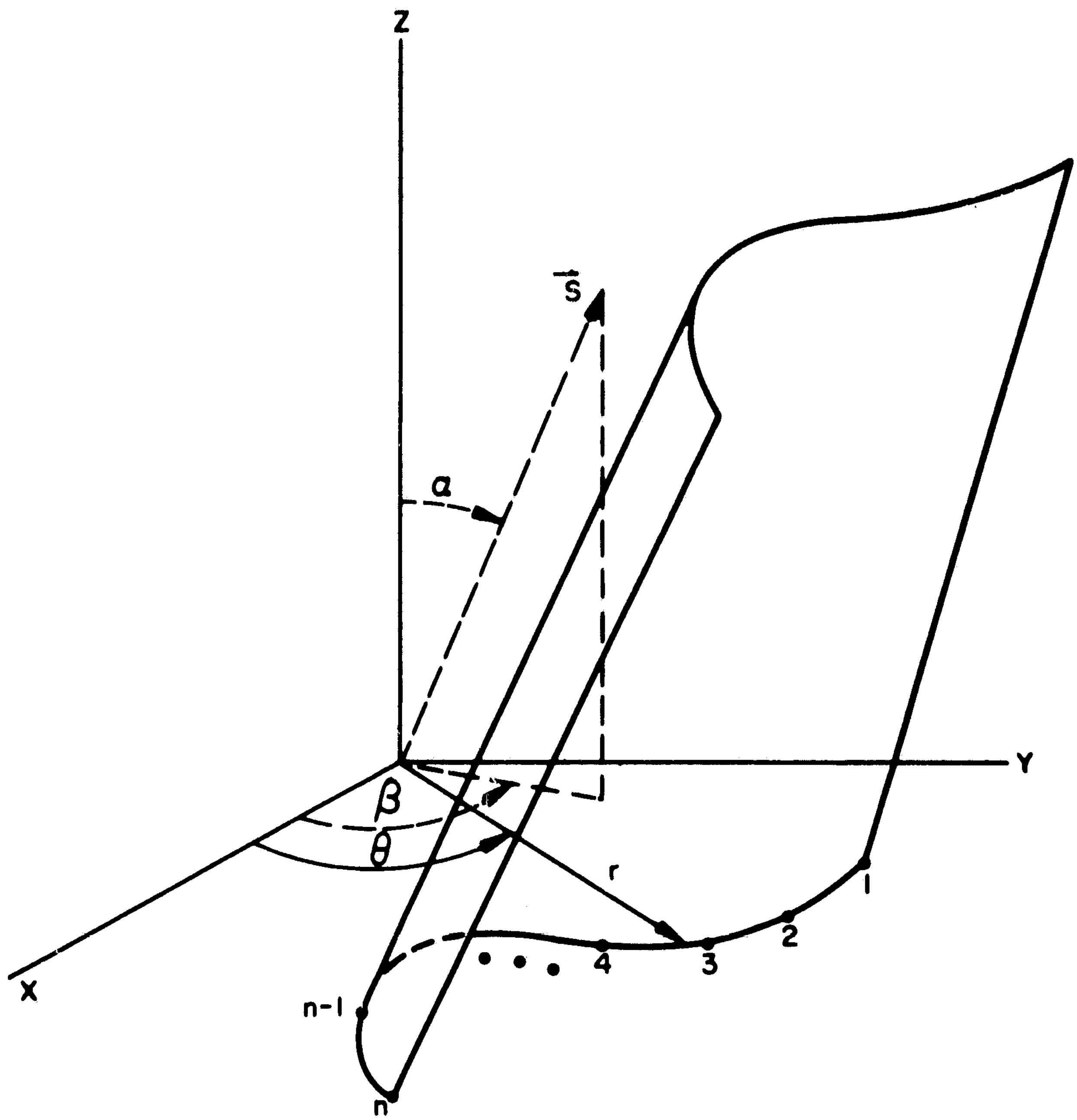


Figure 4–Coordinate System for SHELBY

In the resulting model the grid point spacing in the direction parallel to the x-y plane will be the same as that used to define the plane curve. Grid points in the direction of the z-axis will be located at equal intervals, and the number of such points is specified by the analyst. The x and y coordinates of each point are found by multiplying the coordinates of the corresponding point on the plane curve by the scale factor defined by equation (1). Quadrilateral plate elements are connected to the grid points thus generated to form the shell surface.

The pressure at each grid point is calculated from equation (2), and the pressure loading applied to each element is found by averaging the pressures at the four grid points defining the element.

Finally, whenever the number of grid points in the z direction exceeds the number of grid points parallel to the x-y plane, the grid points are automatically resequenced in order to reduce the bandwidth in the stiffness matrix. The following NASTRAN data cards are generated by SHELBY:

1. (TITLE =) for the case control deck
2. (LOAD =) for the case control deck
3. (BULK DATA) cards
4. (CORD2R) card if the coordinate system is other than the basic system
5. (GRID) cards for all grid points
6. (CQUAD2) and (PQUAD2) cards for all elements
7. (MAT1) material definition card
8. (SEQGP) cards to reorder grid points when necessary to reduce bandwidth
9. (PLOAD) cards defining the pressure loading
10. (ENDDATA) card

SHELBY INPUT DATA

1. Title Card

The problem title may appear anywhere in columns 1-80 of this card.

2. Problem Parameter Card

Column

1-5	= 0 if plane curve defined by Cartesian coordinates
	= 1 if plane curve defined by polar coordinates
6-10	= coordinate system identification number (= 0 for basic system)
11-15	= 0 for open curve in x-y plane
	= 1 for closed curve in x-y plane
16-20	= number of grid points in x-y plane desired for structural model (≤ 1000)
21-25	= number of grid points in z direction desired for the structural model
26-30	= number to be added to all grid points
31-35	= 0 for output in basic coordinate system
	= 1 for output in local coordinate system
36-40	= number to be added to all elements
41-45	= pressure load identification number
51-60	= length of shell in z direction ($\neq 0.0$)

All values through column 45 are integers and must be right adjusted.

3. Material Property and Pressure Load Card (All values must be specified in consistent units.)

Column

1-10 = Young's modulus
11-20 = Poisson's ratio
21-30 = mass density
31-40 = coefficient of thermal expansion

$$\left.\begin{array}{ll} 41\text{-}50 & = P_0 \\ 51\text{-}60 & = P_1 \\ 61\text{-}70 & = P_2 \\ 71\text{-}80 & = P_3 \end{array}\right\} \text{Where } P = P_0 + P_1 x + P_2 y + P_3 z$$

4. Longitudinal Axis and Scale Factor Card

Column

$$\left.\begin{array}{ll} 1\text{-}10 & = \alpha \text{ (degrees)} \\ 11\text{-}20 & = \beta \text{ (degrees)} \end{array}\right\} \text{Where } \alpha \text{ and } \beta \text{ define } \vec{s}$$

$$\left.\begin{array}{ll} 21\text{-}30 & = A_1 \\ 31\text{-}40 & = A_2 \\ 41\text{-}50 & = A_3 \\ 51\text{-}60 & = A_4 \end{array}\right\} \text{Where, scale factor} = \sum_{n=1}^{4} A_n z^n$$

5. Grid Point Coordinate Cards for Describing the Plane Curve (One card for each grid point)

Column	Cartesian	Polar
1-10 =	x	r
11-20 =	y	θ
21-30 =	thickness	thickness

Repeat cards 1-5 for additional cases.

AIRPLANE WING SEGMENT

The SHELBY program has been used to generate the NASTRAN data for an airplane wing segment. The input to the SHELBY program is listed below, and a computer plot of the generated structure is shown in Figure 5.

Input Listing:

```
AIRPLANE WING SEGMENT
    0     0     1   26    10     0     0     0    10       100.0
    1.0E07      0.3       1.0
 20.0        0.0          -0.005
 80.0        0.0           0.01
 70.0        3.5           0.01
 60.0        6.0           0.01
 50.0        9.0           0.01
 40.0       11.0           0.01
 30.0       12.5           0.01
 20.0       14.0           0.01
 10.0       14.5           0.01
  0.0       14.0           0.01
-10.0       13.0           0.01
-20.0       11.0           0.01
-30.0        7.5           0.01
-35.0        4.5           0.01
-40.0        0.0           0.01
-35.0       -3.0           0.01
-30.0       -4.0           0.01
-20.0       -4.5           0.01
-10.0       -4.0           0.01
  0.0       -3.0           0.01
 10.0       -2.8           0.01
 20.0       -2.5           0.01
 30.0       -2.0           0.01
 40.0       -1.8           0.01
 50.0       -1.5           0.01
 60.0       -1.0           0.01
 70.0       -0.5           0.01
```

COONS PROGRAM DESCRIPTION

Given a description of four bounding curves of a free-form shell structure, the COONS program will create a smooth surface passing through those curves and generate the NASTRAN input data describing the surface.

