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PLANETARY EXPLORER STRUCTURAL CONCEPT EVALUATION MODEL USING NASTRAN

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GODDARD SPACE FLIGHT CENTER
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Dennis R. Hewitt
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ABSTRACT

A structural evaluation of the phase A configuration of the Planetary Explorer spacecraft used the NASA structural analysis program NASTRAN. This report describes the modeling techniques used to create a versatile model while reducing computer running time. The evaluation predicted the optimum position of structural members, load paths, and deflections.

CONTENTS

ILLUSTRATIONS

ILLUSTRATIONS (continued)

PLANETARY EXPLORER STRUCTURAL CONCEPT EVALUATION MODEL USING NASTRAN

INTRODUCTION

Figure 1 is the conceptual drawing that evolved from the systems analysis conducted by the Planetary Explorer staff. Structurally, it consisted of:

- A centertube to house the planetary insertion motor and provide support to major structural members
- A honeycomb platform and struts to support experiments in a twelve-bay arrangement
- An electrically despun antenna supported above the centertube by an adapter cone and discrete struts attached to the top of the centertube
- Solar-array panel-support stringers above and below the experiment bays and on the circumference of the spacecraft
- A hydrazine system to be located and supported in the volume bounded by the dotted lines shown

Creation of a workable mathematical model requires an understanding of the functions to be performed by the model. The purpose of this concept-evaluation model was to define static load paths and deflections under predetermined worst-case loading conditions for various configurations of the basic concept.

FUNCTIONS OF THE MODEL

Configuration options to be evaluated by the model were:

- The volume indicated in Figure 1 must take in the mass of the hydrazine system as either discrete spherical tanks or a toroid. Variations in the method of supporting this mass (and resulting load inputs) from the centertube or from the outer framework should be investigated.
- Analysis of the optimum number of struts to support the honeycomb platform and the optimum dimension of the root

- Number and orientation of the antenna-support struts
- Addition or removal of vertical stringers connecting the upper and lower solar array to the platform, in order to isolate the effect of the platform deflections on the outer framework of the array

Worst-case loading conditions to be imposed on the varying configurations included:

- A 30 g axial force coupled with a 120-rpm spin loading, corresponding to prototype levels (1.5 x flight levels) of the third-stage burn and spin of the Delta launch vehicle
- A 3 g lateral load acting through the spacecraft center-of-mass, corresponding to the prototype lateral load experienced during the pitch program of the Delta vehicle
- A 23 g axial load, corresponding to the prototype deceleration level of the planetary-insertion motor burn

Because these loading conditions are axisymmetric, the mathematical model can include only half the spacecraft and still represent the entire structure through the use of proper boundary conditions. This reduces the computer time necessary to solve the problem and eliminates redundant data from the symmetric half.

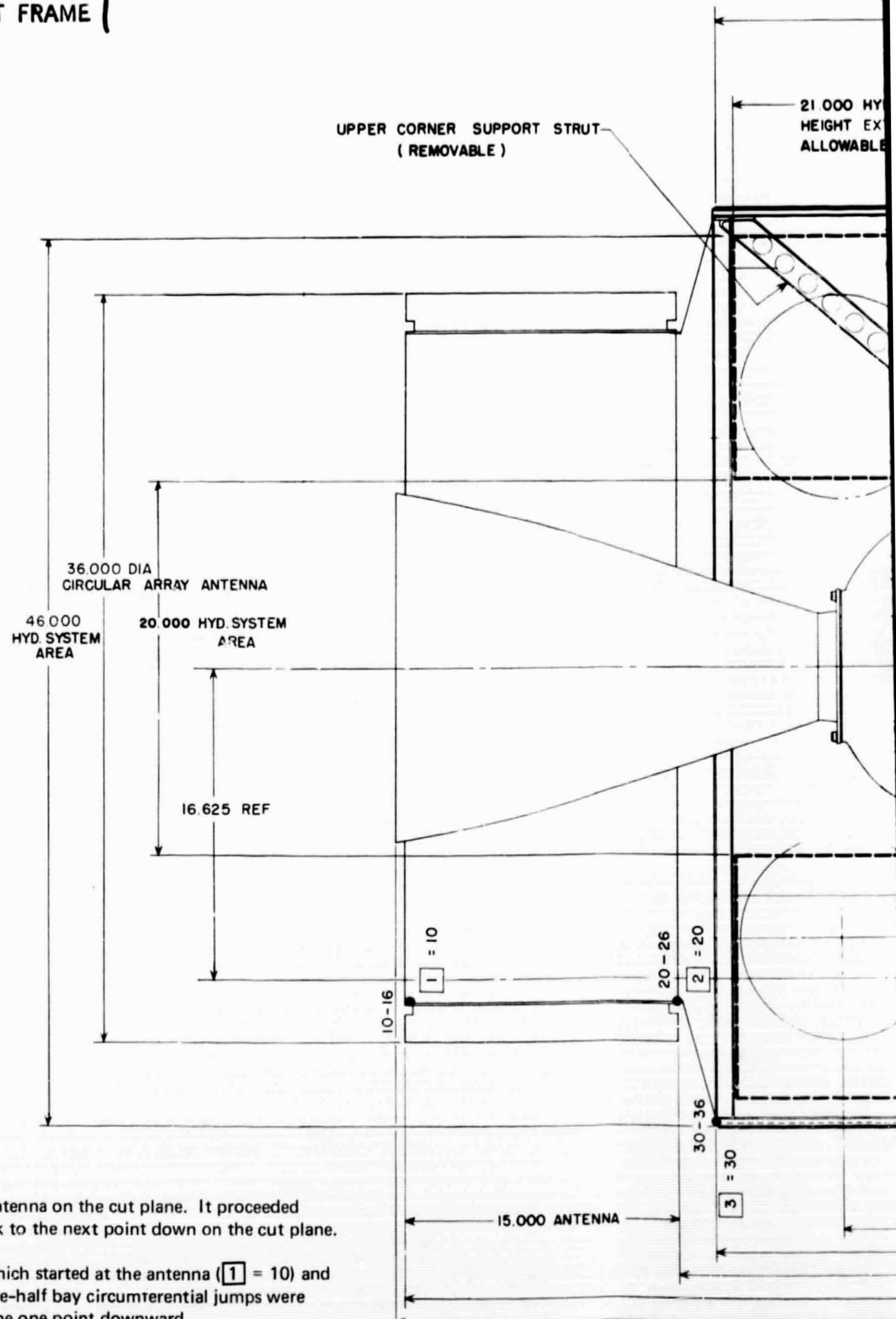
After considering the functions of the model, the actual creation of the NASTRAN (NASA structural analysis program) model begins.

CREATING THE NASTRAN MODEL

The calculation began by defining a cylindrical coordinate system with its origin at the third-stage interface, and the positive Z axis pointing along the spin axis toward the despun antenna (Figure 1). Grid points set up at key intersections of the structural members connected the NASTRAN finite elements to approximate the structure; this grid arrangement permitted addition or removal of various elements in areas where the number and orientation of struts were to be investigated.

In order to budget computer time and obtain meaningful data, care is necessary in choosing the number of elements and the numbering sequence of the grid points. Accuracy in the NASTRAN model is directly related to the fineness of the grid arrangement. Up to a point, decreasing the size of the finite elements

FOLDOUT FRAME 1



Initial numbering started with 10 at the antenna on the cut plane. It proceeded circumferentially for 180 degrees and back to the next point down on the cut plane.

☐ Indicates resequenced grid numbers which started at the antenna ($\boxed{1}$ = 10) and proceeded downward as shown. A few one-half bay circumferential jumps were made, always returning to the original plane one point downward.

FOLDOUT FRAME 2

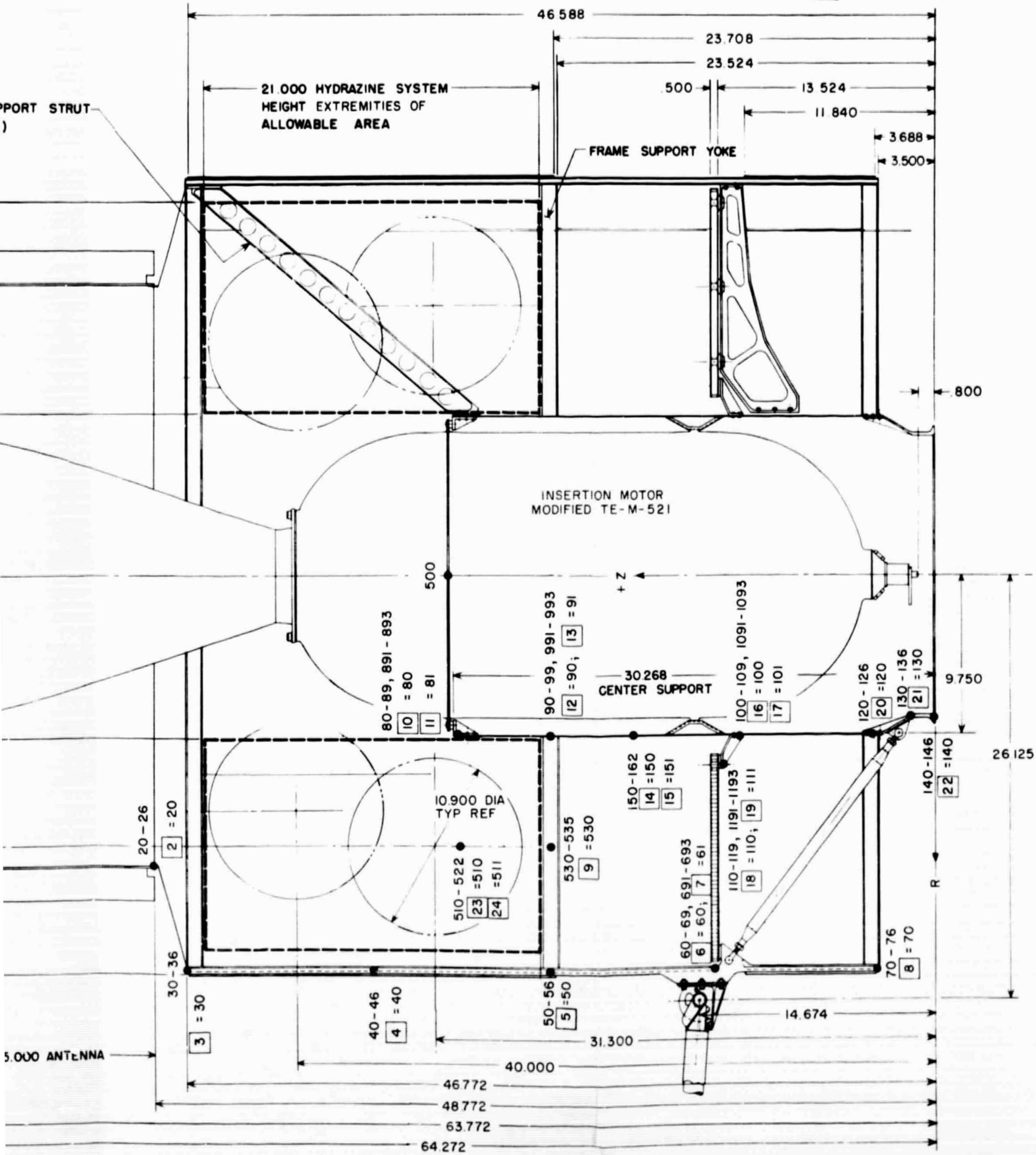


Figure 1. Planetary Explorer Concept (Grid Point Numbering Systems)

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used produces better results; however, as each grid point has 6 degrees-of-freedom associated with it, a fine grid arrangement will produce a large structural matrix, which requires a large amount of computer time for its evaluation.

Figure 2 shows schematically a typical NxN-coupled structural matrix that relates every existing degree-of-freedom to every other degree-of-freedom in the model. The NASTRAN theoretical manual(2) describes this in more detail. The consecutively numbered degrees-of-freedom for each grid point appear along the first row and down the first column. A+ in Figure 2 indicates that a connection between that particular row's and column's degree-of-freedom will appear in the model; a 0 indicates that no connection has been made. NASTRAN decomposes the smallest band of terms on either side of the diagonal of this matrix into a smaller matrix that is easier to evaluate, and stores the terms further away from the diagonal as "active columns."

The numbering system chosen for grid-point identification can give rise to a large number of off-diagonal terms in the coupled structural matrix. A narrow band of terms on either side of the diagonal may not be present; without such a band of nonzero terms, NASTRAN will not work effectively in the decomposition (evaluation), and the calculation will consume much computer time. Resequencing the numbering system for a better bandwidth became necessary in the Planetary Explorer model in order to reduce an initially large decomposition time. Use of the numbering system that appears in Figure 1 (numbers enclosed in boxes) produced a bandwidth of 143 terms, with approximately 700 degrees-of-freedom (a 700 x 700 matrix) and a decomposition time of 86 seconds.

