MSC/NASTRAN Model Checkout

Structures and Dynamics
Development Group
and
Structures and Dynamics
Technology Group
Applied Technology Division
Jet Propulsion Laboratory
Pasadena, California

Presented at the
MSC/NASTRAN User's Conference
March 20-21, 1986
Universal City, California

MSC/NASTRAN Model Checkout

Abstract

This paper describes a procedure for systematically checking and verifying a NASTRAN finite element model. Various methods and levels of model checkout are used at the Jet Propulsion Laboratory (JPL) and all of them are combined in this paper to ensure that the models are consistent, mathematically well-conditioned, and documented. Some of the techniques presented are:

- 1G XYZ Gravity Loads (with guidelines for Epsilon, Max Ratio, and SPC forces and moments)
- Stiffness Matrix Equilibrium Check
- Rigid Body Displacements
- Modal Identification
- Thermal Test Cases

Examples from current projects at JPL, such as the Galileo spacecraft and the Wide Field/Planetary Camera for the Space Telescope, will be utilized to describe the implementation of these methods.

ACKNOWLEDGEMENT

The editors of this document are: Frank Tillman and Robert Galletly of JPL and John Zins, consultant.

The editors wish to acknowledge the significant contribution of the following: R. Bamford of JPL for the development of modal parameters; M. Trubert of JPL for the development of effective mass checks and criteria for modal truncation; M. Salama of JPL for development of the original JPL DMAP routine for MER; T. Rose of JPL for the development of the DMAP routines for Rigid Body Displacements, MER-MREMER-MR-EFMASS, and ALTERS to Solution 3; Swales and Associates, Beltsville, MD, for providing the equilibrium check given in this document; K. Volkert, formerly of JPL, for the identification and implementation of NASTRAN model checks; R. Calvet of JPL and G. Wang, consultant, for the development of the JPL internal report enumerating NASTRAN model checks; J. Staats and T. O'Toole, consultants, for the critique and contributions to NASTRAN model checkout procedures; R. Royster, consultant, for proofreading and offering valuable advice during the preparation of this document.

No doubt there are many whom the editors have overlooked; to them we offer our apology.

NOMENCLATURE AND ACRONYMS

General

CG	Center of Gravity
D	Displacement
DOF	Degree of Freedom
FEM	Finite Element Model
FN	Natural Frequency
G	Gravitational Constant
KE	Kinetic Energy

NOMENCLATURE AND ACRONYMS (cont.)

NASTRAN Related

ALTER	DMAP Instruction
ASET	Analysis Set
AUTOSPC	Single-Point Constraint Generator
DMAP	Direct Matrix Abstraction Program
EFMASS	Effective Mass
EIGR	Eigenvalue Extraction Method
EPSILON	Rigid Body Error Ratio
EQEXIN	Table Correlating Internal and External Degrees of Freedom
FSET	Unconstrained (Free) Structural Coordinates
GDR	Generalized Dynamic Reduction
GRAV	Gravitational Constant
GRDPNT	Grid Point Used for Mass Properties Computation
KRBF	Geometric Reaction Forces
MAX RATIO	Ratio of Stiffness to Factor Diagonal
MPC	Multi-Point Constaint
PARAM	Parameter
RBAR	Rigid Bar Element
RBE	Rigid Body Element
SOL	Solution Sequence
SPC	Single-Point Constraint
TEMPD	Temperature Loading Card

INTRODUCTION

This paper outlines a procedure for systematically checking and documenting a finite element model. Currently many models that are generated at JPL are being transmitted to other agencies for subsequent analysis. Since these models have had various levels of analytical validation and documentation, this report combines various checkout procedures to ensure a uniform level of validation and documentation such that the models will be consistent and mathematically well-conditioned. These procedures, however, are not substitutes for the test verification phase of analysis. They are intended to remove modeling errors early in the design process, rather than during the test updating phase which occurs well after the hardware has been built.

The detailed check programming statements refer to the MSC/NASTRAN structural analysis program, but the overall checks are applicable to any finite element program.

MODEL CHECKOUT PROCEDURE

Once the finite element model is completed and all documentation, such as model schematics ("road maps") as well as material and geometric property calculations, is updated to the final model version, the following series of tests should be performed in order to validate the model. It is recommended that these tests be run on the model and subsystem models during the development stages as well.

Geometry Plots

Either the NASTRAN plotting package or other preprocessor graphics package should be used to obtain visual images of the finite element model from many views in such a way as to provide a clear representation of each element in at least one view and to verify overall geometry and placement of elements. Figure 1 shows the Galileo spacecraft finite element model and Figure 2 shows the Wide Field/Planetary Camera finite element model. A "shrink option" should be used if possible to make sure all elements are present (see Figure 3). This is particularly helpful when Bars or Beams are used to model stringers along the edges of plate elements. Discontinuities show up only with the shrink option.

Checkout Run RF24D32

A "checkout run" using the rigid format alter RF24D32 should be used to check connectivity and duplicate element numbering. Any duplicate numbering should be corrected so that errors with plot sets will not occur. The connectivity table does not include MPC's or rigid elements (RBE1, RBE2, RBE3, or RBAR). The checkout run also supplies all grid locations in basic coordinates and lists the lengths, areas, and volumes of all elements. Table 1 gives a listing of the parameters used and Tables 2 through 9 give examples of the output. These items can be useful for finding anomalies not apparent in plots.

Mass Distribution

PARAM GRDPNT uses the Grid Point Weight Generator, which gives the mass (by direction), the CG, the moments of inertia, and the principal moments of inertia and their direction cosines (see Table 10). Full use should be made of this diagnostic tool to correlate the model with existing hardware or mass properties calculations.

The Grid Point Weight Generator uses only the weight properties and geometry to calculate mass properties. The resultant mass properties are the rigid body mass properties. Note that PARAM WTMASS does not affect the GPWG output - it multiplies the mass matrix later in the program.

1G XYZ Gravity Loading

Static gravity loading can be helpful in checking out various properties of finite element models. Displacements, element forces, and support reactions (SPC forces) derived from 1G loading conditions provide a first check on mass, stiffness, and determinacy of supports. Weight and CG can be calculated from SPC forces which should also be compared to any applied loads or weight. Load paths can also be assessed using the element forces. Epsilon, Max Ratio, and SPC forces (at grids other than legitimate boundary conditions) describe the overall "health" of the stiffness matrix (see Tables 11 and 12).

Allowable values for these quantities are:

Epsilon* $\leq 1.0 \times 10^{-6}$ (large model)
$\leq 1.0 \times 10^{-9}$ (small model)
Max Ratio $\leq 1.0 \times 10^{+5}$
SPC Forces (at internal points) $\leq 1.0 \times 10^{-5}$ (model weight)
SPC Moments (at internal points) $\leq 1.0 \times 10^{-3}$ (model weight) x (unit length)

*Epsilon is machine dependent. The above data is for CDC 64-bit word. Other machines should give smaller numbers (1.0×10^{-8} and 1.0×10^{-11}). Mechanisms or symmetry conditions may require reevaluation of SPC force limits.

The 1G cases also provide a rough approximation of the frequency of the first mode. This can be accomplished by using the displacement (D) at the CG in the equation $FN \sim \frac{1}{2\pi}\sqrt{G/D}$.

If the model has no mass, forces and moments can be applied to generate displacements, element, and SPC forces. The magnitude and point of application of the forces should be representative of typical structural loading, thereby allowing the analyst a good "feel" for the size of displacements and forces as in the 1G cases. It is also helpful to use Element Strain Energy and Grid Point Force Balance with these runs. For information on these see Reference 1.

The 1G case can easily be obtained through the GRAV card. This is preferred over the inertia relief type method.

Equilibrium Check

Using solution 24 and the set of DMAP ALTERS shown in Table 13, an equilibrium check can be run to further validate the stiffness matrix. This check calculates the strain energy resulting from unit translations and rotations. The KRBF matrix (see Table 14) is printed out and is a measure of the force required for the "rigid" body displacements. All elements should be small, e.g.,

Diagonal Translations $<1.0 \times 10^{-2}$

Diagonal Rotations $<2.0 \times 10^{2}$

Off-Diagonal Terms $<2.0 \times 10^{2}$

Also printed is the matrix KRBFN, the forces at the grids normalized to a maximum of 1.0 (see Table 15). As seen from Table 15 this check easily identifies which grids and DOF's are causing problems.

All SUPORT's and SPC's should be removed. Include the following PARAM's in the bulk data: AUTOSPC, YES; EQEXIN, EQEXIN; GPL, GPL; SEQOUT, 1. The output from the AUTOSPC processor should be reviewed carefully (see Table 16 for example of AUTOSPC). This table will include all degrees of freedom which have no stiffness. Each degree of freedom should be checked and if correct should be SPC'd; if it is not correct, then the model must be improved.

Thermal Test Cases

As a further check on connectivity and the stiffness matrix, an isothermal expansion test case can be run with a statically determinate interface. This is done on SOL 24 with a TEMPD for the load. All of the coefficients of expansion should be set to the same value. This is useful for finding artificial stiffness imposed by rigid elements or bar offsets and is essential if the model is to be used for thermal distortion work. Rigid elements will not expand and may generate distortion forces and stresses unless the appropriate degrees of freedom are released. Other potential problem areas are nonrectangular shear panels and warped quadrilaterals (see Figure 4). These forces and stresses will identify the problem areas that need improving for thermal analysis.

Rigid Body Displacement

If the model is primarily used for dynamic analysis, there is a DMAP ALTER that performs an Equilibrium Check in Solution 3. In this case, the unit translations and rotations are considered to be the rigid body displacements of the structure in output coordinates about the SUPORT point. Strain energy, which should be very small, is calculated and printed out. The DMAP for this is shown in Table 17.

The strain energy, the Epsilons, and Max Ratio should also be checked at this point, as they were for the static case (see Table 18).

This ALTER is used with a SUPORT card. The DOF supported must form a determinate interface or high strain energy will result. The model displacements printed represent the displacements caused by moving a support DOF one unit while holding the other support DOF's fixed. The model displacements should be checked for unit values (see Table 19).

The ALTERS to allow the rigid body displacements to be printed in the model basic coordinate system rather than in the local grid displacement system are shown in Table 20.

Other useful ALTERS may be included in the same runstream. Please note that all ALTERS assume mass normalization on EIGR card.

Modal Analysis

One of the main uses of NASTRAN is dynamic analysis. There are several diagnostic tools which can be used to further assess the integrity of the model. These tools (effective mass, strain energy, kinetic energy, deformed plots) are outlined in the following paragraphs.

The ALTERS to obtain the elastic modes are shown in Table 20. The two major means of reducing the number of dynamic degrees of freedom in the modal analysis are outlined below.

A major concern in dynamic analysis is the choice of an appropriate ASET when using Guyan Reduction. The quality of the solution depends upon the reduced mass matrix formed by this ASET. Will it retain sufficient mass in correct distribution to adequately predict modeshapes and frequencies?

There are two rules of thumb to apply: (1) choose the largest masses and (2) choose the masses that are likely to have the largest displacements (the most energetic). The next step is to make a trial run and check the various diagnostics.

Another way to perform the modal analysis (and choose an ASET, if desired) is to use Generalized Dynamic Reduction. If this is done, the ALTERS 416 and 419 shown in Table 20 must be removed and the support point SPC'd. Although the MER matrix is not calculated, the ALTERS for doing so are shown in Table 21.

The results of a GDR run can be used to select an ASET for use in future processing if desired (see Figure 5 for flow chart). If this is the case, the DMAP ALTERS to calculate the kinetic energy (shown later) should be included in the run, along with the ALTERS given in Table 21 for MER. A proven rule-of-thumb for ASET selection is to include all DOF which have more than 2% of the system KE for all major modes (determined by comparing EFMASS to the system weight) and more than 5% for the other modes. One must be careful in the case of assemblies with a fine mesh; although the whole assembly may be moving in a mode, there may not be any individual DOF's with greater than 2% of the system kinetic energy. This is usually evident when a mode has a sizeable EFMASS, and either no terms with a large kinetic energy, or the terms with noticeable kinetic energy do not account for the EFMASS of the mode. If this is the case, then there is no substitute for common sense determination of DOF which describe the subsystem motion.