The algorithm is based on a method presented in reference 2 for the computer-aided design of space figures. Any adjacent surfaces thus generated have the property that the first and second order derivatives are continuous across the boundary, provided the derivatives of contiguous bounding curves are likewise continuous.

Figure 6 shows a surface defined in terms of parameters U and W which take on their extremal values of zero and one along the bounding curves labled 0W, 1W, U0 and U1.

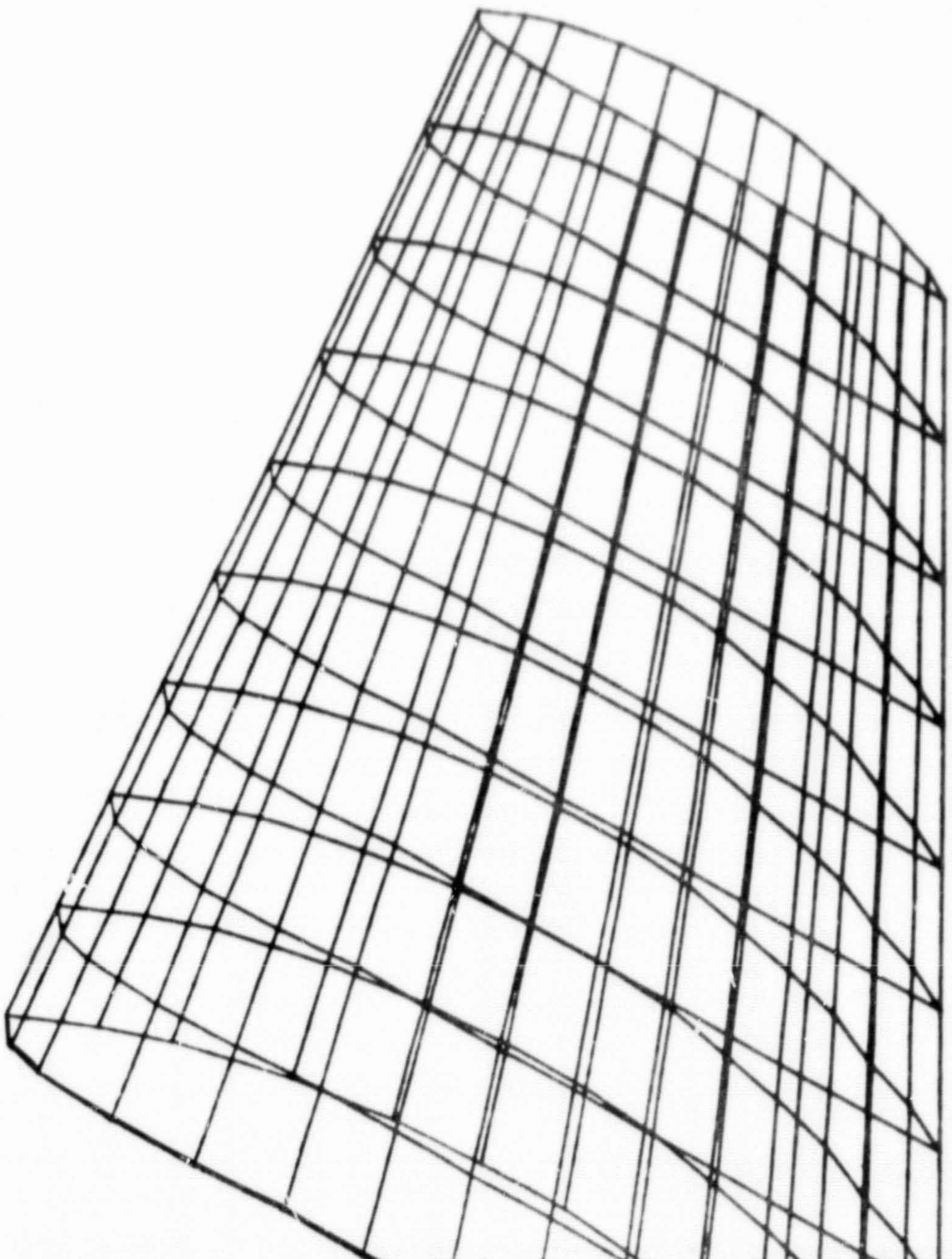


Figure 5–Airplane Wing Segment

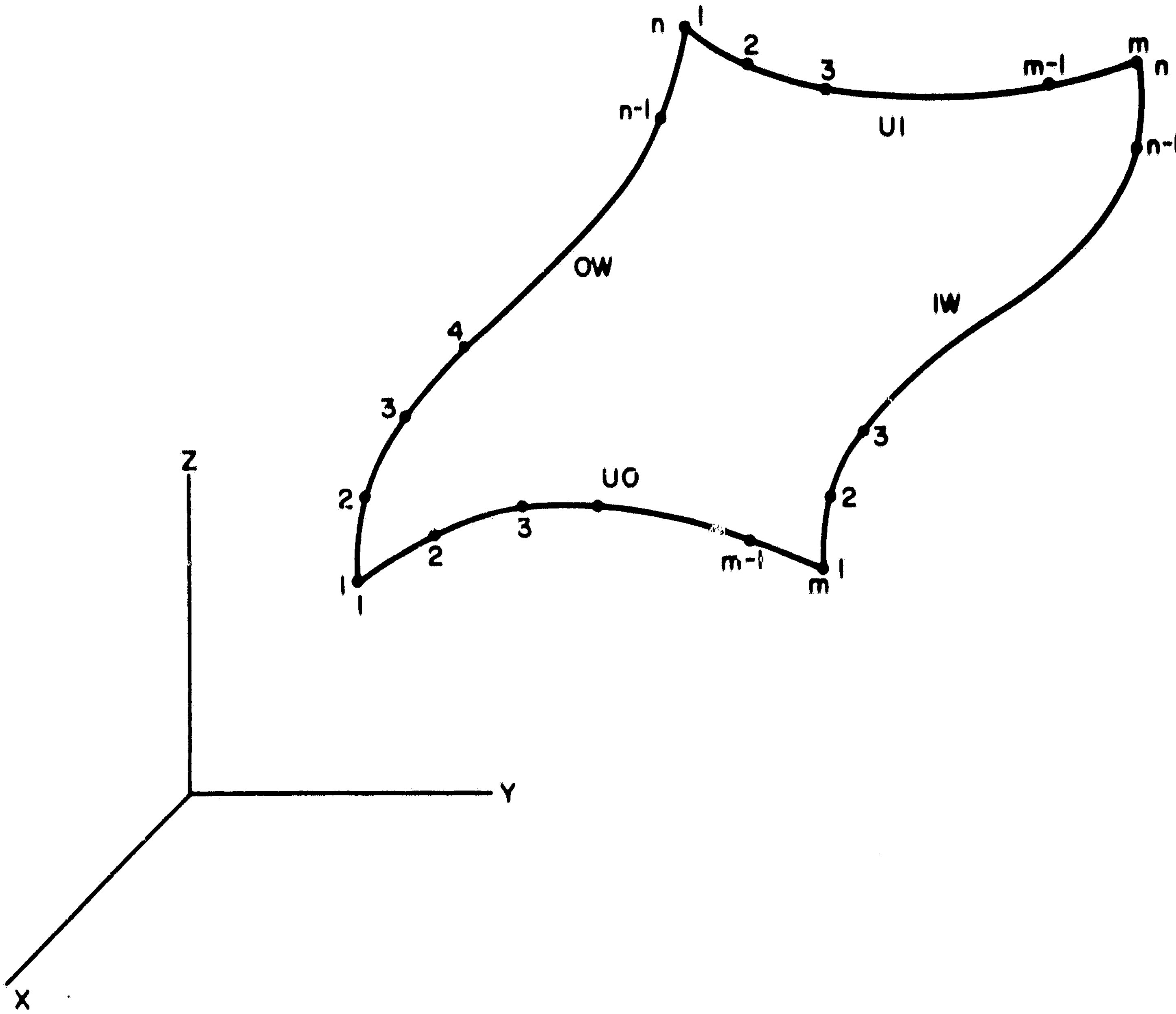


Figure 6–Bounding Curves of Surface

The coordinates (X_1, X_2, X_3) of any point on the surface bounded by these curves may be found from the equation

