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BLADE LOSS TRANSIENT DYNAMICS ANALYSIS

VOLUME III

USER'S MANUAL FOR TETRA PROGRAM

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1.0 INTRODUCTION

The use of any new and unfamiliar tool is often accompanied by errors from misunderstanding or simply from lack of experience. The TETRA program is no exception. However, care has been taken to minimize these problems in the use of TETRA as a computational tool for engine dynamics.

Based on the modal synthesis approach, the component element method employed in TETRA follows a modular or building block scheme both in the construction of the mathematical model of an engine to be analyzed and in the architecture of the program structure, subroutines and nomenclature. It cannot be overemphasized the importance in keeping this idea of modular construction in mind while preparing the schematic of the engine model and the inputs for TETRA.

The turbine engine is described by a reduced system of second order differential equations and a solution for the transient response is obtained through an explicit numerical integration scheme - the central finite difference method. Global stiffness and damping matrices are not assembled and only the right hand side of the system of equations, i.e., the forces, is updated at each time step. The differential equations are formulated in terms of generalized coordinates and model elastic and rigid body elements and elements that represent physical connections. In the former case, the elements are obtained through the coordinate transformations that are associated with the free-free modes and partially constrained modes computed for engine subsystem structures (rotors, case, pylon). In the latter case, the elements describe the physical connections between the subsystem structures. These connections can be nonlinear and are defined with bearing/frame springs and dampers, engine support elements, link elements, rotor-case rub springs or stop elements, and gyroscopic cross-axis coupling elements. The rotor-case rub springs are used to model the additional load path between the rotor and the case that exists for the large rotor excursions caused by high rotor unbalance. For this element, the effect of the force dead band associated with the structural clearance is included in the formulation for the effective restoring forces.

One should begin with a schematic of the structure to be analyzed; this would probably have had its normal modes and frequencies calculated. Using a unified coordinate axis, one would identify the various structural subsystems into which the whole structure could be broken down, to be followed by establishing the connecting elements, their locations, subsystems joined and their mechanical characteristics (spring rates, damping). The normal modes of each structural subsystem may then be calculated in a program such as GE's VAST or finite element programs with eigenvalue capability such as SAP4, NASTRAN, etc. From these modal calculations, one chooses the modes and number of modes to represent each subsystem, and then generate the modal input file.

Next, the engine operating conditions such as speed, amount and location of unbalance, time interval or external excitation are chosen. Finally, the joints where loads and displacements are to be printed out are defined.

The assembly of the entire engine is made by the sequence and type of inputs and the NAMELIST input provides ease and flexibility in input preparation. Following the input instructions closely and in the sequence in which these are presented in this manual, will minimize the errors and any confusion in using this new program.

2.0 DESCRIPTION OF TETRA

The transient dynamic analysis method used in the TETRA (Turbine Engine Transient Response Analysis) program is based on a component element approach. The component elements consist of elastic and rigid body elements described by generalized coordinates obtained by coordinate transformations, and physical connecting elements that model bearing/frame springs and dampers, rotor-case rub springs and gyroscopic cross-axis coupling effects.

The generalized coordinates are based on the free-free modes and partially constrained modes associated with engine subsystem structures (rotor, casing, pylon). The method extends the conventional modal analysis procedure to account for physical damping and symmetric stiffness terms, and rotor-case rubs including the effects of the force deadband associated with the structural clearance.

An efficient numerical time integration scheme - the central finite difference method - is used to obtain the solution through an explicity step-by-step calculation.

For each generalized coordinate, a differential equation is formed which relates the current generalized accelerations to the current generalized forces as follows:

$$m_i \ddot{q}_i = Q_i, \; i : 1, 2, 3, 4, \ldots\ldots \tag{1}$$

$\ddot{q}_i$ are the current generalized accelerations

Q_i are the current generalized forces

m_i are the generalized masses

Figure 1 shows a schematic of a subsystem and physical component element definition for an engine system. The nonlinearities can be treated with the physical connecting elements, and the subsystem natural modes are used to define regions of the engine system which are expected to remain linear. As

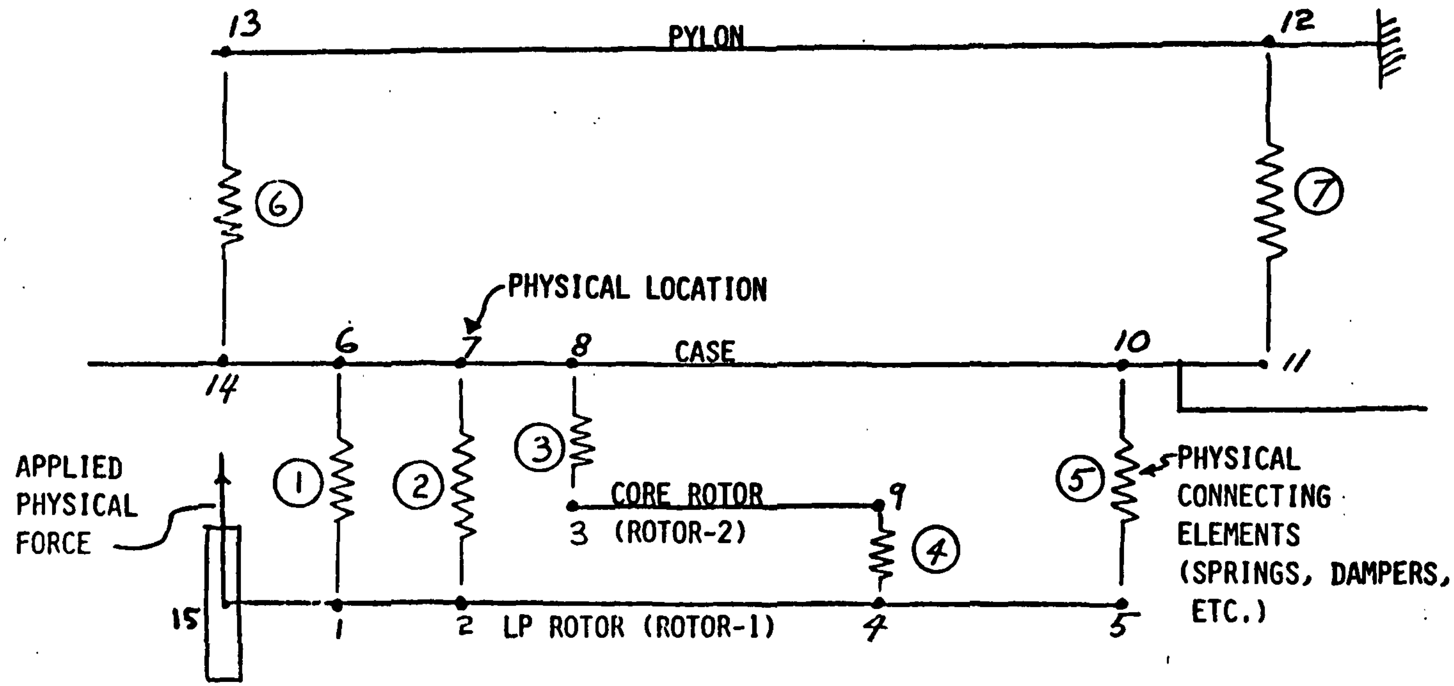


Figure 1. Typical Subsystem and Physical Component Representation of an Engine System.

long as the nonlinearities are not severe enough to induce operating regimes where the original modes are totally unrepresentative, then the use of the natural modes is effective.

The major TETRA subroutines where the transformations and the numerical integration of the generalized differential equations is performed are identified in Figure 2.

The task of establishing the current total generalized forces Q_i acting on each of the generalized coordinates q_i is accomplished in the subroutine GEN. The current physical displacements and velocities, needed to establish the physical coupling forces used by GEN in the formation of the generalized forces, are determined in subroutine CURRT which transforms the modal displacements q_i into real space at each time step. It will be noted that in computing the generalized forces from the physical displacements and velocities, that a transformation from real space to generalized space is performed by subroutine GEN for each time step. The generalized forces also include the effects of applied physical forces which are not displacement or velocity dependent, such as unbalance forces. The generalized forces and the generalized masses are utilized in subroutine TILOOP to compute the generalized accelerations using equation*(6), and to compute the future values of the generalized displacements using the central finite difference method as shown in equation*(9).

*These equations are given as labeled in Section 3.0 Volume II of the "Blade Loss Turbine Engine Dynamic Analysis Program."

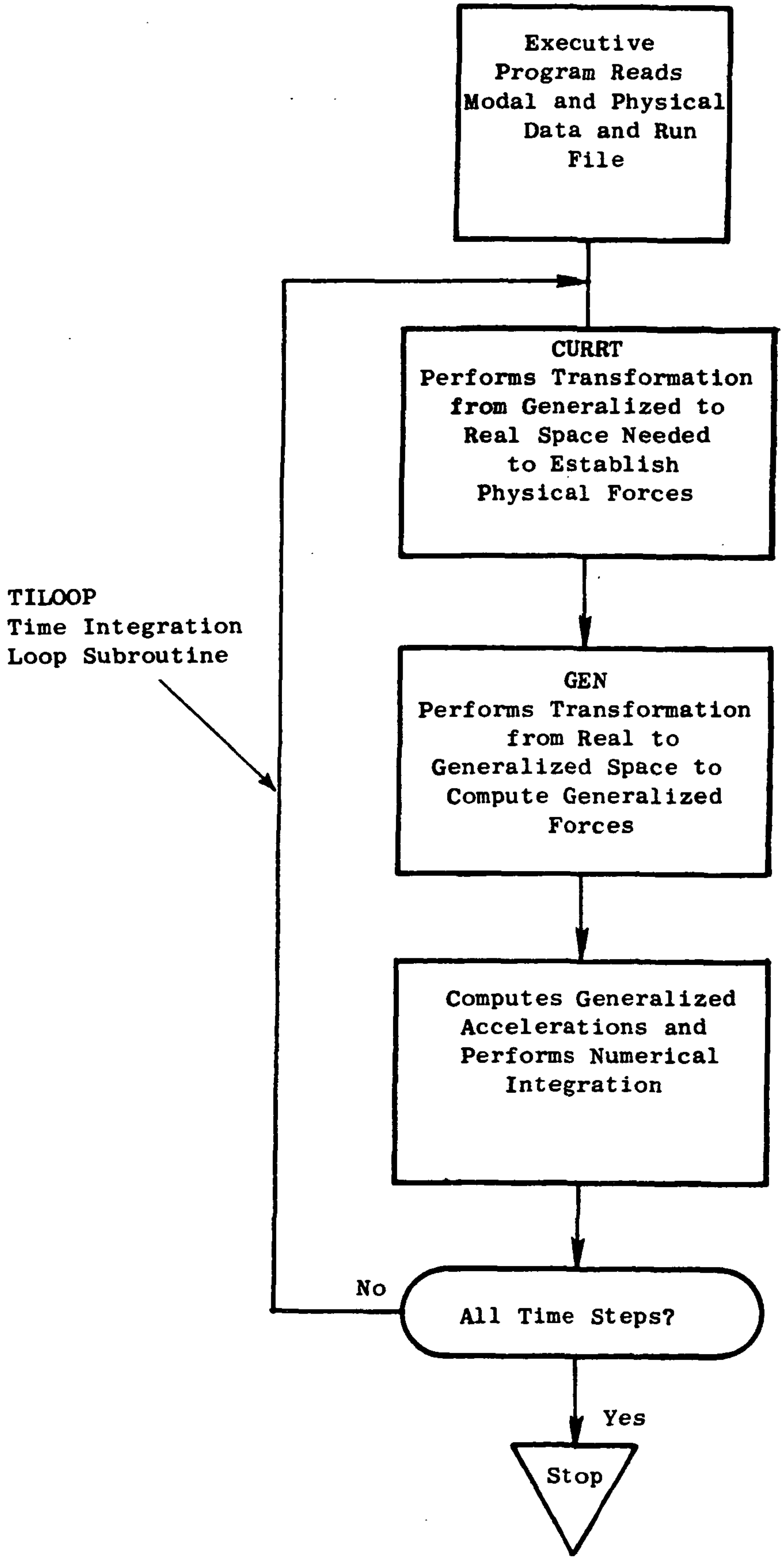


Figure 2. TETRA Routines for Transformations and Numerical Integration.

The modal subsystem numbers, types, and the regions they represent are identified in Figure 3. The number of directions (physical degrees of freedom) and the direction numbers associated with these degrees of freedom are listed in Figure 4.

Eleven triple subscripted arrays are used to store the subsystem mode shape data.

S_i (I, J, K) = Mode shape modal displacements for the i-th modal subsystem.

i = 1, 2, 3, ..., 11 (see Figure 3)

I identifies the generalized coordinate

J identifies the location or point on the mode shape

K identifies the direction (see Figure 4)

The S_i array data are used to define the coupling ratios, B_i, r, d needed to perform the transformations between real and generalized space. The coupling ratio B_i, r, d is the deflection at point r in the direction d for a unit value of the i-th generalized coordinate.

The physical displacement and velocity data for the current time step are stored in the arrays X(I, J) and VEL(I, J), respectively.

I = The point number

J = The direction number (direction numbers 1 - 6)

The generalized coordinate values are stored in the array Z(I, J).

Z(I, J) = Present and previous values for the generalized coordinates

I = Generalized coordinate number

J = 1 for current time (0), 2 for one previous time step (-1), 3 for two previous time steps (-2).

The generalized masses, stiffnesses and damping coefficients for the governing differential equations are stored in the arrays ZM, ZK, and ZC.

ZM(I) = Generalized masses

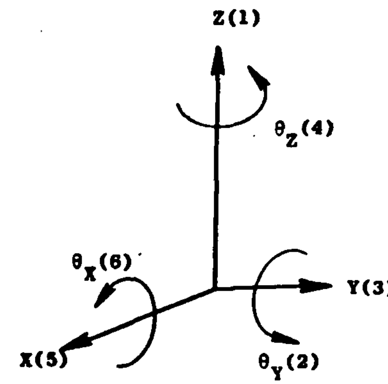
ZK(I) = Generalized stiffnesses

ZC(I) = Generalized damping coefficients

Figure 3. Modal Subsystems.

NO.	SUBSYSTEM	TYPE
1	VERTICAL PLANE ROTOR-1 MODEL	FLEXIBLE-PLANAR
2	HORIZONTAL PLANE ROTOR-1 MODEL	FLEXIBLE-PLANAR
3	3D RIGID BODY ROTOR-1 MODEL	RIGID WITH 5DOF
4	VERTICAL PLANE ROTOR-2 MODEL	FLEXIBLE-PLANAR
5	HORIZONTAL PLANE ROTOR-2 MODEL	FLEXIBLE-PLANAR
6	3D RIGID BODY ROTOR-2 MODEL	RIGID WITH 5DOF
7	VERTICAL PLANE CASE MODEL	FLEXIBLE-PLANAR
8	HORIZONTAL PLANE CASE MODEL	FLEXIBLE-PLANAR
9	3D RIGID BODY CASE MODEL	RIGID WITH 6 DOF
10	TORSIONAL CASE MODEL	FLEXIBLE-TWIST
11	3D FLEXIBLE PYLON (WING) MODEL	FLEXIBLE-3D

SUBSYSTEM MODEL		DIRECTIONS		
SUBSYSTEM	DESCRIPTION	NUMBER	Global DIR. NUMBERS	
1	ROTOR-1 VERT. PLANE FLEX. MODEL	2	K=1 K=2	
2	ROTOR-1 HOR. PLANE FLEX. MODEL	2	K=3 K=4	
3	ROTOR-1 RIGID BODY MODEL	5	K=1 K=2 K=3 K=4 K=5	
4	ROTOR-2 VERT. PLANE FLEX. MODEL	2	K=1 K=2	
5	ROTOR-2 HOR. PLANE FLEX. MODEL	2	K=3 K=4	
6	ROTOR-2 RIGID BODY MODEL	5	K=1 K=2 K=3 K=4 K=5	
7	CASE VERT. PLANE FLEX. MODEL	2	K=1 K=2	
8	CASE HOR. PLANE FLEX. MODEL	2	K=3 K=4	
9	CASE RIGID BODY MODEL	6	K=1 K=2 K=3	K=4 K=5 K=6
10	CASE-TORSIONAL FLEX. MODEL	1	K=6	
11	PYLON-3D FLEX. MODEL	3	K=1 K=3	K=5



Global Coordinate System

Figure 4. Modal Degrees of Freedom.

The physical coupling forces used in the formation of the generalized forces are computed by multiplying the physical displacements and velocities into the connecting element stiffness and damping matrices, respectively and then adding the results. The current values for the physical connecting element data are stored in the arrays AKE_i and ADE_i.

$AKE_i(I,J,K)$ = Stiffness array for the i-th physical connecting element type.

$ADE_i(I,J,K)$ = Damping array for the i-th physical connecting element type.

i = 1,2, ... Identifies the physical connecting element type. For example, the generalized spring-damper element, the rub element, etc.

I Identifies the physical connecting element number.

J Identifies the row number associated with a force for a given point and direction.

K Identifies the column number associated with a displacement for a given point and direction.

The information needed to identify the locations of the AKE and ADE array elements is provided in the following arrays.

ICOMPJ (I) = Number of points for element I.

ICOMPE (I,J) = The global point numbers for element I associated with the J-th point.

ICOMPD (I,J) = The number of directions for element I associated with the J-th point.

ICOMPN (I,J,K) = The direction numbers for element I associated with the J-th point and the K-th direction.

2.1 OVERALL PROGRAM STRUCTURE: DESCRIPTION OF TETRA AND FLOW CHARTS

The TETRA program consists of a main routine, a function subprogram, and twenty-nine subroutines. A brief description of the function subprogram and each of the twenty-nine subroutines is given in Figure 5. Figure 6 shows

IROUND	Function subprogram which rounds off floating point numbers
INIT	Initializes variables and arrays
SYBSYS	Processes data for the modal subsystems
FLEX	Finds flexible subsystem mode shapes
RBODY	Computes rigid body mode shapes
CONEL	Processes data for the physical connecting elements
ELEM1	Processes spring-damper (type 1) physical connecting element data
ELEM2	Processes link-damper (type 2) physical connecting element data
ELEM3	Processes rub (type 3) physical connecting element data
ELEM4	Processes engine support-links (type 4) physical connecting element data
ELEM5	Processes data for the uncoupled point spring-damper (type 5) physical connecting elements
STIFFE	Computes stiffness matrix for engine support element
STIFFT	Computes stiffness matrix for link elements that are to be combined with engine support element
INVERT	Matrix inversion and determinant calculation for engine support-links (type 4) physical connecting element
MATM	Matrix multiplication engine support-links (type 4) physical connecting element
UBAL	Processes unbalance load data
SINCOS	Processes Pcos wt and Psin wt load data
FORHIS	Processes force-time history load data
GYROE	Processes gyroscopic load data
PLOTD	Processes data for output plot file
SCAN	Establishes element/subsystem connections
TILOOP	Time integration loop
ROPROP	Calculates rotor properties (speed, acceleration, and angular displacement)
CURRT	Computes current physical displacements, velocities, and modal forces
FMODES	Provides modal displacements and modal forces
FORCE	Computes physical connecting element and gyro element forces
APFOR	Computer applied forces
GEN	Computes generalized forces
MODES	Computes modal displacements
LISTPF	Prints at least a partial listing of the output plot file

Figure 5. TETRA Subprograms.

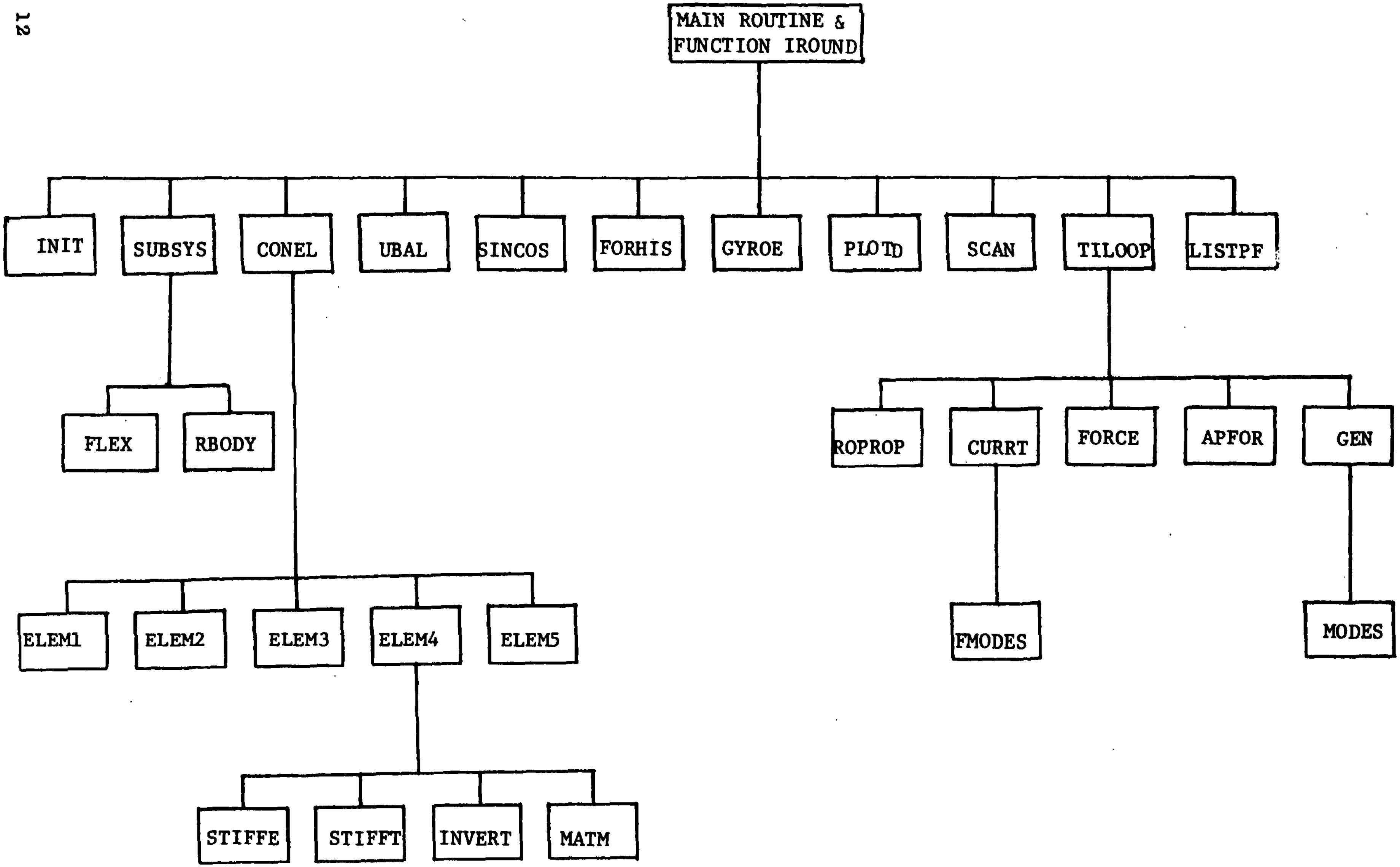


Figure 6. TETRA Program.

the hierarchy of the program, and a flow chart of the overall program is given in Figure 7. Flow charts of the main routine, function subprogram, and all the subroutines are given in Figures 8 through 38.

In general, left to right order in Figure 6 is the order in which the subroutines are executed. First, subroutine INIT, which initializes various program arrays and variables is executed. Then comes the subroutine SUBSYS, which processes data for each of the modal subsystems in turn. If a particular subsystem is a rigid body subsystem (subsystem 3, 6, or 9), subroutine RBODY is called by subroutine SUBSYS to calculate the rigid body mode shapes. If the subsystem is not a rigid body subsystem (subsystem 1, 2, 4, 5, 7, 8, 10, or 11), however, subroutine FLEX is called to find the mode shapes.

Next, subroutine CONEL is called, which processes data for each of the physical connecting elements in turn. For each physical connecting element, subroutine ELEM1, ELEM2, ELEM3, ELEM4, or ELEM5 will be called from subroutine CONEL depending whether the physical connecting element type is 1, 2, 3, 4, or 5, respectively. For type 4 physical connecting elements, subroutines STIFFE, STIFFT, INVERT, and MATM are also called from subroutine ELEM4.

The next subroutines executed are UBAL, SINCOS, FORHIS, GYROE, PLOTD, and SCAN (in that order). Subroutine SCAN is the last subroutine called prior to when the time integration is performed. The purpose of the subroutines mentioned thus far is, in general, to process data in preparation for the time integration. The program progresses very rapidly through subroutine SCAN, since the previously mentioned subroutines are executed only once or a small number of times.

Subroutine TILOOP, which consists of the time integration loop, comes next. For each time step the subroutines ROPROP, CURRT, FORCE, APFOR, and GEN are called by subroutine TILOOP. In addition, subroutine FMODES gets called many times by subroutine CURRT and subroutines MODES gets called many times by subroutine GEN. Nearly all of the process time for the program is used by TILOOP and the associated subroutines (unless there are only a very few time steps).