Note also that this removes the "rigid body" mode check from the run, since the SUPORT card must be removed (unless the run is a free-free run).

MER - MREMER - MR - EFMASS*

An important diagnostic tool is the elastic-rigid coupling matrix (MER), a triple product of the elastic modeshape matrix, the ASET Mass Matrix, and the rigid body displacement matrix with respect to the interface. This N x 6 matrix gives the square root of the effective mass in each retained mode so that the product of each element of this matrix with itself gives the effective mass contained in that mode in the associated direction. These values are in EFMASS. This matrix can be used to determine which modes are energetic in terms of interface loading. Table 22 shows a sample MER matrix taken from Reference 3. The elements of this matrix have been squared and units converted to give recognizable weight units.

The product of MER with itself transposed (MREMER) gives the total effective mass retained using the ASET DOF number of modes. The diagonal of MREMER is compared with that of the rigid mass matrix (MR) to determine if sufficient mass is contained in the selected modes to consider the model valid. The generation of the MR matrix also makes use of the stiffness matrix (see Figure 6). The MR matrix should also be compared to the mass properties of the Grid Point Weight Generator. The inertias are calculated about the SUPORT grid and, unless this is the point selected with PARAM GRDPNT, the inertias will not agree. A typical allowable is a 5% loss of mass. This comparison can then be used to modify the choice of ASET DOF or to increase the number of modes. This diagonal is shown as the "TOTAL" line of Table 22 and is compared against the full model weight.

---

*A complete technical description of these terms can be found in Reference 2.

To calculate the MER and MREMER and to print them out along with the MR, one should use the DMAP statements shown in Table 23 (also given in Tables 20 and 21) when there is a SUPORT card in the bulk data. The model must be "cantilevered" from the SUPORT; that is, the SUPORT DOF are the only constraints preventing rigid-body motion. The G factor 386.0886 in/sec^2 is in the ALTER. If another value is desired, it must be substituted.

Kinetic and Strain Energy

Tables 21 and 23 includes the ALTERS for printing the kinetic energy distribution as a fraction of the total, in the form of eigenvectors, for each mode (ALTER 455). This information is useful for showing the energy distribution within a mode, whereas the MER matrix is useful for determining which mode is energetic. The various grids within a model can be grouped together and the energy then given by subsystem. Table 24 shows a sample taken from Reference 3. Examination of Tables 22 and 24 show that for modes 1 and 2 the PWS subsystem has 100% of the KE, but in terms of effective mass it is negligible (the Plasma Wave Subsystem (PWS) is a very light antenna). In contrast, the probe in mode 5 has not only the predominant percent KE (Table 24) but mode 5 is an energetic mode (Table 20).

Element strain energy can also be used to determine which elastic elements are participating within a given mode. These two diagnostic tools can help isolate a weak or very flexible area of the model which may only be a modeling error.

The whole package is intended for use with SOLUTION 3. The model must have a determinate support point without any SPC's to fix the base. The ALTERS of Tables 17 and 23 are included in their entirety in Table 20.

Deformed Plots

Another diagnostic tool is plotting. Deformed geometry plots, the eigenvector output, and MER help to identify modeshapes and classify them. Plots will also highlight excessive relative deflections that point to stiffness matrix problems.

Information from these diagnostics will feed back to both the stiffness and mass matrices and the ASET degrees of freedom. In only a few iterations all mass and stiffness problems can be rectified and the model will be a realistic representation of the true structure.

The quality of the above checks depends on the quality of ASET chosen. It is good practice to make at least one run using Generalized Dynamic Reduction and to verify the model by comparing the resulting modes to those obtained using the ASET. If the two runs are not comparable, the GDR run should be used to select an ASET. The inclusion of all terms with significant KE usually gives a good ASET, but since large, stiff assemblies might not have large energy at individual grids, common sense should also be used.

DOCUMENTATION REQUIREMENTS

To avoid costly delays when a job is switched from one engineer to another and to make the finite element models more visible or accessible to all concerned, documentation should be maintained through timely performance and periodic updates. The items below constitute a set of information for describing a finite element model.

Model Description

Pictures or drawings of real and/or proposed hardware should be included to provide a good background and visual reference for the model. Written descriptions and an overview of the function of the hardware are useful and highlight important features that will affect modeling philosophy.

An important feature of the model description section should be the road maps. These pictorial representations of the model should be approximately to scale (and noted where not) and have grids and elements labeled. Coordinate axes should be included on the drawing, and surrounding structure should be phantomed in to show the relative location of the model. In some cases it is also important to include MPC's, rigid elements, element offsets, mass points and plate orientations on the road maps.

Geometry plots may be used as road maps if they are sufficiently clear and well-labeled. In any case, plots should be included to verify the geometry and element placement.

All calculations corresponding to geometry and element properties should be available for reference.

Also included should be written descriptions of the numbering schemes for grids and elements, numbers of elements by type, and number of static (FSET) and dynamic (ASET) degrees of freedom. The type of units used should be specified and all coordinate systems given in relation to the basic and other global systems. A model summary table showing the pertinent model parameters (number of grids, finite elements by type, mass DOF, static DOF, etc.) should be provided. A sample of such a summary taken from Reference 3 is shown in Table 25.

The interface (if any) of the model to other portions of structures must be described in detail. If necessary, a special road map should be made showing an enlargement around the interface area. This must be done if there are multiple coordinate systems, rigid elements, and/or element offsets involved.

Mass Distribution

The final mass matrix from the Grid Point Weight Generator should be included. It should be compared with measured or calculated properties and differences noted and explained.

Model Checkout Procedure and Results

Applicable model checks should be performed and the results recorded.

Model Version and Residency

The versions of the model should be specified and dated. Comment or title/subtitle cards can be used to accomplish this. The model report should contain the location of the model file and the physical printout associated with the various accomplished runs.

CONCLUSION

The foregoing paragraphs describe a means of checking and documenting a mathematical model to ensure its numerical consistency and conditioning. The reader is referred to References 3 and 4 for a comprehensive example of such documentation. The following comments are taken in part from References 5 and 6.

There is no single checklist that will ensure a complete check of a comprehensive finite element model. There is no substitute for actual test correlation with the model nor is there a substitute for the analyst's engineering interpretation of the output and one's intuition. "Result prediction," which is determining gross results before the analysis is even attempted, can be used to good advantage. Simple load paths, frequency of equivalent simple beam/mass systems, etc., can be used to remove redundancies and predict the results. In fact this must be accomplished to some degree to size the model initially. This will also provide baseline data, and the effects of finer modeling will then be known.

Relative to preparation of the model, the following are a few suggestions for eliminating or reducing modeling problems.

- Start with simple models and then:
  - Refine with stick or beam models;
  - Use RBE2's and RBE3's where they will simplify;
  - Simplify modeling offsets and local modeling detail;
  - Ignore minor discontinuities.

Further refinement after this initial modeling should yield relatively small changes in the results.

- Do not rely on moment capability of thin plates and long, thin axial members to render the model kinematically stable.
- Make an initial run with membrane-only properties and pinned ended bars, and check for irregularities.
- Avoid use of AUTOSPC in the final model.

The post analysis assessment should include a check of the physical significance of the loads and of the load paths. Mere connection of members does not constitute a load path. Offsets whose moments are not properly accounted for may render soft a very stiff load path. Also, large moments in relatively weak bending members or plates may indicate modeling problems.

Stress analysis should be performed at the detail part level with the loads from the model. The use of element stresses directly from the output of the model requires detailed review in most cases. In fact, model properties may be intentionally different from the actual hardware to obtain correct load distributions and to match test data or dynamic characteristics. Effective thicknesses or reduced bending properties may have been used to reflect panel cutouts or partial beam end fixity. In this event the FEM loads should be used with the actual drawing or as-built dimensions for detail stress analysis. This piece-part assessment ensures a check and balance of the FEM and the stress distributions visualized and treated by the element selection. Also the source of the components of stress are known, that is, whether the predominant stress component is due to bending or axial loads. Load transformation matrices are useful for isolating critical design conditions but are not necessarily a sufficient basis for computing the margin of safety.

An area where an underestimation of load could occur is the local response of small masses during a dynamic analysis. These should be addressed in the detail stress analysis with both the model predictions and an alternate loading such as a specified loading condition. For the model to give correct loads for the local response of a small mass, one needs all of the following:

- Mass must be represented by enough mass points to characterize the critical local mode (a single-point mass may not be sufficient).

- Mass must be supported by proper elastic elements to represent the local mode (RBE2 or RBE3 may not be sufficient).
- Mass must be in the ASET.
- Model and all analysis (input spectra, etc.) must be carried beyond this local critical mode (as far as frequency is concerned).

REFERENCES

1. "MSC/NASTRAN Handbook for Linear Analysis," Version 64, The MacNeal-Schwendler Corporation, August 1985.
2. "Equivalent Spring-Mass System for Normal Modes," R. M. Bamford, B. K. Wada, and W. H. Gayman, NASA Technical Memorandum 33-380, February 1971.
3. "Galileo S/C NASTRAN Model, Descriptive Data, and Checkcase Results," R. Calvet and G. Wang, May 1985.
4. "WF/PC NASTRAN Model, Descriptive Data, and Checkcase Results," Vols. I and II, J. W. Zins, October 30, 1984.
5. "Checks That Pay," J. C. Auker, Proceedings of the MSC/NASTRAN European User's Conference, Munich, W. Germany, May 1984.
6. JSC-20545, "Simplified Design Options for STS Payloads," D. A. Hamilton, May 1985.