The next step in constructing the model was to select the finite elements that would realistically approximate the Planetary Explorer structure. Figures 3 and 4 show several of the NASTRAN finite elements chosen. The bar element of Figure 3, a connection between two grid points, acts as a beam to resolve axial forces and the shears and moments indicated on its ends. An analysis using this element (as with all elements included in NASTRAN) is in agreement with linear small-deflection theory. The plate element in Figure 4 can resolve the forces and moments shown, the output representing an average effect of these forces near the center of the element. The plate element can describe a plate structure of homogeneous cross section, or one of varying composition (such as a honeycomb panel). Structural properties of the finite elements, input in the bulk data portion of the program, include items such as the modulus of elasticity or Poisson's ratio. Connection cards tell NASTRAN the manner in which the elements are joined. Figure 5 shows how these elements were connected to describe the Planetary Explorer structural model.

Use of twelve circumferential flat homogeneous plates at three vertical positions approximated the centertube. The third-stage adapter, the most rigid part of the

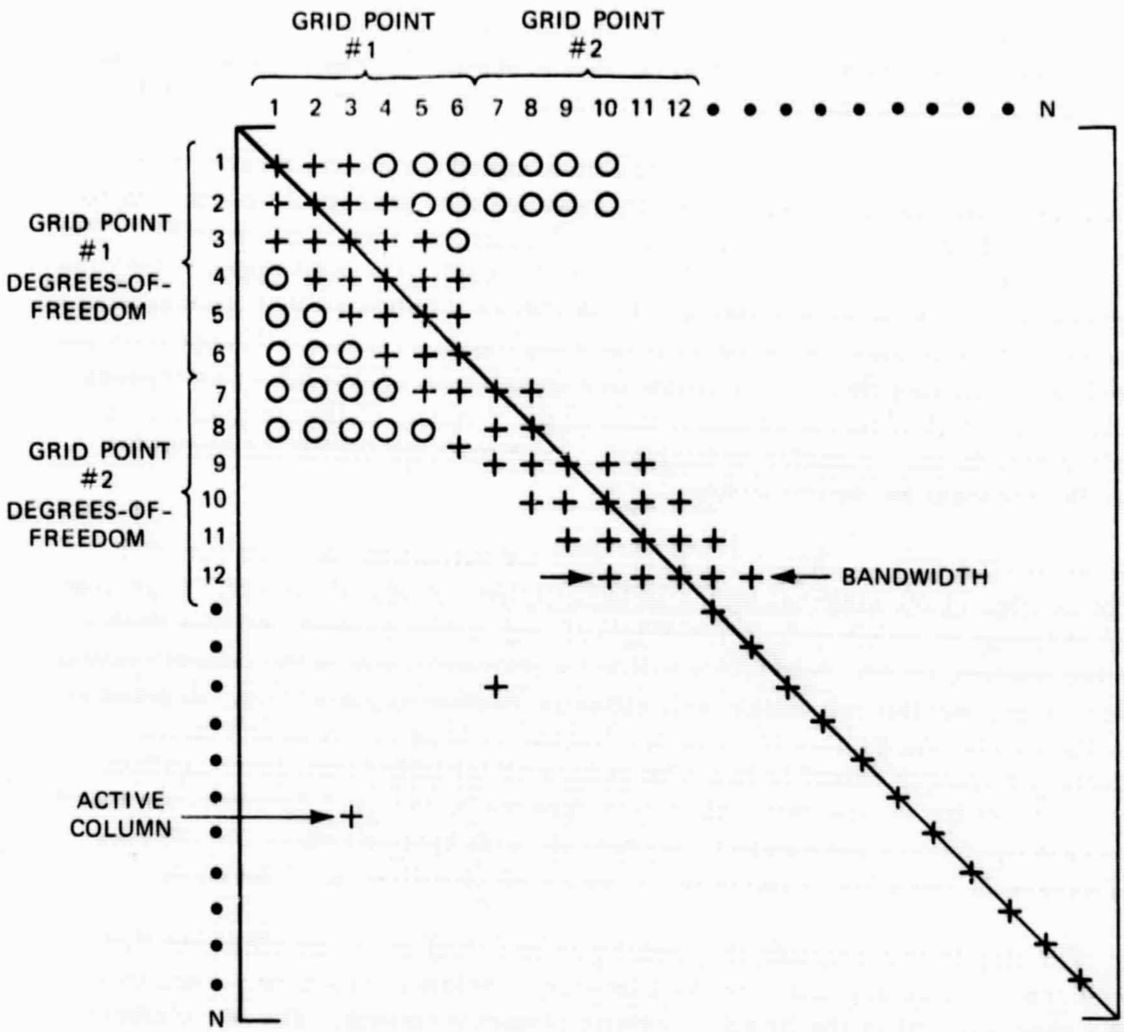


Figure 2. NxN-Coupled Structural Matrix

structure, did not require as fine a grid as the upper section of the centertube; six circumferential flat homogeneous plates at two vertical positions served to represent the adapter. To keep the assumptions embodied in the element-defining equations accurate, the ratio of adjacent plate sides in any location throughout the model did not exceed 2.5:1. Using triangular plate elements (slight variations of the basic plate) below the platform strut supports made it easy to change the dimension of a strut root by redefining only the connection point at that particular vertex. These elements also provided a transition from the fine-grid upper section to the coarse-grid adapter.