Finally, after the time integration is completed, subroutine LISTPF is called, which lists out part or all of the output plot file.

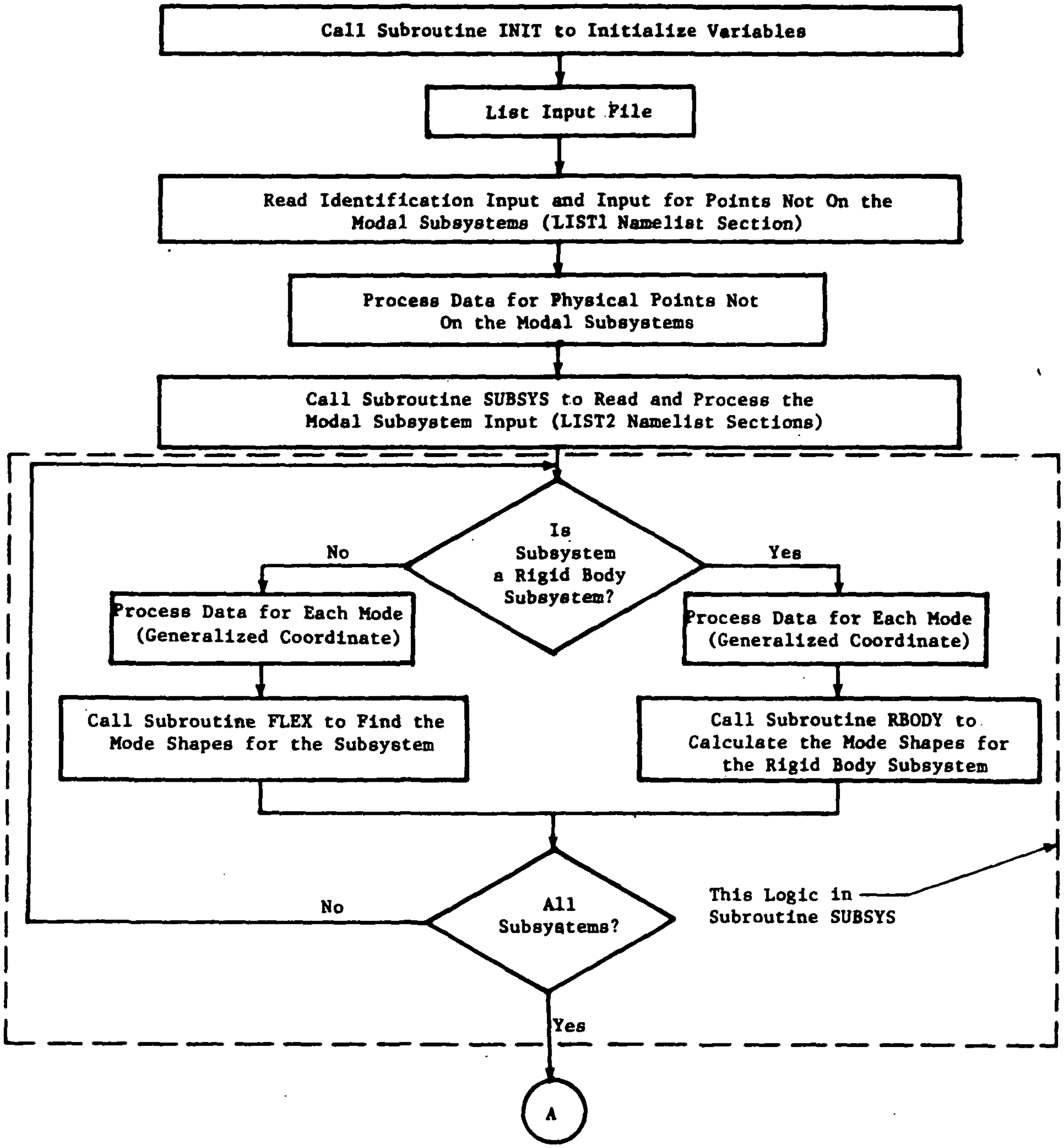


Figure 7. TETRA Flow Chart.

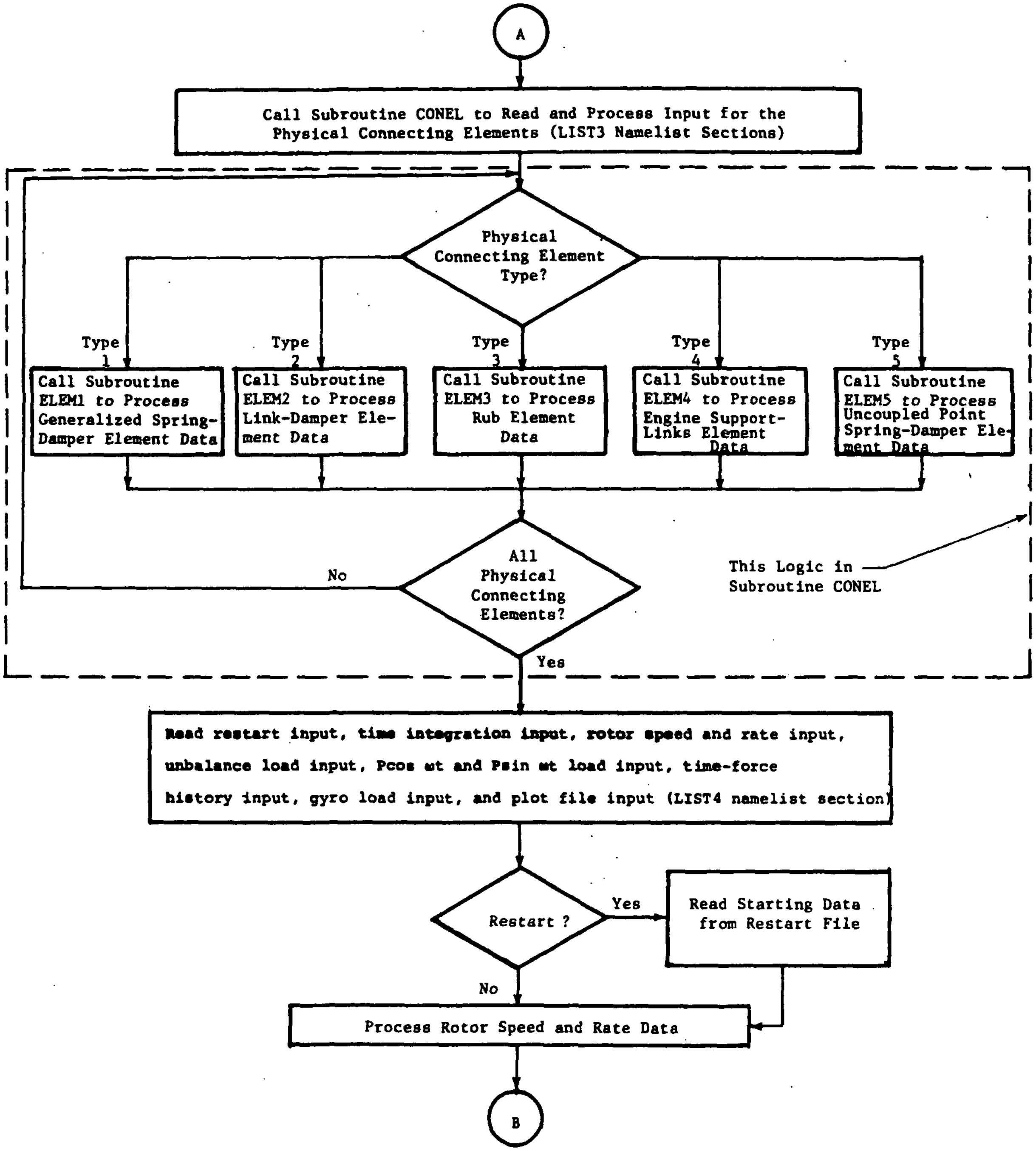


Figure 7. TETRA Flow Chart (Continued).

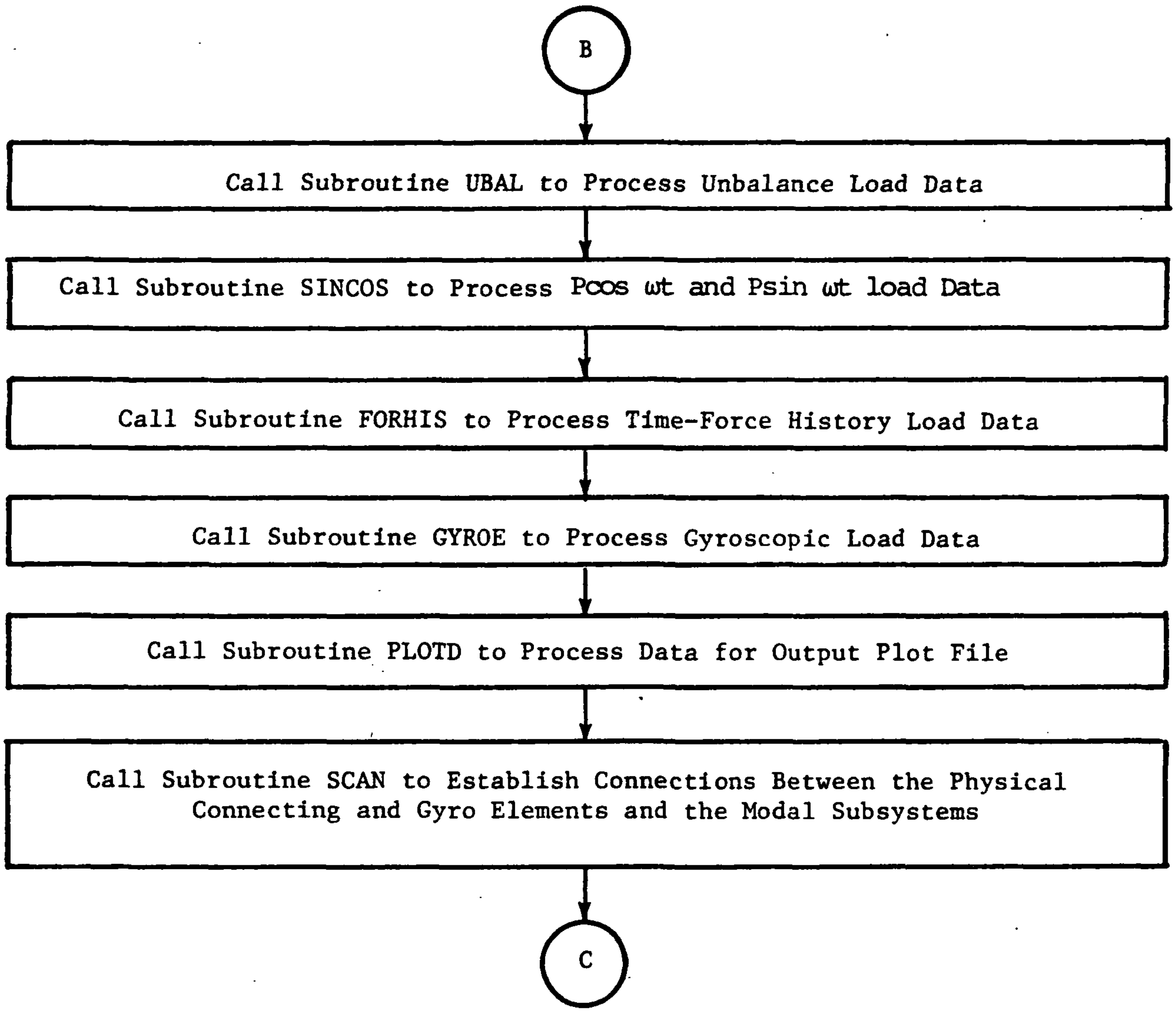


Figure 7. TETRA Flow Chart (Continued).

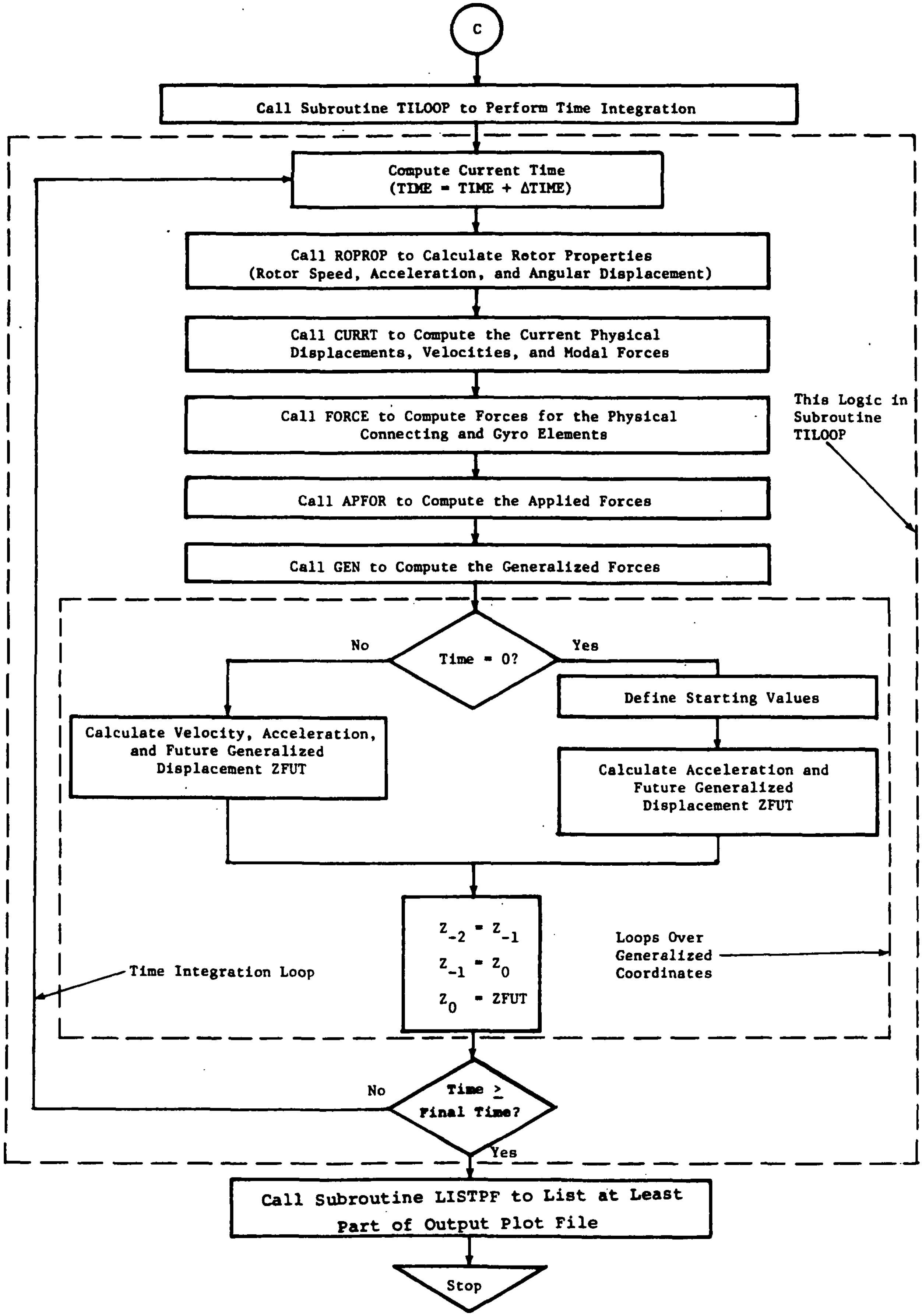


Figure 7. TETRA Flow Chart (Concluded).

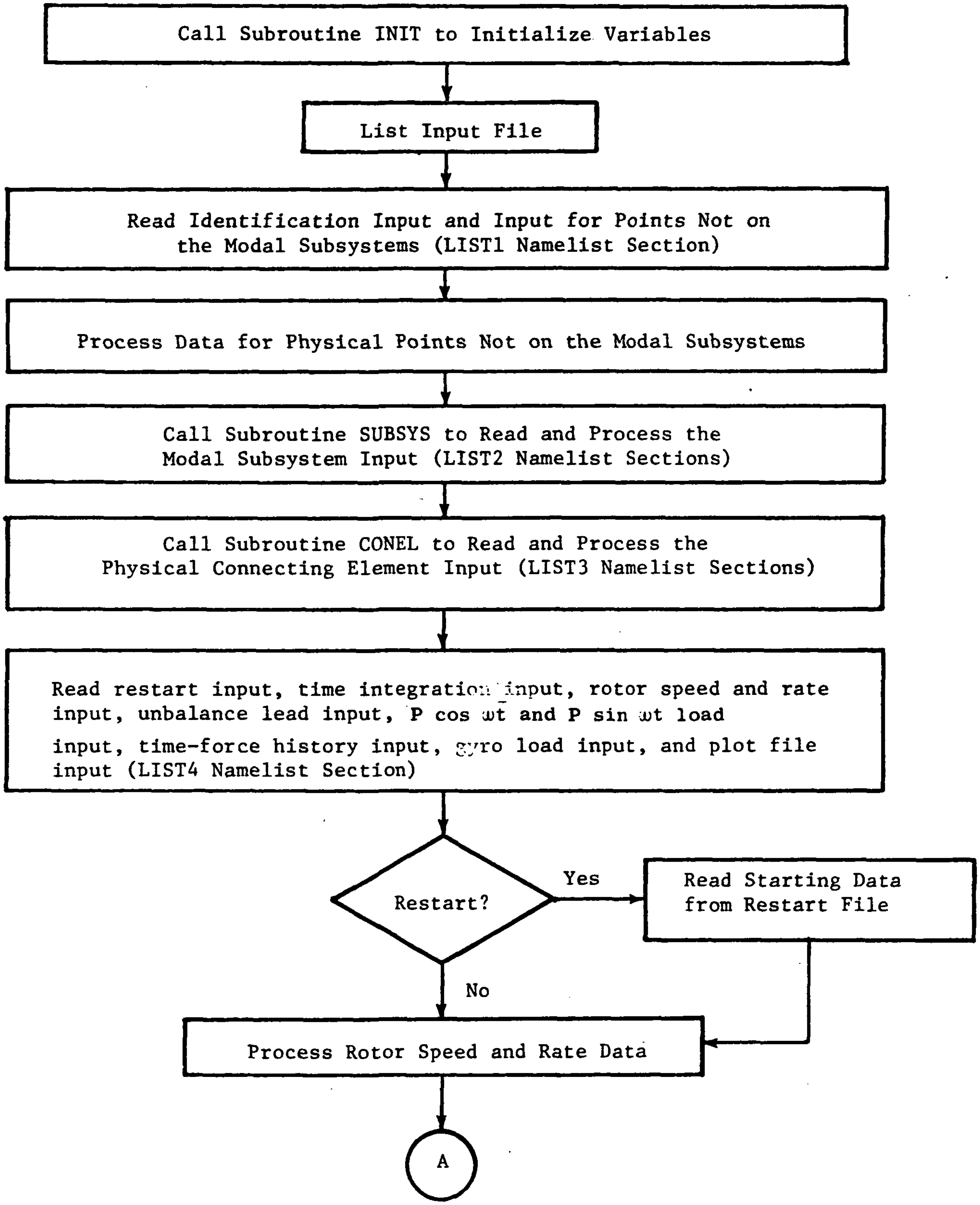


Figure 8. Flow Chart of Main Routine.

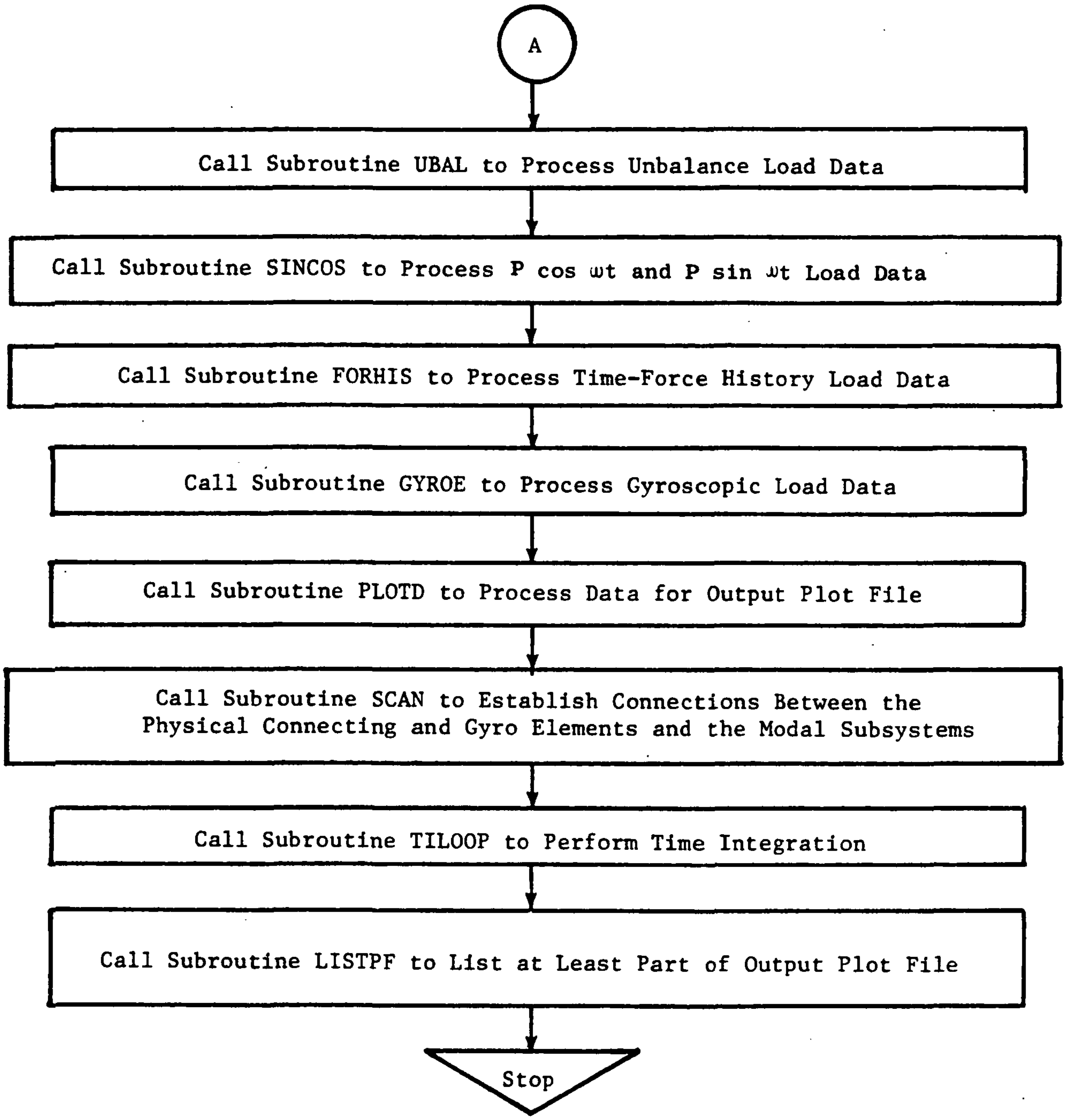


Figure 8. Flow Chart of Main Routine (Concluded).

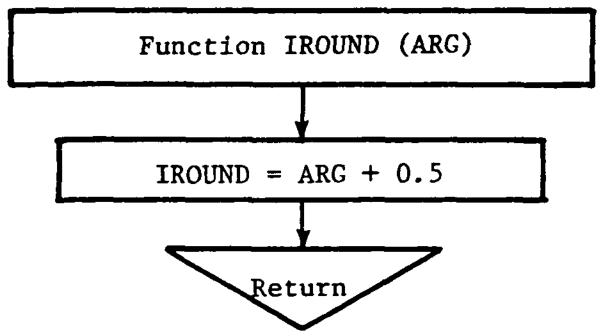


Figure 9. Flow Chart for Function IROUND.

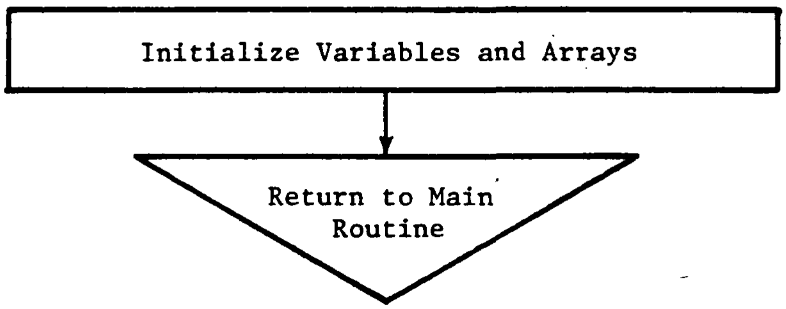


Figure 10. Flow Chart for Subroutine INIT.