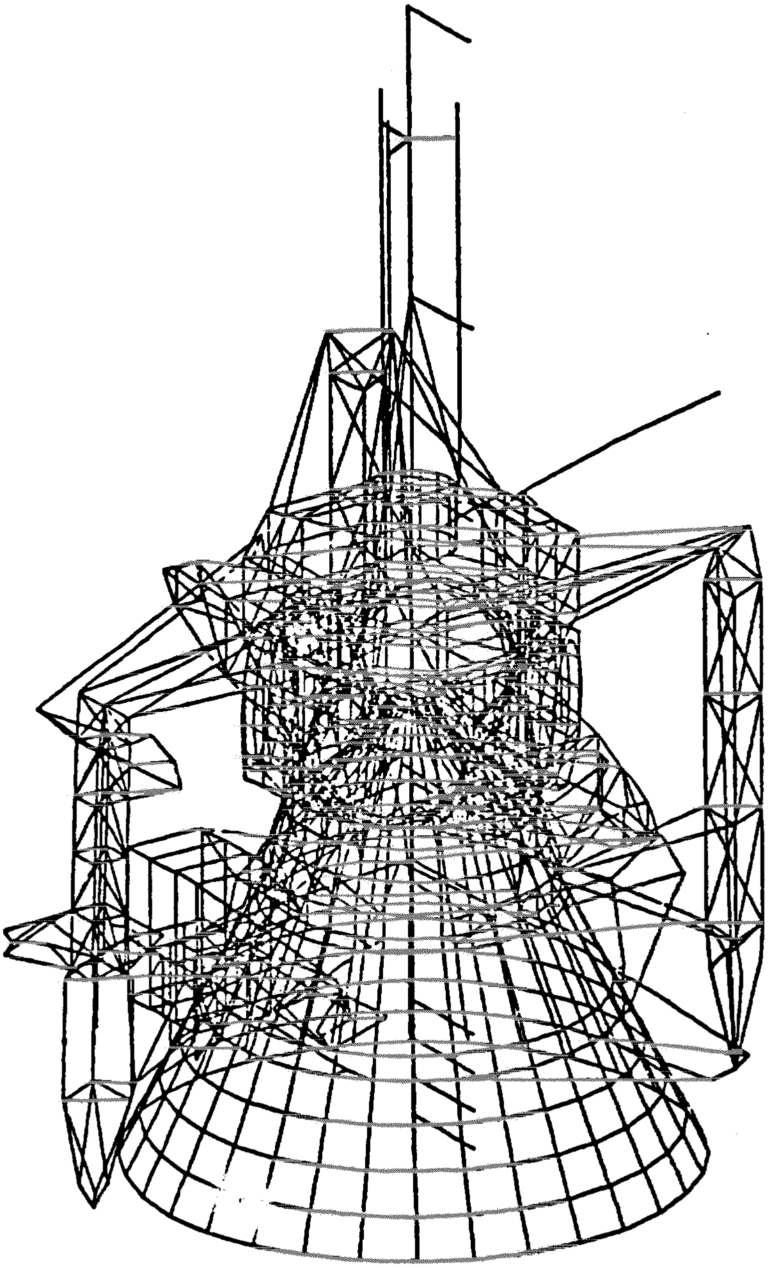


FIGURE 1
GALILEO FINITE ELEMENT MODEL

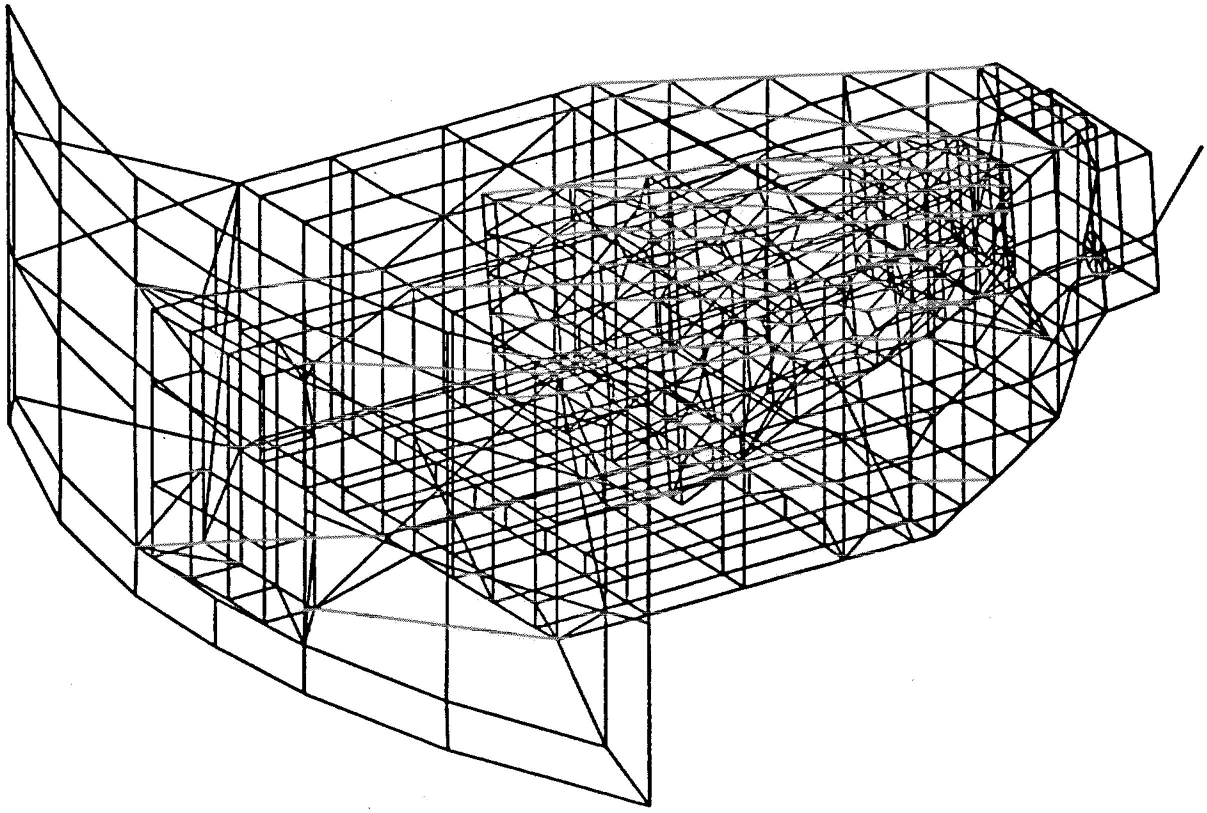
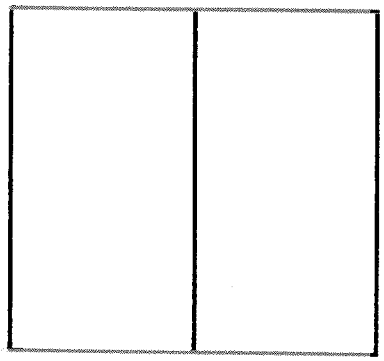
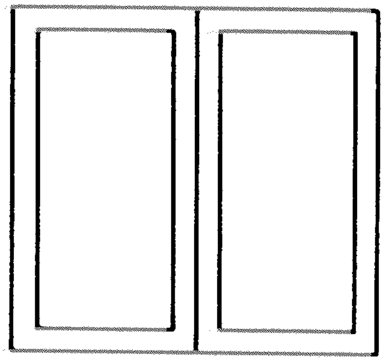


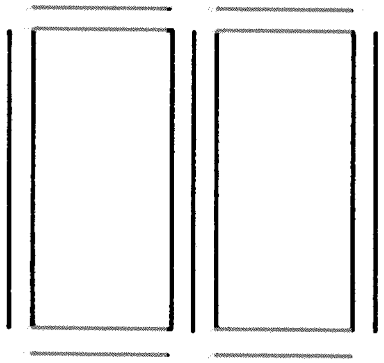
FIGURE 2
WIDE FIELD/PLANETARY CAMERA FINITE ELEMENT MODEL