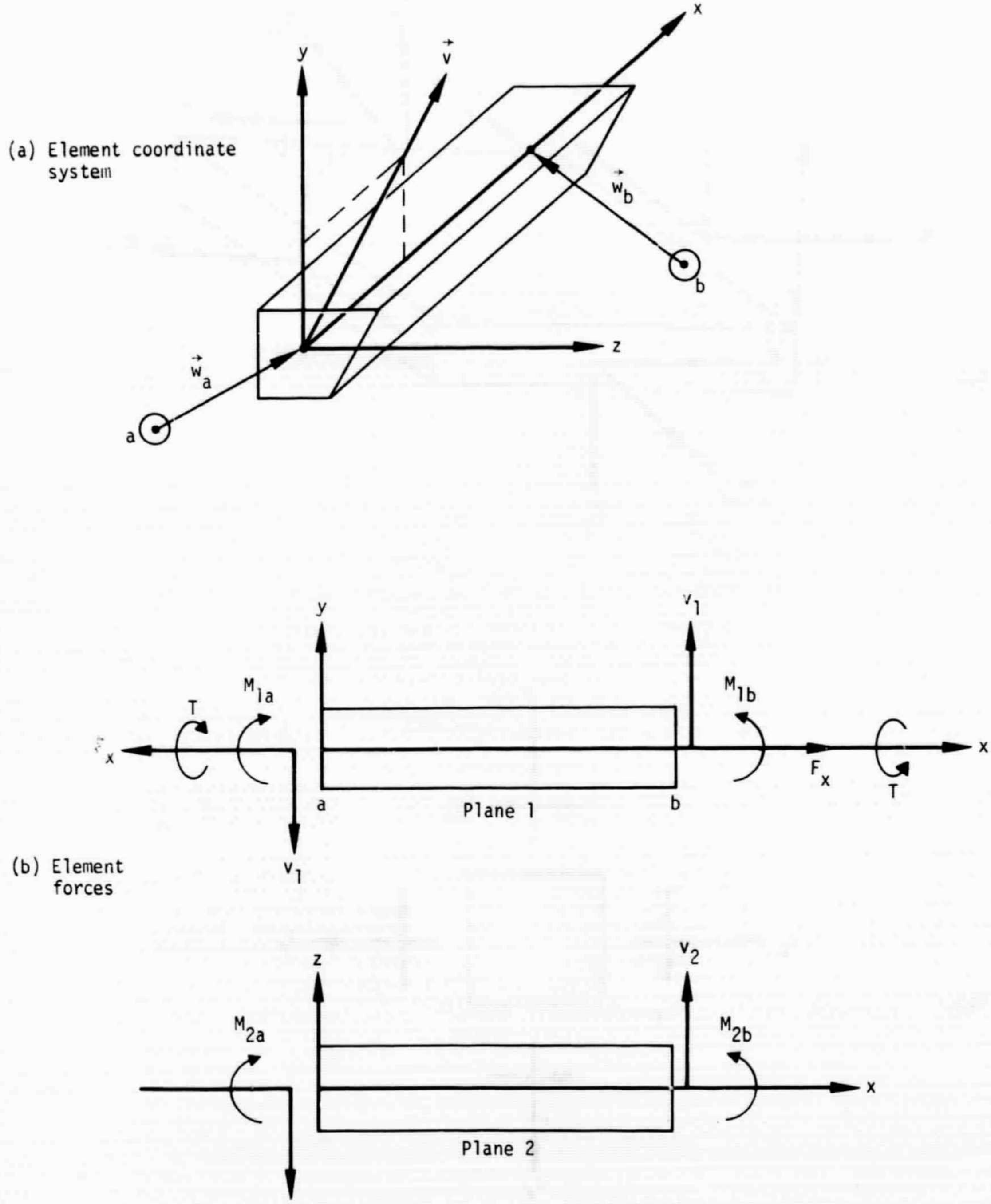


Figure 3. Bar-Element Coordinate System and Element Forces

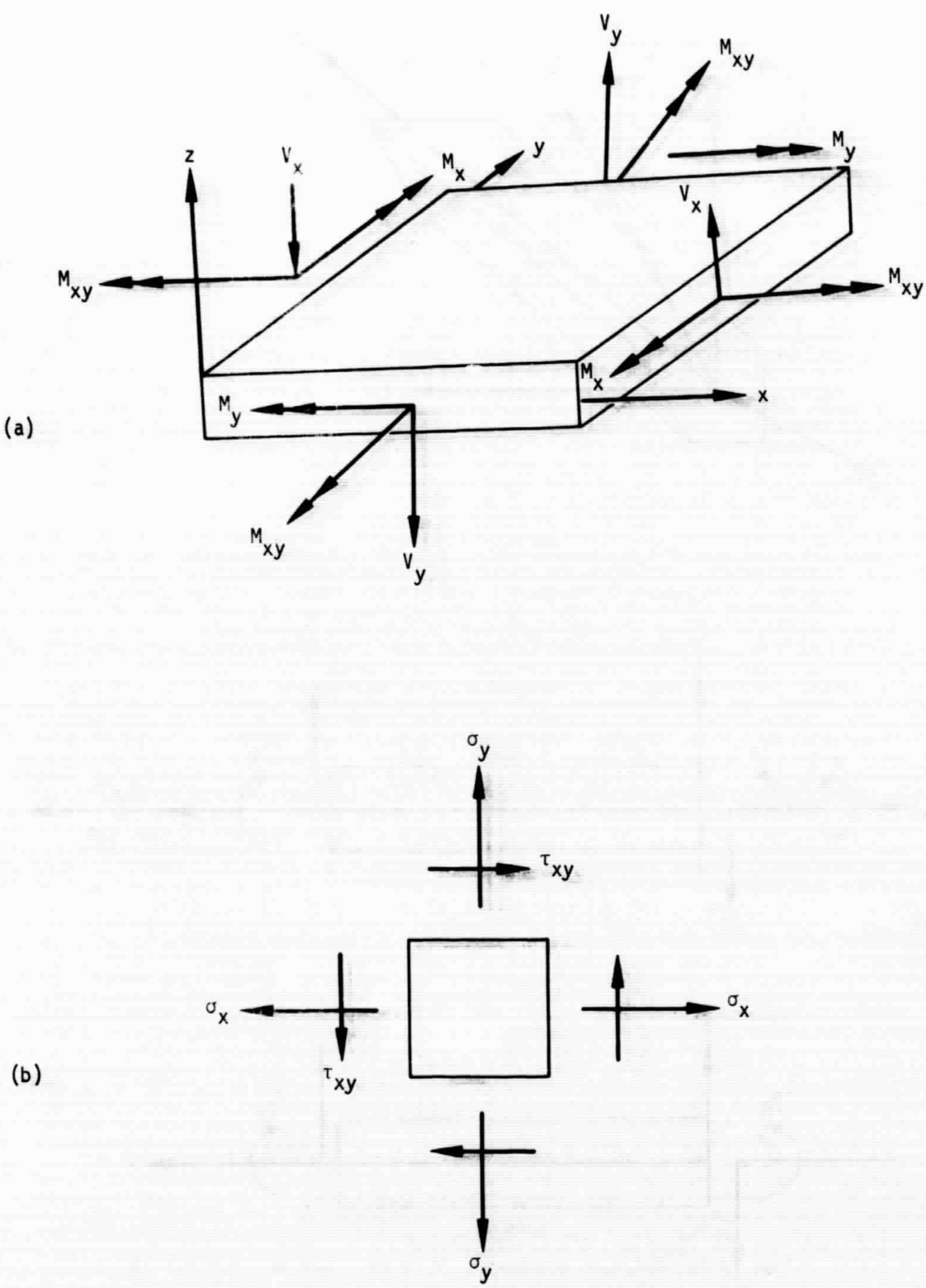


Figure 4. Plate-Element Forces and Stresses

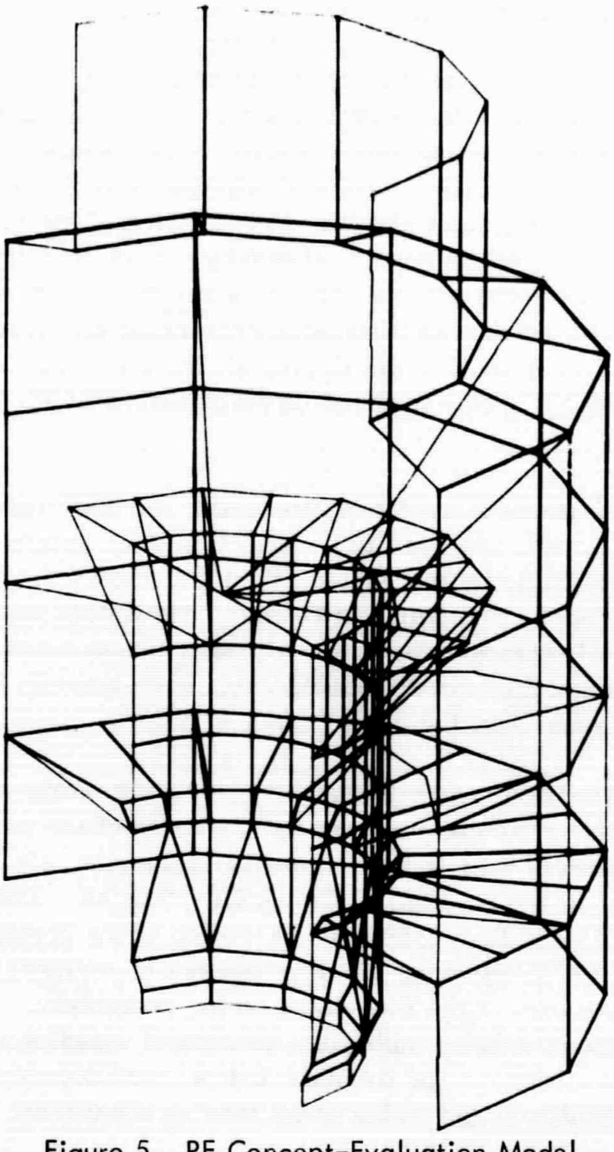


Figure 5. PE Concept-Evaluation Model, Undeformed Shape

Twelve nonhomogeneous plates, also shown in Figure 5, approximated the honeycomb platform. Shear stiffness (based on the honeycomb core) and membrane and bending stiffness (based on the face sheets) were input as plate properties.

The structural design called for cantilevering the platform-support struts from the centertube and fastening them radially to the platform. The I-section tapered struts were to number either six or twelve; the member was to allow a minimum amount of tip deflection under the platform loading. As the primary concerns were the tip deflection and the force input to the centertube, the model of the strut was fairly coarse. The NASTRAN construction consisted entirely of bar elements, using separate bars for each flange and web respectively, as shown in Figure 6. Vectors emanating from existing grid points on the shelf or the centertube served to define the grid points for the flanges and web, forming a rigid connection between existing and referenced grid points and eliminating the need to define new grid points or to constrain degrees-of-freedom when removing or changing the position of struts. Investigation of the root depth of the struts led to modifications of the model, shown by dotted lines in Figure 6; half the inertia and cross sectional area of bar 5 was referenced to point 1, the other half to point 2. This served to develop centertube stiffness at both points 1 and 2, and did not require developing all the stiffness at point 1. It therefore constituted a more realistic approximation of the actual connection.

Homogeneous plate elements served to approximate the body-mounted solar-cell panels; as these panels were not to be load-carrying structural members, according to a predetermined requirement, the elements were given weight (nonstructural mass) but no structural stiffness. The panels were supported by vertical and horizontal stringers that, like all other connections from the outer framework to the centertube, were modeled using bar elements having the cross sections of the conceptual drawing.

A vector in the -Z direction, from an existing grid point on the spin axis in the plane of the top of the centertube, referenced the mass of the planetary-insertion motor; mass properties of this motor (moments-of-inertia, etc.) were input at the end of this vector at the position of the center-of-mass. The existing grid point (500 in Figure 1) was then connected to the top of the centertube by very rigid bars ($E = 90 \times 10^{+6}$), allowing the development of realistic forces and moments at the upper corners of the flat plates on the centertube. This method removes the necessity of writing multipoint constraint equations that relate dependent degrees-of-freedom to one or more independent degrees-of-freedom, and can be difficult to determine under some loading conditions.

This technique of modeling with rigid bars also proved useful in investigating the effects of structural connections from the hydrazine system to the centertube. The system was undefined except for weight and general location, and a rigid torus was assumed as shown in Figure 5. Each bar in the torus had a nonstructural mass equal to 1/24 the total mass of the hydrazine. Modeling the connections to the centertube and outer framework with rigid bars resulted in transmitting realistic forces and moments developed from the g-loading on the hydrazine torus to these areas.

After defining the structural components, the analysis must completely and accurately define the loading conditions. The worst-case loading conditions already

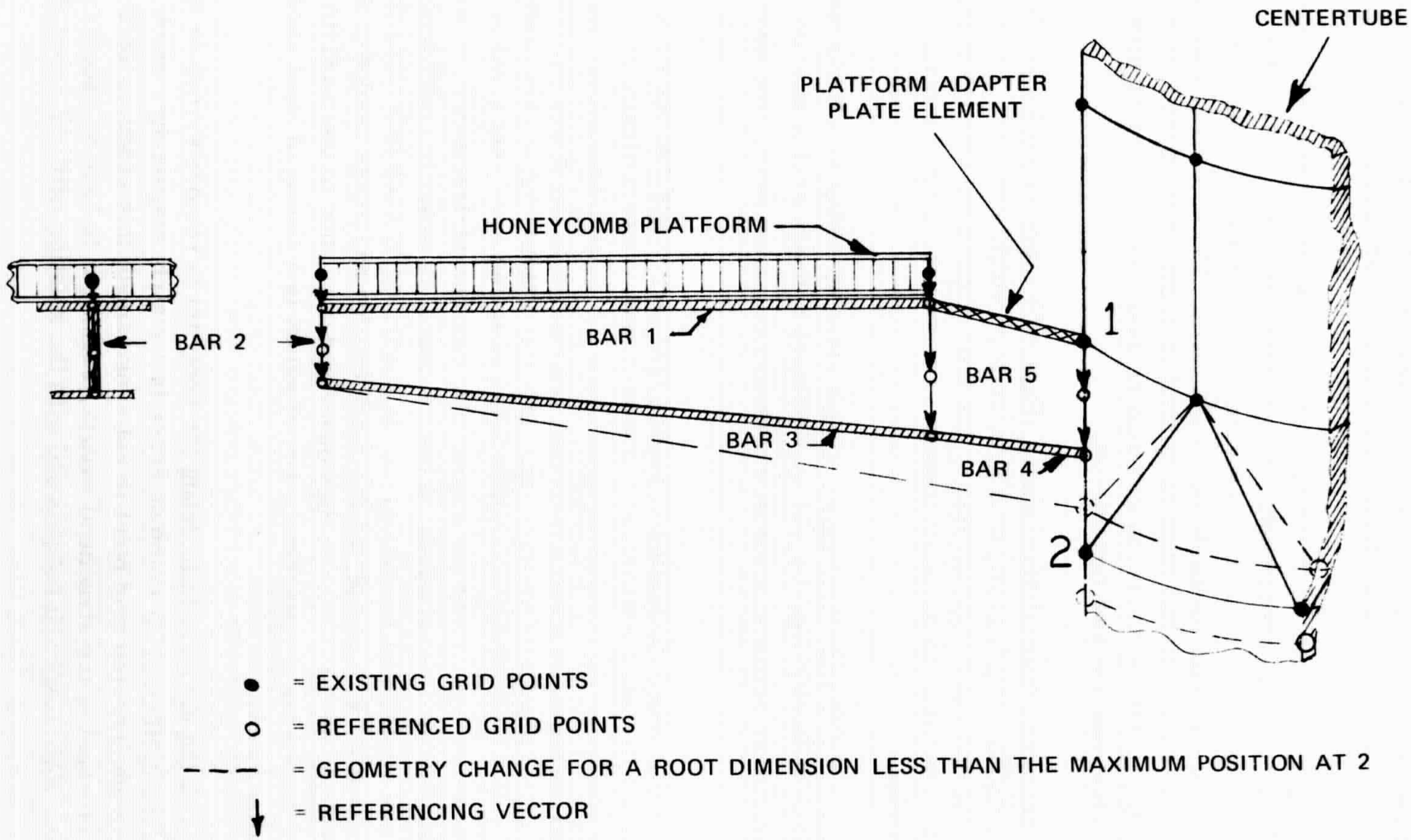


Figure 6. Platform Strut-Referencing Technique

described were input in the proper direction of the g forces: e.g., the side load was defined as a unidirectional g field parallel to the cut plane. The spin load described in NASTRAN applies a g load on the element-defining grid points that is proportional to their radial distance from the rotation center, and to the spin rate.

The appropriate g loading acts upon the internal nonstructural mass associated with certain elements: the experiments, for example, were distributed uniformly over the platform by using this nonstructural mass ($lb/in.^2$) as an input to the properties of the plate elements of the platform. The total weight associated with the area of a particular plate is lumped proportionally at the four defining grid points, and the g-load acts on these lumped masses. Contributions from adjacent elements are also considered.

In the model, aluminum quadrilateral plates (Figure 5) represented the electronically despun antenna weight; giving these plates zero weight and a nonstructural mass equal to the antenna weight divided by the area allowed the antenna to input realistic loads to the antenna supports without regard to the actual structural design of the antenna.

NASTRAN computes the structural mass of each element, using as a basis the material density, cross sectional area, and distance between grid points; on request, it outputs the entire spacecraft weight and the mass properties about a given point.

As mentioned previously, application of proper boundary conditions makes it possible to use a half-spacecraft model. Figure 7 shows schematically the spacecraft cut plane and the numbering system for the three translational and three rotational degrees-of-freedom involved. To represent the actual hardware-test condition of a clamped third-stage interface, the bottom ring of grid points appears in Figure 7 with all degrees-of-freedom removed (i.e., set equal to zero). To effectively model half the spacecraft, degrees-of-freedom 2, 4, and 6 must be removed for all grid points on the cut plane, in order to compensate for the equal and opposite forces and moments generated by each half along this cut plane. This procedure completed the consideration and inputs needed to develop the NASTRAN model, which is then described according to the NASTRAN format and submitted for keypunching. The appendix is a listing of input cards for configuration PE-A.

The next phase of the analysis is to debug the program to remove errors or incorrectly defined elements. A common error is a matrix singularity, which occurs when an unconnected grid point is not constrained; this produces zero terms on the diagonal of the structural matrix, causing it to have an undeterminable value. NASTRAN will not proceed with the solution until the error is removed.

