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Advanced Earth Observation Spacecraft Computer-Aided Design Software—Technical, User, and Programmer Guide

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ADVANCED EARTH OBSERVATION SPACECRAFT COMPUTER-AIDED DESIGN SOFTWARE—TECHNICAL, USER, AND PROGRAMMER GUIDE

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FOREWORD

This report describes the work done in performance of Task 4.3 (Enhance Computer Aided Design Software) of Contract NAS1-16756 sponsored by NASA Langley Research Center. The work was performed at Martin Marietta Denver Aerospace. Technical leads on Task 4.3 were Dr. L. B. Garrett at NASA LaRC and C. E. Farrell at Martin Marietta. Additional Martin Marietta personnel who performed the work were L. D. Krauze and W. Schartel. The remainder of work performed under contract NAS1-16756 will be reported under separate cover.

Use of trade names or names of manufacturers in this report does not constitute an official endorsement of such products or manufacturers, either expressed or implied, by the National Aeronautics and Space Administration.

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SUMMARY

The objective of this effort is to expand and enhance the capabilities of the existing NASA Langley Research Center's (LaRC) Systems and Experiments Branch computer-aided design program. The program permits interactive design and analysis of large space system (LSS) concepts. It provides rapid geometric modeling of different generic LSS structures; performs preliminary structural, thermal, controls, propulsion, and rf analyses; and integrates data required for detailed interdisciplinary analyses. The work performed in this task has resulted in enhancement of four existing modules and creation of five new modules. The enhanced and new modules provide the capabilities to:

1) Automatically generate contiguous box truss models with a box truss feed mast;

2) Interactively define and modify size and location of auxiliary equipment masses;

3) Calculate spacecraft areas and center of pressure matrices for aerodynamic and solar pressure effects;

4) Automatically generate geometry, calculate mass properties, and display LSS in stages of deployment;

5) Select subsystem and science sensor components and determine design parameters based on user-selected missions.

This report contains technical, user, and programmer information for each new or modified module.

1.0 SCOPE OF TASK 3 - COMPUTER-AIDED DESIGN SOFTWARE DEVELOPMENT

The objective of this task is to enhance the interactive computer-aided design capability of the NASA LaRC Systems and Experiments Branch. Existing software is used to perform preliminary and conceptual design of LSS, permitting low-cost quantitative comparison of candidate concepts. As a result of work performed under this task, four existing modules have been modified and five new modules added, as shown in the flow diagram in Figure 1-1. Table 1-1 contains a brief description of each module. The new modules are:

1) Environmental areas module;

2) Contiguous box truss deployment module;

3) Hoop column deployment module;

4) Subsystem properties module;

5) Sensor properties module.

The modules modified to reflect requirements for analysis of spacecraft concepts conceived during this contract are:

1) Contiguous box truss model generator (Ref 1);

2) Mass properties module (Ref 1);

3) Control analysis module (Ref 2);

4) Rf analysis module (Ref 1).

Section 2.0 contains the documentation pertaining to each of the nine modules. The test cases in the user sections reflect the baseline mission and concept of the overall study described in Reference 3.

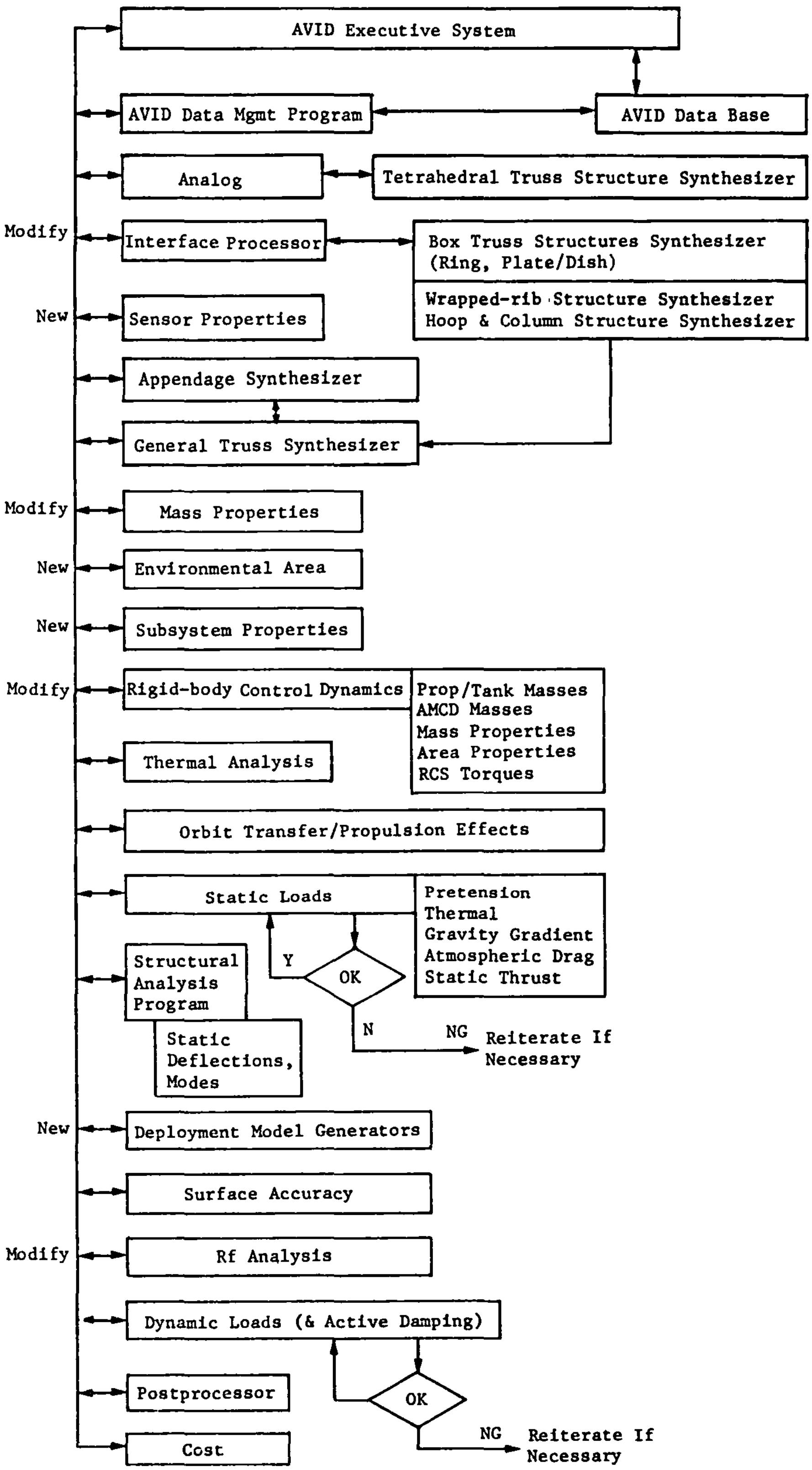

Figure 1-1 Flow Diagram of LASS with Expanded Capability

Table 1-1 Earth Observation Satellite Software

Module	Description
Contiguous Box Truss Model Generator	Creates finite element model of flat or parabolic box truss structure. Generates area and center of pressure data. The addition of a box truss mast is an option.
Contiguous Box Truss Deployment	Calculates box truss mass/inertia properties at various stages of deployment. Box truss mast may also be included with the dish. Uses mass properties file and deployment sequence instructions. Displays structural model at selected deployment stages.
Hoop Column Deployment	Calculates hoop column mass/inertia properties and generates graphical output data at user-selected deployment stages.
Mass Properties	Calculates mass properties of individual components and total mass, inertia, and center of mass for the spacecraft. Allows subsystem mass additions. Uses input files from model generators.
Environmental Areas	Calculates total areas projected to aerodynamic and solar radiation pressure and center of pressure matrices using area and finite element model data from model generator and mass properties programs. Can accommodate reflector areas as an option.
Rigid Body Control Dynamics	Calculates environmental forces and torques due to atmospheric pressure, solar pressure, and gravity gradient. Computes propellant requirements due to environmental perturbations, limit-cycle losses, and maneuvers. Uses data base, mass properties, and area files. Interactive plots of forces/torques are available.
Rf Analysis	Predicts primary beam gain and losses due to feed factors, blockage, and root mean square (rms) surface distortion. Predicts losses for a spherical versus ideal paraboloid surface as an option.
Subsystem Properties	Computes approximate masses, power, and cost for 10 different subsystems of a large space structure. (Only three subsystems are presently implemented.)
Sensor Properties	Contains sensor descriptions for land resources, oceanic, and atmospheric missions; design algorithms for microwave radiometer and sensor data rates; and detailed instrument descriptions of existing instruments. Can select sensor complement.

2.0 COMPUTER PROGRAM DOCUMENTATION

This chapter contains documentation necessary to use or modify each of the modules. Each section has three subsections that contain technical, user, and programmer information. The software is written in FORTRAN IV for execution on the LaRC CDC Cyber computer system. The module test cases contained in this report were executed remotely using the A or Y CDC resources. The actual field length required for modules with an interactive plot capability cannot be determined until the Martin Marietta graphics utility calls are replaced with their counterparts at LaRC.

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2.1 CONTIGUOUS BOX TRUSS (CBT) MODEL GENERATOR MODULE

The CBT model generator module creates the geometry, property, and material records necessary to define a finite element model (FEM) of box truss derivative structures. The structures may have a flat or parabolic surface. In addition to the FEM-related records generated, structural element projected areas are defined. Area and center of pressure (cp) calculations for a reflective surface are also included in the module.

The module was created by modifying a module developed under Contract NAS1-16447 (Ref 1). Figure 2.1-1 shows the flow during module execution. In the present version, a maximum of 300 nodes and 1250 elements are permitted for any model.

2.1.1 CBT Module Technical Description

2.1.1.1 Dish Model Characteristics - Each box truss has four basic element types, as shown in Figure 2.1-2. The horizontal (surface) tubes are cylindrical, thin-walled structures and are modeled as BAR elements. The vertical elements are finned tubes with the cross-sectional profile shown in Figure 2.1-3. The horizontal and vertical diagonals are solid ROD elements. The section and material properties are specified for each element type to provide definition of spacecraft area and FEM property and material records.

Included in the program is the capability to define different structural element properties as a function of their distance from the geometric model center. The zones are specified as some multiple of box length. The program automatically determines which elements fall within the zones. A separate number of zones may be specified for each type of element modeled.

The physical and material properties of the dish elements are specified before execution. The material properties specified include E, G, η, and ρ , (Young's modulus, shear modulus, Poisson's ration, and density, respectively). These are used in the definition of the dynamic model input file, for creation of a mass properties and matrices file, and for creation of an area matrices file, all of which are later used to execute the mass properties module or the environmental areas module.

Each bay consists of the structural members discussed previously, plus end fittings, midlink hinges for folding members, and the diagonal attachment fittings. The masses of the end fittings (AMNODE) are represented as concentrated masses at grid points whose coordinates are at the end fittings. The origin (0,0,0) is at the top center of the model (top is the surface normally away from Earth), and the X axis is tangent to the orbital path, the Z axis is vertical to Earth, and the Y axis is orthogonal to X and Z. Midlink hinge mass (AMHING) and diagonal fittings masses are also concentrated at the grid points.

2.1.1.2 Box Truss Feed Mast - The structures generated using the contiguous truss approach lend themselves to incorporation of box truss feed masts that are inherently stiffer than other types of deployable feed masts (e.g., astromasts and lattice masts). The basic implementation scheme for box truss masts is to create a series of truss pairs with the same structural characteristics as the outermost dish structure bays. Figure 2.1-4 shows a contiguous box truss concept that includes a box truss mast.

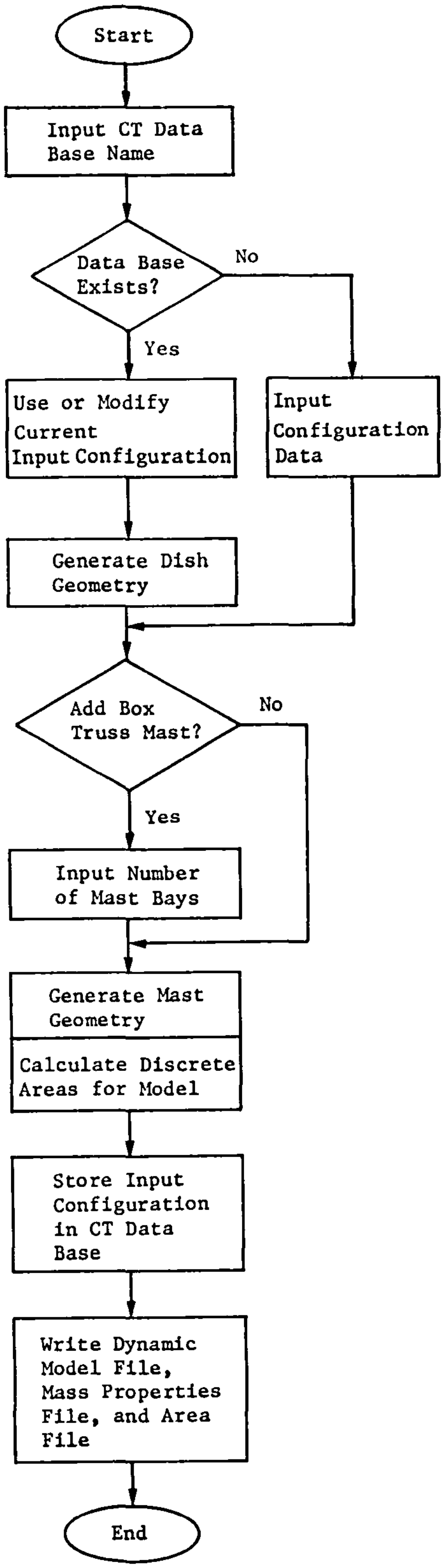

Figure 2.1-1
Contiguous Box-Truss Flow Diagram

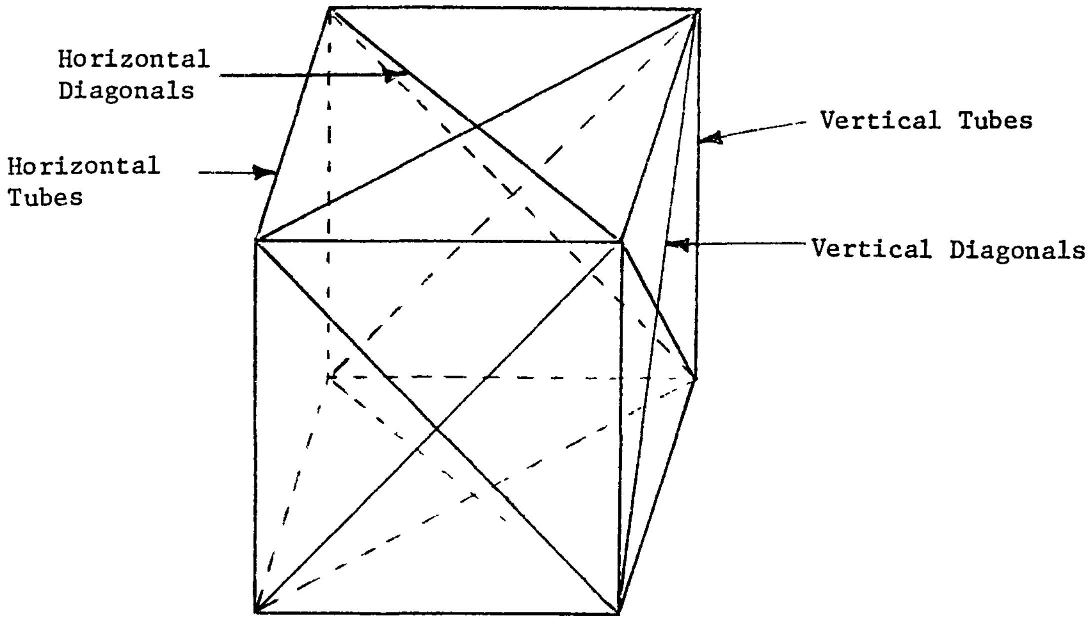

Figure 2.1-2 Definition of Box Truss Elements

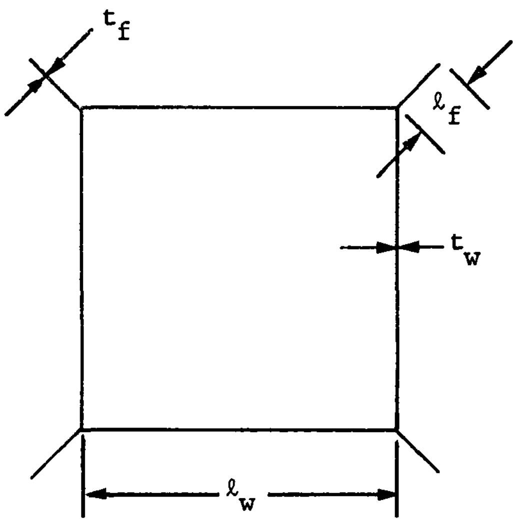

Figure 2.1-3
Vertical, Finned-Tube Cross Section

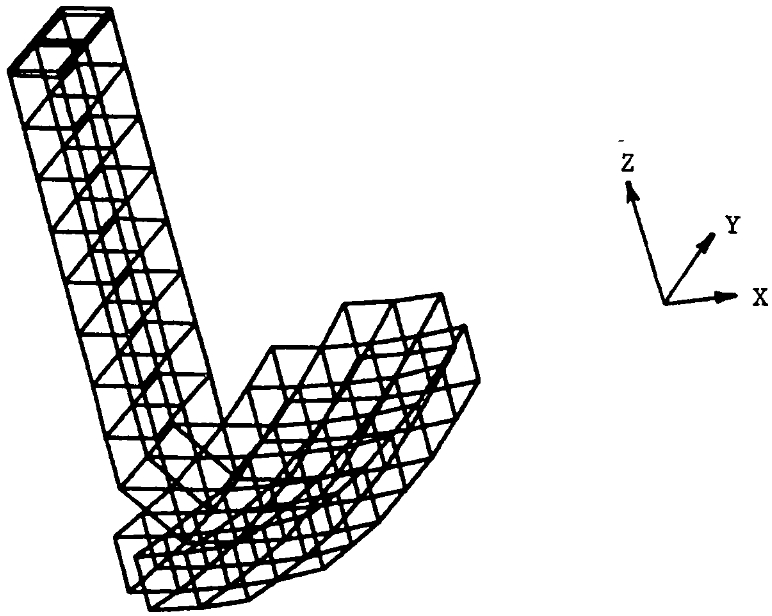

Figure 2.1-4 EOS Spacecraft Concept

Stowage of the feed mast is accomplished in a horizontal plane. This results in structural elements that correspond to those of the dish structure. There are three additional folding members (channel tubes) that are unlike any dish elements. Their properties are most similar to the vertical bar tubes and are modeled as this type element.

The algorithm used to generate box feed masts assumes the following:

1) Feed masts are two bays wide and one deep;

2) Masts connect to the dish at outermost bottom dish nodes, as shown in Figure 2.1-5;

3) All structural and material properties of mast elements are identical to those of the dish bays to which the mast is attached.

The node numbering sequence for the box mast starts with 500001 and continues as shown in Figure 2.1-5. The common nodes for the mast and dish are 121n11, 121n12, and 221n12, where n = 1 plus the number of rows of bays in each quadrant. For the configuration of Figure 2.1-4, these nodes are 121311, 121312, and 221312. The vertical mast length is obtained by dividing the antenna focal length by the number of mast bays.

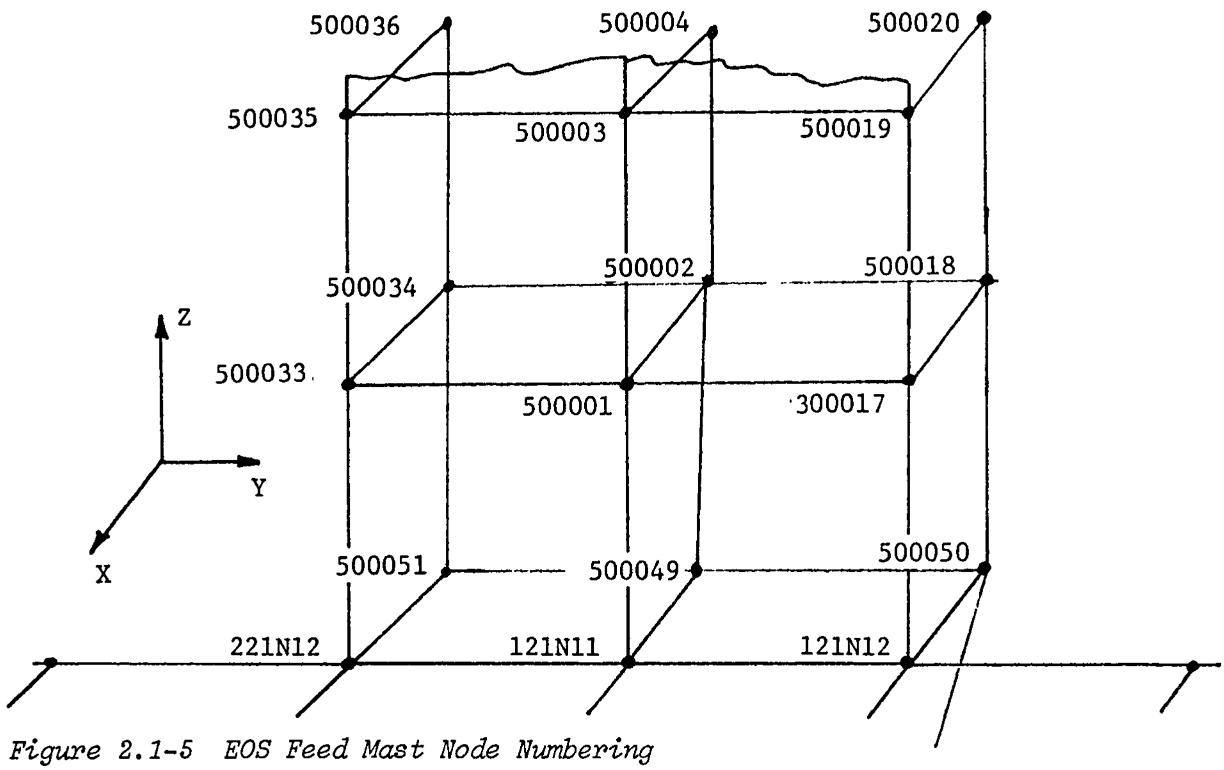

Figure 2.1-5 EOS Feed Mast Node Numbering

Element identification starts at 500001. Property and material reference numbers are the same as those of the structural elements of the outer dish bays. As discussed previously in Paragraph 2.1.1.1, these reference numbers are set to the element type number. For the mast, these reference numbers will be:

1) Surface tubes - Number of horizontal property zones (NZHOR);

2) Vertical finned tubes - NZHOR + number of vertical zones (NZVER);

3) Surface diagonals - NZHOR + NZVER + number of diagonal zones (NZDIA);

4) Interior diagonals - NZHOR + NZVER + 2 NZDIA.

2.1.1.3 Mass Modeling - The data necessary to determine model mass properties are created and written to the mass properties matrices file. Mass densities for each element and the rf reflector are defined at start of module execution. Element cross-sectional areas, or parameters necessary to calculate these areas, are defined via interactive prompts to the user and are input by the user. The average of corner cube fitting and end fittings masses is defined by variable AMNODE during input data definition. The total reflector mass is determined from the reflector mass density and reflector surface area. The area is calculated from the overall model x and y dimensions. The reflector mass is average over the nodes to which it is connected. The sum of AMNODE and this averaged reflector mass per node are stored in Column 5 of array GRIDD. For mesh surface only, top surface nodes have the added mass. For membrane surfaces, both top and bottom node masses are increased. These mass data are written to the mass properties matrices file upon termination of module execution. The arrays and their attributes are:

1) TUBP (7) - cross-sectional area (m^2);

2) TUBP (8) - mass density (kg/m^3);

3) GRIDD (i,2) - node i x-coordinate;

4) GRIDD (i,3) - node i y-coordinate;

5) GRIDD (i,4) - node i z-coordinate;

6) GRIDD (i,5) - node i concentrated mass.

2.1.1.4 Area Modeling - The data necessary to calculate model area projected to environmental perturbations are created and written to the area file for subsequent use in the environmental areas module. Structural element diameters, widths, and thicknesses are defined in the input phase. These values are used to define effective member x, y, and z widths in the model coordinate system. The length of each structural element, normal to the x, y, or z axes, is determined and multiplied by the appropriate width to determine each element's projected area. Half of each area is assigned to the two-element endpoint nodes. These node areas are assigned to array GRIDA.

The area of the rf reflective surface is determined from its overall area and a mesh optical transmissivity factor, AMESH. For membrane surfaces, AMESH must be set to 1. The z axis projected area of a mesh surface is obtained by multiplying the z area by AMESH. The x and y components of mesh area are determined as follows. Upon leaving the module, necessary area data are written to the area file. These data are:

1) GRIDA (i,1) - node i x area;

2) GRIDA (i,2) - node i y area;

3) GRIDA (i,3) - node i z area;

4) XM,YM,ZM - reflective surface center of pressure coordinates;

5) AXM,AYM,AZM - reflective surface x, y, z areas.

If the spacecraft is an antenna, the area of the rf reflective surface must be included. Because the reflector will normally be a paraboloid, the side areas may be calculated from:

[1] $A = 2/3\ bh$

where b and h are shown in Figure 2.1-6.

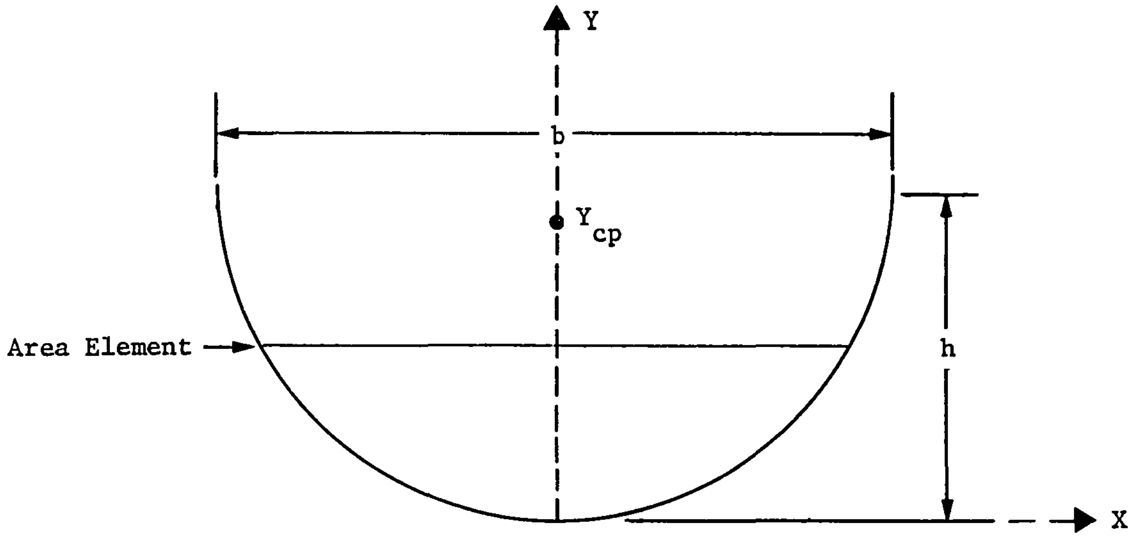

Figure 2.1-6 Cross Section of Parabolic Reflector Surface

The center of pressure of a parabola can be found from:

$$[2] \quad Y_{cp} = \frac{\int_o^h yxdy}{\int_o^h xdy}$$

where xdy is the area element and $x = 2\sqrt{(fy)}$ dy. The integration yields:

$$[3] \quad Y_{cp} = \frac{2f^{\frac{1}{2}} \int_o^h y^{\frac{3}{2}} dy}{2f^{\frac{1}{2}} \int_o^h y^{\frac{1}{2}} dy}$$

$$[4] \quad Y_{cp} = \left. \frac{2/5 \; y^{\frac{5}{2}}}{2/3 \; y^{\frac{3}{2}}} \right|_o^h = \frac{3}{5}h$$

Thus the reflector area may be included as an area of 2/3bh at coordinates (0, 0, 3/5h). Because this reflector may be a wire mesh, a factor must be included to result in an area indicative of the degree of openness of the surface mesh. The reflector area projected in the z direction will be the overall area times the area blockage factor. A typical mesh will present an area that is 90 percent open in the normal direction. The side area factor will be greater because of the effective decrease in distance seen between mesh wires. From tests performed on mesh surfaces, the effective optical transmissivity is as shown in Figure 2.1-7. For aerodynamic drag, the incidence angle can be approximated from the average slope from the vertex to the outer edge of the reflector. The slope at the outer edge will be:

[5] $$\mathrm{Tan}\theta = \frac{1}{4\left(\frac{f}{d}\right)}$$

where f/d = antenna focal length to diameter ratio.

The average slope is 1/2 of the value, so that θ is:

[6] $$\theta = \mathrm{Tan}^{-1}\frac{1}{8\left(\frac{f}{d}\right)}$$

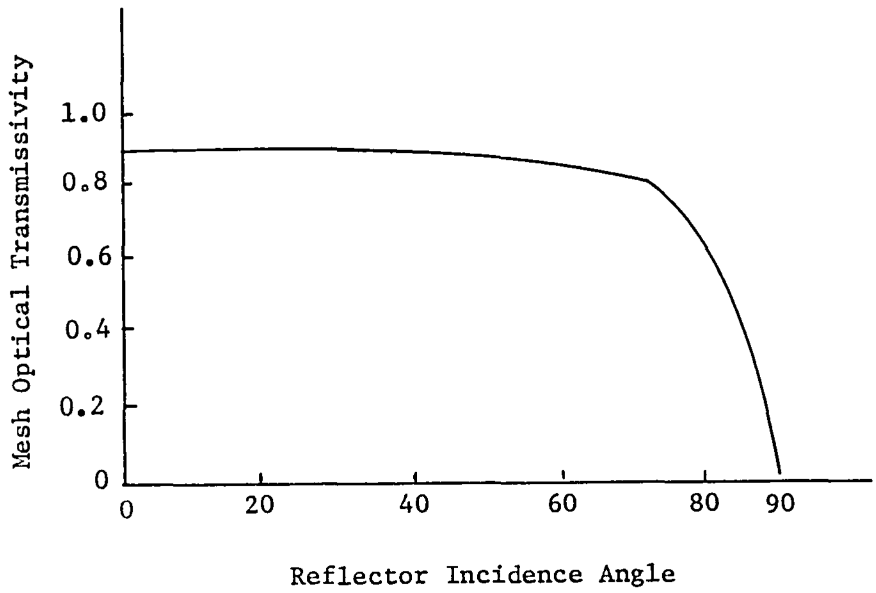

Figure 2.1-7
Mesh Reflector Optical Transmissivity vs Incidence Angle

Because most LSSs have an f/d ratio of less than 2, a worst-case value can be approximated as:

[7] $\theta = \mathrm{Tan}^{-1} \frac{1}{16} \approx 3.6°$

This gives an average angle of incidence of about 86 degrees, resulting in an optical transmissivity of about 0.4. This corresponds to 60 percent blockage in x and y for aerodynamic drag.

The mesh area effect for solar force is more difficult to determine because the incidence angle can change during a single orbit through the range of 0 to 90 degrees. For this case, the average transmissivity would be near the centroid of the transmissivity curve. This is also about 0.4. Thus, a mesh blockage of 60 percent can be used in the analysis for both aerodynamic and solar drag calculations. Because the type of reflector and f/d ratio are specified in the model generators, this blockage factor of 0.6 is included in the calculation in those modules. The areas and cp coordinates are then transferred to the area module through an area matrices file.

2.1.2 CBT Module User Instructions

Execution of the module on the LaRC CDC Cyber system is started by the command:

BEGIN,, LSSCTPR

The first prompt requires the user to identify the terminal type being used.

```
OENTER BAUD RATE

? 1200
OENTER 1 FOR 4006, 4010, 4012, OR 4013
        2 FOR 4014 OR 4015
     OR 3 FOR 4014 OR 4015 WITH ENHANCED GRAPHICS
      OR 4 FOR TERMINAL OTHER THAN TEKTRONIX
```

Next, the user is prompted to enter the desired input data base file.

```
 INPUT THE NAME OF THE C  T  DATA BASE FILE.
? LOSBASE
```

The present values of the module input items are then displayed, and the user is permitted to modify them as desired.

```
CONTIGUOUS BOX TRUSS INPUT ITEMS

    60 000          1   RFDM    -RADIO FREQUENCY DIAMETER (METERS)
    1.0000          2   SHAPE   -SHAPE FLAG: 1=PARABOLA, 2=SPHERE, 3=FLAT
    2.0000          3   FOVERD  -FOCAL LENGTH TO RF DIAMETER RATIO
    2.0000          4   SODM    -MESH STAND-OFF DISTANCE (METERS)
   0.               5   NMODE   -NUMBER OF MODE SHAPES (0=NO SAP MODELS)
   0.               6   TUBTYP  -STRUT TYPE: 0=L/R, 1=EULER, 2=ISOG, 3=TRUSS
    15 140          7   DEP     -BOX TRUSS DEPTH (METERS)
    .10000          8   AMESH   -MESH AREA BLOCKAGE FACTOR
   0.               9   BLANK   -NOT USED
    1.9000         10   AMNODE  -CONCENTRATED MASS OF CORNER FITTING(KG)
   0.              11   AMVER   -CONCENTRATED MASS OF VERTICAL HINGE(KG)
    4.0000         12   RBOXX   -NUMBER OF COLUMNS IN ROW 1 OF QUADRANT 1
   0.              13   IFPIN   -PIN FLAG(0=NOT PINNED, 1=PINNED)
    2.0000         14   NBOXY   -NUMBER OF ROWS OF BOXES IN QUADRANT 1
    1.0000         15   NZHOR   -NUMBER OF HORIZONTAL TUBE PROPERTY ZONES
    1.0000         16   NZVER   -NUMBER OF VERTICAL TUBE PROPERTY ZONES
    1.0000         17   NZDIA   -NUMBER OF DIAGONAL TUBE PROPERTY ZONES
   4.40000E-02     18   SURFDN  -REFLECTOR MASS DENSITY(KG/SQ.M)
    1.0000         19   SURTYP  -REFLECTOR TYPE(0=NONE1=MESH,2=E2=CMM
ENTER 0 IF INPUT IS OK
     1 TO CHANGE DATA ITEMS VIA THE KEYBOARD
     2 TO ENTER A NEW TITLE
  OR 9 TO RETURN TO THE EXEC.
? 0
```

The next set of input prompts is controlled by the value of Item 14, the number of rows of box structures in the model. A prompt will be displayed requesting definition of the geometry for Quadrant 1. The user must input the number of boxes for each row in Quadrant 1 of the contiguous box truss structure until values have been provided for the number of rows specified. For example, the following prompts and inputs correspond to the contiguous box truss structure shown in Figure 2.1-4.

```
 INPUT THE # OF BOXES FOR EACH ROW OF QUADRANT 1
 ROW  1
? 4
 ROW  2
? 3
```

After the number of boxes in each row of Quadrant 1 has been specified, property zones may be defined. The user inputs the zone radius factor for each zone. In the test case there is one zone for each element so that the property zone prompts are not displayed. If they were, they would have the form shown on the following page.

```
                 1              2
    ROW       RADIUS         RADIUS

       1      50000         4.0000
 ENTER 0 IF INPUT IS OK
         1 TO CHANGE DATA ITEMS VIA THE KEYBOARD
         2 TO ENTER A NEW TITLE
     OR 9 TO RETURN TO THE EXEC.
? 0
```

The next inputs define the structural element sizes. For horizontal cylindrical tubes, the user must specify the tube wall thickness and end diameters:

```
+          HORIZONTAL TUBE DIMENSIONS(M)


                   1              2              3
    ROW     THICKNESS      DIAM. 1        DIAM. 2

       1    6.60000E-04 8.30000E-02 8.30000E-02
 ENTER 0 IF INPUT IS OK
         1 TO CHANGE DATA ITEMS VIA THE KEYBOARD
         2 TO ENTER A NEW TITLE
     OR 9 TO RETURN TO THE EXEC.
? 0
```

For the vertical finned tubes, the parameters required are the side length wall thickness, fin length, and fin thickness. After the vertical tube sizes are defined, the user must specify the diagonal cross-sectional areas, diagonal width, and diagonal thickness. For cylindrical diagonals, the width and thickness are the diameter. The cross-sectional areas are written to the dynamic model file records. The width and thickness (or diameter) are used only in projected area calculations.

```
1
+        VERTICAL TUBE DIMENSIONS(M)                                            VERB   MATRIX

                 1           2           3          4
   ROW    FIN THICK   FIN LENGTH  WALL THICK  WALL LEN

      1    1 27000E-03 5 08000E-02 1 27000E-03 2 54000E-02
 ENTER 0 IF INPUT IS OK
        1 TO CHANGE DATA ITEMS VIA THE KEYBOARD
        2 TO ENTER A NEW TITLE
     OR 9 TO.RETURN TO THE EXEC
7 0
1
+        DIAGONAL TAPE SECTION PROPS                                            DIAR   MATRIX

                 1           2           3
   ROW         AREA        WIDTH     THICKNESS

      1    2 97000E-05 6 14000E-03 6 14000E-03
      2    5 75000E-05 8 56000E-03 8 56000E-03
 ENTER 0 IF INPUT IS OK
        1 TO CHANGE DATA ITEMS VIA THE KEYBOARD
        2 TO ENTER A NEW TITLE
     OR 9 TO RETURN TO THE EXEC
7 0
```

The final input matrix to be displayed permits definition of material properties. The properties that may be defined are Young's modulus, Shear modulus, Poisson's ratio, material density, coefficient of thermal expansion (CTE), thermal reference temperature, and structural damping coefficient. The current values are displayed as:

```
TUBE PROPERTIES(ROW 1=HORIZ , 2=VERT.   3=HOR  DIA 4=VER. DIA                                PMATS  MATRIX

            1            2          3          4          5        6         7         8
ROW         E            G          NU         RHO        CTE      TREF      GE        BLANK

    1   1 46000E+11 1 31000E+10  .19300      1605.4     72 000    0         0         0
    2   1.83000E+11 1.43000E+10   35000      1716 2     72 000    0         0         0
    3   2 35000E+08 0           0.           1642.3    -91 700    0         0         0
    4   2 35000E+08 0           0            1642.3    -91 700    0.        0         0
ENTER 0 IF INPUT IS OK
     1 TO CHANGE DATA ITEMS VIA THE KEYBOARD
     2 TO ENTER A NEW TITLE
  OR 9 TO RETURN TO THE EXEC
? 0
```

The next user inputs determine whether a box truss feed mast is desired and, if so, the number of bays in the mast. The prompts are:

```
 DO YOU WISH TO ADD A BOX TRUSS FEED MAST
? YES

 NUMBER OF BAYS IN FEED MAST
? 8
```

After all inputs have been selected, the module performs the functions necessary to create a dynamic model file, a mass properties matrices file, and an area matrices file. The user inputs the name of a data base file, which can be the present file or a new file. Next, the dynamic model file name must be specified. This file contains the dynamic analysis program input data including GRID, CBAR, CROD, CONM2, and related records. After input of the dynamic model file name, the user must specify the name of the mass properties matrices file. This file contains the information necessary to calculate and/or modify the model mass properties in a subsequent execution of the mass properties module. The last output file contains area information required for the environmental areas module. Prompts and responses are:

```
 INPUT NAME DATA BASE FILE IS TO BE REPLACED AS
           (0 = DEFAULT (LASSDB)
? EOSBASE
 INPUT NAME OF DYNAMIC MODEL FILE TO BE SAVED
? DYEOS
 INPUT NAME OF MASS PROPERTIES MATRICES FILE
? MASSEOS

 INPUT NAME OF AREA FILE
? AREAEOS
```

The final user input requested determines whether to terminate module execution or to create another model.

```
 DO YOU WISH TO GENERATE ANOTHER CONTIGUOUS TRUSS MODEL
? NO
```

2.1.3 CBT Module Programmer Information

There are two primary overlays that are sectioned as input and output, and as model generation. The code has been internally commented to facilitate revision. This section provides general information for program modification or for interfacing with other programs. The discussion sections correspond to the primary overlays. The main overlay contains the calls to these primary overlays.

2.1.3.1 Overlay (1,0) - This overlay contains the input/output codes. The data statements contain variables, arrays, and headers necessary for communicating with the data base file, dynamic model file, and mass properties matrices file. These data are found in subroutine BOXINPT, which contains some tests on critical input parameters. A maximum of 10 different structural element types is permitted. This restricts the sum of the number of property zones (NZHOR, NZVER, NZDIA) to 10. If more zones are desired, the test must be changed and the dimension of TUBP in COMMON/PROPS/ increased by 14 for each additional zone or type desired.

The maximum number of bays allowed is controlled by the dimensions of GRIDD and IELM from COMMON/MASDAT/. At present, a maximum of 300 nodes on 1250 structural elements is permissible. Creating a larger model will require increasing dimensions of one or both of these arrays. These arrays are used to transfer node coordinates and element connectivity information for model generation and, optionally, for plot file creation.

2.1.3.2 Overlay (2,0) - This overlay contains the model generation code and associated subroutines. The grid identification numbers are sequenced based on quadrant location, location on top or bottom surface, row location, and column location. Nodes common to more than one quadrant are identified with the lowest common quadrant number.