A. SHEARS AND BARS, NO SHRINK

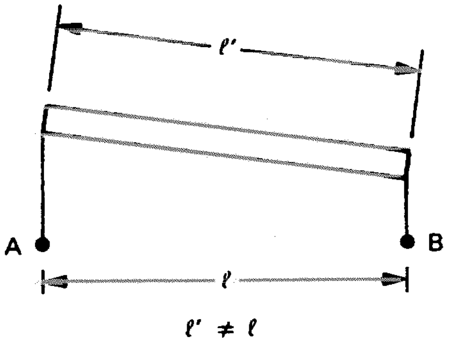


B. BARS REGULAR SIZE, SHEARS SHRUNK

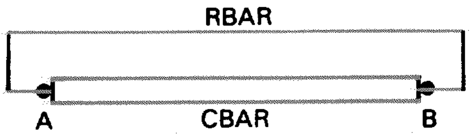


C. BARS AND SHEARS BOTH SHRUNK

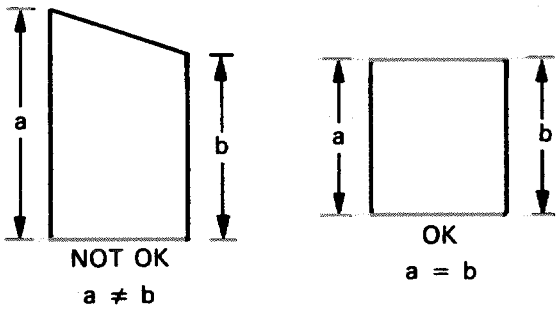
FIGURE 3
NASTRAN SHRINK OPTION



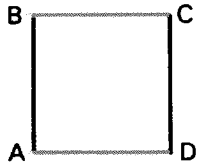
A. OFFSETS THAT CHANGE MEMBER LENGTH



B. RIGID ELEMENTS WHICH RESTRAIN THERMAL GROWTH



C. NON RECTANGULAR CSHEARS



GRID D DOES NOT LIE IN SAME PLANE AS GRIDS A, B AND C

D. OUT OF PLANE QUADS

FIGURE 4
PROBLEM AREAS FOR THERMAL TEST CASE

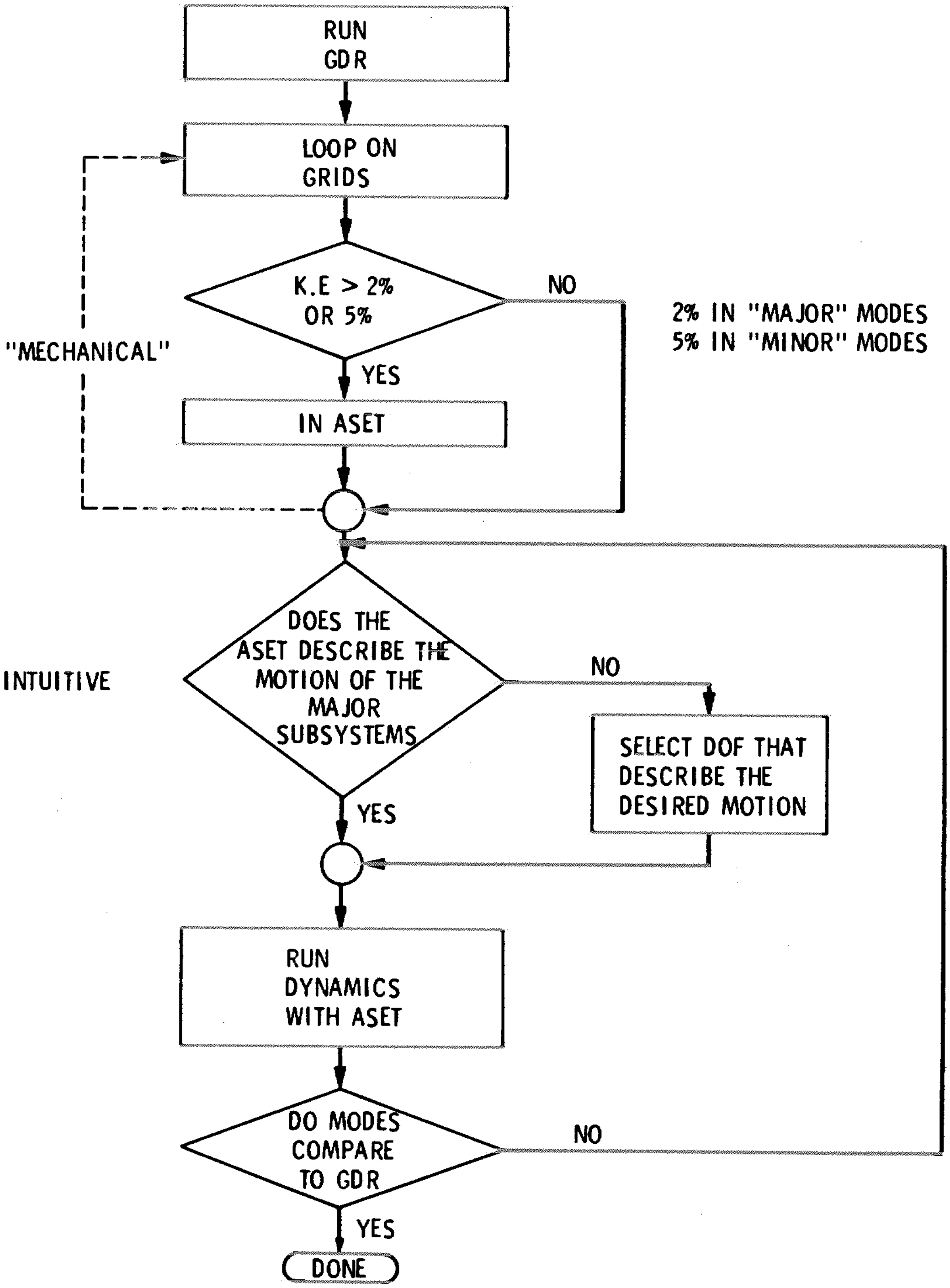


FIGURE 5

ASET SELECTION FLOW CHART

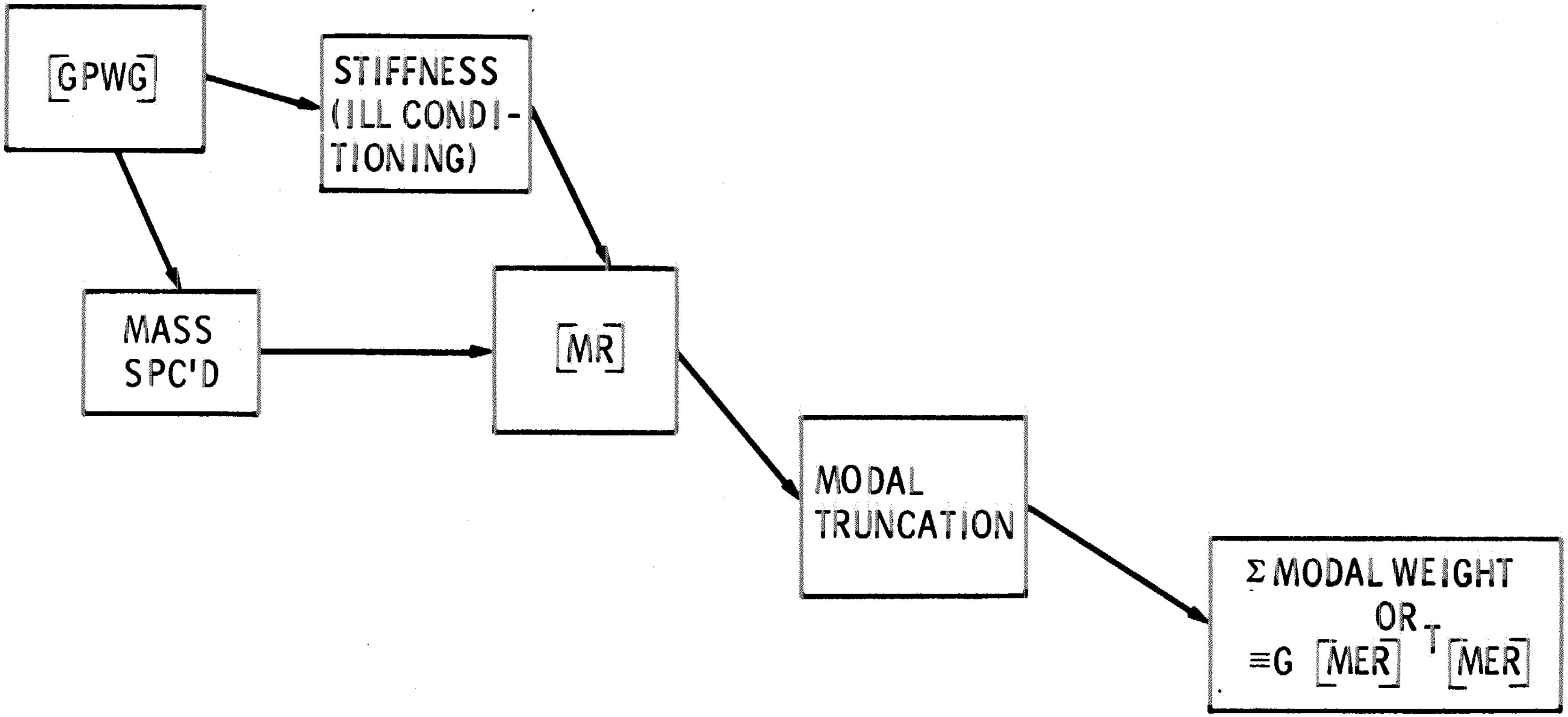


FIGURE 6
DEVELOPMENT OF MASS MATRICES

TABLE 1

Check Out Run

```
$ BEGINNING OF RF ALTER 24$32
$ + + + + + + + + + + + + + +             10 DEC 1979             + + + +
$
$  CHECK INPUT DATA
$       10 DEC 1979     R I G I D  F O R M A T   24
$
$  CHECK CONTROL INPUT
$       CASE CONTROL DECK THAT WILL BE USED IN PRODUCTION RUN.
$
$       UNDEFORMED PLOTS MAY BE REQUESTED INCLUDING PROPERTY IDS
$              AND SPC POINTS
$
$  BULK DATA INPUT
$       COMPLETE BULK DATA DECK TO BE SUBMITTED FOR PRODUCTION RUN
$ THE FOLLOWING PARAMETERS MUST BE SET TO THE INDICATED VALUES TO OBTAIN
$       OUTPUT FOR-
$        1. GPL    - SET PARAMETER GPL TO GPL
$        2. EQEXIN - SET PARAMETER EQEXIN TO EQEXIN
$        3. GPDT   - SET PARAMETER GPDT TO GPDT
$        4. CSTM   - SET PARAMETER CSTM TO CSTM
$        5. BGPDT  - SET PARAMETER BGPDT TO BGPDT
$        6. MGG    - SET PARAMETER PRTMGG TO +1
$        7. ETT    - SET PARAMETER GPTT TO GPTT
$        8. GPECT  - SET PARAMETER GPECT TO +1 TO OBTAIN LIST OF ELEMENTS
$           CONNECTED TO GRIDS.
$        9. PROUT -- SET TO POSITIVE VALUE TO OBTAIN SORTED LIST OF
$           ELEMENT IDS.
$       10. EST   -- SET TO POSITIVE VALUE TO OBTAIN LENGTHS, AREAS,
$           OR VOLUMES OF ELEMENTS.
$       11. PG    -- SET PRTPG=+1 TO PRINT THE LOAD VECTOR MATRIX
$       12. A SUMMATION OF LOAD IN BASIC WILL AUTOMATICALLY BE PRINTED
$
$  THE ITEMS CHECKED INCLUDE - GRID CONNECTION AND PROPERTY CARDS, MASS
$       PROPERTIES OF STRUCTURE, LOADS, TEMPERATURES AND CONSTRAINTS
$       AS WELL AS SOME GEOMETRY AND MATERIAL PROPERTIES
$       FOR EACH SUBCASE IN ALL BOUNDARY CONDITIONS.
$
$  THE ITEMS NOT CHECKED INCLUDE - GEOMETRY, MATERIAL PROPERTIES AND
$       GRID POINT SINGULARITIES
$
$-----------------------------------------------------------------------
```

NOTES: 1. Output from the Grid Point Weight Generator is recommended. Set PARAM, GRDPNT point to a positive integer. The value of the integer indicates the grid point to be used as the reference point. If the integer is zero or an undefined grid, the origin of the basic coordinate system is the reference point.

TABLE 2

FORMATTED LIST OF TABLE DATA BLOCK EQEXIN (RECORD 1)

EXTERNAL SORT ID	EXTERNAL GRID OR SCALAR ID	INTERNAL NUMBER	EXTERNAL GRID OR SCALAR ID	INTERNAL NUMBER	EXTERNAL GRID OR SCALAR ID	INTERNAL NUMBER	EXTERNAL GRID OR SCALAR ID	INTERNAL NUMBER
1	10	1	11	2	12	3	13	4
5	14	5	15	6	16	7	19	8
9	20	9	21	10	22	11	23	12
13	24	13	$\boxed{25}$	⑭	26	15	29	16
17	30	17	31	18	32	19	33	20

NOTES:

1. Grid IDs as found in the Bulk Data are listed in numerical increasing order from left to right (four per row) and are listed under the column heading "External Grid or Scalar ID".
2. The corresponding Internal ID number is given to the immediate right of the grid number under the column heading "Internal Number".
3. In the example above grid number 25 has internal sort number 14.
4. First column marked "External Sort ID" may be ignored (it simply increments by 4 as there are 4 External Grid/Internal Numbers pairs per line).
5. RF24D32 provides similar information in the following tables: GPL Record 1, GPL Record 2, and Eqexin Record 2. Table Eqexin Record 1 as shown above was chosen because its format is easier to explain.
6. This output obtained by using RFALTER RF24D32 and PARAM, EQEXIN, EQEXIN.

TABLE 3

FORMATTED LIST OF TABLE DATA BLOCK GPDT (RECORD 1)

INTERNAL ID	COORDINATE SYSTEM ID	COORDINATES IN DEFINING COORDINATE SYSTEM			DISPLACEMENT COORDINATE SYSTEM ID	CONSTRAINT CODE
		X	Y	Z		
1	10	0.00000E+00	0.00000E+00	4.22100E+00	10	0
2	10	0.00000E+00	0.00000E+00	4.92100E+00	10	0
3	10	0.00000E+00	0.00000E+00	8.30800E+00	10	0
4	10	0.00000E+00	0.00000E+00	4.92100E+00	10	0
5	10	0.00000E+00	0.00000E+00	8.30800E+00	10	0
6	10	0.00000E+00	0.00000E+00	8.48800E+00	10	0
7	10	0.00000E+00	0.00000E+00	9.25000E+00	10	0
8	1000	1.73000E+01	−4.11000E+00	0.00000E+00	0	123456
9	20	0.00000E+00	0.00000E+00	4.22100E+00	20	0

Internal grid ID number as found from Table Exeqin Record 1

Coordinate system in which grid point geometry is defined

Spatial location of grid points in defining coordinate system

Coordinate system ID for grid point displacements, forces, and constraints

Permanent single-point constraints defined on GRID Bulk Data cards

<u>Notes</u>: 1. This output is obtained by using RFALTER RF24D32 and PARAM, GPDT, GPDT.

TABLE 4

FORMATTED LIST OF TABLE DATA BLOCK CSTM (RECORD 1)

N	ID	TYPE	R(I,1)	R(I,2)	R(I,3)	T(I)
1	80	1	1.00000000E+00	0.00000000E+00	0.00000000E+00	0.00000000E+00
			0.00000000E+00	1.00000000E+00	0.00000000E+00	0.00000000E+00
			0.00000000E+00	0.00000000E+00	1.00000000E+00	5.61500015E+01
2	5	2	0.00000000E+00	1.00000000E+00	0.00000000E+00	0.00000000E+00
			0.00000000E+00	0.00000000E+00	1.00000000E+00	0.00000000E+00
			1.00000000E+00	0.00000000E+00	0.00000000E+00	−1.26000004E+01
3	5000	2	9.99999940E−01	4.76837192E−09	0.00000000E+00	0.00000000E+00
			−4.75675632E−09	9.97564018E−01	−6.97565004E−02	−3.13941073E+00
			−3.32624928E−10	6.97565004E−02	9.97564018E−01	−4.06719875E+00

Transformation matrix from the global (local) to the basic coordinate system. An identity matrix here indicates the coordinate system is parallel to the basic system.

The origin of the coordinate system given in the basic coordinate system

Coordinate system type is: 1 = rectangular; 2 = cylindrical; 3 = spherical

Coordinate system ID as found in Bulk Data. Not listed in numerical order.

Internal coordinate system number given in numerical order

NOTES: 1. This output is obtained by using RFALTER RF24D32 and PARAM, CSTM, CSTM.

TABLE 5

FORMATTED LIST OF TABLE DATA BLOCK BGPDT (RECORD 1)

INTERNAL ID	COORDINATE SYSTEM ID	COORDINATES IN BASIC COORDINATE SYSTEM X	Y	Z
1	10	1.35806E+00	−5.25850E+00	2.43840E+00
2	10	1.58327E+00	−4.73337E+00	2.84278E+00
3	10	2.67300E+00	−2.19252E+00	4.79939E+00
4	10	1.58327E+00	−4.73337E+00	2.84278E+00
5	10	2.67300E+00	−2.19252E+00	4.79939E+00
6	10	2.73091E+00	−2.05749E+00	4.90337E+00
7	10	2.97608E+00	−1.48585E+00	5.34357E+00

Spatial location of grid points in basic coordinate system

Internal grid ID number
as found in Table Exeqin
Record 1

Coordinate system ID for grid points displacements, forces, and constraints

Notes: 1. This output obtained by using RFALTER RF24D32 and PARAM, BGPDT, BGPDT.

TABLE 6

ELEMENT TYPE COUNT

```
THERE ARE    705 BAR      ELEMENTS FIRST EID   =     10 LAST EID   =   15408
THERE ARE      2 BEAM     ELEMENTS FIRST EID   =    100 LAST EID   =     900
THERE ARE      6 ELAS2    ELEMENTS FIRST EID   =   1040 LAST EID   =    1045
THERE ARE    117 CONM2    ELEMENTS FIRST EID   =    998 LAST EID   =    5250
THERE ARE    438 QUAD4    ELEMENTS FIRST EID   =   1019 LAST EID   =   31451
THERE ARE    101 SHEAR    ELEMENTS FIRST EID   =   1057 LAST EID   =   11657
THERE ARE    223 TRIA3    ELEMENTS FIRST EID   =    731 LAST EID   =   31071
```

NOTES: 1. This output obtained by using RFALTER RF24D32 and PARAM,PROUT,+1.