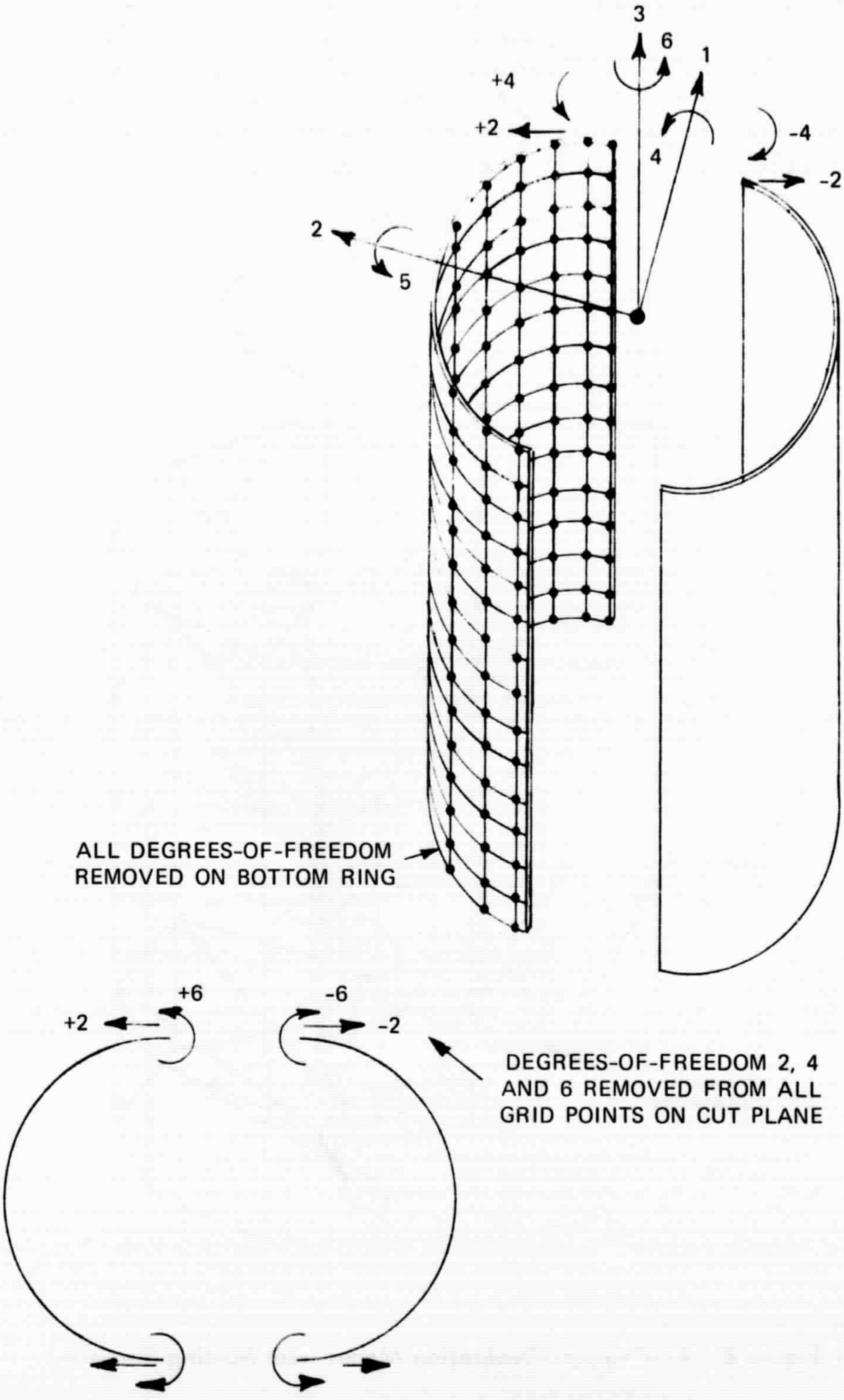


Figure 7. PE Concept-Evaluation Model Boundary Conditions

NASTRAN outputs diagnostic messages to inform the user of errors; however, as the problem can run to completion with an improperly connected model, the graphics portion of NASTRAN can serve to check for proper connections. In the Planetary Explorer model, a plot was made of all connections input for each configuration. Figure 8 shows an example of a disjoint model immediately discarded as incorrect because of missing structural connections.

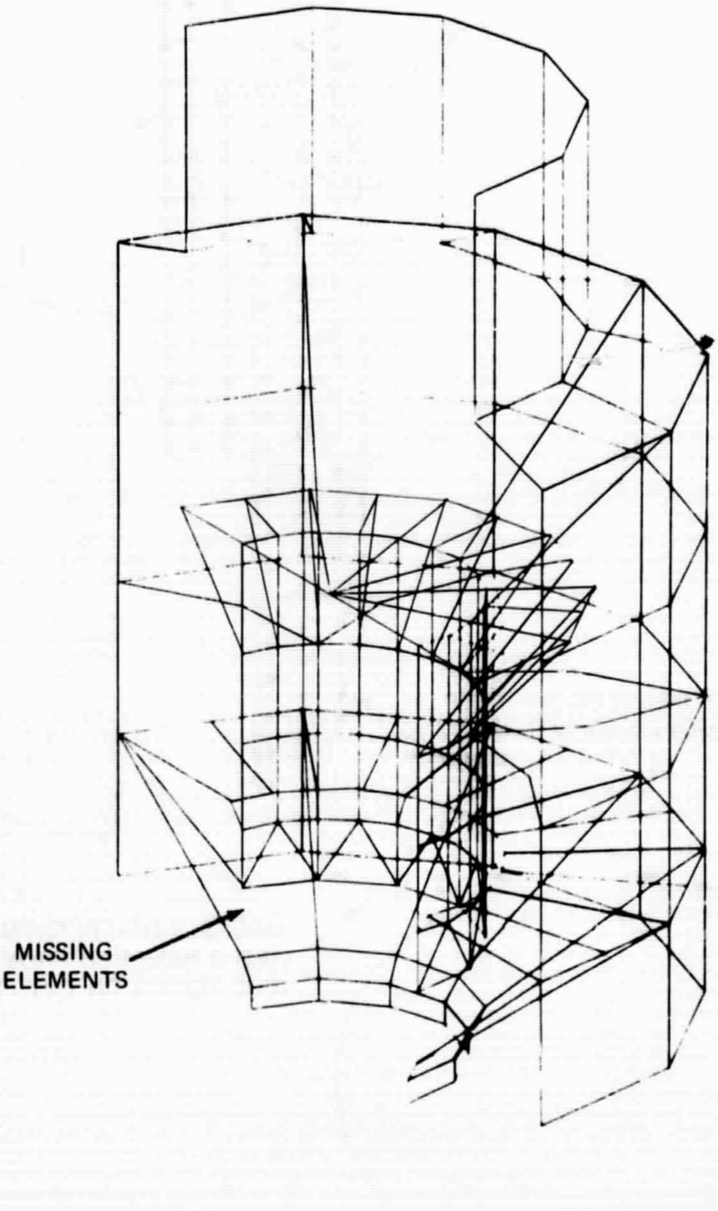


Figure 8. PE Concept-Evaluation Model with Missing Elements

Once the model is working correctly, some procedure is necessary for efficiently analyzing the many stress and deflection numbers output by NASTRAN. The graphic output made it easy to evaluate the relative deformations under a particular loading; using this NASTRAN option, the maximum deformation is set equal to a desired length and the plotted structure is normalized to it. The deformed structure (greatly exaggerated) was plotted on the same graph as the undeformed structure (Figure 9).

A meeting held after each computer run discussed the next configuration to be analyzed. Figure 10 describes the various configurations considered in this study. Figures 11 through 16 show the sketches used to efficiently portray the results of each run and compare them with those from previous configurations; the small figure in the lower righthand corner of each two-bay sketch shows the hydrazine-mounting scheme for that particular run. Loads and deflections in the Z direction at grid points were also recorded on these two-bay section sketches of the model. Using these figures and the plotted deformed structure made it possible to clearly define the changes induced by each configuration in turn, and to make engineering judgment on the design based on proper load paths, distribution of loads, and allowable deflections, without exceeding the design stress.

For example, Figure 11 shows the relative amount of load carried by the outer framework (57 to 414 lbf). Removal of the outer-frame vertical connection (Figure 13) considerably decreased the load on the other frame member (9.5 to 15.4 lbf). The large deflection of the outer edge of the platform (Figure 13) and the large load input to the outer framework (Figure 11) suggested the need for a stronger strut design. Concept-evaluation models PE-I and PE-K (Figures 14 and 16) were iterations of the platform-strut dimension in an attempt to minimize the conditions mentioned.

Figure 12 shows that use of the hydrazine system to support the platform tended to reduce the loading on the outer framework as well as the platform deflection; however, the final configuration reflected the philosophy that the hydrazine system should be a self-supporting independent system with no significant impact on the rest of the structure. For example, vibrations initiated at the area of the hydrazine system would under the latter support arrangement load up the solar array; this unacceptable condition could be negated only by removing any structural support of the outer framework by the hydrazine system.