The scheme for numbering bottom surface nodes is shown in Figure 2.1-8. The top surface nodes differ only in the second digit. For example, the bottom surface node number of 111112 corresponds to 121112 in the top surface.

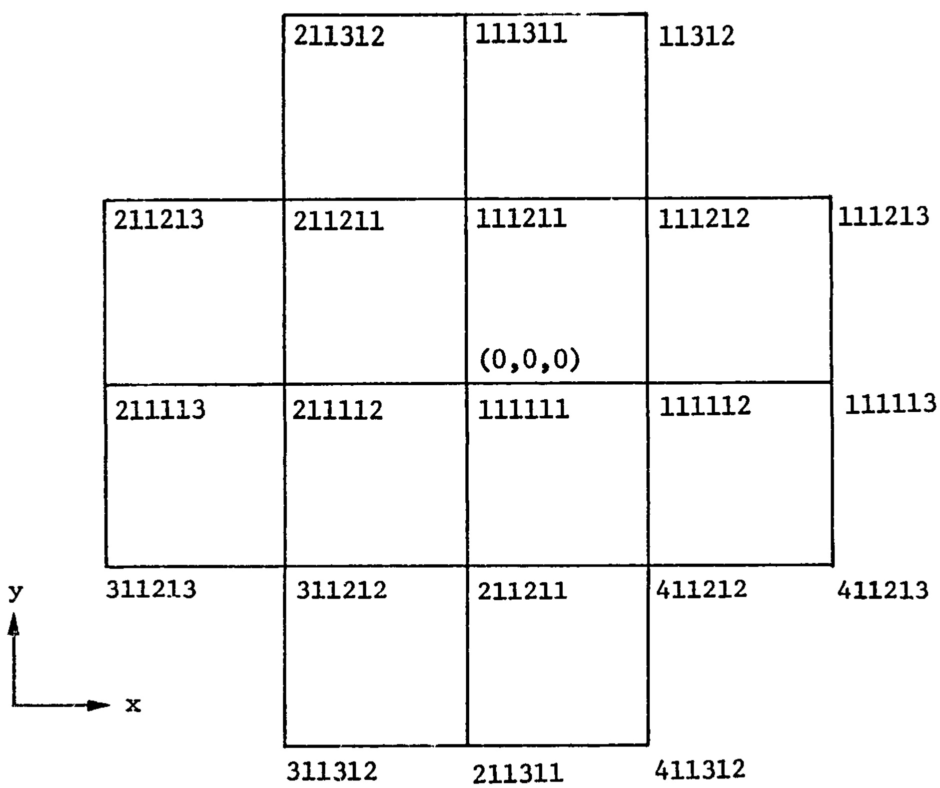

Figure 2.1-8 Box-Truss Numbering

Two subroutines, BOXMAST and MASTUB, create the box mast structure. BOXMAST contains code to generate the mast nodes based on the number of vertical mast bays (NBAYV). The length of each bay is calculated from the mast length (LMAST), which is derived from the reflector aperture diameter (RFDM) and f/d ratio (FOVERD).

MASTUB is called from BOXMAST after all necessary nodes are defined. All required structural element records are created with properties defined by NZHOR, NZVER, and NZDIA.

The graphic display of the model in Figure 2.1-4 was generated at Martin Marietta Denver Aerospace using the DISSPLA* graphics package. This requires generation of data for initializing the plot routines and for drawing the necessary line segments. The labeled COMMON "PDATA" contains the following parameters:

PTYPE - flag to define output device
XORG - x coordinate of output display origin
YORG - y coordinate of output display origin
ZORG - z coordinate of output display origin
XS - x axis step
YS - y axis step
ZS - z axis step

XMAX - x axis maximum value
YMAX - y axis maximum value
ZMAX - z axis maximum value

For segment endpoint coordinates, subroutine PLTFIL (located in library LSSLIB) may be called. It will use arrays GRIDD and IELM to determine endpoint coordinates and write them to local unit 13 using an E13.5 format. TAPE13 can then be used to draw the model. TAPE13 is not presently rewound in PLTFIL. It must be before attempting to read it.

CBT model area calculations are performed in subroutines CTAREA and TAREA. Each element's area components are calculated individually from element-projected width and effective projected length. Half the element area is assigned to each associated grid. Each grid area is summed and written to array GRIDA. This array, dimensioned at (300,6) contains the total x, y, z areas for each grid in Columns 1, 2, and 3 and a blockage limit angle in Columns 4, 5, and 6. At present, these limit angles are assumed to be zero (i.e., no blockage, worst-case total area).

*DISSPLA is a trade name of ISSCO Corporation.

2.2 MASS PROPERTIES MODULE

The mass properties (MP) module calculates mass properties of structural models created by the automated model generators. In addition, the module permits the user to add or delete masses representing auxiliary equipment, permitting interactive determination and iteration of spacecraft mass properties. The module outputs include the mass properties data required for subsequent analyses (e.g., controls and orbital transfer) and an updated input file for dynamic analysis.

2.2.1 Mass Properties Module Technical Description

The model generators that interface with the mass properties module include the box ring, radial rib, hoop and column, and contiguous box truss modules (Ref 1). These modules create a mass properties matrices file that contains the grid, element, and element properties data required for mass properties definition. These data are read at the start of execution of this module. The concentrated masses of the end fittings and midlink hinges (for truss-type structures) are retrieved from the structural model data base.

The masses of nodes defined in model generators include the distributed mass of the reflective mesh or membrane. The total mass of the reflector is obtained by subtracting the total mass of all end fittings from the total of the nodes' concentrated mass. The concentrated masses enter through array GRIDD as item (n,5), where the range of n is from 1 to NG, the number of grids in the model. For nontruss models (e.g., radial rib), the concentrated mass includes only the reflective surface and the central hub mass.

Auxiliary or subsystem equipment masses are also maintained in the data base. The number of these masses is presently limited to 50 for any one model. Any model node may be assigned an equipment mass.

If any of the nodes' masses are to be changed (to represent redefinition or relocation of subsystem components), the mass properties matrices file and dynamic model file will be regenerated to reflect these changes. After changing masses, the calculation of total mass, center of mass (CM), and inertia properties are started. Each concentrated mass is multiplied by its appropriate x, y, and z coordinates to obtain $\sum m\vec{r}$, and the masses are summed to determine total mass from all concentrated masses. The masses of tubes and their effect on inertias are determined from tube area, length, material density, and coordinates of the tubes' midpoints. It is assumed that the mass of a tube is concentrated at its midpoint.

2.2.2 MP Module User Instructions

The following is a sample run of the MP module for the EOS baseline mission. Execution is started on the LaRC CDC Cyber by input of the command:

```
BEGIN,, MPPROC
```

The first inputs requested define the user's terminal type from:

```
0ENTER BAUD RATE

? 1200
0ENTER 1 FOR 4006, 4010, 4012, OR 4013
       2 FOR 4014 OR 4015
    OR 3 FOR 4014 OR 4015 WITH ENHANCED GRAPHICS
     OR 4 FOR TERMINAL OTHER THAN TEKTRONIX
        ?
? 4
```

Next, the data base file name is required from:

```
 INPUT NAME OF STRUCTURAL MODEL DATA BASE FILE
? MASEOSA
```

If a complete data base, including added masses, does not exist from a previous module execution, the pertinent structural model data base may be input. If so, an error message will be displayed as shown. This will not affect module execution. It reflects the absence of any equipment masses.

```
*** ERROR  NDEL    NOT IN DATA BASE ***


*** ERROR  EMASS   NOT IN DATA BASE ***
*** ERROR  EMASS   NOT IN DATA BASE ***
```

The parameters pertaining to execution of the MP module are then displayed as:

```
+          MASS PROPERTIES DEFINITION


 MASS PROPERTIES STRUCTURAL DEFINITION

     60.000          1  RFDM   -RADIO FREQUENCY DIAMETER (METERS)
     2.0000          2  FOVERD -FOCAL LENGTH TO RF DIAMETER RATIO
     1.9000          3  AMNODE -END FITTING MASS(KG)
    0.               4  AMHING -HINGE MASS(KG))
     23.000          5  NDEL   -NUMBER OF EQUIPMENT MASSES
 ENTER 0 IF INPUT IS OK
       1 TO CHANGE DATA ITEMS VIA KEYBOARD,
       2 TO ENTER A NEW TITLE,
    OR 9 TO RETURN TO THE EXEC.
? 0
```

The next two prompts request input of the mass properties matrices file and the dynamic model file, which were defined during execution of the model generator module or appendage synthesizer.

```
 INPUT NAME OF MASS PROPERTIES MATRICES FILE
? MASSEOS


 INPUT NAME OF DYNAMIC MODEL FILE
? DYEOS
```

At this point the user has the option of modifying the model by adding or deleting equipment masses at existing nodes by answering "YES" to the prompt:

```
DO YOU WISH TO CHANGE DISCRETE MAS(ES)
? Y
```

If mass changes are requested, the user is asked whether a listing of nodes is desired. The prompt is:

```
DO YOU WISH TO LIST GRID IDS AND MASSES
? Y
```

If it is desired to list nodes, they will appear in the form shown as follows, 20 nodes maximum per display. (A complete listing of the nodal masses appears in Section 3.0.)

```
DO YOU WISH TO LIST GRID IDS AND MASSES
? YES
```

GRID NUMBER	MODEL COORDINATES (M) X	Y	Z	MASS (KG) STRUCTURE	EQUIPMENT
111111	0 00	0.00	0.00	1.90	
111112.	0.00	15.14	48	1.90	
211112.	0.00	-15 14	.48	1.90	
111113	0 00	30 22	1.90	1.90	
211113.	0.00	-30.22	1.90	1.90	
111114	0.00	45.19	4 25	1.90	
211114.	0.00	-45.19	4.25	1.90	
111115.	0.00	59.99	7.50	1.90	
211115.	0.00	-59,99	7.50	1.90	
111211	-15.14	0.00	.48	1.90	
211211	15.14	0.00	48	1.90	
111212.	-15.14	15 14	.96	1.90	
211212.	-15.14	-15.14	.96	1.90	
311212.	15.14	-15.14	.96	1.90	
411212.	15.14	15.14	.96	1.90	
111213.	-15.14	30.22	2.38	1.90	
211213.	-15.14	-30.22	2.38	1.90	
311213.	15.14	-30 22	2.38	1.90	
411213	15.14	30.22	2.38	1.90	
111214.	-15.14	45.19	4.73	1.90	

The user is asked to input the grid number where an equipment mass will be modified and to input the new mass in kg:

```
ENTER GRID NUMBER, A COMMA, AND NEW EQUIPMENT MASS(KG);
? 500016,52 5                                ENTER 0,0 TO STOP
? 500031,286.4,500047,286.4
? 500032,119,500048,119,0,0

DO YOU WISH TO LIST GRID IDS AND MASSES
? NO
```

A prompt is now issued to permit redisplay and verification of the discrete masses. Section 3.0 contains a listing of the EOS baseline masses. It should be noted that the effective node concentrated mass can be modified by input of an added mass. This may be desirable to create a more detailed structural model because the node masses from the model generator are single values that represent the average node concentrated mass.

```
 CONTINUE LISTING GRIDS
? YES
 211214.      -15 14     -45 19      4.73      1.90
 311214        15.14     -45 19      4.73      1.90
 411214        15 14      45.19      4.73      1.90
 111215.      -15.14      59.99      7 98      1.90     100.00
 211215       -15 14     -59.99      7.98      1.90     100.00
 311215.       15 14     -59.99      7.98      1.90     100.00
 411215        15.14      59.99      7.98      1.90     100.00
 111311.      -30.22       0.00      1.90      1.90
 211311.       30.22       0.00      1.90      1.90
 111312       -30.22      15.14      2.38      1.90
 211312.      -30.22     -15.14      2.38      1.90
 311312.       30.22     -15 14      2.38      1.90
 411312.       30.22      15.14      2.38      1.90
 111313.      -30.22      30.22      3.81      1.90
 211313.      -30.22     -30.22      3.81      1.90
 311313.       30.22     -30 22      3.81      1.90
 411313.       30.22      30.22      3.81      1.90
 111314       -30.22      45.19      6.16      1 90      54.00
 211314.      -30.22     -45.19      6.16      1.90      54.00
 311314.       30 22     -45.19      6.16      1.90      54.00
```

At this point, the program automatically regenerates the mass properties matrices and dynamic model files via the prompts:

```
 ENTER NAME FOR UPDATED MASS PROPS. FILE ( 7 CHARACTERS MAX.
? MASASSA

 ENTER NAME FOR UPDATED DYNAMIC MODEL ( 7 CHARACTERS MAX.)
? DYASSA
```

The mass properties are now calculated and displayed in the following form:

```
MASS PROPERTIES DEFINITION


 CENTRE OF MASS COORDINATES: XCM=   -.12019E+02
                             YCM =   -.65469E-13
                             ZCM =     .48654E+02


 TOTAL S/C MASS(KG)=    .65571E+04
 MASS OF RF REFLECTOR AND AUXILIARY EQUIPMENT =,     .40320E+04

 MASS OF  133 ENDFITTINGS =    .25270E+03
 MASS OF 218 TYPE  1 TUBES =    .91043E+03
 MASS OF  71 TYPE  2 TUBES =     72662E+03
 MASS OF 176 TYPE  3 TUBES =     18581E+03
 MASS OF 220 TYPE  4 TUBES =    .44949E+03

INERTIAS ABOUT MODEL ORIGIN       INERTIAS ABOUT CM

        XXM =    .41251E+08              XXM =     .25729E+08
        YYM =   .38591E+08               YYM =    .22122E+08
        ZZM =     13589E+08              ZZM =     .12642E+08
        PXY =     15367E-07              PXY =   - 10207E-07
        PXZ =   -.88566E+07              PXZ =     .50223E+07
        PYX =   -.15832E-07              PYX =   -.50537E-08
```

The last user interaction is for definition of the MP data base and matrices files.

```
 INPUT NAME OF MASS PROPS. DATA BASE FILE
? MASEOSA


 INPUT NAME OF MASS PROPERTIES MATRICES FILE
? EOSOUTM
```

2.2.3 Mass Properties Module Programmer Information

The MP module consists of a main and three primary overlays. There are four labeled common blocks that contain the variables and arrays required for module calculations. MASSIN contains data variables brought in through access to the structural model data base file. MASDAT contains the arrays accessed in the mass properties matrices file. PROPS contains 14 properties for up to 10 different types of BAR or ROD structural elements, and MASPP contains the mass and inertia properties calculated during module execution.

Primary overlay (1,0) contains the code required for initialization and termination. The variable ICASE in labeled common FLAGS is used to select either the input or output section of this overlay. If ICASE equals one initialization, an input mode is entered. For ICASE equal to two, the output mode is entered. Overlay (1,0) contains DATA statements to define alphanumeric data used to describe input data and to write to the data base file. The output section also controls display of mass properties information.

Overlay (2,0) contains the code that determines the basic mass and inertia properties. A maximum of 10 element property sets is currently allowed. If more should be required, the dimension of array TUBP must be increased. TUBP contains 10 sets of 14 properties. The properties used in this module are the cross-sectional area (No. 1 in each set) and the material density (No. 8 in each set).

The first operation involves extraction of the reflector and end fitting or hub masses from the concentrated mass records stored in GRIDD (N,5). These calculations are performed through a sequential call to subroutines SUBMASS and MASMAT. SUBMASS controls iteration through all grid points. MASMAT calculates the sum of discrete mass multiplied by distance from the origin (0,0,0) as SX, SY, and SZ. The total mass due to grid masses, x, y, and z inertias, and inertia products is also summed in MASMAT. Each grid in the model requires a call to MASMAT. The end fitting mass for truss models is contained in variable AMNODE. For nontruss models, AMNODE will be zero. At exit from SURMASS, the total reflector mass (REFMAS) and end fitting mass (GMAS) will be defined.

The next set of mass contributions to be determined are for midlink hinges. All elements are interrogated for type IELM (1,N). Tubes that fold have a type number greater than 10. For these tubes the hinge mass (AMHING from the structural model) is used to determine contribution to total mass and inertias. The hinge is assumed at the tube midpoint coordinates.

The element mass properties calculations are performed in subroutine TUBMAS. The arrays IELM, GRIDD, and TUBP are used to obtain each element area, length, density, and mass. Each different type of tube and the cumulative mass of that type are stored in arrays NTUB and TUBMAS, respectively.

The final set of masses is the equipment masses. Arrays DELTA and GRIDD are searched to find each equipment mass, its grid number, and the x, y, and z coordinates of the grid.

The inertias are calculated along with the mass contributions. The final step in the mass calculation is calculation of the center of mass coordinates. This is followed by transformation of the inertia values from the model origin to the center of mass location. This is performed in subroutine CMINER.

Overlay (3,0) contains the code required to change mass records. The equipment masses themselves are assigned to array DELTA (2,50). Each row of DELTA contains the grid identification and its associated equipment mass. The subroutines used in this overlay and their functions are:

CHNGMAS - executive for changing masses
GETCHNG - input and modification of equipment masses
CHAMODL - modify dynamic model file concentrated mass records
LISMASS - interactive display of grid identification, coordinates, and masses

Considerable commentary is provided in the code and will not be repeated here. If masses are modified, the dynamic model file (TAPE2) is searched for appropriate CONM2 records, and the record is changed to reflect the new mass. Each record, whether changed or not, is written in the same format as TAPE3. After all changes are made, TAPE3 is written as a new dynamic model file using subroutine PFM. Similarly, any modified masses are reflected in a change to array GRIDD (n,5). A new mass properties matrices file is generated by writing IELM, GRIDD, NEL, NG, and TUBP to TAPE2 and then to a permanent file, again using subroutine PFM. After executing this section, control passes to Overlay (2,0) to calculate mass properties. The mass properties module flow diagram is shown in Figure 2.2-1.

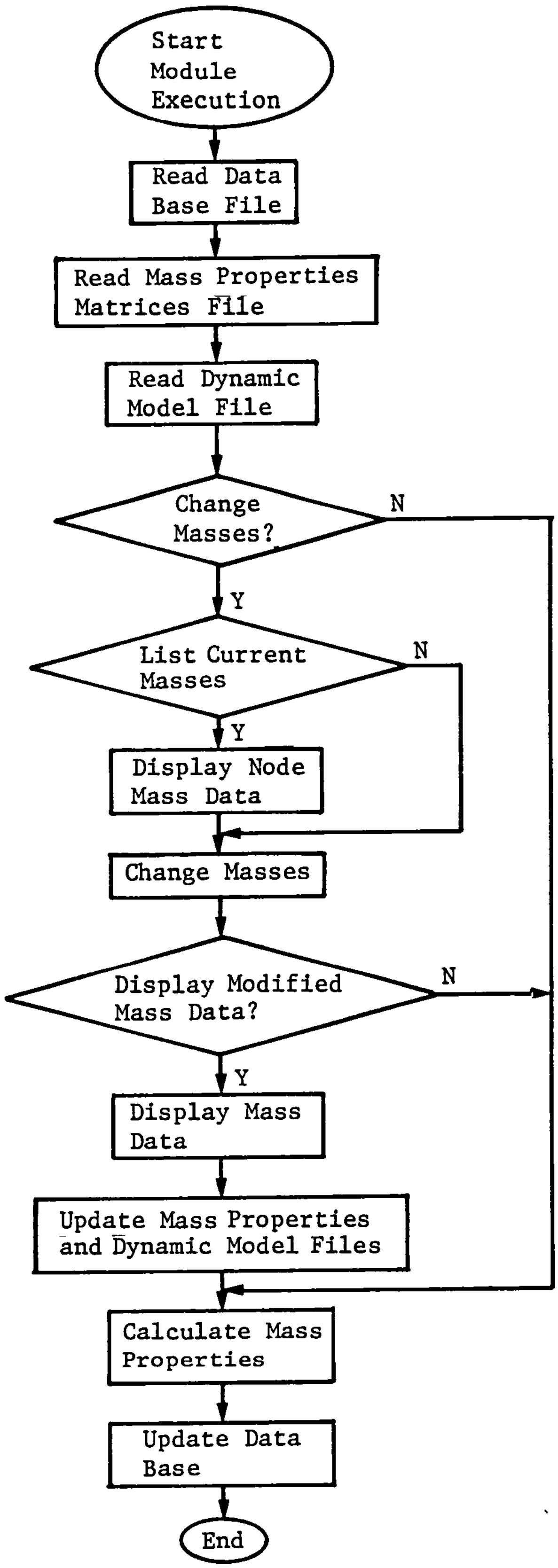

Figure 2.2-1
Mass Properties Module Flow Diagram

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2.3 ENVIRONMENTAL AREAS MODULE

The environmental areas module calculates the total areas projected to aerodynamic and solar radiation pressures. Also, individual structural element areas are used to calculate center of pressure matrices for aerodynamic drag and solar pressure effects. These structural element areas are calculated previously in the appropriate model generator module and are written to the area file. These areas are read into array GRIDA at the start of area module execution. When applicable, the center of pressure coordinates and total areas of a reflector surface (e.g., mesh) are also read from the area file.

2.3.1 Environmental Areas Module Technical Description

The area of the structure is obtained by determining each structural member's length and multiplying by projected width. These calculations are performed in a standalone module that interfaces model generators with the controls module. This interfacing flow is shown in Figure 2.3-1. At this time only the contiguous truss model generator module interface is implemented.

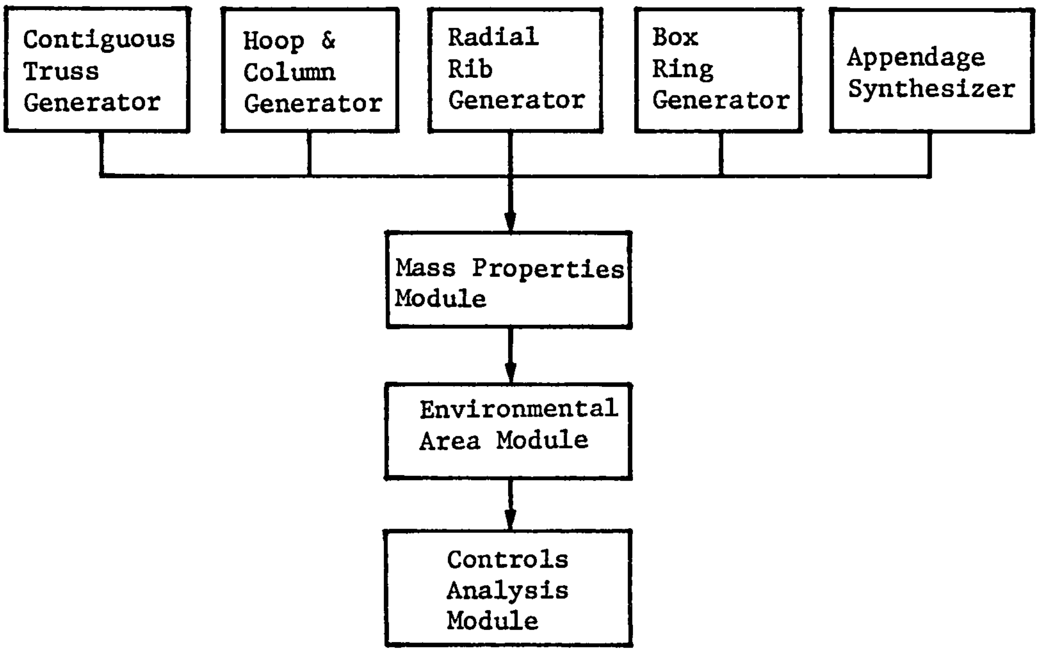


Figure 2.3-1 Structural/Controls Interfacing

The width of each structural member is input during execution of the appropriate model generator. During execution, the grid and element data are generated as necessary to define element endpoint coordinates. These coordinates are used to determine x, y, and z element lengths, which are used with projected width to calculate A_x, A_y, and A_x. Half of each area is allocated to each element and grid. These area data are stored in the array GRIDA for access by the environmental area module.

Each model generator module and the appendage synthesizer module (Ref 1) must create structural geometry and define these equivalent areas. If required, the area of the reflective surface (for antennas) is also calculated in the model generators and added to the areas of the elements. The x, y, z areas of corner fittings are also added to the grid areas.

Figure 2.3-2 shows the model orientations that must be considered in determining cp location. From the orientation of Figure 2.3-2a, a cp in the y and z directions will be obtained from:

[8] $$Y_{cpx} = \frac{\Sigma(A_x \cdot y)}{\Sigma A_x}$$

[9] $$Z_{cpx} = \frac{\Sigma(A_x \cdot z)}{\Sigma A_x}$$

where A_x is the area projected in the x direction. Similarly, Figure 2.3-2b and 2c orientations will give x, y, and z cp coordinates as:

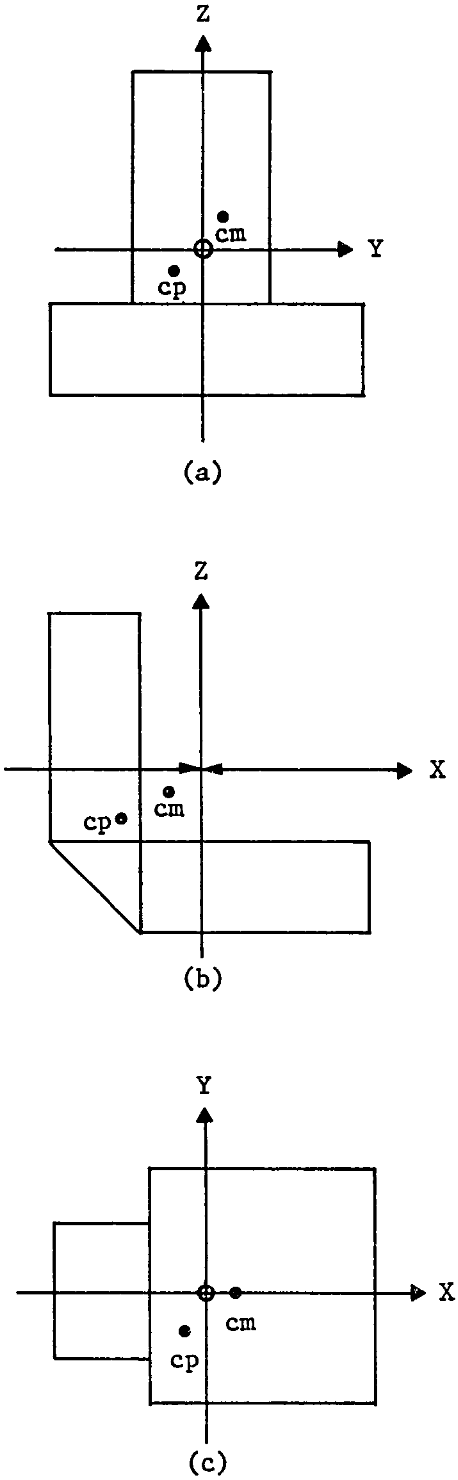
[10] $$X_{cpy} = \frac{\Sigma(A_y \cdot x)}{\Sigma A_y}$$

[11] $$Z_{cpy} = \frac{\Sigma(A_y \cdot z)}{\Sigma A_y}$$

[12] $$X_{cpz} = \frac{\Sigma(A_z \cdot x)}{\Sigma A_z}$$

[13] $$Y_{cpz} = \frac{\Sigma(A_z \cdot y)}{\Sigma A_z}$$

These coordinates are calculated in the environmental area module from the grid and area matrices (GRIDD and GRIDA) that are defined by the model generators.



(a) $Y_{cm} > Y_{cp}$ — $T_z > 0$

$Z_{cm} > Z_{cp}$ — $T_y < 0$

(b) $X_{cm} > X_{cp}$ — $T_z < 0$

$Z_{cm} > Z_{cp}$ — $T_x > 0$

(c) $X_{cm} > X_{cp}$ — $T_y > 0$

$Y_{cm} > Y_{cp}$ — $T_x < 0$

Figure 2.3-2 Structural Model Center-of-Pressure Orientation

Two cp matrices are calculated, one for aerodynamic drag effects and one for solar drag effects. The requirement for two matrices arises from the difference in solar-projected area for a reflective versus nonreflective surface. Because the solar drag is essentially due to momentum exchange, a reflective surface produces elastic collisions. This essentially doubles the solar drag force when compared to a nonreflective material (Ref 4). Included in the cp matrices is the contribution of an rf reflective surface for those LSSs that are antennas. Explanation of the solar area calculation for the EOS model is contained in Para 2.1.1.4.

2.3.2 Environmental Areas Module User Instructions

The module is executed by input of:

BEGIN,,AREAPR

The first prompts ask the user to specify the terminal characteristics from:

```
OENTER BAUD RATE

? 1200
OENTER 1 FOR 4006, 4010, 4012, OR 4013
       2 FOR 4014 OR 4015
    OR 3 FOR 4014 OR 4015 WITH ENHANCED GRAPHICS
    OR 4 FOR TERMINAL OTHER THAN TEKTRONIX
      ?

?4
```

The next prompt is for selection of the area definition mode from:

```
 SELECT AREA DEFINITION MODE--1=MODEL GENERATOR
                              2=MANUAL INPUT


? 1
```

The manual mode is not yet implemented. It is intended to provide growth capability for analyzing spacecraft other than LSSs. It will permit creation of the necessary inputs to the controls analysis module for spacecraft that have no associated model generator. In addition, it will permit input of areas for any auxiliary equipment added in the mass properties module.

The next prompts for the area and mass matrices files are:

```
       INPUT NAME OF AREA MATRICES FILE
? AREAEOS


       INPUT NAME OF MASS PROPERTIES MATRICES FILE
? EOSOUTM
```

The area file is created in the box truss generator module. The mass properties matrices file is from the MP module only if masses were added during a prior execution of the mass properties module. If there are no added masses, this file comes from the generator module. Input of valid file names results in calculation of the total projected areas and center of pressure matrices:

```
AREA PROJECTED TO SOLAR PRESSURE(SQ. M)
   X          Y          Z
 .102E+04   662E+03   .947E+03

CP SOLAR MATRIX
0.         -.706E+01 -.413E+01
-.190E-13 0.         -.168E-13
 .264E+02  .285E+02 0.


AREA PROJECTED TO AERO DRAG(SQ. M)
   X        Y          Z
 .664E+03  .482E+03  .626E+03

CP AERO MATRIX
0.         -.969E+01 -.625E+01
-.293E-13 0.         -.254E-13
 .291E+02  .311E+02 0.
```

The coordinate system for the area outputs is the same as that shown for the model in Section 2.1. The final prompt is for creating the area output file used during execution of the controls analysis module:

```
 INPUT NAME OF AREAGP FILE
? RCDAREA
```

2.3.3 Environment Areas Module Programmer Information

The area module consists of a main program, AREAS, and two subroutines, ACPCAL and MANAREA. Other subroutines required are located in libraries LASSLIB and AVIDLIB. Figure 2.3-3 shows the program flow during execution. Table 2.3-1 contains a description of key variables and arrays.

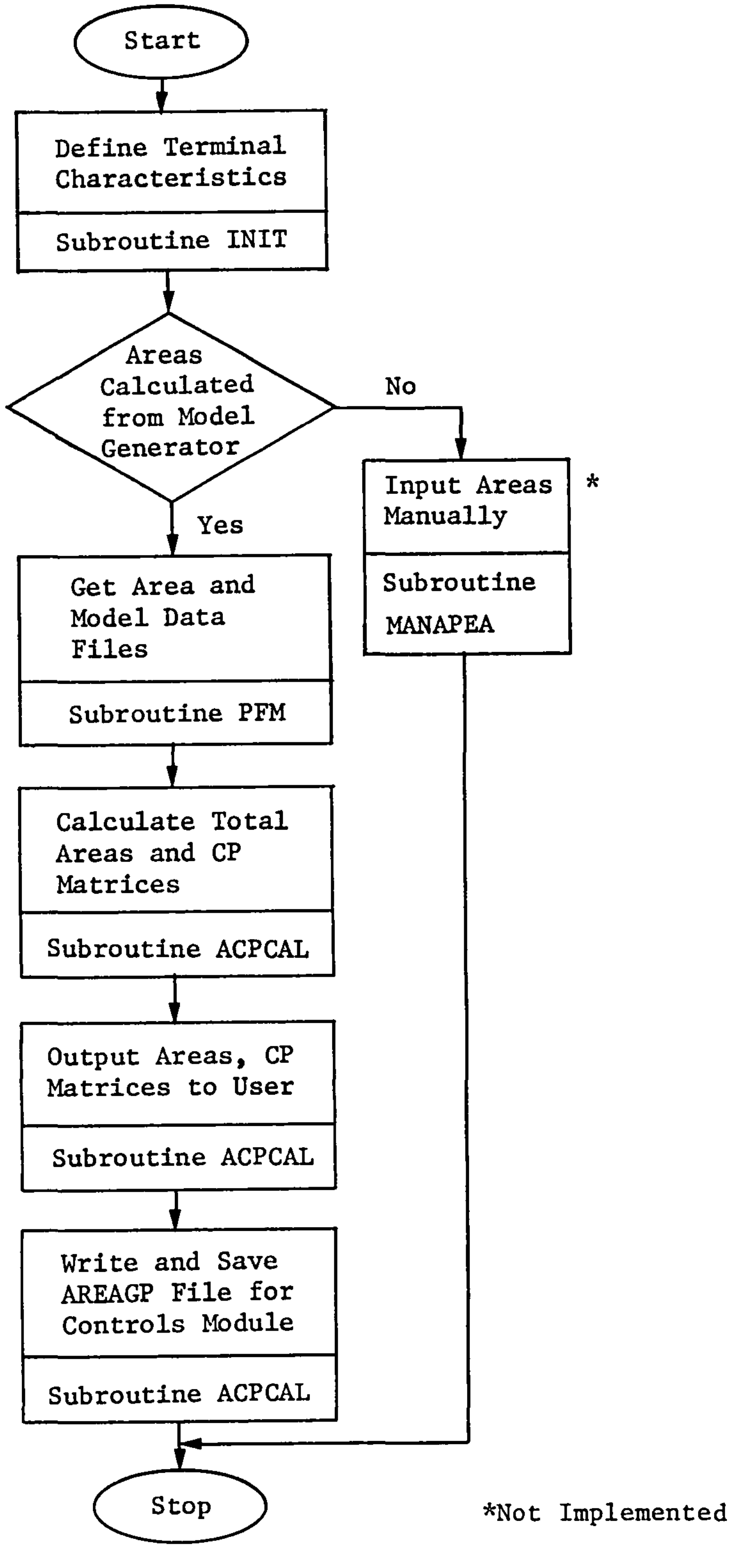


Figure 2.3-3
Environmental Areas Module Flow Diagram

Table 2.3-1 Area Module Array and Variable Definitions

Array/Variable	Definition
GRIDDA (n,1)	x Projected Area at Node
GRIDDA (n,2)	y Projected Area at Node
GRIDDA (n,3)	z Projected Area at None
GRIDDA (n,4) GRIDDA (n,5) GRIDDA (n,6)	Blockage Limit Angles
XM,YM,ZM	Reflector Center of Pressure Coordinates
AXM,AYM,AZM	Reflector Projected Areas
CP (3,3)	Center of Pressure Matrix for Solar Pressure
CPA (3,3)	Center of Pressure Matrix for Aerodynamic Pressure
SUMAX SUMAY SUMAZ	Total Model Projected Areas for Solar Pressure
SUMAXA SUMAYA SUMAZA	Total Model Projected Areas for Aerodynamic Pressure
GRIDD (n,5)	Nodes' Concentrated Mass

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2.4 RIGID-BODY CONTROLS DYNAMICS (RCD) MODULE

The RCD module calculates environmental forces and torques due to atmospheric pressure, solar pressure, and gravity gradient. These forces and torques are used to determine attitude control system (ACS) and orbit-keeping impulse requirements based upon user-defined orbital parameters and control system configuration. The discussion here describes the approach taken to analyze large antennas that can be modeled by the model generators described in Reference 1 and in Section 2.1.

2.4.1 RCD Module Technical Description

The RCD module is a modified version of a module developed originally by General Dynamics Corp (Ref 2). It uses mass, inertia, and area data generated by the mass properties and environmental area modules. It assumes a fixed spacecraft orientation (Fig. 2.4-1) with the initial Euler angles θ, ϕ, and ψ defined by the user. Transformations corresponding to nonzero values of these attitude angles are performed in the subroutines that perform the force and torque calculations. Force and torque calculations can be performed for an Earth-nadir pointing or inertially oriented spacecraft. However, the force and torque equations used accommodate only small Euler angle deviations in roll (ϕ) and yaw (ψ).

2.4.1.1 Atmospheric Drag - Atmospheric drag effects are calculated using the 1976 U.S. standard average atmospheric model. This model is defined for altitudes from 300 to 1000 kilometers. For altitudes greater than 1000 km, the atmospheric mass density is arbitrarily set to zero. The center of pressure matrix, CPA, is input through the environmental areas module output file. This is used along with the dynamic pressure, q, and spacecraft orientation on the orbital path to calculate the aerodynamic forces and torques using the following relationships:

[14] $q = \frac{1}{2}\rho V^2$

where ρ is average atmospheric mass density (kg/m^3), and V is orbital velocity (V_x, m/second).

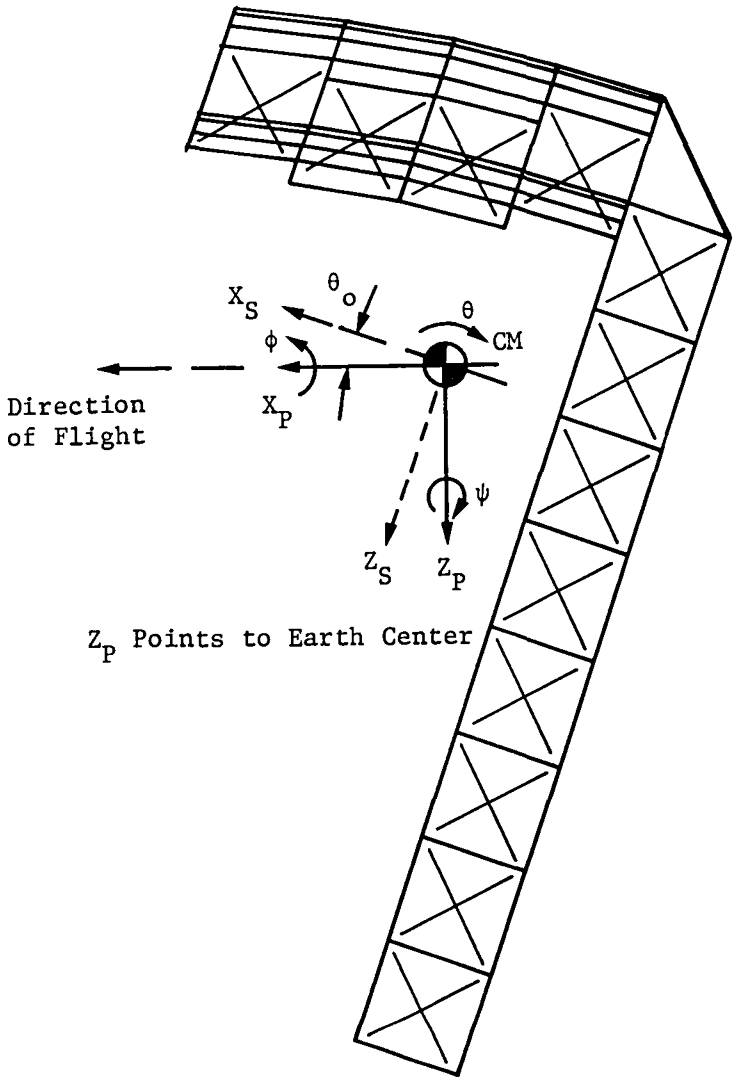


Figure 2.4-1
Flight Orientation with Respect to Principal Axis

[15] $F_x = A_x C_d\ q\ \text{Cos}\theta\text{Cos}\psi$

[16] $F_y = A_y C_d\ q\ \text{Sin}\psi\text{Cos}\phi$

[17] $F_z = A_z C_d\ q\ \text{Sin}\theta\text{Cos}\phi$

[18] $T_x = F_y C_{p23} - F_z C_{p32}$

[19] $T_y = - F_x C_{p13} + F_z C_{p31}$

[20] $T_z = F_x C_{p12} - F_y C_{p21}$

where

$A_{x,y,z}$ = spacecraft-projected areas,
C_d = ballistic drag coefficient,
Cp_{ij} = the effective leverage from the aerodynamic center of pressure to the center of mass.

2.4.1.2 Solar Pressure Effects - The forces and torques on a spacecraft that result from solar pressure are calculated from the general relationships:

[21] $F_j = k\, P_s A_s \text{Cos}^k E$

[22] $T_j = F_j\, L_j$

where

P_s = solar pressure constant (4.6206×10^{-6} N/m^2),
k = 1 for nonreflective surfaces and 2 for reflective surfaces.

As discussed in Section 2.3 the projected area is increased for reflective surfaces when appropriate. Because the solar force is determined from total area and is also a function of position in the orbit, it is impractical to incorporate the cos ^{k}E term. The worst cast (highest force) occurs when k = 1. This is the value used in the module. The solar forces and torques then are:

[23] $F_x = A_{sx} P_s \text{Cos}\beta \text{Cos}(\theta+\varepsilon)\text{Cos}\psi$

[24] $F_y = A_{sy} P_s \text{Sin}\beta \text{Cos}\psi \text{Cos}\phi$

[25] $F_z = A_{sz} P_s \text{Cos}\beta \text{Sin}(\theta+\varepsilon)\text{Cos}\phi$

[26] $T_x = F_y Cp_{s23} - F_z Cp_{s32}$

[27] $T_y = F_x Cp_{s13} + F_z Cp_{s31}$

[28] $T_z = F_x Cp_{s12} - F_y Cp_{s21}$

where

$A_{sx,y,z}$ = areas projected to solar pressure,
β = the solar incidence angle on the orbital plane,
θ, ϕ , ψ = the spacecraft Euler angles,
Cp_s = the effective leverage from the solar center of pressure to vehicle CM,
ε = orbit anomaly angle 3.