2. Elements not accounted for include MPC's, RBAR's, RBE1's, RBE2's, RBE3's.

TABLE 7

ELEMENTS LISTED IN NUMERICAL ORDER

```
         ID     TYPE        ID       TYPE        ID    TYPE      ID    TYPE      ID    TYPE

         10     BAR         11       BAR         12    BAR       13    BAR       14    BAR
         15     BAR         16       BAR         20    BAR       21    BAR       22    BAR

****   1001     BAR       DUPLICATES A CONM2
       1002     CONM2
****   1002     BAR       DUPLICATES A CONM2
       1003     BAR         1004     BAR
       1015     CONM2       1016     CONM2     1011    BAR     1012    BAR     1014    CONM2
                                               1017    BAR     1018    BAR     1019    CONM2
```

Asterisks indicate a duplicated element number

<u>NOTES</u>: 1. This output obtained by using RFALTER RF24D32 and PARAM, PROUT, +1.

TABLE 8

GRID POINT – ELEMENT CONNECTION LIST

GRID POINT	CONNECTED ELEMENTS		CONNECTED ELEMENTS		CONNECTED ELEMENTS		CONNECTED ELEMENTS		CONNECTED ELEMENTS	
	ID	TYPE	ID	TYPE	ID	TYPE	ID	TYPE	ID	TYPE
1032	11001	BAR	11022	BAR	11047	BAR	11048	BAR	1032	CONM2
1032	1744	QUAD4	1732	SHEAR	1748	SHEAR	1719	TRIA3	1720	TRIA3
1032	1721	TRIA3								
1033	11001	BAR	11002	BAR	11026	BAR	11027	BAR	1732	SHEAR
1033	1733	SHEAR	1748	SHEAR	1749	SHEAR				
1034	11002	BAR	11003	BAR	11031	BAR	11032	BAR	1733	SHEAR
1034	1734	SHEAR	1749	SHEAR	1750	SHEAR				

NOTES: 1. This output obtained by using RFALTER RF24D32 and PARAM,GPECT,+1.

2. Elements not accounted for include MPC's, RBAR's, RBE1's, RBE2's, RBE3's.

TABLE 9

ELEMENT LENGTH, AREA, OR VOLUME

ELEMENT TYPE = BAR

ELEMENT ID	LENGTH	VOLUME	ELEMENT ID	LENGTH	VOLUME	ELEMENT ID	LENGTH	VOLUME	ELEMENT ID	LENGTH	VOLUME
1832	5.13666	0.405796	1833	5.23643	0.413678	1834	11.07	0.87453	1835	8.82	0.69678
1836	11.07	0.87453	1837	8.82	0.69678	1838	11.07	0.87453	1839	8.82	0.69678
1850	6.275	1.56875	1851	5.15759	1.2894	1852	6.64324	1.66081	1853	5.13666	1.28417

ELEMENT TYPE = BAR

ELEMENT ID	LENGTH	VOLUME	ELEMENT ID	LENGTH	VOLUME	ELEMENT ID	LENGTH	VOLUME	ELEMENT ID	LENGTH	VOLUME
15302	1.33939	0.001339	15303	1.33939	0.001339	15304	1.33939	0.001339	15305	1.33939	0.001339
15306	1.33939	0.001339	15307	1.33939	0.001339	15308	1.75	0.00175	15309	1.75	0.00175
15400	4.73394	2.36697	15401	2.02678	1.01339	15402	2.5042	1.2521	15403	2.45211	1.22606
15404	2.45231	1.22616	15405	5.06811	2.53406	15406	4.85001	2.425	15407	5.6528	2.8264
15408	5.65271	2.82636									

ELEMENT TYPE = BEAM

ELEMENT ID	LENGTH	VOLUME	ELEMENT ID	LENGTH	VOLUME	ELEMENT ID	LENGTH	VOLUME	ELEMENT ID	LENGTH	VOLUME
100	7.44262	16.7905	900	7.03656	5.91071						

ELEMENT TYPE = QUAD4

ELEMENT ID	AREA	VOLUME	ELEMENT ID	AREA	VOLUME	ELEMENT ID	AREA	VOLUME	ELEMENT ID	AREA	VOLUME
1019	18.3429	1.10057	1020	18.4783	0.923916	1021	22.1611	1.32967	1022	20.6317	1.2379
1023	21.5992	1.72794	1024	36.013	2.88104	1025	31.36	2.1952	1026	36.013	2.16078
1027	35.3506	2.12103	1028	7.06676	0.565341	1030	2.7875	0.39025	1061	10.035	1.4049

ELEMENT TYPE = SHEAR

ELEMENT ID	AREA	VOLUME	ELEMENT ID	AREA	VOLUME	ELEMENT ID	AREA	VOLUME	ELEMENT ID	AREA	VOLUME
1734	21.808	1.74464	1735	35.2222	2.81778	1736	29.7567	2.38054	1737	35.2222	2.81778
1738	13.8272	1.10618	1739	11.6816	0.934528	1740	13.8272	1.10618	1741	21.1265	1.69012
1742	19.787	1.58296	1743	21.1265	1.69012	1748	16.24	1.2992	1749	13.72	1.0976

ELEMENT TYPE = TRIA3

ELEMENT ID	AREA	VOLUME	ELEMENT ID	AREA	VOLUME	ELEMENT ID	AREA	VOLUME	ELEMENT ID	AREA	VOLUME
731	1.08276	0.378965	732	1.08276	0.378965	733	1.08276	0.378965	734	1.08276	0.378965
735	1.08276	0.378965	736	1.08276	0.378965	737	1.08276	0.378965	738	1.08276	0.378965
1078	0.0725	0.019125	1079	0.0725	0.018125	1155	4.32	2.4192	1156	4.32	2.4192

NOTES: 1. This is special output and is obtained by using RFALTER RF24D32 and PARAM, EST, + 1.

TABLE 10

PARAM GRDPNT WEIGHT INERTIA MATRIX

OUTPUT FROM GRID POINT WEIGHT GENERATOR

```
                                          REFERENCE POINT =  1000 }-GRID POINT OR ORIGIN OF BASIC
                                                 MO                 COORDINATE SYSTEM
 *   1.562092E+00  -1.669640E-17  -1.040834E-17  -4.440892E-16   5.894034E+01  -1.359722E+01  *
 *  -1.767218E+17   1.562092E+00  -1.416518E-16  -5.894034E+01  -4.973032E-16   3.635694E-01  *
 *  -1.040834E-17  -1.419229E-16   1.562092E+00   1.359722E+01  -3.635694E-01  -4.440892E-16  *
 *   4.440892E-16  -5.894034E+01   1.359722E+01   3.191095E+03   3.648479E+00  -2.795030E+00  *
 *   5.894034E+01   2.972035E-16  -3.635694E-01   3.648479E+00   3.283023E+03  -5.082753E+02  *
 *  -1.359722E+01   3.635694E-01   2.220446E-16  -2.795030E+00  -5.082753E+02   4.852746E+02  *
                                                  S
                *   1.000000E+00         0.                  0.                *  } TRANSFORMATION MATRIX
                *   0.                   1.000000E+00        0.                *  } FROM THE BASIC SYSTEM
                *   0.                   0.                  1.000000E+00      *  } TO THE PRINCIPAL MASS AXES

           DIRECTION
     MASS AXIS SYSTEM (S)       MASS          X-C.G.           Y-C.G.          Z-C.G.
              X             1.562092E+00   0.0              8.704492E+00    3.773167E+01
              Y             1.562092E+00   2.327452E-01     0.0             3.773167E+01
              Z             1.562092E+00   2.327452E-01     8.704492E+00    0.0
                                                I ( S )
                *    8.488209E+02       -6.813166E+00       -1.092305E+01      *  } MOMENTS OF INERTIA IN THE
                *   -6.813166E+00        1.059020E+03       -4.770467E+00      *  } BASIC COORDINATE SYSTEM
                *   -1.092305E+01       -4.770467E+00        3.668331E+02      *  }
                                                I ( Q )
                *    1.059279E+03                                              *  }
                *                        8.488406E+02                          *  } PRINCIPLE MOMENTS OF INERTIA
                *                                            3.665549E+02      *  }
                                                  Q
                *   -3.274377E-02       -9.992094E-01        2.254901E-02      *  } DIRECTION COSINES FROM
                *   -9.994364E-01        3.290163E-02        6.665341E-03      *  } BASIC COORDINATES TO
                *   -7.401970E-03       -2.231805E-02       -9.997235E-01      *  } PRINCIPAL INERTIA AXES
```

PRINCIPLE MASSES AND ASSOCIATED CENTERS OF GRAVITY RELATIVE TO THE REFERENCE POINT

RIGID BODY MASS MATRIX RELATIVE TO THE REFERENCE POINT IN THE BASIC COORDINATE SYSTEM

TABLE 11

EPSILON, STRAIN ENERGY AND MAX RATIO FROM STATICS RUN

```
*** USER INFORMATION MESSAGE 4158—STATISTICS FOR SYMMETRIC DECOMPOSITION OF DATA BLOCK KOO FOLLOW
    MAXIMUM RATIO OF MATRIX DIAGONAL TO FACTOR DIAGONAL = 3.9E+03 AT ROW NUMBER 594

*** USER INFORMATION MESSAGE 3035 FOR DATA BLOCK KLL

LOAD SEQ.
   NO.          EPSILON          STRAIN    ENERGY     EPSILONS LARGER THAN 0.001 ARE FLAGGED WITH ASTERISKS

    1       -3.0539089E-14     8.2555099E+01
    2        1.0082989E-14     8.7870163E+01
    3        9.0509631E-16     2.3730776E+01

*** USER INFORMATION MESSAGE 3035 FOR DATA BLOCK KOO

LOAD SEQ.
   NO.          EPSILON          STRAIN    ENERGY     EPSILONS LARGER THAN 0.001 ARE FLAGGED WITH ASTERISKS

    1        6.5035202E-15       2.2547545E-01
    2        7.3623740E-15       2.2061828E-01
    3        2.0116192E-15       1.3978869E-01
```

TABLE 12

FORCES OF SINGLE-POINT CONSTRAINT

SUBCASE 1

1.0G (+X)

POINT ID.	TYPE	T1	T2	T3	R1	R2	R3
201	G	0.0	0.0	0.0	0.0	2.797872E-13	0.0
2611	G	0.0	1.778028E-06	0.0	0.0	0.0	0.0
2711	G	0.0	-3.070124E-06	0.0	0.0	0.0	0.0
3197	G	0.0	0.0	0.0	0.0	0.0	2.731404E-09
3198	G	0.0	0.0	0.0	0.0	0.0	3.327725E-09
3297	G	0.0	0.0	0.0	0.0	0.0	2.494900E-09
3298	G	0.0	0.0	0.0	0.0	0.0	-1.839192E-09
3397	G	0.0	0.0	0.0	0.0	0.0	-4.187774E-10
3398	G	0.0	0.0	0.0	0.0	0.0	-4.716660E-09
3497	G	0.0	0.0	0.0	0.0	0.0	1.664817E-09
3498	G	0.0	0.0	0.0	0.0	0.0	8.814997E-11
5602	G	0.0	0.0	0.0	0.0	0.0	6.451412E-05
5603	G	0.0	0.0	0.0	0.0	0.0	-8.358259E-05
5604	G	0.0	0.0	0.0	0.0	0.0	3.047899E-05
5605	G	0.0	0.0	0.0	0.0	0.0	-3.166949E-05
5606	G	0.0	0.0	0.0	0.0	0.0	2.126513E-05
5607	G	0.0	0.0	0.0	0.0	0.0	2.643013E-05
5608	G	0.0	0.0	0.0	0.0	0.0	-4.914991E-05
5609	G	0.0	0.0	0.0	0.0	0.0	4.414012E-05
5610	G	0.0	0.0	0.0	0.0	0.0	-3.978080E-05
5611	G	0.0	0.0	0.0	0.0	0.0	3.061714E-05
9999	G	-5.640888E+03	5.932931E-06	-1.097669E-07	1.562507E-04	4.669583E+05	-4.979101E+02