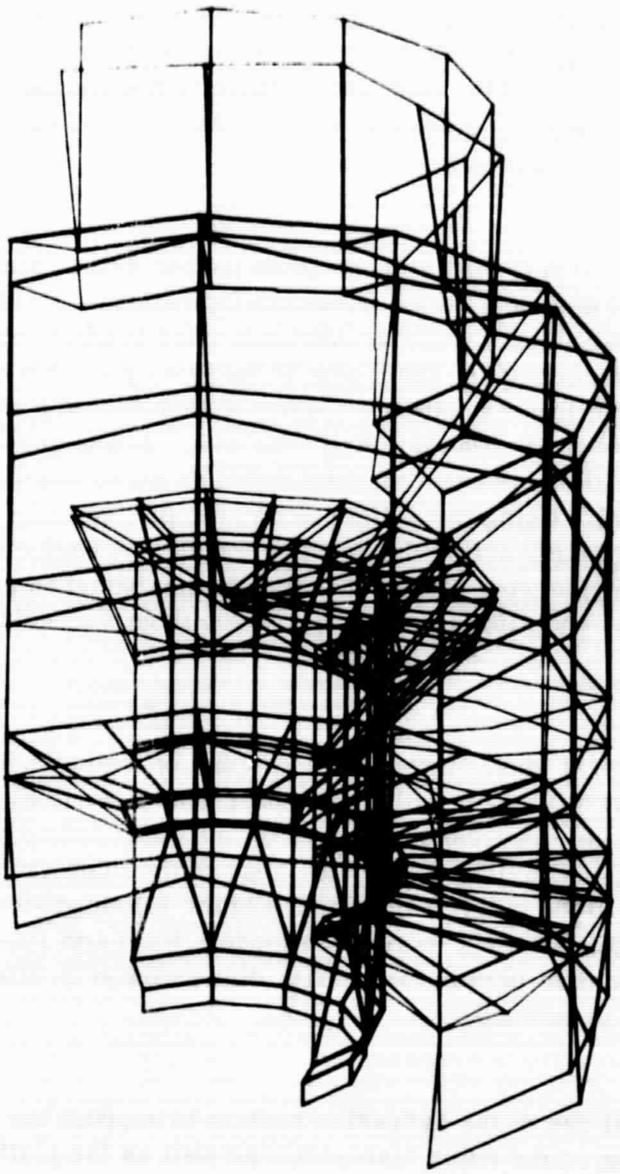


Figure 9. PE Concept-Evaluation Model with Static Deformation

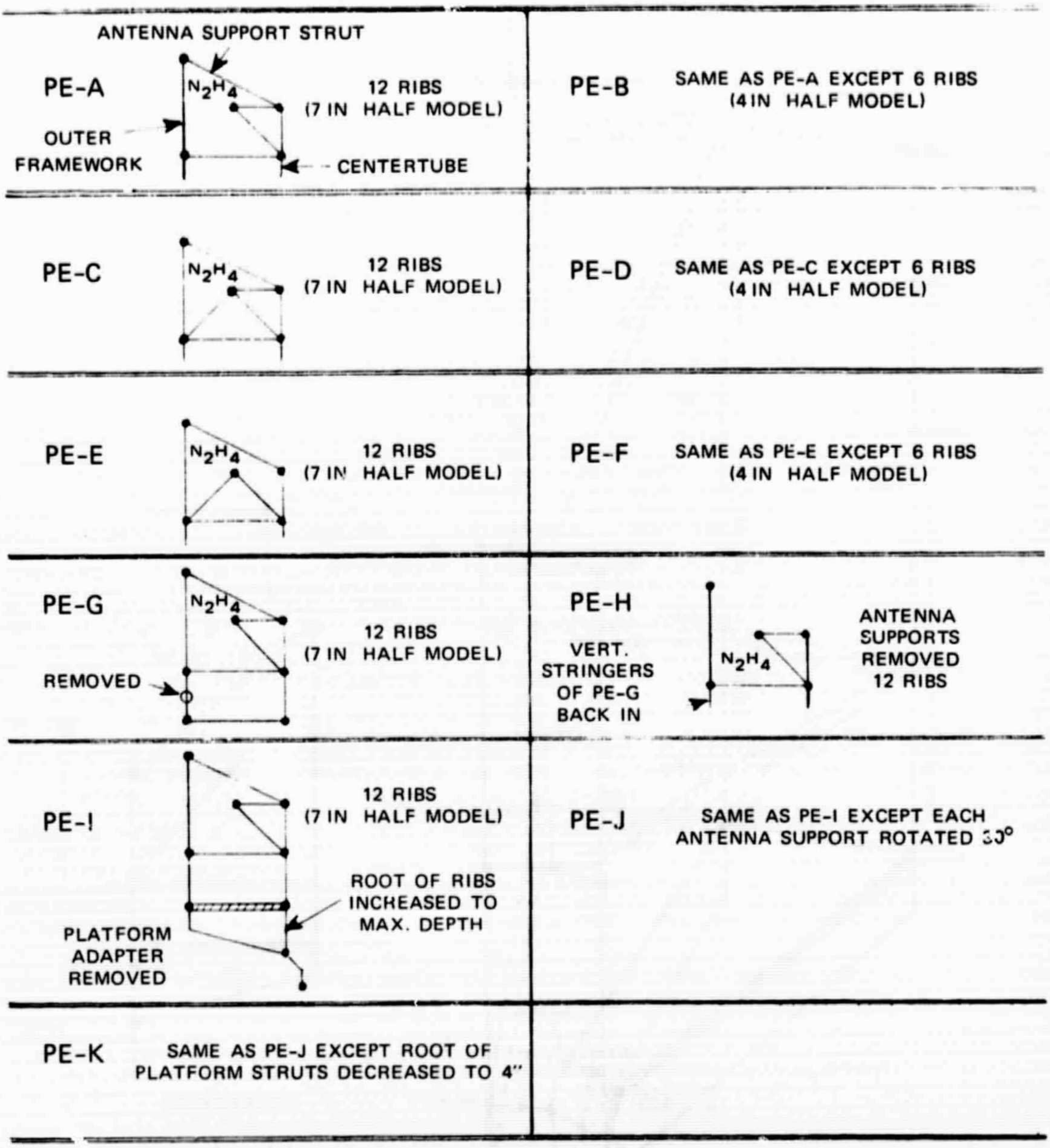


Figure 10. PE Concept-Evaluation Models Used in Study

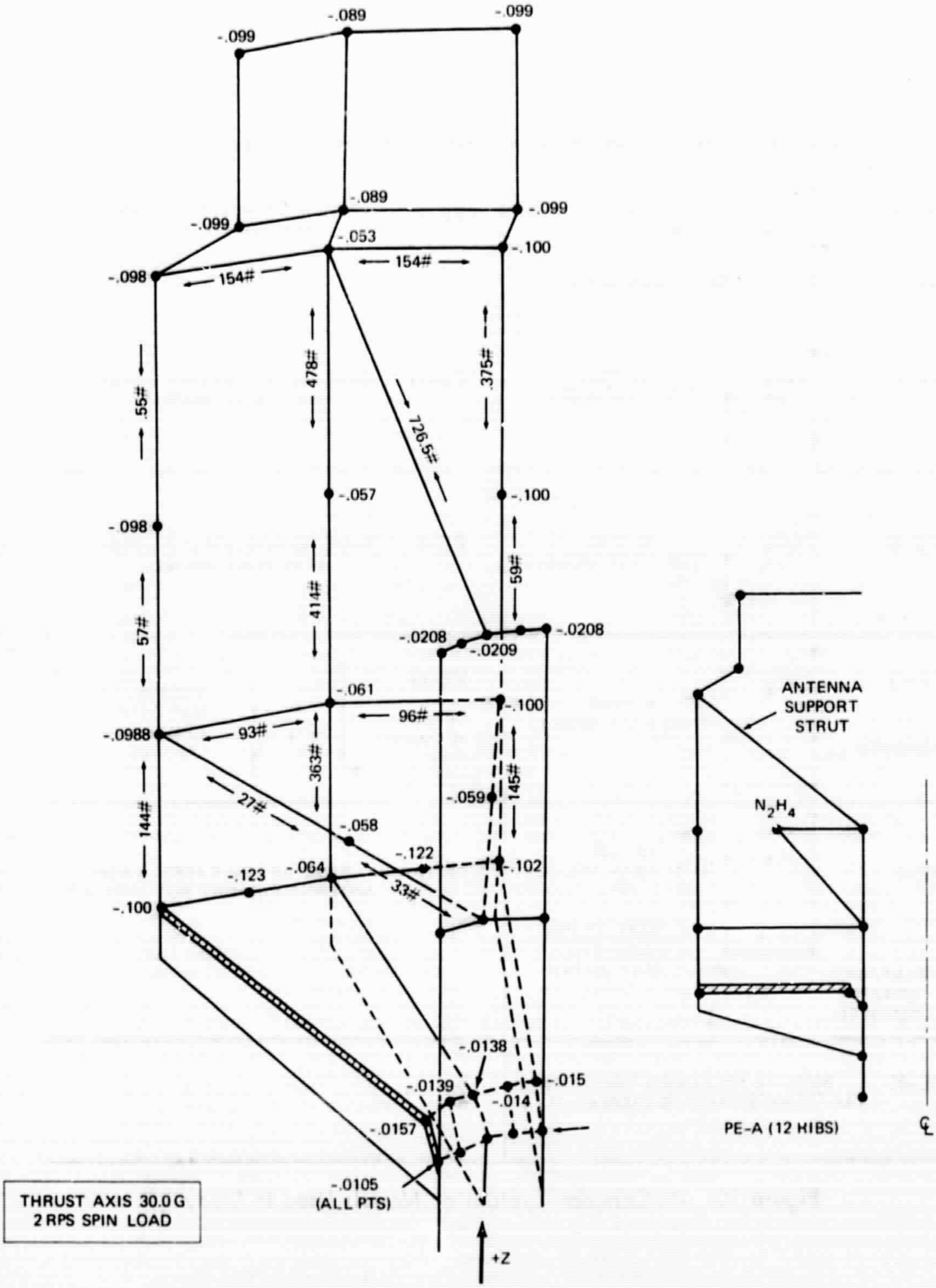


Figure 11. Planetary Explorer Model, Configuration A

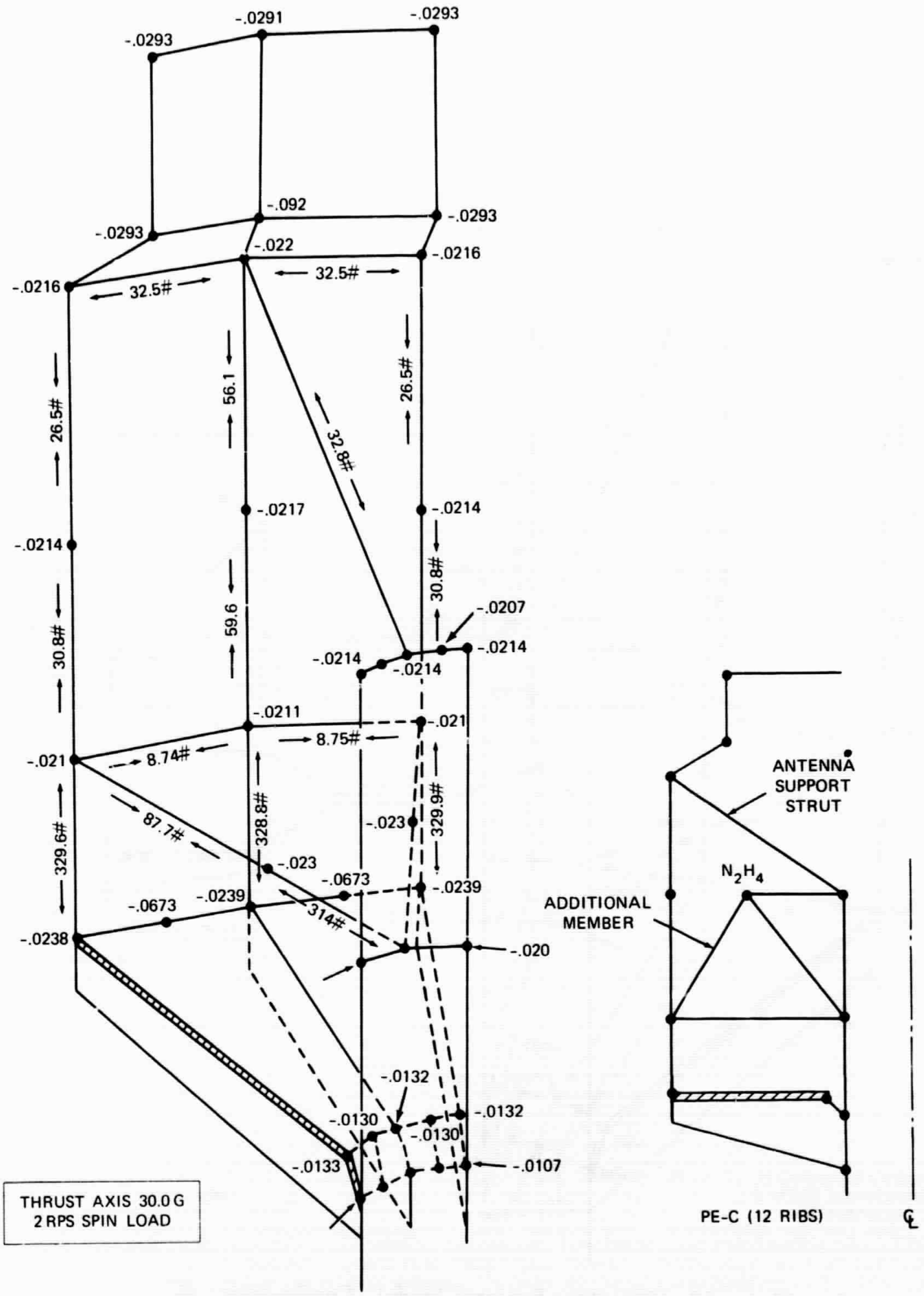


Figure 12. Planetary Explorer Model, Configuration C

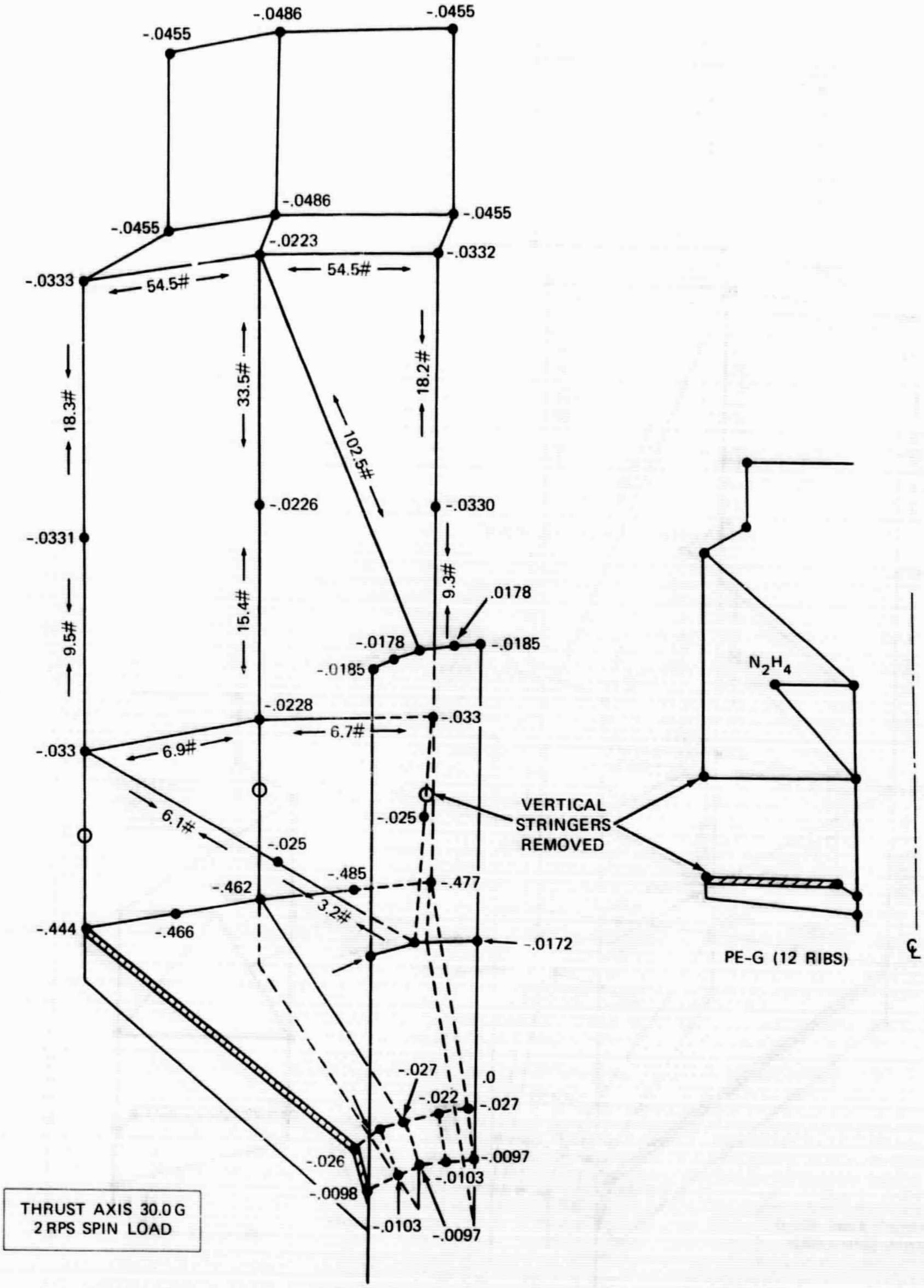


Figure 13. Planetary Explorer Model, Configuration G

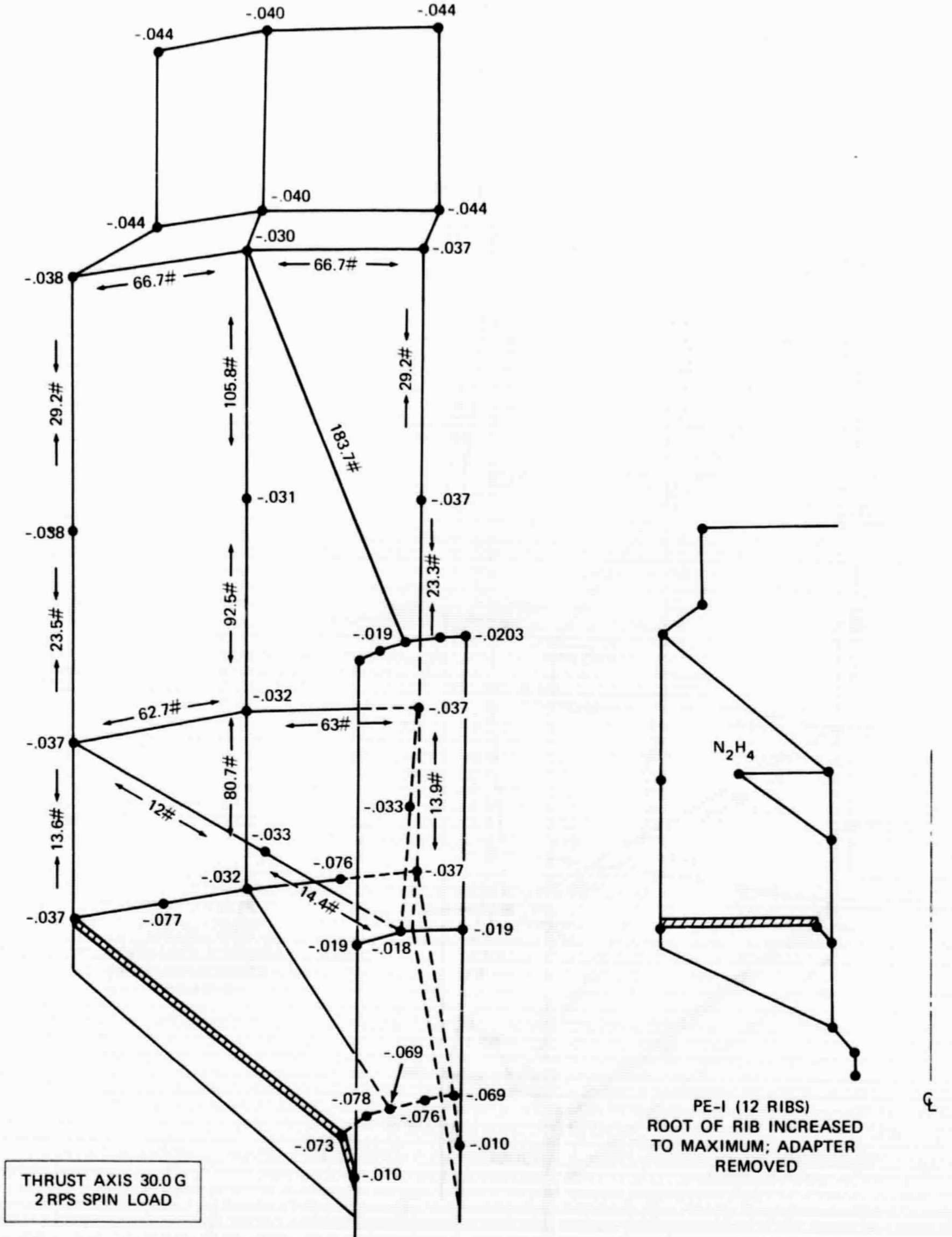


Figure 14. Planetary Explorer Model, Configuration I

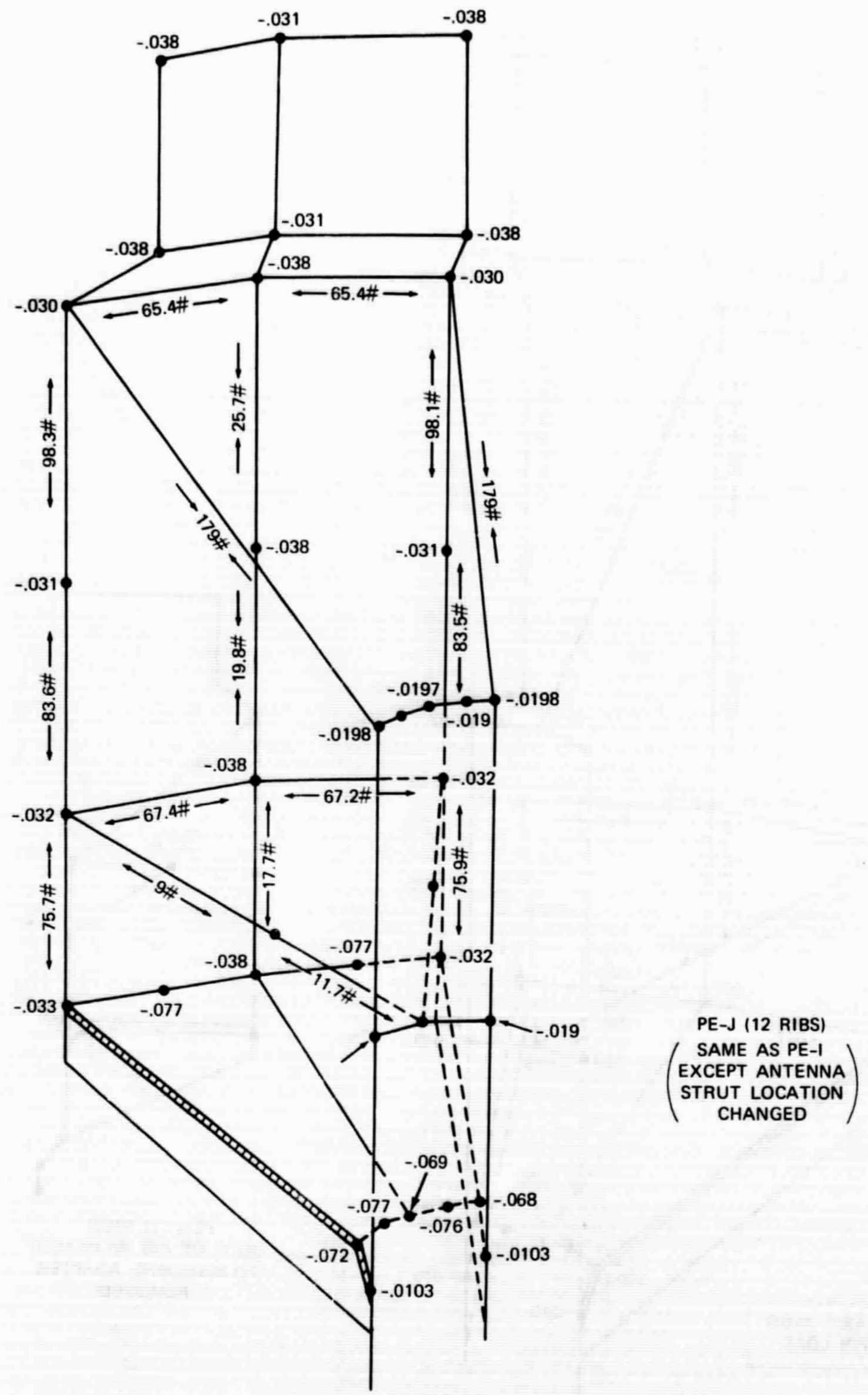
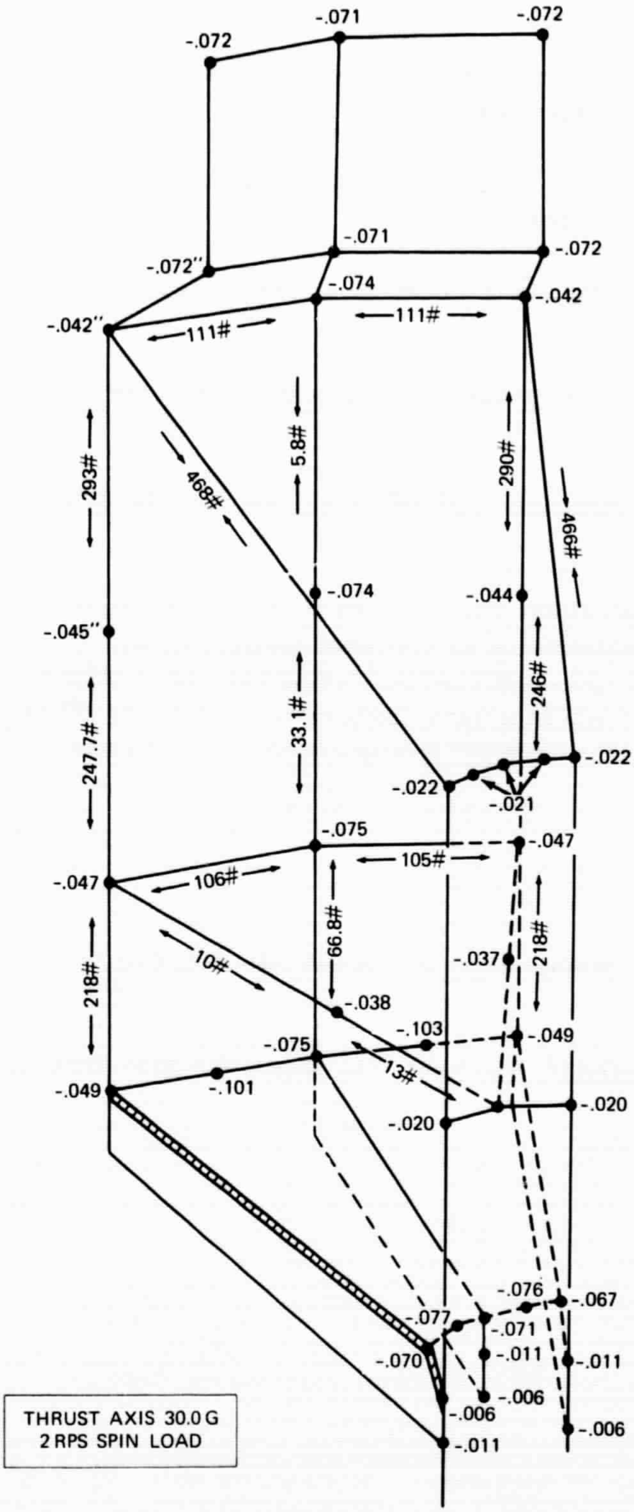


Figure 15. Planetary Explorer Model, Configuration J



PE-K
SAME AS PE-J
EXCEPT ROOT DEPTH
DECREASED TO 4 INCHES

Figure 16. Planetary Explorer Model, Configuration K

CONCLUSION

Figures 16 and 17 show the final structural configuration recommended for the Planetary Explorer, with the following characteristics:

- Twelve platform-support struts with root dimensions of approximately 4 inches, positioned as shown in Figure 16

- Six antenna-support struts directly above every other platform-support strut, as shown in Figure 16

- Removal of the platform-adapter ring connecting the platform to the centertube

- Adequacy of the cross section and size of all other members of the concept drawing

NASTRAN was most useful in this evaluation, where relative effects of structural changes were the criteria for establishing an optimum configuration. NASTRAN analysis accomplished in 3 months a task that would have been almost impossible to perform by hand calculation in a much longer period of time. With only slight modifications, the model can serve for a future study amounting to a complete dynamic analysis.