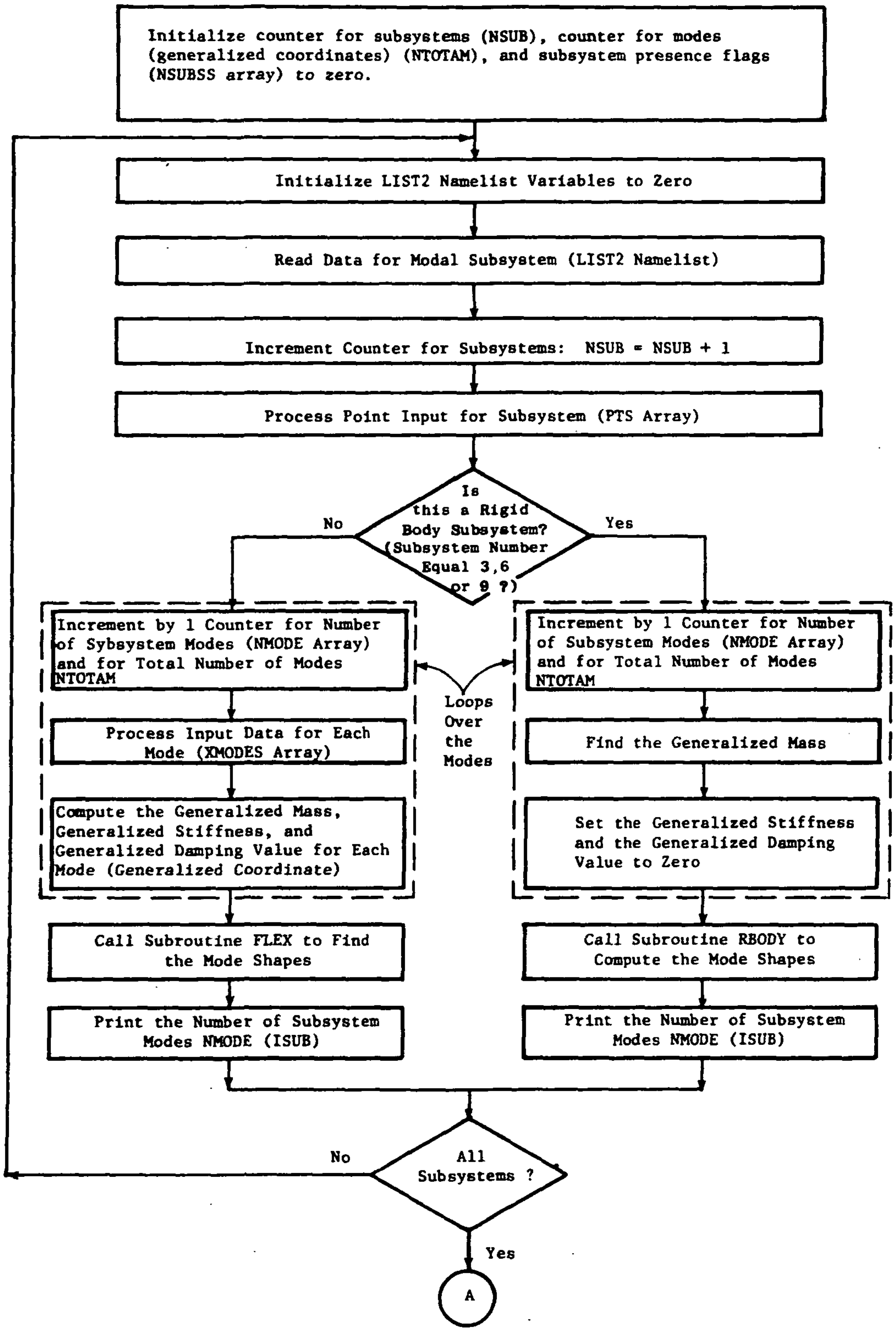


Figure 11. Flow Chart of Subroutine SUBSYS.

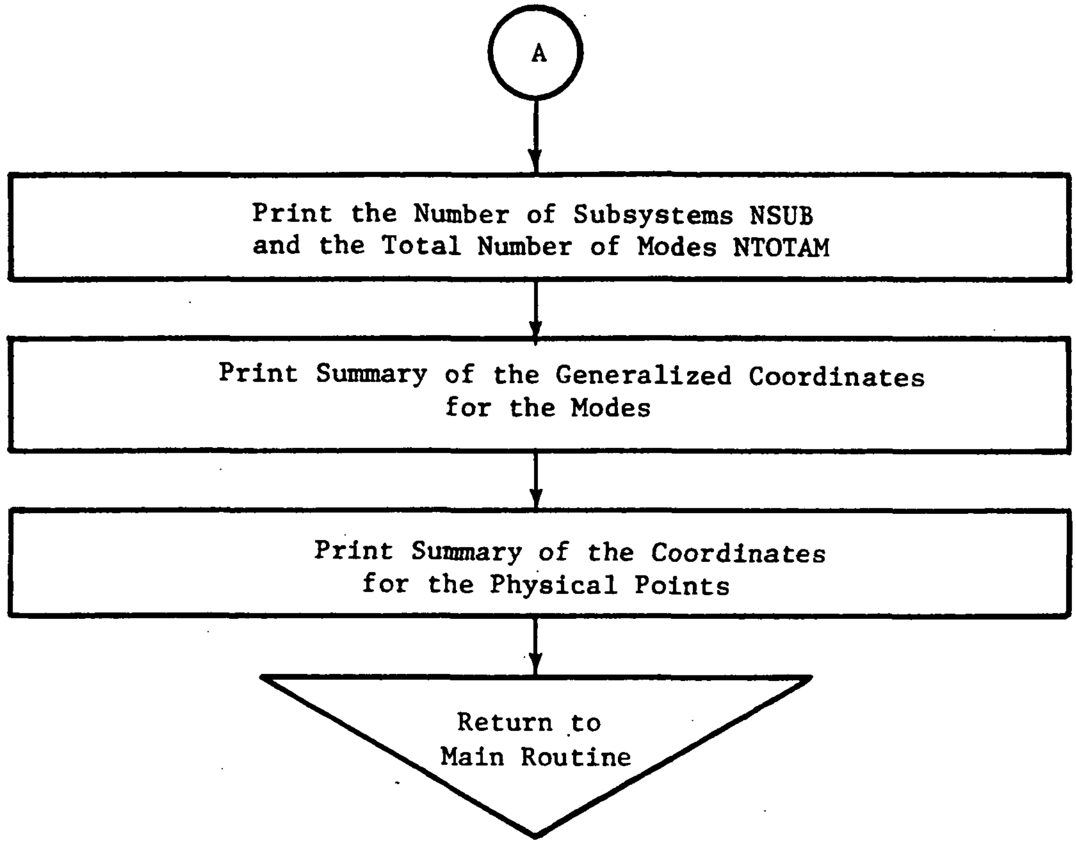


Figure 11. Flow Chart of Subroutine SUBSYS (Concluded).

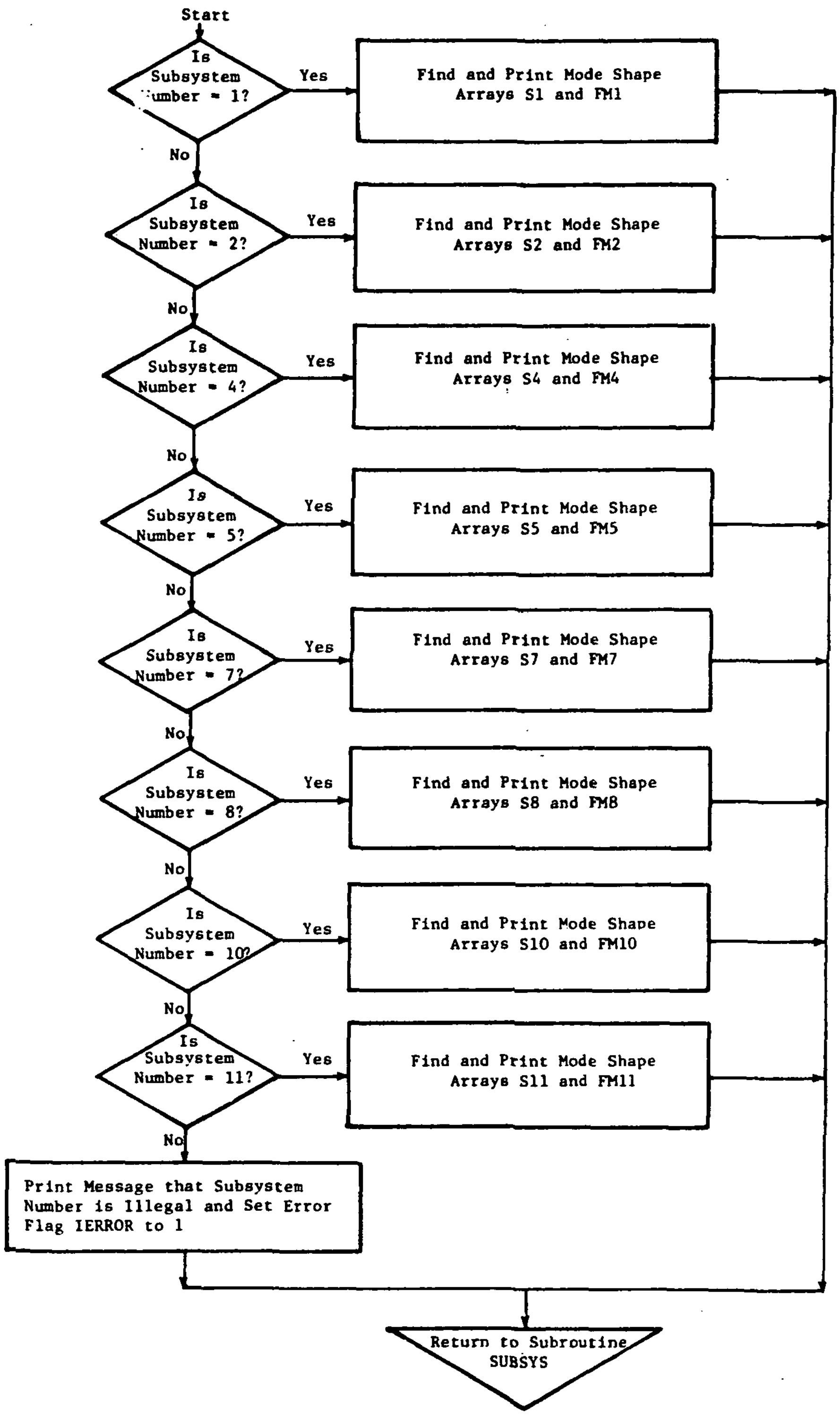


Figure 12. Flow Chart of Subroutine FLEX.

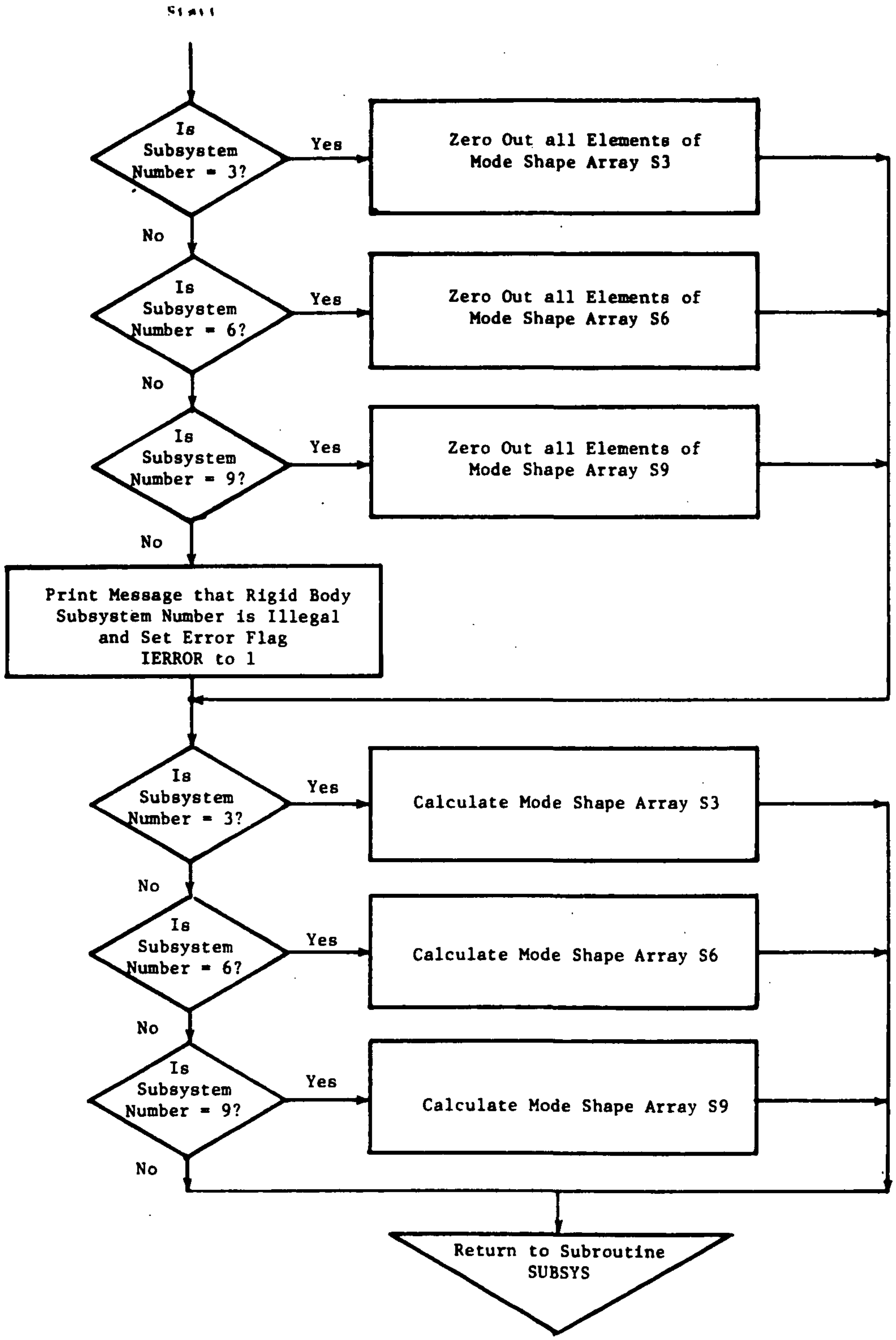


Figure 13. Flow Chart of Subroutine RBODY.

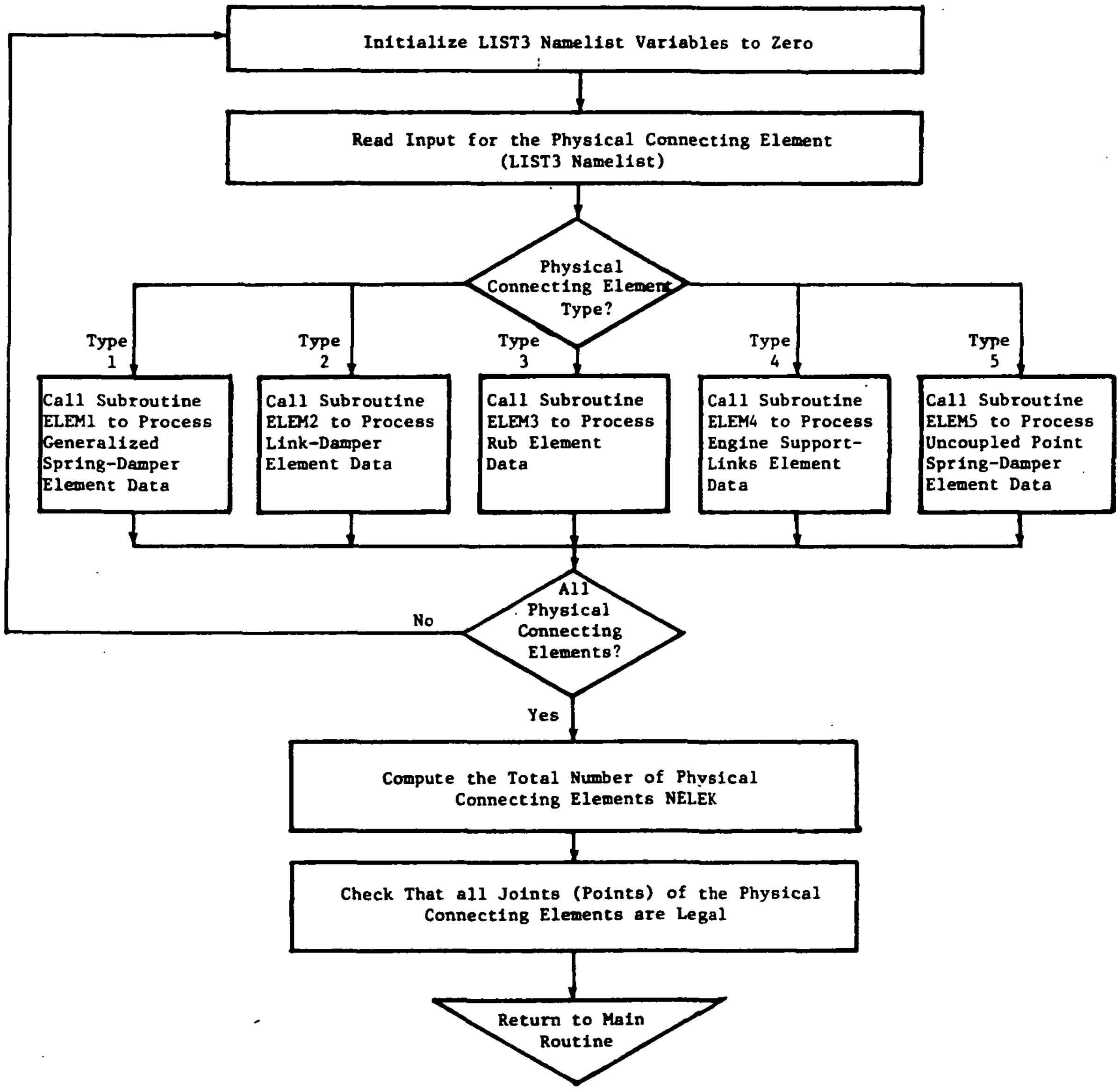


Figure 14. Flow Chart for Subroutine CONEL.

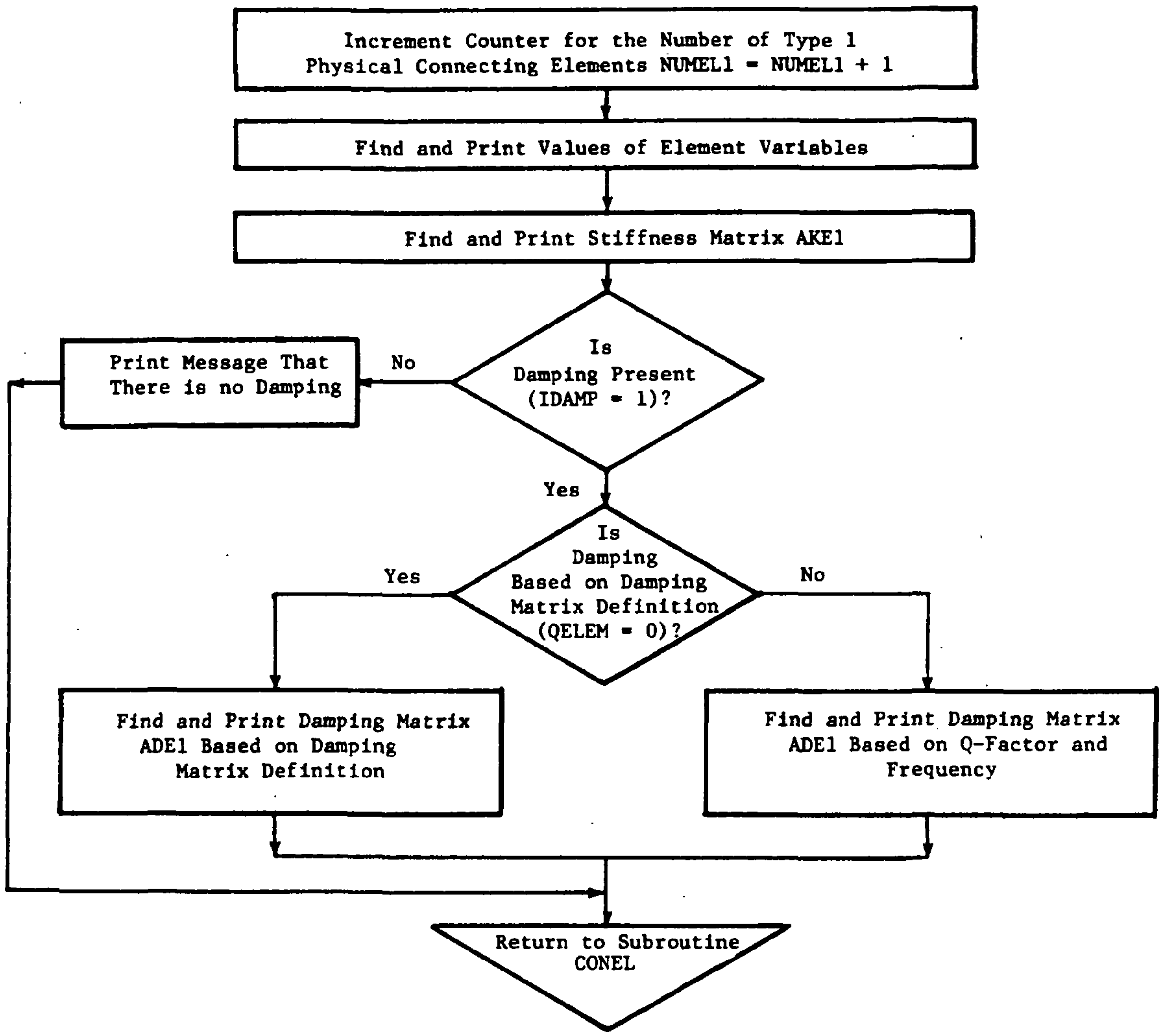


Figure 15. Flow Chart of Subroutine ELEM1.

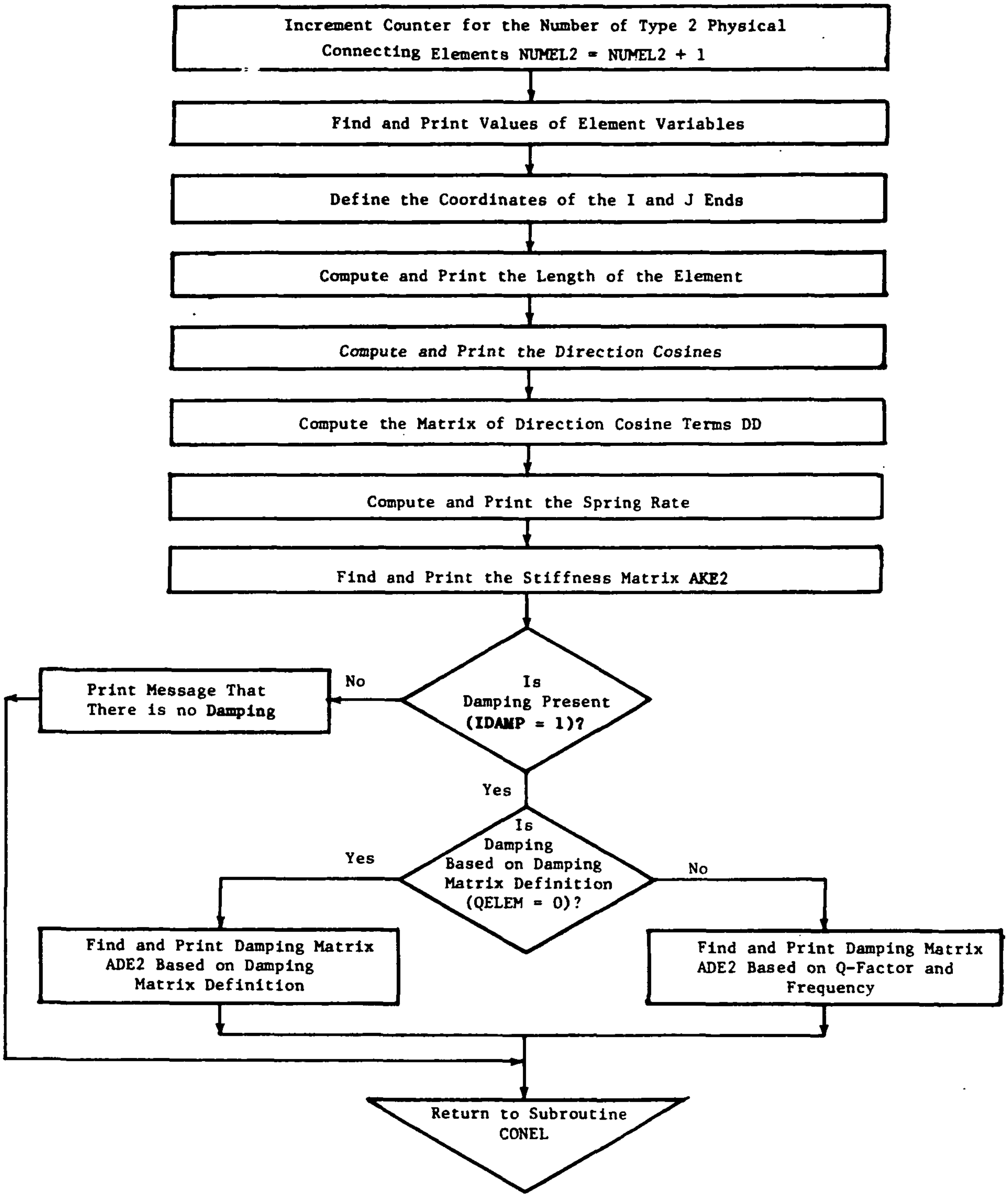


Figure 16. Flow Chart of Subroutine ELEM2.