$$
\begin{aligned}
X_i\,(U,W) = {} & X_i\,(0,W)\,F_0\,(U) + X_i\,(1,W)\,F_1\,(U) \\
& + X_i\,(U,0)\,F_0\,(W) + X_i\,(U,1)\,F_1\,(W) \\
& - X_i\,(0,0)\,F_0\,(U)\,F_0\,(W) - X_i\,(0,1)\,F_0\,(U)\,F_1\,(W) \\
& - X_i\,(1,0)\,F_1\,(U)\,F_0\,(W) - X_i\,(1,1)\,F_1\,(U)\,F_1\,(W), \\
& \qquad\qquad i = 1,\ 2,\ 3;
\end{aligned}
\tag{1}
$$

where F_0 and F_1 are called "blending functions" and are defined as

$$
\begin{aligned}
F_1(\xi) &= 10\xi^3 - 15\xi^4 + 6\xi^5 \\
F_0(\xi) &= 1 - F_1(\xi)
\end{aligned}
\tag{2}
$$

In using the COONS program, the analyst describes each bounding curve by listing the coordinates of a set of "defining points" along its length in a local or basic Cartesian coordinate system.

A pressure loading on the shell may be generated for linearly varying pressures which are of the form

$$
P = P_0 + P_1 x + P_2 y + P_3 z, \tag{3}
$$

where P_0, P_1, P_2 and P_3 are constants (positive, negative or zero) specified by the analyst.

In the resulting model the defining points are used to calculate a polynomial approximation to each bounding curve of order N-1, where N is the number of defining points. Grid points are positioned at equal intervals along each bounding curve, while points on the interior of the surface are determined from equations (1) and (2). The desired number of grid points in each direction is specified by the analyst.

Quadrilateral plate elements are connected to the grid points thus generated to form the shell surface.

The pressure at each grid point is calculated from equation (3), and the pressure loading applied to each element is found by averaging the pressures at the four grid points defining the element.

Finally, whenever the number of grid points in the U direction exceeds the number in the W direction, the grid points are automatically resequenced in order to reduce the bandwidth in the stiffness matrix. The following NASTRAN data cards are generated by COONS:

1. (TITLE =) card for the case control deck
2. (LOAD =) card for the case control deck
3. (BULK DATA) card

4. (GRID) cards for all grid points
5. (CQUAD2) and (PQUAD2) cards
6. (MAT1) material definition card
7. (SEQGP) cards to reorder the grid points when necessary to reduce the bandwidth
8. (PLOAD) cards defining the pressure loading
9. (ENDDATA) card

COONS INPUT DATA

1. Title Card

The problem title may appear anywhere in columns 1-80 of this card.

2. Problem Parameter Card

Column

1-5	= coordinate system ID number
6-10	= number of defining points in U direction
11-15	= number of defining points in W direction
16-20	= number of model grid points in U direction
21-25	= number of model grid points in W direction
26-30	= number to be added to all grid points
31-35	= 0 for output in basic coordinate system
	= 1 for output in local coordinate system
36-40	= number to be added to all elements
41-45	= pressure load identification number
51-60	= thickness of the shell

All values through column 45 are integers and must be right adjusted.

3. Material Property and Pressure Load Card (All values must be specified in consistent units).

Column

1-10	= Young's Modulus
11-20	= Poisson's Ratio
21-30	= mass density
31-40	= coefficient of thermal expansion

Column

41-50 = P_0
51-60 = P_1
61-70 = P_2
71-80 = P_3

$$\left.\begin{array}{l} P_0 \\ P_1 \\ P_2 \\ P_3 \end{array}\right\} \text{Where } P = P_0 + P_1 x + P_2 y + P_3 z$$

4. Coordinates of Points Defining U0 and U1 Curves (one card for each pair of defining points)

Column

1-10 = x coordinate of point on U0 curve
11-20 = y coordinate of point on U0 curve
21-30 = z coordinate of point on U0 curve
31-40 = x coordinate of point on U1 curve
41-50 = y coordinate of point on U1 curve
51-60 = z coordinate of point on U1 curve

5. Coordinates of Points Defining 0W and 1W Curves (one card for each pair of defining points)

Column

1-10 = x coordinate of point on 0W curve
11-20 = y coordinate of point on 0W curve
21-30 = z coordinate of point on 0W curve
31-40 = x coordinate of point on 1W curve
41-50 = y coordinate of point on 1W curve
51-60 = z coordinate of point on 1W curve

Repeat cards 1-5 for additional cases.

AIRPLANE FUSELAGE SECTION

The COONS program has been used to generate the NASTRAN data for a section of an airplane fuselage. The structure is composed of three segments, the COONS input data for which is listed below. Each segment is labeled on the computer plot of the generated structure shown in Figure 7.