SOURCE

NASTRAN User's Manual. Caleb W. McCormick, ed. NASA SP-222, October 1969

NASTRAN Theoretical Manual. Richard H. MacNeal, ed. NASA SP-221, 1970

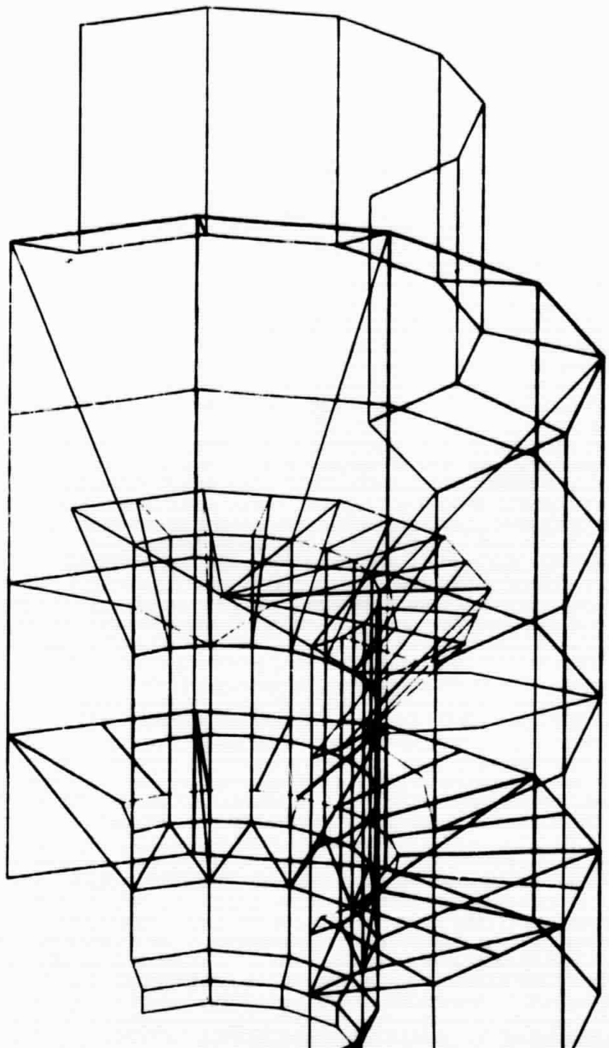


Figure 17. Planetary Explorer Model, Final Configuration

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APPENDIX

LISTING OF INPUT CARDS FOR CONCEPT EVALUATION MODEL PE-A

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```
$ PLANETARY EXPLORER - CONCEPT EVALUATION MODEL
ID PEMODEL1.RUNPEH-1
APP DISPLACEMENT
SOL 1.0
TIME 9
ALTER 5
TABPT GPL....// $
ENDALTER
CEND
TITLE # PLANETARY EXPLORER. CONCEPT EVALUATION MODEL
  SPC#1
OUTPUT
  OLOAD # ALL
  DISP # ALL
  ELFORCE # ALL
  STRESS # ALL
  SPCFORCE # ALL
SUBCASE 1
SUBTITLE# THRUST AXIS 30.0 G LOAD   2 RPS SPIN LOAD
  LOAD # 100
PLOTID # PE CONCEPT EVALUATION MODEL STATIC ANAYLIS
OUTPUT%PLOT<
PLOTTER SC
MAXIMUM DEFORMATION 4.
SET 1 INCLUDE ALL
FIND SCALE.ORIGIN 1.SET 1
PLOT STATIC DEFORMATIONS 0.SET 1.ORIGIN 1
PLOT STATIC DEFORMATIONS 1.SET 1.ORIGIN 1.SHAPE
VIEW 90.0.0.0.0.0
FIND SCALE.ORIGIN 1.SET 1
PLOT STATIC DEFORMATIONS 0.SET 1.ORIGIN 1
PLOT STATIC DEFORMATIONS 1.SET 1.ORIGIN 1.SHAPE
BEGIN BULK
$ GRID CARDS
CORD2C  1       0       0.0     0.0     0.0     0.0     0.0     1.0     &CORD2C2
&CORD2C21.0     0.0     1.0
GRID    10      1       16.0    0.0     63.272  1
GRID    11      1       16.0    30.0    63.272  1
GRID    12      1       16.0    60.0    63.272  1
GRID    13      1       16.0    90.0    63.272  1
GRID    14      1       16.0    120.0   63.272  1
GRID    15      1       16.0    150.0   63.272  1
GRID    16      1       16.0    180.0   63.272  1
GRID    20      1       16.0    0.0     48.272  1
GRID    21      1       16.0    30.0    48.272  1
GRID    22      1       16.0    60.0    48.272  1
GRID    23      1       16.0    90.0    48.272  1
GRID    24      1       16.0    120.0   48.272  1
GRID    25      1       16.0    150.0   48.272  1
GRID    26      1       16.0    180.0   48.272  1
GRID    30      1       23.5    0.0     46.272  1
GRID    31      1       23.5    30.0    46.272  1
GRID    32      1       23.5    60.0    46.272  1
GRID    33      1       23.5    90.0    46.272  1
GRID    34      1       23.5    120.0   46.272  1
GRID    35      1       23.5    150.0   46.272  1
GRID    36      1       23.5    180.0   46.272  1
GRID    40      1       23.5    0.0     34.740  1
GRID    41      1       23.5    30.0    34.740  1
GRID    42      1       23.5    60.0    34.740  1
```

GRID	43	1	23.5	90.0	34.740	1
GRID	44	1	23.5	120.0	34.740	1
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GRID	46	1	23.5	180.0	34.740	1
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GRID	67	1	22.6992	105.0	13.275	1
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GRID	69	1	22.6992	135.0	13.275	1
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GRID	74	1	23.5	120.0	3.684	1
GRID	75	1	23.5	150.0	3.684	1
GRID	76	1	23.5	180.0	3.684	1
GRID	80	1	9.77	0.0	31.0	1
GRID	81	1	9.77	15.0	31.0	1
GRID	82	1	9.77	30.0	31.0	1
GRID	83	1	9.77	45.0	31.0	1
GRID	84	1	9.77	60.0	31.0	1
GRID	85	1	9.77	75.0	31.0	1
GRID	86	1	9.77	90.0	31.0	1
GRID	530	1	16.5	15.0	23.52	1
GRID	534	1	16.5	135.0	23.52	1
GRID	533	1	16.5	105.0	23.52	1
GRID	87	1	9.77	105.0	31.0	1
GRID	88	1	9.77	120.0	31.0	1
GRID	89	1	9.77	135.0	31.0	1
GRID	891	1	9.77	150.0	31.0	1
GRID	892	1	9.77	165.0	31.0	1
GRID	893	1	9.77	180.0	31.0	1
GRID	90	1	9.77	0.0	23.52	1
GRID	91	1	9.77	15.0	23.52	1
GRID	92	1	9.77	30.0	23.52	1
GRID	93	1	9.77	45.0	23.52	1
GRID	94	1	9.77	60.0	23.52	1
GRID	95	1	9.77	75.0	23.52	1
GRID	96	1	9.77	90.0	23.52	1
GRID	97	1	9.77	105.0	23.52	1
GRID	98	1	9.77	120.0	23.52	1
GRID	99	1	9.77	135.0	23.52	1
GRID	991	1	9.77	150.0	23.52	1
GRID	992	1	9.77	165.0	23.52	1
GRID	993	1	9.77	180.0	23.52	1

GRID	100	1	9.77	0.0	11.713	1	
GRID	101	1	9.77	15.0	11.713	1	
GRID	102	1	9.77	30.0	11.713	1	
GRID	103	1	9.77	45.0	11.713	1	
GRID	104	1	9.77	60.0	11.713	1	
GRID	106	1	9.77	90.0	11.713	1	
GRID	105	1	9.77	75.0	11.713	1	
GRID	107	1	9.77	105.0	11.713	1	
GRID	108	1	9.77	120.0	11.713	1	
GRID	109	1	9.77	135.0	11.713	1	
GRID	1091	1	9.77	150.0	11.713	1	
GRID	1092	1	9.77	165.0	11.713	1	
GRID	1093	1	9.77	180.0	11.713	1	
GRID	110	1	11.0	0.0	13.275	1	
GRID	111	1	11.0	15.0	13.275	1	
GRID	112	1	11.0	30.0	13.275	1	
GRID	113	1	11.0	45.0	13.275	1	
GRID	114	1	11.0	60.0	13.275	1	
GRID	115	1	11.0	75.0	13.275	1	
GRID	116	1	11.0	90.0	13.275	1	
GRID	117	1	11.0	105.0	13.275	1	
GRID	118	1	11.0	120.0	13.275	1	
GRID	119	1	11.0	135.0	13.275	1	
GRID	1191	1	11.0	150.0	13.2	1	
GRID	1192	1	11.0	165.0	13.2	1	
GRID	1193	1	11.0	180.0	13.2	1	
GRID	130	1	8.73	0.0	1.5	1	
GRID	131	1	8.73	30.0	1.5	1	
GRID	132	1	8.73	60.0	1.5	1	
GRID	133	1	8.73	90.0	1.5	1	
GRID	134	1	8.73	120.0	1.5	1	
GRID	135	1	8.73	150.0	1.5	1	
GRID	136	1	8.73	180.0	1.5	1	
GRID	140	1	8.73	0.0	0.0	1	
GRID	141	1	8.73	30.0	0.0	1	
GRID	142	1	8.73	60.0	0.0	1	
GRID	143	1	8.73	90.0	0.0	1	
GRID	144	1	8.73	120.0	0.0	1	
GRID	145	1	8.73	150.0	0.0	1	
GRID	146	1	8.73	180.0	0.0	1	
GRID	150	1	9.77	0.0	17.4815	1	
GRID	151	1	9.77	15.0	17.4815	1	
GRID	152	1	9.77	30.0	17.4815	1	
GRID	153	1	9.77	45.0	17.4815	1	
GRID	154	1	9.77	60.0	17.4815	1	
GRID	155	1	9.77	75.0	17.4815	1	
GRID	156	1	9.77	90.0	17.4815	1	
GRID	157	1	9.77	105.0	17.4815	1	
GRID	158	1	9.77	120.0	17.4815	1	
GRID	159	1	9.77	135.0	17.4815	1	
GRID	160	1	9.77	150.0	17.4815	1	
GRID	161	1	9.77	165.0	17.4815	1	
GRID	162	1	9.77	180.0	17.4815	1	
GRID	400	1	23.5	0.0	500.0	1	123456
GRID	401	1	23.5	30.0	500.0	1	123456
GRID	402	1	23.5	60.0	500.0	1	123456
GRID	403	1	23.5	90.0	500.0	1	123456
GRID	404	1	23.5	120.0	500.0	1	123456
GRID	405	1	23.5	150.0	500.0	1	123456
GRID	406	1	23.5	180.0	500.0	1	123456

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GRID	510	1	16.625	0.0	31.0	1		
GRID	511	1	15.98	15.0	31.0	1		
GRID	512	1	16.625	30.0	31.0	1		
GRID	513	1	15.98	45.0	31.0	1		
GRID	514	1	16.625	60.0	31.0	1		
GRID	515	1	15.98	75.0	31.0	1		
GRID	516	1	16.625	90.0	31.0	1		
GRID	517	1	15.98	105.0	31.0	1		
GRID	518	1	16.625	120.0	31.0	1		
GRID	519	1	15.98	135.0	31.0	1		
GRID	520	1	16.625	150.0	31.0	1		
GRID	521	1	15.98	165.0	31.0	1		
GRID	522	1	16.625	180.0	31.0	1		
GRID	531	1	16.5	45.0	23.52	1		
GRID	532	1	16.5	75.0	23.52	1		
GRID	535	1	16.5	165.0	23.52	1		
GRID	170	1	9.77	0.0	3.062	1		
GRID	171	1	9.77	30.0	3.062	1		
GRID	172	1	9.77	60.0	3.062	1		
GRID	173	1	9.77	90.0	3.062	1		
GRID	174	1	9.77	120.0	3.062	1		
GRID	175	1	9.77	150.0	3.062	1		
GRID	176	1	9.77	180.0	3.062	1		
GRID	120	1	9.77	0.0	7.713	1		
GRID	121	1	9.77	30.0	7.713	1		
GRID	122	1	9.77	60.0	7.713	1		
GRID	123	1	9.77	90.0	7.713	1		
GRID	124	1	9.77	120.0	7.713	1		
GRID	125	1	9.77	150.0	7.713	1		
GRID	126	1	9.77	180.0	7.713	1		
SEQGP	10	1	20	2	30	3	40	4
SEQGP	50	5	60	6	61	7	70	8
SEQGP	530	9	80	10	81	11	90	12
SEQGP	91	13	150	14	151	15	100	16
SEQGP	101	17	110	18	111	19	120	20
SEQGP	130	21	140	22	510	23	511	24
SEQGP	11	25	21	26	31	27	41	28
SEQGP	51	29	62	30	63	31	71	32
SEQGP	531	33	82	34	83	35	92	36
SEQGP	93	37	152	38	153	39	102	40
SEQGP	103	41	112	42	113	43	121	44
SEQGP	131	45	141	46	512	47	513	48
SEQGP	12	49	22	50	32	51	42	52
SEQGP	52	53	64	54	65	55	72	56
SEQGP	532	57	84	58	85	59	94	60
SEQGP	95	61	154	62	155	63	104	64
SEQGP	105	65	114	66	115	67	122	68
SEQGP	132	69	142	70	514	71	515	72
SEQGP	13	73	23	74	33	75	43	76
SEQGP	53	77	66	78	67	79	73	80
SEQGP	533	81	86	82	87	83	96	84
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SEQGP	107	89	116	90	117	91	123	92
SEQGP	133	93	143	94	516	95	517	96
SEQGP	14	97	24	98	34	99	44	100
SEQGP	54	101	68	102	69	103	74	104
SEQGP	534	105	88	106	89	107	98	108
SEQGP	99	109	158	110	159	111	108	112
SEQGP	109	113	118	114	119	115	124	116

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SEQGP   134     117     144     118     518     119     519     120
SEQGP   15      121     25      122     35      123     45      124
SEQGP   55      125     691     126     692     127     75      128
SEQGP   535     129     891     130     892     131     991     132
SEQGP   992     133     160     134     161     135     1091    136
SEQGP   1092    137     1191    138     1192    139     125     140
SEQGP   135     141     145     142     520     143     521     144
SEQGP   16      145     26      146     36      147     46      148
SEQGP   56      149     693     150     76      151
SEQGP   893     153     993     154     162     155     1093    156
SEQGP   1193    157     126     158     136     159     146     160
SEQGP   522     161     500     162
SEQGP   170     20.1    171     44.1    172     68.1    173     92.1
SEQGP   174     116.1   175     140.1   176     158.1
$ CONNECTION CARDS
CQUAD2  440     9       20      21      11      10
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CQUAD2  442     9       22      23      13      12
CQUAD2  443     9       23      24      14      13
CQUAD2  444     9       24      25      15      14
CQUAD2  445     9       25      26      16      15
CQUAD2  386     8       20      21      31      30
CQUAD2  387     8       21      22      32      31
CQUAD2  388     8       22      23      33      32
CQUAD2  389     8       23      24      34      33
CQUAD2  390     8       24      25      35      34
CQUAD2  391     8       25      26      36      35
CBAR    374     6       30      31      401                     2
CBAR    375     6       31      32      402                     2
CBAR    376     6       32      33      403                     2
CBAR    377     6       33      34      404                     2
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CBAR    420     7       40      50      80                      2
CBAR    421     7       41      51      82                      2
CBAR    422     7       42      52      84                      2
CBAR    423     7       43      53      86                      2
CBAR    424     7       44      54      88                      2
CBAR    425     7       45      55      891                     2
CBAR    426     7       46      56      893                     2
CBAR    427     7       30      40      80                      2
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CBAR    380     6       50      51      401                     2
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CBAR    385     6       55      56      406                     2