MODEL WEIGHT
RECOVERED AT
THE BOUNDARY

MOMENT CONSISTENT
WITH MODEL WEIGHT
AND C.G. DATA

SPC FORCES AND MOMENTS IN THE ACCEPTABLE RANGE

TABLE 13

Equilibrium Check

EXECUTIVE CONTROL DECK

```
ID WFPC,MODAL
APP DISPLACEMENT
SOL 24
DIAG 6,14
TIME 30
$
$       RESEQUENCE AND PRINT USET TABLES
$
ALTER 8
SEQP    GEOM1,GEOM2,GEOM4,/GEOM1Q,MATPARM/C,Y,SEQOUT=0/V,Y,NEWSEQ=+3//
        C,Y,SUPER= 0/C,Y,FACTOR=10000/C,Y,MPCX=0/C,Y,START=0 $
EQUIV    GEOM1Q,GEOM1/ALWAYS $
ALTER 99
TABPRT    USET,EQEXIN//USET/V,Y,USETPRT=0/V,Y,USETSEL=0 $
ALTER 110
$$
$$$$ EQUILIBRIUM CHECK OF FSET STIFFNESS MATRIX
$$
$$
VECPLOT, ,BGPDT,EQEXIN,CSTM,,/RBGLOBAL/V,Y,MPFPNT=0//$ $
VEC USET/VRB/G/F/COMP $
PARTN RBGLOBAL,VRB,/RBFSET,,,/+1 $
TRNSP RBFSET/RBTF $
MPYAD KFF,RBTF,/KRB/ $
MPYAD RBFSET,KRB,/KRBF/ $
NORM KRB/KRBFN/ $
MATPRN KRBF// $
MATGPR GPL,USET,SIL,KRBFN//F///1.-2 $ This prints only terms >1% of the
$       maximum (all scaled such that the maximum is 1.0).
EXIT $
ENDALTER
CEND
```

BULK DATA DECK

```
PARAM  AUTOSPC  YES
PARAM  EQEXIN   EQEXIN
PARAM  GPL      GPL
PARAM  GRDPNT   n
PARAM  SEQOUT   1
```

NOTES:
1. Remove SUPORT and SPC cards from bulk data.
2. ASET cards should not be used.
3. See Reference 5 for use of PARAM GRDPNT.

TABLE 14

KRBF MATRIX

```
     MATRIX KRBF    ( GINO NAME 101 )  IS  A  DB  PREC   6  COLUMN  X   6  ROW  SQUARE  MATRIX.
COLUMN    1       ROWS       1  THRU       6 ---------------------------------------------------
   ROW
    1)  5.6036D-06   6.2035D-08  -9.8440D-08  -8.1671D-07   1.7130D-04   1.1562D-05
COLUMN    2       ROWS       1  THRU       6 ---------------------------------------------------
   ROW
    1)  6.2502D-08   6.3425D-06   8.2305D-07  -8.1379D-05   1.1740D-07  -9.2047D-06
COLUMN    3       ROWS       1  THRU       6 ---------------------------------------------------
   ROW
    1) -9.7452D-08   8.2517D-07   5.5577D-06  -1.9905D-05  -1.3735D-06   1.2302D-06
COLUMN    4       ROWS       1  THRU       6 ---------------------------------------------------
   ROW
    1) -7.2425D-07  -8.2143D-05  -2.0377D-05   2.5692D+01  -3.6712D-04   2.2372D-04
COLUMN    5       ROWS       1  THRU       6 ---------------------------------------------------
   ROW
    1)  1.7143D-04   7.7165D-08  -3.1777D-06  -3.7383D-04   7.8407D+00   4.3714D-01
COLUMN    6       ROWS       1  THRU       6 ---------------------------------------------------
   ROW
    1)  1.1508D-05  -9.3303D-06   1.1475D-06   2.3130D-04   4.3714D-01   1.4307D+00
```

NOTES:

1. Forces due to translations (circled) should be less than 1.E-2
2. Moments due to rotations (rectangle) should be less than 2.0E+2
3. Off diagonal terms should be less than 2.0E+2

TABLE 15

KRBFN MATRIX

DOF FOR RIGID BODY MOTION

KRBFN

COLUMN ① (225-T1)

POINT	VALUE	POINT	VALUE	POINT	VALUE	POINT	VALUE	POINT	VALUE
11051 T2	-3.74471E-02	11051 T3	-3.02346E-02	11051 R2	1.21603E-02	11051 R3	-1.72736E-02	23 T1	4.24163E-02
23 T3	-2.39963E-02	23 R2	2.12711E-02	1200 T2	1.62373E-02	1200 T3	1.85256E-02	8018 T1	1.70890E-02
8018 T2	-2.07496E-02	1300 T1	-1.14074E-02	1300 T3	4.24825E-02	8017 T1	4.70847E-02	1350 T3	1.01157E-02
7017 T2	1.40387E-02	6010 T3	1.00000E+00	8011 T2	-2.90140E-02	1400 T1	-1.42188E-02	1400 T3	5.53219E-02

GRID DOF

1.0 IS THE MAXIMUM NORMALIZED VALUE AND INDICATES THE MAXIMUM STRAIN ENERGY

NORMALIZED VALUE OF STRAIN ENERGY GREATER THAN .01.

<u>NOTES</u>:

1. T1, T2, T3 are translations, R1, R2, R3 are rotations.
2. The normalized value of strain energy greater than .01 is controlled in the DMAP statements. It may be set by the user.
3. In this example grid 6010 DOF 3 has the maximum strain energy for rigid body motion in the "1" direction.

TABLE 16

GRID POINT SINGULARITY TABLE

POINT ID	TYPE	FAILED DIRECTION	STIFFNESS RATIO	OLD USET	NEW USET
1000	G	4	0.00E+00	O	S
1000	G	5	0.00E+00	O	S
1000	G	6	0.00E+00	O	S

TABLE 17

Rigid Body Displacements

```
ALTER    251
$        THE NUMBER 6 ON THE NEXT TWO CARDS IS THE NUMBER OF SUPORT
$        DOF
MATGEN   /IDENT/1/6/ $
MATGEN   /RBM/4/6/3/0/1/1/3/0/6/ $
UMERGE   USET,DM,IDENT/DEAR1/A/L/R $
SDR1     USET,,DEAR1,,,GO,GM,,KFS,,/DEAR,,DEARQG/1/REIG $
MATPRN   DM,MR,,,// $
LAMX     RBM,/LM $
$        THE FOLLOWING CARDS ARE USED TO CALCULATE DISPLACEMENTS,
$        ELEMENT STRESSES, AND FORCES
SDR2     CASECC,CSTM,MPT,DIT,EQEXIN,SIL,ETT,,BGPDT,LM,DEARQG,DEAR,EST,
         XYCDB/DEAROPG1,DEAROQG1,ODEAR,DEAROES1,DEAROEF1,PDEAR/REIG $
OFP      ODEAR,DEAROPG1,DEAROQG1,DEAROEF1,DEAROES1//S,N,CARDNO $
$
$        THE FOLLOWING CARDS FIND THE ELEMENT STRAIN ENERGY (IF
$        REQUESTED BY CASE CONTROL)
SETVAL   ////////////V,N,SOLTYPE/REIG $
COND     NOESED,GPFDR $
COND     NOESED1,ESE $
GPFDR    CASECC,DEAR,KELM,KDICT,ECT,EQEXIN,GPECT,,,BGPDT,SIL,CSTM/
         DONRGY,DOGPFB1/SOLTYPE/C,Y,TINY $
OFP      DONRGY,DOGPFB1//S,N,CARDNO $
LABEL    NOESED $
LABEL    NOESED1 $
```

Notes:

1. If this alter is being used for a check run, the final cards of the alter should be:

   ```
   JUMP FINIS $
   ENDALTER
   ```

   Otherwise the job will continue and perform a free-free eigensolution. Refer to Section on Modal Analysis and Table 20 for cantilever modes.

2. The case control should include commands for any desired output for the rigid-body modes.

   (ex. DISP = ALL)

3. SUPORT card with the DOF supported by a determinate interface must be used.

TABLE 18

EPSILON, STRAIN ENERGY AND MAX RATIO
FROM RIGID BODY MODES RUN

```
*** USER INFORMATION MESSAGE 4158—STATISTICS FOR SYMMETRIC DECOMPOSITION OF DATA BLOCK KOO
    FOLLOW MAXIMUM RATIO OF MATRIX DIAGONAL TO FACTOR DIAGONAL = 7.4E+04 AT ROW NUMBER 702

*** USER INFORMATION MESSAGE 3035 FOR DATA BLOCK KLR

SUPPORT
 PT. NO.       EPSILON        STRAIN    ENERGY   EPSILONS LARGER THAN 0.001 ARE FLAGGED WITH ASTERISKS
   1        1.2895072E-16    0.0000000E+00
   2        1.2895072E-16   -7.2759576E-12
   3        1.2895072E-16   -5.4569682E-12
   4        1.2895072E-16   -2.2351742E-08
   5        1.2895072E-16   -4.4703484E-08
   6        1.2895072E-16   -7.4505806E-09
```

<u>NOTE</u>: 1. Support card required for epsilon and strain energy.

TABLE 19

RIGID BODY MODE SHAPES

EIGENVALUE = 0.000000E+00
CYCLES = 0.000000E+00

REAL EIGENVECTOR NO. 2

POINT ID.	TYPE	T1	T2	T3	R1	R2	R3
2001	G	0.0	0.0	0.0	0.0	0.0	0.0
2002	G	0.0	0.0	0.0	0.0	0.0	0.0
2003	G	0.0	0.0	0.0	0.0	0.0	0.0
2102	G	0.0	1.000000E+00	0.0	0.0	0.0	0.0
2131	G	0.0	1.000000E+00	0.0	0.0	0.0	0.0
2704	G	0.0	1.000000E+00	0.0	0.0	0.0	0.0
2732	G	0.0	1.000000E+00	0.0	0.0	0.0	0.0
7010	G	4.446353E-01	8.957117E-01	0.0	0.0	0.0	0.0
7011	G	-4.446353E-01	8.957117E-01	0.0	0.0	0.0	0.0
7012	G	-4.446353E-01	8.957117E-01	0.0	0.0	0.0	0.0

GRIDS 7010 THRU 7012 OUTPUT
IN A LOCAL COORDINATE SYSTEM

EIGENVALUE = 0.000000E+00
CYCLES = 0.000000E+00

REAL EIGENVECTOR NO. 3

POINT ID.	TYPE	T1	T2	T3	R1	R2	R3
2001	G	0.0	0.0	0.0	0.0	0.0	0.0
2002	G	0.0	0.0	0.0	0.0	0.0	0.0
2003	G	0.0	0.0	0.0	0.0	0.0	0.0
2102	G	0.0	0.0	1.000000E+00	0.0	0.0	0.0
2131	G	0.0	0.0	1.000000E+00	0.0	0.0	0.0
2704	G	0.0	0.0	1.000000E+00	0.0	0.0	0.0
2732	G	0.0	0.0	1.000000E+00	0.0	0.0	0.0
7010	G	0.0	0.0	1.000000E+00	0.0	0.0	0.0
7011	G	0.0	0.0	1.000000E+00	0.0	0.0	0.0
7012	G	0.0	0.0	1.000000E+00	0.0	0.0	0.0

NOTES: 1. Eigenvalues and cycles are set equal to zero by the DMAP Alter Package.