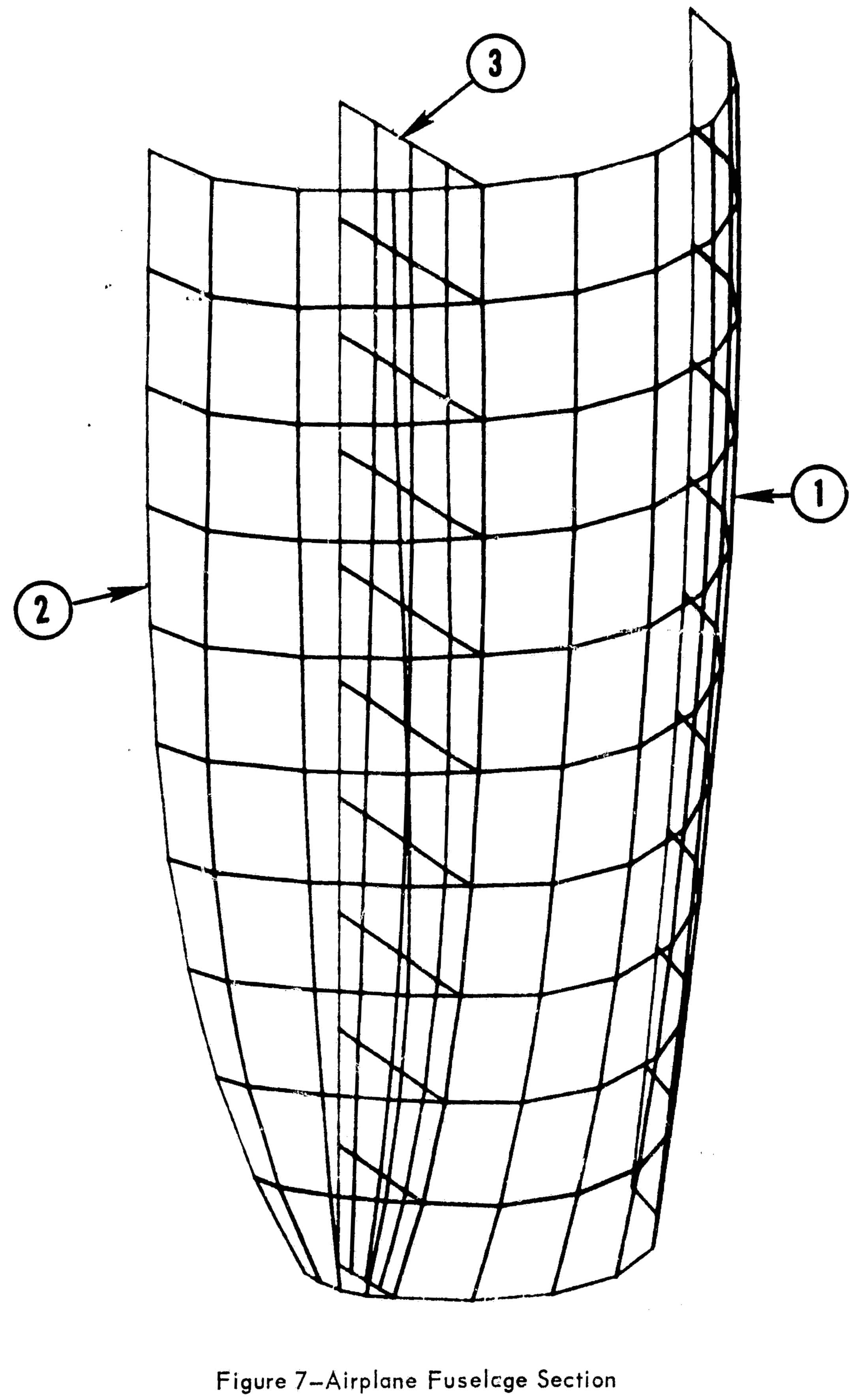


Figure 7–Airplane Fuselage Section

Input Listing:

```
FUSELAGE       *      SEGMENT 1
    0    5    4   7   11    0    0    0              0.01
    1.0E07   0.3     0.10
20.0       0.0       50.0      50.0      0.0       300.0
34.0       20.0      50.0      56.0      30.0      300.0
36.0       40.0      50.0      48.0      56.0      300.0
24.0       60.0      50.0      30.0      74.0      300.0
0.0        70.0      50.0      0.0       83.0      300.0
20.0       0.0       50.0      0.0       70.0       50.0
38.0       0.0       100.0     0.0       76.0      100.0
50.0       0.0       200.0     0.0       83.0      200.0
50.0       0.0       300.0     0.0       83.0      300.0
FUSELAGE       *      SEGMENT 2
    0    4    4   5   11 1000    0 1000              0.01
    1.0E07   0.3     0.10
0.0        -8.0      50.0      0.0       -45.0     300.0
8.0        -7.5      50.0      19.0      -42.0     300.0
15.0       -5.0      50.0      39.0      -22.0     300.0
20.0        0.0      50.0      50.0      0.0       300.0
0.0        -8.0      50.0      20.0      0.0       50.0
0.0        -30.0     100.0     38.0      0.0       100.0
0.0        -45.0     200.0     50.0      0.0       200.0
0.0        -45.0     300.0     50.0      0.0       300.0
FUSELAGE       *      SEGMENT 3
    0    2    4   5   11 2000    0 2000              0.01
    1.0E07   0.3     0.25
0.0        0.0       50.0      0.0       0.0       300.0
20.0       0.0       50.0      50.0      0.0       300.0
0.0        0.0       50.0      20.0      0.0        50.0
0.0        0.0       100.0     38.0      0.0       100.0
0.0        0.0       200.0     50.0      0.0       200.0
0.0        0.0       300.0     50.0      0.0       300.0
```

TELEPHONE RECEIVER

The COONS program has been used to generate the NASTRAN data for a portion of the case of a telephone receiver. This example was chosen to illustrate the complexity of the problems to which the program is applicable. The structure is composed of five segments, the COONS input data for which is listed below. Each segment is labeled on the computer plot of the generated structure shown in Figure 8. Notice that by defining the 0W curve in segment 4 as a single point, a three-sided segment is produced which contains a row of quadrilateral elements degenerated to triangles. Such elements should be replaced by triangular plate elements before submission to NASTRAN.