2.4.1.3 Gravity Gradient Torque - Gravity gradient causes only a torque. It is calculated from:

$$[29] \quad T_{GGX} = 3\omega_0^2\Big[-\mathrm{Sin}\theta\mathrm{Cos}\theta\mathrm{Cos}\phi I_{xy} + \mathrm{Sin}\theta\mathrm{Cos}\theta\mathrm{Sin}\phi I_{xz} + \mathrm{Sin}\phi\mathrm{Cos}\phi\mathrm{Cos}^2\theta(I_{zz} - I_{yy}) + (\mathrm{Cos}^2\phi - \mathrm{Sin}^2\phi)\mathrm{Cos}^2\phi I_{yz}\Big]$$

$$[30] \quad T_{GGY} = 3\omega_0^2\Big[(\mathrm{Sin}^2\theta - \mathrm{Cos}^2\phi\mathrm{Cos}^2\theta)I_{xz} - \mathrm{Sin}\phi\mathrm{Cos}\phi\mathrm{Cos}^2\theta I_{xy} - \mathrm{Sin}\theta\mathrm{Sin}\phi\mathrm{Cos}\theta I_{yz} - \mathrm{Sin}\theta\mathrm{Cos}\theta\mathrm{Cos}\phi(I_{xx} - I_{zz})\Big]$$

$$[31] \quad T_{GGZ} = 3\omega_0^2\Big[\mathrm{Sin}\phi\mathrm{Cos}\phi\mathrm{Cos}^2\theta I_{xz} + \mathrm{Sin}\theta\mathrm{Cos}\theta\mathrm{Cos}\phi I_{yz} - \mathrm{Sin}\theta\mathrm{Cos}\theta\mathrm{Sin}\phi(I_{yy} - I_{xx}) + (\mathrm{Sin}^2\phi\mathrm{Cos}^2\theta - \mathrm{Sin}^2\theta)I_{xy}\Big]$$

where ω_0 = orbital angular velocity (rad/second).

2.4.1.4 Attitude Control Impulse Requirement - The x, y, and z components of each force and torque are determined for each of 60 points in the orbit. These are used to determine the orbit-keeping impulse requirement, ACS momentum buildup, ACS impulse requirement to counter momentum, and total number of reaction control system (RCS) thruster pulses to perform orbit keeping and attitude control. In addition to the impulse required to overcome environmental perturbations, impulse expenditure due to ACS limit cycle and required reorientation maneuvers is included.

Orbit-Keeping Impulse - The orbit keeping impulse is obtained by integrating the total environmental force components over an orbit using:

$$[32] \quad \mathrm{ORKEEP}_i = \sum_{n=1}^{60} \left| F_t(i,n) + F_t(i, n-1) \right| \Delta t/2$$

where F_t = total environmental force (N).

ACS Momentum Buildup - The total angular momentum resulting from environmental perturbations is determined from:

$$[33] \quad H_i = \sum_{n=1}^{60} \left| L_t(i,n) + L_t(i, n-1) \right| \Delta t/2$$

where L_t = total environmental torque component (N-m).

ACS Impulse Requirement - The ACS impulse requirement is determined by dividing the total momentum buildup by the effective thruster leverage (R_i). The value of R_i is obtained from:

$$[34] \quad R_i = \Sigma F_{ij} \bar{S}_i / \Sigma F_{ij}$$

where

R_i = effective leverage of a j component force, producing torque about the i axis (m),
S_i = distance from the thruster location to the i axis (m).

The impulse requirement for the i axis is then:

$$[35] \quad L_i = \frac{(H_i - H_R)\Delta t}{R_i}$$

where H_R = the momentum capability per orbit from CMGs, AMCDs, etc (N-m-second)

Limit-Cycle Losses - From Reference 2, these losses for an RCS system can be approximated.

Depending upon the attitude control accuracy requirement and RCS minimum impulse, limit-cycle losses can exceed the environment reaction requirement. Both the attitude accuracy requirement and the RCS minimum impulse are input data supplied by the user. The limit cycle losses are given by:

$$[36] \quad L_{tc} = T/4 \sum_{\ell=1}^{3} R_\ell \, L_{m\ell}{}^2/(\varepsilon_\ell I_{\ell\ell})$$

where

L_{tc} = the impulse per orbit requirement due to RCS attitude control limit cycling,

$L_{m\ell}$ = the user-supplied ℓ axis RCS thruster minimum linear impulse,
ε_ℓ = the ℓ axis attitude accuracy requirement,
$I_{\ell\ell}$ = the spacecraft ℓ axis moment of inertia.

The impact of a stringent accuracy requirement and high thruster minimum impulse in causing a high RCS impulse or fuel requirement is evident.

Maneuver requirements are estimated from user-supplied maneuver angular acceleration and rate requirements:

$$[37] \quad L_{tm} = 2N_m \sum_{\ell=1}^{3} \left[\frac{(\omega_m^3)_\ell \; I_{\ell\ell}}{R_\ell} \right]$$

where

L_{tm} = the maneuver impulse per orbit requirement,
N_m = the user-supplied number of maneuvers per orbit,
R_ℓ = thrust leverage about the ℓ axis,
$I_{\ell\ell}$ = the ℓ axis moment of inertia,
ω_m = the axis spacecraft maneuver rate requirement, rad/second.

The total RCS impulse is:

[38] $L_t = L_{te} + L_{tc} + L_{tm}$

The total impulse for attitude control is obtained by summing the impulse requirement due to environmental perturbations, limit-cycle losses, and maneuvering losses. Using the minimum impulse bit for the RCS thrusters, the total number of pulses per orbit and total for mission lifetime (TFUEL-yrs) can be predicted from:

[39] $N_p = \sum_{i=1}^{3} L_{ti}/(LM_i \cdot R_i)$

[40] $N_{PT} = \sum_{i=1}^{3} N_p \cdot T_m/t$

The total number of pulses for orbit keeping is calculated in a similar fashion and added to obtain total number of thruster pulses for a given RCS configuration. It should be noted that the value for the minimum impulse bit is the impulse that is obtainable after any thrust vectoring loss.

The existing capabilities of defining RCS thrusters do not permit the existence of forces in both positive and negative directions at a single node location. This required circumventing the existing annular momentum control device (AMCD) sizing software when analyzing the spacecraft concepts developed during this contract.

When analyzing spacecraft modeled by an automatic model generator, all masses except the propellant masses should be entered in the mass properties module. The GTSM matrix should be used to input the propellant masses and equipment areas, if desired. This permits use of the existing automatic propellant sizing routine.

2.4.2 RCD Module User Instructions

The following sample run is for the EOS baseline mission. Execution of the RCD module starts by input of:

BEGIN,,LASSE

The first user prompts define terminal characteristics from:

```
OENTER BAUD RATE

? 1200
OENTER 1 FOR 4006, 4010, 4012, OR 4013
       2 FOR 4014 OR 4015
    OR 3 FOR 4014 OR 4015 WITH ENHANCED GRAPHICS.
     OR 4 FOR TERMINAL OTHER THAN TEKTRONIX
        ?
? 4
```

The user is now requested to input the names of the RCD data base file, dynamic model file, and area matrices file.

```
 ENTER NAME OF INPUT DATA BASE FILE
    0 - DEFAULT FILE (LASSDB)
  PFN - PERMANENT FILE NAME
? EOSMIS1
 ENTER NAME OF INPUT DYNMOD FILE
    0 - DEFAULT FILE (DYNMOD)
  PFN - PERMANENT FILE NAME
? DYEOS
 ENTER NAME OF INPUT AREAGP FILE
    0 - DEFAULT FILE (AREAGP)
  PFN - PERMANENT FILE NAME
? RCDAREA
```

The next prompt results in display of the RCD module inputs obtained from the data base and permits their modification.

```
1
+         EOS BASELINE DESIGN--POST ORBITAL TRANSFER

 RIGID-BODY CONTROL DYNAMICS (RCD) INPUT

    7 00000E+05     1  H       - ORBIT ALTITUDE (METERS)
     1 7100         2  INCLIN  - ORBIT INCLINATION (RADIANS)
    0               3  PSIN    - ORBIT ASCENDING NODE (RADIANS)
     2 3000         4  BETA    - ORBIT SOLAR INCIDENCE ANGLE (DEG )
     10 000         5  TFUEL   - TIME BETWEEN REFUELING (YEARS)
     21560          6  ISP     - SPECIFIC IMPULSE (NEWTON-SECONDS PER KILOGRAM)
     2 3000         7  CD      - AERODYNAMIC DRAG COEFFICIENT
     2 0000         8  IE      - ORIENTATION FLAG (= 1  FOR INERTIAL OR = 2  FOR EARTH)
    0               9  OPSI    - EULER ANGLES (3) DEFINING ORIENTATION OF SPACECRAFT FOR BOTH
      32740        10  OTHETA      INERTIAL AND EARTH   OPSI IS ROTATION ABOUT THE Z AXIS.
    0              11  OPHI        OTHETA ABOUT THE NEW Y AXIS. OPHI ABOUT X   (RADIANS)
    1 00000E-06    12  WM3(1) - SPACECRAFT MANEUVER RATE REQUIREMENT X, Y, Z COMPONENTS
    1 00000E-06    13  WM3(2)      RESPECTIVELY (RADIANS PER SECOND)
    1 00000E-06    14  WM3(3)
    1 00000E-06    15  ALFAM3 - SPACECRAFT MANEUVER ACCELERATION REQUIREMENT X, Y, Z
    1 00000E-06    16     (2)      COMPONENTS RESPECTIVELY (RADIANS PER SECOND SQUARED)
    1 00000E-06    17     (3)
      10000        18  NM      - NUMBER OF MANEUVERS PER ORBIT
    1 00000E-03    19  E3(1)   - INERTIAL ATTITUDE ACCURACY REQUIREMENT X, Y, Z COMPONENTS
    1 00000E-03    20  E3(2)       RESPECTIVELY (RADIANS)
    1 00000E-03    21  E3(3)
    0              22  UAS3(1)- UNIT VECTOR ALONG AMCD SPIN AXIS X, Y, Z COMPONENTS
    0              23  UAS3(2)     RESPECTIVELY
     1 0000        24  UAS3(3)
    1 00000E-02    25  GAMMA   - AMCD PIVOT AXIS ANGULAR RANGE (RADIANS)
     330 00        26  RO      - AMCD UNIT WHEEL RADIUS (METERS)
     1 1000        27  EMA     - RATIO OF TOTAL TO DOUBLE WHEEL MASS
     200 00        28  KU      - AMCD MASS SIZING PROPORTIONALITY FACTOR (METERS PER SECOND)
     1 0000        29  NORDES  - NUMBER OF ORBITS BETWEEN DESATURATIONS
     500 00        30  MACS    - MASS OF ACS EXCLUDING AMCD ACTUATION ASSEMBLY (KILOGRAMS)
     1000 0        31  PACS    - POWER REQUIREMENT OF ACS EXCLUDING AMCD SPIN AXIS (WATTS)
    2 00100E-02    32  LM(1)   - MINIMUM LINEAR IMPULSE BIT WHEN CONTROLLING TORQUE,
    2 00100E-02    33  LM(2)       X, Y, Z AXES RESPECTIVELY (NEWTON-SECONDS)
    2 00100E-02    34  LM(3)
     8 0000        35  NRCSGP - NUMBER OF THRUSTER GRIDPOINTS (= NUMBER OF ROWS IN RCSMAT)
OENTER 0 IF INPUT IS OK,
      1 TO CHANGE DATA ITEMS VIA THE KEYBOARD,
      7 TO ENTER A NEW TITLE,
   OR 9 TO RETURN TO THE EXEC.
     ?
? 0
```

If any parameters are modified, the parameters are displayed again, and the process is repeated until the user accepts the orbit and control system configuration. Next, the RCS matrix is displayed showing the grid identification numbers where thrusters will be located. The values for thruster forces shown do not correspond to the actual RCS design as discussed previously. The locations are used for calculating the effective thruster leverage. The actual forces are not useful for sizing thruster force levels if gimballed systems are used, as with the EOS spacecraft.

```
1
+        EOS BASELINE DESIGN--POST ORBITAL TRANSFER

                   1            2           3           4           5           6           7
   ROW      GRIDPOINT         FYX         FZX         FXY         FZY         FXZ         FYZ

     1    1 11314E+05 -667 00      1334 0     -1334 0     0            1334 0     0
     2    2 11314E+05 -667 00      1334 0     0           -667 00      1334 0     -667 00
     3    3 11314E+05 -667 00     -1334 0     -1334 0     0           -1334 0     0
     4    4 11314E+05 -667 00     -1334 0     0           -667 00     -1334 0     -667 00
     5    5 00031E+05  667 00      667 00      667 00     0             667 00    0
     6    5 00032E+05  667 00     -667 00      667 00     0            -667 00    0
     7    5 00047E+05  667 00      667 00      667 00      667 00       667 00     667 00
     8    5 00048E+05  667 00     -667 00      667 00      667 00      -667 00     667 00
OENTER 0 IF INPUT IS OK,
       1 TO CHANGE DATA ITEMS VIA THE KEYBOARD,
       2 TO ENTER A NEW TITLE,
       3 TO CHANGE NUMBER OF ROWS IN RCSMAT,
    OR 9 TO RETURN TO THE EXEC,
     ?
? 0
```

The next prompt permits display of the mass and inertia properties fed in by the area and data base files:

```
OENTER 1 IF YOU WISH TO REVIEW CATEGORY 2 INPUT ITEMS
       0 IF NOT
     ?
? 1
1
+          EOS BASELINE DESIGN--POST ORBITAL TRANSFER

 RCD CATAGORY 2 INPUT ITEMS

     6385 1          1  TWRM   - TOTAL WEIGHT OF THE SPACECRAFT EXCLUDING RCD (KILOGRAMS)
    -1202 5          2  BXM    - SPACECRAFT CENTER OF MASS FOR TWRM X, Y, Z COORDINATES
   -6 60927E-12      3  BYM        RESPECTIVELY (CENTIMETERS)
     4872 9          4  BZM
    2 48449E+07      5  XXM    - MOMENT OF INERTIA XX FOR TWRM (KILOGRAM-METERS SQUARED)
    2 13266E+07      6  YYM    - MOMENT OF INERTIA YY FOR TWRM (KILOGRAM-METERS SQUARED)
    1 22171E+07      7  ZZM    - MOMENT OF INERTIA ZZ FOR TWRM (KILOGRAM-METERS SQUARED)
   -9 82645E-09      8  PXYM   - PRODUCT OF INERTIA XY FOR TWRM (KILOGRAM-METERS SQUARED)
    4 83656E+06      9  PXZM   - PRODUCT OF INERTIA XZ FOR TWRM (KILOGRAM-METERS SQUARED)
   -4 73138E-09     10  PYZM   - PRODUCT OF INERTIA YZ FOR TWRM (KILOGRAM-METERS SQUARED)
     1 0000         11  KALKTK - PROP  TANK M  AND A  FLAG (>0 USER DEF , =0 PROP , <0 AUTO )
     8 0000         12  NOPROP - NUMBER OF PROPELLANT MASSES
    0               13  NMAMCD - NUMBER OF AMCD MASSES
     8 0000         14  ANBAYS - ANALYSIS NUMBER OF BAYS
     133 00         15  NOGPAR - NUMBER OF GRIDPOINTS IN ANALYSIS (= NO  OF ROWS IN GPAREA)
OENTER 0 IF INPUT IS OK,
       1 TO CHANGE DATA ITEMS VIA THE KEYBOARD,
       2 TO ENTER A NEW TITLE,
    OR 9 TO RETURN TO THE EXEC
     ?
? 0
```

The next input section permits definition of the thruster propellant masses:

```
1
+        EOS STUDY BASELINE MISSION

                 1             2             3             4             5
   ROW       GRIDPOINT       MASS         X AREA        Y AREA        Z AREA

      1   1.11314E+05   30.000      0.            0.            0.
      2   2.11314E+05   30.000      0.            0.            0.
      3   3.11314E+05   30.000      0.            0.            0.
      4   4.11314E+05   30.000      0.            0.            0.
      5   5.00031E+05   15.000      0.            0.            0.
      6   5.00032E+05   15.000      0.            0.            0.
      7   5.00047E+05   15.000      0.            0.            0.
      8   5.00048E+05   15.000      0.            0.            0.
OENTER 0 IF INPUT IS OK,
       1 TO CHANGE DATA ITEMS VIA THE KEYBOARD,
       2 TO ENTER A NEW TITLE,
       3 TO CHANGE NUMBER OF PROPELLANTS,
       4 TO CHANGE NUMBER OF AMCD MASSES,
    OR 9 TO RETURN TO THE EXEC.
     ?
? 0
```

The values shown in these cp matrices differ from the values displayed in the environmental areas module. The matrices in the environmental areas module are based on the model origin, but these are based on the model center of mass. This transformation is performed in RCD because the model CM may be modified in the RCD module. The area and cp matrices are now displayed.

```
 ENTER 1 IF YOU WISH TO REVIEW AREA PROPERTIES
       0 IF NOT
? 1
```

PROJECTED AREA AND CP MATRIX FOR SOLAR PRESSURE

```
1
+        EOS STUDY BASELINE MISSION


                  1            2            3
   ROW     X PROJ. A.   Y PROJ. A.   Z PROJ. A.

     1    1023.9       661.65       946.91
0ENTER 0 IF PROJECTED AREAS ARE OK,
    OR 1 TO CHANGE DATA ITEMS VIA THE KEYBOARD.
     ?
? 0
1
+        EOS STUDY BASELINE MISSION


                  1            2            3
   ROW

     1   0.           -4.71059E-14  22.283
     2   -4.9678       0.           20.192
     3   -7.8961      -4.92841E-14  0.
0ENTER 0 IF THE CP MATRIX IS OK,
    OR 1 TO CHANGE DATA ITEMS VIA THE KEYBOARD.
     ?
? 0
```

AREAS PROJECTED TO AREA DRAG

```
1
+        EOS STUDY BASELINE MISSION


                  1            2            3
   ROW     X PROJ. A.   Y PROJ. A.   Z PROJ. A.

     1    663.97       481.69       625.54
0ENTER 0 IF PROJECTED AREAS ARE OK,
    OR 1 TO CHANGE DATA ITEMS VIA THE KEYBOARD.
     ?
? 0
1
+        EOS STUDY BASELINE MISSION


                  1            2            3
   ROW

     1   0.           -3.68136E-14  19 678
     2   -2.3312       0            17.616
     3   -5.7747      -4.06487E-14  0.
0ENTER 0 IF THE CP MATRIX IS OK,
    OR 1 TO CHANGE DATA ITEMS VIA THE KEYBOARD.
     ?
? 0
```

This completes the input section. The module now performs all calculations associated with the impulse requirements and displays the following outputs. The orbit-keeping impulse is the time integral of total force on the spacecraft. The ACS impulse is the time integral of ACS momentum minus any reaction wheel momentum, divided by the effective RCS lever arm for each axis. The values shown do not include limit-cycle losses or maneuver requirements.

	X-AXIS	Y-AXIS	Z-AXIS
TOTAL STATIONKEEPING IMPULSE	.16391E+02	.47263E+00	.11236E+02
ACS IMPULSE REQUIREMENT	.36082E+03	.15273E+05	.88771E+02

```
GRAVITY GRADIENT COMPONENTS (X,Y,Z)
2    .42149E-14    -.30190E-01    .14315E-14
```

Interactive plots of forces and torques may now be displayed, as shown in Figures 2.4-2, 2.4-3, and 2.4-4. (To display these plots at sites other than Martin Marietta Denver Aerospace, refer to Section 2.4.3.)

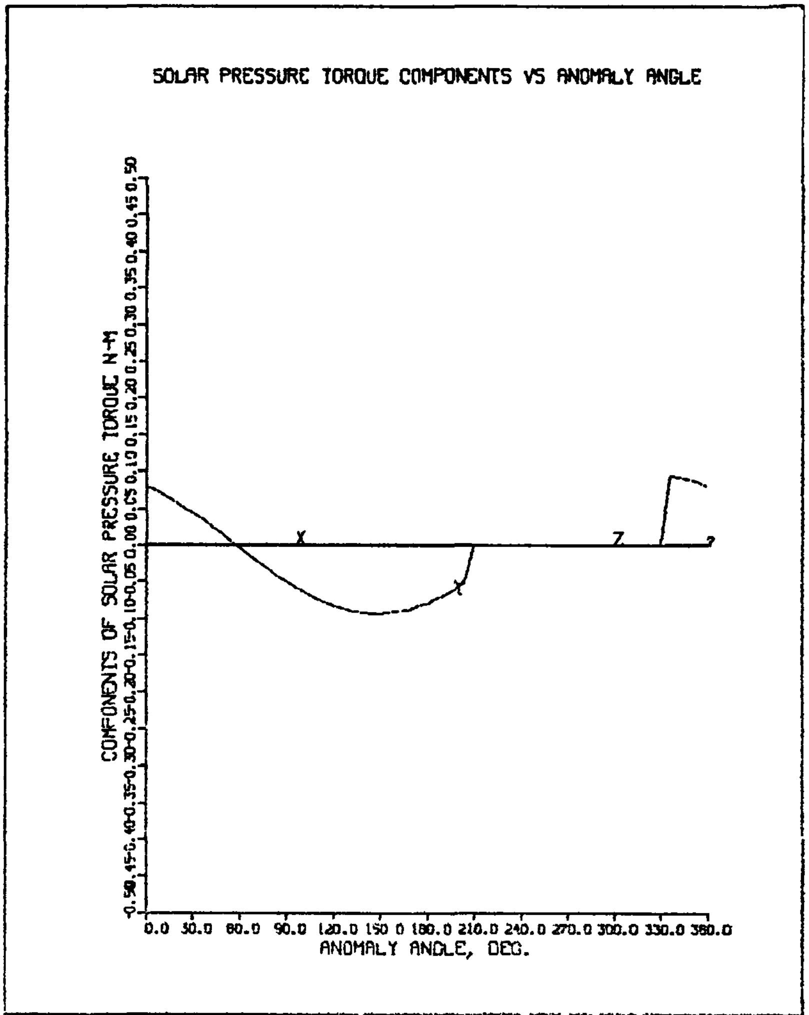


Figure 2.4-2 EOS Baseline Solar Torque Plot

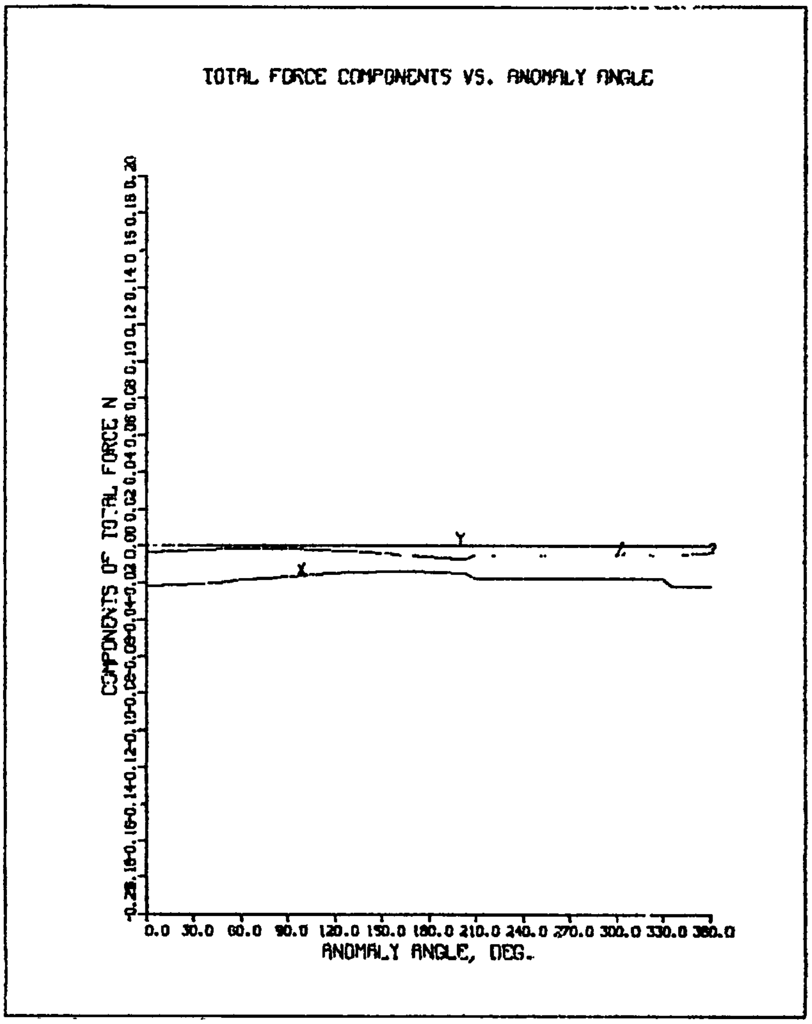


Figure 2.4-3
EOS Baseline Total Environmental Forces Plot

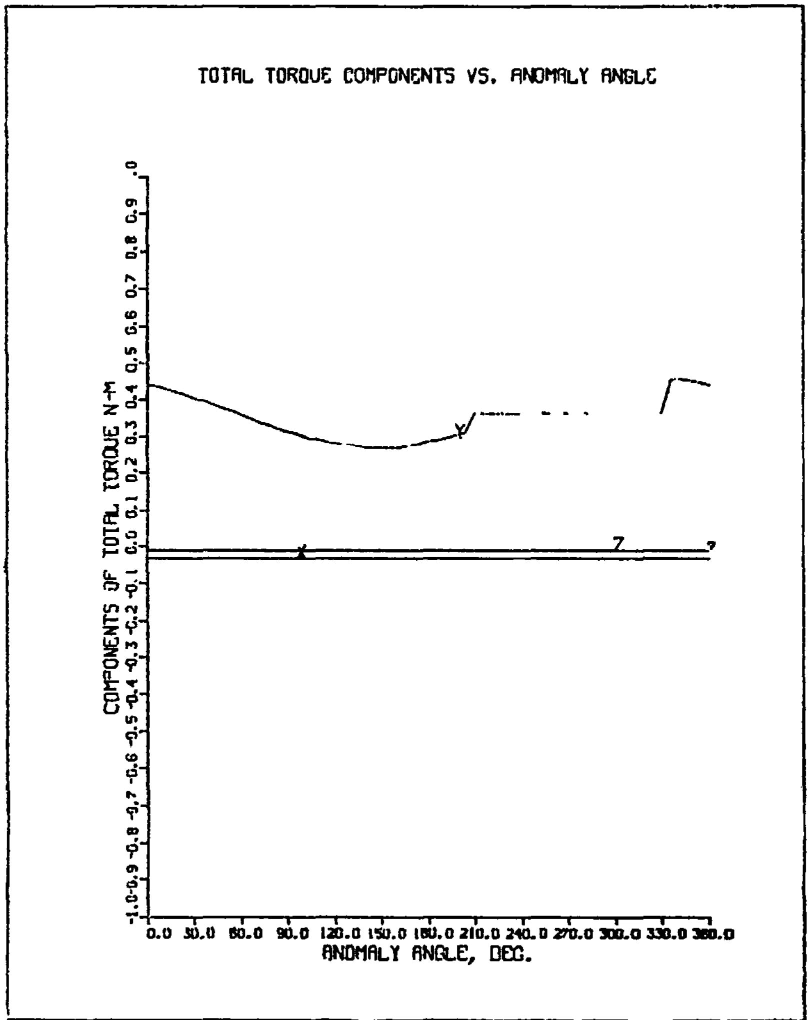


Figure 2.4-4
EOS Baseline Total Environmental Torques Plot

An additional tabular listing of forces, torques, etc may be obtained at the end of module execution. This is discussed at the end of this section.

The user is now given the opportunity to size the RCS system. If sizing is desired, RCS design requirements are displayed as follows. The number of pulses is the sum of the total impulses shown above divided by the minimum impulse bit and effective RCS lever arm for each axis.

```
 DO YOU WISH TO SIZE RCS SYSTEM
? Y


NUMBER OF THRUSTER PULSES PER ORBIT FOR ATTITUDE
CONTROL IS     16865.


NUMBER OF PULSES PER ORBIT FOR STATION
KEEPING IS      1404.


TOTAL PULSES FOR MISSION LIFETIME IS  .9722E+08
TOTAL PROPELLANT MASS WITHOUT VECTORING LOSS(KG)     90.228
THE PROPELLANT CAPABILITY RATIO =       2.0

+     EOS BASELINE DESIGN--POST ORBITAL TRANSFER

            THE PROPELLANT MASS REQUIRED (KILOGRAMS) = 9.814E+01
            THE PROPELLANT CAPABILITY RATIO =          1.834E+00
            THE AUTOMATIC PROPELLANT MASS FIX RATIO =  5.998E-01
0ENTER 1 IF CAPABILITY RATIO(S) O.K.
       2 TO INVOKE THE AUTOMATIC FIX
       3 TO INPUT YOUR OWN FIX RATIOS
    OR 4 TO RETURN TO THE EXECUTIVE.
     ?
```

The total propellant mass shown is the value that would be required for a 10-year mission (input item No. 5), assuming no vectoring losses. The EOS concept uses gimballed thrusters. The worst case for gimballing losses reduces the effective axis thrust by 50 percent ($\cos^2[45]$). Including limit-cycle and maneuver losses, the baseline propellant capability of 180 kg will meet requirements of all four EOS missions. Each mission's required propellant is shown in Table 2.4-1.

Table 2.4-1 EOS Attitude Control Requirements

Mission	Per Orbit		
	Orbit Keeping, n seconds	Attitude Control, nm seconds	Lifetime Propellant Mass, kg
1	27	309	82
2, 3	32	473	128
4β = 0 deg	26	297	79
β = 90 deg	28	535	154

The next user prompt permits performance of another controls analysis:

```
ENTER A 1 IF YOU WISH TO RUN ANOTHER CASE
OR A 0 IF NOT
```

If no more analyses are desired, the user is prompted to define names of the data files, either those used for input or new files if modifications have been made during the analysis. Module execution is now terminated.

```
? 0
 ENTER NAME DATA BASE FILE IS TO BE REPLACED AS
    0 - DEFAULT FILE (LASSDB)
  PFN - PERMANENT FILE NAME
? EOSMIS1

 ENTER NAME DYNMOD FILE IS TO BE REPLACED AS
    0 - DEFAULT FILE (DYNMOD)
  PFN - PERMANENT FILE NAME
? 0
ENTER NAME AREAGP FILE IS TO BE REPLACED AS
    0 - DEFAULT FILE (AREAGP)
  PFN - PERMANENT FILE NAME

? 0
```

As mentioned previously, a complete tabular listing of input and output data is available. To display this output interactively, the following commands are required when running under the CDC NOS operating system:

```
REWIND, LPRINT.
COPY, LPRINT.
```

For transferring the data to a line printer the following commands should be entered:

```
REWIND, LPRINT.
DELIVER.__________B1232________ (your name)
ROUTE, LPRINT, DC = PR.
```

Routing the output in this manner eliminates the local version of file LPRINT from the current user session. Section 3.0 contains a listing of the LPRINT file for the EOS baseline (Mission 1).

2.4.3 RCD Module Programmer Information

Previous programmer information for the RCD module software has been documented by General Dynamics and Martin Marietta Denver Aerospace (Ref 1 and 6). New software developed under this contract contains considerable comment. Martin Marietta Denver Aerospace uses the DISSPLA software package for interactive plotting and display. The calls to DISSPLA must be replaced by corresponding calls to that display utility used at the user's location. A functional description of each DISSPLA subroutine used is contained in the code in subroutine SOLRPR. The previous RCD module existing at LaRC should be replaced or interfaced with this version to perform the analyses described here.

2.5 CONTIGUOUS BOX TRUSS DEPLOYMENT MODULE

This module allows the user to take a structural model of an EOS-type LSS, redefine the geometry, and display the structure for various deployment stages. Mass properties of the spacecraft at each stage of deployment are calculated and output.

2.5.1 CBT Deployment Module Technical Description

To use the program, two input files are required: a mass properties file and a file of deployment instructions. The mass properties file should be from the box truss model generator program to obtain usable output from BTDEPLY.

The deployment instruction file is created by this program, so there is no deployment instruction file the first time a model is run through this program. The user must input the data needed to define the spacecraft deployment sequence. On subsequent runs using the same model, the deployment instruction file may be read in and modified for use, or a new file of deployment instructions may be created. Names of both the mass properties and deployment instruction files will be requested at the start of program execution.

The deployment instruction file specifies the steps needed to simulate spacecraft deployment by defining a volume about a portion of the spacecraft and how to move that volume (and the included portion of the spacecraft). The volume is defined by maximum and minimum values in the spacecraft's x, y, and z directions. The program will search for any grid points located within that volume and move these grid points as specified. These grid points may be translated in any direction or rotated about a line parallel to one of the coordinate axes and passing through any point.

There are three arrays within the deployment instruction file. An example of each is given in Section 2.5.2, User Instructions. The first array sets flags to determine if a picture is drawn and mass properties are saved for each deployment step. A description of each deployment step may also be included. The second array is the volume matrix, which defines a volume in space that contains the spacecraft nodes to be moved for each deployment step. Defining the volumes requires the user to know the coordinates of all the spacecraft nodes. The third array specifies how the volume for each deployment step is to be moved.

During program execution, the deployment instructions are carried out beginning with the last step and stepping backward to the first one. For this reason, it is necessary to set up the deployment instruction file with the last step being the fully deployed model (or one fold from fully deployed) and Step 1 being the completely folded model. If the user has requested a picture of a particular step, the structure configuration at that step is shown, as are corresponding mass and inertia values. Examples of the program output are shown in Figures 2.5-1, 2.5-2, and 2.5-3.

Figure 2.5-1 shows the fully deployed model (with the feed mast coming out of the paper). Note that the coordinate system shown differs from that of Figure 2.1-4 because of a 90-deg rotation about the spacecraft y axis. This was done to obtain a view of the spacecraft dish surface. Also, the axes shown are for direction reference only, not to indicate node coordinate values. The second page shows one side of the surface folded in. This was accomplished by defining a control volume around the six nodes on one side of the surface. The volume was then moved in toward the center of the structure. The third display shows the other side folded in.

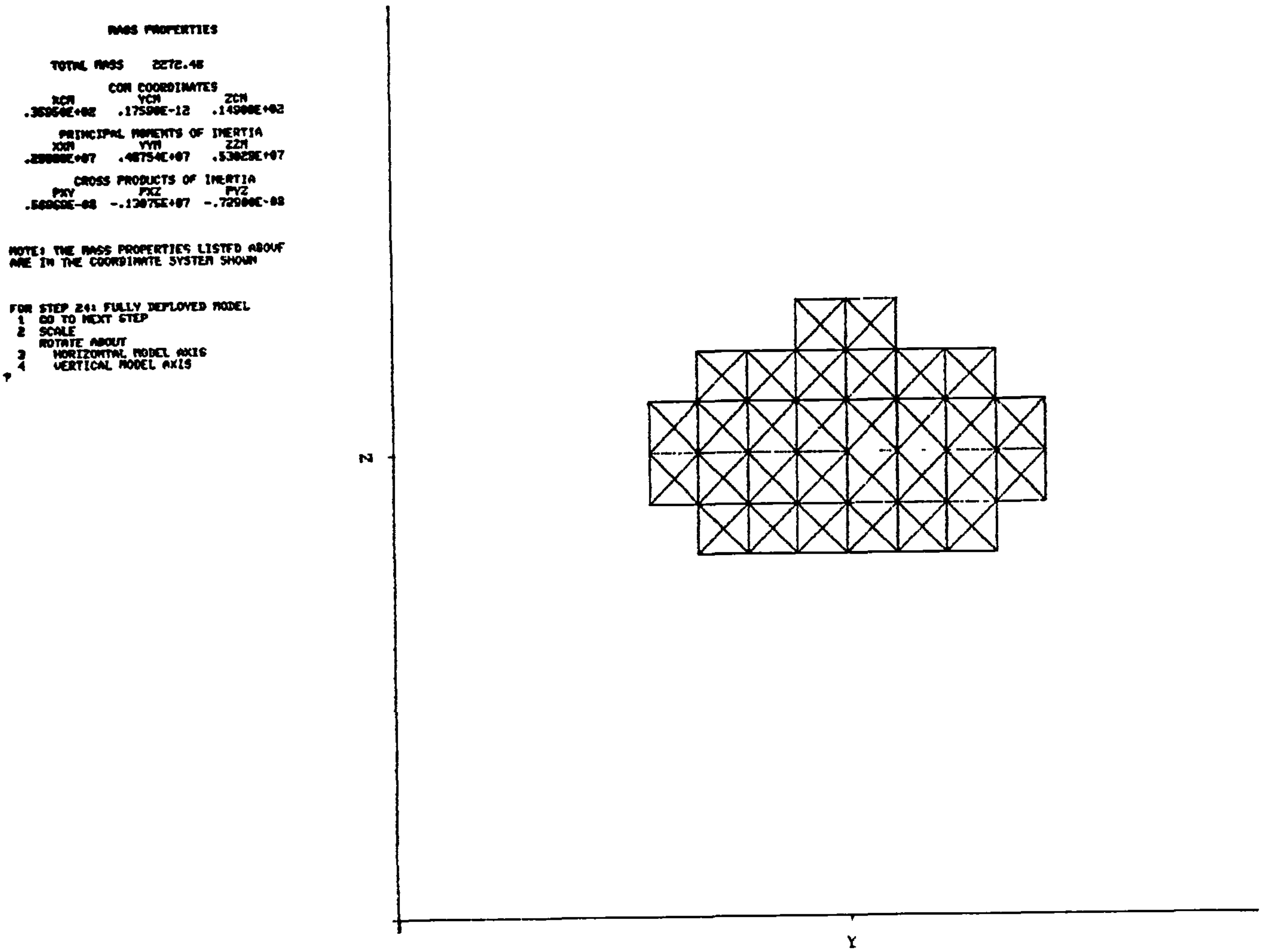


Figure 2.5-1 Box Truss Model Fully Deployed

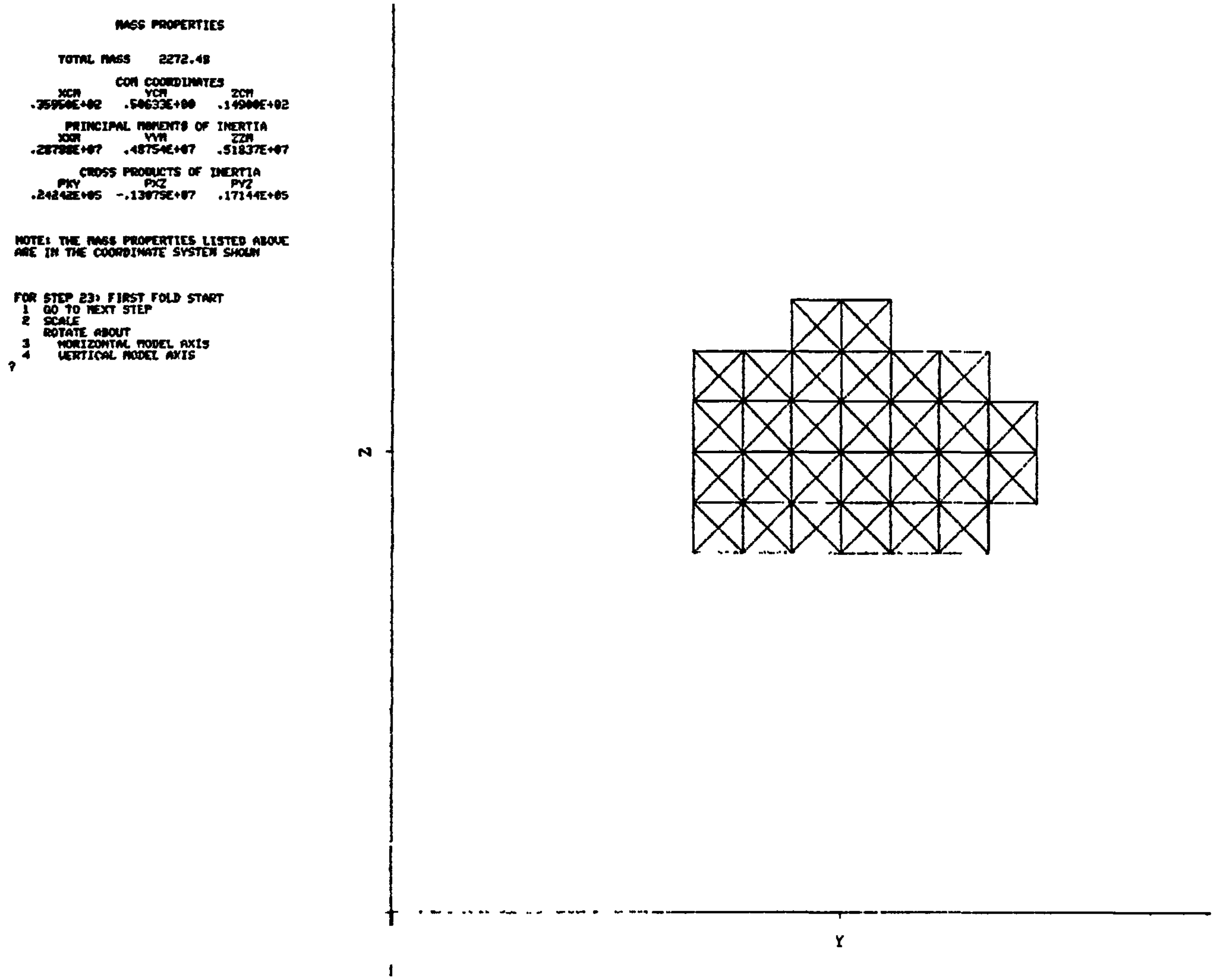


Figure 2.5-2 One Side Deployed

MASS PROPERTIES

TOTAL MASS 2272.48

COM COORDINATES

XCM	YCM	ZCM
.35064E+02	.15669E-12	.14900E+02

PRINCIPAL MOMENTS OF INERTIA

XXM	YYM	ZZM
.27618E+07	.48754E+07	.50657E+07

CROSS PRODUCTS OF INERTIA

PXY	PXZ	PYZ
.41875E-08	-.13075E+07	-.74748E-08

NOTE: THE MASS PROPERTIES LISTED ABOVE ARE IN THE COORDINATE SYSTEM SHOWN

FOR STEP 22: FIRST FOLD CON'T
1 GO TO NEXT STEP
2 SCALE
ROTATE ABOUT
3 HORIZONTAL MODEL AXIS
4 VERTICAL MODEL AXIS
?