TABLE 20

Alters To Be Used In NASTRAN Solution 3

```
$
$
$
$ ALTERS TO GENERATE RIGID BODY MODES - WORKS FOR 6 - DOF ON ONE
$      GRID SUPPORTED - GENERATES RIGID BODY MODES ABOUT THAT
$       POINT - NOTE....IF AN INDETERMINATE INTERFACE IS BEING
$       USED THEN THE ALTER CREATES THE "CONSTRAINT" MODES TO BE
$       USED IN COMPONENT MODAL SYNTHESIS USING THE CRAIG-BAMPTON
$       METHOD
ALTER 251
$ THE NUMBER 6 ON THE NEXT 2 CARDS IS THE NUMBER OF SUPORT D.O.F.
MATGEN /IDENT/1/6/ $
MATGEN /RBM/4/6/3/0/1/1/3/0/6/ $
UMERGE USET,DM,IDENT/DEAR1/A/L/R $
SDR1   USET,,DEAR1,,,GO,GM,,KFS,,/DEAR,,DEARQG/1/REIG $
MATPRN DM,MR,,,// $
$
$ FOLLOWING  LINES ADDED TO CONVERT 'RIGID BODY' MODES TO              (START 1)
$      BASIC COORDINATES - ONLY FOR INFORMATION AND CHECKING -
$      THAT IS IF CHECKING THE RIGID BODY MODES FOR CONSTRAINTS,
$      IT IS USUALLY EASIER TO LOOK AT THEM IN THE BASIC COORDINATE
$      SYSTEM, RATHER THAN IN THE GLOBAL (OUTPUT) COORDINATES.
$
$VECPLOT DEAR1,BGPDT,EQEXIN,CSTM,CASECC,/DEARBAS/0/0/1 $
LAMX   RBM,/LM $
$SDR2   CASECC,CSTM,MPT,DIT,EQEXIN,SIL,,,BGPDT,LM,,DEARBAS,,/
$       ,,ODEARBAS,,,/REIG $
$OFP    ODEARBAS,,,,//S,N,CARDNO $
$
$ END OF ALTER TO PRINT DEAR IN BASIC COORD                              (END 1)
$
$$
$$ FOLLOWING CARDS FOR DEAR IN OUTPUT COORD                            (START 2)
$$       THESE ARE THE RIGID BODY - OR INTERFACE - MODES IN OUTPUT
$$       COORDINATES.  THE ALTERS WILL ALSO CALCULATE THE ELEMENT
$$       FORCES, STRESS, AND STRAIN ENERGY IF REQUESTED IN THE CASE
$$       CONTROL. THESE ARE USEFUL IN FINDING ANY CONSTRAINTS IN THE
$$       MODEL IN THE RIGID BODY MODES AND ARE PART OF THE LOAD
$$       TRANSFORM MATRIX IN COMPONENT MODAL SYNTHESIS
$$
$ LAMX   RBM,/LM $
$ SDR2   CASECC,CSTM,MPT,DIT,EQEXIN,SIL,,,BGPDT,LM,,DEAR,,/
$       ,,ODEAR,,,/REIG $
$$ THE FOLLOWING CARD IS USED TO PRINT OUT THE RIGID BODY (OR
$$       INTERFACE) MODES
$ OFP    ODEAR,,,,//S,N,CARDNO $
$$
```

Notes: 1. Use mass normalization on the EIGR card.

TABLE 20 (Continued)

Alters To Be Used In NASTRAN Solution 3

```
$$$  FOLLOWING 3 CARDS USED TO CALCULATE THE ELEMENT STRESSES         (START 3)
$$$     AND FORCES ARE DESIRED FOR 'RIGID-BODY' (INTERFACE)
$$$     MODES.
$$$
SDR2    CASECC,CSTM,MPT,DIT,EQEXIN,SIL,ETT,,BGPDT,LM,DEARQG,DEAR,EST,
        XYCDB/DEAROPG1,DEAROQG1,ODEAR,DEAROES1,DEAROEF1,PDEAR/REIG $
OFP     ODEAR,DEAROPG1,DEAROQG1,DEAROEF1,DEAROES1//S,N,CARDNO $
$   THE FOLLOWING CARDS FIND THE ELEMENT STRAIN ENERGY (IF REQUESTED)
$       FOR THE RIGID BODY (INTERFACE) MODES
SETVAL   ////////////V,N,SOLTYPE/REIG $
COND NOESED,GPFDR $
COND NOESED1,ESE $
GPFDR CASECC,DEAR,KELM,KDICT,ECT,EQEXIN,GPECT,,,BGPDT,
      SIL,CSTM/DONRGY,DOGPFB1/SOLTYPE/C,Y,TINY $
$ THE FOLLOWING CARD PRINTS THE ELEMENT STRAIN ENERGY FOR THE
$      RIGID BODY (INTERFACE) MODES.
OFP DONRGY,DOGPFB1//S,N,CARDNO $
LABEL NOESED  $
LABEL NOESED1 $
$$$
$$$ END OF CARDS TO PRINT ELEMENT FORCES AND STRESSES                 (END 3)
$$$
$$
$$ END OF ALTER TO PRINT DEAR IN OUTPUT COORD                         (END 2)
$$
ALTER 416,416
$ PERFORM CANTILEVERED MODAL ANALYSIS - THE SUPORT D.O.F. ARE
$      CONSTRAINED AND THE ELASTIC ('CONSTRAINED') MODES ARE
$      CALCULATED
READ   KLL,MLL,,,EED,,CASECC/LAMA,PHIL,MI,OEIGS/C,N,MODES/S,N,NEIGV $
ALTER 419
$ THE FOLLOWING CARDS CALCULATE THE 'MER' (ELASTIC-RIGID) MATRIX
$    THIS MATRIX CAN BE USED IN THE CASE OF A DETERMINATE NUMBER
$    OF SUPORT D.O.F. TO FIND THE MODAL MASS
$
UMERGE USET,PHIL,/PHIX/V,N,MAJOR=A/V,N,SUBO=L/V,N,SUB1=R $
MPYAD  MLL,DM,MLR/TMP/C,N,0/C,N,1/C,N,1/C,N,1 $
MPYAD  PHIL,TMP,/MER/C,N,1/C,N,1/C,N,0/C,N,1 $
MPYAD  MER,MER,/MREMER/1//// $
TRNSP  MER/MERT $
TRNSP  MER/MERT1 $
$    THE FOLLOWING CARDS FIND THE 'EFMASS' OR EFFECTIVE MODAL MASS
$        MATRIX. IN THE CASE OF A DETERMINATE INTERFACE THIS MATRIX
$        REPRESENTS THE AMOUNT OF THE STRUCTURE'S TOTAL WEIGHT WHICH
$        IS ACTIVE IN EACH MODE. THE TOTAL OF THE TERMS GIVES AN IDEA
$        OF HOW WELL THE SYSTEM IS DEFINED BY THE NUMBER OF MODES
$        SELECTED. THE FACTOR OF 386.0886 IS USED TO SCALE THE VALUES
$        TO WEIGHT. THIS VALUE SHOULD BE CHANGED FOR DIFFERENT UNITS.
```

TABLE 20 (Continued)

Alters To Be Used In NASTRAN Solution 3

```
ADD    MERT,MERT1/EFMASS/(386.0886,0.)//C,Y,OPT=1 $
$  THE FOLLOWING CARD PRINTS THE MER,MR EFMASS AND MREMER MATRICES.
$      IN THE CASE OF A DETERMINATE INTERFACE, THE MERMRE MATRIX IS
$      THE AMOUNT OF THE RIGID BODY (MR) MASS MATRIX WHICH IS IN THE
$      MODES SELECTED.
MATPRN MER,MR,EFMASS,MREMER,// $
$
$ ALTER TO CALCULATE PERCENT ENERGY AT DISP SET FOR ALL MODES        (START 4)
$       THIS WILL CALCULATE THE KINETIC ENERGY AT ALL MASS D.O.F.
$       FOR THE MODES FOUND. THE VALUES ARE ALL SCALED SUCH THAT
$       THE SUM OF ALL THE TERMS FOR ANY MODE WILL ADD UP TO 1.0.
$       NOTE THAT THERE IS A FILTER OF .01 OR 1% APPLIED TO THE
$       VALUES BEFORE THEY ARE PRINTED OUT. THE OUTPUT IS IN THE
$       FORM OF AN EIGENVECTOR, EXCEPT THERE ARE MANY 0.0 TERMS
$       DUE TO THE FILTER AND POINTS WHICH HAVE NO MASS. THIS
$       MAKES THIS AN EFFECTIVE WAY TO IDENTIFY THE MODES.
ALTER 455
MPYAD  UGV,MGG,/PHITM/1//// $
TRNSP  PHITM/PHITMT $
ADD    PHITMT,UGV/ENERG///C,Y,OPT=1 $ ENERG=INTERNAL SORT
MATMOD ENERG,,,,,/ENERG1,/2////.01 $ TO REMOVE TERMS < 1%
SDR2   CASECC,CSTM,MPT,DIT,EQEXIN,SIL,,,BGPDT,LAMA,,ENERG1,,/
       ,,ENERGY,,,PENERGY/REIG $
OFP    ENERGY,,,,//S,N,CARDNO $
$
$ FOLLOWING ALTERS TO PLOT 'ENERGY'                                  (START 5)
$         THESE ARE EXPERIMENTAL AND NOT VERIFIED AS YET. THEY
$         ARE SUPPOSED TO PLOT THE ENERGY VALUES AS IF THEY
$         WERE A MODE SHAPE. THERE HAS TO BE PLOT CASE CONTROL. I
$         RECOMMEND A VECTOR PLOT OF THE DISPLACEMENTS.
$ALTER 480,480
$GPFDR  CASEXX,ENERGY,KELM,KDICT,ECT,EQEXIN,GPECT,PG1,QG,BGPDT,SIL,CSTM,
$       VELEM/ONRGY1,OGPFB1/SOLTYPE/C,Y,TINY $
$ALTER 500,500
$PLOT   PLTPAP,GPSETP,ELSETP,CASEXX,BGPDT,EQEXIN,SIL,PENERGY,PENERGY,
$       GPECT,OES1/PLOTX2/DSIL/LUSET/JUMPPLOT/PLTFLG/S,N,PFILE $
$
$ END OF ALTER TO PLOT ENERGY                                          (END 5)
$
$
$ END OF ALTER TO CALCULATE ENERGY AT DISP SET                         (END 4)
$
ENDALTER
$
$
$ MLS DELIVERABLE MODEL - DYNAMICS RUN WITH FIXED INTERFACE D.O.F.
$
```

TABLE 21

Alters To Be Used In NASTRAN Solution 3

```
SOL 3
TIME 100
$
$ NASTRAN ALTERS TO CALCULATE EFFECTIVE MASS AND THE ENERGY DISTRIBUTION OF A
$ MODE
$
$         WRITTEN AT J.P.L.
$                 BY TED ROSE
$
ALTER 449
$
$ ALTER TO CALCULATE EFFECTIVE MASS OF THE MODES
VECPLOT ,,BGPDT,EQEXIN,CSTM,,/RBMODES/V,Y,MPFPNT=0//4 $
TRNSP  RBMODES/RBMTRN $
SMPYAD UGV,MGG,RBMTRN,,,/MER/3////-1//// $
MPYAD  MER,MER,/MREMER/1//// $
TRNSP  MER/MERT $
TRNSP  MER/MERT1 $
ADD    MERT,MERT1/EFMASS/(386.0886,0.)//C,Y,OPT=1 $
MATPRN MER,MR,EFMASS,MREMER,// $
$
$ ALTER TO CALCULATE PERCENT ENERGY AT DISP SET FOR ALL NODES        (START 4)
$
ALTER 455
MPYAD  UGV,MGG,/PHITM/1//// $
TRNSP  PHITM/PHITMT $
ADD    PHITMT,UGV/ENERG///C,Y,OPT=1 $ ENERG=INTERNAL SORT
MATMOD ENERG,,,,,/ENERG1,/2////.0025 $ TO REMOVE TERMS < .25%
SDR2   CASECC,CSTM,MPT,DIT,EQEXIN,SIL,,,BGPDT,LAMA,,ENERG1,,/
       ,,ENERGY,,,PENERGY/REIG $
$OFP    ENERGY,,,,//S,N,CARDNO $
MATGPR GPL,USET,SIL,ENERG//G///1.-2 $
$
ENDALTER
```

Notes: 1. Use mass normalization on EIGR card.