CBAR    407     7       70      60      100                     2
CBAR    408     7       62      71      103                     2
CBAR    409     7       64      72      105                     2
CBAR    410     7       66      73      107                     2
CBAR    411     7       68      74      109                     2
CBAR    412     7       691     75      1092                    2
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CBAR	392	6	70	71	401		2
CBAR	393	6	71	72	402		2
CBAR	394	6	72	73	403		2
CBAR	395	6	73	74	404		2
CBAR	396	6	74	75	405		2
CBAR	397	6	75	76	406		2
CQUAD1	446	10	30	31	41	40	
CQUAD1	447	10	31	32	42	41	
CQUAD1	448	10	32	33	43	42	
CQUAD1	449	10	33	34	44	43	
CQUAD1	450	10	34	35	45	44	
CQUAD1	451	10	35	36	46	45	
CQUAD1	462	10	40	41	51	50	
CQUAD1	463	10	41	42	52	51	
CQUAD1	464	10	42	43	53	52	
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CQUAD1	467	10	45	46	56	55	
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CQUAD1	457	10	62	64	72	71	
CQUAD1	458	10	64	66	73	72	
CQUAD1	459	10	66	68	74	73	
CQUAD1	460	10	68	691	75	74	
CQUAD1	461	10	691	693	76	75	
CBAR	515	15	500	80	30		2
CBAR	516	15	500	82	31		2
CBAR	517	15	500	84	32		2
CBAR	518	15	500	86	33		2
CBAR	519	15	500	88	34		2
CBAR	520	15	500	891	35		2
CBAR	521	15	500	893	36		2
CQUAD2	362	2	80	81	91	90	
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CQUAD2	364	2	82	83	93	92	
CQUAD2	365	2	83	84	94	93	
CQUAD2	366	2	84	85	95	94	
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CQUAD2	368	2	86	87	97	96	
CQUAD2	369	2	87	88	98	97	
CQUAD2	370	2	88	89	99	98	
CQUAD2	371	2	89	891	991	99	
CQUAD2	372	2	891	892	992	991	
CQUAD2	373	2	892	893	993	992	
CQUAD2	486	2	90	91	151	150	
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CQUAD2	503	2	155	156	106	105			
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CQUAD2	506	2	158	159	109	108			
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CQUAD1	338	5	110	111	61	60			
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CQUAD1	345	5	117	118	68	67			
CQUAD1	346	5	118	119	69	68			
CQUAD1	347	5	119	1191	691	69			
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CQUAD1	349	5	1192	1193	693	692			
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CBAR	414	7	51	62	112			2	
CBAR	415	7	52	64	114			2	
CBAR	416	7	53	66	116			2	
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CBAR	418	7	55	691	1191			2	
CBAR	419	7	56	693	1193			2	
CBAR	508	14	60	110	80			2	&CBAR9
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CBAR	510	14	64	114	84			2	&CBAR11
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CTRIA2	476	3	109	1091	125	0.0			
CTRIA2	477	3	1091	1092	125	0.0			
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CTRIA2	479	3	1092	1093	126	0.0			
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CQUAD2	304	1	134	135	145	144	
CQUAD2	305	1	135	136	146	145	
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CBAR	551	16	511	512	81		2
CBAR	552	16	512	513	82		2
CBAR	553	16	513	514	83		2
CBAR	554	16	514	515	84		2
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CBAR	556	16	516	517	86		2
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CBAR	564	15	82	512	513		2
CBAR	565	15	83	513	514		2
CBAR	566	15	84	514	515		2
CBAR	567	15	85	515	516		2
CBAR	568	15	86	516	517		2
CBAR	569	15	87	517	518		2
CBAR	570	15	88	518	519		2
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CBAR	601	17	96	533	53		2
CBAR	602	17	533	54	53		2
CBAR	603	17	54	534	55		2
CBAR	604	17	534	991	993		2
CBAR	605	17	991	535	55		2
CBAR	606	17	535	56	55		2
CQUAD2	306	1	170	171	131	130	
CQUAD2	307	1	171	172	132	131	
CQUAD2	308	1	172	173	133	132	
CQUAD2	309	1	173	174	134	133	
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CQUAD2	311	1	175	176	136	135	

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CQUAD2  510     2       170     171     121     120
CQUAD2  511     2       171     172     122     121
CQUAD2  512     2       172     173     123     122
CQUAD2  513     2       173     174     124     123
CQUAD2  514     2       174     175     125     124
CQUAD2  515     2       175     176     126     125
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CBAR    702     14      62      121     82                      2       &CBARU
&CBARU                  0.0     0.0     -1.587  0.0     0.0     0.0
CBAR    704     14      64      122     84                      2       &CBARW
&CBARW                  0.0     0.0     -1.587  0.0     0.0     0.0
CBAR    706     14      66      123     86                      2       &CBARY
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CBAR    708     14      68      124     88                      2       &CBARUU
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CBAR    710     14      691     125     891                     2       &CBARWW
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CBAR    712     14      693     126     893                     2       &CBARYY
&CBARYY                 0.0     0.0     -1.587  0.0     0.0     0.0
CBAR    630     19      80      30      400                     2
CBAR    631     18      84      32      402                     2
CBAR    632     18      88      34      404                     2
CBAR    634     19      893     36      406                     2
CBAR    325     14      100     110     80                      2       &CBARA
&CBARA                  0.0     0.0     1.562   0.0     0.0     -.275
CBAR    327     14      102     112     82                      2       &CBARC
&CBARC                  0.0     0.0     1.562   0.0     0.0     -.275
CBAR    329     14      104     114     84                      2       &CBARE
&CBARE                  0.0     0.0     1.562   0.0     0.0     -.275
CBAR    331     14      106     116     86                      2       &CBARG
&CBARG                  0.0     0.0     1.562   0.0     0.0     -.275
CBAR    333     14      108     118     88                      2       &CBARI
&CBARI                  0.0     0.0     1.562   0.0     0.0     -.275
CBAR    335     14      1091    1191    891                     2       &CBARK
&CBARK                  0.0     0.0     1.562   0.0     0.0     -.275
CBAR    337     14      1093    1193    893                     2       &CBARM
&CBARM                  0.0     0.0     1.562   0.0     0.0     -.275
$ PROPERTY CARDS
PBAR    14      8       .0375    1.76-3 4.76-3                          &PBAR1
&PBAR1    .375    0.0   0.0      .025   0.0     -.025   0.0     0.0
PQUAD2  1       3        .49
PQUAD2  2       4       .040                    4       3       .040
PTRIA2  3       4       .080
PQUAD1  5              1 .016           1.001062        2.5     .195    &P1
&P1     0.25    -0.25
PBAR    6       9       .04595  7416.-6 3096.-10                        &PBAR2
&PBAR2   0.0     .609   0.0     -.609    .016   0.0     -.016   0.0
PBAR    7       9       .121    3857.-5 2046.-6                         &PBAR4
&PBAR4  0.0     0.0     .125    0.0     -.125   0.0     .267    1.0
PQUAD2  8       4        .026
PQUAD2  9       5        .040   495.-5
PQUAD1  10      7       .001    7       966.-9  6       .125            &PQUAD12
&PQUAD12 .0655  -.0655
PQUAD2  11      3        .040
PBAR    12      8       .0625   325559-51302.-8                         &PBAR3
&PBAR3   .025     0.0   0.0      .625   0.0     1.25    0.0     -.025
PQUAD2  13      3        .094           2       4        .040
PBAR    15      10      4.0      1.33   1.333   2.6                     &PBAR10
&PBAR10  .5      0.0    -.5      0.0     0.0    .5       0.0    -.5
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PBAR    16      10      64.0    341.3   341.3   50.0    1.33
PBAR    17      9       .0725   .87194  .006358                         &PBAR20
&PBAR20 0.0     .625    0.0     0.0     -.375
PBAR    18      9       .129168 .051042 .004586                         &PBAR21
&PBAR21 0.0     -.625   0.0     -1.25   .5      0.0
PBAR    19      9       .064584 .025521 .002293                         &PBAR22
&PBAR22 0.0     -.625   0.0     -1.25   .5      0.0
$ MATERIAL CARDS
MAT1    1       10.E6           .3      .100    12.9-6  68.             &M1
&M1     70.E3   70.E3   41.E3
MAT1    2       100.0   14000.          .001331 12.9-6  68.             &M2
&M2     10.0    140.0   14000.
MAT1    3       6.5E6   2.4E6   .35     .064    14.-6   68.             &M3
&M3     22.E3   16.E3   21.E3
MAT1    4       10.5E6  4.0E6   .33     .10     128.-7  68.0            &MAT14
&MAT14  64.E3   37.E3   39.E3
MAT1    5       10.5E6  4.0E6   .33     0.0     128.-7  68.0            &MAT17
&MAT17  64.E3   37.E3   39.E3
MAT1    6       35.6    20.E3           .0018   12.9-6  68.0            &MAT11
&MAT11  10.0    250.0   20.E3
MAT1    7       2.E6            .3      .07     14.-6   68.0
MAT1    8       6.5E6   2.4E6           .0659   14.-6   68.0            &MAT15
&MAT15  36.E3   30.E3   22.E3
MAT1    9       9.9E6   3.8E6   .33     .098    13.-6   68.0            &MAT16
&MAT16  36.E3   35.E3   27.E3
MAT1    10      90.E6           .3              30.-6   68.0
PARAM   WTMASS  .00259
PARAM   GRDPNT  500
$ SINGLE POINT CONSTRAINT CARDS
SPC1    1       246     10      20      30      40      50      60      &SPC12
&SPC12  70      80      90      100     110     120     130     16      &SPC13
&SPC13  26      36      46      56      693     76      893     993     &SPC14
&SPC14  1093    1193    126     136     510     150     162     522     &SPC22
&SPC22  170     176
SPC1    1       123456  140     141     142     143     144     145     &SPC15
&SPC15  146
SPC1    1       6       61      63      65      67      69      692     &SPC555
&SPC555 111     113     115     117
GRAV    700     1       385.76  0.0     0.0     -1.0
GRAV    701     1       385.76  1.0     0.0     0.0
GRAV    702     1       385.76  -1.0    0.0     0.0
GRAV    703     1       385.76  0.0     0.0     1.0
CONM2   500     500     1       210.    0.0     0.0     -6.327          &500
&500    31443.5 0.0     31443.5 0.0     0.0     8930.5
RFORCE  800     500     1       2.0     0.0     0.0     1.0
LOAD    100     1.0     30.0    700     1.0     800
LOAD    200     1.0     20.0    703     .25     800
ENDDATA
/*
                                                                      0589 CARDS
```