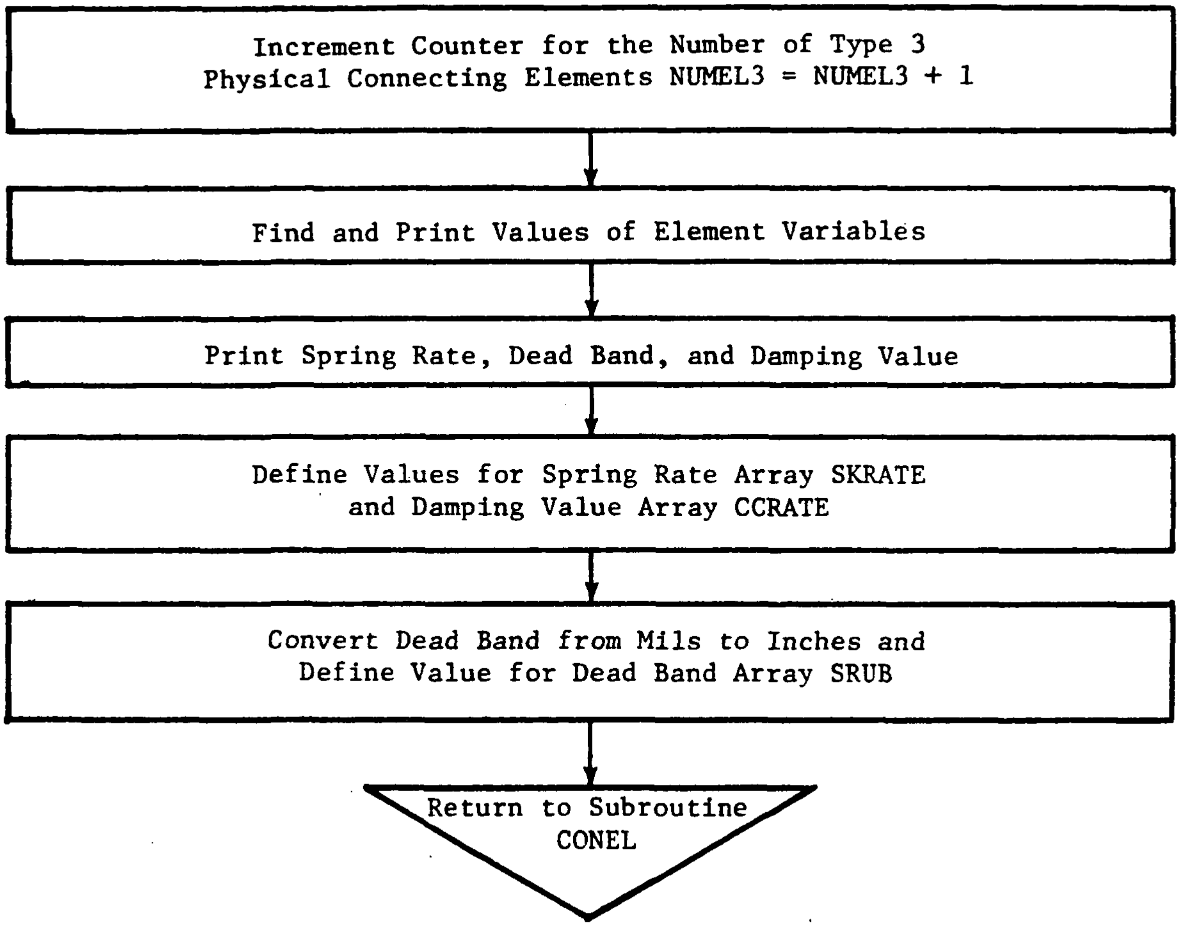


Figure 17. Flow Chart of Subroutine ELEM3.

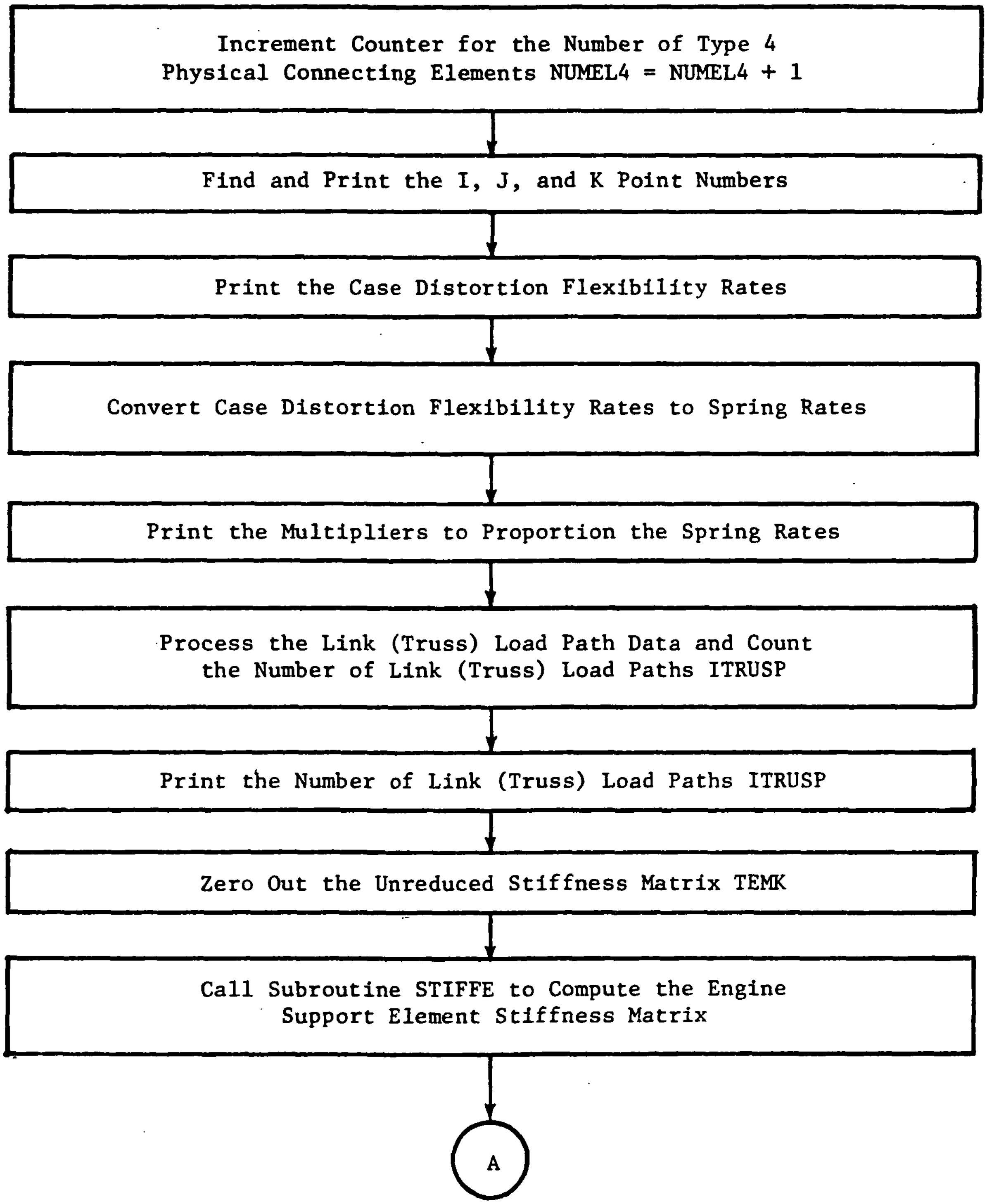


Figure 18. Flow Chart of Subroutine ELEM4.

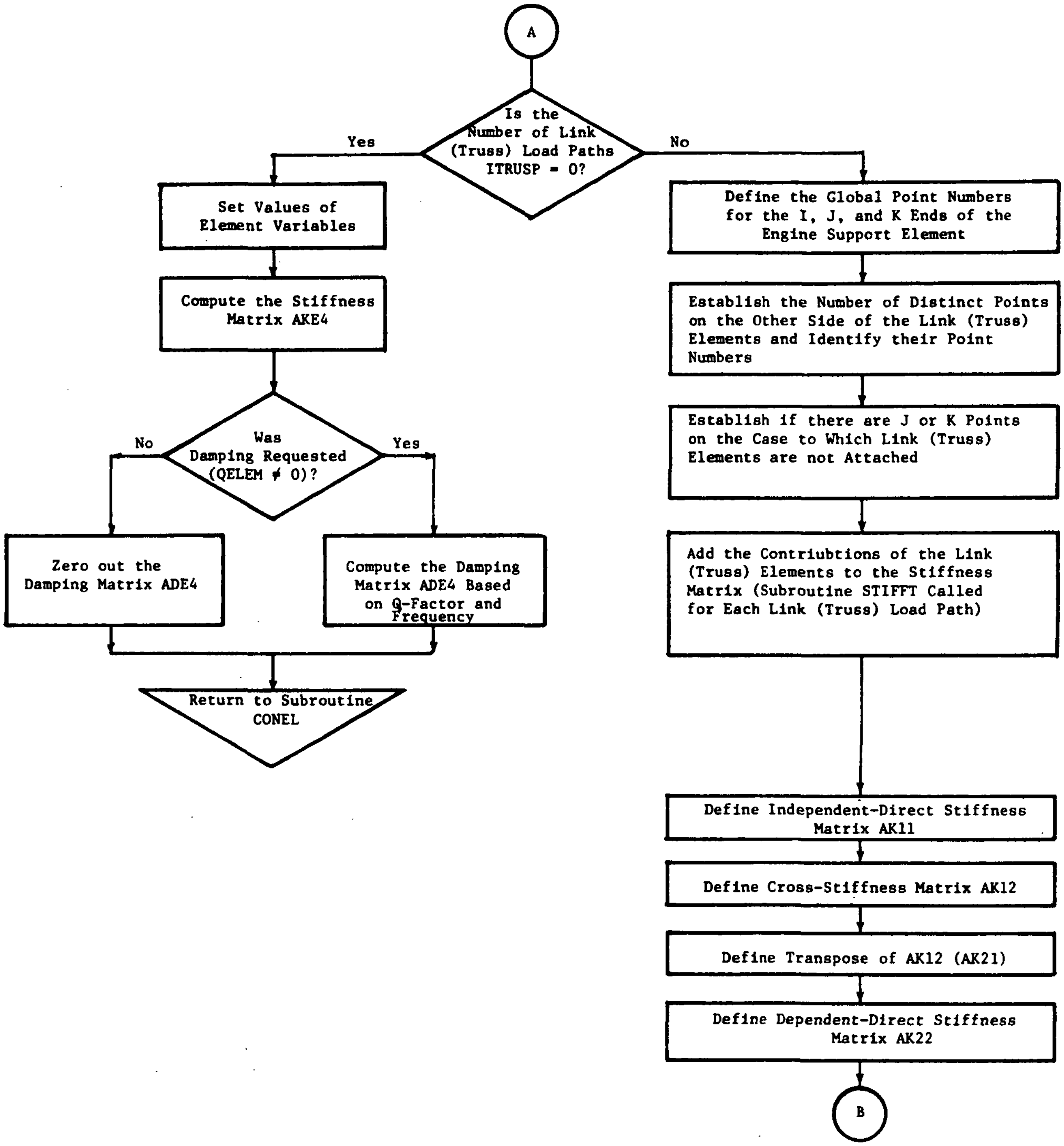


Figure 18. Flow Chart of Subroutine ELEM4 (Continued).

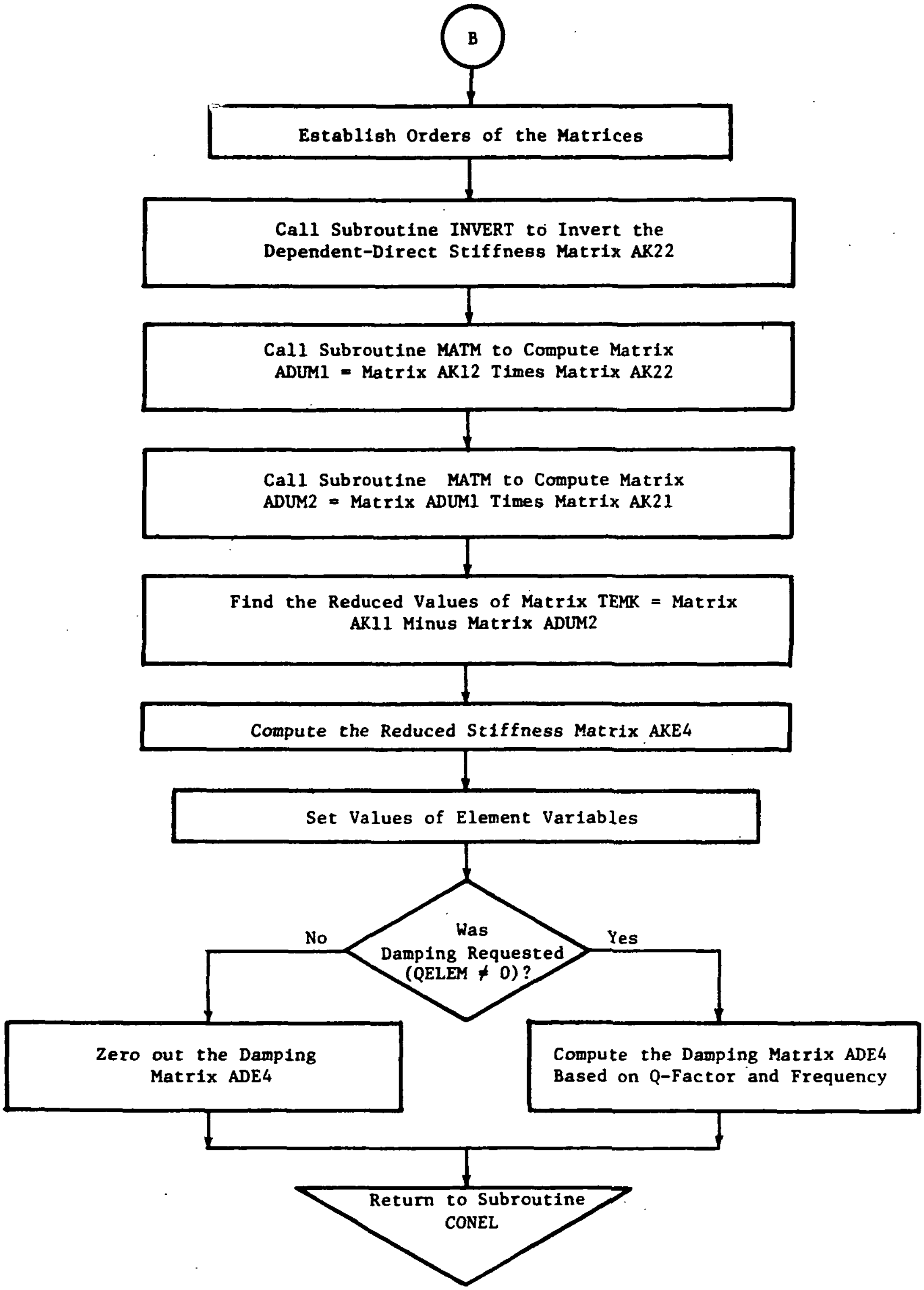


Figure 18. Flow Chart of Subroutine ELEM4 (Concluded).

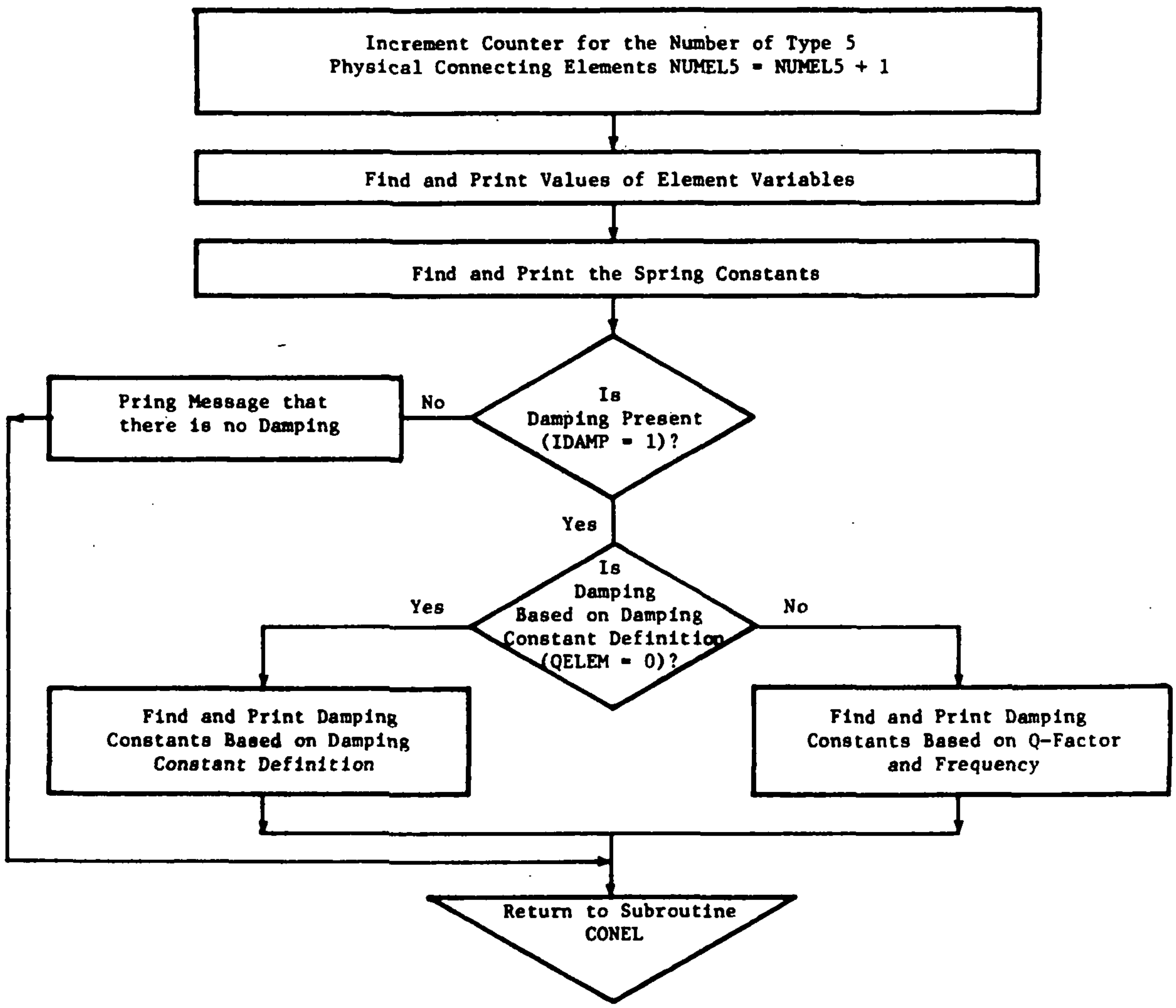


Figure 19. Flow Chart for Subroutine ELEM5.

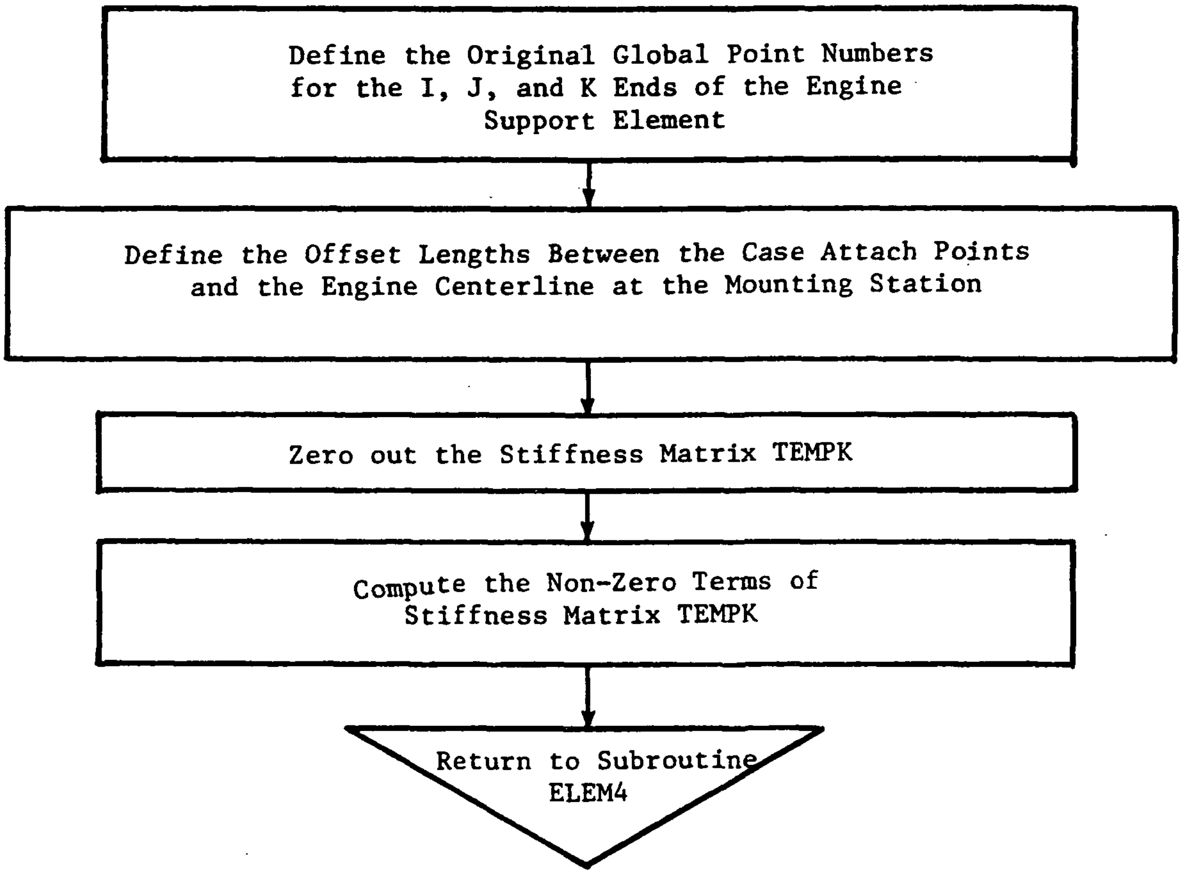


Figure 20. Subroutine STIFFE.

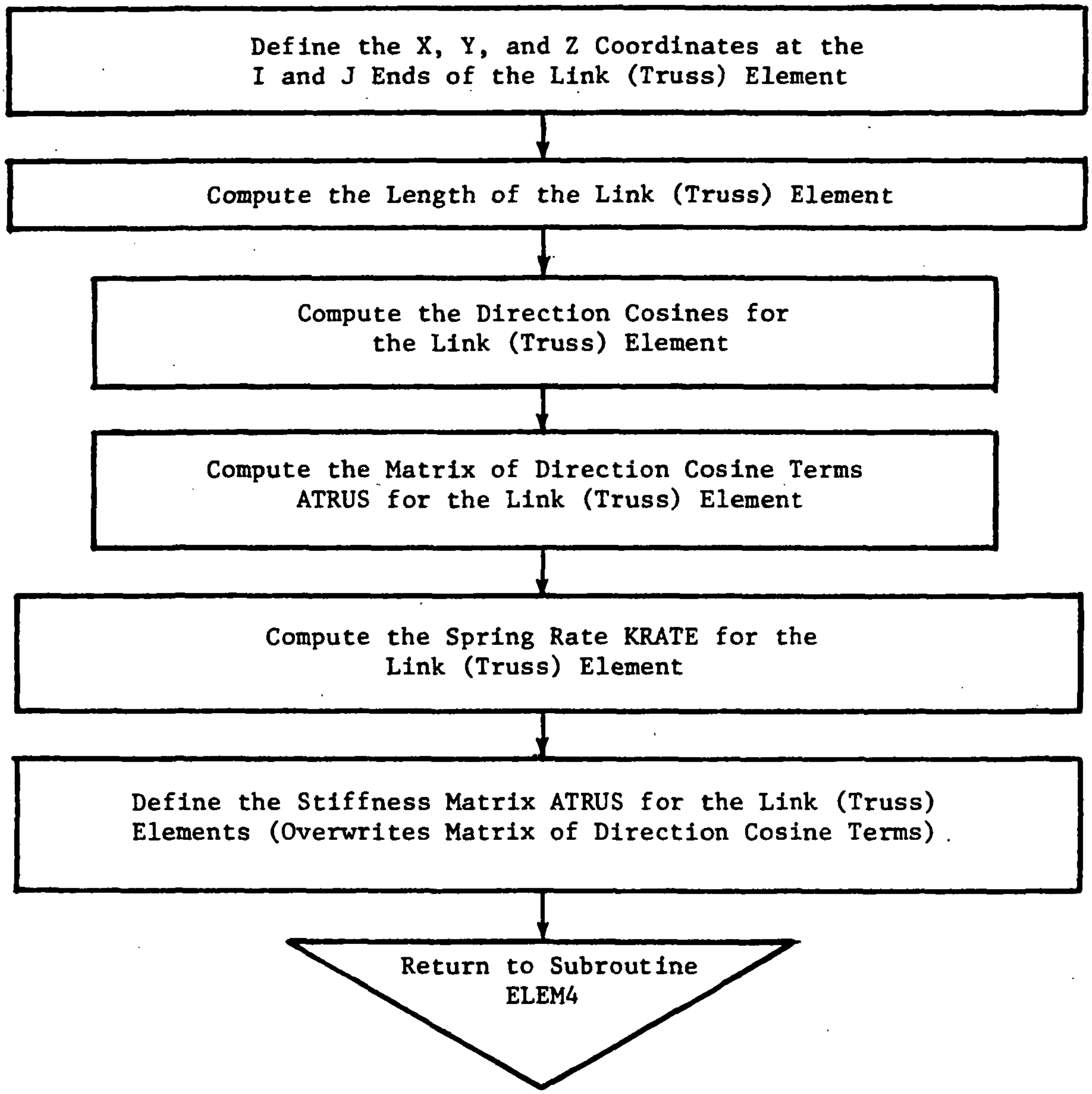


Figure 21. Subroutine STIFFT.