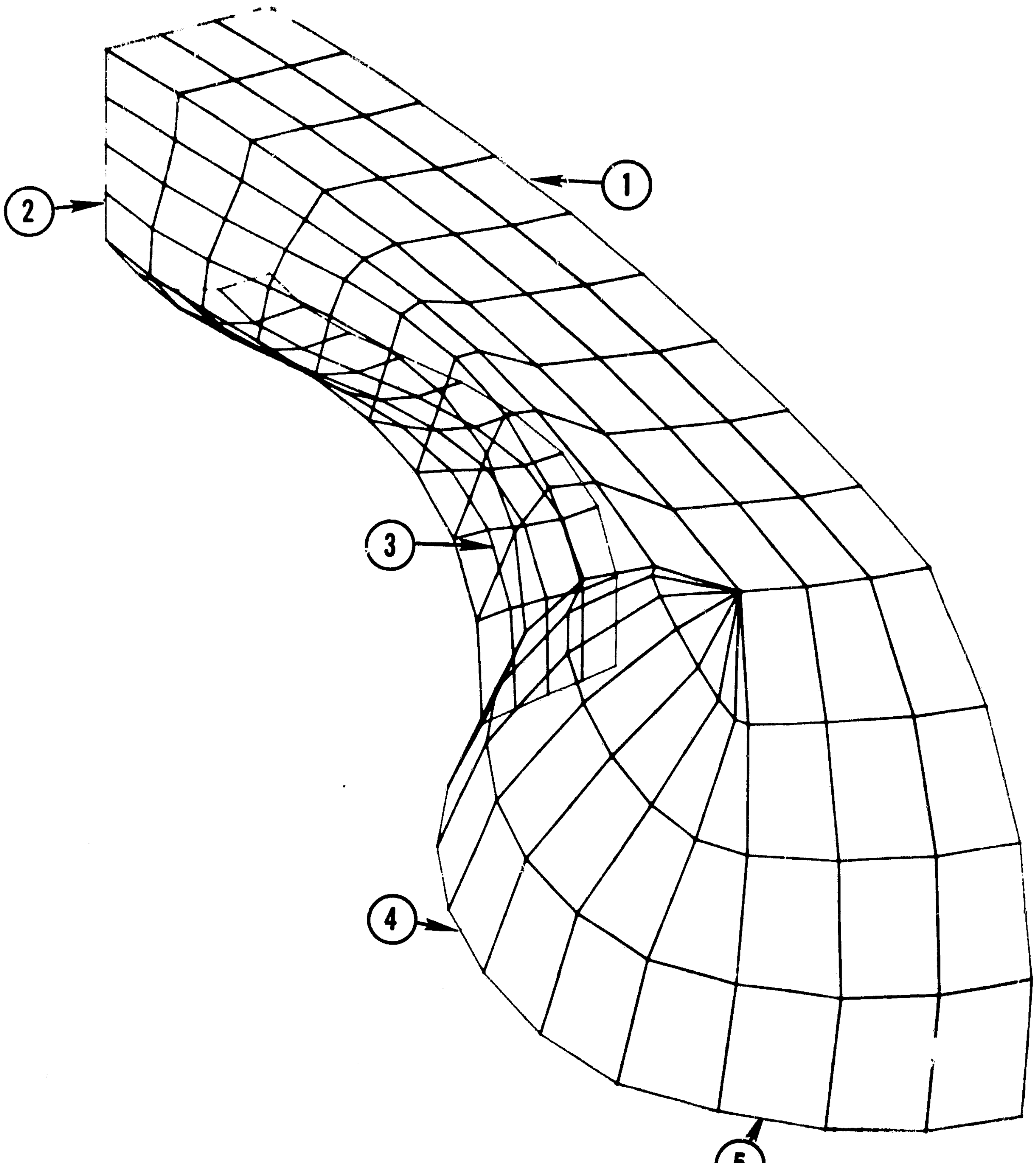


Figure 8–Telephone Receiver

Input Listing:

```
TELEPHONE RECEIVER      *      SEGMENT 1
    0    3    4    4    10     0     0     0               0.15
    2.0E05    0.35    0.08
 0.0        0.0        2.13      3.60      0.0       1.55
 0.0       -0.3        2.13      3.55     -0.3       1.55
 0.0       -0.6        2.13      3.45     -0.6       1.55
 0.0        0.0        2.13      0.0      -0.6       2.13
 1.0        0.0        2.10      1.0      -0.6       2.10
 2.4        0.0        1.90      2.4      -0.6       1.90
 3.60       0.0        1.55      3.45     -0.6       1.55
TELEPHONE RECEIVER      *      SEGMENT 2
    0    3    4    5    10 1000     0 1000               0.15
    2.0E05    0.35    0.08
 0.0       -0.6        2.13      3.45     -0.6       1.55
 0.0       -0.6        1.80      2.55     -0.6       1.25
 0.0       -0.6        1.50      2.05     -0.6       0.60
 0.0       -0.6        2.13      0.0      -0.6       1.50
 1.0       -0.6        2.10      1.0      -0.6       1.45
 2.4       -0.6        1.90      1.8      -0.6       1.25
 3.45      -0.6        1.55      2.05     -0.6       0.60
TELEPHONE RECEIVER      *      SEGMENT 3
    0    3    4    5    10 2000     0 2000               0.20
    2.0E05    0.35    0.08
 0.0       -0.6        1.50      2.05     -0.6       0.6
 0.0       -0.4        1.30      1.95     -0.2       0.6
 0.0        0.0        1.25      1.9       0.0       0.6
 0.0       -0.6        1.50      0.0       0.0       1.25
 1.0       -0.6        1.45      1.0       0.0       1.25
 1.8       -0.6        1.25      1.8       0.0       1.10
 2.05      -0.6        0.60      1.9       0.0       0.6
TELEPHONE RECEIVER      *      SEGMENT 4
    0    3    5    5     8 3000     0 3000               0.15
    2.0E05    0.35    0.08
 3.45      -0.6        1.55      3.45     -0.6       1.55
 2.55      -0.6        1.25      3.8      -0.8       1.0
 2.05      -0.6        0.60      3.8      -0.9       0.0
 3.45      -0.6        1.55      2.05     -0.6       0.60
 3.45      -0.6        1.55      2.4      -1.0       0.45
 3.45      -0.6        1.55      3.05     -1.25      0.25
 3.45      -0.6        1.55      3.5      -1.18      0.1
 3.45      -0.6        1.55      3.8      -0.9       0.0
TELEPHONE RECEIVER      *      SEGMENT 5
    0    3    3    4     5 4000     0 4000               0.15
    2.0E05    0.35    0.08
3.6         0.0        1.55      4.13      0.0      -0.1
3.55       -0.3        1.55      4.05     -0.5      -0.07
3.45       -0.6        1.55      3.8      -0.9       0.0
3.6         0.0        1.55      3.45     -0.6       1.55
4.10        0.0        0.8       3.8      -0.8       1.0
4.13        0.0       -0.1       3.8      -0.9       0.0
```

BANDAID PROGRAM DESCRIPTION

The BANDAID program will automatically resequence the grid points of a structural problem to achieve a reduced bandwidth in the stiffness matrix, given the NASTRAN data deck for the problem.

The method may be summarized briefly as follows:

From the grid point connection information provided in the input data, a square symmetric matrix A is formed such that A (i, j) = 1 for all grid points i and j which are connected by a structural element or where i = j. All other terms of the matrix are zero. Each term of the matrix is represented in core by a single bit.

It is assumed that the bandwidth of the A matrix (which is based on the grid point numbering) and of the NASTRAN stiffness matrix (which is based on the degree-of-freedom numbering) will both be a minimum for the same ordering of the grid points.

The algorithm for minimizing the bandwidth of A is as follows:

1. Calculate for each row (i) of the matrix the mean column position of the 1's, i.e.,

$$\mathrm{MEAN}_i = \frac{\sum_{j=1}^{n} A_{ij} \times j}{\sum_{j=1}^{n} A_{ij}}.$$

2. Resequence the grid points in order of increasing value of MEAN_i, and reorder the A matrix accordingly.

3. Repeat steps 1 and 2 until two consecutive orderings of the grid points are identical.

The only input required for the BANDAID program is the NASTRAN data deck for the structure whose grid points are to be resequenced. Although the entire deck may be input, the only portion required is that defining the grid points and element connections. The only other restriction is that the first data card will be interpreted as an identification card for the job and will not be processed.

There are no programming restrictions on the size of the NASTRAN problem submitted to BANDAID, or on the grid point numbering scheme used by the analyst.

In general, the maximum number of iterations performed will be equal to the number of grid points in the structure, although for problems with more than fifty grid points, the program will halt after twenty iterations in order to avoid using an excessive amount of computer time.

If the analyst desires to band only a portion of his structure by BANDAID, he need merely remove the grid point cards for the portion of the structure not to be considered; the program will then ignore any connection information pertaining to those grid points. This feature is useful whenever the analyst anticipates that certain grid points will correspond to active columns in the stiffness matrix, and he wishes to remove them from consideration when banding the remainder of the structure.

It should be emphasized that BANDAID will ignore all single- and multipoint constraint information and will recognize only the following element types:

CBAR	CQUAD1	CTRIA1
CELAS1	CQUAD2	CTRIA2
CELAS2	CQUAD3	CTRMEM
CONROD	CROD	CTRPLT
CQDMEM	CSHEAR	CTUBE
CQDPLT	CTRBSC	CTWIST

The following output is generated by BANDAID:

1. A listing of the resequenced grid points, showing both internal and external sequencing.

2. A corresponding set of SEQGP cards suitable for insertion in the NASTRAN program (if desired).

3. A record of the total number of iterations.

4. A diagram of both the original and the final form of the A matrix.

BANDAID INPUT DATA

1. Title Card

The problem title may appear anywhere in columns 1-80 of this card.

2. NASTRAN Data Deck

The deck must contain all grid point cards and element connection cards for that portion of the structure to be banded.

JAVELIN PAYLOAD RACK

The BANDAID program has been used to resequence the grid points of a model of a sounding rocket payload rack. Figure 9 shows the grid point numbering scheme used by the analyst in preparing the NASTRAN input data. The output generated by the BANDAID program is listed below (excluding the SEQGP cards used for resequencing the problem.) Notice that the semi-bandwidth of the A matrix has been reduced from 28 to 20. Assuming approximately five degrees of freedom per grid point, a reduction of 40 in the semibandwidth in the NASTRAN stiffness matrix may be expected.