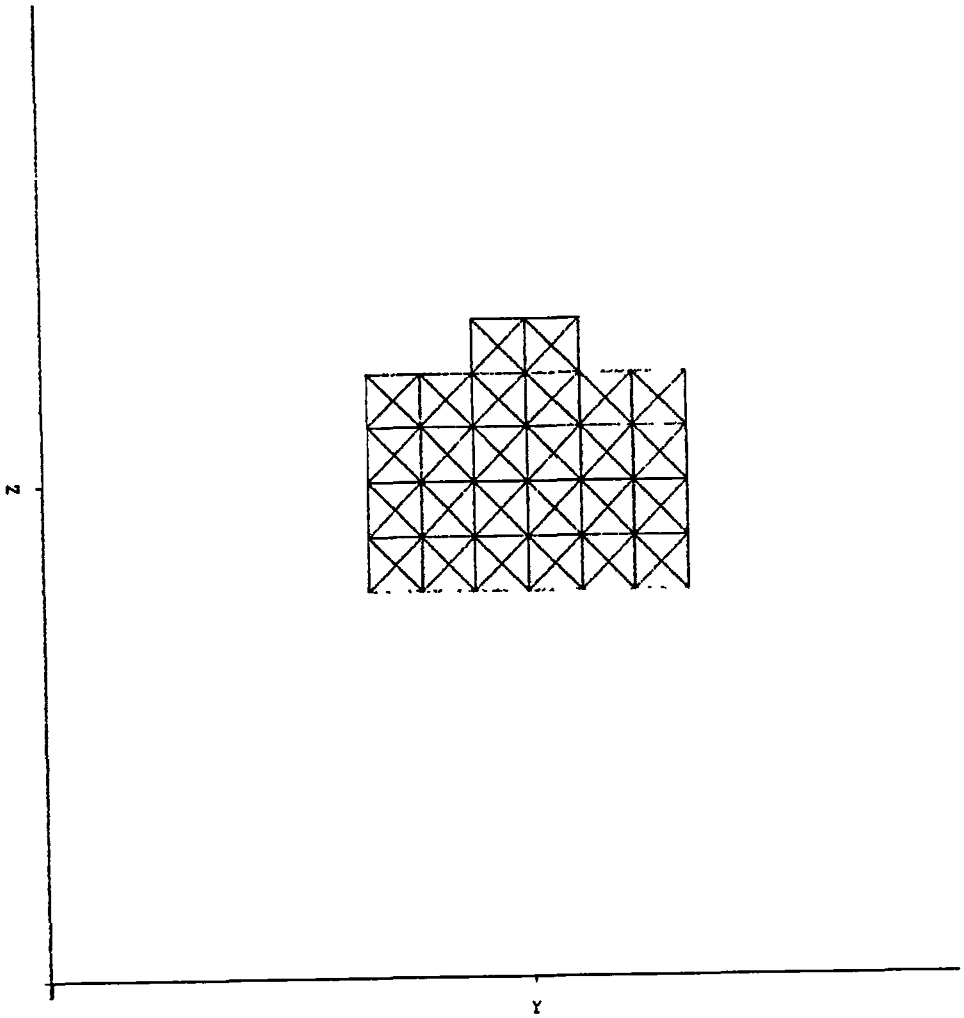


Figure 2.5-3 Two Sides Deployed

After a configuration has been displayed, the user has the option of scaling or rotating the model to look at other views, or of proceeding to the next step. The display also includes a note stating that the mass properties calculated are for the coordinate system shown. This is included because the coordinate system axes will be different if the model has been rotated by rotating a control volume that includes the whole model (i.e., has been rotated as part of the deployment instruction sequence). Rotations using the menu with the displayed picture do not change the coordinate system.

After all the steps in the deployment sequence have been completed, the mass and inertia data may be tabulated, as shown in Table 2.5-1.

Table 2.5-1 Mass Properties

Step Number and Direction	COM Coordinates	Principal Inertias	Cross Products of Inertia	Equivalent Direction in Fig. 2.1-4
24 X (XY)	0.3595 E+2	0.2900E+7	0.5697 E-8	Z
Y (YZ)	0	0.4875E+7	-0.7290 E-8	Y
Z (XZ)	0.1490 E+2	0.5303E+7	-0.1308 E+7	X
23 X (XY)	0.3595 E+2	0.2880 E+7	0.2424 E+5	Z
Y (YZ)	0.5063 E+0	0.4875 E+7	0.1714 E+5	Y
Z (XZ)	0.1490 E+2	0.5183 E+7	-0.1308 E+7	X
22 X (XY)	0.3595 E+2	0.2762 E+7	0.4128 E-8	Z
Y (YZ)	0	0.4875 E+7	0.7475 E-8	Y
Z (XZ)	0.1490 E+2	0.5066 E+7	-0.1308 E+7	X

Element connectivity remains constant during deployment, and elements that cross the control volume require special treatment. The density of affected elements is altered to correspond with their new length to maintain a constant mass and cross-sectional area. Although the mass properties of the structural members represented by such elements are not modeled exactly, this approach yields an adequate first-order analysis. Transformations that result in zero length elements are not permitted.

2.5.2 CBT Deployment Module User Instructions

To execute the program, type in the following: BEGIN,,BTDPPR

The first prompts issued when entering the module are for the file names that contain the desired model's mass properties and deployment instructions:

```
ENTER NAME OF MASS PROPERTIES FILE
(7 CHARACTERS MAX.;   0 = DEFAULT OF MASSIN)
? MASSEOS
DO YOU WANT A FILE OF EXISTING INSTRUCTIONS (Y/N)
?Y
ENTER NAME OF DEPLOYMENT INSTRUCTIONS FILE
(7 CHARACTERS MAX.;   0 = DEFAULT OF DEPLINS)
? DEPTEST
```

The user has the option of using an existing file of deployment instructions or a default test set.

2.5.2.1 Verify Instructions - Three groups of deployment instructions are automatically displayed, and the user may modify them as required. The first group names each deployment step and indicates if a picture will be drawn and the corresponding mass properties file saved.

NOW, PLEASE VERIFY THE FOLLOWING INPUT DATA

STEP	PICTURE DRAWN?	MASS PROPS SAVED?	NAME
1	OFF	OFF	
2	OFF	OFF	
3	OFF	OFF	
4	OFF	OFF	
5	OFF	OFF	
6	OFF	OFF	
7	OFF	OFF	
8	OFF	OFF	FEED MAST FOLDING
9	OFF	OFF	
10	OFF	OFF	
11	OFF	OFF	
12	OFF	OFF	
13	OFF	OFF	
14	OFF	OFF	
15	OFF	OFF	
16	OFF	OFF	
17	OFF	OFF	
18	OFF	OFF	SURFACE SIDES FOLDED IN
19	OFF	OFF	
20	OFF	OFF	
21	OFF	OFF	
22	ON	OFF	FIRST FOLD CON'T
23	ON	OFF	FIRST FOLD START
24	ON	ON	FULLY DEPLOYED MODEL

```
FNTER 1 TO USE DIFFERENT FILES
      2 IF INPUT IS OK
      3 TO CHANGE NUMBER OF STEPS
      4 TO CHANGE PICTURE ON/OFF
      5 TO CHANGE MASS PROPERTY SAVE ON/OFF
      6 TO CHANGE NAME
      7 TO RETURN TO EXECUTIVE
3
```

The user may change the number of steps in the deployment (Option 3):

```
ENTER NUMBER OF STEPS (BETWEEN 0 AND 49)
? 24
```

The user may modify the description of a step (Options 4, 5, and 6) by first specifying the number of the step to be modified:

```
ENTER STEP TO BE MODIFIED (BETWEEN 1 AND 24)
? 24
```

For Options 4 and 5, the value of the item is switched automatically. For Option 6, the user enters a new step name:

```
ENTER NAME (BETWEEN 1 AND 50 CHAR.)
1234567891         1         3         4         5
```

After the user enters Option 2 (input OK), the second group of instructions defining a volume in space that contains the nodes to be moved is displayed.

VOLUME MATRIX

ROW	1 X MIN (M)	2 X MAX (M)	3 Y MIN (M)	4 Y MAX (M)	5 Z MIN (M)	6 Z MAX (M)
1	-100 00	100 00	-100 00	100 00	40 000	50 000
2	-100 00	100 00	10 000	20 000	-100 00	100 00
3	-100.00	100.00	-20.000	-10 000	-100 00	100 00
4	-1000 0	1000 0	-1000 0	1000 0	-1000 0	1000 0
5	-20 000	20 000	-40 000	-17 030	25 000	50 000
6	-20 000	20 000	-140 00	-30 000	25 000	50 000
7	-20 000	20 000	-140 00	-45 000	25 000	50 000
8	-20 000	20 000	-140 00	-60 000	25 000	50 000
9	-20 000	20 000	-140 00	-75 000	25.000	50 000
10	-20 000	20 000	-140 00	-90 000	25 000	50 000
11	-20 000	20 000	-140 00	-105 00	25 000	50 000
12	-20 000	20 000	-140 00	-120 00	25 000	50 000
13	-1000 0	1000 0	-1000 0	1000 0	-1000 0	1000 0
14	-5 0000	30 000	-20 000	20 000	10 000	20 000
15	-5 0000	30 000	-20 000	20 000	-5 0000	5 0000
16	-5 0000	30 000	-20 000	20 000	-20 000	-10 000
17	-5 0000	30 000	-20 000	20 000	-35 000	-25 000
18	-5 0000	30 000	25 000	35 000	-35 000	35 000
19	-5 0000	30 000	-35 000	-25 000	-35 000	35 000
20	-5 0000	30 000	40 000	50 000	-35 000	35 000
21	-5.0000	30 000	-50 000	-40 000	-35 000	35.000
22	-5·0000	30 000	55 000	65.000	-20.000	20 000
23	-5 0000	30 000	-65 000	-55 000	-20 000	20 000
24	-1 00000E+99	1 00000E+99	-1 00000E+99	1 00000E+99	-1 00000E+99	1 00000E+99

ENTER 1 TO RESPECIFY DESCRIPTION
2 IF INPUT IS OK
3 TO CHANGE AN ITEM IN VOLUME
4 TO RETURN TO THE EXECUTIVE

? 2

Nodes on the boundary of the volume will be included within the volume. All coordinates are based on the model's coordinate system. Each maximum value must be at least as large as its corresponding minimum. The third group defines how to move the nodes in the control volume:

CONTRL MATRIX

ROW	1 TYPE (0-3)	2 X (M)	3 Y (M)	4 Z (M)	5 ANGLE-DEG
1	0.	0.	0.	-14 920	0.
2	0.	0.	-14.920	0.	0.
3	0.	0	14.920	0.	0
4	3.0000	0.	0.	0	89 000
5	1.0000	0.	-17.043	30 219	-90.000
6	0.	0.	14.780	0	0.
7	0.	0.	14.780	0.	0.
8	0.	0.	14 780	0.	0.
9	0.	0	14 780	0.	0
10	0.	0	14 780	0.	0.
11	0.	0	14.780	0	0
12	0.	0.	14.780	0.	0
13	3.0000	0.	0.	0.	-89 000
14	0.	0.	0.	14.860	0.
15	0.	0	0	14 920	0
16	0	0.	0	14 920	0
17	0.	0.	0.	14.860	0
18	0	0.	-14 860	0	0.
19	0.	0.	14.860	0	0
20	0.	0.	-14.750	0.	0.
21	0.	0.	14.750	0	0.
22	0.	0.	-14 750	0	0
23	0	0.	14.750	0	0
24	2 0000	0.	0	0.	90 000

ENTER 1 TO RESPECIFY CONTROL VOLUME
2 IF INPUT IS OK
3 TO CHANGE AN ITEM IN CONTROL
4 TO RETURN TO THE EXECUTIVE

TYPE specifies the type of transform to be performed:

0 = Shift control volume as indicated by x, y, and z;

1 = Rotate control volume ANGLE degrees around a line parallel to the x axis and passing through point y, z;

2 = Rotate around the y axis through point x, z; and

3 = Rotate around the z axis through points x, y.

Values for TYPE outside of the above range generate an error message. For values of TYPE between 1 and 3, ANGLE must be greater than zero. For example, Step 24 tells the program to rotate the corresponding control volume about the model y axis, and Step 23 tells the program to move the control volume 14.750 meters in the model's positive y direction.

2.5.2.2 Transform Model - Once the deployment sequence is defined, the program steps through the process, beginning with the last step (fully deployed model) and stepping backward toward the first step. If a picture is requested for a given step, the structure at that phase of deployment, as well as mass and inertia values, will be displayed. If the user requests the mass properties of a particular step, the appropriate file name is requested:

```
    FOR STEP 24,
    ENTER NAME OF UPDATED MASS PROPERTIES FILE
    (7 CHARACTERS MAX.;  0 = DEFAULT OF MASSE24)
?   0
    FILE ALREADY EXISTS.  OK TO OVERWRITE (Y/N)
?   Y
```

2.5.2.3 Terminate - Once all the sequences have been performed, the program prompts for the file name of the updated instructions and asks if another run is desired:

```
    ENTER NAME OF UPDATED DEPLOYMENT INSTRUCTIONS
    (7 CHARACTERS MAX.;  0 - DEFAULT OF DEPTEST)
?   0
    FILE ALREADY EXTSTS.  OK TO OVERWRITE  (Y/N)
?   Y
    RUN ANOTHER CASE  (Y/N)
?   N
REVERT.
```

If another case is desired, the program begins again by requesting new input files.

2.5.3 CBT Deployment Module Programmer Information

BTDEPLY is composed of one main program and 21 supporting subroutines and functions. The description of each module, including required inputs, expected outputs, local variables, and external calls, is contained at the beginning of the module in a block of comments. Major sections of code within each module are also commented.

Seven modules supporting BTDEPLY are not found in BTDEPLY listings. These modules are from the LASSLIB and LIBFTEK libraries. PFM and LEFI called by MGRFILE are from LASSLIB. PRNTIM and CHNGIM called by MODVOLM and MODTRAN are also from LASSLIB. MATMUL is called by TRANSF and is also from LASSLIB. PRNTIM calls TSEND and NEWPAG from the Tektronix PLOT10 library, LIBFTEK. TSEND dumps the terminal buffer, and NEWPAG clears the screen. Refer to the Tektronix PLOT10 Terminal Control System User's Manual for further information.

Because the mass properties file is composed of unlistable binary records, the IOFILES module has some diagnostic reads and writes that are currently commented out. These diagnostics may be used to read and write free-formatted mass property files for testing purposes. A list of the deployment instruction file appears in Section 3.0.

2.6 HOOP COLUMN DEPLOYMENT MODULE

The hoop column deployment module uses an input data base file created from execution of the hoop column model generator (Ref 1) to generate hoop column model geometry in any desired deployment stage. It is not intended for use in kinematic deployment analysis. It can be used to generate graphic output display of a hoop column configuration and to calculate mass properties of the hoop column antenna in its selected deployment stage. A fully deployed model is illustrated in Figure 2.6-1.

2.6.1 Hoop Column Deployment Module Technical Description

The deployment sequence for the hoop column configuration requires that the column be fully deployed before the hoop starts deployment. Hoop deployment is assumed, as shown in Figure 2.6-2. The locus of hoop segment nodes is a cylinder whose axis coincides with the column vertical axis. This is the model z axis. The geometry in deployed mode is determined by modifying model dimensions as a function of the percent deployment of the column (DEPPCM) or hoop (DEPPCH). The minimum stowed z dimension is calculated as the length of a hoop element. The minimum stowed radius is arbitrarily set at 3 meters to permit stowage in the STS cargo bay.

Each column segment's length is calculated by multiplying the fully deployed length by the percent column deployment. Thus, the lower segment lengths are:

[41] $$L_{lower} = \frac{HC \times DEPPCM}{100\ RNSEGL}$$

where

HC = height of central stay attach point,
DEPPCM = percent deployment for column,
RNSEGL = number of lower column segments.

The upper segment lengths are obtained similarly, with HC replaced by the quantity HF-HC, where HF is the column height at the feed. Note that the origin for the model (0,0,0) is at the hub, the end of the column opposite the feed.

Hoop segment lengths do not vary. The hoop node coordinates are calculated from the relations shown in Figure 2.6-3. The value of DZ is added to or subtracted from the nominal hoop height to obtain the z coordinates of hoop element endpoints. The x, y coordinates are obtained as shown in Figure 2.6-4.

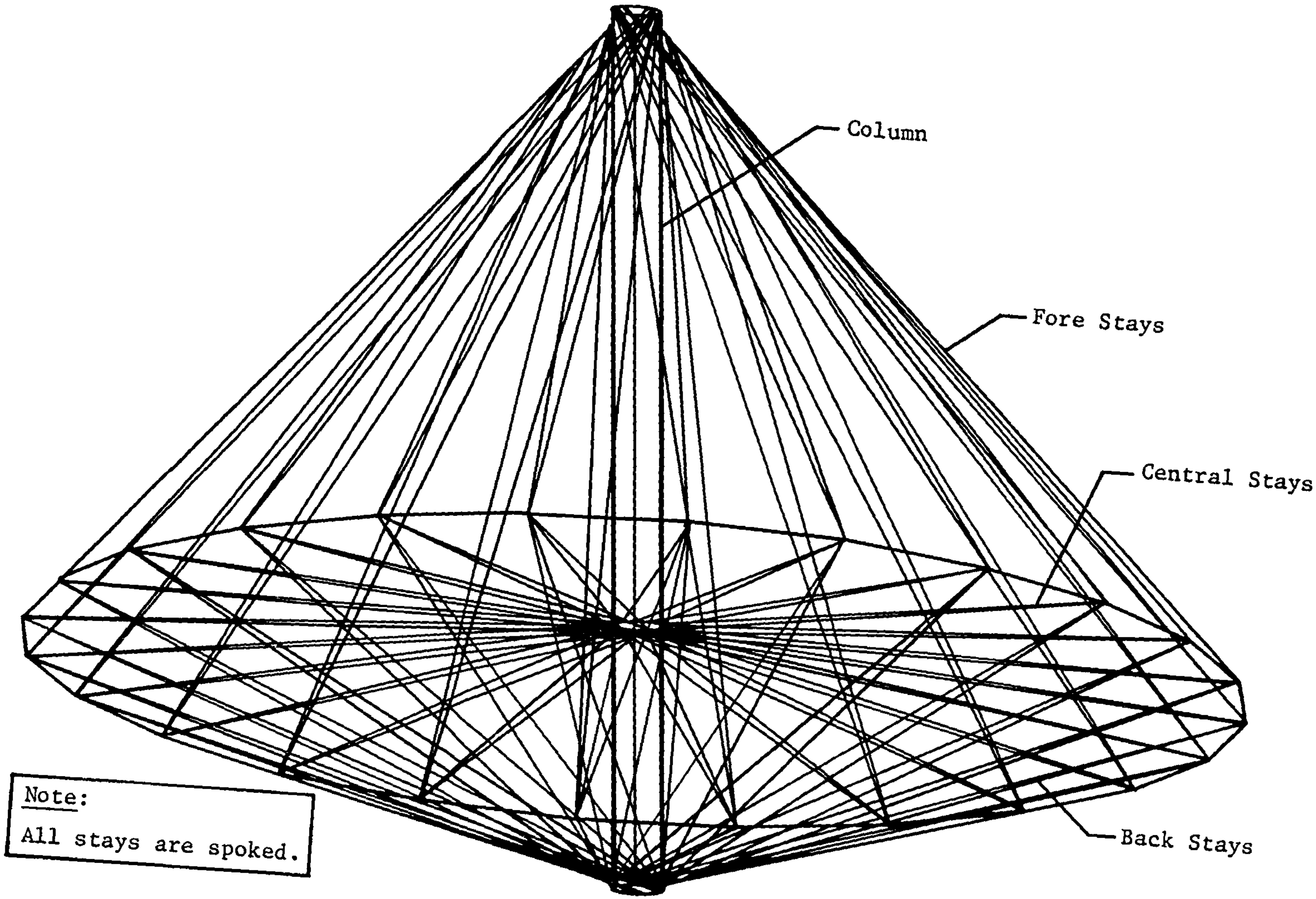


Figure 2.6-1 Hoop and Column Configuration with Spoked Stays

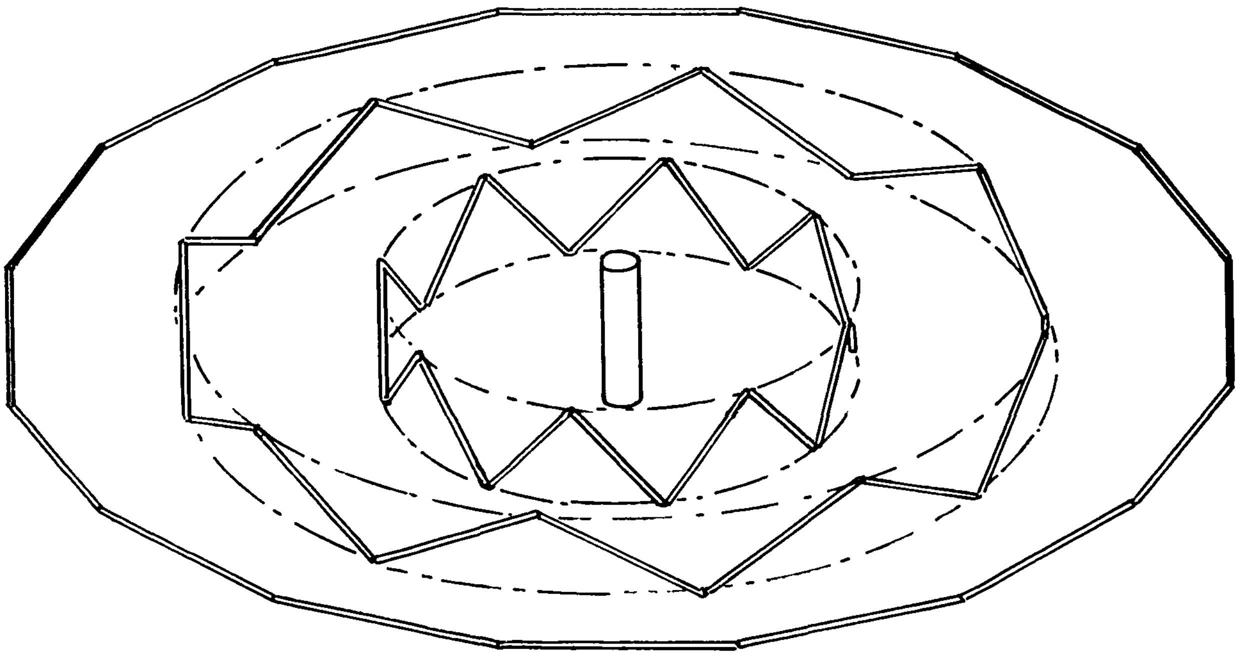


Figure 2.6-2 Hoop Deployment Representation

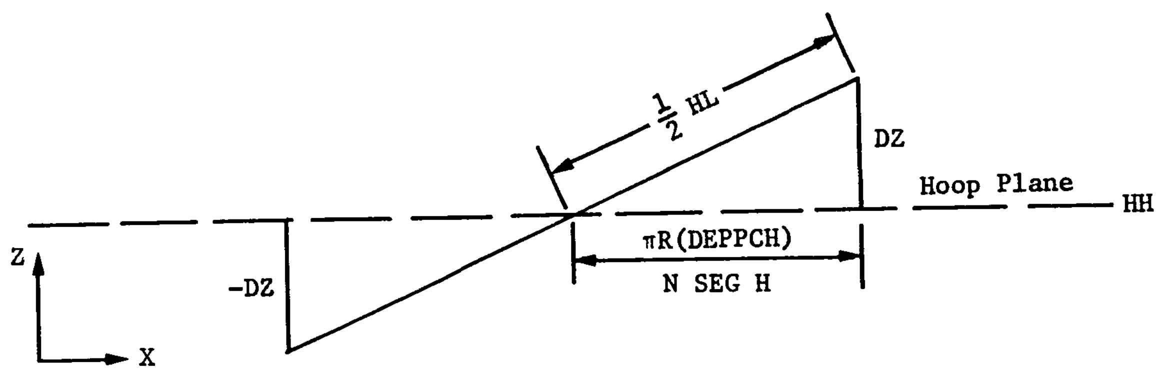
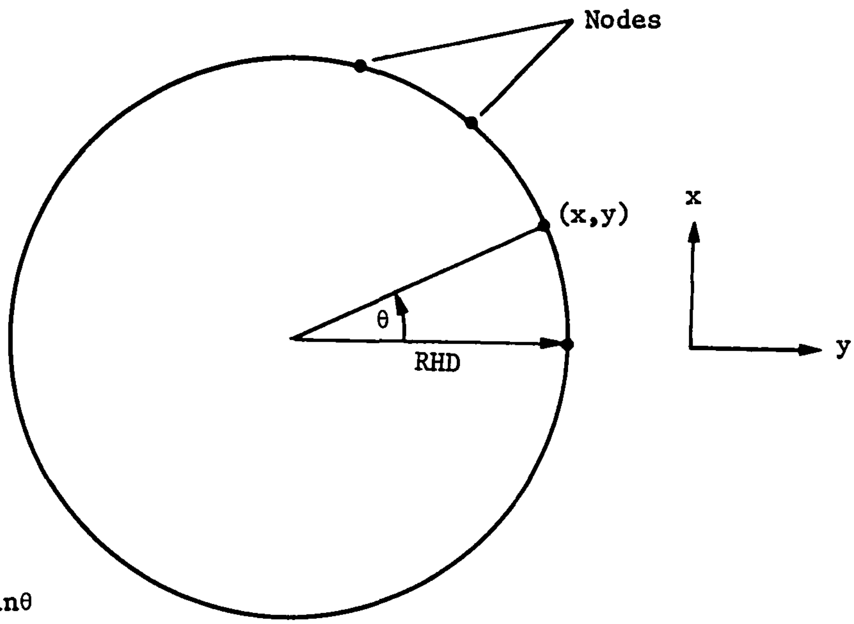


Figure 2.6-3 Hoop Element Z Coordinates Definition



$$\theta = \frac{2\pi}{N\ SEG}$$

$$x = RHD\ Sin\theta$$

$$y = RHD\ Cos\theta$$

Figure 2.6-4 Coordinates x, y of Hoop Element Nodes

The mass properties of the model are obtained by modifying the densities of column and stay elements to correspond to the ratio of each element's fully deployed length to partially deployed length. The element densities are maintained in the module data base file. To transfer information to the mass properties module, the eighth item in each element's property matrix, TUBP(IA+7), is modified. The real density is therefore maintained in the data base.

2.6.2 Hoop Column Deployment Module User Instructions

Execution of the hoop column deployment module is started by input of:
BEGIN,, HCDEPPR

The first prompts are for definition of user terminal characteristics:

```
OENTER BAUD RATE

? 1200
OENTER 1 FOR 4006, 4010, 4012, OR 4013
        2 FOR 4014 OR 4015
     OR 3 FOR 4014 OR 4015 WITH ENHANCED GRAPHICS.
      OR 4 FOR TERMINAL OTHER THAN TEKTRONIX
        ?
? 4
```

The next prompt asks for input of the hoop column deployment module data base file.

```
 INPUT NAME OF HOOP/COLUMN DATA BASE FILE
? HOOP50
```

This file can be a data base file created for executing the hoop column **model** generator module. If so, an error message will be displayed as:

```
*** ERROR DEPPCH NOT IN DATA BASE ***
*** ERROR DEPPCM NOT IN DATA BASE ***
```

This does not prevent execution of the deployment module. The user must, however, input values for the two variables. This is accomplished as shown with the next display and prompt.

```
 ENTER 0 IF INPUT IS OK
       1 TO CHANGE DATA ITEMS VIA KEYBOARD,
       2 TO ENTER A NEW TITLE,
    OR 9 TO RETURN TO THE EXEC.
? 1

? 100,16,50,17,0,0
```

If the requested deployment configuration is for partial hoop deployment without full column deployment, the following message will be displayed and the user prompted to redefine the deployment commands. This initial set of inputs will be followed by the prompts to specify column, hoop, and stay properties:

```
*** ERROR - COLUMN MUST BE DEPLOYED BEFORE HOOP STARTS ***

 HOOP/COLUMN MODEL DEFINITION

     1.0000        1  DB     -COLUMN DIAMETER AT BACK STAY/HUB A
     .50000        2  DC     -COLUMN DIAMETER AT CENTRAL STAY AT
     1.0000        3  DF     -COLUMN DIAMETER AT FORE STAY/FEED
     30.000        4  HC     -HEIGHT OF CENTRAL STAY ATTACH POIN
     100.00        5  HF     -HEIGHT OF FEED ABOVE HUB(M)
     25.000        6  HH     -HEIGHT OF HOOP ABOVE HUB(M)
     100.00        7  DH     -HOOP DIAMETETER(M)
     3.0000        8  NSEGL  -NUMBER OF SEGMENTS ALONG LOWER POR
     3.0000        9  NSEGU  -NUMBER OF SEGMENTS ALONG UPPER POR
     24.000       10  NSEGH  -NUMBER OF HOOP SEGMENTS
     1.0000       11  ISTAYC -FLAG TO INDICATE CENTRAL STAYS(0=N
     .10000       12  SURFRHO-REFLECTING SURFACE MASS/AREA(KG/SQ
     .70000       13  SURFALP-PERCENT TOTAL SURFACE MASS LUMPED
     1000.0       14  HUBMASS-HUB MASS(KG)
     300.00       15  FEEDTIP-FEED ARRAY TIP MASS(KG)
     100.00       16  DEPPCM -PERCENT COLUMN DEPLOYED
     50.000       17  DEPPCH -PERCENT HOOP DEPLOYED
 ENTER 0 IF INPUT IS OK
       1 TO CHANGE DATA ITEMS VIA KEYBOARD
       2 TO ENTER A NEW TITLE
    OR 9 TO RETURN TO THE EXEC.
? 0
```

```
+          HOOP COLUMN DEPLOYMENT--HOOP 50% DEPLOYED


    FORE AND BACK STAY PROPERTIES

       0.                 1   ISPOKF -FLAG TO INDICATE SPOKED(0=NO, 1=YES)
       1.10000E-06        2   ASTAYF -FORE STAY AREA (SQ.M)
       0.                 3   AJSTAYF-FORE STAY TORSIONAL INERTIA(M**4)
       1.30000E+11        4   STAYEF -YOUNG'S MODULUS(NT/SQ.M)
       1.50000E+10        5   STAYGF -SHEAR MODULUS(NT/SQ.M)
        1909.0            6   STAYROF-DENSITY(KG/SQ.M)
        1.0000            7   ISPOKB -FLAG TO INDICATE SPOKED(0=NO, 1=YES)
       1.10000E-06        8   ASTAYB -BACK STAY AREA(SQ.M)
       0.                 9   AJSTAYB-TORSIONAL INERTIA(M**4)
       1.38000E+11       10   STAYEB -YOUNG'S MODULUS(NT/SQ.M)
       2.30000E+10       11   STAYGB -SHEAR MODULUS(NT/SQ.M)
        1939.0           12   STAYROB-DENSITY(KG/SQ.M)
    ENTER 0 IF INPUT IS OK
          1 TO CHANGE DATA ITEMS VIA KEYBOARD
          2 TO ENTER A NEW TITLE
       OR 9 TO RETURN TO THE EXEC.
   ? 0


          HOOP COLUMN DEPLOYMENT--HOOP 50% DEPLOYED


 CENTRAL STAY PROPERTIES

     1.0000           1   ISPOKC -FLAG TO INCLUDE CENTRAL STAYS(0=NO, 1=YES)
    1.10000E-06       2   ASTAYC -CENTRAL STAY AREA(SQ.M)
    0.                3   AJSTAYC-TORSIONAL INERTIA(M**4)
    1.38000E+11       4   STAYEC -YOUNG'S MODULUS
    2.30000E+10       5   STAYGC -SHEAR MODULUS
     1939.0           6   STAYROC-DENSITY(KG/SQ.M)
 ENTER 0 IF INPUT IS OK
       1 TO CHANGE DATA ITEMS VIA KEYBOARD
       2 TO ENTER A NEW TITLE
    OR 9 TO RETURN TO THE EXEC.
? 0
```

```
              HOOP COLUMN DEPLOYMENT--HOOP 50% DEPLOYED


 COLUMN PROPERTIES

       .10000           1   ACOLB   -COLUMN CROSS-SECTIONAL AREA AT HUB(SQ.M)
      1.2500            2   AICOLB  -BENDING INERTIA AT HUB(M**4)
      2.5000            3   AJCOLB  -TORSIONAL INERTIA AT HUB(M**4)
       .20000           4   ACOLC   -C-S AREA AT CENTRAL STAY ATTACH(SQ.M)
       .20000           5   AICOLC  -BENDING INERTIA AT CENTRAL STAY ATTACH(M**4)
       .40000           6   AJCOLC  -TORSIONAL INERTIA AT CENTRAL STAY ATTACH
       .10000           7   ACOLF   -C-S AREA AT FEED(SQ.M)
      1.2500            8   AICOLF  -BENDING INERTIA AT FEED
      2.5000            9   AJCOLF  -TORSIONAL INERTIA AT FEED
    1.32000E+11        10   COLE    -YOUNG'S MODULUS
    1.51000E+10        11   COLG    -SHEAR MODULUS
     1900.0            12   COLRHO  -DENSITY(KG/CU.M)
 ENTER 0 IF INPUT IS OK
       1 TO CHANGE DATA ITEMS VIA KEYBOARD
       2 TO ENTER A NEW TITLE
    OR 9 TO RETURN TO THE EXEC.
? 0



+             HOOP COLUMN DEPLOYMENT--HOOP 50% DEPLOYED


 HOOP PROPERTIES

    4.50000E-03         1   AHOOP   -HOOP C-S AREA(SQ.M)
    9.60000E-06         2   AIHOOP1-BENDING INERTIA IN HOOP PLANE
    1.07000E-05         3   AIHOOP2-BENDING INERTIA IN PLANE NORMAL TO HOOP PLANE
    1.21000E-05         4   AJHOOP  -TORSIONAL INERTIA
    7.01000E+10         5   HOOPE   -YOUNG'S MODULUS
    1.01000E+10         6   HOOPG   -SHEAR MODULUS
     2000.0             7   HOOPRHO-DENSITY(KG/CU.M)
 ENTER 0 IF INPUT IS OK
       1 TO CHANGE DATA ITEMS VIA KEYBOARD
       2 TO ENTER A NEW TITLE
    OR 9 TO RETURN TO THE EXEC.
? 0
```

Upon definition or acceptance of these input parameters, the program computes the necessary geometry and property data to be interfaced with the mass properties module. The deployment model is now displayed as shown in Figure 2.6-5. The last three user interactions define output files for the hoop column deployment module. These files are the data base file, dynamic model file to interface with the GTS module (Ref 2), and the mass properties file. The prompts and typical responses are:

```
 NAME DATA BASE IS TO BE SAVED AS
? HOOP50
 NAME OF DYNAMIC MODEL FILE
? DY50
 NAME OF MASS PROPERTIES MATRICES FILE
? MASS50
```

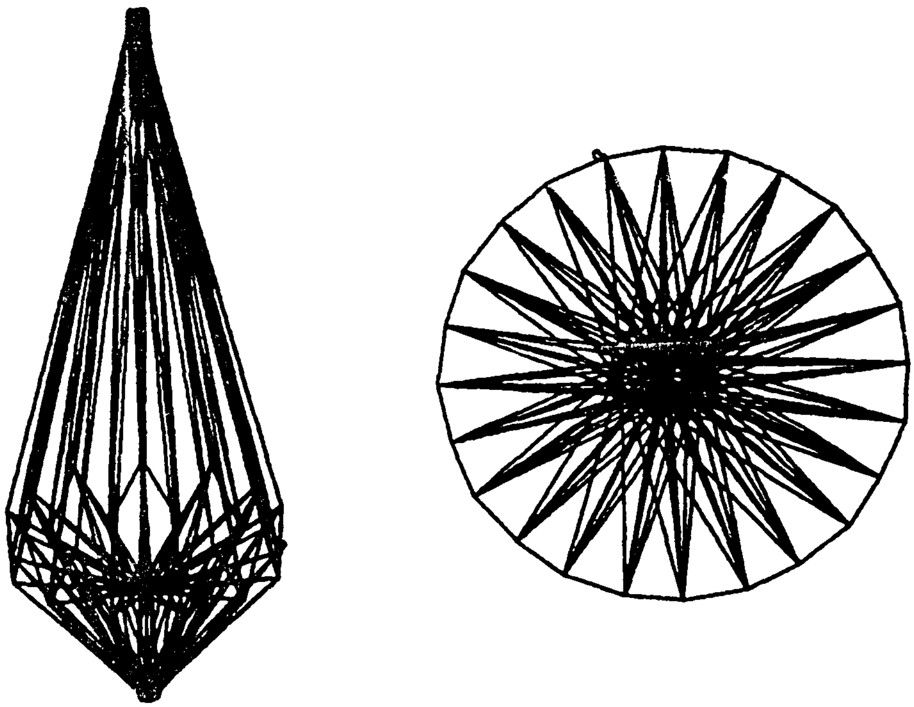


Figure 2.6-5 Hoop Column Model with Hoop 50 Percent Deployed

Upon definition of these file names, module execution is complete. To calculate and display the mass properties, the mass properties module must be executed. Outputs from the MP module for this case are:

```
MASS PROPERTIES DEFINITION


 CENTRE OF MASS COORDINATES: XCM=  -.22714E-13
                             YCM =  -.81509E-14
                             ZCM =   .40593E+02


 TOTAL S/C MASS(KG)=   .28638E+05
 MASS OF RF REFLECTOR AND AUXILIARY EQUIPMENT =,    .54978E+03
 RADIAL RIB MODEL HUB MASS (KG) =   .15356E+04
 MASS OF   1 TYPE  1 TUBES =   .31342E+04
 MASS OF   1 TYPE  2 TUBES =   .28500E+04
 MASS OF   1 TYPE  3 TUBES =   .34833E+04
 MASS OF   1 TYPE  4 TUBES =   .62278E+04
 MASS OF   1 TYPE  5 TUBES =   .47500E+04
 MASS OF   1 TYPE  6 TUBES =   .32722E+04
 MASS OF  24 TYPE  7 TUBES =   .28254E+04


INERTIAS ABOUT CM

         XXM =   .17040E+08
         YYM =   .17040E+08
         ZZM =   .20810E+07
         PXY =   .45474E-08
         PXZ =  -.56061E-08
         PYX =  -.29307E-08
```

2.6.3 Hoop Column Deployment Module Programmer Information

The primary purpose of this module is to generate and display hoop column configurations in various levels of deployment. Because of the existence of different graphics software at Martin Marietta and LaRC, the delivered software must be modified to create model plots. The plot file data are contained in local file TAPE13. It consists of endpoint coordinates of the segments used to define all structural elements. In addition, it contains plot definition data.

The first records on TAPE13 will be written in 9E13,5 format. The nine items are:

XMAS - x coordinate of 3-D window origin
XS - x step
XMAX - maximum x coordinate value

YORG -)
YS -) y axis counterparts of x values
YMAX -)

ZORG -)
ZS -) z axis counterparts of x, y values
ZMAX -)

Each successive record is written in 6E13.5 format. Each consists of the x, y, and z coordinates of each endpoint of the segment. The number of these records equals the total number of structural elements in the model, defined by the variable NEL. This information should be sufficient for creating graphic output with the particular user's graphic package.

The program is heavily commented with descriptions of variables. Additional information may be obtained from Reference 1. A flow diagram of the module is shown in Figure 2.6-6.