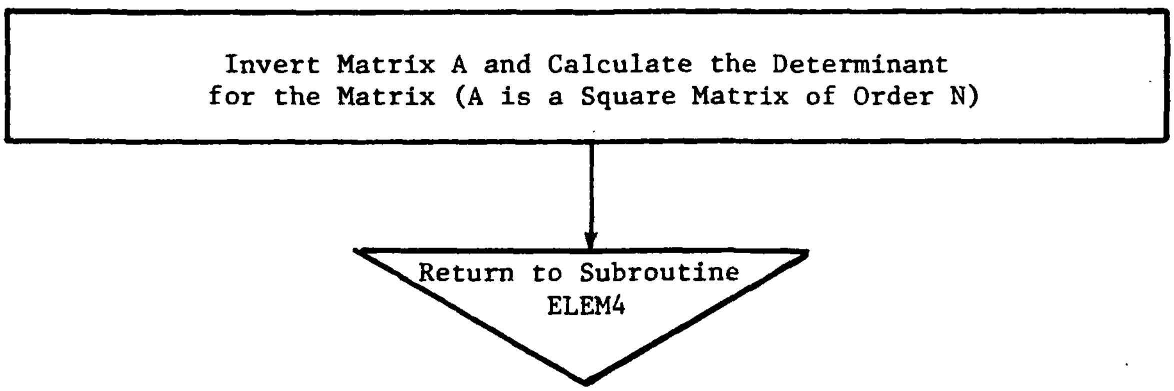


Figure 22. Flow Chart of Subroutine INVERT.

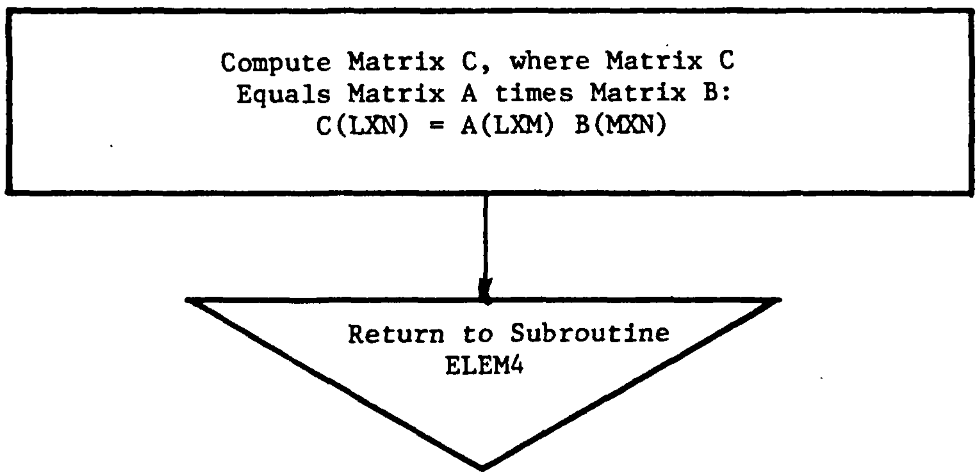


Figure 23. Flow Chart of Subroutine MATM.

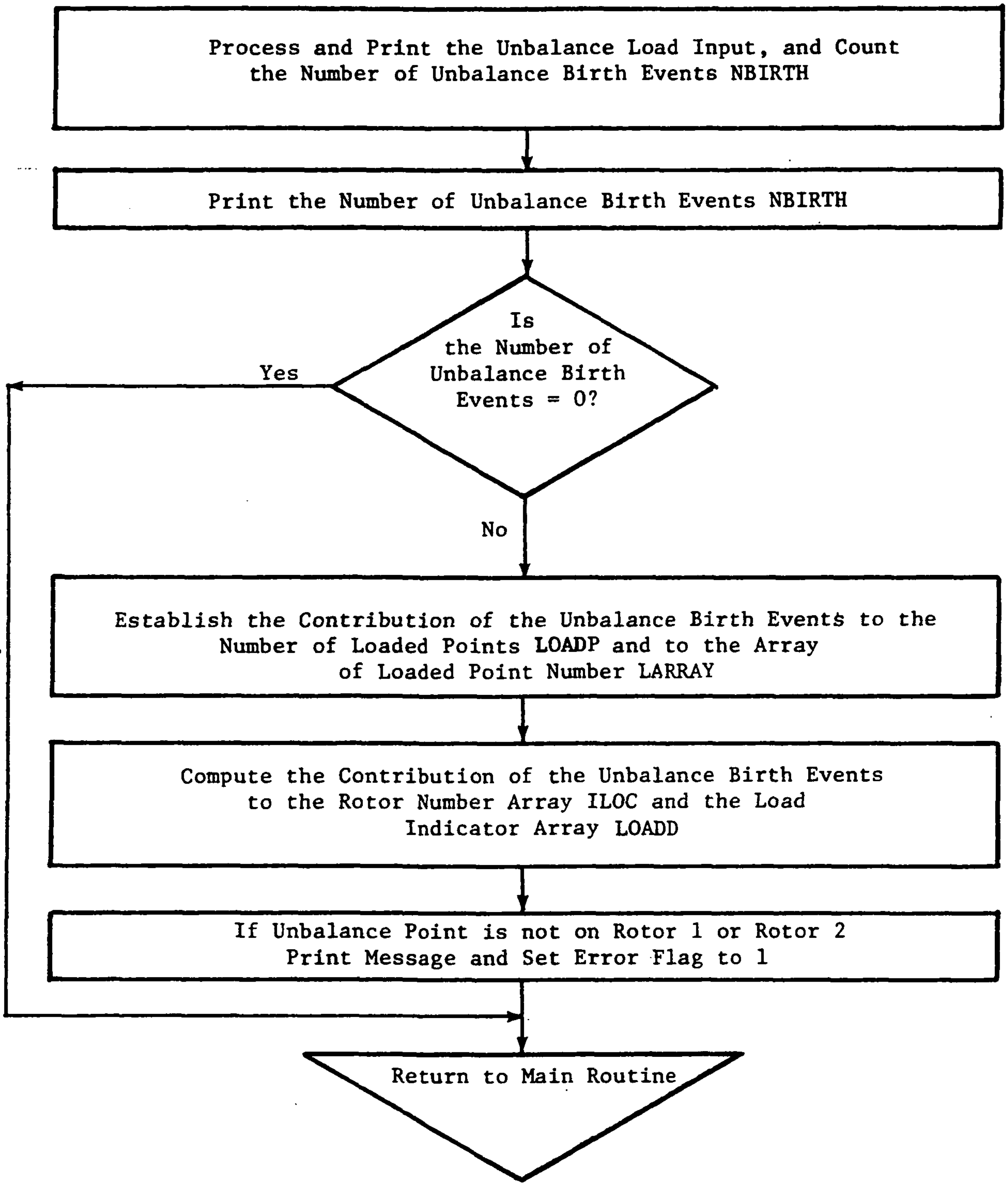


Figure 24. Flow Chart of Subroutine UBAL.

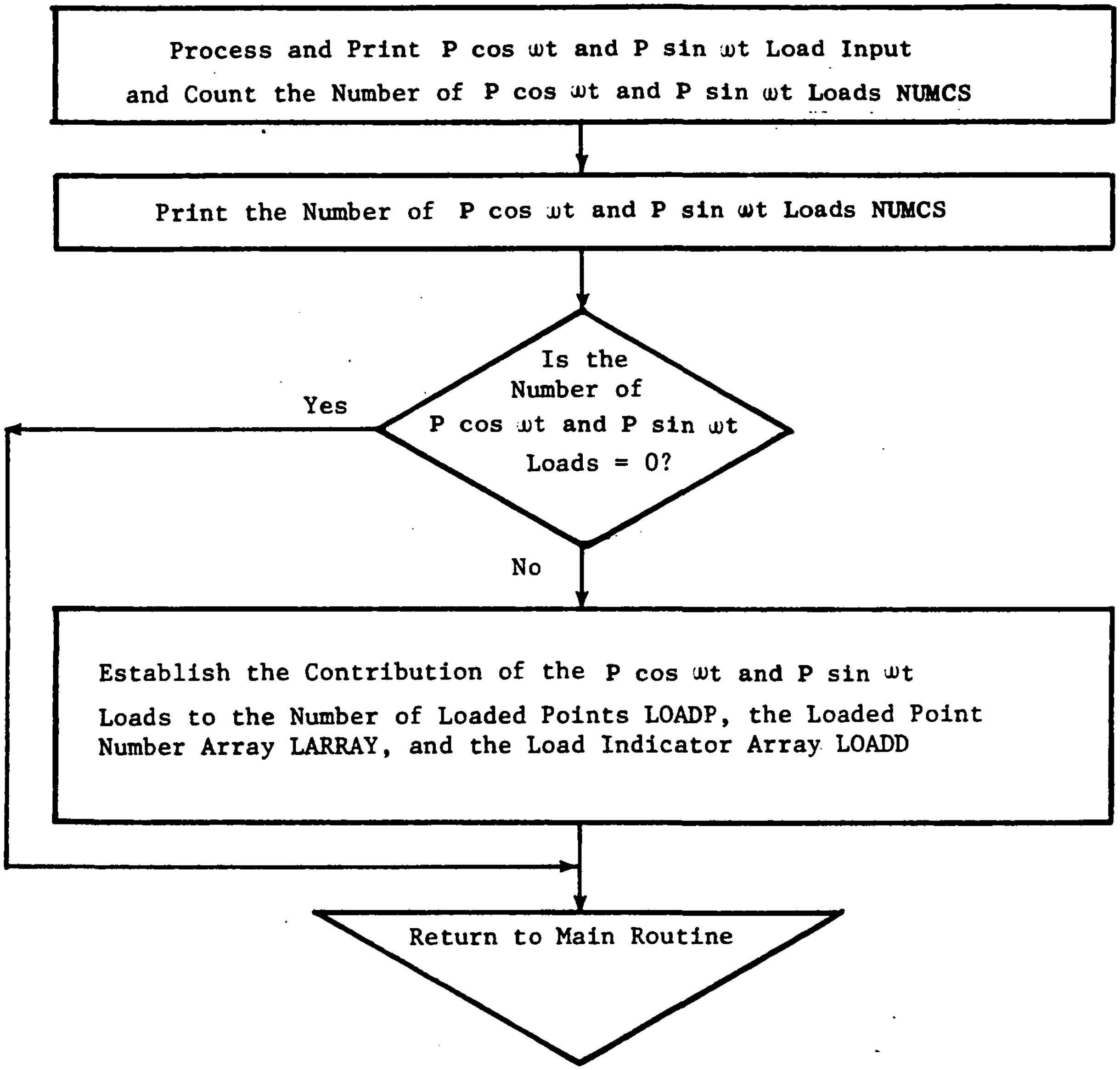


Figure 25. Flow Chart of Subroutine SINCOS.

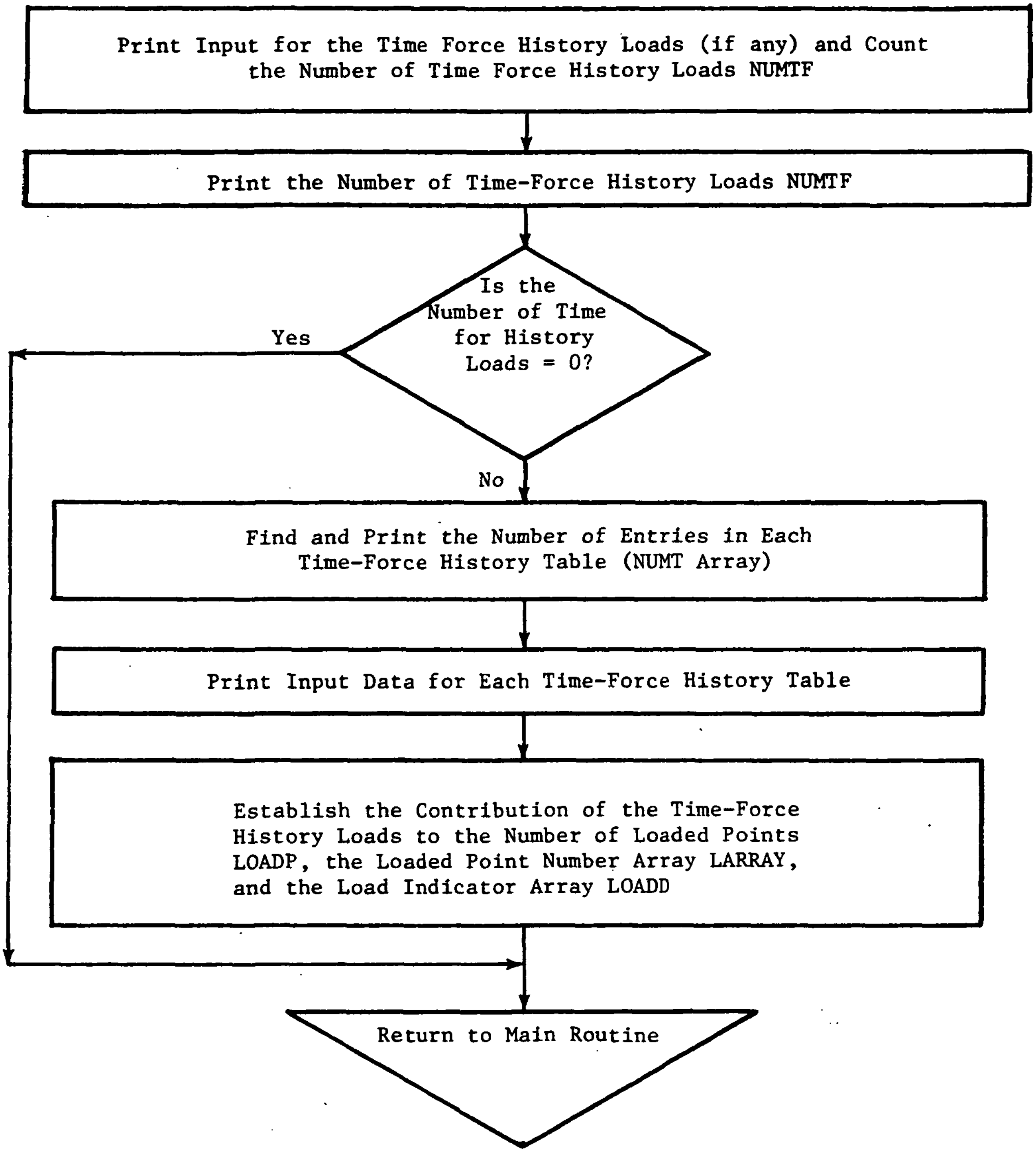


Figure 26. Flow Chart of Subroutine FORHIS.

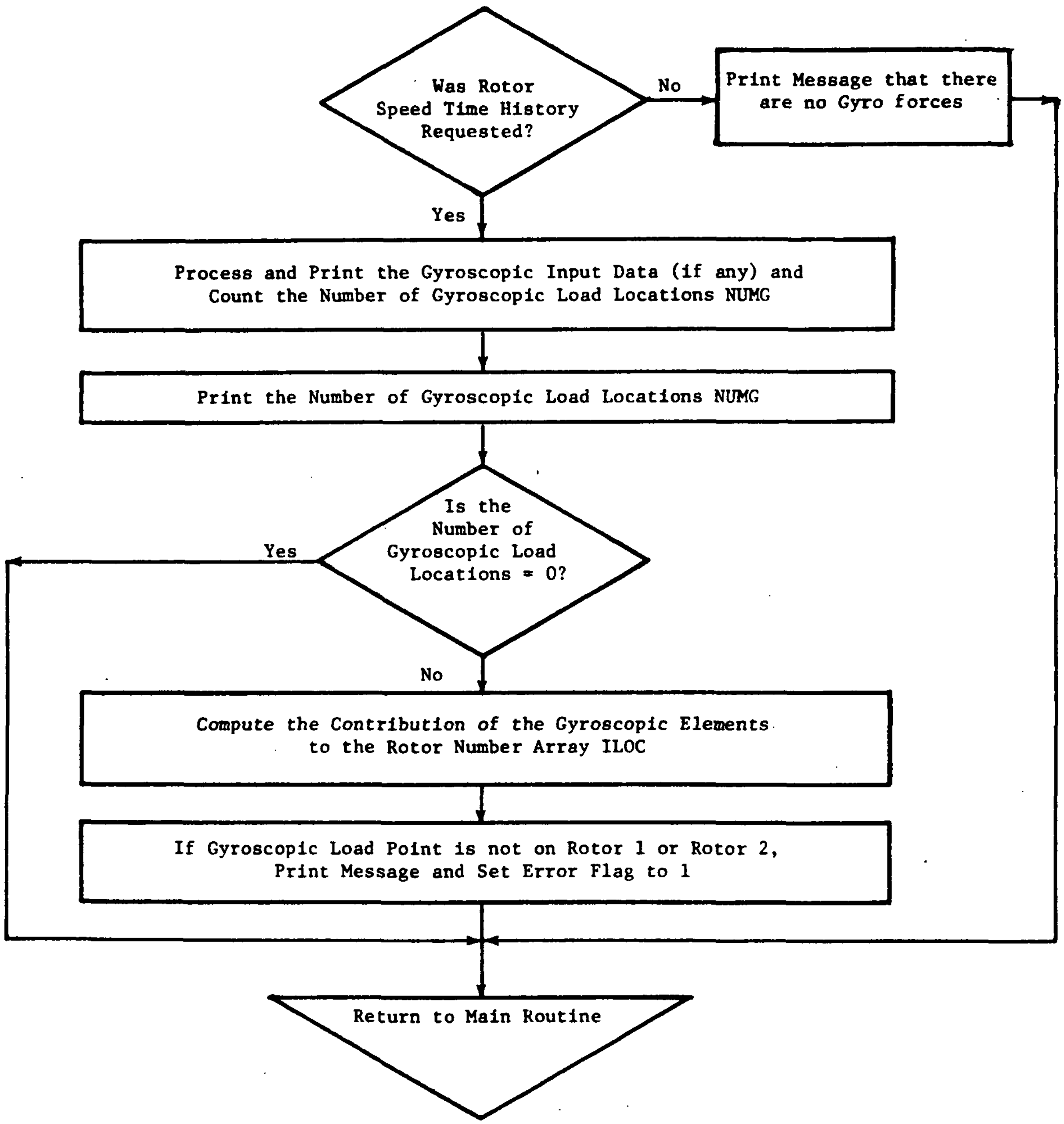


Figure 27. Flow Chart of Subroutine GYROE.

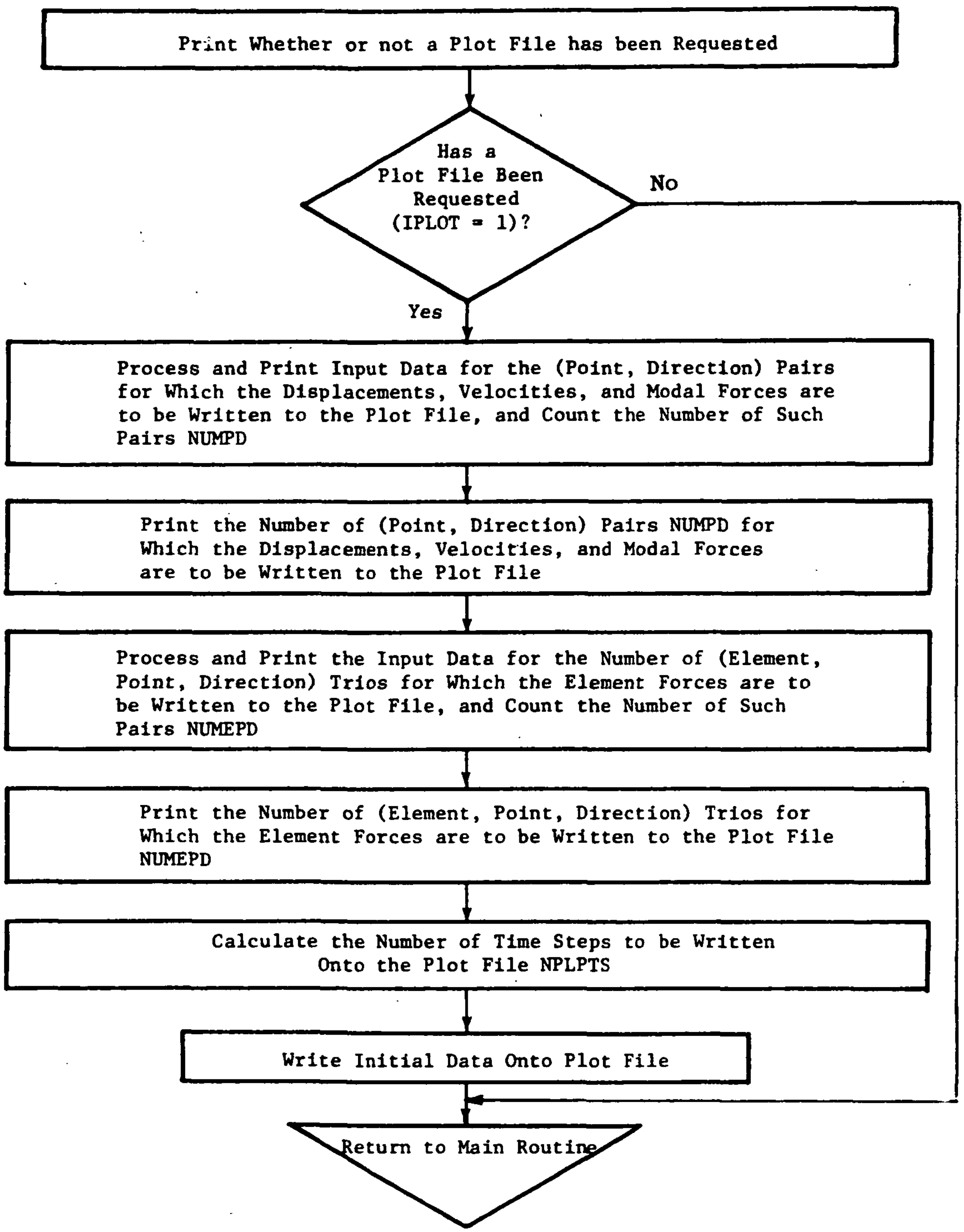


Figure 28. Flow Chart of Subroutine PLOTD.