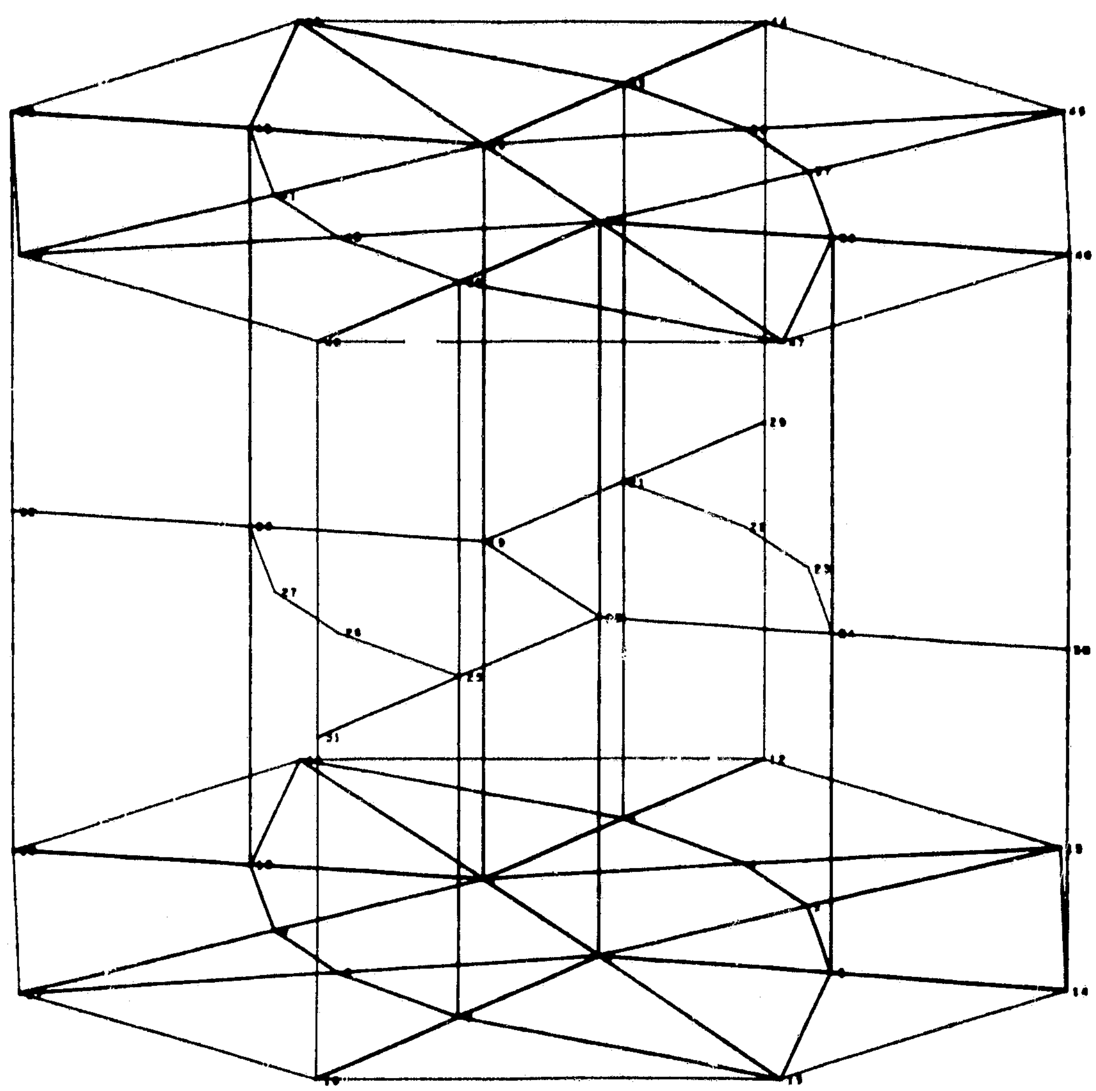


Figure 9–Javelin Payload Rack

Output Listings: EXTERNAL NUMBERING

OLD	NEW
13	1
4	2
5	3
12	4
11	5
3	6
9	7
14	8
8	9
1	10
17	11
15	12
6	13
2	14
18	15
10	16
16	17
7	18
22	19
29	20
21	21
23	22
30	23
24	24
19	25
20	26
28	27
32	28
25	29
31	30
26	31
27	32
35	33
44	34
38	35
46	36
33	37
45	38
34	39
36	40
37	41
42	42
43	43
39	44
50	45
47	46
48	47
41	48
40	49
49	50
129	129
130	130
131	131
132	132

JAVELIN PAYLOAD RACK

DIAGRAM OF ORIGINAL A MATRIX

```
*****00****0000000***000000*00000000000000000000000000
**0******00000*000**000**00000000000000000000000000000
*0**000000***00000*0*0000000*0000000000000000000000000
*****000000**00000000000000000000000000000000000000000
**0***000000**0000000000000000000000000000000000000000
0*00**000000***000*0000*00000*000000000000000000000000
0*0000**00000***00*0000*0000*0000000000000000000000000
**0000***000000**0000000000000000000000000000000000000
**00000***00000**0000000000000000000000000000000000000
*000000***000***0000000000*000*00000000000000000000000
*0*00000***00000*0000000000000000000000000000000000000
00**0000***00000000*00000000*0000000000000000000000000
00****0000***00000000000000000000000000000000000000000
0000**00000***00000000*00000*0000000000000000000000000
0*000**000000***00000000000000000000000000000000000000
00000**000000***000000*00000*0000000000000000000000000
00000****00000***0000000000000000000000000000000000000
00000000***0000**0000000000*000*0000000000000000000000
***000000*00000000***000000*0000***000000*000000000000
**000**00000000000**000**0000000**000**000000000000000
*0*00000000*000000*0*000000*000*0*0000000*000000000000
000000000000000000000*00000000000000000000000000000000
0000000000000000000000*0000000000000000000000000000000
0*000*0000000*00000*000*00000*000*000*0000000*00000000
0*0000*00000000*000*0000*00000*00*0000*00000000*000000
0000000000000000000000000*0000000000000000000000000000
00000000000000000000000000*000000000000000000000000000
*00000000*0000000**00000000*000**00000000*0000000*0000
00*00000000*00000000*0000000*00000*0000000*00000000000
00000*0000000*000000000*00000*0000000*0000000*00000000
000000*00000000*0000000*00000*0000000*0000000*00000000
000000000*0000000*00000000*000*000000000*0000000*00000
00000000000000000000***00000*0000*****00****0000000000
0000000000000000000**000**0000000**0*****0000*00000000
0000000000000000000*0*000000*000*0**00000***0000000000
00000000000000000000000000000000****000000**0000000000
00000000000000000000000000000000**0***000000**00000000
0000000000000000000*000*00000*000*00**000000***0000000
0000000000000000000*0000*00000*00*000**000000***000000
00000000000000000000000000000000**0000***000000**00000
00000000000000000000000000000000**00000***000000**0000
000000000000000000*00000000*000**0000000***00000**0000
00000000000000000000000000000000*0*000000***00000*0000
0000000000000000000*0000000*00000**000000***0000000000
0000000000000000000000000000000000****00000***00000000
00000000000000000000000*00000*000000**000000***0000000
000000000000000000000000000000000*000**000000***000000
000000000000000000000000*00000*000000**000000***000000
00000000000000000000000000000000000000****00000***0000
0000000000000000000000000000*000*0000000***00000**0000
00000000000000000000000000000000000000000000000000****
00000000000000000000000000000000000000000000000000****
00000000000000000000000000000000000000000000000000****
00000000000000000000000000000000000000000000000000****
```

JAVELIN PAYLOAD RACK

DIAGRAM OF FINAL A MATRIX

```
****0*0*0000*00000000000000000000000000000000000000000
****0*000*000*0000000000000000000000000000000000000000
***0000*0*00**0000000000000000000000000000000000000000
**0***0000000000000**000000000000000000000000000000000
000***000*0000**00000000000000000000000000000000000000
**0***000*000000000**000*00000000000000000000000000000
000000*0***00***00000000000000000000000000000000000000
*0*0000*000**000000000**000000000000000000000000000000
000000*0***00*00**000000000000000000000000000000000000
0**0***0**000*0*0000*000***000000000000000000000000000
000000*0*0*000****000000000000000000000000000000000000
0000000*000***00**000000000000000000000000000000000000
*0*0000*000***00000000**0*0000000000000000000000000000
0**000*0**0***000*00000***00*0000000000000000000000000
0000*0*000*000**0000000000**00000000000000000000000000
0000*0*00**000**00000000*0**00000000000000000000000000
00000000*0**0000**0000000000**000000000000000000000000
00000000*0**0*00**0000000*00**000000000000000000000000
000000000000000000*00000000000000000000000000000000000
000*0*0000000000000**00000000000**00000000000000000000
000*0*000*000000000**000*0000000**00*00000000000000000
000000000000000000000*00000000000000000000000000000000
0000000*0000*000000000**0000000000**000000000000000000
0000000*0000**00000000**0*00000000**00*000000000000000
00000*000*000*0*0000*000***00000*000*0*00*000000000000
000000000*00**000*00000***00*00000*0*0*0000*0000000000
000000000*0000**00000000*0**00000000*0000*00*000000000
00000000000000**0000000000**0000000000000*00*000000000
0000000000000*00**0000000*00**00000000*0000*00*0000000
0000000000000000**0000000000**0000000000000*00*0000000
000000000000000000000000000000*00000000000000000000000
0000000000000000000000000000000*0000000000000000000000
0000000000000000000**000*0000000**00**0*00*00000000000
0000000000000000000**00000000000**000*0*00*00000000000
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000000000000000000000000*0**00000000*0000**0*00*0*0000
00000000000000000000000000000000**00*0000**0*000000000
0000000000000000000000000*00**00000000*0000*0**0**0000
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0000000000000000000000000000000000**00*0000*0**0000000
0000000000000000000000000000**0000000000000*0**0**0000
000000000000000000000000000000000000*0*00*00*00***0000
000000000000000000000000000000000000*0*0000*00****0000
00000000000000000000000000000000000000000*0**0****0000
00000000000000000000000000000000000000000000000000****
00000000000000000000000000000000000000000000000000****
00000000000000000000000000000000000000000000000000****
00000000000000000000000000000000000000000000000000****
```

MOVE PROGRAM DESCRIPTION

For those structural models consisting of two or more identical segments (see Figures 10 and 11), a technique has been devised for generating the finite element model of the complete structure, given the grid points and elements of a single segment.

Input to the MOVE program consists of the NASTRAN data deck describing a segment of the structure, followed by a set of orientation cards, describing how the segment is translated and/or rotated to generate each succeeding segment.

GRID cards must be included in the NASTRAN data deck for all grid points associated with the segment, including those to be connected to adjacent segments. This latter group of grid points must be divided into two groups, A and B, based on the following criterion: when the segment is moved to its next orientation, each grid point in group A will coincide with the corresponding grid point in Group B. Figures 10 and 11 show the grid points included in each group for two representative structures. The specification of these corresponding groups of grid points is accomplished by means of IMAG cards which are inserted directly in the NASTRAN input data, and whose format is shown in Figure 12.