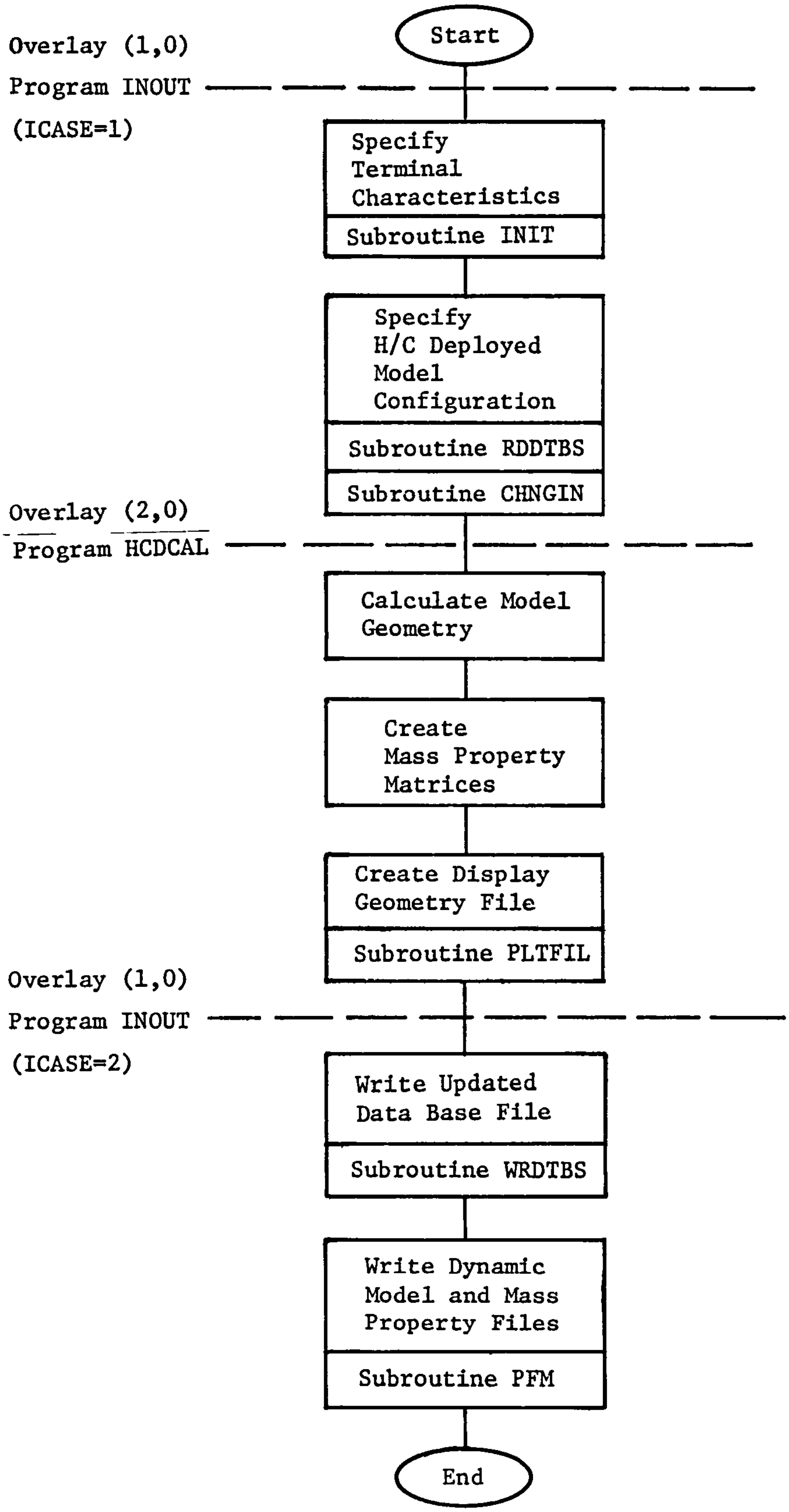


Figure 2.6-6 Hoop/Column Deployment Module Flow Diagram

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2.7 RF ANALYSIS MODULE

The rf analysis module provides for prediction of primary beam gain and gain losses due to feed factor, blockage, and rms surface distortion. The losses associated with use of a spherical surface instead of an ideal paraboloid may also be predicted.

2.7.1 Rf Module Technical Description

The following equations can be obtained from any general text on elementary antenna theory. The treatment here is from a text by Silver.

The primary beam gain of a parabolic antenna is given by:

$$[42] \quad G = \frac{16\pi^2 f^2}{\lambda^2}\left|\int_0^{\psi} [G_F(\psi)]^{\frac{1}{2}} \mathrm{Tan}\psi/2 \, d\psi\right|^2$$

where

f = focal length,
λ = wavelength,
G_f = feed pattern gain.

The gain efficiency of an aperture is a function of the feed pattern and the angular aperture (or antenna half-angle). Referring to Figure 2.7-1, the relationship between angular aperture (ψ), focal length (f), and aperture diameter (d) is:

$$[43] \quad \mathrm{Tan}\psi/2 = \frac{D/4}{(f - \delta)}$$

For a paraboloid with vertex at (0,0) the value of δ is given by:

$$[44] \quad \delta = \frac{1}{4f}(D^2/4) = D^2/16f$$

This results in an expression for the angle $\frac{\psi}{2}$:

$$[45] \quad \mathrm{Tan}\psi/2 = D/4(f - D^2/16f)$$

$$[46] \quad (f - D^2/16f)\mathrm{Tan}\psi/2 = D/4\ f = 0$$

$$[47] \quad (f^2 - D^2/16)\mathrm{Tan}\psi/2 - D/4\ f^2 = 0$$

$$[48] \quad f^2 - (D/4\ \mathrm{Cot}\ \psi/2)f - D^2/4 = 0$$

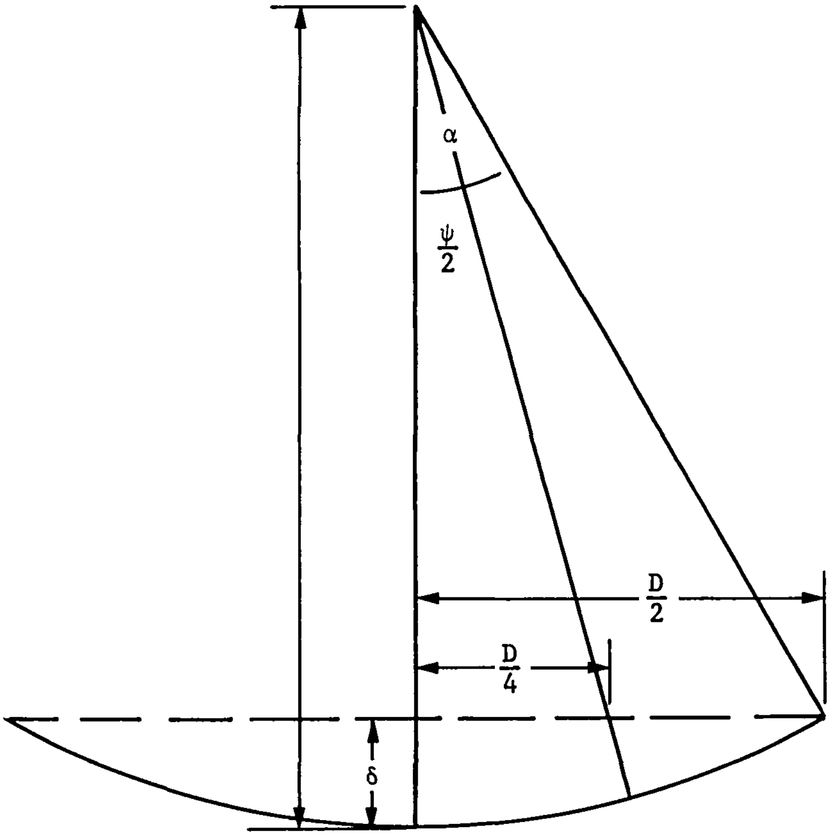

Figure 2.7-1 Representation of Antenna Surface

Solving for f and discarding the extraneous solution, we have:

[49] $$f = \frac{D}{4}(\tfrac{1}{2}\ \mathrm{Cot}\ \psi/2 + \tfrac{1}{2}\sqrt{\mathrm{Cot}^2\ \psi/2 + 1}$$

Substituting into Eq 40 results in:

[50] $$G = \left(\frac{\pi D}{\lambda}\right)^2 \left[\tfrac{1}{2}\ \mathrm{Cot}\ \psi/2\ \sqrt{\mathrm{Cot}^2\ \psi/2 + 1}\right]^2 \left[\int_0^{\psi} \sqrt{G_F(\psi)\mathrm{Tan}\psi/2}\ d\psi\right]^2$$

The factor $\left(\frac{\pi D}{\lambda}\right)^2$ is the gain of a uniformly illuminated constant phase aperture. The remainder of Eq 48 is the gain factor (G_f), or gain efficiency. Thus, the gain is a function of only the feed pattern and angular aperture. For a given feed pattern, the efficiency is the same for all paraboloids having the same f/d ratio.

For the class of feed patterns defined by:

$$[51] \quad G_F(\psi) = G_0^n \operatorname{Cos}^n\psi \qquad 0 \leq \psi \leq \pi/2$$

$$[52] \quad G_F(\psi) = 0 \qquad \psi > \pi/2$$

the gain factor becomes:

$$[53] \quad G_f = 2(n+1)\left[\tfrac{1}{2}(\operatorname{Cot}\psi/2) + \sqrt{\operatorname{Cot}^2\psi/2 + 1}\right]^2 \left[\int_0^{\psi} \operatorname{Cos}^{n/2}\psi \operatorname{Tan}\psi/2 \, d\psi\right]^2$$

Equation 45 permits calculation of ψ from:

$$[54] \quad \psi = 2 \operatorname{Tan}^{-1} \frac{1}{4\left[\frac{f}{D} - \frac{1}{16\frac{f}{D}}\right]}$$

By specifying a frequency, a feed power, and f/d ratio, the paraboloidal gain may be calculated. In the rf analysis module, the integration is performed using trapezoidal integration with $\Delta\psi$ equal to 0.01ψ .

Aperture Blockage - The losses due to blockage of the illuminated aperture are approximated by assuming an energy loss of twice the ratio of blockage area (A_b) to aperture area (A). The factor of two results from the blockage of energy to the reflector and an additional blockage from reflector to feed. This loss is then:

$$[55] \quad G_{loss} = 2\frac{A_b}{A} G_{ideal}$$

Surface Distortion Losses - If the reflector surface is distorted from an ideal paraboloid and if the periodicity of these distortions is small with respect to aperture diameter, an additional gain loss may be estimated from the Ruze equation:

$$[56] \quad G_{loss} = \exp\left[-\left(4\pi\frac{\delta}{\lambda}\right)^2\right]$$

Spherical Aberration Losses - Spherical reflectors are used for antennas that use multiple feeds. The feeds may be located on a great circle segment of a concentric sphere. By positioning the feeds at approximately reflector surface radius of curvature, the spherical surface approximates the characteristics of an ideal paraboloidal reflector. The use of such a spherical reflector does create inherent errors due to the deviation from the ideal paraboloid. The effect upon primary beam gain may be estimated by calculating an rms surface distortion and then applying the Ruze equation, which can also be expressed as shown below in Eq 57.

[57] $dB_{loss} = 686\ (Z_{rms}/\lambda)^2$

Figure 2.7-2 shows a side view of a spherical reflector with the ideal paraboloidal surface represented by dashed lines.

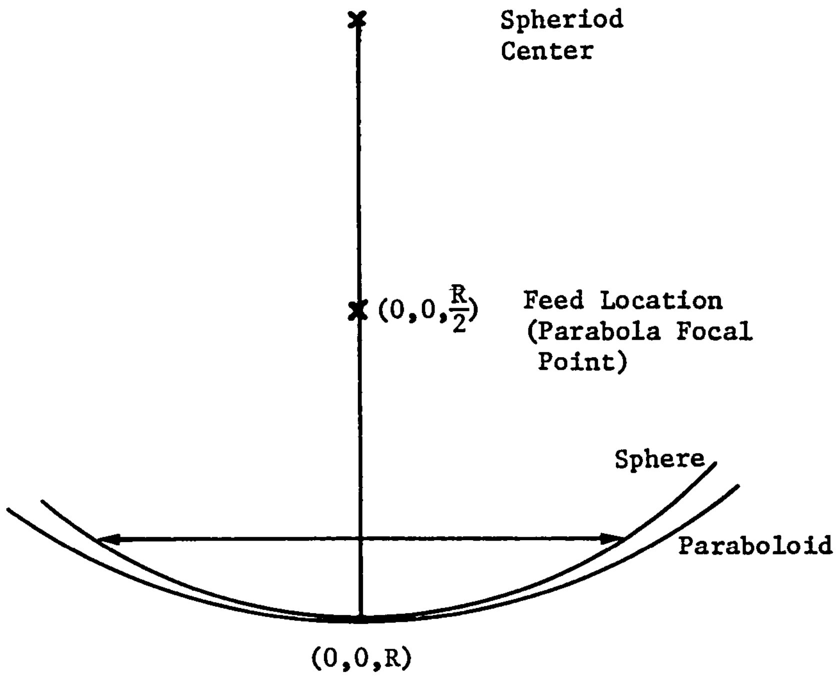

Figure 2.7-2
Comparison of Parabolic and Spherical Reflector Surface Positions

The equation of a sphere with center at (0,0,0) is given by:

[58] $X^2 + Y^2 + Z^2 = R^2$

Solving for Z_s results in:

[59] $Z_s = \sqrt{R^2 - (X^2 + Y^2)}$

The general equation for a paraboloid of revolution is:

[60] $\frac{(X - a)^2 + (Y - b)^2}{4f} = mZ_p - c$

For the case represented by Figure 2.7-2, a and b are both zero, and m is -4f, resulting in:

[61] $$Z_p - C = \frac{-1}{4f}(x^2 + y^2).$$

The value of c reflects the displacement of the vertex of the paraboloid from the origin. If the focal point is displaced from the 1/2R point by an amount (ε), then Z_p is:

[62] $$Z_p = \frac{-1}{4f}(x^2 + y^2) + C - \varepsilon.$$

Then Z_p finally becomes:

[63] $$Z_p = -\frac{1}{4f}(x^2 + y^2) + R(1.5 - k).$$

The distortion error (ΔZ) may be expressed as:

[64] $$\Delta Z = Z_s - Z_p$$

[65] $$\Delta Z = \sqrt{R^2 - (x^2 + y^2)} - \frac{1}{4kR}(x^2 + y^2)$$

The quantity $(x^2 + y^2)$ represents the x-y plane radial distance (r) from the reflector vertex. Defining the spherical reflector in terms of radius of curvature (R_c), focal length to aperture diameter ($\frac{f}{d}$), and aperture diameter (d), Z_s at any point (x,y) becomes:

[66] $$Z_s = \sqrt{R^2 - r^2}$$

The associated Z_p is:

[67] $$Z_p = \frac{r^2}{4f} + R(1.5 - k)$$

The rms error in ΔZ is now:

[68] $$\Delta Z_{rms} = \sqrt{\int (Z_s - Z_p)^2 \, P(k)dA}$$

[69] $$\Delta Z_{rms} = \sqrt{\sum_{i=1}^{N} \Delta Z^2 \, P(\Delta Z)}$$

where $P(\Delta Z)$, the probability function for ΔZ, is the area corresponding to a given ΔZ. From Figure 2.7-3 it can be seen that $P(\Delta Z)$ for any ΔZ is:

[70] $$P(\Delta Z) = \frac{\pi\left(r_k^2 - r_{k-1}^2\right)}{\pi R^2} = \frac{r_k^2 - r_{k-1}^2}{R^2}$$

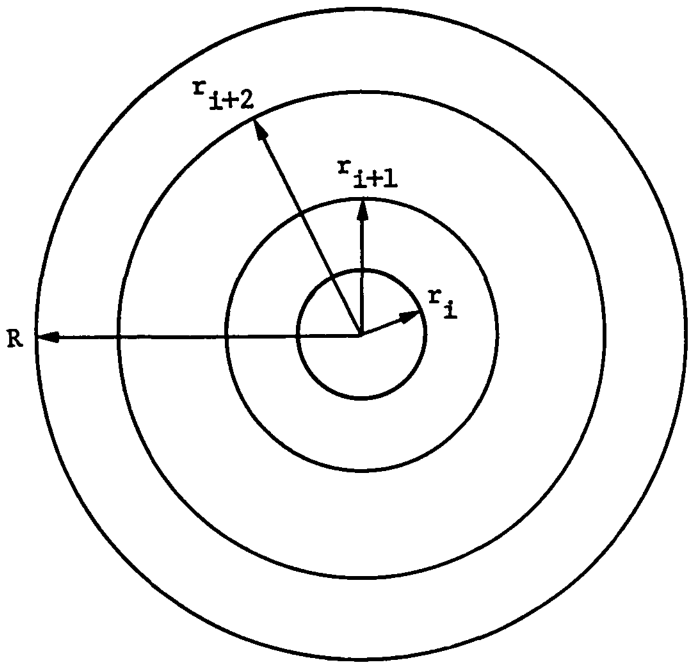

Figure 2.7-3
Radial Segments for Defining rms Surface Distortion

For a constant sampling interval $(r_k - r_{k-1})$, $P(\Delta Z)$ may be expressed as:

[71] $$P(\Delta Z) = \frac{(k\Delta r)^2 - [(k - 1)\Delta r]^2}{(N\Delta r)^2}$$

where:

$\Delta r = r_k - r_{k-1}$
N = total number of samples

Then the value of $P(\Delta Z)$ may be expressed in terms of the number of samples as:

[72] $$P(\Delta Z) = \frac{k^2 - (k - 1)^2}{N^2} = \frac{2k - 1}{N^2}$$

This permits use of a digital technique for predicting rms distortion of spherical surfaces where N can be defined as a function of wavelength.

[73]
$$\Delta Z_{rms} = \sqrt{\sum_{i=1}^{N} (\Delta Z_i)^2 \left(\frac{2i - 1}{N^2}\right)}$$

where N is number of points at which ΔZ is calculated along a two-dimensional cut.

To maintain consistency in calculating distortion for different rf frequencies, the number of points can be made a function of frequency by using an increment of $\lambda/4$ for r.

2.7.2 Rf Analysis Module User Instructions

A sample run follows. Execution requires the following command after logging onto user number 262597C at LaRC:

BEGIN,, RFPRN

As shown in the sample run, the user must supply the type of rf analysis where 1 = GENERAL should be selected for any antenna other than the ECMM type reflector designed under contract NAS1-16447 (Ref 5). Values are supplied for the aperture diameter illuminated by a single feed, the ratio of focal length to this diameter, the rf frequency being used, the power factor for the simulated feed, the total blockage area between the feed and aperture, and the rms distortion of the surface (e.g., due to manufacturing tolerance and surface saddling). If the choice had been for analysis of an ECMM antenna, the rms distortion would be calculated within the program and interfaced. The prompt for input of rms distortion would not appear.

If a spherical surface is being investigated, the user is prompted to define the desired displacement of the feed from the nominal (1/2R). The module calculates a predicted spherical aberration loss. A summary of antenna characteristics and primary beam gain is then output. The user is next prompted to perform another analysis or to terminate execution. The following is a sample run for the three frequencies proposed for the EOS baseline (Mission 1).

```
 THE ECMM PART OF THIS PROGRAM CALCULATES
 AN ESTIMATED RMS SURFACE ERROR FOR AN ECMM SURFACE.
 THE TIME REQUIRED TO CALCULATE THE DISTORTION INCREASES
 EXPONENTIALLY WITH THE ILLUMINATED SPOT SIZE.  FOR THE ASSA
 BASELINE ABOUT 5 MIN. IS REQUIRED FOR A CDC 730 MACHINE.
 A FASTER ESTIMATE CAN BE OBTAINED BY USING AN ILLUMINATED
SPOT SMALLER THAN THE ACTUAL APERTURE.
 ALSO, IF THE INPUT CONDITIONS DO NOT REPRESENT A REAL CASE,
THE PROGRAM WILL BLOW UP.


 SELECT TYPE OF RF ANALYSIS;
   1 = GENERAL
   2 = ECMM
? 1

 APERTURE DIAMETER IN METERS IS
? 58

 FOCAL LENGTH TO DIAMETER RATIO IS
? 2

 FREQUENCY IN GHZ IS
? 1.41


 WHAT POWER IS FEED PATTERN--(N FOR COS TO N'TH
? 84

 TOTAL AREA OF APERTURE BLOCKAGE IN SQ. METERS
? 0


 IS THE ANTENNA SURFACE SPHERICAL
? Y

 METERS FOCAL POINT IS TO BE DISPLACED FROM NOMINAL
 OF .5R(NEGATIVE MEANS AWAY FROM SURFACE)
? -.002


 ZRMS(M)=    .21649E-02
 ABERRATION LOSS=    .71025E-01

 DO YOU WISH TO ITERATE ON FEED LOCATION
? NO
```

```
                ANTENNA CHARACTERISTICS

   APERTURE DIAMETER(M)-----   .58000000E+02
   F TO D RATIO-------------   .20000000E+01
   FREQUENCY(GHZ)-----------   .14100000E+01
   FEED POWER--------------- 84

 IDEAL GAIN       =    .73341778E+06    =     58.65 DB
 GAIN EFFICIENCY =       .38
 REDUCED GAIN=          .27975263E+06    =     54.47 DB
 PERCENT APERTURE BLOCKAGE =        0.0
 GAIN WITH BLOCKAGE =            .27975263E+06    =     54.47 DB
 GAIN WITH RMS LOSS=             .27975263E+06    =     54.47 DB
 GAIN WITH ABERRATION LOSS =     .27521475E+06    =     54.40 DB


 DO YOU WANT TO PERFORM ANOTHER ANALYSIS
? Y

 APERTURE DIAMETER IN METERS IS
? 58

 FOCAL LENGTH TO DIAMETER RATIO IS
? 2

 FREQUENCY IN GHZ IS
? 5.5


 WHAT POWER IS FEED PATTERN--(N FOR COS TO N'TH
? 84

 TOTAL AREA OF APERTURE BLOCKAGE IN SQ. METERS
? 0


 IS THE ANTENNA SURFACE SPHERICAL
? Y

 METERS FOCAL POINT IS TO BE DISPLACED FROM NOMINAL
 OF .5R(NEGATIVE MEANS AWAY FROM SURFACE)
? -.002


 ZRMS(M)=    .21584E-02
 ABERRATION LOSS=     10742E+01
```

```
 DO YOU WISH TO ITERATE ON FEED LOCATION
? Y

 METERS FOCAL POINT IS TO BE DISPLACED FROM NOMINAL
 OF .5R(NEGATIVE MEANS AWAY FROM SURFACE)
? -.0025


 ZRMS(M)=    .21296E-02
 ABERRATION LOSS=    .10456E+01

 DO YOU WISH TO ITERATE ON FEED LOCATION
? Y

 METERS FOCAL POINT IS TO BE DISPLACED FROM NOMINAL
 OF .5R(NEGATIVE MEANS AWAY FROM SURFACE)
? -.00225


 ZRMS(M)=    .21294E-02
 ABERRATION LOSS=    .10455E+01

 DO YOU WISH TO ITERATE ON FEED LOCATION
? Y

 METERS FOCAL POINT IS TO BE DISPLACED FROM NOMINAL
 OF .5R(NEGATIVE MEANS AWAY FROM SURFACE)
? -.004


 ZRMS(M)=    .26766E-02
 ABERRATION LOSS=    .16518E+01

 DO YOU WISH TO ITERATE ON FEED LOCATION
? Y

 METERS FOCAL POINT IS TO BE DISPLACED FROM NOMINAL
 OF .5R(NEGATIVE MEANS AWAY FROM SURFACE)
? -.0024


 ZRMS(M)=    .21260E-02
 ABERRATION LOSS=    .10421E+01

 DO YOU WISH TO ITERATE ON FEED LOCATION
? N
```

```
                ANTENNA CHARACTERISTICS

    APERTURE DIAMETER(M)-----  .58000000E+02
    F TO D RATIO-------------  .20000000E+01
    FREQUENCY(GHZ)-----------  .55000000E+01
    FEED POWER--------------- 84

  IDEAL GAIN       =   .11159342E+08   =    70.48 DB
  GAIN EFFICIENCY =       .38
  REDUCED GAIN=         .42565853E+07   =    66.29 DB
  PERCENT APERTURE BLOCKAGE =       0.0
  GAIN WITH BLOCKAGE =          .42565853E+07   =    66.29 DB
  GAIN WITH RMS LOSS=           .42565853E+07   =    66.29 DB
  GAIN WITH ABERRATION LOSS =   .33484887E+07   =    65.25 DB


  DO YOU WANT TO PERFORM ANOTHER ANALYSIS
 ? Y

  APERTURE DIAMETER IN METERS IS
 ? 58

  FOCAL LENGTH TO DIAMETER RATIO IS
 ? 2

  FREQUENCY IN GHZ IS
 ? 10.68


  WHAT POWER IS FEED PATTERN--(N FOR COS TO N'TH
 ? 84

  TOTAL AREA OF APERTURE BLOCKAGE IN SQ. METERS
 ? 0


  IS THE ANTENNA SURFACE SPHERICAL
 ? Y

  METERS FOCAL POINT IS TO BE DISPLACED FROM NOMINAL
  OF .5R(NEGATIVE MEANS AWAY FROM SURFACE)
 ? -.002


  ZRMS(M)=    .21589E-02
  ABERRATION LOSS=    .40522E+01

  DO YOU WISH TO ITERATE ON FEED LOCATION
 ? Y

  METERS FOCAL POINT IS TO BE DISPLACED FROM NOMINAL
  OF .5R(NEGATIVE MEANS AWAY FROM SURFACE)
 ? -.0025
```

```
 ZRMS(M)=    .21300E-02
 ABERRATION LOSS=    .39444E+01

 DO YOU WISH TO ITERATE ON FEED LOCATION
? Y

 METERS FOCAL POINT IS TO BE DISPLACED FROM NOMINAL
 OF .5R(NEGATIVE MEANS AWAY FROM SURFACE)
? -.003


 ZRMS(M)=    .22165E-02
 ABERRATION LOSS=    .42713E+01

 DO YOU WISH TO ITERATE ON FEED LOCATION
? Y

 METERS FOCAL POINT IS TO BE DISPLACED FROM NOMINAL
 OF .5R(NEGATIVE MEANS AWAY FROM SURFACE)
? -.0025


 ZRMS(M)=    .21300E-02
 ABERRATION LOSS=    .39444E+01

 DO YOU WISH TO ITERATE ON FEED LOCATION
? Y

 METERS FOCAL POINT IS TO BE DISPLACED FROM NOMINAL
 OF .5R(NEGATIVE MEANS AWAY FROM SURFACE)
? -.0026


 ZRMS(M)=    .21382E-02
 ABERRATION LOSS=    .39750E+01

 DO YOU WISH TO ITERATE ON FEED LOCATION
? N


            ANTENNA CHARACTERISTICS

   APERTURE DIAMETER(M)-----  .58000000E+02
   F TO D RATIO-------------  .20000000E+01
   FREQUENCY(GHZ)-----------  .10680000E+02
   FEED POWER--------------- 84

  IDEAL GAIN       =    .42078060E+08    =     76.24 DB
  GAIN EFFICIENCY =        .38
  REDUCED GAIN=          .16050127E+08    =     72.05 DB
  PERCENT APERTURE BLOCKAGE =        0.0
  GAIN WITH BLOCKAGE =             .16050127E+08    =     72.05 DB
  GAIN WITH RMS LOSS=              .16050127E+08    =     72.05 DB
  GAIN WITH ABERRATION LOSS =      .64265204E+07    =     68.08 DB
```

2.8 SUBSYSTEM PROPERTIES MODULE

This module allows the user to roughly determine the mass, power, and cost requirements for the ten different subsystems of a large space structure listed below:

1) Guidance, navigation, and control (GNC),

2) Orbit transfer propulsion,

3) Attitude control,

4) Power,

5) Communications,

6) Thermal control,

7) Command and data handling (C&DH),

8) Pyrotechnics,

9) Structure,

10) Rendezvous and servicing.

Many subsystems and types of equipment can be sized at one time allowing the user to perform tradeoffs for different equipment and/or different missions. At this time, only the codes for the attitude control, power, and command and data handling subsystems have been completed. Costs for these subsystems have been omitted because of insufficient data.

2.8.1 Subsystem Properties Module Technical Description

This module is written for interactive use and is set up in overlay structure with the code for sizing each subsystem in a separate overlay. For this analysis, each subsystem is considered a separate "black box" with no interaction between subsystems (although inputs to the power subsystem are actually determined by the power needs of all the other subsystems). During execution, the user chooses program options from a menu format. These menus are displayed on the user's terminal, as are the prompts for user input and program outputs.

The mass and power relations for the attitude control subsystem were taken from graphs presented in Reference 6. Data from these graphs were curve fit, and the resultant equations coded into the program. The equations used are presented in Table 2.8-1.

The power subsystem uses the following relations (constants) for calculating mass (Ref 7):

Solar arrays and batteries - Low-Earth Orbit (LEO)	6.6 Watts/kg
Solar arrays and batteries - Geosynchronous Orbit (GEO)	15.4 Watts/kg
Radioisotope thermoelectric generators	2.2 Watts/kg
Dynamic isotope power systems	6.6 Watts/kg

Table 2.8-1 Attitude Control Mass and Power Relations

Equipment	Mass Relations	Power Relations
Single-Axis Reaction When 500 rpm Max Motor Speed 2000 rpm Max Motor Speed 6000 rpm Max Motor Speed	 $Wt = 17.3\ (MOM)^{0.6069}$ $Wt = 10.61\ (MOM)^{0.5678}$ $Wt = 15.25\ (MOM)^{0.397}$ (for MOM 900) $Wt = 18.26\ (MOM)^{0.437}$ (for MOM 900)	 $P=68.57(tq)^{0.792}$ $P=146.9(tq)^{0.924}$ $P=349.0(tq)^{0.957}$
Control Moment Gyros 3-Gyro Configuration 6000 rpm 12000 rpm 24000 rpm	 $Wt = 31.92\ (MOM)^{0.5234}$ (for MOM 300) $Wt = 53.88\ (MOM)^{0.405}$ (MOM 300) $Wt = 53.88\ (MOM)^{0.405}$ (MOM 300)	 $P=3.78(MOM)^{0.512}$ (for MOM 400) P=.284(MOM)+20.49 (12 MOM 400) $P=13.14\ (MOM)^{0.529}$ (MOM 12)
4-Gyro Configuration 6000 rpm 12000 rpm 24000 rpm	 $Wt = 15.59\ (MOM)^{0.5096}$ (MOM 3000) $Wt = 28.84\ (MOM)^{0.412}$ (90 MOM 3000) $Wt = 28.84\ (MOM)^{0.412}$ (MOM 90)	 $P=1.133(MOM)^{0.5}$ (MOM 3000) $P=3.646(MOM)^{0.460}$ $P=7.46(MOM)^{0.474}$
6-Gyro Configuration 12000 rpm 24000 rpm	 $Wt = 33.69\ (MOM)^{0.426}$ (MOM 130) $Wt = 33.69\ (MOM)^{0.426}$	 $P=3.63(MOM)^{0.4793}$ $P=10.59\ (MOM)^{0.438}$
Magnetic Torquers	Sizing Data Not Implemented Yet	
Thrusters Bipropellant Electric	 Wt = 0.004 (Im) + 40 Wt = 0.0064 (Im) + 26	 Not Available Not Available
Legend: MOM = Momentum tq = Torque Im = Impulse		

Note: Equations are later multiplied by a constant to obtain metric units.

Note that the actual EOS baseline configuration falls between the LEO and GEO values given by this program. For the command and data handling subsystem, the following relations were used:

	Mass Relation	Power Relation
Centralized Computer		
Computer	= (speed)(mass/speed)	= (speed)(power/speed)
Cabling	= (length)(mass/length)	= 0

When possible, subsystem sizing data were input as a data statement to allow future updates to be easily accomplished. This was done for the power subsystem where the relationships were constants. Where the relationship was more complex (as in attitude control), the sizing data are an integral part of the code, and updating will be a little more difficult.

2.8.2 Subsystem Properties Module User Instructions

When execution of the subsystem properties module begins, the user is asked to choose a subsystem:

```
 WELCOME TO THE SUBSYSTEMS PROPERTIES PROGRAM
 NOTES:
    1.   THESE PROPERTIES DO NOT INCLUDE REDUNDANCY.

 WHAT SUBSYSTEM DO YOU WANT:
    1   FINISH
    2   GUIDANCE, NAVIGATION, AND CONTROL (GNC)
    3   ORBIT TRANSFER PROPULSION
    4   ATTITUDE CONTROL
    5   POWER
    6   COMMUNICATIONS
    7   THERMAL CONTROL
    8   COMMAND AND DATA HANDLING (C&DH)
    9   PYROTECHNICS
   10   STRUCTURE
   11   RENDEZVOUS AND SERVICING
? 4
```

The overlay containing the sizing data for the requested subsystem is called, and a brief description of that subsystem, as well as a choice to size it or return to the main menu, is displayed:

```
THIS MODULE CONTAINS THE INFORMATION AND DATA
NEEDED TO ROUGHLY DETERMINE WEIGHT AND POWER
REQUIREMENTS FOR SPACECRAFT ATTITUDE CONTROL.
THE CONTROL SYSTEMS UNDER CONSIDERATION ARE LISTED BELOW:

   REACTION WHEELS AND CMG'S
            GOOD FOR CYCLIC DISTURBANCES,BUT CAN CROSS COUPLE
            WITH VEHICLE MOTION AND ALSO REQUIRES A WAY TO DESATURATE
   MAGNETIC TORQUERS
            USED FOR DESATURATION, BUT IS STRONGLY DEPENDANT ON
            THE EARTH'S MAGNETIC FIELD
   THRUSTERS
            ELECTRIC HAVE HIGH SPECIFIC IMPULSE FOR LONG MISSIONS,
            BUT HAVE LOW THRUST-HIGH POWER REQUIREMENTS
            CHEMICAL HAVE HIGH THRUST, BUT LOW SPECIFIC IMPULSE
            AND WEIGHT CAN BE A PROBLEM

 DO YOU WANT TO
     1   RETURN TO THE MAIN MENU
     2   CHOOSE A SYSTEM TO SIZE
? 2
```

The user is then prompted for an equipment choice for that subsystem (if applicable):

```
 WHAT TYPE OF SYSTEM DO YOU WISH TO SIZE?
  1   REACTION WHEELS AND CMG'S
  2   MAGNETIC TORQUERS
  3   THRUSTERS
? 1
1
1
```

Inputs are displayed, and the user may run the analysis with the data shown or may modify it, after which mass, power, and cost outputs will be displayed:

```
 REQUIRED INPUTS·

    0.                  1 TOTAL MOMENTUM (N-M-S)
    0.                  2 MAXIMUM STALL TORQUE (N-M)

 DO YOU WISH TO MODTFY THE INPUT DATA (Y/N)
? Y
OENTER VALUE,N UNTIL DONE   THEN ENTER 0,0

? 1000.,1,1000.,2,0,0
1
+


 REQUIRED INPUTS:

      1000.0            1 TOTAL MOMENTUM (N-M-S)
      1000.0            2 MAXIMUM STALL TORQUE (N-M)

 DO YOU WISH TO MODIFY THE INPUT DATA (Y/N)
? N



    SUBSYSTEM                        SUBSYSTEM       POWER        SUBSYSTEM
                                     MASS (KG)     REQ'D (W)      COST ($)

-------------------------------------------------------------------------------

SINGLE AXIS REACTION WHEEL
   500 RPM MAX MOTOR SPEED             431.70       12806 64
   2000 RPM MAX MOTOR SPEED            204.51       65595.35
   6000 RPM MAX MOTOR SPEED             95.16      193782 35

CONTROL MOMENT GYRO
   3 GYRO CONFIGURATION
      6000 RPM GYRO SPEED              458 92         111.12
      12000 RPM GYRO SPEED               0.00           0.00
      24000 RPM GYRO SPEED               0.00           0 00
   4 GYRO CONFIGURATION
      6000 RPM GYRO SPEED                0.00           0 00
      12000 RPM GYRO SPEED             198 70          76 03
      24000 RPM GYRO SPEED             198.70           0 00
   6GYRO CONFIGURATION
      12000 RPM GYRO SPEED             254 59          85 99
      24000 RPM GYRO SPEED             254.59           0 00
```

The user again has the choice of returning to the main menu or sizing a system. For subsystem sections that have not yet been completed, a message to that effect and the main menu are again displayed:

```
ORBIT TRANSFER PROPERTIES ARE NOT AVAILABLE

WHAT SUBSYSTEM DO YOU WANT:
  1  FINISH
  2  GUIDANCE, NAVIGATION, AND CONTROL (GNC)
  3  ORBIT TRANSFER PROPULSION
  4  ATTITUDE CONTROL
  5  POWER
  6  COMMUNICATIONS
  7  THERMAL CONTROL
  8  COMMAND AND DATA HANDLING (C&DH)
  9  PYROTECHNICS
 10  STRUCTURE
 11  RENDEZVOUS AND SERVICING
? 1
REVERT
/
```

2.8.3 Subsystem Properties Module Programmer Information

The code for the subsystems properties module is written in FORTRAN IV for interactive use. The program contains one zero-level overlay, one primary overlay, and ten secondary overlays. A description of each overlay, including required inputs, outputs, local variables, and external calls, is written as a block of comment statements at the beginning of each overlay. Shown on the following page is the comment block for the power subsystem code.

```
  TITLE:
     POWER SUBSYSTEM PROPERTIES
C
C PURPOSE
C    THIS MODULE CONTAINS POWER SUBSYSTEM PROPERTIES
C
C INPUTS:
C    DAT       REAL ARRAY      PEAK POWER & TOTAL ENERGY REQUIRED
C    DESC      ALPHA ARRAY     DESCRIPTION OF INPUT VALUES
C    HEAD      ALPHA ARRAY     HEADING FOR USER INPUTS
C
C OUTPUTS
C    DOUT   REAL ARRAY      MASS & COST VALUES
C
C LOCALS
C    WDEN       REAL ARRAY      POWER DENSITY (W/KG)
C    WHDEN      REAL ARRAY      ENERGY DENSITY (WHR/KG)
C    WDENC      REAL ARRAY      POWER COST DENSITY ($/W)
C    WHDENC     REAL ARRAY      ENERGY COST DENSITY ($/WHR)
C    VALUES IN THE ABOVE FOUR ARRAYS ARE FOR THE FOLLOWING APPLICATIONS:
C    COL 1    SOLAR ARRAYS AND BATTERIES-LOW EARTH ORBIT
C    COL 2    SOLAR ARRAYS AND BATTERIES-GEOSYNCH
C    COL 3    RADIOISOTOPE THERMOELECTRIC GENERATORS
C    COL 4    DYNAMIC ISOTOPE POWER SYSTEMS
C    WM,WHM     REAL            INTERMEDIATE MASS VALUES
     WMC,WHMC   REAL            INTERMEDIATE COST VALUES
     NY         ALPHA           USER ANS (Y/N) TO CHANGE INPUT DATA
     NSTART     INT             FLAG FOSIZING SUBSYS OR RETURNING TO MAIN MENU
C
C EXTERNALS:
C    PRNTIN   SUBROUTINE     PRINT INPUT DATA & DESCRIPTION
C    CHNGIN   SUBROUTINE     CHANGE INPUT DATA
C
C DECLARATIONS:
        .
        .
        .
        .
        .
C  EXECUTABLES
        .
        .
        .
        .
        .
```

The primary overlay asks the user to choose a subsystem to size and then calls a secondary overlay corresponding to that subsystem (Fig. 2.8-1). Three subsystem overlays are completed: attitude control, command and data handling, and power. Subroutines PRNTIN and CHNGIN are called by each secondary overlay to print and allow the user to change input data. Both are from the LASSLIB library.