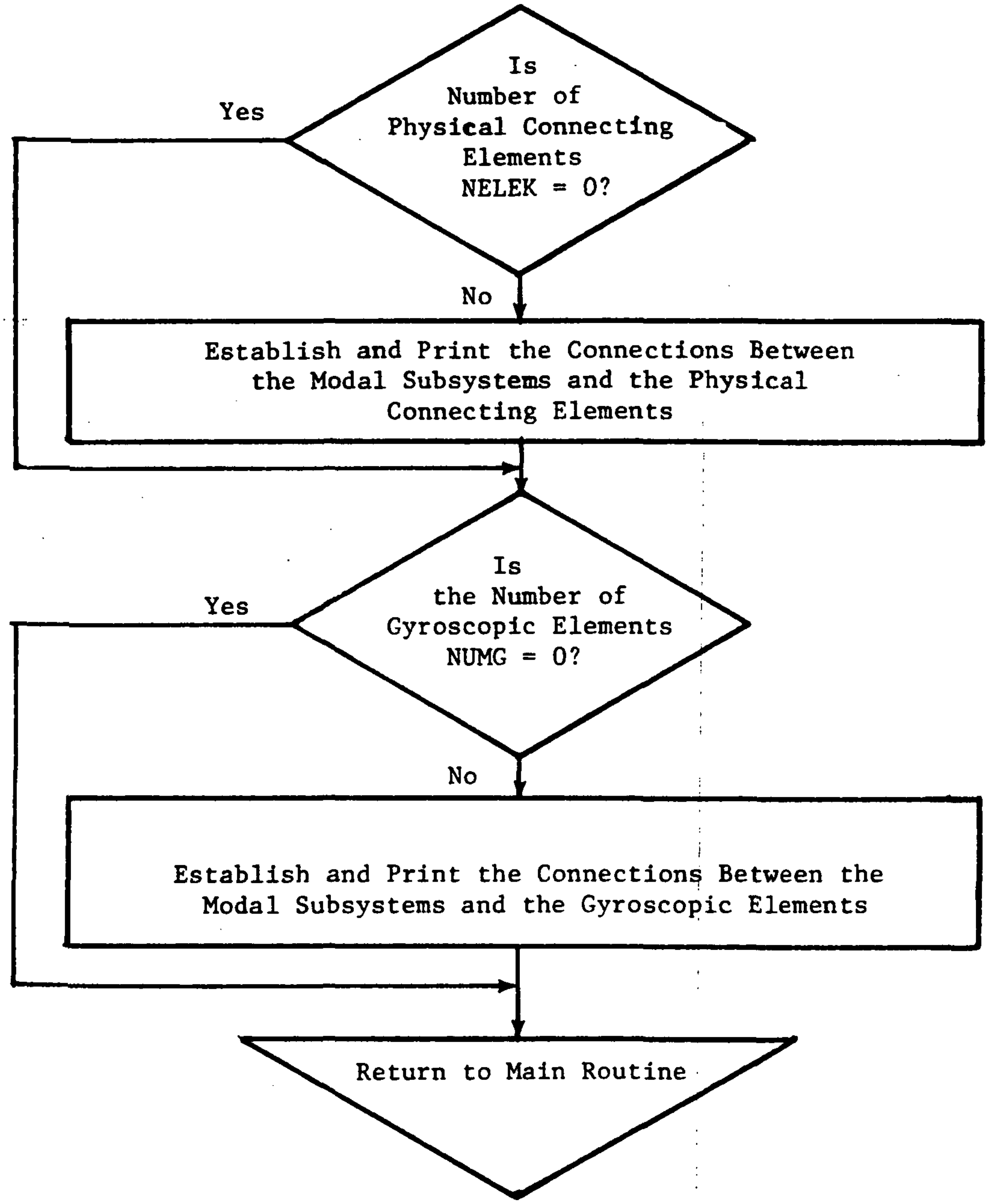


Figure 29. Flow Chart of Subroutine SCAN.

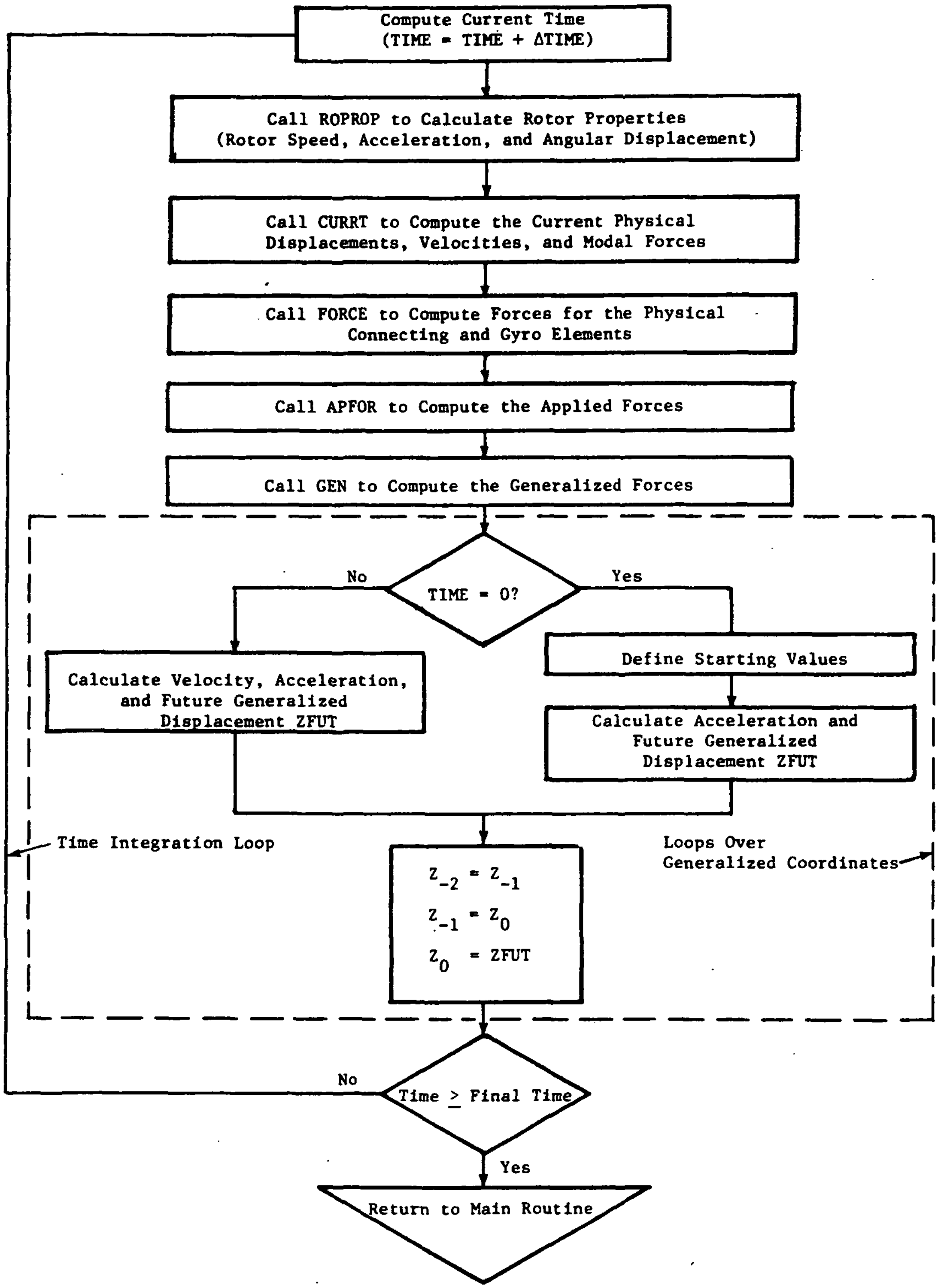


Figure 30. Flow Chart for Subroutine TILOOP.

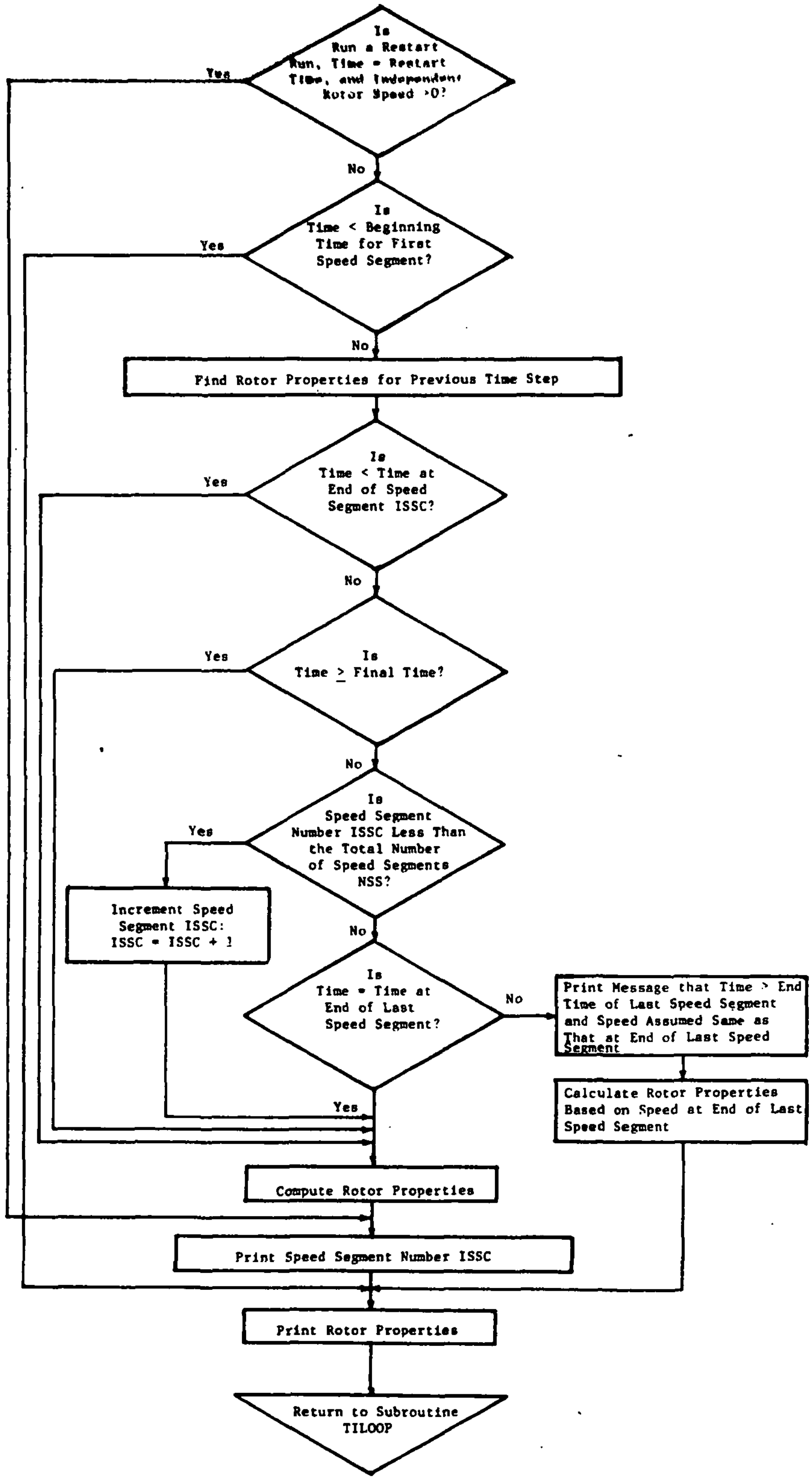


Figure 31. Flow Chart for Subroutine ROPROP.

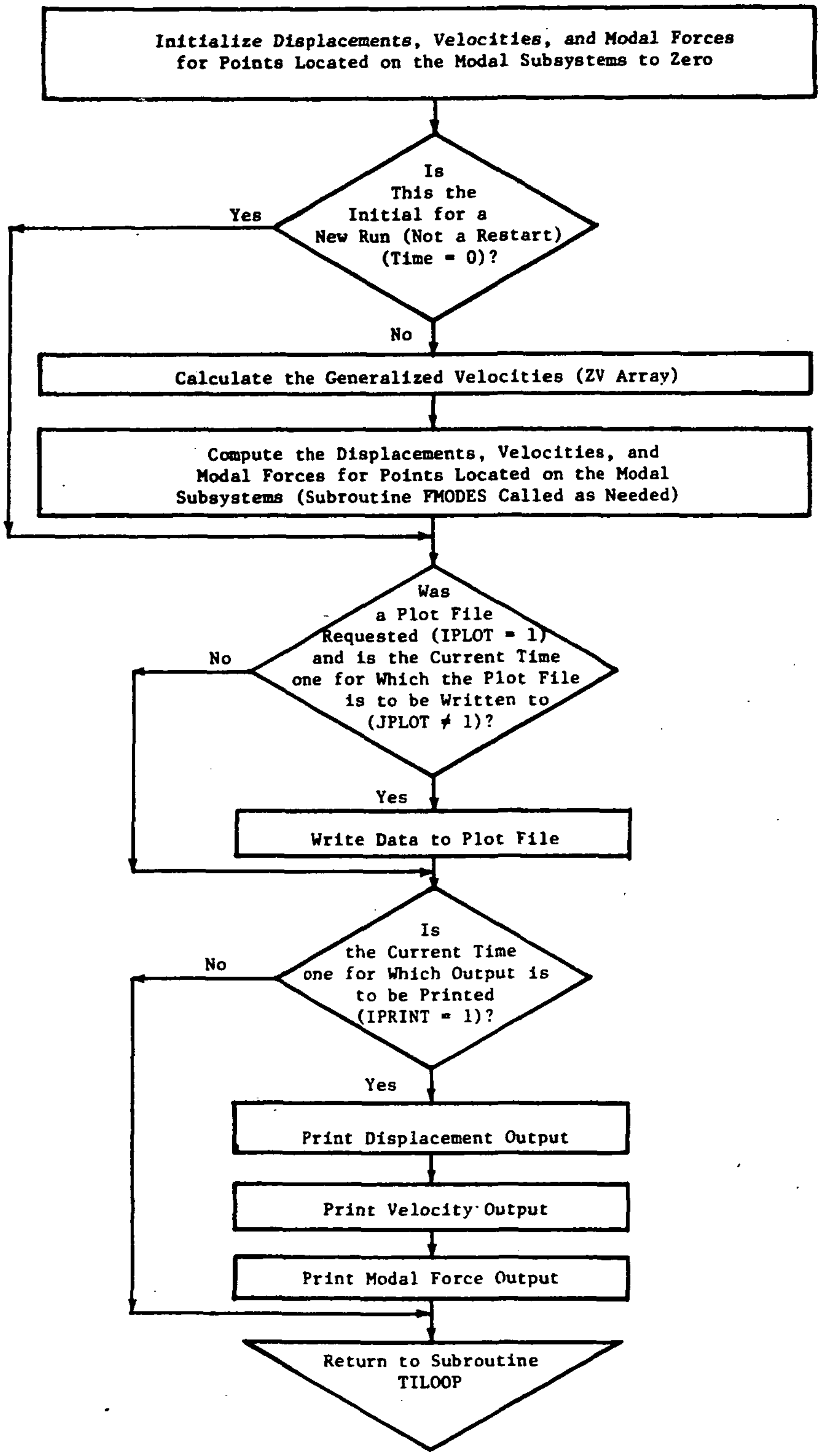


Figure 32. Flow Chart of Subroutine CURRT.

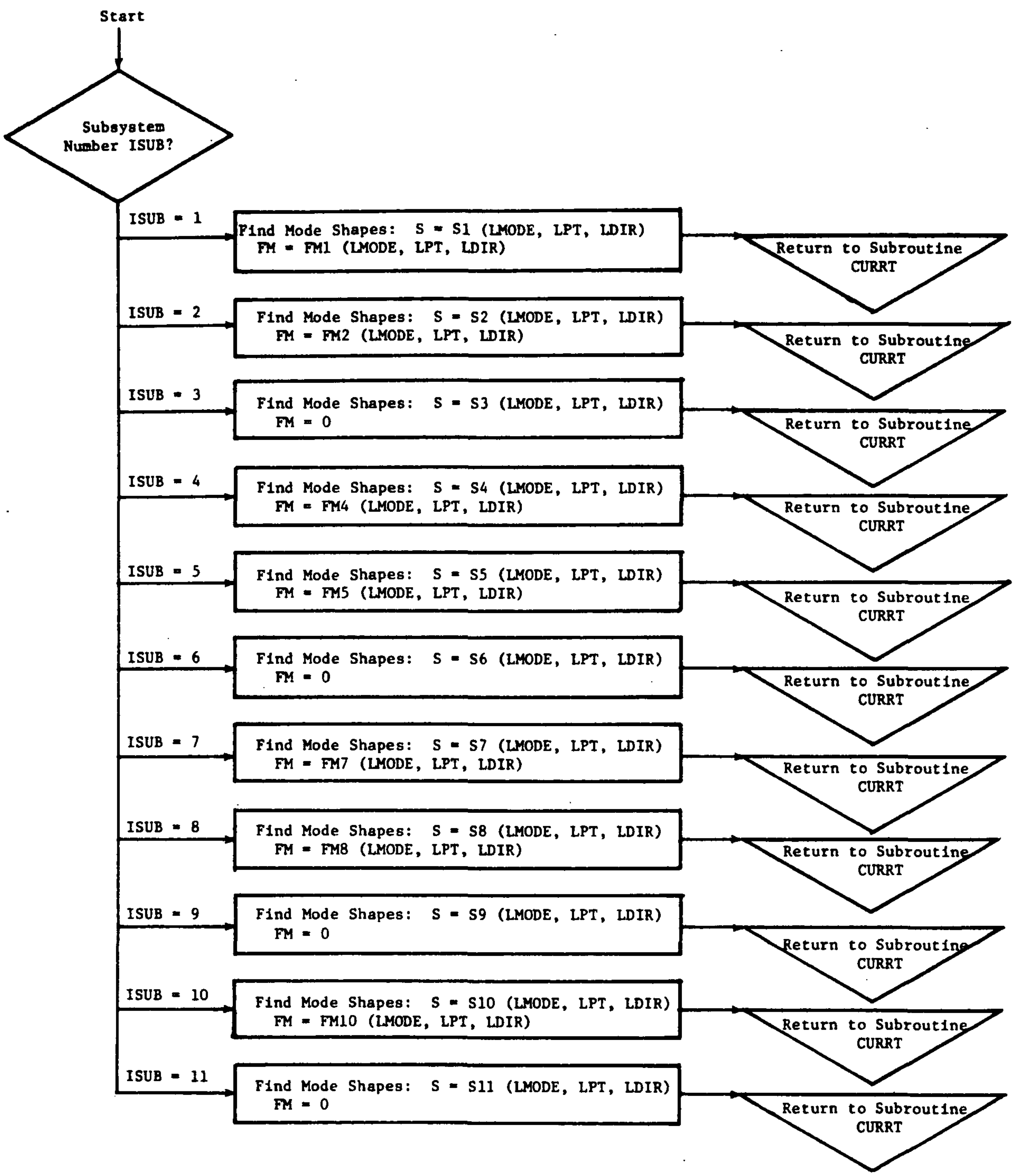


Figure 33. Flow Chart of Subroutine FMODES.

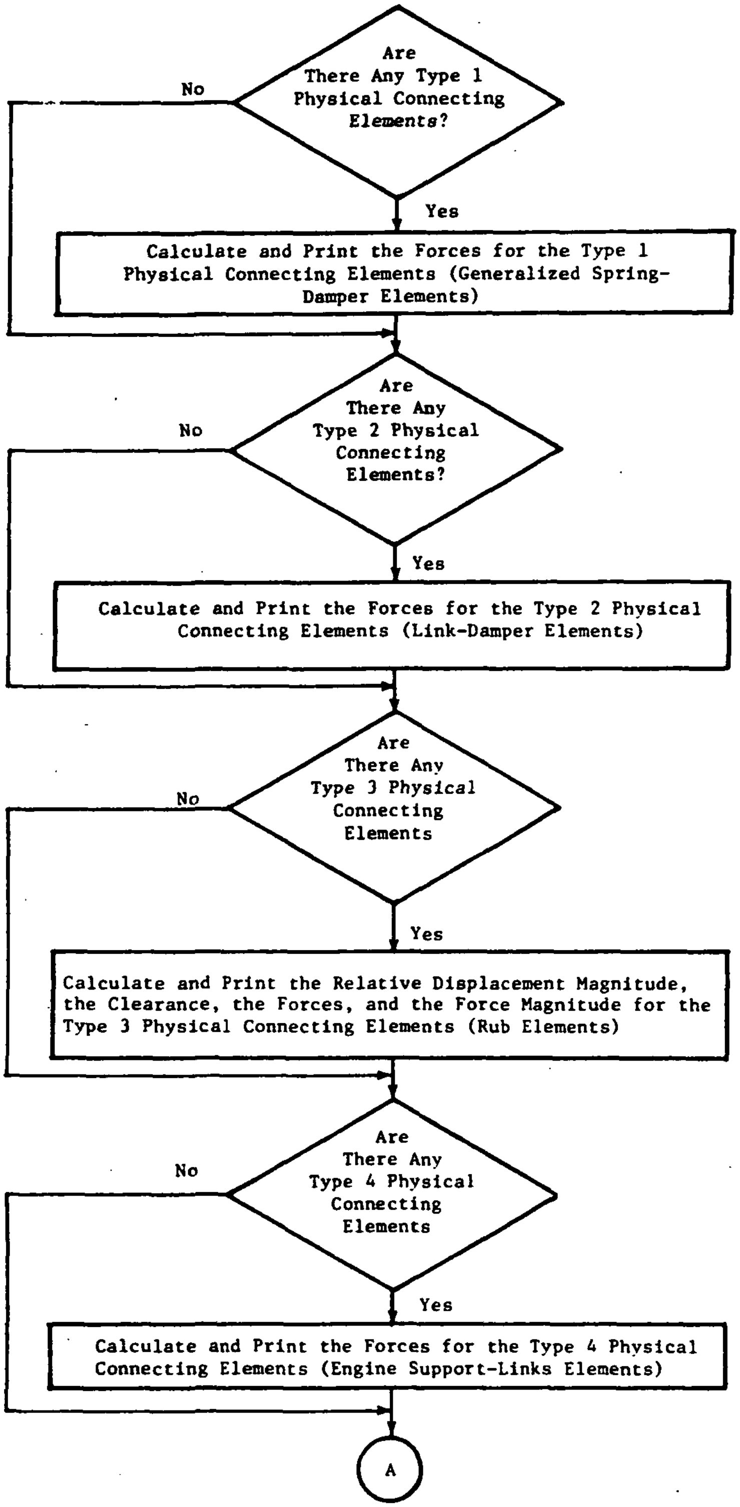


Figure 34. Flow Chart of Subroutine FORCE.

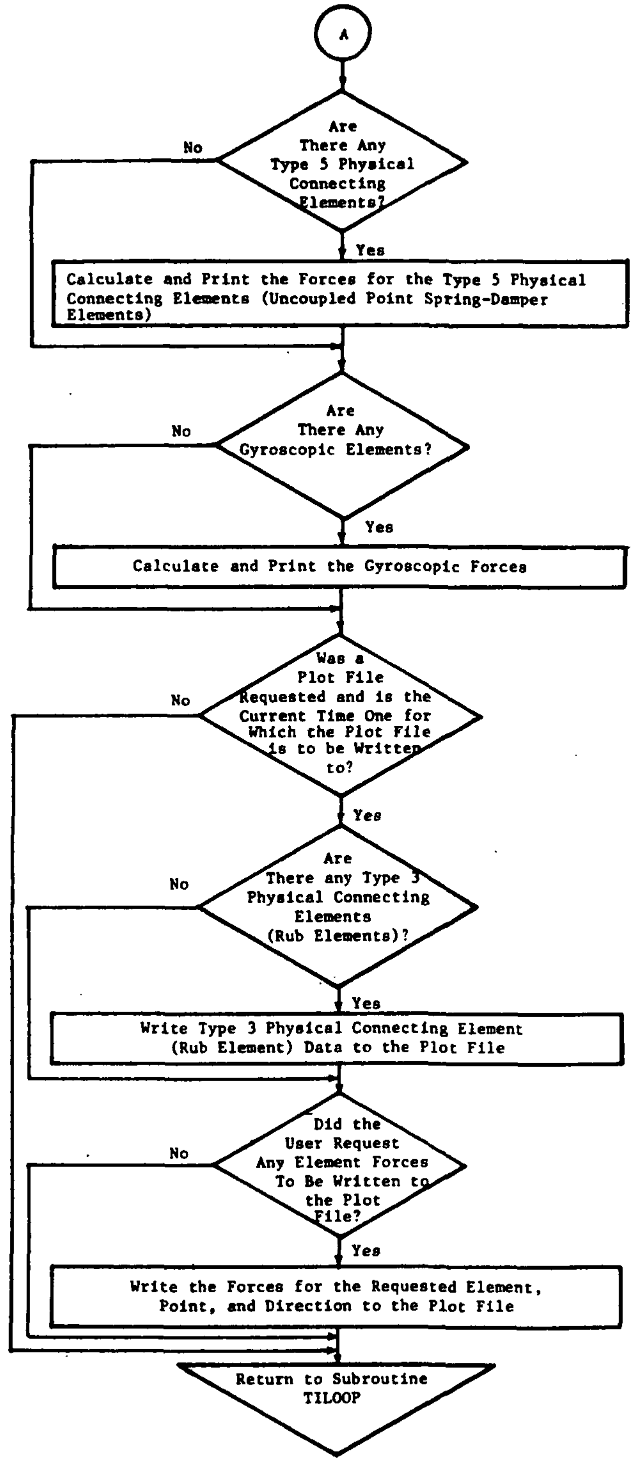


Figure 34. Flow Chart of Subroutine FORCE (Concluded).