The NASTRAN input data must include element connection information for all elements except those connected solely between grid points in group B. In other words, those elements must be omitted which would be duplicated when the segment is rotated to each successive orientation. The included elements are represented by heavy lines in Figures 10 and 11. Care must be exercised that the magnitude of each rotation or translation is correct and that the numbers added to all grid point and element identifications are sufficiently large to guarantee a unique identification for each grid point and element.

The NASTRAN data generated by the MOVE program will include all the grid point and element descriptions for the entire structure. For problems where the segment is rotated about an axis, as in Figure 10, the final segment is attached to the original when the sum of the rotation angles equals 360.0°

If no IMAG cards are included in the NASTRAN data deck, the generated segments are not connected to each other in any manner.

The NASTRAN cards which are generated for the grid points will call for output in whatever coordinate system specified is on the original GRID cards.

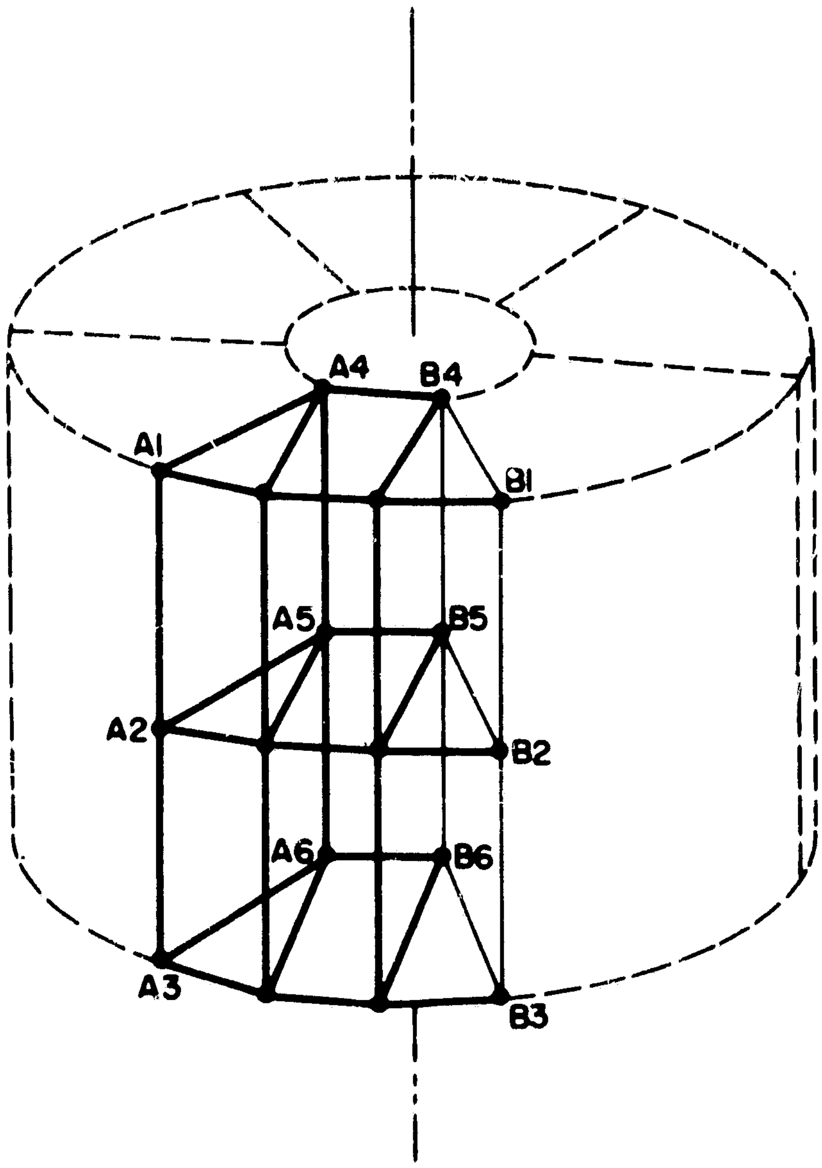

Figure 10–Model Generated by MOVE

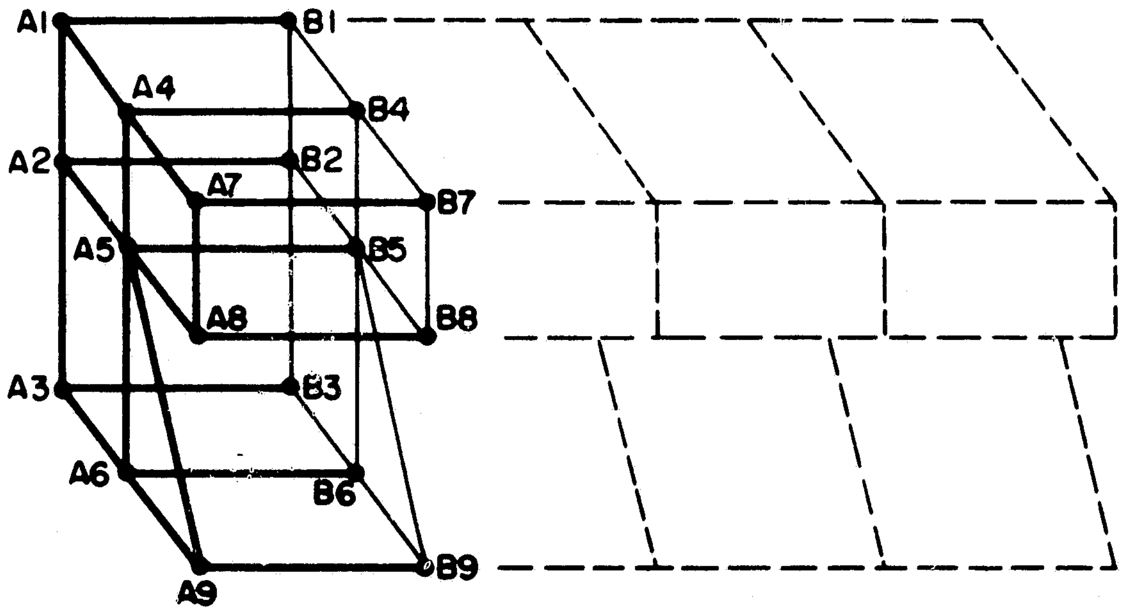

Figure 11–Model Generated by MOVE

Format and Example

1	2	3	4	5	6	7	8	9	10
IMAG	IA	IB	IA	IB	IA	IB	IA	IB	
IMAG	2	12			4	14	8	36	

Field	Contents
IMAG	The mnemonic IMAG beginning in column 1
IA	A grid point from group A (integer > 0)
IB	The corresponding grid point in group B. (integer > 0)

Comments:

1. Each field is 8 columns long
2. The integers in fields IA and IB may appear anywhere in the field.
3. Four sets of points may be included on a single card. As many cards may be used as are required.

Figure 12–Input Data Card IMAG

MOVE INPUT DATA

1. Title Card

The problem title may appear anywhere in columns 1-80 of this card.

2. NASTRAN-Data Deck (ending with a card containing ENDDATA in columns 1 through 7.) The deck must include:

a. all grid cards
b. all element connection cards
c. a coordinate system identification card if other than the basic system

All IMAG cards which are to be included should be inserted somewhere prior to the ENDDATA card.

3. Orientation Cards (one for each new orientation)

Column

1-5	= coordinate system ID for new orientation
6-10	= 0 for output in same coordinate system as for original segment
	= 1 for output in new local coordinate system
11-15	= number to be added to all grid points
16-20	= number to be added to all elements
21-25	= 1 for rotation about x-axis
	= 2 for rotation about y-axis
	= 3 for rotation about z-axis
31-40	= magnitude of the rotation in degrees
41-50	= magnitude of translation in x-direction
51-60	= magnitude of translation in y-direction
61-70	= magnitude of translation in z-direction

All values through column 25 are integers but need not be right adjusted.

ORBITING ASTRONOMICAL OBSERVATORY

The MOVE program has been used to generate the NASTRAN data for the Orbiting Astronomical Observatory (OAO). A segment representing one-eighth the total structure was rotated in 45 degree increments around the z-axis to generate the complete structural model shown in Figure 13. The input to the MOVE program is listed below.