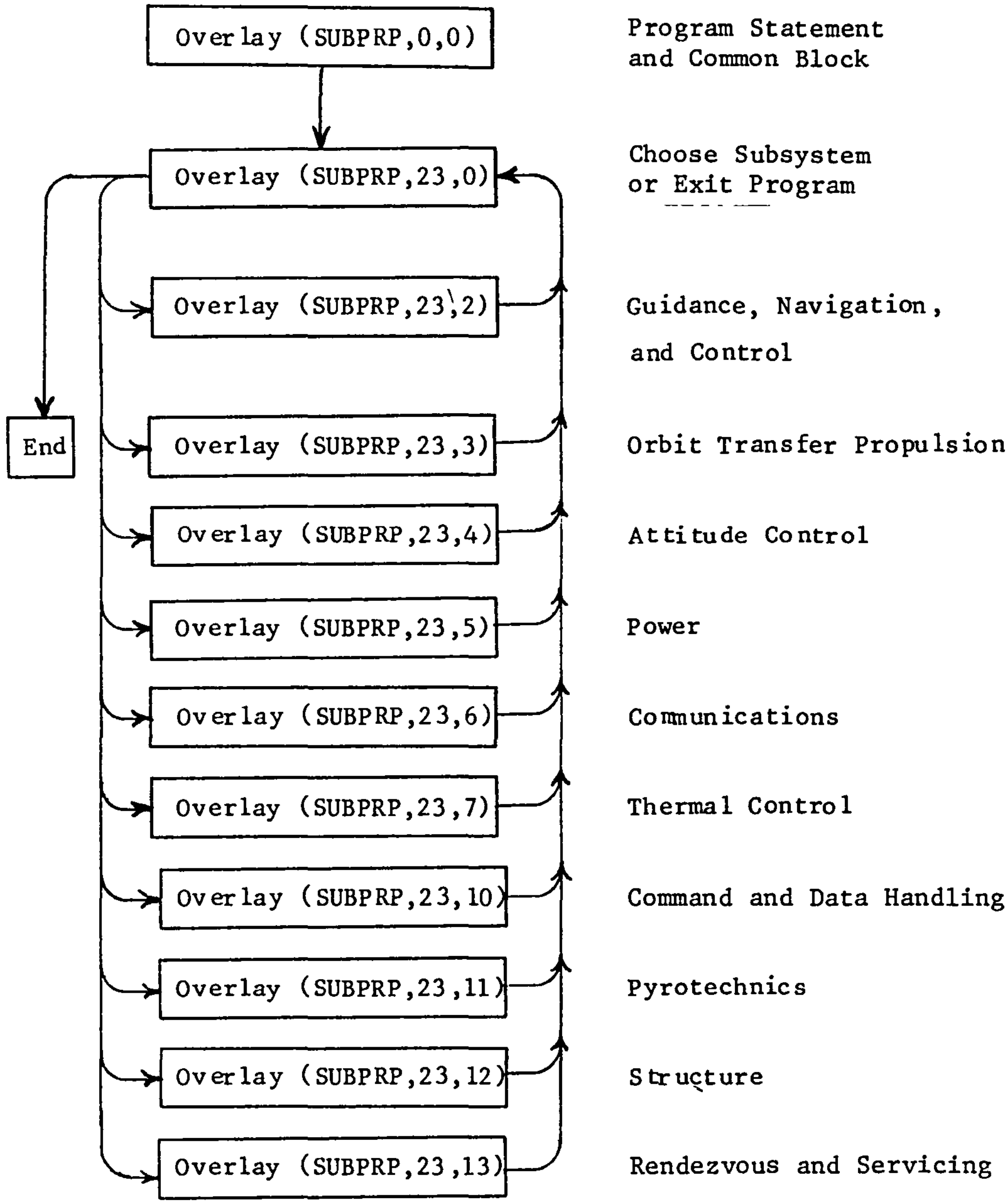

Figure 2.8-1 Subsystems Properties Module Program Structure

2.9 SENSOR PROPERTIES MODULE

2.9.1 Technical Description

The sensor properties module consists of three sections, each of which can be accessed by the user. They are: description and applications, design algorithms, and specific instrument data. The initial display upon logging on is a brief description of the three sections, which forms a table of contents. The user is asked to choose one of the three sections.

2.9.1.1 Descriptions and Applications - This section is not currently implemented.

2.9.1.2 Instrument Data - The instrument data section lists in outline form data pertinent to the design and selection of a particular sensor to satisfy an observation need. Included are physical properties, spectral bands, and heritage. Each description is designed to fit on one CRT screen.

2.9.1.3 Design Algorithms - This section presently consists of two parts: (1) sensor telemetry rates and (2) microwave radiometer design. It permits the user to calculate the data rates from a multiband sensor. The user can select the part of his choice using a linear array. The radiometer design part calculates the preliminary dimensions for a push-broom radiometer.

The telemetry rate algorithm requests the following inputs:

1) Swath dimensions (cross-track [CROSS], along-track [ALONG]),

2) Resolution in meters (cross-track [XGNDRES], along-track [AGNDRES]),

3) Bit quantization (QUANT; number of bits used to describe one pixel),

4) Number of spectral bands (NBANDS),

5) Orbit altitude (ORBALI).

The number of pixels (picture elements) per band per scene (PXBNDSC) from the first two inputs is:

[74]   PXBNDSC = ((CROSS * 1000)/XGNDRES) * ((ALONG * 1000)/AGNDRES).

The total bits per scene (TLBTSSC) is calculated from inputs 3, 4, and 5:

[75]   TLBTSSC = NBANDS * QUANT * PXBNDSC.

The data rate (DATART) is given by:

[76]   DATART = TLBTSSC/TMSCENE

where TMSCENE = VELGND/ALONG.

The ground velocity (VELGND) is calculated from the equation:

[77] VELGND = ERADIUS + SQRT (G * EMASS)/(ERADIUS + ORBALT)** 1.5.

The output is the total bits per scene (TLBTSSC).

The microwave design section request from the user is:

1) Ground resolution, frequency, altitude;

2) Swath width, quantization, predetection bandwidth (MHz).

The required HPBW is determined from the orbit altitude and the desired ground resolution. A conservative and an optimistic aperture are given:

[78] APERAT1 = 1.22 λ/HPBW1 (Optimistic)

[79] APERAT2 = 5 λ/HPBW2 (Conservative).

The number of horns is:

[80] NHORNS = FOV/GNDRES.

The data rate is:

[81] DRATE = NHORNS * BITS PER SAMPLE/TIME,

where TIME = GNDRES/VELGND.

The radiometric sensitivity is from the standard equation:

[82] TEMPSEN = 2 * TEMPSYS/$\sqrt{\text{BNDWDTH * TIME)}}$

and provides the following outputs:

1) Data rate, system temperature;

2) Number of horns, aperture dimensions (optimistic, conservative);

3) Radiometric temperature sensitivity.

The aperture dimensions are calculated from two different criteria. The optimistic criterion assumes that the HPBW (3-dB level) should subtend the same angle as the ground spot or resolution element. The conservative criterion assumes that the angle of the antenna main beam should be 1/2 the angle subtended by the resolution element.

2.9.2 Sensor Properties Module User Instructions

The procedure is: BEGIN,, SENSPR.

A sample run is presented to illustrate the use of this module. Upon entering the module, the following menu is displayed:

```
SENSOR PROPERTIES

THE SENSOR PROPERTIES MODULE CONSISTS OF THREE SECTIONS:

     1) SENSOR DESCRIPTIONS AND APPLICATIONS.  THIS COVERS LAND
RESOURCES, OCEANIC, AND ATMOSPHERIC MISSIONS.  OPERATING CONSTRAINTS
WILL BE ADDRESSED

     2) DESIGN ALGORITHMS FOR:  MICROWAVE RADIOMETER
                                SENSOR DATA RATES

     3) DETAILED INSTRUMENT DESCRIPTIONS OF EXISTING INSTRUMENTS  THE
USER IS GIVEN THE OPPORTUNITY TO REVIEW THESE SENSORS AS EXAMPLES OF
CLASSES OR TYPES OF INSTRUMENTATION  THEN SELECT A SENSOR COMPLEMENT
AND DISPLAY PERTINENT ENGINEERING DATA


WHICH SECTION DO YOU WISH TO SEE?
          1) DESCRIPTION AND APPLICATIONS
          2) DESIGN ALGORITHMS
          3) INSTRUMENT DATA
          4) END SESSION
? 2
```

Choosing the design section returns with:

```
PICK:    (1)   SENSOR TELEMETRY         (2)   RADIOMETER
```

Selecting (1) returns with a series of input requests.

```
 ENTER(KM): X-TRACK LENGTH, ALONG-TRACK
? 185,180

 ENTER(M): X-TRACK RESOLUTION, ALONG-TRK RES
?
  30,30

 ENTER: QUANTIZATION, #BANDS, ORBALT
? 8,4,700
```

The output statement returns with:

```
THE DATA RATE FOR THIS CONFIGURATION = 44900000.0
```

The user is then asked if he wants to continue or return to the menu:

```
DO YOU WANT TO RUN ANOTHER CASE?  YES=1  NO=2
```

Upon returning to the menu, the user can select another, such as instrument description. In this section a new menu is displayed with the appropriate prompt.

SENSOR PROPERTIES

THE SENSOR PROPERTIES MODULE CONSISTS OF THREE SECTIONS:

1) SENSOR DESCRIPTIONS AND APPLICATIONS. THIS COVERS LAND RESOURCES, OCEANIC, AND ATMOSPHERIC MISSIONS. OPERATING CONSTRAINTS WILL BE ADDRESSED.

2) DESIGN ALGORITHMS FOR: MICROWAVE RADIOMETER
SENSOR DATA RATES

3) DETAILED INSTRUMENT DESCRIPTIONS OF EXISTING INSTRUMENTS THE USER IS GIVEN THE OPPORTUNITY TO REVIEW THESE SENSORS AS EXAMPLES OF CLASSES OR TYPES OF INSTRUMENTATION. THEN SELECT A SENSOR COMPLEMENT AND DISPLAY PERTINENT ENGINEERING DATA

```
WHICH SECTION DO YOU WISH TO SEE?
          1) DESCRIPTION AND APPLICATIONS
          2) DESIGN ALGORITHMS
          3) INSTRUMENT DATA
          4) END SESSION
? 3
```

```
 WHICH SENSOR DATA LIST DO YOU WANT TO SEE?
          LAND OBSERVATION INSTRUMENTATION
                         1) HEAT CAPACITY MAPPING RADIOMETER
                         2) THEMATIC MAPPER
                         3) MULTISPECTRAL SCANNER
                         4) MULTISPECTRAL RESOURCE SCANNER
          OCEANIC INSTRUMENTATION
                         5) COASTAL ZONE COLOR SCANNER
                         6) RADAR ALTIMETER
                         7) RADAR SCATTEROMETER
                         8) SCANNING MULTICHANNEL MICROWAVE RADIOMETER
          ATMOSPHERIC INSTRUMENTATION
                         9) TEMPERATURE HUMIDITY INFRARED RADIOMETER
                         10)MEASUREMENT OF POLLUTION FROM SHUTTLE
                         11)CIMATS
? 2
```

```
THEMATIC MAPPER

PURPOSE:        MUI TIDTSCIPLTNE & MULTISPECTRAL LAND IMAGING
                 LANDSAT 4

TYPE·           24 CHANNEL IMAGING SPECTRORADIOMETER
    OBJECT PLANE, MECHANICALLY SCANNED

SPECTRAL        BAND 1:          45 - .52 UM
                BAND 2·          52 -  60 UM
                BAND 3·         .63 - .69 UM
                BAND 4·         .76 - .90 UM

WEIGHT          47.6 KG
DATA RATE:      80 MB/S
DIMENSIONS:      9M X   9M X 1.8M
POWER·          250 W

SWATH WIDTH·    185 KM @ 705 KM ALTITUDE

DO YOU WISH TO SEE SENSOR LIST AGAIN/
? 2
```

The selection is made, and the information is displayed. If the user responds YES (1) to the prompt, the sensor menu is displayed again, and the process continues. If the response is NO, the reply is

DO YOU WISH TO COMPILE A SENSOR SET?

If the response is NO (2), the program terminates. If the response is YES (1), the available sensor catalogue is displayed. A total of five sensors can be included. These are entered (separating each number by a comma), and the result is displayed.

```
LAND OBSERVATION INSTRUMENTATION
                1) HEAT CAPACITY MAPPING RADIOMETER
                2) THEMATIC MAPPER
                3) MULTISPECTRAL SCANNER
                4) MULTISPECTRAL RESOURCE SCANNER
OCEANIC INSTRUMENTATION
                5) COASTAL ZONE COLOR SCANNER
                6) RADAR ALTIMETER
                7) RADAR SCATTEROMETER
                8) SCANNING MULTICHANNEL MICROWAVE RADIOMETER
ATMOSPHERIC INSTRUMENTATION
                9) TEMPERATURE HUMIDITY INFRARED RADIOMETER
                10)MEASUREMENT OF POLLUTION FROM SHUTTLE
                11)CIMATS

SELECT THE SENSOR YOU WISH TO INCLUDE
? 4,5,6,7,9
```

```
                                     POWER(W)  MASS(KG)   DATA
MULTISPECTRAL RESOURCE SCANNER          85        55    15000000
COASTAL ZONE COLOR SCANNER              12        30      800000
RADAR ALTIMETER                        177        90        8500
RADAR SCATTEROMETER                     80       130        1000
TEMPERATURE HUMIDITY IR RAD              8        10        5000

                    TOTALS             362       315    15814500
? 1
```

The main menu is again displayed, and the user can exercise the available options.

```
WHICH SECTION DO YOU WISH TO SEE?
        1) DESCRIPTION AND APPLICATIONS
        2) DESIGN ALGORITHMS
        3) INSTRUMENT DATA
        4) END SESSION
? 4
     158 CP SECONDS EXECUTION TIME
/BYE
```

2.9.3 <u>Sensor Properties Module Programmer Information</u>

The sensor properties module is divided into three sections: description and applications, radiometer design algorithm, and specific instrument data. Each is described below. The introductory leader is contained in TAPE39 and is a file containing text. It is called from subroutine FRNTEND (front end). FRNTEND also questions the user as to selection and returns the reply in variable IREPLY1.

2.9.3.1 <u>Instrument Data</u> - This section calls TAPE41 and TAPE45. A list of the sensors is displayed, and the user is asked to select by number. If the reply is not 12, TAPE41 is rewound, and the proper sensor is found by comparing the number of times end-of-record (EOR) is found in Columns 1 through 3. When IANS equals the number of records counted, the next record is printed on the screen until the next EOR, and then terminates.

The data file for the sensor compilation is contained in TAPE45. The data in this file are formatted as I2, 2A10, 3I5, F10.7 and correspond to an index, name of sensor, power, mass, and data rate, respectively.

2.9.3.2 <u>Design Algorithm</u> - The design algorithm section is contained in the main body of the program and does not call other routines or tapes. The user is asked the desired section--either telemetry data rate or radiometer design, and the reply is contained in IREPLY. The user can iterate through the design or return to the menu via GOTO 1111.

3.0 DATA FILES DESCRIPTION

This section contains listings of source files and output generated during analysis of the EOS baseline mission. They are, in order, the dynamic model file (DYEOS), node and equipment masses from the MP module, and RCD module outputs, file LPRINT. At the end of the section are listings of the procedure files used at LaRC to execute the nine modules. Table 3-1 contains a definition of the input and output files for each module test case.

Table 3-1 Module Software File Definitions

Module	Type of File	File Names to Run From	
		Martin Marietta	LaRC
Contiguous Box Truss Synthesizer	Procedure	Begin,,LSSCTPR	Same
	Catalog	CTBIN,LSSLIB	BOXGEN
	FORTRAN IV Source Code	LSSCTN	Same
	Binaries (Compiled from Source)	CTBIN	Not Reqd
	Absolutes (RUN File from Source)	None	BOXGEN
	Libraries	LASSLIB, AVIDLIB RAUSYS, NMACFTN, LIBFTEK, LSSLIB	Same
Mass Properties	Procedure	BEGIN,,MPPROC	Same
	Catalog	MASNEW2	MASFIL
	FORTRAN IV Source	MASNEW2	Same
	Absolutes	None	MASFIL
	Libraries	LASSLIB,AVIDLIB, RAUSYS, NMACFTN, LIBFTEK	Same
Environmental Areas	Procedure	BEGIN,,MPPROC	Same
	Catalog	AREA	ENVAREA
	FORTRAN IV	AREA	Same
	Absolutes	None	ENVAREA
	Libraries	LASSLIB,AVIDLIB, RAUSYS, NMACFTN, LIBFTEK	Same
Controls Analysis	Procedure	BEGIN,,LASSE	BEGIN,,RCDPR
	Catalog	MAINRCD, RCDLIB (No Plotting)	RCDMMA
	FORTRAN IV Source	MAINRCD	Same
	Absolutes	None	RCDMMA
	Libraries	LASSLIB, AVIDLIB RAUSYS, NMACFTN, LIBFTEK, RCDLIB	Same

Table 3-1 (concl)

Module	Type of File	File Names to Run From	
Contiguous Box Truss Deployment	Procedure	GET, BIDPABS PPR	BEGIN,,BTDDE
	Catalog	BTDPAS	Same
	FORTRAN IV Source	BTDPFTN	Same
	Absolutes	BTDPABS (Not Available)	BTDPABS (Available)
	Job File to Create Absolutes	BTDPRUN	Not Reqd
	Libraries	LASSLIB, AVIDLIB, LSSLIBN, TCSLIB, DISSPLA (Last 3 Not Available)	LASSLIB, AVIDLIB LIBFTEK
	Input Command File	DEPLINS	Same
Hoop Column Deployment	Procedure	BEGIN,,HCDEPR	Same
	Catalog	HOOPDEP,LSSLIB (No Plotting)	HOOPC
	FORTRAN IV Source	HOOPDEP	Same
	Absolutes	None	HOOPC
	Libraries	LASSLIB,AVIDLIB, RAUSYS, NMACFTN, LIBFTEK, LSSLIB	Same
Rf Analysis	Procedure	BEGIN,,REPRN	Same
	Catalog	RENEW	RFNABS
	FORTRAN IV Source	RFNEW	Same
	Absolutes	None	RFNABS
	Libraries	LASSLIB,AVIDLIB RAUSYS, NMACFTN LIBFTEK	Same
Subsystem Properties	Procedure	BEGIN,,PROPRUN	Same
	Catalog	PROPBIN	SUBPRP
	FORTRAN IV Source	PROPFIN	Same
	Binaries	PROPBIN	Not Reqd
	Procedure to Create Binaries from Source	PROPCOM	Same
	Absolutes	None	SUBPRP
Sensor Properties	Procedure	BEGIN,,SENSPR	Same
	Catalog	SENSORS, TAPE 39, TAPE 41, TAPE 45	SENSABS, Tape 39, TAPE 41, TAPE 45
	FORTRAN IV Source	SENSORS	Same
	Absolutes	None Reqd	SENSABS
	Libraries	None	None

```
BEGIN BULK
$ TITLE = MPTEST
$ GRIDWORK
GRID      111111            0.000   0.000   0.000         123456
GRID      111112           15.141   0.000    .478         123456
GRID      211112          -15.141   0.000    .478         123456
GRID      111113           30.219   0.000   1.903         123456
GRID      211113          -30.219   0.000   1.903         123456
GRID      111114           45.189   0.000   4 254         123456
GRID      211114          -45.189   0.000   4.254         123456
GRID      111115           59.994   0.000   7.498         123456
GRID      211115          -59.994   0.000   7.498         123456
GRID      111211            0.000  15.141    .478         123456
GRID      211211            0.000 -15.141    .478         123456
GRID      111212           15.141  15.141    .955         123456
GRID      211212          -15.141  15.141    .955         123456
GRID      311212          -15.141 -15.141    .955         123456
GRID      411212           15.141 -15.141    .955         123456
GRID      111213           30.219  15.141   2.380         123456
GRID      211213          -30.219  15.141   2.380         123456
GRID      311213          -30.219 -15.141   2.380         123456
GRID      411213           30.219 -15.141   2.380         123456
GRID      111214           45.189  15.141   4.732         123456
GRID      211214          -45.189  15.141   4.732         123456
GRID      311214          -45.189 -15.141   4.732         123456
GRID      411214           45.189 -15.141   4.732         123456
GRID      111215           59.994  15.141   7.976         123456
GRID      211215          -59.994  15.141   7.976         123456
GRID      311215          -59.994 -15.141   7.976         123456
GRID      411215           59.994 -15.141   7.976         123456
GRID      111311            0.000  30.219   1.903         123456
GRID      211311            0.000 -30.219   1.903         123456
GRID      111312           15.141  30.219   2.380         123456
GRID      211312          -15.141  30.219   2.380         123456
GRID      311312          -15.141 -30.219   2.380         123456
GRID      411312           15.141 -30.219   2.380         123456
GRID      111313           30.219  30.219   3.805         123456
GRID      211313          -30.219  30.219   3.805         123456
GRID      311313          -30.219 -30.219   3.805         123456
GRID      411313           30.219 -30.219   3.805         123456
GRID      111314           45.189  30.219   6.157         123456
GRID      211314          -45.189  30.219   6.157         123456
GRID      311314          -45.189 -30.219   6.157         123456
GRID      411314           45.189 -30.219   6.157         123456
GRID      121111            0.000   0.000  15.140         123456
GRID      121112           15.141   0.000  15.618         123456
GRID      221112          -15.141   0.000  15.618         123456
GRID      121113           30.219   0.000  17.043         123456
GRID      221113          -30.219   0.000  17.043         123456
GRID      121114           45.189   0.000  19.394         123456
GRID      221114          -45.189   0.000  19.394         123456
GRID      121115           59.994   0.000  22.638         123456
GRID      221115          -59.994   0.000  22.638         123456
GRID      121211            0.000  15.141  15.618         123456
GRID      221211            0.000 -15.141  15.618         123456
??
```

```
   [illegible]
GRID    221211          0.000 -15.141  15.618          123456
GRID    121212         15.141  15.141  16.095          123456
GRID    221212        -15.141  15.141  16.095          123456
GRID    321212        -15.141 -15.141  16.095          123456
GRID    421212         15.141 -15.141  16.095          123456
GRID    121213         30.219  15.141  17.520          123456
GRID    221213        -30.219  15.141  17.520          123456
GRID    321213        -30.219 -15.141  17.520          123456
GRID    421213         30.219 -15.141  17.520          123456
GRID    121214         45.189  15.141  19.872          123456
GRID    221214        -45.189  15.141  19.872          123456
GRID    321214        -45.189 -15.141  19.872          123456
GRID    421214         45.189 -15.141  19.872          123456
GRID    121215         59.994  15.141  23.116          123456
GRID    221215        -59.994  15.141  23.116          123456
GRID    321215        -59.994 -15.141  23.116          123456
GRID    421215         59.994 -15.141  23.116          123456
GRID    121311          0.000  30.219  17.043          123456
GRID    221311          0.000 -30.219  17.043          123456
GRID    121312         15.141  30.219  17.520          123456
GRID    221312        -15.141  30.219  17.520          123456
GRID    321312        -15.141 -30.219  17.520          123456
GRID    421312         15.141 -30.219  17.520          123456
GRID    121313         30.219  30.219  18.945          123456
GRID    221313        -30.219  30.219  18.945          123456
GRID    321313        -30.219 -30.219  18.945          123456
GRID    421313         30.219 -30.219  18.945          123456
GRID    121314         45.189  30.219  21.297          123456
GRID    221314        -45.189  30.219  21.297          123456
GRID    321314        -45.189 -30.219  21.297          123456
GRID    421314         45.189 -30.219  21.297          123456
CBAR    110001      1  111111  1111121.0      0.0      0.0
CBAR    110002      1  111112  1111131.0      0.0      0.0
CBAR    110003      1  111113  1111141.0      0.0      0.0
CBAR    110004      1  111114  1111151.0      0.0      0.0
CBAR    110005      1  111211  1112121.0      0.0      0.0
CBAR    110006      1  111212  1112131.0      0.0      0.0
CBAR    110007      1  111213  1112141.0      0.0      0.0
CBAR    110008      1  111214  1112151.0      0.0      0.0
CBAR    110009      1  111311  1113121.0      0.0      0.0
CBAR    110010      1  111312  1113131.0      0.0      0.0
CBAR    110011      1  111313  1113141.0      0.0      0.0
CBAR    110012      1  111111  1112111.0      0.0      0.0
CBAR    110013      1  111112  1112121.0      0.0      0.0
CBAR    110014      1  111113  1112131.0      0.0      0.0
CBAR    110015      1  111114  1112141.0      0.0      0.0
CBAR    110016      1  111115  1112151.0      0.0      0.0
CBAR    110017      1  111211  1113111.0      0.0      0.0
CBAR    110018      1  111212  1113121.0      0.0      0.0
CBAR    110019      1  111213  1113131.0      0.0      0.0
CBAR    110020      1  111214  1113141.0      0.0      0.0
CBAR    110021      1  111111  2111121.0      0.0      0.0
CBAR    110022      1  211112  2111131.0      0.0      0.0
CBAR    110023      1  211113  2111141.0      0.0      0.0
CBAR    110024      1  211114  2111151.0      0.0      0.0
```

r5U

CBAR	110024	1	211114	2111151 0	0.0	0 0
CBAR	110025	1	111211	2112121 0	0 0	0.0
CBAR	110026	1	211212	2112131.0	0.0	0 0
CBAR	110027	1	211213	2112141.0	0.0	0.0
CBAR	110028	1	211214	2112151.0	0.0	0.0
CBAR	110029	1	111311	2113121 0	0.0	0.0
CBAR	110030	1	211312	2113131.0	0.0	0.0
CBAR	110031	1	211313	2113141.0	0.0	0.0
CBAR	110032	1	211112	2112121.0	0.0	0 0
CBAR	110033	1	211113	2112131 0	0.0	0 0
CBAR	110034	1	211114	2112141.0	0.0	0.0
CBAR	110035	1	211115	2112151.0	0.0	0.0
CBAR	110036	1	211212	2113121.0	0.0	0.0
CBAR	110037	1	211213	2113131.0	0.0	0.0
CBAR	110038	1	211214	2113141.0	0.0	0.0
CBAR	110039	1	211211	3112121.0	0.0	0.0
CBAR	110040	1	311212	3112131.0	0.0	0.0
CBAR	110041	1	311213	3112141.0	0.0	0.0
CBAR	110042	1	311214	3112151 0	0.0	0.0
CBAR	110043	1	211311	3113121.0	0.0	0.0
CBAR	110044	1	311312	3113131.0	0.0	0 0
CBAR	110045	1	311313	3113141.0	0.0	0.0
CBAR	110046	1	111111	2112111.0	0.0	0.0
CBAR	110047	1	211211	2113111.0	0.0	0.0
CBAR	110048	1	211112	3112121.0	0.0	0.0
CBAR	110049	1	211113	3112131.0	0.0	0.0
CBAR	110050	1	211114	3112141 0	0 0	0.0
CBAR	110051	1	211115	3112151.0	0.0	0 0
CBAR	110052	1	311212	3113121.0	0.0	0.0
CBAR	110053	1	311213	3113131 0	0.0	0.0
CBAR	110054	1	311214	3113141.0	0.0	0 0
CBAR	110055	1	211211	4112121.0	0.0	0.0
CBAR	110056	1	411212	4112131.0	0.0	0.0
CBAR	110057	1	411213	4112141.0	0.0	0.0
CBAR	110058	1	411214	4112151.0	0 0	0.0
CBAR	110059	1	211311	4113121.0	0.0	0.0
CBAR	110060	1	411312	4113131.0	0.0	0 0
CBAR	110061	1	411313	4113141.0	0.0	0.0
CBAR	110062	1	111112	4112121.0	0.0	0.0
CBAR	110063	1	111113	4112131 0	0.0	0 0
CBAR	110064	1	111114	4112141.0	0.0	0.0
CBAR	110065	1	111115	4112151.0	0.0	0.0
CBAR	110066	1	411212	4113121.0	0.0	0.0
CBAR	110067	1	411213	4113131.0	0.0	0.0
CBAR	110068	1	411214	4113141.0	0.0	0.0
CBAR	120001	1	121111	1211121.0	0.0	0.0
CBAR	120002	1	121112	1211131.0	0 0	0.0
CBAR	120003	1	121113	1211141.0	0.0	0.0
CBAR	120004	1	121114	1211151.0	0 0	0.0
CBAR	120005	1	121211	1212121.0	0.0	0 0
CBAR	120006	1	121212	1212131.0	0.0	0.0
CBAR	120007	1	121213	1212141.0	0.0	0.0
CBAR	120008	1	121214	1212151.0	0.0	0.0
CBAR	120009	1	121311	1213121.0	0.0	0.0
CBAR	120010	1	121312	1213131.0	0.0	0.0

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CBAR	120010	1	121312	1213131.0	0.0	0.0
CBAR	120011	1	121313	1213141.0	0.0	0.0
CBAR	120012	1	121111	1212111.0	0.0	0.0
CBAR	120013	1	121112	1212121.0	0.0	0.0
CBAR	120014	1	121113	1212131.0	0 0	0.0
CBAR	120015	1	121114	1212141.0	0.0	0.0
CBAR	120016	1	121115	1212151.0	0.0	0.0
CBAR	120017	1	121211	1213111.0	0.0	0.0
CBAR	120018	1	121212	1213121.0	0.0	0.0
CBAR	120019	1	121213	1213131.0	0.0	0.0
CBAR	120020	1	121214	1213141.0	0.0	0.0
CBAR	120021	1	121111	2211121.0	0.0	0.0
CBAR	120022	1	221112	2211131.0	0.0	0.0
CBAR	120023	1	221113	2211141.0	0.0	0.0
CBAR	120024	1	221114	2211151.0	0 0	0.0
CBAR	120025	1	121211	2212121.0	0.0	0.0
CBAR	120026	1	221212	2212131.0	0.0	0.0
CBAR	120027	1	221213	2212141.0	0.0	0.0
CBAR	120028	1	221214	2212151.0	0.0	0.0
CBAR	120029	1	121311	2213121.0	0.0	0.0
CBAR	120030	1	221312	2213131.0	0.0	0.0
CBAR	120031	1	221313	2213141.0	0.0	0.0
CBAR	120032	1	221112	2212121.0	0.0	0.0
CBAR	120033	1	221113	2212131.0	0.0	0.0
CBAR	120034	1	221114	2212141.0	0.0	0.0
CBAR	120035	1	221115	2212151.0	0.0	0.0
CBAR	120036	1	221212	2213121.0	0.0	0.0
CBAR	120037	1	221213	2213131.0	0.0	0.0
CBAR	120038	1	221214	2213141.0	0.0	0.0
CBAR	120039	1	221211	3212121.0	0.0	0.0
CBAR	120040	1	321212	3212131.0	0.0	0.0
CBAR	120041	1	321213	3212141.0	0.0	0.0
CBAR	120042	1	321214	3212151.0	0.0	0.0
CBAR	120043	1	221311	3213121.0	0.0	0.0
CBAR	120044	1	321312	3213131.0	0.0	0.0
CBAR	120045	1	321313	3213141.0	0.0	0.0
CBAR	120046	1	121111	2212111.0	0.0	0.0
CBAR	120047	1	221211	2213111.0	0.0	0.0
CBAR	120048	1	221112	3212121.0	0.0	0.0
CBAR	120049	1	221113	3212131.0	0.0	0.0
CBAR	120050	1	221114	3212141.0	0.0	0.0
CBAR	120051	1	221115	3212151.0	0.0	0.0
CBAR	120052	1	321212	3213121.0	0.0	0.0
CBAR	120053	1	321213	3213131.0	0.0	0.0
CBAR	120054	1	321214	3213141.0	0.0	0.0
CBAR	120055	1	221211	4212121.0	0 0	0.0
CBAR	120056	1	421212	4212131.0	0.0	0.0
CBAR	120057	1	421213	4212141.0	0.0	0.0
CBAR	120058	1	421214	4212151.0	0.0	0.0
CBAR	120059	1	221311	4213121.0	0.0	0.0
CBAR	120060	1	421312	4213131.0	0.0	0.0
CBAR	120061	1	421313	4213141.0	0.0	0.0
CBAR	120062	1	121112	4212121.0	0.0	0.0
CBAR	120063	1	121113	4212131.0	0.0	0.0
CBAR	120064	1	121114	4212141.0	0.0	0.0

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CBAR      120064      1   121114  4212141.0     0.0      0.0
CBAR      120065      1   121115  4212151 0     0.0      0.0
CBAR      120066      1   421212  4213121.0     0.0      0.0
CBAR      120067      1   421213  4213131.0     0.0      0.0
CBAR      120068      1   421214  4213141.0     0.0      0.0
$ VERTICAL BEAMS
CBAR      120069      2   111111  1211110.0     1.0      0.0
CBAR      120070      2   111112  1211120.0     1.0      0.0
CBAR      120071      2   211112  2211120.0     1.0      0.0
CBAR      120072      2   111113  1211130.0     1.0      0.0
CBAR      120073      2   211113  2211130.0     1.0      0.0
CBAR      120074      2   111114  1211140.0     1.0      0.0
CBAR      120075      2   211114  2211140.0     1.0      0.0
CBAR      120076      2   111115  1211150 0     1.0      0.0
CBAR      120077      2   211115  2211150.0     1.0      0.0
CBAR      120078      2   111211  1212110.0     1.0      0.0
CBAR      120079      2   211211  2212110.0     1.0      0.0
CBAR      120080      2   111212  1212120.0     1.0      0.0
CBAR      120081      2   211212  2212120.0     1.0      0.0
CBAR      120082      2   311212  3212120.0     1.0      0.0
CBAR      120083      2   411212  4212120.0     1.0      0.0
CBAR      120084      2   111213  1212130.0     1.0      0.0
CBAR      120085      2   211213  2212130.0     1.0      0.0
CBAR      120086      2   311213  3212130.0     1.0      0.0
CBAR      120087      2   411213  4212130.0     1.0      0.0
CBAR      120088      2   111214  1212140.0     1.0      0.0
CBAR      120089      2   211214  2212140.0     1.0      0.0
CBAR      120090      2   311214  3212140.0     1.0      0.0
CBAR      120091      2   411214  4212140.0     1.0      0.0
CBAR      120092      2   111215  1212150.0     1.0      0.0
CBAR      120093      2   211215  2212150.0     1.0      0.0
CBAR      120094      2   311215  3212150.0     1.0      0.0
CBAR      120095      2   411215  4212150.0     1.0      0.0
CBAR      120096      2   111311  1213110.0     1.0      0.0
CBAR      120097      2   211311  2213110.0     1.0      0.0
CBAR      120098      2   111312  1213120.0     1.0      0.0
CBAR      120099      2   211312  2213120.0     1.0      0.0
CBAR      120100      2   311312  3213120.0     1.0      0.0
CBAR      120101      2   411312  4213120.0     1.0      0.0
CBAR      120102      2   111313  1213130.0     1.0      0.0
CBAR      120103      2   211313  2213130.0     1.0      0.0
CBAR      120104      2   311313  3213130.0     1.0      0.0
CBAR      120105      2   411313  4213130.0     1.0      0.0
CBAR      120106      2   111314  1213140.0     1.0      0.0
CBAR      120107      2   211314  2213140.0     1.0      0.0
CBAR      120108      2   311314  3213140.0     1.0      0.0
CBAR      120109      2   411314  4213140.0     1.0      0.0
$ HORIZONTAL DIAGONALS
CROD      140001      3   111111  111212
CROD      140002      3   111211  111112
CROD      150001      3   121111  121212
CROD      150002      3   121211  121112
CROD      140003      3   111112  111213
CROD      140004      3   111212  111113
CROD      150003      3   121112  121213
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CROD	150003	3	121112	121213
CROD	150004	3	121212	121113
CROD	140005	3	111113	111214
CROD	140006	3	111213	111114
CROD	150005	3	121113	121214
CROD	150006	3	121213	121114
CROD	140007	3	111114	111215
CROD	140008	3	111214	111115
CROD	150007	3	121114	121215
CROD	150008	3	121214	121115
CROD	140009	3	111211	111312
CROD	140010	3	111311	111212
CROD	150009	3	121211	121312
CROD	150010	3	121311	121212
CROD	140011	3	111212	111313
CROD	140012	3	111312	111213
CROD	150011	3	121212	121313
CROD	150012	3	121312	121213
CROD	140013	3	111213	111314
CROD	140014	3	111313	111214
CROD	150013	3	121213	121314
CROD	150014	3	121313	121214
CROD	140015	3	111111	211212
CROD	140016	3	211112	111211
CROD	140017	3	121111	221212
CROD	140018	3	221112	121211
CROD	140019	3	111111	311212
CROD	140020	3	211112	211211
CROD	140021	3	121111	321212
CROD	140022	3	221112	221211
CROD	140023	3	111111	411212
CROD	140024	3	111112	211211
CROD	140025	3	121111	421212
CROD	140026	3	121112	221211
CROD	140027	3	211112	211213
CROD	140028	3	211113	211212
CROD	140029	3	221112	221213
CROD	140030	3	221113	221212
CROD	140031	3	211112	311213
CROD	140032	3	211113	311212
CROD	140033	3	221112	321213
CROD	140034	3	221113	321212
CROD	140035	3	111112	411213
CROD	140036	3	111113	411212
CROD	140037	3	121112	421213
CROD	140038	3	121113	421212
CROD	140039	3	211113	211214
CROD	140040	3	211114	211213
CROD	140041	3	221113	221214
CROD	140042	3	221114	221213
CROD	140043	3	211113	311214
CROD	140044	3	211114	311213
CROD	140045	3	221113	321214
CROD	140046	3	221114	321213
CROD	140047	3	111113	411214

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CROD        140047      3  111113  411214
CROD        140048      3  111114  411213
CROD        140049      3  121113  421214
CROD        140050      3  121114  421213
CROD        140051      3  211114  211215
CROD        140052      3  211115  211214
CROD        140053      3  221114  221215
CROD        140054      3  221115  221214
CROD        140055      3  211114  311215
CROD        140056      3  211115  311214
CROD        140057      3  221114  321215
CROD        140058      3  221115  321214
CROD        140059      3  111114  411215
CROD        140060      3  111115  411214
CROD        140061      3  121114  421215
CROD        140062      3  121115  421214
CROD        140063      3  111211  211312
CROD        140064      3  211212  111311
CROD        140065      3  121211  221312
CROD        140066      3  221212  121311
CROD        140067      3  211211  311312
CROD        140068      3  311212  211311
CROD        140069      3  221211  321312
CROD        140070      3  321212  221311
CROD        140071      3  211211  411312
CROD        140072      3  411212  211311
CROD        140073      3  221211  421312
CROD        140074      3  421212  221311
CROD        140075      3  211212  211313
CROD        140076      3  211213  211312
CROD        140077      3  221212  221313
CROD        140078      3  221213  221312
CROD        140079      3  311212  311313
CROD        140080      3  311213  311312
CROD        140081      3  321212  321313
CROD        140082      3  321213  321312
CROD        140083      3  411212  411313
CROD        140084      3  411213  411312
CROD        140085      3  421212  421313
CROD        140086      3  421213  421312
CROD        140087      3  211213  211314
CROD        140088      3  211214  211313
CROD        140089      3  221213  221314
CROD        140090      3  221214  221313
CROD        140091      3  311213  311314
CROD        140092      3  311214  311313
CROD        140093      3  321213  321314
CROD        140094      3  321214  321313
CROD        140095      3  411213  411314
CROD        140096      3  411214  411313
CROD        140097      3  421213  421314
CROD        140098      3  421214  421313
$ VERTICAL DIAGONALS
CROD        160001      4  121111  111112
CROD        160002      4  121112  111111
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CROD	160002	4	121112	111111
CROD	160003	4	121112	111113
CROD	160004	4	121113	111112
CROD	160005	4	121113	111114
CROD	160006	4	121114	111113
CROD	160007	4	121114	111115
CROD	160008	4	121115	111114
CROD	160009	4	121211	111212
CROD	160010	4	121212	111211
CROD	160011	4	121212	111213
CROD	160012	4	121213	111212
CROD	160013	4	121213	111214
CROD	160014	4	121214	111213
CROD	160015	4	121214	111215
CROD	160016	4	121215	111214
CROD	160017	4	121311	111312
CROD	160018	4	121312	111311
CROD	160019	4	121312	111313
CROD	160020	4	121313	111312
CROD	160021	4	121313	111314
CROD	160022	4	121314	111313
CROD	160023	1	121211	111111
CROD	160024	1	121111	111211
CROD	160025	1	121212	111112
CROD	160026	1	121112	111212
CROD	160027	1	121213	111113
CROD	160028	1	121113	111213
CROD	160029	1	121214	111114
CROD	160030	1	121114	111214
CROD	160031	1	121215	111115
CROD	160032	1	121115	111215
CROD	160033	1	121311	111211
CROD	160034	1	121211	111311
CROD	160035	1	121312	111212
CROD	160036	1	121212	111312
CROD	160037	1	121313	111213
CROD	160038	1	121213	111313
CROD	160039	1	121314	111214
CROD	160040	1	121214	111314
CROD	260001	4	121111	211112
CROD	260002	4	221112	111111
CROD	260003	4	221112	211113
CROD	260004	4	221113	211112
CROD	260005	4	221113	211114
CROD	260006	4	221114	211113
CROD	260007	4	221114	211115
CROD	260008	4	221115	211114
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CROD	260011	4	221212	211213
CROD	260012	4	221213	211212
CROD	260013	4	221213	211214
CROD	260014	4	221214	211213
CROD	260015	4	221214	211215
CROD	260016	4	221215	211214

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CROD	260016	4	221215	211214
CROD	260017	4	121311	211312
CROD	260018	4	221312	111311
CROD	260019	4	221312	211313
CROD	260020	4	221313	211312
CROD	260021	4	221313	211314
CROD	260022	4	221314	211313
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CROD	260024	1	221112	211212
CROD	260025	1	221213	211113
CROD	260026	1	221113	211213
CROD	260027	1	221214	211114
CROD	260028	1	221114	211214
CROD	260029	1	221215	211115
CROD	260030	1	221115	211215
CROD	260031	1	221312	211212
CROD	260032	1	221212	211312
CROD	260033	1	221313	211213
CROD	260034	1	221213	211313
CROD	260035	1	221314	211214
CROD	260036	1	221214	211314
CROD	360001	4	221211	311212
CROD	360002	4	321212	211211
CROD	360003	4	321212	311213
CROD	360004	4	321213	311212
CROD	360005	4	321213	311214
CROD	360006	4	321214	311213
CROD	360007	4	321214	311215
CROD	360008	4	321215	311214
CROD	360009	4	221311	311312
CROD	360010	4	321312	211311
CROD	360011	4	321312	311313
CROD	360012	4	321313	311312
CROD	360013	4	321313	311314
CROD	360014	4	321314	311313
CROD	360015	1	221211	111111
CROD	360016	1	121111	211211
CROD	360017	1	321212	211112
CROD	360018	1	221112	311212
CROD	360019	1	321213	211113
CROD	360020	1	221113	311213
CROD	360021	1	321214	211114
CROD	360022	1	221114	311214
CROD	360023	1	321215	211115
CROD	360024	1	221115	311215
CROD	360025	1	221311	211211
CROD	360026	1	221211	211311
CROD	360027	1	321312	311212
CROD	360028	1	321212	311312
CROD	360029	1	321313	311213
CROD	360030	1	321213	311313
CROD	360031	1	321314	311214
CROD	360032	1	321214	311314
CROD	460001	4	221211	411212
CROD	460002	4	421212	211211