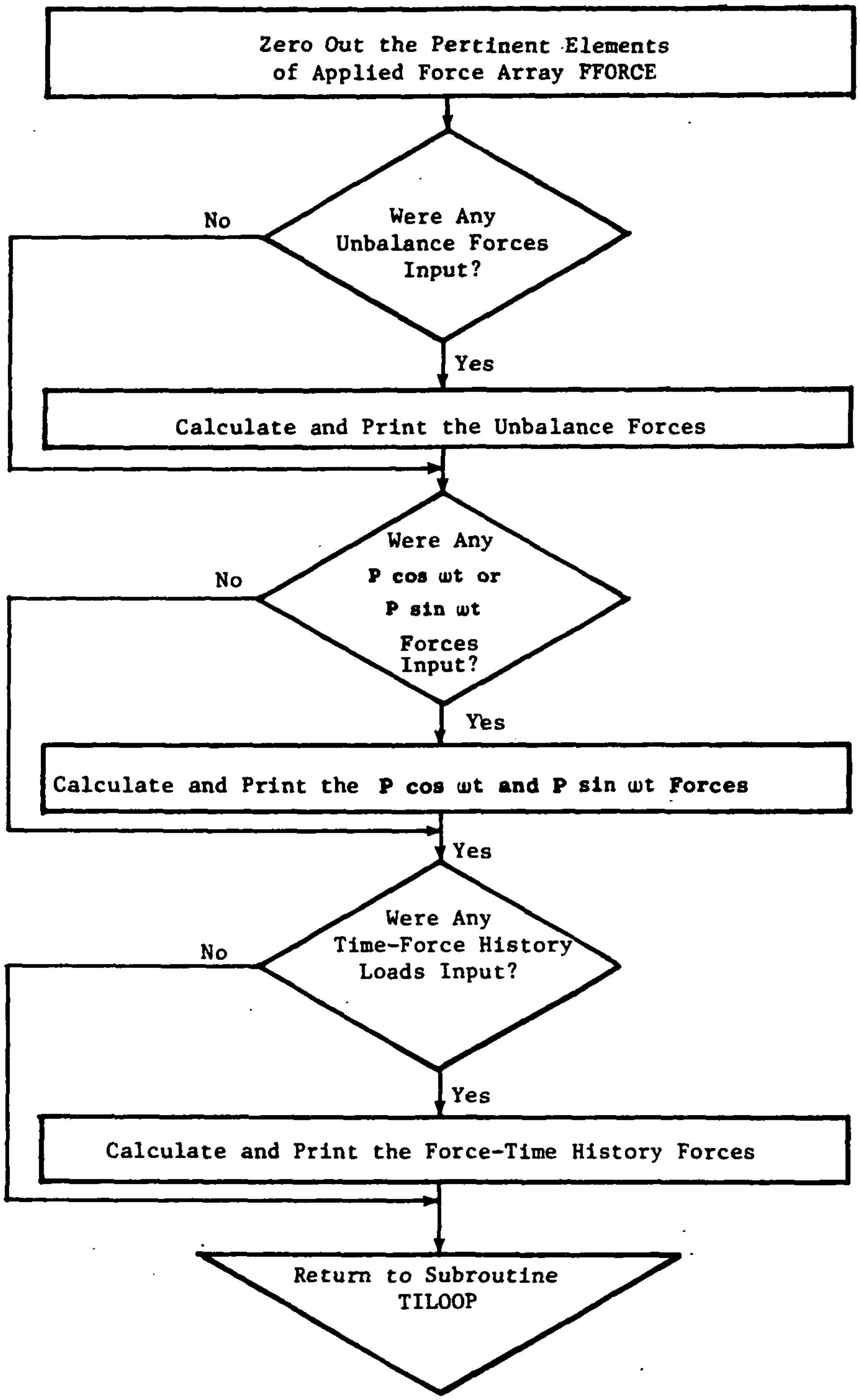


Figure 35. Flow Chart of Subroutine APFOR.

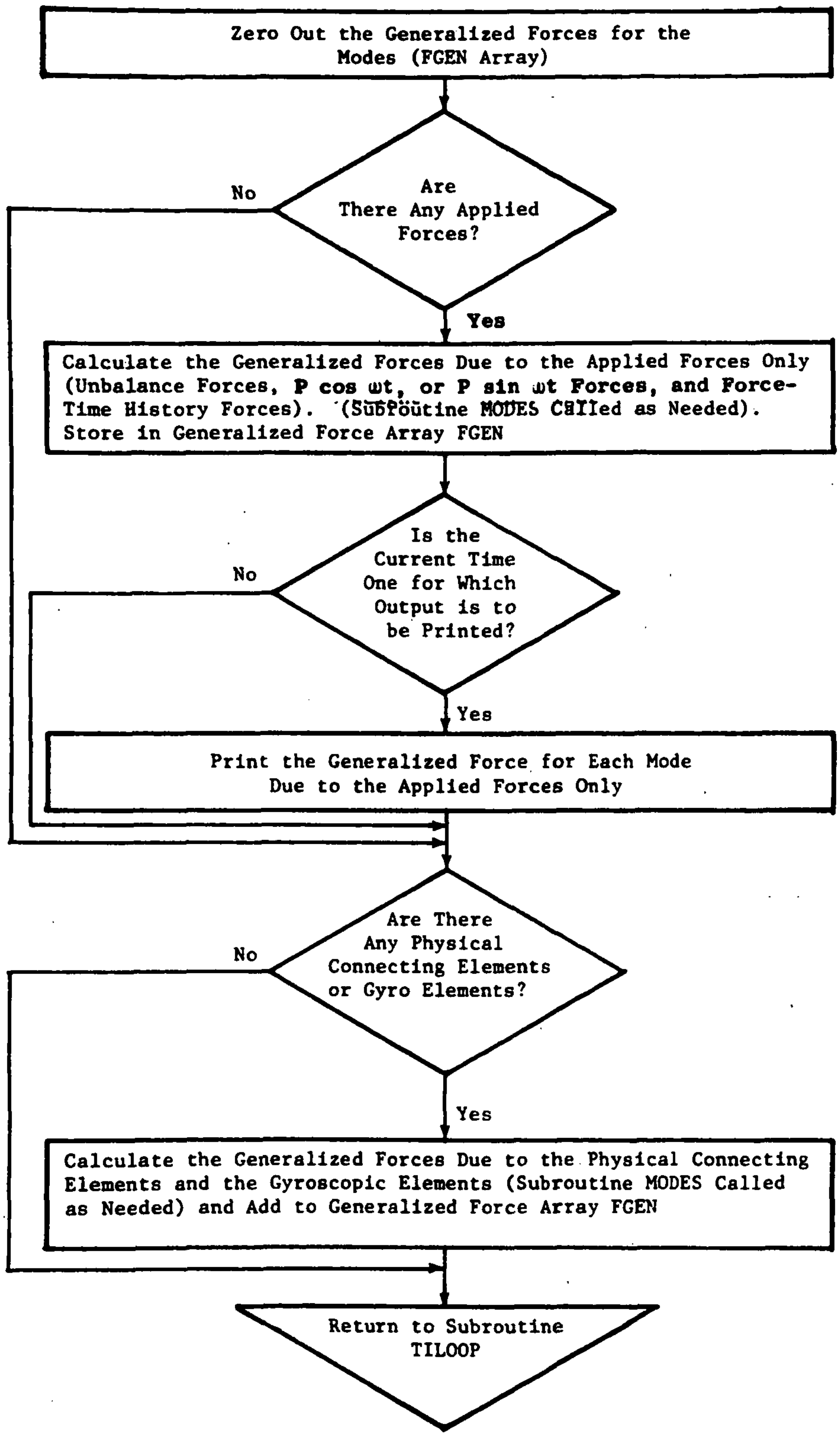


Figure 36. Flow Chart of Subroutine GEN.

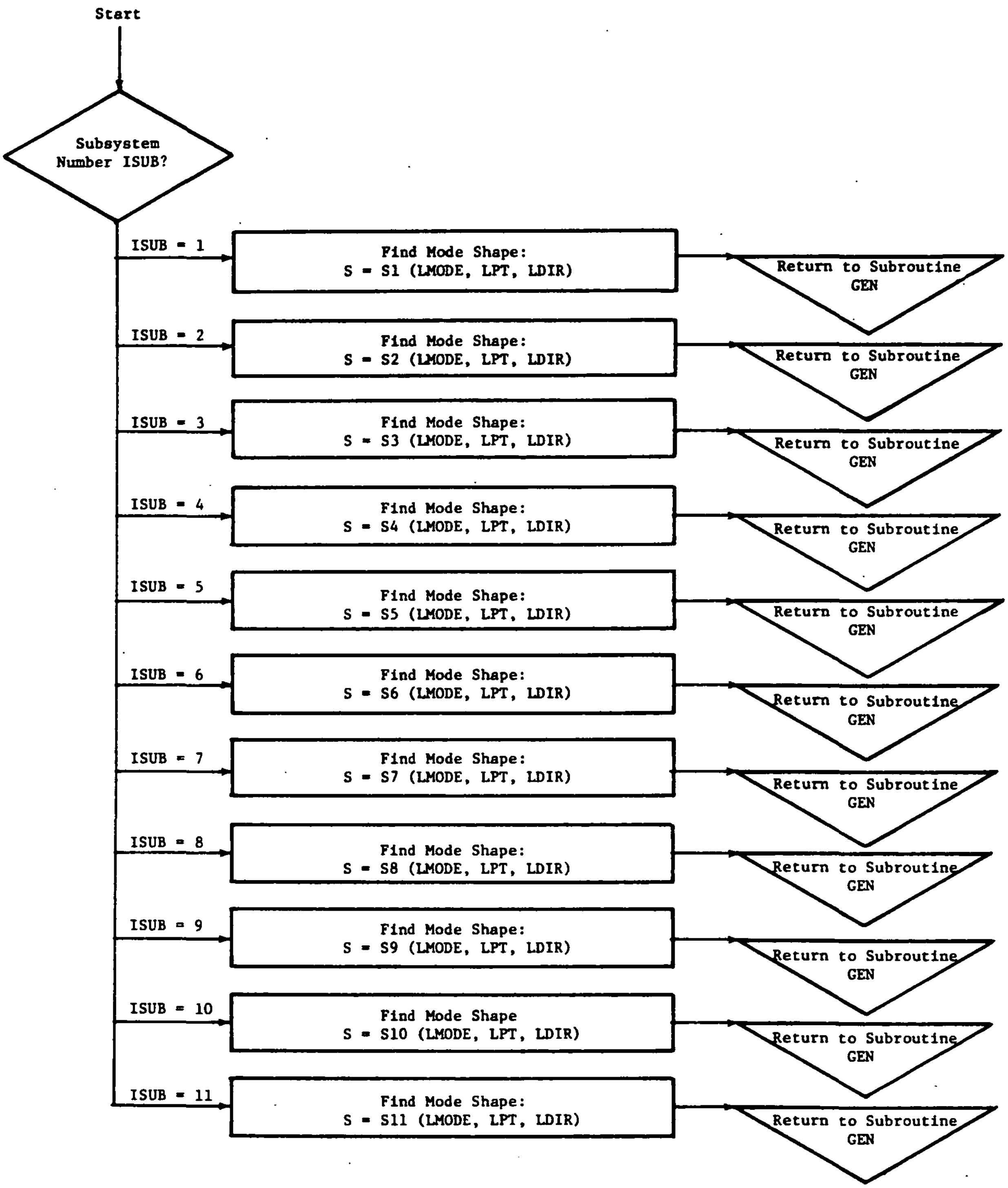


Figure 37. Flow Chart of Subroutine MODES.

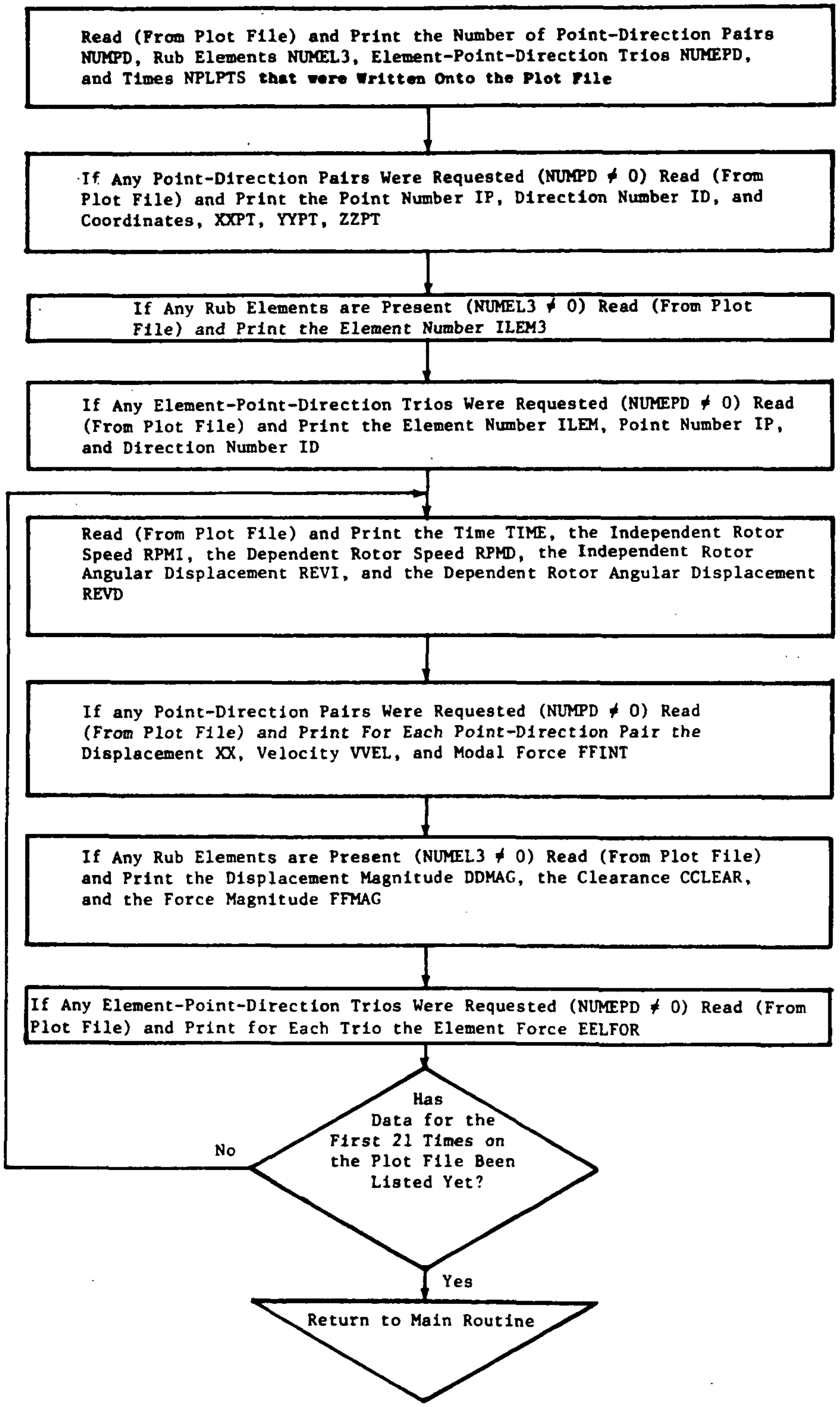


Figure 38. Flow Chart of Subroutine LISTPF.

3.0 MODULAR ELEMENT MODELING

Modal representations obtained by transforming the degrees-of-freedom from real space to modal space are used to define the structural dynamic properties of the subsystems. The real space formulations for the subsystems are based on beam-like finite element (discrete mass and stiffness) subsystem models of the engine rotor(s) and case and a three-dimensional finite element model of the pylon, all described with respect to a ground fixed coordinate system. Figure 39 shows typical subsystem normal modes and coupling ratios for a rotor finite element model. The flexual vibration characteristics of equivalent nonrotating shaft(s) are used to define the rotor(s). The whirl phenomenon is addressed by using Euler's law for angular motions to establish cross-axis coupling forces that are dependent on angular velocities in two planes and proportional to the polar inertia; these forces are applied as external forces to the modal coordinates that represent the rotor in two planes.

The free-free undamped modes in both the vertical and horizontal planes for the rotor(s) and the case are derived from planar finite element models. In addition, a single dimension (single degree-of-freedom at each station) torsional model is also used to model the case. The rigid body modes for the rotor(s) and case in the vertical and horizontal directions can be defined either with the "soft spring" rigid body modes or can be defined with separate modal subsystems representing computed rigid body modes based on the mass properties and the geometry. The torsional direction rigid body modes for the case are represented either with the "soft spring" rigid body modes or with a rigid body modal subsystem. It will be noted that the case torsional direction is important for modeling the engine mounting system load paths. The fore-and-aft motions are represented with rigid body modal subsystems for both the rotor(s) and the case. The pylon finite element model is used to define a set of three-dimensional cantilevered modes. Figure 40 shows the global coordinate system, direction numbers, and a typical engine mounting arrangement. Table I identifies the physical degree-of-freedom associated with each subsystem. Relative to defining the the rigid body mode shapes for separate rigid body subsystems, it will be noted that in general an

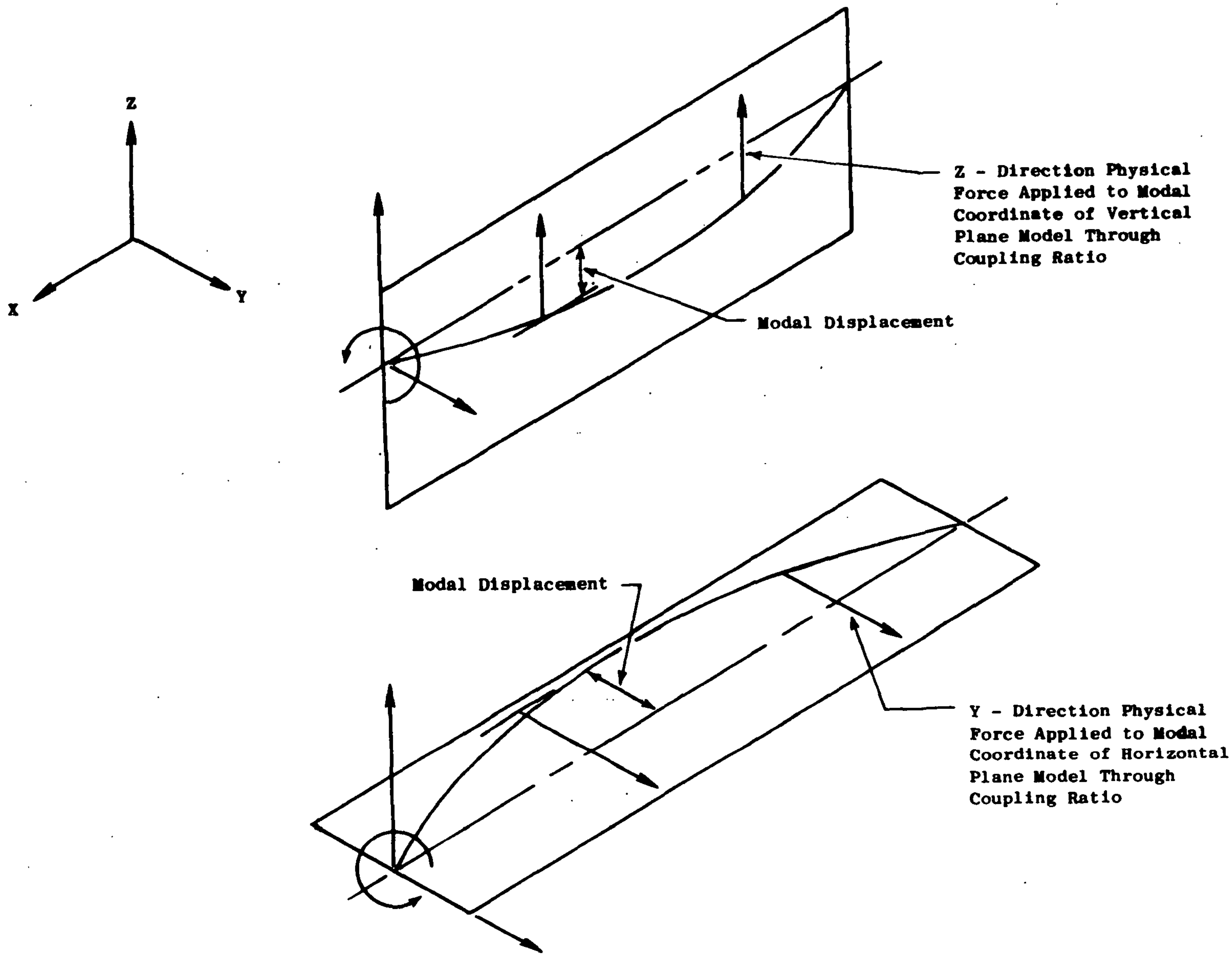


Figure 39. Engine Rotor Subsystem Normal Modes in Two Orthogonal Planes.

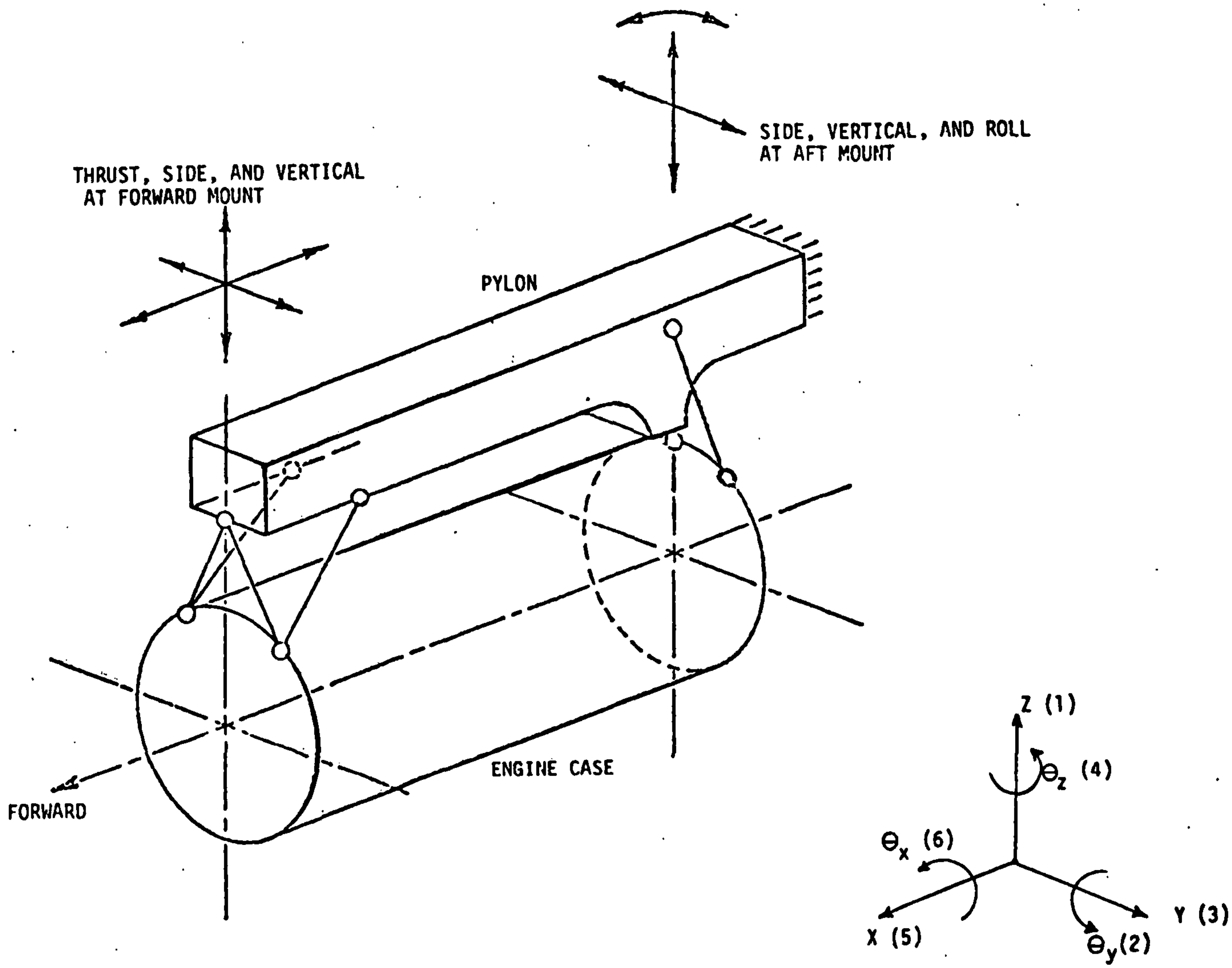
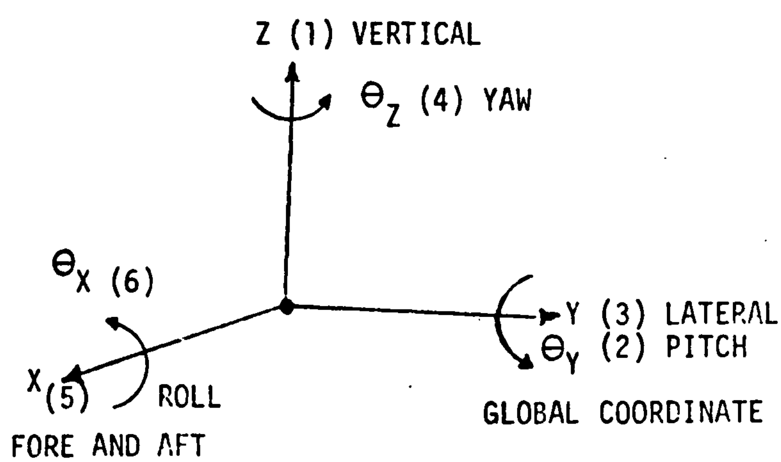


Figure 40. Typical Mounting Arrangement and Coordinate System.