Input Listing:

```
TITLE#  ORBITING ASTRONOMICAL OBSERVATORY %OAO<
CORD2C  20      0       0.0     0.0     0.0     0.0     0.0     1.0     20
&20     0.0     1.0     0.0
GRID    1       20      39.75   0.0     44.5    0       456
GRID    2       20      24.0    0.0     44.5    0       456
GRID    3       20      39.75   0.0     61.0    0       456
GRID    4       20      24.0    0.0     61.0    0       456
GRID    5       20      39.75   0.0     81.0    0       456
GRID    6       20      24.0    0.0     81.0    0       456
GRID    7       20      39.75   0.0     100.0   0       456
GRID    8       20      24.0    0.0     100.0   0       456
GRID    9       20      39.75   0.0     119.0   0       456
GRID    10      20      24.0    0.0     119.0   0       456
GRID    11      20      39.75   0.0     139.0   0       456
GRID    12      20      24.0    0.0     139.0   0       456
```

```
GRID    13      20      39.75   0.0     155.5   0       456
GRID    14      20      24.0    0.0     155.5   0       456
GRID    101     20      39.75   45.0    44.5    0       456
GRID    102     20      24.0    45.0    44.5    0       456
GRID    103     20      39.75   45.0    61.0    0       456
GRID    104     20      24.0    45.0    61.0    0       456
GRID    105     20      39.75   45.0    81.0    0       456
GRID    106     20      24.0    45.0    81.0    0       456
GRID    107     20      39.75   45.0    100.0   0       456
GRID    108     20      24.0    45.0    100.0   0       456
GRID    109     20      39.75   45.0    119.0   0       456
GRID    110     20      24.0    45.0    119.0   0       456
GRID    111     20      39.75   45.0    139.0   0       456
GRID    112     20      24.0    45.0    139.0   0       456
GRID    113     20      39.75   45.0    155.5   0       456
GRID    114     20      24.0    45.0    155.5   0       456
CROD    1       100     1       2       2       100     3       4
CROD    3       100     5       6       4       100     7       8
CROD    5       100     9       10      6       100     11      12
CROD    7       100     13      14      8       200     1       3
CROD    9       200     3       5       10      200     5       7
CROD    11      200     7       9       12      200     9       11
CROD    13      200     11      13      14      200     2       4
CROD    15      200     4       6       16      200     6       8
CROD    17      200     8       10      18      200     10      12
CROD    19      200     12      14      20      300     1       4
CROD    21      300     2       3       22      300     3       6
CROD    23      300     4       5       24      300     5       8
CROD    25      300     6       7       26      300     7       10
CROD    27      300     8       9       28      300     9       12
CROD    29      300     10      11      30      400     12      13
CROD    31      500     1       101     32      500     2       102
CROD    33      500     3       103     34      500     4       104
CROD    35      500     5       105     36      500     6       106
CROD    37      500     7       107     38      500     8       108
CROD    39      500     9       109     40      500     10      110
CROD    41      500     11      111     42      500     12      112
CROD    43      500     13      113     44      500     14      114
CQDMEM  45      600     1       2       102     101
CQDMEM  46      600     3       4       104     103
CQDMEM  47      600     5       6       106     105
CQDMEM  48      600     7       8       108     107
CQDMEM  49      600     9       10      110     109
CQDMEM  50      600     11      12      112     111
CQDMEM  51      600     13      14      114     113
CQDMEM  52      700     2       4       104     102
CQDMEM  53      700     4       6       106     104
CQDMEM  54      700     6       8       108     106
CQDMEM  55      700     8       10      110     108
CQDMEM  56      700     10      12      112     110
CQDMEM  57      700     12      14      114     112
IMAG    1       101     2       102     3       103     4       104
IMAG    5       105     6       106     7       107     8       108
IMAG    9       109     10      110     11      111     12      112
IMAG    13      113     14      114
ENDDATA
    100     0   100   100     3      45.0       0.0       0.0       0.0
    200     0   200   200     3      90.0       0.0       0.0       0.0
    300     0   300   300     3     135.0       0.0       0.0       0.0
    400     0   400   400     3     180.0       0.0       0.0       0.0
    500     0   500   500     3     225.0       0.0       0.0       0.0
    600     0   600   600     3     270.0       0.0       0.0       0.0
    700     0   700   700     3     315.0       0.0       0.0       0.0
```

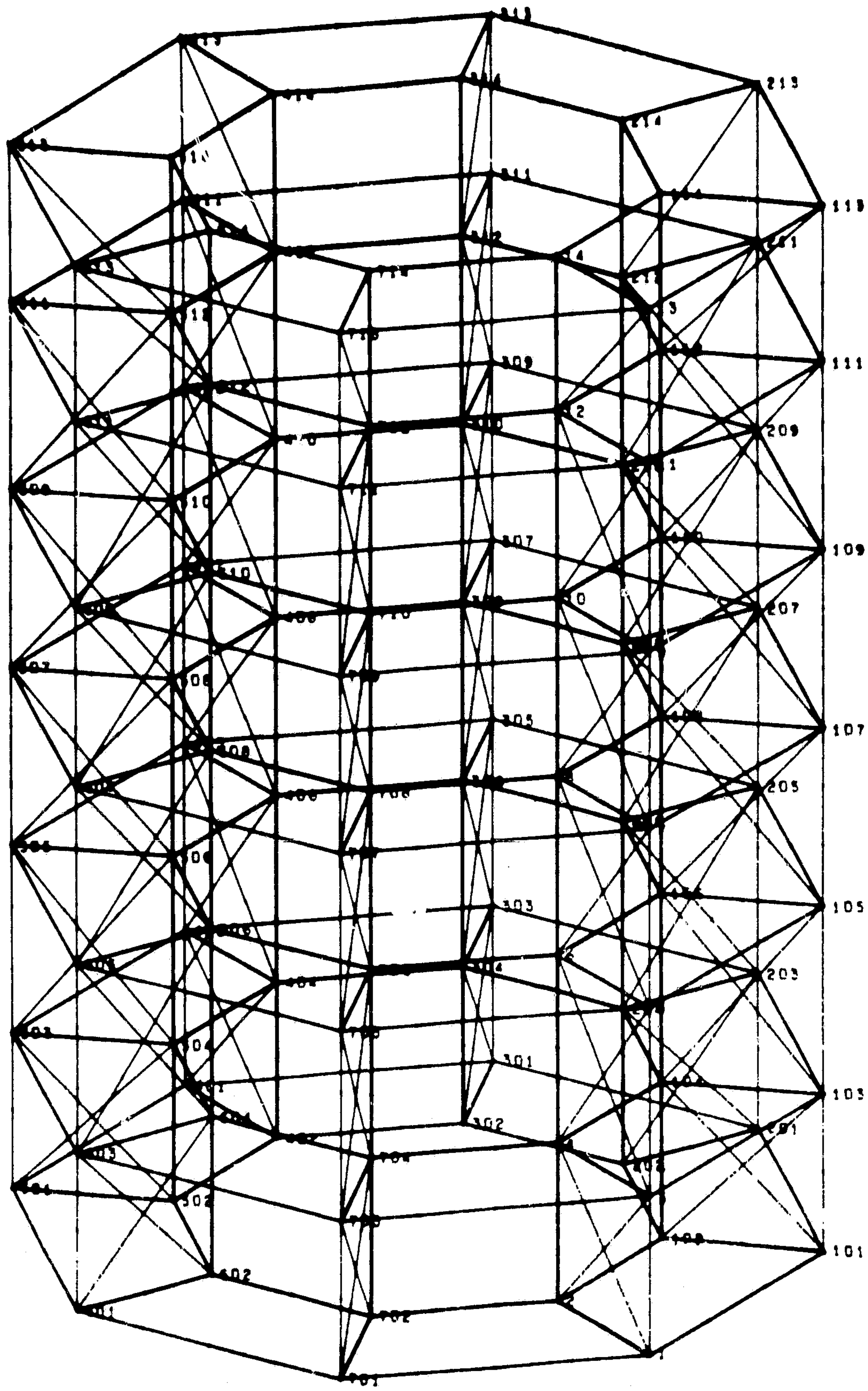

Figure 13–Orbiting Astronomical Observatory

REFERENCES

1. "NASTRAN Users' Manual," NASA Publication, no document number available (due for release last quarter of 1969).

2. S. Coons, "Surfaces for Computer-aided Design of Space Figures," Mechanical Engineering Department, MIT, 1964.