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CROD      460003        4  421212  411213
CROD      460004        4  421213  411212
CROD      460005        4  421213  411214
CROD      460006        4  421214  411213
CROD      460007        4  421214  411215
CROD      460008        4  421215  411214
CROD      460009        4  221311  411312
CROD      460010        4  421312  211311
CROD      460011        4  421312  411313
CROD      460012        4  421313  411312
CROD      460013        4  421313  411314
CROD      460014        4  421314  411313
CROD      460015        1  421212  111112
CROD      460016        1  121112  411212
CROD      460017        1  421213  111113
CROD      460018        1  121113  411213
CROD      460019        1  421214  111114
CROD      460020        1  121114  411214
CROD      460021        1  421215  111115
CROD      460022        1  121115  411215
CROD      460023        1  421312  411212
CROD      460024        1  421212  411312
CROD      460025        1  421313  411213
CROD      460026        1  421213  411313
CROD      460027        1  421314  411214
CROD      460028        1  421214  411314
$ BEAM PROPERTIES
PBAR            1       11.72E-041.48E-071.48E-070.
MAT1            11.66E+111.31E+101.93E-01  1605.40.       0.
+BC     1.5E-07 1.5E-07 0.
PBAR            2       23.87E-042.30E-102.30E-100.
MAT1            21.83E+111.43E+103.50E-01  1716.70.       0.
+BC     2.3E-10 2.3E-10 0
$ ROD PROPERTIES
PROD            3       3.297E-04.140E-09.614E-02********
MAT1            32.35E+080.      0.        1662.30        0.
+BC     0.      0.      0.
PROD            4       4.575E-04.526E-09 856E-02********
MAT1            42.35E+080.      0.        1662.30.       0.
+BC     0.      0.      0.
$ CONCENTRATED MASSES FROM SURFACE ARRAY
CONM2     111111  111111          1 900
CONM2     111112  111112          1.900
CONM2     211112  211112          1.900
CONM2     111113  111113          1 900
CONM2     211113  211113          1 900
CONM2     111114  111114          1.900
CONM2     211114  211114          1.900
CONM2     111115  111115          1.900
CONM2     211115  211115          1.900
CONM2     111211  111211          1.900
CONM2     211211  211211          1.900
CONM2     111212  111212          1.900
CONM2     211212  211212          1.900
```

[illegible]

CONM2	211212	211212	1.900
CONM2	311212	311212	1.900
CONM2	411212	411212	1.900
CONM2	111213	111213	1.900
CONM2	211213	211213	1.900
CONM2	311213	311213	1.900
CONM2	411213	411213	1.900
CONM2	111214	111214	1.900
CONM2	211214	211214	1.900
CONM2	311214	311214	1.900
CONM2	411214	411214	1.900
CONM2	111215	111215	1.900
CONM2	211215	211215	1.900
CONM2	311215	311215	1.900
CONM2	411215	411215	1.900
CONM2	111311	111311	1.900
CONM2	211311	211311	1.900
CONM2	111312	111312	1.900
CONM2	211312	211312	1.900
CONM2	311312	311312	1.900
CONM2	411312	411312	1.900
CONM2	111313	111313	1.900
CONM2	211313	211313	1.900
CONM2	311313	311313	1.900
CONM2	411313	411313	1.900
CONM2	111314	111314	1.900
CONM2	211314	211314	1.900
CONM2	311314	311314	1.900
CONM2	411314	411314	1.900
CONM2	121111	121111	8.795
CONM2	121112	121112	8.795
CONM2	221112	221112	8.795
CONM2	121113	121113	8.795
CONM2	221113	221113	8.795
CONM2	121114	121114	8.795
CONM2	221114	221114	8.795
CONM2	121115	121115	8.795
CONM2	221115	221115	8.795
CONM2	121211	121211	8.795
CONM2	221211	221211	8.795
CONM2	121212	121212	8.795
CONM2	221212	221212	8.795
CONM2	321212	321212	8.795
CONM2	421212	421212	8.795
CONM2	121213	121213	8.795
CONM2	221213	221213	8.795
CONM2	321213	321213	8.795
CONM2	421213	421213	8.795
CONM2	121214	121214	8.795
CONM2	221214	221214	8.795
CONM2	321214	321214	8.795
CONM2	421214	421214	8.795
CONM2	121215	121215	8.795
CONM2	221215	221215	8.795
CONM2	321215	321215	8.795

[illegible]

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```
CONM2     321215  321215            8.795
CONM2     421215  421215            8.795
CONM2     121311  121311            8.795
CONM2     221311  221311            8.795
CONM2     121312  121312            8.795
CONM2     221312  221312            8.795
CONM2     321312  321312            8.795
CONM2     421312  421312            8.795
CONM2     121313  121313            8.795
CONM2     221313  221313            8.795
CONM2     321313  321313            8.795
CONM2     421313  421313            8.795
CONM2     121314  121314            8.795
CONM2     221314  221314            8.795
CONM2     321314  321314            8.795
CONM2     421314  421314            8.795
$ GRAVITY LOADINGS
GRAV    100                     0.00 0.00000 0.00000 0.00000
GRAV    200                     0.00 0.00000 0.00000 0.00000
$ PARAMETERS
PARAM   GRDPNT  100000
ENDDATA
GRID      500001              0.000  30.219  32.043          123456
CONM2     500001  500001              1.900
CONM2     500002  500002              1.900
GRID      500002              0.000  45.359  32.043          123456
GRID      500003              0.000  30.219  47.043          123456
CONM2     500003  500003              1.900
CONM2     500004  500004              1.900
GRID      500004              0.000  45.359  47.043          123456
GRID      500005              0.000  30.219  62.043          123456
CONM2     500005  500005              1.900
CONM2     500006  500006              1.900
GRID      500006              0.000  45.359  62.043          123456
GRID      500007              0.000  30.219  77.043          123456
CONM2     500007  500007              1.900
CONM2     500008  500008              1.900
GRID      500008              0.000  45.359  77.043          123456
GRID      500009              0.000  30.219  92.043          123456
CONM2     500009  500009              1.900
CONM2     500010  500010              1.900
GRID      500010              0.000  45.359  92.043          123456
GRID      500011              0.000  30.219 107.043          123456
CONM2     500011  500011              1.900
CONM2     500012  500012              1.900
GRID      500012              0.000  45.359 107.043          123456
GRID      500013              0.000  30.219 122.043          123456
CONM2     500013  500013              1.900
CONM2     500014  500014              1.900
GRID      500014              0.000  45.359 122.043          123456
GRID      500015              0.000  30.219 137.043          123456
CONM2     500015  500015              1.900
CONM2     500016  500016              1.900
GRID      500016              0.000  45.359 137.043          123456
GRID      500017             15.141  30.219  32.520          123456
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GRID	500017		15.141	30.219	32.520	123456
CONM2	500017	500017		1.900		
CONM2	500018	500018		1.900		
GRID	500018		15.141	45.359	32.520	123456
GRID	500019		15.141	30.219	47.520	123456
CONM2	500019	500019		1.900		
CONM2	500020	500020		1.900		
GRID	500020		15.141	45.359	47.520	123456
GRID	500021		15.141	30.219	62.520	123456
CONM2	500021	500021		1.900		
CONM2	500022	500022		1.900		
GRID	500022		15.141	45.359	62.520	123456
GRID	500023		15.141	30.219	77.520	123456
CONM2	500023	500023		1.900		
CONM2	500024	500024		1.900		
GRID	500024		15.141	45.359	77.520	123456
GRID	500025		15.141	30.219	92.520	123456
CONM2	500025	500025		1.900		
CONM2	500026	500026		1.900		
GRID	500026		15.141	45.359	92.520	123456
GRID	500027		15.141	30.219	107.520	123456
CONM2	500027	500027		1.900		
CONM2	500028	500028		1.900		
GRID	500028		15.141	45.359	107.520	123456
GRID	500029		15.141	30.219	122.520	123456
CONM2	500029	500029		1.900		
CONM2	500030	500030		1.900		
GRID	500030		15.141	45.359	122.520	123456
GRID	500031		15.141	30.219	137.520	123456
CONM2	500031	500031		1.900		
CONM2	500032	500032		1.900		
GRID	500032		15.141	45.359	137.520	123456
GRID	500033		-15.141	30.219	32.520	123456
CONM2	500033	500033		1.900		
CONM2	500034	500034		1.900		
GRID	500034		-15.141	45.359	32.520	123456
GRID	500035		-15.141	30.219	47.520	123456
CONM2	500035	500035		1.900		
CONM2	500036	500036		1.900		
GRID	500036		-15.141	45.359	47.520	123456
GRID	500037		-15.141	30.219	62.520	123456
CONM2	500037	500037		1.900		
CONM2	500038	500038		1.900		
GRID	500038		-15.141	45.359	62.520	123456
GRID	500039		-15.141	30.219	77.520	123456
CONM2	500039	500039		1.900		
CONM2	500040	500040		1.900		
GRID	500040		-15.141	45.359	77.520	123456
GRID	500041		-15.141	30.219	92.520	123456
CONM2	500041	500041		1.900		
CONM2	500042	500042		1.900		
GRID	500042		-15.141	45.359	92.520	123456
GRID	500043		-15.141	30.219	107.520	123456
CONM2	500043	500043		1.900		
CONM2	500044	500044		1.900		

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   F35
CONM2     500044  500044            1.900
GRID      500044          -15.141  45.359 107.520         123456
GRID      500045          -15.141  30.719 122.520         123456
CONM2     500045  500045            1.900
CONM2     500046  500046            1.900
GRID      500046          -15.141  45.359 122.520         123456
GRID      500047          -15.141  30.719 137.520         123456
CONM2     500047  500047            1.900
CONM2     500048  500048            1.900
GRID      500048          -15.141  45.359 137.520         123456
GRID      500049            0.000  45.359  17.043         123456
CONM2     500049  500049            1.900
GRID      500050           15.141  45.359  17.520         123456
CONM2     500050  500050            1.900
GRID      500051          -15.141  45.359  17.520         123456
CONM2     500051  500051            1.900
CBAR      500001       1  500001  5000031.0       0.0     0.0
CBAR      500002       1  500002  5000041.0       0.0     0.0
CBAR      500003       1  500003  5000051.0       0.0     0.0
CBAR      500004       1  500004  5000061.0       0.0     0.0
CBAR      500005       1  500005  5000071.0       0.0     0.0
CBAR      500006       1  500006  5000081.0       0.0     0.0
CBAR      500007       1  500007  5000091.0       0.0     0.0
CBAR      500008       1  500008  5000101.0       0.0     0.0
CBAR      500009       1  500009  5000111.0       0.0     0.0
CBAR      500010       1  500010  5000121.0       0.0     0.0
CBAR      500011       1  500011  5000131.0       0.0     0.0
CBAR      500012       1  500012  5000141.0       0.0     0.0
CBAR      500013       1  500013  5000151.0       0.0     0.0
CBAR      500014       1  500014  5000161.0       0.0     0.0
CBAR      500015       1  500017  5000191.0       0.0     0.0
CBAR      500016       1  500018  5000201.0       0.0     0.0
CBAR      500017       1  500019  5000211.0       0.0     0.0
CBAR      500018       1  500020  5000221.0       0.0     0.0
CBAR      500019       1  500021  5000231.0       0.0     0.0
CBAR      500020       1  500022  5000241.0       0.0     0.0
CBAR      500021       1  500023  5000251.0       0.0     0.0
CBAR      500022       1  500024  5000261.0       0.0     0.0
CBAR      500023       1  500025  5000271.0       0.0     0.0
CBAR      500024       1  500026  5000281.0       0.0     0.0
CBAR      500025       1  500027  5000291.0       0.0     0.0
CBAR      500026       1  500028  5000301.0       0.0     0.0
CBAR      500027       1  500029  5000311.0       0.0     0.0
CBAR      500028       1  500030  5000321.0       0.0     0.0
CBAR      500029       1  500033  5000351.0       0.0     0.0
CBAR      500030       1  500034  5000361.0       0.0     0.0
CBAR      500031       1  500035  5000371.0       0.0     0.0
CBAR      500032       1  500036  5000381.0       0.0     0.0
CBAR      500033       1  500037  5000391.0       0.0     0.0
CBAR      500034       1  500038  5000401.0       0.0     0.0
CBAR      500035       1  500039  5000411.0       0.0     0.0
CBAR      500036       1  500040  5000421.0       0.0     0.0
CBAR      500037       1  500041  5000431.0       0.0     0.0
CBAR      500038       1  500042  5000441.0       0.0     0.0
CBAR      500039       1  500043  5000451.0       0.0     0.0
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CBAR	500039	1	500043	5000451.0	0.0	0.0
CBAR	500040	1	500044	5000461.0	0.0	0.0
CBAR	500041	1	500045	5000471.0	0.0	0.0
CBAR	500042	1	500046	5000481.0	0.0	0.0
CBAR	500043	1	500001	5000171.0	0 0	0 0
CBAR	500044	1	500001	5000331.0	0.0	0.0
CBAR	500045	1	500002	5000181.0	0.0	0.0
CBAR	500046	1	500002	5000341.0	0.0	0.0
CBAR	500047	1	500003	5000191 0	0.0	0.0
CBAR	500048	1	500003	5000351.0	0.0	0.0
CBAR	500049	1	500004	5000201.0	0 0	0.0
CBAR	500050	1	500004	5000361.0	0.0	0.0
CBAR	500051	1	500005	5000211.0	0.0	0.0
CBAR	500052	1	500005	5000371.0	0.0	0.0
CBAR	500053	1	500006	5000221.0	0.0	0 0
CBAR	500054	1	500006	5000381.0	0.0	0.0
CBAR	500055	1	500007	5000231 0	0.0	0.0
CBAR	500056	1	500007	5000391.0	0.0	0.0
CBAR	500057	1	500008	5000241.0	0.0	0.0
CBAR	500058	1	500008	5000401 0	0.0	0.0
CBAR	500059	1	500009	5000251.0	0.0	0.0
CBAR	500060	1	500009	5000411.0	0.0	0.0
CBAR	500061	1	500010	5000261.0	0.0	0.0
CBAR	500062	1	500010	5000421.0	0 0	0.0
CBAR	500063	1	500011	5000271 0	0.0	0.0
CBAR	500064	1	500011	5000431.0	0.0	0 0
CBAR	500065	1	500012	5000281.0	0.0	0.0
CBAR	500066	1	500012	5000441.0	0.0	0.0
CBAR	500067	1	500013	5000291.0	0.0	0.0
CBAR	500068	1	500013	5000451.0	0.0	0.0
CBAR	500069	1	500014	5000301.0	0.0	0.0
CBAR	500070	1	500014	5000461.0	0.0	0.0
CBAR	500071	1	500015	5000311.0	0.0	0.0
CBAR	500072	1	500015	5000471.0	0.0	0.0
CBAR	500073	1	500016	5000321.0	0.0	0.0
CBAR	500074	1	500016	5000481.0	0 0	0.0
CBAR	500075	1	500049	5000501.0	0.0	0.0
CBAR	500076	1	500049	5000511.0	0.0	0.0
CBAR	500077	2	121311	5000491 0	0.0	0.0
CBAR	500078	2	121312	5000501.0	0.0	0.0
CBAR	500079	2	221312	5000511.0	0.0	0.0
CBAR	500080	2	500001	5000021.0	0.0	0.0
CBAR	500081	2	500003	5000041.0	0.0	0 0
CBAR	500082	2	500005	5000061.0	0.0	0.0
CBAR	500083	2	500007	5000081.0	0.0	0.0
CBAR	500084	2	500009	5000101 0	0.0	0.0
CBAR	500085	2	500011	5000121.0	0.0	0.0
CBAR	500086	2	500013	5000141 0	0.0	0.0
CBAR	500087	2	500015	5000161.0	0.0	0.0
CBAR	500088	2	500017	5000181 0	0.0	0.0
CBAR	500089	2	500019	5000201 0	0.0	0.0
CBAR	500090	2	500021	5000221 0	0.0	0.0
CBAR	500091	2	500023	5000241.0	0.0	0.0
CBAR	500092	2	500025	5000261 0	0.0	0.0
CBAR	500093	2	500027	5000281 0	0.0	0 0

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CBAR	500093	2	500027	5000281.0	0.0	0.0
CBAR	500094	2	500029	5000301.0	0.0	0.0
CBAR	500095	2	500031	5000321.0	0 0	0.0
CBAR	500096	2	500033	5000341 0	0.0	0.0
CBAR	500097	2	500035	5000361.0	0 0	0.0
CBAR	500098	2	500037	5000381.0	0.0	0.0
CBAR	500099	2	500039	5000401.0	0.0	0 0
CBAR	500100	2	500041	5000421 0	0.0	0.0
CBAR	500101	2	500043	5000441.0	0.0	0.0
CBAR	500102	2	500045	5000461.0	0.0	0.0
CBAR	500103	2	500047	5000481 0	0.0	0 0
CBAR	500104	1	121311	5000011.0	0.0	0 0
CBAR	500105	1	500049	5000021.0	0 0	0.0
CBAR	500106	1	121312	5000171 0	0.0	0 0
CBAR	500107	1	500050	5000181.0	0.0	0 0
CBAR	500108	1	221312	5000331.0	0.0	0.0
CBAR	500109	1	500051	5000341.0	0.0	0.0
CBAR	500110	2	111311	5000491.0	0.0	0.0
CBAR	500111	2	111312	5000501.0	0 0	0.0
CBAR	500112	2	211312	5000511.0	0 0	0 0
CROD	500113	4	500001	500004		
CROD	500114	4	500002	500003		
CROD	500115	4	500003	500006		
CROD	500116	4	500004	500005		
CROD	500117	4	500005	500008		
CROD	500118	4	500006	500007		
CROD	500119	4	500007	500010		
CROD	500120	4	500008	500009		
CROD	500121	4	500009	500012		
CROD	500122	4	500010	500011		
CROD	500123	4	500011	500014		
CROD	500124	4	500012	500013		
CROD	500125	4	500013	500016		
CROD	500126	4	500014	500015		
CROD	500127	4	500017	500020		
CROD	500128	4	500018	500019		
CROD	500129	4	500019	500022		
CROD	500130	4	500020	500021		
CROD	500131	4	500021	500024		
CROD	500132	4	500022	500023		
CROD	500133	4	500023	500026		
CROD	500134	4	500024	500025		
CROD	500135	4	500025	500028		
CROD	500136	4	500026	500027		
CROD	500137	4	500027	500030		
CROD	500138	4	500028	500029		
CROD	500139	4	500029	500032		
CROD	500140	4	500030	500031		
CROD	500141	4	500033	500036		
CROD	500142	4	500034	500035		
CROD	500143	4	500035	500038		
CROD	500144	4	500036	500037		
CROD	500145	4	500037	500040		
CROD	500146	4	500038	500039		
CROD	500147	4	500039	500042		

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CROD	500147	4	500039	500042
CROD	500148	4	500040	500041
CROD	500149	4	500041	500044
CROD	500150	4	500042	500043
CROD	500151	4	500043	500046
CROD	500152	4	500044	500045
CROD	500153	4	500045	500048
CROD	500154	4	500046	500047
CROD	500155	3	500001	500019
CROD	500156	3	500001	500035
CROD	500157	3	500003	500017
CROD	500158	3	500003	500033
CROD	500159	3	500002	500020
CROD	500160	3	500002	500036
CROD	500161	3	500004	500018
CROD	500162	3	500004	500034
CROD	500163	3	500003	500021
CROD	500164	3	500003	500037
CROD	500165	3	500005	500019
CROD	500166	3	500005	500035
CROD	500167	3	500004	500022
CROD	500168	3	500004	500038
CROD	500169	3	500006	500020
CROD	500170	3	500006	500036
CROD	500171	3	500005	500023
CROD	500172	3	500005	500039
CROD	500173	3	500007	500021
CROD	500174	3	500007	500037
CROD	500175	3	500006	500024
CROD	500176	3	500006	500040
CROD	500177	3	500008	500022
CROD	500178	3	500008	500038
CROD	500179	3	500007	500025
CROD	500180	3	500007	500041
CROD	500181	3	500009	500023
CROD	500182	3	500009	500039
CROD	500183	3	500008	500026
CROD	500184	3	500008	500042
CROD	500185	3	500010	500024
CROD	500186	3	500010	500040
CROD	500187	3	500009	500027
CROD	500188	3	500009	500043
CROD	500189	3	500011	500025
CROD	500190	3	500011	500041
CROD	500191	3	500010	500028
CROD	500192	3	500010	500044
CROD	500193	3	500012	500026
CROD	500194	3	500012	500042
CROD	500195	3	500011	500029
CROD	500196	3	500011	500045
CROD	500197	3	500013	500027
CROD	500198	3	500013	500043
CROD	500199	3	500012	500030
CROD	500200	3	500012	500046
CROD	500201	3	500014	500028

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CROD	500201	3	500014	500028
CROD	500202	3	500014	500044
CROD	500203	3	500013	500031
CROD	500204	3	500013	500047
CROD	500205	3	500015	500029
CROD	500206	3	500015	500045
CROD	500207	3	500014	500032
CROD	500208	3	500014	500048
CROD	500209	3	500016	500030
CROD	500210	3	500016	500046
CROD	500211	4	121311	500002
CROD	500212	3	121311	500017
CROD	500213	3	121311	500033
CROD	500214	4	500001	500049
CROD	500215	3	500001	121312
CROD	500216	3	500001	221312
CROD	500217	4	500034	221312
CROD	500218	4	500033	500051
CROD	500219	4	500018	121312
CROD	500220	4	500017	500050
CROD	500221	3	500002	500050
CROD	500222	3	500002	500051
CROD	500223	3	500049	500018
CROD	500224	3	500049	500034
CROD	500225	4	500001	500018
CROD	500226	4	500001	500034
CROD	500227	4	500002	500017
CROD	500228	4	500002	500033
CROD	500229	4	500003	500020
CROD	500230	4	500003	500036
CROD	500231	4	500004	500019
CROD	500232	4	500004	500035
CROD	500233	4	500005	500022
CROD	500234	4	500005	500038
CROD	500235	4	500006	500021
CROD	500236	4	500006	500037
CROD	500237	4	500007	500024
CROD	500238	4	500007	500040
CROD	500239	4	500008	500023
CROD	500240	4	500008	500039
CROD	500241	4	500009	500026
CROD	500242	4	500009	500042
CROD	500243	4	500010	500025
CROD	500244	4	500010	500041
CROD	500245	4	500011	500028
CROD	500246	4	500011	500044
CROD	500247	4	500012	500027
CROD	500248	4	500012	500043
CROD	500249	4	500013	500030
CROD	500250	4	500013	500046
CROD	500251	4	500014	500029
CROD	500252	4	500014	500045
CROD	500253	4	500015	500032
CROD	500254	4	500015	500048
CROD	500255	4	500016	500031

```
   [illegible]
CROD        500255        4  500016  500031
CROD        500256        4  500016  500047
CROD        500257        4  121311  500050
CROD        500258        4  500049  121312
CROD        500259        4  121311  500051
CROD        500260        4  500049  221312
· ·-EOR--
END OF FILE
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GRID	MODEL	COORDINATES (M)		MASS (KG)	
NUMBER	X	Y	Z	STRUCTURE	EQUIPMENT
111111.	0.00	0.00	0.00	1.90	
111112	0.00	15 14	.48	1.90	
211112.	0 00	-15.14	.48	1.90	
111113	0.00	30.22	1 90	1.90	
211113	0.00	-30.22	1.90	1.90	
111114.	0.00	45.19	4.25	1.90	
211114	0.00	-45 19	4.25	1.90	
111115	0.00	59 99	7.50	1.90	
211115.	0.00	-59.99	7.50	1.90	
111211.	-15.14	0.00	.48	1.90	
211211.	15.14	0.00	.48	1.90	
111212.	-15.14	15.14	.96	1.90	
211212	-15.14	-15.14	.96	1.90	
311212.	15.14	-15.14	.96	1.90	
411212.	15.14	15.14	.96	1 90	
111213.	-15.14	30.22	2.38	1.90	
211213.	-15.14	-30.22	2.38	1.90	
311213.	15 14	-30.22	2.38	1.90	
411213.	15.14	30.22	2.38	1.90	
111214	-15.14	45.19	4.73	1.90	

CONTINUE LISTING GRIDS

? Y

211214.	-15.14	-45.19	4.73	1.90	
311214.	15.14	-45.19	4.73	1.90	
411214.	15.14	45.19	4.73	1.90	
111215.	-15.14	59.99	7.98	1.90	100.00
211215.	-15.14	-59.99	7.98	1.90	100.00
311215.	15 14	-59.99	7.98	1.90	100.00
411215.	15.14	59.99	7.98	1.90	100.00
111311.	-30.22	0.00	1.90	1.90	
211311	30.22	0.00	1.90	1.90	
111312.	-30.22	15.14	2.38	1.90	
211312.	-30.22	-15.14	2.38	1.90	
311312.	30.22	-15.14	2.38	1.90	
411312.	30 22	15.14	2.38	1.90	
111313.	-30.22	30 22	3.81	1.90	
211313.	-30.22	-30.22	3.81	1.90	
311313	30.22	-30.22	3.81	1 90	
411313.	30 22	30.22	3.81	1.90	
111314.	-30.22	45.19	6.16	1.90	84.00
211314.	-30.22	-45.19	6.16	1.90	84.00
311314.	30.22	-45.19	6.16	1.90	84.00

CONTINUE LISTING GRIDS
? Y

411314.	30 22	45.19	6.16	1 90	84.00
121111.	0.00	0.00	15.14	8.80	
121112.	0.00	15.14	15.62	8.80	
221112	0.00	-15.14	15 62	8.80	
121113	0.00	30 22	17.04	8 80	
221113.	0.00	-30.22	17 04	8.80	
121114.	0.00	45.19	19.39	8.80	
221114.	0.00	-45.19	19.39	8.80	
121115	0.00	59.99	22.64	8.80	
221115.	0.00	-59.99	22.64	8.80	
121211.	-15.14	0.00	15.62	8 80	
221211.	15.14	0.00	15.62	8.80	
121212.	-15 14	15.14	16.10	8.80	
221212.	-15.14	-15.14	16.10	8.80	
321212.	15.14	-15.14	16.10	8.80	
421212.	15.14	15 14	16.10	8.80	
121213	-15.14	30.22	17.52	8.80	
221213.	-15.14	-30.22	17.52	8.80	
321213.	15.14	-30.22	17.52	8.80	
421213	15.14	30.22	17.52	8.80	

CONTINUE LISTING GRIDS
? Y

121214.	-15.14	45.19	19.87	8.80	
221214.	-15.14	-45.19	19.87	8.80	
321214	15.14	-45.19	19.87	8.80	
421214.	15.14	45.19	19.87	8.80	
121215.	-15 14	59.99	23.12	8.80	50.00
221215.	-15.14	-59.99	23 12	8.60	50.00
321215.	15.14	-59.99	23.12	8.80	50.00
421215.	15.14	59.99	23.12	8.80	50.00
121311.	-30.22	0.00	17.04	8.80	
221311.	30.22	0.00	17 04	8.80	125.00
121312	-30 22	15.14	17.52	8.80	
221312.	-30.22	-15.14	17.52	8.80	
321312.	30.22	-15.14	17.52	8.80	
421312.	30 22	15.14	17.52	8.80	
121313	-30.22	30.22	18.95	8.80	
221313.	-30 22	-30.22	18 95	8.80	
321313.	30.22	-30 22	18.95	8.80	
421313	30.22	30 22	18 95	8.80	
121314.	-30.22	45.19	21.30	8.80	348.00
221314.	-30.22	-45.19	21.30	8.80	348.00

CONTINUE LISTING GRIDS
? Y

321314	30.22	-45.19	21.30	8 80	336.00
421314.	30.22	45.19	21.30	8.80	336.00
500001.	-30.22	0.00	32.04	1.90	
500002.	-45.36	0.00	32.04	1.90	
500003.	-30.22	0.00	47.04	1.90	
500004	-45.36	0 00	47 04	1.90	
500005.	-30 22	0.00	62.04	1.90	
500006.	-45.36	0 00	62.04	1.90	
500007.	-30 22	0.00	77 04	1.90	
500008.	-45.36	0.00	77.04	1.90	
500009.	-30.22	0.00	92.04	1.90	
500010.	-45 36	0.00	92.04	1.90	
500011	-30.22	0.00	107.04	1.90	
500012.	-45.36	0.00	107.04	1.90	
500013.	-30.22	0.00	122.04	1 90	
500014.	-45.36	0.00	122.04	1.90	
500015.	-30.22	0.00	137.04	1.90	457 00
500016.	-45.36	0 00	137.04	1 90	53 00
500017	-30.22	15.14	32.52	1.90	
500018.	-45 36	15.14	32.52	1.90	

CONTINUE LISTING GRIDS
? Y

500019.	-30 22	15 14	47.52	1.90	
500020	-45.36	15.14	47 52	1 90	
500021.	-30.22	15.14	62.52	1.90	
500022.	-45.36	15 14	62.52	1.90	
500023.	-30.22	15.14	77.52	1.90	
500024.	-45.36	15.14	77.52	1.90	
500025	-30.22	15.14	92 52	1.90	
500026	-45.36	15.14	92 52	1 90	
500027.	-30 22	15 14	107.52	1.90	
500028.	-45.36	15.14	107.52	1.90	
500029	-30.22	15.14	122.52	1.90	
500030	-45 36	15.14	122.52	1 90	
500031.	-30.22	15 14	137.52	1.90	286.00
500032.	-45.36	15.14	137.52	1.90	120 00
500033.	-30 22	-15 14	32.52	1 90	
500034.	-45.36	-15.14	32.52	1 90	
500035.	-30.22	-15.14	47 52	1.90	
500036.	-45.36	-15.14	47.52	1.90	
500037	-30.22	-15.14	62.52	1.90	
500038.	-45.36	-15.14	62.52	1.90	

```
 CONTINUE LISTING GRIDS
? Y
 500039.      -30.22     -15.14      77.52      1.90
 500040.      -45.36     -15.14      77.52      1.90
 500041.      -30.22     -15.14      92.52      1.90
 500042.      -45.36     -15.14      92 52      1.90
 500043.      -30.22     -15.14     107.52      1.90
 500044.      -45.36     -15.14     107.52      1.90
 500045.      -30.22     -15.14     122.52      1.90
 500046.      -45.36     -15.14     122.52      1.90
 500047.      -30.22     -15.14     137.52      1.90      286.00
 500048.      -45.36     -15 14     137.52      1.90      120.00
 500049.      -45.36       0.00      17.04      1.90
 500050.      -45.36      15.14      17.52      1.90
 500051.      -45.36     -15.14      17.52      1.90
```