2. The above ALTER package works with or without a SUPORT card.

TABLE 22

Galileo Spacecraft Baseline Model
Modal Weight and Inertia (Lb, Lb-in^2)

Mode	X	Y	Z	RX	RY	RZ
1	0	0	0	2.5E+00	2.3E+03	8.3E+01
2	0	0	1	2.3E+03	3.4E-01	5.0E-02
3	1188	479	0	7.9E+06	2.1E+07	2.2E+03
4	489	1144	0	2.0E+07	8.7E+06	6.2E+02
5	2	1888	3	8.2E+06	1.2E+04	1.0E+02
6	1097	5	0	1.7E+05	5.7E+06	9.2E+05
7	1007	10	0	3.1E+05	5.5E+06	3.2E+05
8	1	296	0	5.2E+06	8.9E+03	2.1E+05
9	45	3	0	9.4E+04	2.4E+05	1.2E+05
10	11	554	33	3.5E+06	5.3E+04	1.5E+02
11	533	0	31	2.0E+02	3.2E+06	2.8E+04
12	5	6	221	3.5E+04	2.9E+04	9.0E+05
13	41	25	770	1.1E+05	1.9E+05	4.0E+05
14	3	29	84	1.8E+05	3.5E+04	7.0E+05
15	9	0	7	7.9E+02	9.2E+04	5.2E+05
16	0	24	6	3.3E+04	3.4E+02	1.4E+04
17	2	0	63	3.9E+04	4.6E+03	3.6E+03
18	50	86	1	6.9E+04	7.7E+04	6.1E+05
19	2	0	35	2.8E+04	3.4E+03	1.1E+04
20	27	196	0	1.6E+05	3.4E+04	3.8E+05
21	55	6	1	2.4E+03	7.3E+04	7.8E+03
22	15	51	40	4.6E+04	2.9E+04	1.2E+04
23	6	19	3055	2.2E+04	2.6E+04	6.5E+04
24	100	0	479	4.3E+04	2.9E+05	1.2E+05
25	8	15	5	1.0E+04	2.5E+04	1.4E+04
26	157	7	15	3.6E+03	2.2E+05	5.2E+03
27	1	1	149	3.1E+04	1.8E+03	1.5E+04
28	21	1	30	7.0E+04	2.8E+04	1.5E+04
29	0	1	0	6.6E+03	1.6E+03	5.0E+00
30	10	1	0	1.2E+03	1.2E+04	9.0E+03
31	71	138	9	4.2E+05	1.3E+05	7.0E+03
32	67	5	0	2.6E+04	5.3E+04	1.6E+02
33	22	38	20	8.9E+04	6.7E+04	3.8E+02
34	2	47	6	1.3E+03	4.2E+04	3.1E+01
35	67	49	1	8.2E+04	2.0E+05	2.2E+02
36	0	0	0	1.5E+02	1.4E+01	1.4E+01
37	0	0	0	3.5E+02	4.1E+02	1.2E+02
38	0	10	0	5.4E+04	2.7E+04	3.0E+02
39	13	1	6	4.7E+03	8.6E+03	1.8E+03
40	6	22	0	1.5E+03	1.8E+03	1.8E+04
41	7	2	8	2.3E+01	3.4E+03	8.7E+03
42	12	11	41	4.9E+04	1.4E+04	5.6E+03
43	0	8	1	8.9E+03	3.6E+01	1.9E+04

TABLE 22 (Continued)

Galileo Spacecraft Baseline Model
Modal Weight and Inertia (Lb, Lb-in^2)

Mode	X	Y	Z	RX	RY	RZ
44	0	3	8	1.4E+04	1.2E+03	2.9E+04
45	0	0	49	1.3E+04	4.1E+01	6.7E+03
46	9	29	0	1.7E+04	2.2E+04	5.3E+03
47	1	0	4	1.6E+03	6.2E-01	4.9E+03
48	0	2	13	1.9E+04	5.0E+02	4.1E+03
49	4	3	66	1.2E+04	1.8E+04	1.7E+04
50	0	0	4	1.0E+03	6.7E+02	6.1E+02
51	0	18	0	1.6E+04	6.2E+03	3.7E-02
52	1	4	3	1.8E+04	8.9E+02	4.6E+02
53	2	7	1	2.6E+04	4.1E+03	4.2E+02
54	0	0	1	2.6E+02	7.5E+03	8.3E+02
55	14	3	0	1.4E+04	8.4E+04	2.5E+02
56	0	6	0	7.5E+03	9.3E+03	2.8E+03
57	9	14	1	1.1E+04	1.3E+03	3.5E+02
58	0	0	2	1.8E+03	2.6E+03	4.6E+03
59	27	15	0	3.8E+04	3.6E+04	8.4E+03
60	1	25	4	6.4E+04	6.5E+03	3.6E+03
61	42	12	3	3.7E+04	6.8E+04	9.1E+03
62	15	11	0	1.5E+04	2.6E+04	3.3E+04
63	0	1	0	1.4E+03	3.8E+03	2.8E+00
64	31	11	0	3.5E+03	6.6E+04	1.2E+05
65	3	1	1	1.0E+02	6.9E+02	2.1E+04
66	0	0	0	6.6E+02	3.4E+01	1.5E+03
67	2	0	4	4.5E+02	1.3E+04	1.4E+04
68	3	3	0	3.4E+03	9.3E+02	1.7E+03
69	0	0	2	4.1E-01	2.5E+02	8.1E+01
70	0	8	0	4.1E+04	4.7E+01	1.0E+04
TOTAL:	5316	5355	5287	4.69E+07	4.61E+07	5.76E+06
RIGID	5591	5591	5591	4.74E+07	4.67E+07	6.19E+06
MODAL%	0.95	0.96	0.95	0.99	0.99	0.93

TABLE 23

MER-MREMER-MR-EFMASS

```
$        PERFORM CANTILEVERED MODAL ANALYSIS
ALTER    416,416
READ     KLL,MLL,,,EED,,CASECC/LAMA,PHIL,MI,OEIGS/C,N,MODES/S,N,
         NEIGV $
ALTER    419
$        THE FOLLOWING CARDS CALCULATE 'MER'
UMERGE   USET,PHIL,/PHIX/V,N,MAJOR=A/V,N,SUBO=L/V,N,SUB1=R $
MPYAD    MLL,DM,MLR/TMP/C,N,0/C,N,1/C,N,1/C,N,1 $
MPYAD    PHIL,TMP,/MER/C,N,1/C,N,1/C,N,0/C,N,1 $
MPYAD    MER,MER,MREMER/1//// $
TRNSP    MER/MERT $
TRNSP    MER/MERT1 $
$        CALCULATE THE EFFECTIVE MODAL MASS MATRIX
ADD      MERT,MERT1/EFMASS/(386.0886,0.)//C,Y,OPT=1 $
$        PRINT THEM OUT
MATPRN   MER,MR,EFMASS,MREMER,// $
$
$        CALCULATE KINETIC ENERGY OF MODES AT MASS DOF.
$        NORMALIZED TO UNITY, WITH A .01 FILTER
$
ALTER    455
MPYAD    UGV,MGG,/PHITM/1//// $
TRNSP    PHITM/PHITMT $
ADD      PHITMT,UGV/ENERG//C,Y,OPT=1 $ ENERG=INTERNAL SORT
MATMOD   ENERG,,,,,/ENERG1,/2////.01 $ TO REMOVE TERMS < 1%
SDR2     CASECC,CSTM,MPT,DIT,EQEXIN,SIL,,,BGPDT,LAMA,,ENERG1,,/,,
         ENERGY,,,PENERGY/REIG $
OFP      ENERGY,,,,//S,N,CARDNO $ Prints as Eigenvectors
MATGPR   GPL,USET,SIL,ENERG//G///1.-2 $ Prints Summary
```

Notes: 1. Use mass normalization on the EIGR card.

2. Use of SUPORT card is required.

TABLE 24

Galileo Baseline S/C Modal Frequencies

Mode	Freq	Mode Description	Kinetic Energy Distribution
1	6.3	PWS Antenna	PWS, 100%
2	6.8	PWS Antenna	PWS, 100%
3	13.7	SXA bending, X	SXA 45%, RPM 22%
4	13.7	SXA bending, Y	SXA 48%, RPM 21%
5	16.7	Probe, Y	Probe 83%
6	18.2	Sciboom X, core torsion	Sciboom 45%, SXA 20%
7	18.5	Probe X	Probe 53%
8	18.6	SXA Y	SXA 41%, Probe 9%
9	19.0	Probe X, SXA X	SXA 34%, Probe 32%
10	22.2	Sciboom Z bounce	Sciboom 57%
11	22.7	RTGs Z bounce, -phase	RTGs 61%, RPM 19%
12	23.8	Nutation damper lateral	Nutation Damper 51%
13	24.3	RTGs Z bounce, in phase	RTGs 61%
14	25.7	Nutation damper lateral	Nutation Damper 52%,
15	27.0	Nutation damper lateral	Nutation Damper 70%,
16	28.5	RRH Antenna, Y	RRH 48%, EPD 22%
17	28.7	Scan platform theta X	Scan platform 96%
18	29.7	-X RTG lateral (Y)	-X RTG 96%
19	31.9	Scan sunshade (Z)	Sunshade 92%
20	32.5	+X RTG lateral (Y)	+X RTG 93%
21	33.7	PLS+RRH+Sciboom	PLS 31%
22	35.4	EPD+PLS+Sciboom	PLS 31%
23	38.0	S/C Z bounce	RPM 54%, Probe 10%
24	38.3	Scan platform X	Scan 73%, RPM 16%
25	38.6	PLS+EPD+Thrusters	PLS 40%, EPD 21%
26	40.4	Probe torsion, RPM	Probe 50%
27	40.8	-X Thruster, RPM	RPM 53%
28	41.3	Sciboom mag tip, box	Sciboom 47%
29	43.1	Thrusters lateral (Y)	Thrusters 89%
30	43.3	RRH antenna X	RRH 95%
31	44.9	RPM tanks, probe torsion	RPM 38%, Probe 17%
32	45.8	-X RTG X motion	-RTG 57%
33	46.1	Sciboom, misc	Sciboom 49%, Scan 20%
34	46.7	Scan platform Z, X	Scan platform 53%
35	47.7	400N engine, Probe tors	400N 13%, Probe 10%
36	48.0	-X Thruster torsion	-X Thruster 95%
37	48.1	+X Thruster torsion	+X Thruster 95%
38	48.3	400N engine X, SBA	400N 56%, SBA 27%
39	48.8	400N engine Y, SBA	400N 43%, SBA 19%
40	49.6	RPM+Despun Box Z bounce	RPM 32%, Despun box 17%

TABLE 24 (Continued)

Galileo Baseline S/C Modal Frequencies

Mode	Freq	Mode	Freq	Mode	Freq
41	50.0	51	61.1	61	77.4
42	50.9	52	63.6	62	78.9
43	51.7	53	64.2	63	80.3
44	52.2	54	66.6	64	80.7
45	53.4	55	69.1	65	81.9
46	54.5	56	71.8	66	82.4
47	55.0	57	72.3	67	83.2
48	55.9	58	74.3	68	83.8
49	57.1	59	75.6	69	84.2
50	58.8	60	76.1	70	87.0

TABLE 25

Model Summary

No. of GRIDS	1651
No. of Static DOF	6772
No. of Finite Elements	2928
CBAR	1591
CBEAM	72
CELAS2	3
CONM2	306
CONROD	119
CQUAD4	627
CROD	98
CSHEAR	114
CTRIA3	304
RBAR	43
RBE2	122
RBE3	76
No. of MASS DOF	1675*
No. of DYNAMIC DOF (ASET)	182
No. of Modes Retained - Loads Anal.	70
Frequency Upper Bound - Loads Anal.	87.0

*Contains approximately 700 DOF through use of density option on the material cards.