The deployment instruction file has the following format (see next page). The first number in the file indicates the number of deployment steps. Each deployment step then requires 3 lines in the instruction file. The first determines if a picture will be drawn, if a mass properties file will be written, and the title for that phase of deployment. The second line is the volume to be moved with the numbers corresponding to X min, X max, Y min, Y max, Z min, and Z max. The third line defines how the volume is to be moved.

```
24
F F "            " "           " "           " "           " "           "
-100. 100  -100. 100. 40. 50.
0. 0. 0. -14.92 0.
F F "            " "           " "           " "           " "           "
-100. 100  10. 20. -100. 100.
0. 0. -14.92 0. 0
F F "            " "           " "           " "           " "           "
-100. 100. -20. -10  -100  100.
0. 0. 14.92 0. 0.
F F "            " "           " "           " "           " "           "
-1000. 1000. -1000. 1000. -1000. 1000.
3. 0. 0  0  89.
F F "            " "           " "           " "           " "           "
-20. 20. -40  -17.03 25. 50.
1. 0  -17.043 30.219 -90
F F "            " "           " "           " "           " "           "
-20. 20. -140. -30. 25. 50.
0. 0. 14.78 0. 0
F F "            " "           " "           " "           " "           "
-20. 20. -140. -45  25. 50.
0. 0. 14.78 0. 0.
F F "FEED MAST " "FOLDING    " "           " "           " "           "
-20. 20  -140. -60. 25. 50.
0. 0. 14.78 0. 0.
F F "            " "           " "           " "           " "           "
-20. 20. -140. -75. 25. 50.
0. 0. 14.78 0  0.
F F "            " "           " "           " "           " "           "
-20  20. -140. -90  25. 50.
0. 0. 14 78 0. 0.
F F "            " "           " "           " "           " "           "
-20. 20. -140. -105. 25. 50.
0. 0. 14.78 0. 0.
F F "            " "           " "           " "           " "           "
-20. 20  -140. -120. 25. 50.
0. 0. 14.78 0. 0.
F F "            " "           " "           " "           " "           "
-1000. 1000. -1000. 1000. -1000. 1000
3. 0. 0  0. -89.
F F "            " "           " "           " "           " "           "
-5. 30. -20. 20  10. 20.
0  0  0  14.86 0
F F "            " "           " "           " "           " "           "
-5. 30. -20  20. -5. 5.
0. 0. 0. 14.92 0.
F F "            " "           " "           " "           " "           "
-5. 30. -20. 20  -20. -10
0. 0  0. 14.92 0.
F F "            " "           " "           " "           " "           "
-5. 30. -20. 20  -35  -25.
0. 0. 0. 14.86 0.
F F "SURFACE SI" "DES FOLDED" " IN        " "           " "           "
-5. 30. 25. 35. -35  35.
0  0  -14.86 0. 0.
```

```
  PRG
 0. 0  -14 86 0. 0.
 F F "            " "            " "            " "            " "            "
 -5. 30. -35. -25.' -35. 35
 0  0. 14 86 0. 0
 F F "            " "            " "            " "            " "            "
 -5. 30  40  50. -35  35.
 0. 0. -14.75 0  0
 F F "            " "            " "            " "            " "            "
 -5. 30. -50  -40. -35. 35
 0  0  14 75 0  0
 T F "FIRST FOLD" " CON'T     " "            " "            " "            "
 -5  30. 55  65. -20. 20.
 0  0. -14.75 0  0.
 I F "FIRST FOLD" " START     " "            " "            " "            "
 -5. 30  -65. -55. -20  20
 0. 0  14.75 0. 0.
 T T "FULLY DEPL" "OYED MODEL" "            " "            " "            "
 -1.E+99 1 E+99 -1.E+99 1 E+99 -1.E+99 1.E+99
 2  0  0  0  90.
--EOR--
END OF FILE
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ORBIT POINT	ANOMALY ANGLE	SOLAR PRESSURE FORCE (N) XDIRECTION	YDIRECTION	ZDIRECTION	SOLAR PRESSURE TORQUE (N-M) XDIRECTION	YDIRECTION	ZDIRECTION
1	0.	-.398E-02	.112E-03	.107E-02	.219E-02	.789E-01	.483E-03
2	.105E+00	-.381E-02	.112E-03	.140E-02	.219E-02	.732E-01	.483E-03
3	.209E+00	-.361E-02	.112E-03	.171E-02	.219E-02	.668E-01	.483E-03
4	.314E+00	-.337E-02	.112E-03	.200E-02	.219E-02	.596E-01	.483E-03
5	.419E+00	-.308E-02	.112E-03	.227E-02	.219E-02	.517E-01	.483E-03
6	.524E+00	-.277E-02	.112E-03	.251E-02	.219E-02	.433E-01	.483E-03
7	.628E+00	-.242E-02	.112E-03	.273E-02	.219E-02	.344E-01	.483E-03
8	.733E+00	-.205E-02	.112E-03	.291E-02	.219E-02	.251E-01	.483E-03
9	.838E+00	-.166E-02	.112E-03	.307E-02	.219E-02	.155E-01	.483E-03
10	.942E+00	-.125E-02	.112E-03	.319E-02	.219E-02	.580E-02	.483E-03
11	.105E+01	-.819E-03	.112E-03	.328E-02	.219E-02	-.398E-02	.483E-03
12	.115E+01	-.384E-03	.112E-03	.333E-02	.219E-02	-.137E-01	.483E-03
13	.126E+01	.556E-04	.112E-03	.334E-02	.219E-02	-.233E-01	.483E-03
14	.136E+01	.494E-03	.112E-03	.332E-02	.219E-02	-.327E-01	.483E-03
15	.147E+01	.928E-03	.112E-03	.326E-02	.219E-02	-.416E-01	.483E-03
16	.157E+01	.135E-02	.112E-03	.316E-02	.219E-02	-.502E-01	.483E-03
17	.168E+01	.176E-02	.112E-03	.303E-02	.219E-02	-.581E-01	.483E-03
18	.178E+01	.215E-02	.112E-03	.287E-02	.219E-02	-.655E-01	.483E-03
19	.188E+01	.251E-02	.112E-03	.268E-02	.219E-02	-.721E-01	.483E-03
20	.199E+01	.285E-02	.112E-03	.245E-02	.219E-02	-.779E-01	.483E-03
21	.209E+01	.316E-02	.112E-03	.220E-02	.219E-02	-.829E-01	.483E-03
22	.220E+01	.343E-02	.112E-03	.193E-02	.219E-02	-.870E-01	.483E-03
23	.230E+01	.367E-02	.112E-03	.163E-02	.219E-02	-.901E-01	.483E-03
24	.241E+01	.386E-02	.112E-03	.132E-02	.219E-02	-.922E-01	.483E-03
25	.251E+01	.401E-02	.112E-03	.990E-03	.219E-02	-.933E-01	.483E-03
26	.262E+01	.412E-02	.112E-03	.651E-03	.219E-02	-.934E-01	.483E-03
27	.272E+01	.418E-02	.112E-03	.305E-03	.219E-02	-.925E-01	.483E-03
28	.283E+01	.420E-02	.112E-03	-.442E-04	.219E-02	-.906E-01	.483E-03
29	.293E+01	.417E-02	.112E-03	-.393E-03	.219E-02	-.876E-01	.483E-03
30	.304E+01	.410E-02	.112E-03	-.737E-03	.219E-02	-.837E-01	.483E-03
31	.314E+01	.398E-02	.112E-03	-.107E-02	.219E-02	-.789E-01	.483E-03
32	.325E+01	.381E-02	.112E-03	-.140E-02	.219E-02	-.732E-01	.483E-03
33	.335E+01	.361E-02	.112E-03	-.171E-02	.219E-02	-.668E-01	.483E-03
34	.346E+01	.337E-02	.112E-03	-.200E-02	.219E-02	-.596E-01	.483E-03
35	.356E+01	.308E-02	.112E-03	-.227E-02	.219E-02	-.517E-01	.483E-03
36	.367E+01	0.	0.	0.	0.	0.	0.
37	.377E+01	0.	0.	0.	0.	0.	0.
38	.387E+01	0.	0.	0.	0.	0.	0.
39	.398E+01	0.	0.	0.	0.	0.	0.
40	.408E+01	0.	0.	0.	0.	0.	0.
41	.419E+01	0.	0.	0.	0.	0.	0.
42	.429E+01	0.	0.	0.	0.	0.	0.
43	.440E+01	0.	0.	0.	0.	0.	0.
44	.450E+01	0.	0.	0.	0.	0.	0.
45	.461E+01	0.	0.	0.	0.	0.	0.
46	.471E+01	0.	0.	0.	0.	0.	0.
47	.482E+01	0.	0.	0.	0.	0.	0.
48	.492E+01	0.	0.	0.	0.	0.	0.
49	.503E+01	0.	0.	0.	0.	0.	0.
50	.513E+01	0.	0.	0.	0.	0.	0.
51	.524E+01	0.	0.	0.	0.	0.	0.
52	.534E+01	0.	0.	0.	0.	0.	0.
53	.545E+01	0.	0.	0.	0.	0.	0.
54	.555E+01	0.	0.	0.	0.	0.	0.
55	.565E+01	0.	0.	0.	0.	0.	0.
56	.576E+01	0.	0.	0.	0.	0.	0.
57	.586E+01	-.418E-02	.112E-03	-.305E-03	.219E-02	.925E-01	.483E-03
58	.597E+01	-.420E-02	.112E-03	.442E-04	.219E-02	.906E-01	.483E-03
59	.607E+01	-.417E-02	.112E-03	.393E-03	.219E-02	.876E-01	.483E-03
60	.618E+01	-.410E-02	.112E-03	.737E-03	.219E-02	.837E-01	.483E-03

ORBIT	SUM OF EXTERNAL TORQUES (N-M)			GRAVITY GRADIENT TORQUE (N-M)			VEHICLE CROSS PRODUCT TORQUE (N-M)		
POINT	X-COMPONENT	Y-COMPONENT	Z-COMPONENT	X-COMPONENT	Y-COMPONENT	Z-COMPONENT	X-COMPONENT	Y-COMPONENT	Z-COMPONENT
1	.21852E-02	.49740E+00	.48282E-03	-.37660E-13	-.34336E-03	-.12790E-13	0.	0.	0.
2	.21852E-02	.49173E+00	.48282E-03	-.37660E-13	-.34336E-03	-.12790E-13	0.	0.	0.
3	.21852E-02	.48525E+00	.48282E-03	-.37660E-13	-.34336E-03	-.12790E-13	0.	0.	0.
4	.21852E-02	.47804E+00	.48282E-03	-.37660E-13	-.34336E-03	-.12790E-13	0.	0.	0.
5	.21852E-02	.47018E+00	.48282E-03	-.37660E-13	-.34336E-03	-.12790E-13	0.	0.	0.
6	.21852E-02	.46175E+00	.48282E-03	-.37660E-13	-.34336E-03	-.12790E-13	0.	0.	0.
7	.21852E-02	.45285E+00	.48282E-03	-.37660E-13	-.34336E-03	-.12790E-13	0.	0.	0.
8	.21852E-02	.44357E+00	.48282E-03	-.37660E-13	-.34336E-03	-.12790E-13	0.	0.	0.
9	.21852E-02	.43402E+00	.48282E-03	-.37660E-13	-.34336E-03	-.12790E-13	0.	0.	0.
10	.21852E-02	.42429E+00	.48282E-03	-.37660E-13	-.34336E-03	-.12790E-13	0.	0.	0.
11	.21852E-02	.41450E+00	.48282E-03	-.37660E-13	-.34336E-03	-.12790E-13	0.	0.	0.
12	.21852E-02	.40476E+00	.48282E-03	-.37660E-13	-.34336E-03	-.12790E-13	0.	0.	0.
13	.21852E-02	.39517E+00	.48282E-03	-.37660E-13	-.34336E-03	-.12790E-13	0.	0.	0.
14	.21852E-02	.38583E+00	.48282E-03	-.37660E-13	-.34336E-03	-.12790E-13	0.	0.	0.
15	.21852E-02	.37685E+00	.48282E-03	-.37660E-13	-.34336E-03	-.12790E-13	0.	0.	0.
16	.21852E-02	.36833E+00	.48282E-03	-.37660E-13	-.34336E-03	-.12790E-13	0.	0.	0.
17	.21852E-02	.36035E+00	.48282E-03	-.37660E-13	-.34336E-03	-.12790E-13	0.	0.	0.
18	.21852E-02	.35302E+00	.48282E-03	-.37660E-13	-.34336E-03	-.12790E-13	0.	0.	0.
19	.21852E-02	.34640E+00	.48282E-03	-.37660E-13	-.34336E-03	-.12790E-13	0.	0.	0.
20	.21852E-02	.34057E+00	.48282E-03	-.37660E-13	-.34336E-03	-.12790E-13	0.	0.	0.
21	.21852E-02	.33559E+00	.48282E-03	-.37660E-13	-.34336E-03	-.12790E-13	0.	0.	0.
22	.21852E-02	.33152E+00	.48282E-03	-.37660E-13	-.34336E-03	-.12790E-13	0.	0.	0.
23	.21852E-02	.32841E+00	.48282E-03	-.37660E-13	-.34336E-03	-.12790E-13	0.	0.	0.
24	.21852E-02	.32628E+00	.48282E-03	-.37660E-13	-.34336E-03	-.12790E-13	0.	0.	0.
25	.21852E-02	.32516E+00	.48282E-03	-.37660E-13	-.34336E-03	-.12790E-13	0.	0.	0.
26	.21852E-02	.32506E+00	.48282E-03	-.37660E-13	-.34336E-03	-.12790E-13	0.	0.	0.
27	.21852E-02	.32599E+00	.48282E-03	-.37660E-13	-.34336E-03	-.12790E-13	0.	0.	0.
28	.21852E-02	.32793E+00	.48282E-03	-.37660E-13	-.34336E-03	-.12790E-13	0.	0.	0.
29	.21852E-02	.33087E+00	.48282E-03	-.37660E-13	-.34336E-03	-.12790E-13	0.	0.	0.
30	.21852E-02	.33476E+00	.48282E-03	-.37660E-13	-.34336E-03	-.12790E-13	0.	0.	0.
31	.21852E-02	.33957E+00	.48282E-03	-.37660E-13	-.34336E-03	-.12790E-13	0.	0.	0.
32	.21852E-02	.34525E+00	.48282E-03	-.37660E-13	-.34336E-03	-.12790E-13	0.	0.	0.
33	.21852E-02	.35173E+00	.48282E-03	-.37660E-13	-.34336E-03	-.12790E-13	0.	0.	0.
34	.21852E-02	.35894E+00	.48282E-03	-.37660E-13	-.34336E-03	-.12790E-13	0.	0.	0.
35	.21852E-02	.36680E+00	.48282E-03	-.37660E-13	-.34336E-03	-.12790E-13	0.	0.	0.
36	-.37295E-13	.41849E+00	-.14154E-13	-.37660E-13	-.34336E-03	-.12790E-13	0.	0.	0.
37	-.37295E-13	.41849E+00	-.14154E-13	-.37660E-13	-.34336E-03	-.12790E-13	0.	0.	0.
38	-.37295E-13	.41849E+00	-.14154E-13	-.37660E-13	-.34336E-03	-.12790E-13	0.	0.	0.
39	-.37295E-13	.41849E+00	-.14154E-13	-.37660E-13	-.34336E-03	-.12790E-13	0.	0.	0.
40	-.37295E-13	.41849E+00	-.14154E-13	-.37660E-13	-.34336E-03	-.12790E-13	0.	0.	0.
41	-.37295E-13	.41849E+00	-.14154E-13	-.37660E-13	-.34336E-03	-.12790E-13	0.	0.	0.
42	-.37295E-13	.41849E+00	-.14154E-13	-.37660E-13	-.34336E-03	-.12790E-13	0.	0.	0.
43	-.37295E-13	.41849E+00	-.14154E-13	-.37660E-13	-.34336E-03	-.12790E-13	0.	0.	0.
44	-.37295E-13	.41849E+00	-.14154E-13	-.37660E-13	-.34336E-03	-.12790E-13	0.	0.	0.
45	-.37295E-13	.41849E+00	-.14154E-13	-.37660E-13	-.34336E-03	-.12790E-13	0.	0.	0.
46	-.37295E-13	.41849E+00	-.14154E-13	-.37660E-13	-.34336E-03	-.12790E-13	0.	0.	0.
47	-.37295E-13	.41849E+00	-.14154E-13	-.37660E-13	-.34336E-03	-.12790E-13	0.	0.	0.
48	-.37295E-13	.41849E+00	-.14154E-13	-.37660E-13	-.34336E-03	-.12790E-13	0.	0.	0.
49	-.37295E-13	.41849E+00	-.14154E-13	-.37660E-13	-.34336E-03	-.12790E-13	0.	0.	0.
50	-.37295E-13	.41849E+00	-.14154E-13	-.37660E-13	-.34336E-03	-.12790E-13	0.	0.	0.
51	-.37295E-13	.41849E+00	-.14154E-13	-.37660E-13	-.34336E-03	-.12790E-13	0.	0.	0.
52	-.37295E-13	.41849E+00	-.14154E-13	-.37660E-13	-.34336E-03	-.12790E-13	0.	0.	0.
53	-.37295E-13	.41849E+00	-.14154E-13	-.37660E-13	-.34336E-03	-.12790E-13	0.	0.	0.
54	-.37295E-13	.41849E+00	-.14154E-13	-.37660E-13	-.34336E-03	-.12790E-13	0.	0.	0.
55	-.37295E-13	.41849E+00	-.14154E-13	-.37660E-13	-.34336E-03	-.12790E-13	0.	0.	0.
56	-.37295E-13	.41849E+00	-.14154E-13	-.37660E-13	-.34336E-03	-.12790E-13	0.	0.	0.
57	.21852E-02	.51098E+00	.48282E-03	-.37660E-13	-.34336E-03	-.12790E-13	0.	0.	0.
58	.21852E-02	.50904E+00	.48282E-03	-.37660E-13	-.34336E-03	-.12790E-13	0.	0.	0.
59	.21852E-02	.50611E+00	.48282E-03	-.37660E-13	-.34336E-03	-.12790E-13	0.	0.	0.
60	.21852E-02	.50221E+00	.48282E-03	-.37660E-13	-.34336E-03	-.12790E-13	0.	0.	0.

ORBIT	INERTIAL REF FRAME TORQUE (N-M)			INERTIAL REF FRAME MOMENTUM (N-M-S)			VEHICLE REF FRAME MOMENTUM (N-M-S)		
POINT	X-COMPONENT	Y-COMPONENT	Z-COMPONENT	X-COMPONENT	Y-COMPONENT	Z-COMPONENT	X-COMPONENT	Y-COMPONENT	Z-COMPONENT
1	0.	0.	0.	0.	0.	0.	0.	0.	0.
2	.21852E-02	.49173E+00	.48282E-03	.10792E+00	.24285E+02	.23845E-01	0.	0.	0.
3	.21852E-02	.48525E+00	.48282E-03	.32375E+00	.72534E+02	.71534E-01	0.	0.	0.
4	.21852E-02	.47804E+00	.48282E-03	.53959E+00	.12011E+03	.11922E+00	0.	0.	0.
5	.21852E-02	.47018E+00	.48282E-03	.75542E+00	.16694E+03	.16691E+00	0.	0.	0.
6	.21852E-02	.46175E+00	.48282E-03	.97126E+00	.21296E+03	.21460E+00	0.	0.	0.
7	.21852E-02	.45285E+00	.48282E-03	.11871E+01	.25813E+03	.26229E+00	0.	0.	0.
8	.21852E-02	.44357E+00	.48282E-03	.14029E+01	.30240E+03	.30998E+00	0.	0.	0.
9	.21852E-02	.43402E+00	.48282E-03	.16188E+01	.34574E+03	.35767E+00	0.	0.	0.
10	.21852E-02	.42429E+00	.48282E-03	.18346E+01	.38813E+03	.40536E+00	0.	0.	0.
11	.21852E-02	.41450E+00	.48282E-03	.20504E+01	.42956E+03	.45305E+00	0.	0.	0.
12	.21852E-02	.40476E+00	.48282E-03	.22663E+01	.47002E+03	.50074E+00	0.	0.	0.
13	.21852E-02	.39517E+00	.48282E-03	.24821E+01	.50952E+03	.54843E+00	0.	0.	0.
14	.21852E-02	.38583E+00	.48282E-03	.26979E+01	.54809E+03	.59612E+00	0.	0.	0.
15	.21852E-02	.37685E+00	.48282E-03	.29138E+01	.58576E+03	.64381E+00	0.	0.	0.
16	.21852E-02	.36833E+00	.48282E-03	.31296E+01	.62256E+03	.69150E+00	0.	0.	0.
17	.21852E-02	.36035E+00	.48282E-03	.33454E+01	.65855E+03	.73919E+00	0.	0.	0.
18	.21852E-02	.35302E+00	.48282E-03	.35613E+01	.69378E+03	.78687E+00	0.	0.	0.
19	.21852E-02	.34640E+00	.48282E-03	.37771E+01	.72832E+03	.83456E+00	0.	0.	0.
20	.21852E-02	.34057E+00	.48282E-03	.39929E+01	.76225E+03	.88225E+00	0.	0.	0.
21	.21852E-02	.33559E+00	.48282E-03	.42088E+01	.79564E+03	.92994E+00	0.	0.	0.
22	.21852E-02	.33152E+00	.48282E-03	.44246E+01	.82858E+03	.97763E+00	0.	0.	0.
23	.21852E-02	.32841E+00	.48282E-03	.46405E+01	.86118E+03	.10253E+01	0.	0.	0.
24	.21852E-02	.32628E+00	.48282E-03	.48563E+01	.89351E+03	.10730E+01	0.	0.	0.
25	.21852E-02	.32516E+00	.48282E-03	.50721E+01	.92568E+03	.11207E+01	0.	0.	0.
26	.21852E-02	.32506E+00	.48282E-03	.52880E+01	.95779E+03	.11684E+01	0.	0.	0.
27	.21852E-02	.32599E+00	.48282E-03	.55038E+01	.98995E+03	.12161E+01	0.	0.	0.
28	.21852E-02	.32793E+00	.48282E-03	.57196E+01	.10222E+04	.12638E+01	0.	0.	0.
29	.21852E-02	.33087E+00	.48282E-03	.59355E+01	.10548E+04	.13115E+01	0.	0.	0.
30	.21852E-02	.33476E+00	.48282E-03	.61513E+01	.10877E+04	.13591E+01	0.	0.	0.
31	.21852E-02	.33957E+00	.48282E-03	.63671E+01	.11210E+04	.14068E+01	0.	0.	0.
32	.21852E-02	.34525E+00	.48282E-03	.65830E+01	.11548E+04	.14545E+01	0.	0.	0.
33	.21852E-02	.35173E+00	.48282E-03	.67988E+01	.11892E+04	.15022E+01	0.	0.	0.
34	.21852E-02	.35894E+00	.48282E-03	.70146E+01	.12243E+04	.15499E+01	0.	0.	0.
35	.21852E-02	.36680E+00	.48282E-03	.72305E+01	.12601E+04	.15976E+01	0.	0.	0.
36	-.37295E-13	.41849E+00	-.14154E-13	.73384E+01	.12989E+04	.16214E+01	0.	0.	0.
37	-.37295E-13	.41849E+00	-.14154E-13	.73384E+01	.13403E+04	.16214E+01	0.	0.	0.
38	-.37295E-13	.41849E+00	-.14154E-13	.73384E+01	.13816E+04	.16214E+01	0.	0.	0.
39	-.37295E-13	.41849E+00	-.14154E-13	.73384E+01	.14229E+04	.16214E+01	0.	0.	0.
40	-.37295E-13	.41849E+00	-.14154E-13	.73384E+01	.14643E+04	.16214E+01	0.	0.	0.
41	-.37295E-13	.41849E+00	-.14154E-13	.73384E+01	.15056E+04	.16214E+01	0.	0.	0.
42	-.37295E-13	.41849E+00	-.14154E-13	.73384E+01	.15469E+04	.16214E+01	0.	0.	0.
43	-.37295E-13	.41849E+00	-.14154E-13	.73384E+01	.15883E+04	.16214E+01	0.	0.	0.
44	-.37295E-13	.41849E+00	-.14154E-13	.73384E+01	.16296E+04	.16214E+01	0.	0.	0.
45	-.37295E-13	.41849E+00	-.14154E-13	.73384E+01	.16709E+04	.16214E+01	0.	0.	0.
46	-.37295E-13	.41849E+00	-.14154E-13	.73384E+01	.17123E+04	.16214E+01	0.	0.	0.
47	-.37295E-13	.41849E+00	-.14154E-13	.73384E+01	.17536E+04	.16214E+01	0.	0.	0.
48	-.37295E-13	.41849E+00	-.14154E-13	.73384E+01	.17949E+04	.16214E+01	0.	0.	0.
49	-.37295E-13	.41849E+00	-.14154E-13	.73384E+01	.18363E+04	.16214E+01	0.	0.	0.
50	-.37295E-13	.41849E+00	-.14154E-13	.73384E+01	.18776E+04	.16214E+01	0.	0.	0.
51	-.37295E-13	.41849E+00	-.14154E-13	.73384E+01	.19189E+04	.16214E+01	0.	0.	0.
52	-.37295E-13	.41849E+00	-.14154E-13	.73384E+01	.19603E+04	.16214E+01	0.	0.	0.
53	-.37295E-13	.41849E+00	-.14154E-13	.73384E+01	.20016E+04	.16214E+01	0.	0.	0.
54	-.37295E-13	.41849E+00	-.14154E-13	.73384E+01	.20430E+04	.16214E+01	0.	0.	0.
55	-.37295E-13	.41849E+00	-.14154E-13	.73384E+01	.20843E+04	.16214E+01	0.	0.	0.
56	-.37295E-13	.41849E+00	-.14154E-13	.73384E+01	.21256E+04	.16214E+01	0.	0.	0.
57	.21852E-02	.51098E+00	.48282E-03	.74463E+01	.21715E+04	.16453E+01	0.	0.	0.
58	.21852E-02	.50904E+00	.48282E-03	.76621E+01	.22219E+04	.16930E+01	0.	0.	0.
59	.21852E-02	.50611E+00	.48282E-03	.78780E+01	.22720E+04	.17407E+01	0.	0.	0.
60	.21852E-02	.50221E+00	.48282E-03	.80938E+01	.23218E+04	.17884E+01	0.	0.	0.

ORBIT POINT	ICLE REF FRAME AERODYNAMIC FORCE (N) X-COMPONENT	Y-COMPONENT	Z-COMPONENT	VEHICLE REF FRAME AE ANIC TORQUE (N-M) X-COMPONENT	Y-COMPONENT	Z-COMPONENT	SUM OF EXTERNAL FORCES (N) X-COMPONENT	Y-COMPONENT	Z-COMPONENT
1	-.17886E-01	0.	-.48290E-02	.36515E-15	.41883E+00	-.13639E-14	-.21863E-01	.11212E-03	-.37551E-02
2	-.17886E-01	0.	-.48290E-02	.36515E-15	.41883E+00	-.13639E-14	-.21700E-01	.11212E-03	-.34305E-02
3	-.17886E-01	0.	-.48290E-02	.36515E-15	.41883E+00	-.13639E-14	-.21496E-01	.11212E-03	-.31212E-02
4	-.17886E-01	0.	-.48290E-02	.36515E-15	.41883E+00	-.13639E-14	-.21251E-01	.11212E-03	-.28306E-02
5	-.17886E-01	0.	-.48290E-02	.36515E-15	.41883E+00	-.13639E-14	-.20970E-01	.11212E-03	-.25618E-02
6	-.17886E-01	0.	-.48290E-02	.36515E-15	.41883E+00	-.13639E-14	-.20655E-01	.11212E-03	-.23180E-02
7	-.17886E-01	0.	-.48290E-02	.36515E-15	.41883E+00	-.13639E-14	-.20310E-01	.11212E-03	-.21016E-02
8	-.17886E-01	0.	-.48290E-02	.36515E-15	.41883E+00	-.13639E-14	-.19938E-01	.11212E-03	-.19151E-02
9	-.17886E-01	0.	-.48290E-02	.36515E-15	.41883E+00	-.13639E-14	-.19543E-01	.11212E-03	-.17606E-02
10	-.17886E-01	0.	-.48290E-02	.36515E-15	.41883E+00	-.13639E-14	-.19131E-01	.11212E-03	-.16397E-02
11	-.17886E-01	0.	-.48290E-02	.36515E-15	.41883E+00	-.13639E-14	-.18705E-01	.11212E-03	-.15537E-02
12	-.17886E-01	0.	-.48290E-02	.36515E-15	.41883E+00	-.13639E-14	-.18270E-01	.11212E-03	-.15036E-02
13	-.17886E-01	0.	-.48290E-02	.36515E-15	.41883E+00	-.13639E-14	-.17830E-01	.11212E-03	-.14899E-02
14	-.17886E-01	0.	-.48290E-02	.36515E-15	.41883E+00	-.13639E-14	-.17392E-01	.11212E-03	-.15128E-02
15	-.17886E-01	0.	-.48290E-02	.36515E-15	.41883E+00	-.13639E-14	-.16958E-01	.11212E-03	-.15721E-02
16	-.17886E-01	0.	-.48290E-02	.36515E-15	.41883E+00	-.13639E-14	-.16535E-01	.11212E-03	-.16670E-02
17	-.17886E-01	0.	-.48290E-02	.36515E-15	.41883E+00	-.13639E-14	-.16127E-01	.11212E-03	-.17966E-02
18	-.17886E-01	0.	-.48290E-02	.36515E-15	.41883E+00	-.13639E-14	-.15738E-01	.11212E-03	-.19594E-02
19	-.17886E-01	0.	-.48290E-02	.36515E-15	.41883E+00	-.13639E-14	-.15372E-01	.11212E-03	-.21536E-02
20	-.17886E-01	0.	-.48290E-02	.36515E-15	.41883E+00	-.13639E-14	-.15034E-01	.11212E-03	-.23771E-02
21	-.17886E-01	0.	-.48290E-02	.36515E-15	.41883E+00	-.13639E-14	-.14727E-01	.11212E-03	-.26276E-02
22	-.17886E-01	0.	-.48290E-02	.36515E-15	.41883E+00	-.13639E-14	-.14455E-01	.11212E-03	-.29021E-02
23	-.17886E-01	0.	-.48290E-02	.36515E-15	.41883E+00	-.13639E-14	-.14220E-01	.11212E-03	-.31977E-02
24	-.17886E-01	0.	-.48290E-02	.36515E-15	.41883E+00	-.13639E-14	-.14026E-01	.11212E-03	-.35113E-02
25	-.17886E-01	0.	-.48290E-02	.36515E-15	.41883E+00	-.13639E-14	-.13874E-01	.11212E-03	-.38392E-02
26	-.17886E-01	0.	-.48290E-02	.36515E-15	.41883E+00	-.13639E-14	-.13766E-01	.11212E-03	-.41780E-02
27	-.17886E-01	0.	-.48290E-02	.36515E-15	.41883E+00	-.13639E-14	-.13703E-01	.11212E-03	-.45239E-02
28	-.17886E-01	0.	-.48290E-02	.36515E-15	.41883E+00	-.13639E-14	-.13686E-01	.11212E-03	-.48732E-02
29	-.17886E-01	0.	-.48290E-02	.36515E-15	.41883E+00	-.13639E-14	-.13714E-01	.11212E-03	-.52220E-02
30	-.17886E-01	0.	-.48290E-02	.36515E-15	.41883E+00	-.13639E-14	-.13789E-01	.11212E-03	-.55665E-02
31	-.17886E-01	0.	-.48290E-02	.36515E-15	.41883E+00	-.13639E-14	-.13908E-01	.11212E-03	-.59029E-02
32	-.17886E-01	0.	-.48290E-02	.36515E-15	.41883E+00	-.13639E-14	-.14071E-01	.11212E-03	-.62275E-02
33	-.17886E-01	0.	-.48290E-02	.36515E-15	.41883E+00	-.13639E-14	-.14276E-01	.11212E-03	-.65368E-02
34	-.17886E-01	0.	-.48290E-02	.36515E-15	.41883E+00	-.13639E-14	-.14520E-01	.11212E-03	-.68274E-02
35	-.17886E-01	0.	-.48290E-02	.36515E-15	.41883E+00	-.13639E-14	-.14802E-01	.11212E-03	-.70962E-02
36	-.17886E-01	0.	-.48290E-02	.36515E-15	.41883E+00	-.13639E-14	-.17886E-01	0.	-.48290E-02
37	-.17886E-01	0.	-.48290E-02	.36515E-15	.41883E+00	-.13639E-14	-.17886E-01	0.	-.48290E-02
38	-.17886E-01	0.	-.48290E-02	.36515E-15	.41883E+00	-.13639E-14	-.17886E-01	0.	-.48290E-02
39	-.17886E-01	0.	-.48290E-02	.36515E-15	.41883E+00	-.13639E-14	-.17886E-01	0.	-.48290E-02
40	-.17886E-01	0.	-.48290E-02	.36515E-15	.41883E+00	-.13639E-14	-.17886E-01	0.	-.48290E-02
41	-.17886E-01	0.	-.48290E-02	.36515E-15	.41883E+00	-.13639E-14	-.17886E-01	0.	-.48290E-02
42	-.17886E-01	0.	-.48290E-02	.36515E-15	.41883E+00	-.13639E-14	-.17886E-01	0.	-.48290E-02
43	-.17886E-01	0.	-.48290E-02	.36515E-15	.41883E+00	-.13639E-14	-.17886E-01	0.	-.48290E-02
44	-.17886E-01	0.	-.48290E-02	.36515E-15	.41883E+00	-.13639E-14	-.17886E-01	0.	-.48290E-02
45	-.17886E-01	0.	-.48290E-02	.36515E-15	.41883E+00	-.13639E-14	-.17886E-01	0.	-.48290E-02
46	-.17886E-01	0.	-.48290E-02	.36515E-15	.41883E+00	-.13639E-14	-.17886E-01	0.	-.48290E-02
47	-.17886E-01	0.	-.48290E-02	.36515E-15	.41883E+00	-.13639E-14	-.17886E-01	0.	-.48290E-02
48	-.17886E-01	0.	-.48290E-02	.36515E-15	.41883E+00	-.13639E-14	-.17886E-01	0.	-.48290E-02
49	-.17886E-01	0.	-.48290E-02	.36515E-15	.41883E+00	-.13639E-14	-.17886E-01	0.	-.48290E-02
50	-.17886E-01	0.	-.48290E-02	.36515E-15	.41883E+00	-.13639E-14	-.17886E-01	0.	-.48290E-02
51	-.17886E-01	0.	-.48290E-02	.36515E-15	.41883E+00	-.13639E-14	-.17886E-01	0.	-.48290E-02
52	-.17886E-01	0.	-.48290E-02	.36515E-15	.41883E+00	-.13639E-14	-.17886E-01	0.	-.48290E-02
53	-.17886E-01	0.	-.48290E-02	.36515E-15	.41883E+00	-.13639E-14	-.17886E-01	0.	-.48290E-02
54	-.17886E-01	0.	-.48290E-02	.36515E-15	.41883E+00	-.13639E-14	-.17886E-01	0.	-.48290E-02
55	-.17886E-01	0.	-.48290E-02	.36515E-15	.41883E+00	-.13639E-14	-.17886E-01	0.	-.48290E-02
56	-.17886E-01	0.	-.48290E-02	.36515E-15	.41883E+00	-.13639E-14	-.17886E-01	0.	-.48290E-02
57	-.17886E-01	0.	-.48290E-02	.36515E-15	.41883E+00	-.13639E-14	-.22069E-01	.11212E-03	-.51341E-02
58	-.17886E-01	0.	-.48290E-02	.36515E-15	.41883E+00	-.13639E-14	-.22086E-01	.11212E-03	-.47848E-02
59	-.17886E-01	0.	-.48290E-02	.36515E-15	.41883E+00	-.13639E-14	-.22057E-01	.11212E-03	-.44360E-02
60	-.17886E-01	0.	-.48290E-02	.36515E-15	.41883E+00	-.13639E-14	-.21983E-01	.11212E-03	-.40915E-02

RIGID-BODY CONTROL DYNAMICS (RCD) INPUT

7 00000E+05	1	H	- ORBIT ALTITUDE (METERS)
1 7100	2	INCLIN	- ORBIT INCLINATION (RADIANS)
0	3	PSIN	- ORBIT ASCENDING NODE (RADIANS)
2 3000	4	BETA	- ORBIT SOLAR INCIDENCE ANGLE (DEG)
10 000	5	TFUEL	- TIME BETWEEN REFUELING (YEARS)
21560	6	ISP	- SPECIFIC IMPULSE (NEWTON-SECONDS PER KILOGRAM)
2 3000	7	CD	- AERODYNAMIC DRAG COEFFICIENT
2 0000	8	IE	- ORIENTATION FLAG (= 1 FOR INERTIAL OR = 2 FOR EARTH)
0	9	OPSI	- EULER ANGLES (3) DEFINING ORIENTATION OF SPACECRAFT FOR BOTH
32740	10	OTHETA	INERTIAL AND EARTH OPSI IS ROTATION ABOUT THE Z AXIS,
0	11	OPHI	OTHETA ABOUT THE NEW Y AXIS, OPHI ABOUT X (RADIANS)
1 00000E-06	12	WM3(1)	- SPACECRAFT MANEUVER RATE REQUIREMENT X, Y, Z COMPONENTS
1 00000E-06	13	WM3(2)	RESPECTIVELY (RADIANS PER SECOND)
1 00000E-06	14	WM3(3)	
1 00000E-06	15	ALFAM3	- SPACECRAFT MANEUVER ACCELERATION REQUIREMENT X, Y, Z
1 00000E-06	16	(2)	COMPONENTS RESPECTIVELY (RADIANS PER SECOND SQUARED)
1 00000E-06	17	(3)	
10000	18	NM	- NUMBER OF MANEUVERS PER ORBIT
1 00000E-03	19	E3(1)	- INERTIAL ATTITUDE ACCURACY REQUIREMENT X, Y, Z COMPONENTS
1 00000E-03	20	E3(2)	RESPECTIVELY (RADIANS)
1 00000E-03	21	E3(3)	
0	22	UAS3(1)	- UNIT VECTOR ALONG AMCD SPIN AXIS X, Y, Z COMPONENTS
0	23	UAS3(2)	RESPECTIVELY
1 0000	24	UAS3(3)	
1 00000E-02	25	GAMMA	- AMCD PIVOT AXIS ANGULAR RANGE (RADIANS)
330 00	26	RO	- AMCD UNIT WHEEL RADIUS (METERS)
1 1000	27	EMA	- RATIO OF TOTAL TO DOUBLE WHEEL MASS
200 00	28	KU	- AMCD MASS SIZING PROPORTIONALITY FACTOR (METERS PER SECOND)
1 0000	29	NORDES	- NUMBER OF ORBITS BETWEEN DESATURATIONS
500 00	30	MACS	- MASS OF ACS EXCLUDING AMCD ACTUATION ASSEMBLY (KILOGRAMS)
1000 0	31	PACS	- POWER REQUIREMENT OF ACS EXCLUDING AMCD SPIN AXIS (WATTS)
2 00100E-02	32	LM(1)	- MINIMUM LINEAR IMPULSE BIT WHEN CONTROLLING TORQUE,
2 00100E-02	33	LM(2)	X, Y, Z AXES RESPECTIVELY (NEWTON-SECONDS)
2 00100E-02	34	LM(3)	
8 0000	35	NRCSGP	- NUMBER OF THRUSTER GRIDPOINTS (= NUMBER OF ROWS IN RCSMAT)

1
\+ EOS BASELINE DESIGN--POST ORBITAL TRANSFER RCSMAT MATRIX

	1	2	3	4	5	6	7	8	9	10
ROW	GRIDPOINT	FYX	FZX	FXY	FZY	FXZ	FYZ	X COORD	Y COORD	Z COORD
1	1 11314E+05	-667 00	1334 0	-1334 0	0	1334 0	0	-30 219	45 189	6 1568
2	2 11314E+05	-667 00	1334 0	0	-667 00	1334 0	-667 00	-30 219	-45 189	6 1568
3	3 11314E+05	-667 00	-1334 0	-1334 0	0	-1334 0	0	30 219	-45 189	6 1568
4	4 11314E+05	-667 00	-1334 0	0	-667 00	-1334 0	-667 00	30 219	45 189	6 1568
5	5 00031E+05	667 00	667 00	667 00	0	667 00	0	-30 219	15 141	137 52
6	5 00032E+05	667 00	-667 00	667 00	0	-667 00	0	-45 359	15 141	137 52
7	5 00047E+05	667 00	667 00	667 00	667 00	667 00	667 00	-30 219	-15 141	137 52
8	5 00048E+05	667 00	-667 00	667 00	667 00	-667 00	667 00	-45 359	-15 141	137 52

1
\+ EOS BASELINE DESIGN--POST ORBITAL TRANSFER
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\+ EOS BASELINE DESIGN--POST ORBITAL TRANSFER

RCD CATAGORY 2 INPUT ITEMS

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6385 1	1	TWRM	- TOTAL WEIGHT OF THE SPACECRAFT EXCLUDING RCD (KILOGRAMS)
-1202 5	2	BXM	- SPACECRAFT CENTER OF MASS FOR TWRM X, Y, Z COORDINATES
-6 60927E-12	3	BYM	RESPECTIVELY (CENTIMETERS)
4872 9	4	BZM	
2 48449E+07	5	XXM	- MOMENT OF INERTIA XX FOR TWRM (KILOGRAM-METERS SQUARED)
2 13266E+07	6	YYM	- MOMENT OF INERTIA YY FOR TWRM (KILOGRAM-METERS SQUARED)
1 22171E+07	7	ZZM	- MOMENT OF INERTIA ZZ FOR TWRM (KILOGRAM-METERS SQUARED)
-9 82645E-09	8	PXYM	- PRODUCT OF INERTIA XY FOR TWRM (KILOGRAM-METERS SQUARED)
4 83656E+06	9	PXZM	- PRODUCT OF INERTIA XZ FOR TWRM (KILOGRAM-METERS SQUARED)
-4 73138E-09	10	PYZM	- PRODUCT OF INERTIA YZ FOR TWRM (KILOGRAM-METERS SQUARED)
1 0000	11	KALKTK	- PROP TANK M AND A FLAG (>0 USER DEF , =0 PROP , <0 AUTO)
8 0000	12	NOPROP	- NUMBER OF PROPELLANT MASSES
0	13	NMAMCD	- NUMBER OF AMCD MASSES
8 0000	14	ANBAYS	- ANALYSIS NUMBER OF BAYS
133 00	15	NOGPAR	- NUMBER OF GRIDPOINTS IN ANALYSIS (= NO OF ROWS IN GPAREA)

1

\+ EOS BASELINE DESIGN--POST ORBITAL TRANSFER GTSM MATRIX

ROW	1 GRIDPOINT	2 MASS	3 X AREA	4 Y AREA	5 Z AREA
1	1 11314E+05	30 000	0	0	0
2	2 11314E+05	30 000	0	0	0
3	3 11314E+05	30 000	0	0	0
4	4 11314E+05	30 000	0	0	0
5	5 00031E+05	15 000	0	0	0
6	5 00032E+05	15 000	0	0	0
7	5 00047E+05	15 000	0	0	0
8	5 00048E+05	15 000	0	0	0

1

\+ EOS BASELINE DESIGN--POST ORBITAL TRANSFER

RCD CATAGORY 3 INPUT ITEMS

3 70000E-02	1	PTKMER	- PROPELLANT TANK MASS ESTIMATED RELATIONSHIP
2 90000E-02	2	PTKAER	- PROPELLANT TANK AREA ESTIMATED RELATIONSHIP

1

\+ EOS BASELINE DESIGN--POST ORBITAL TRANSFER

	ORBIT RADIUS (METERS) =	7 078E+06
	ORBIT VELOCITY (METERS PER SECOND) =	7 504E+03
	ORBIT PERIOD (SECONDS) =	5 926E+03
0	PROPELLANT MASS FIX RATIO =	5 998E-01
	PROPELLANT MASS (KILOGRAMS) =	1 800E+02
0	SPACECRAFT TOTAL MASS (KILOGRAMS) =	6 565E+03
	SPACECRAFT MASS LESS PROPELLANT (KILOGRAMS) =	6 385E+03
	X DISTANCE TO CENTER OF MASS IN FRAME 4 (METERS) =	-1 170E+01

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X DISTANCE TO CENTER OF MASS IN FRAME 4 (METERS) = -1.170E+01
Y DISTANCE TO CENTER OF MASS IN FRAME 4 (METERS) = -6.428E-14
Z DISTANCE TO CENTER OF MASS IN FRAME 4 (METERS) = 4.739E+01

MASS MOMENT OF INERTIA (KILOGRAM-SQUARE METERS)			DISTANCE FROM CENTER OF GRAVITY TO CENTER OF PRESSURE (METERS)		
2.484E+07	9.826E-09	-4.837E+06	0.	-4.711E-14	2.228E+01
9.826E-09	2.133E+07	4.731E-09	-4.968E+00	0.	2.019E+01
-4 837E+06	4.731E-09	1 222E+07	-7.896E+00	-4.928E-14	0.

TORQUE RESULTING FROM RCSMAT ASSUMING ALL THRUSTERS FIRE AT NOMINAL VALUE

(NEWTON-METERS)			INVERSE MATRIX		
-3.505E+05	-2.020E+04	-1.752E+05	1.407E-04	7.090E-06	-4.892E-04
1.411E+05	4.009E+05	0.	-4.951E-05	6.370E-19	1.721E-04
-1.008E+05	5.821E-11	-5.041E+04	-2.814E-04	-1.418E-05	9.585E-04

EFF RADII FOR APPLICATION OF TORQUE			SPACECRAFT PROJECTED AREAS		
2.627E+01	5.009E+01	4.724E+00	1.024E+03	6.617E+02	9.469E+02

1
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EOS BASELINE DESIGN--POST ORBITAL TRANSFER

```
 GET,AREAPR
/COPY,AREAPR
.PROC,REPRN
DELIVER      GARRETT      1232
MAP,OFF
GET,L=LASSLIB,AV=AVIDLIB/UN=403180N.
REWIND,*
GET,RAUSYS/UN=727850N
SETCORE,ZERO
GET,NMACFTN/UN=LIBRARY
LIBRARY,NMACFTN
ATTACH,LIBFTEK/UN=LIBRARY
GET,AREA
FTN,I=AREA,L=T.
LDSET,LIB=L/FORTRAN/AV/RAUSYS/LIBFTEK/LSSLIB,PRESETA=0
LGO
DAYFILE,OP=I,DAY
REPLACE,DAY
EXIT
REWIND,DAY.
DAYFILE,OP=I,DAY
REPLACE,DAY
REVERT,RREX.
 EOI ENCOUNTERED.
/
```

```
GET,HOOPDEPR
/COPY,HOOPDEPR
 PROC,RREX
GET,LASSLIB,AVIDLIB/UN=403180N.
REWIND,*
MAP,OFF
GET,LS=LSSLIB
GET,RAUSYS/UN=727850N
SETCORE,ZERO.
GET,NMACFTN/UN=LIBRARY.
LIBRARY,NMACFTN.
ATTACH,LIBFTEK/UN=LIBRARY
GET,HOOPDEP
FTN,I=HOOPDEP,L=T
LDSET,LIB=LASSLIB/FORTRAN/AVIDLIB/RAUSYS/LIBFTEK/LS.
LGO
DAYFILE,OP=T,DAY
REPLACE,DAY
EXIT
REWIND,DAY.
DAYFILE,OP=I,DAY
REPLACE,DAY
REVERT,RREX
 EOI ENCOUNTERED.
/
```

```
 GET,LSSCTPR
/COPY,LSSCTPR
 PROC,RFPRN.
DELIVER     GARRETT     1232
MAP,OFF
GET,L=LASSLIB,AV=AVIDLIB/UN=403180N.
REWIND,*.
GET,RAUSYS/UN=727850N.
SETCORE,ZERO.
GET,NMACFTN/UN=LIBRARY.
LIBRARY,NMACFTN
ATTACH,LIBFTEK/UN=LIBRARY.
GET,CTBIN,LSSLIB
LDSET,LIB=L/FORTRAN/AV/RAUSYS/LIBFTEK/LSSLIB,PRESETA=0.
CTBIN
DAYFILE,OP=I,DAY
REPLACE,DAY.
EXIT.
REWIND,DAY
DAYFILE,OP=I,DAY.
REPLACE,DAY.
REVERT,RREX.
 EOI ENCOUNTERED.
/

 GET,MPPROC
/COPY,MPPROC
.PROC,RREX.
REWIND,*.
GET,LASSLIB,AVIDLIB/UN=403180N.
GET,RAUSYS/UN=727850N
GET,NMACFTN/UN=LIBRARY.
LIBRARY,NMACFTN.
ATTACH,LIBFTEK/UN=LIBRARY
GET,MASNEW2
MAP,OFF.
FTN,I=MASNEW2,L=T
LDSET,LIB=LASSLIB/FORTRAN/AVIDLIB/RAUSYS/LIBFTEK,PRESETA=0.
LGO.
DAYFILE,OP=I,DAY.
REPLACE,DAY.
EXIT.
REWIND,DAY.
DAYFILE,OP=I,DAY.
REPLACE,DAY
REVERT,RREX
 EOI ENCOUNTERED
/
```

```
 GET,LASSE
/COPY,LASSE
.PROC,RREX.
GET,LASSLIB,AVIDLIB/UN=403180N.
REWIND,*.
GET,RAUSYS/UN=727850N.
MAP,OFF.
SETCORE,ZERO.
GET,NMACFTN/UN=LIBRARY.
LIBRARY,NMACFTN.
ATTACH,LIBFTEK/UN=LIBRARY.
GET,RCDLIB,MAINRCD.
FTN,I=MAINRCD,L=T,B=RCDB.
LDSET,LIB=LASSLIB/FORTRAN/AVIDLIB/RAUSYS/LIBFTEK/RCDLIB,PRESETA=0.
LDSET,USEP=RCBLKD.
RCDB.
REWIND,LPRINT.
REPLACE,LPRINT.
DAYFILE,OP=I,DAY.
REPLACE,DAY.
EXIT.
REWIND,DAY.
DAYFILE,OP=I,DAY.
REPLACE,DAY.
REVERT,RREX.
 EOI ENCOUNTERED.
/
```

4.0 REFERENCES

1. C. E. Farrell: "Advanced Space System Analysis Software - Technical, User, and Programmer Guide," NASA Contractor Report CR-165798, September 1981.

2. A. Leondis: "Large Advanced Space Systems Computer-Aided Design and Analysis Program," NASA Contractor Report, CR 159131, July 1980.

3. J. Herbert: "Technology Needs of Advanced Earth Observation Spacecraft," NASA CR, May 1983

4. R. M. Georgovic: "The Solar Radiation Pressure Force and Torque Model," J. F. Astron Sc, Vol XX, No. 5, March-April 1973.

5. A. L. Brook: "Conceptual Design and Analysis of a Large Antenna Utilizing Electrostatic Membrane Management," NASA CR-3522, May 1982.

6. A. Greensite: "Analysis and Design of Spare Vehicle Flight Control Systems," Vol XII, NASA Contractor Report, CR-831, August 1962.

7. T. Mahefkey: "Future Space Power - The D.O.D. Perspective," IECEC Conference, 1980.

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15 Supplementary Notes

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16 Abstract

The IDEAS computer program of NASA LaRC is a tool for interactive preliminary design and analysis of LSS. This document describes the additions to IDEAS as a result of completion of Contract NAS1-16756. Nine analysis modules were either modified or created. These modules include the capabilities of automatic model generation, model mass properties calculation, model area calculation, nonkinematic deployment modeling, rigid-body controls analysis, rf performance prediction, subsystem properties definition, and EOS science sensor selection. For each module, a section is provided that contains technical information, user instructions, and programmer documentation.

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