Table I. Physical Global Degree-of-Freedom and Direction Numbers for the Subsystems.

SUBSYSTEMS	GLOBAL DEGREES-OF-FREEDOM					
	Z	Θ_Y	Y	Θ_Z	X	Θ_X
	1	2	3	4	5	6
VERTICAL PLANE FLEXIBLE ROTOR (S)	●	●				
HORIZONTAL PLANE FLEXIBLE ROTOR (S)			●	●		
RIGID BODY ROTOR (S)	●	●	●	●	●	
VERTICAL PLANE FLEXIBLE CASE	●	●				
HORIZONTAL PLANE FLEXIBLE CASE			●	●		
RIGID BODY CASE	●	●	●	●	●	●
TORSIONAL FLEXIBLE CASE						●
3D FLEXIBLE PYLON	●		●		●	



GLOBAL COORDINATE SYSTEM

unconstrained rigid body is free to move in space in six directions. Such "rigid body" motion corresponds, in rectilinear coordinates, to translations in X, Y, Z and rotations in θ_x, θ_y, and θ_z. The equations describing these motions are as follows:

$$
\underset{\text{Applied Physical Forces}}{\begin{Bmatrix} F_x \\ F_y \\ F_z \\ M_x \\ M_y \\ M_z \end{Bmatrix}} = \underset{\text{Inertia Matrix}}{\begin{bmatrix} m & 0 & 0 & 0 & 0 & 0 \\ 0 & m & 0 & 0 & 0 & 0 \\ 0 & 0 & m & 0 & 0 & 0 \\ 0 & 0 & 0 & I_x & 0 & 0 \\ 0 & 0 & 0 & 0 & I_y & 0 \\ 0 & 0 & 0 & 0 & 0 & I_z \end{bmatrix}} \cdot \underset{\text{Physical Accelerations of the C.G.}}{\begin{Bmatrix} \ddot{X} \\ \ddot{Y} \\ \ddot{Z} \\ \ddot{\theta}_x \\ \ddot{\theta}_y \\ \ddot{\theta}_z \end{Bmatrix}} \tag{17}
$$

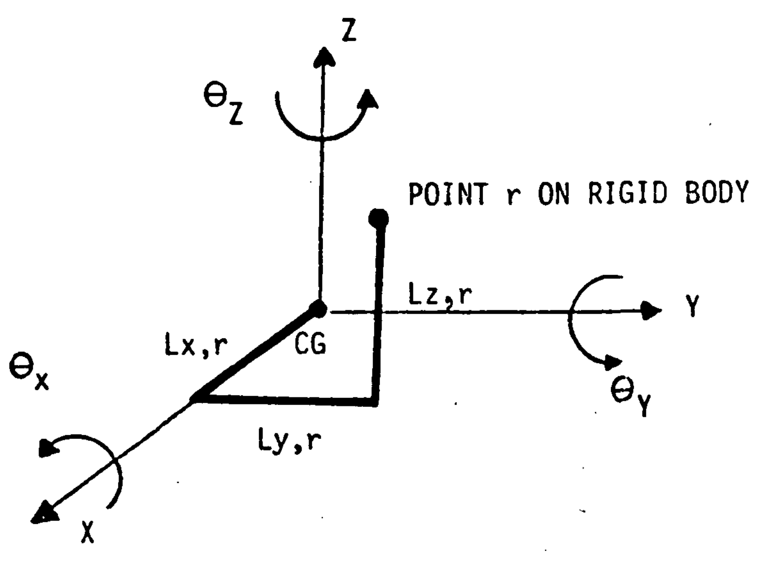
These equations are included in the set defined by equation (1). In this special case, m_i corresponds to the physical mass properties m, I_x, I_y, or I_z, q_i corresponds to the physical coordinates X, Y, Z, θ_x, θ_y, or θ_z of the C.G., and the k_i terms are equal to zero. Note that for a general (nonprincipal) set of axes, the inertia matrix of equation (17) would include off-diagonal terms. For a three dimensional body where the planes of symmetry pass through the center of mass there is not inertia coupling and the inertia matrix corresponds to that of equation (17). The eigenvectors for the six rigid body "modes" are shown in Table II.

In general, the flexible beam like rotor and case finite element models will be used to generate modal data for a single plane, say the vertical plane. This modal data can also be used to represent the horizontal plane. However, it will be noted that the sign of the modal data in either the Y or θ_z directions must be changed in order to maintain a sign convention that is consistent with a right hand global coordinate system. This is shown in Figure 41.

Table II. Mode Shapes for the Six Rigid Body Modes for a Subsystem.

PHYSICAL DIRECTION AND COORDINATE FOR POINT r		GENERALIZED COORDINATE q_i					
DIRECTION NUMBER	COORDINATE	X	Y	Z	Θ_x	Θ_y	Θ_z
5	Xr, 5	1.0	0	0	0	$L_{z,r}$	$-L_{y,r}$
3	Xr, 3	0	1.0	0	$-L_{z,r}$	0	$L_{x,r}$
1	Xr, 1	0	0	1.0	$L_{y,r}$	$-L_{x,r}$	0
6	Xr, 6	0	0	0	1.0	0	0
2	Xr, 2	0	0	0	0	1.0	0
4	Xr, 4	0	0	0	0	0	1.0
		ϕ_1	ϕ_2	ϕ_3	ϕ_4	ϕ_5	ϕ_6

COLUMNS CORRESPOND TO RIGID-BODY MODE SHAPES



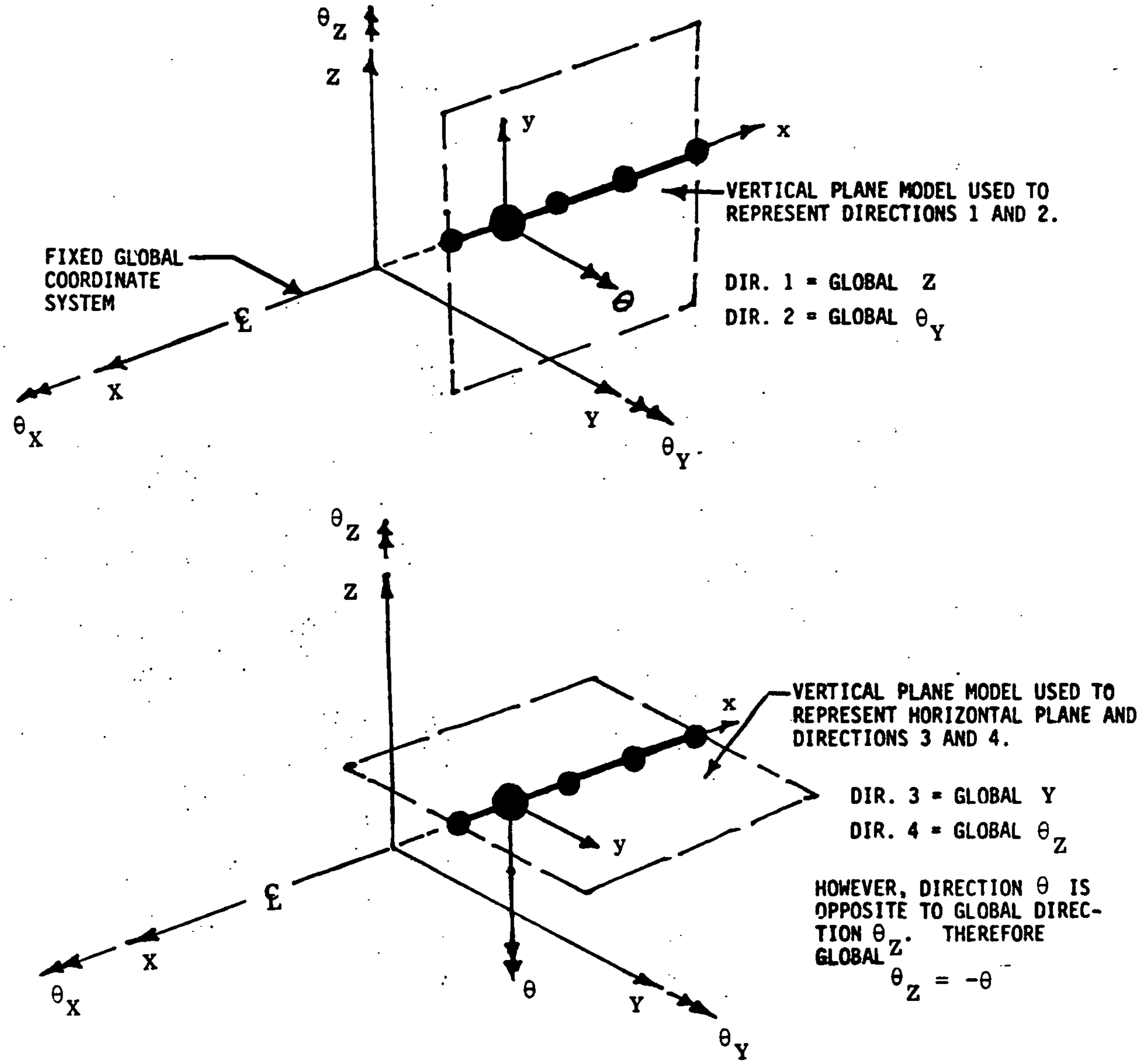


Figure 41. Modal Planes.

Physical Connecting Elements

The force-displacement and force-velocity relationships for the physical connecting elements that connect the modal subsystems are expressed in terms of the stiffness and damping matrices shown in equation (18).

$$\{F\} = - [K_e] \{X\} - [C_e] \{\dot{X}\} \tag{18}$$

Equation (18) defines the physical forces exerted by the physical connecting element on the modal subsystems to which it is connected.

Generalized Spring-Damper Element (Type 1 Physical Connecting Element)

This element is associated with two physical points located at arbitrary locations in global space. Each of these points is assigned six degrees of freedom, three translational displacements (or velocities), and three rotational displacements (or velocities). Thus, the dimension for both the stiffness or damping matrix is equal to twelve.

This element can be used to represent simple uncoupled point springs and dampers that are useful in modeling rolling element bearings. Among the other load path configurations that this element can be used to model are engine frame/sump structures, hydrodynamic bearing definitions with direct and cross stiffness and damping, and cross axis stiffness coupling arising from aerodynamic effects. A sketch of this element is shown in Figure 42.

Typically, the stiffness elements in $[K_e]$ are computed via a finite element program, or with a closed form solution for an idealized model, or are obtained from static or dynamic testing. The damping elements in $[C_e]$ are computed if analytical expressions are available, or are obtained from dynamic testing, or are based on the assumption that the damping is proportional to the stiffness. In this latter case, $[C_e] \alpha [K_e]$ and the proportionality can be based on a specified percent of critical damping at a selected frequency as shown in equation (19).

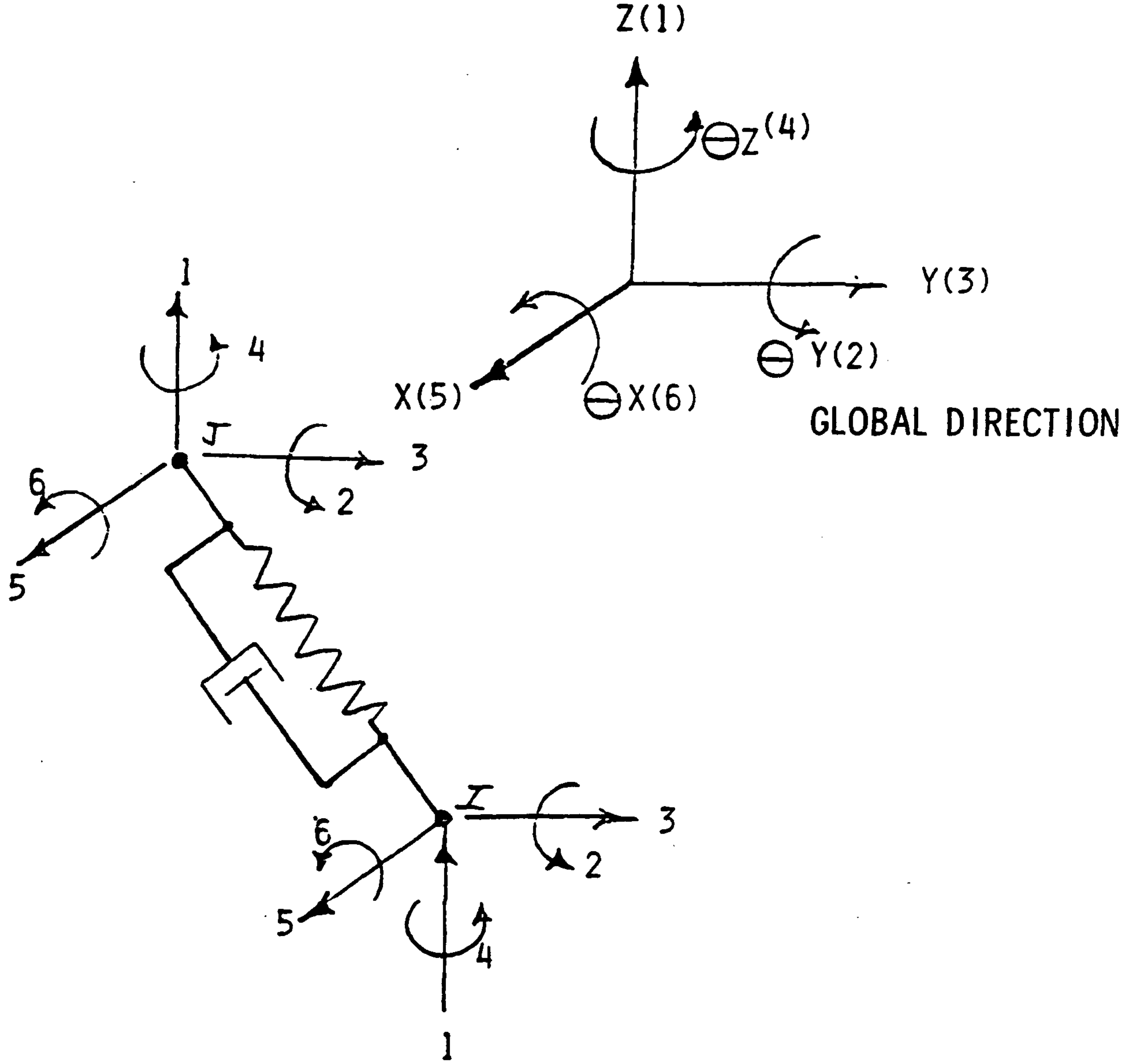


Figure 42. General Spring-Damper Element (Typical Physical Connecting Element).

$$[C_e] = \frac{1}{\omega Q_F} [K_e] \tag{19}$$

Q_F = specified Q - factor = $\frac{1}{2\ C/C_c}$

ω = selected frequency, radians/second.

<u>Space Link-Damper Element</u> (Type 2 Physical Connecting Element)

The space link-damper element sketched in Figure 43 is described by 6th order stiffness and damping matrices.

$$[K_e] = \frac{AE}{L} \begin{bmatrix} n^2 & nm & nl & -n^2 & -nm & -nl \\ nm & m^2 & ml & -nm & -m^2 & -lm \\ nl & ml & l^2 & -ln & -lm & -l^2 \\ -n^2 & -nm & -ln & n^2 & nm & nl \\ -nm & -m^2 & -lm & nm & m^2 & ml \\ -nl & -lm & -l^2 & ln & ml & l^2 \end{bmatrix} \tag{20}$$

n, m, and l are the direction cosines, and the column and row order còrrespond to directions 1, 3, and 5 at points I and J, respectively.

A = cross section area, in^2

E = Young's modules

L = length

The damping matrix $[C_e]$ can be defined either in terms of translational (dashpot) damping directed along the axis of the link or by proportional damping.

In the former case, $[C_e] = \frac{L}{AE}\ C\ [K_e]$ (21)

C $\frac{lb/sec}{in}$ is a specified scalar damping value.

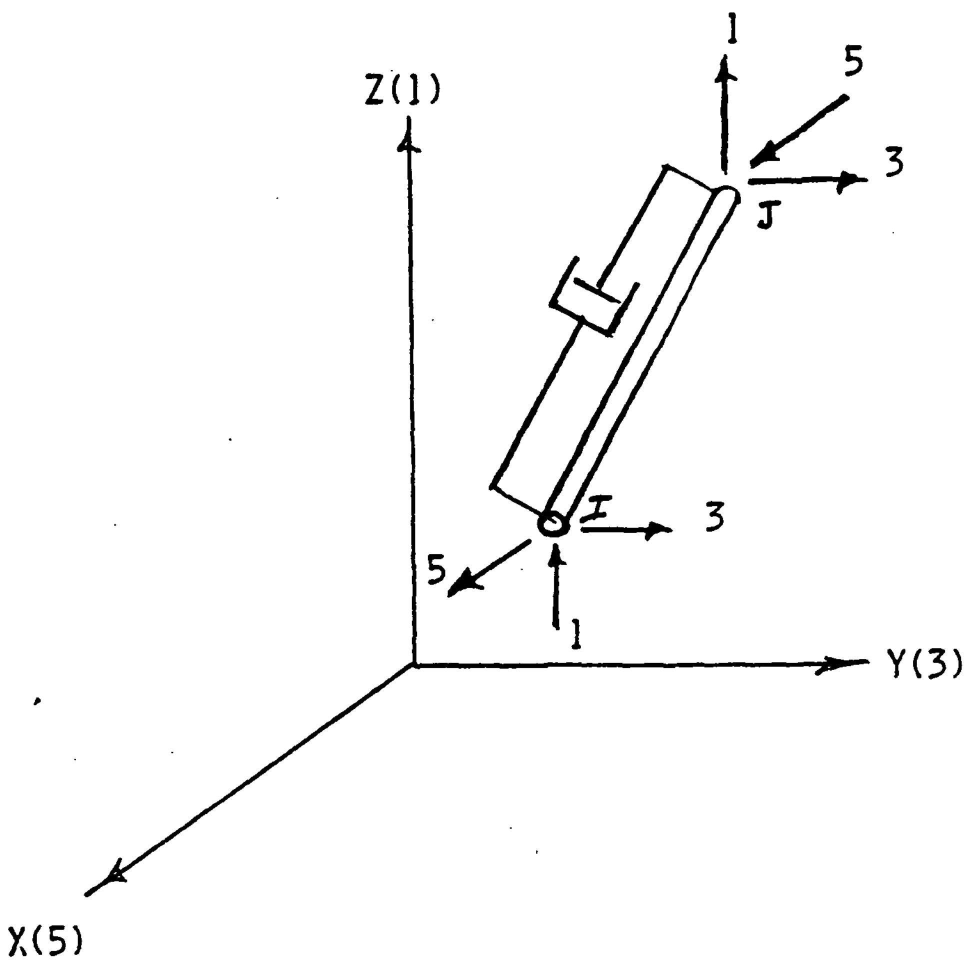


Figure 43. Space Link-Damper Element (Type 2 Physical Connecting Element).

In the latter case, the form of the damping matrix is that shown in equation (19).

Rub Element (Type 3 Physical Connecting Element)

The large rotor amplitudes associated with blade loss cause heavy rotor-case rubs that are usually accompanied by severe local damage to blades and case. It is to some degree fortunate that this local damage does occur because the loads acting on the bearings and frames are reduced by the action of the additional load path between the rotor and case that is provided through the mechanism of the heavy rubs. As a consequence of this action, the engine may be capable of withstanding without catastrophic structural failure, the transient loading induced by the blade loss.

The rub element allows the mathematical modeling of the nonlinear tip rub that includes the dead band displacement interval prior to closure between the rotor and case. Upon closure, an equivalent linear spring, representing the local case distortion and blade compliance, is used to define the rotor-to-case load path. The net result is a bilinear spring with zero slope over the dead band and a finite slope over the region of interference.

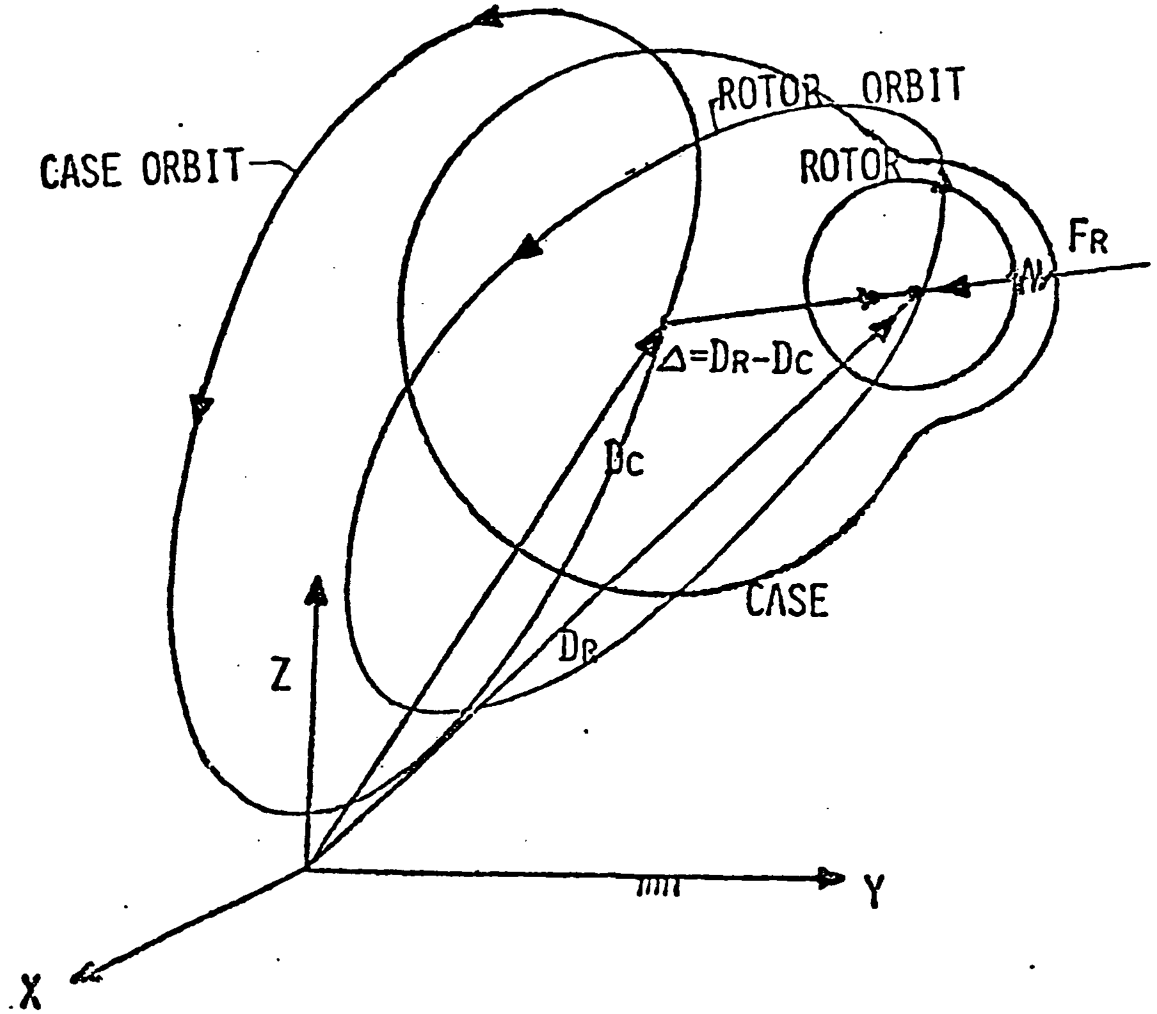
Figure 44 shows the relationships between the rub force and the position vectors of the rotor and case centers. Neglecting friction, the rub force can be defined as a force that acts in the direction defined by the line of centers. The vector rub force acting on the rotor can be written as:

$$
\begin{aligned}
F_r &= -\frac{\Delta}{|\Delta|}\left(|\Delta| - \varepsilon_o\right) K - (V_R - V_C)C \qquad \text{For } |\Delta| > \varepsilon_o \\
F_r &= 0 \qquad \text{For } |\Delta| \leq \varepsilon_o
\end{aligned}
\tag{21}
$$

Where K = Radial spring rate representing the local case distortion (represented by the bulge shown in Figure 44) and the blade compliance.

ε_o = Structural clearance

Δ = $(D_r - D_c)$ = vector difference between the position vectors of the rotor and case centers.



AT TIME = τ, VECTORS, DC AND DR DEFINE POSITIONS OF CASE & ROTOR CENTERS.

VECTOR DIFFERENCE = Δ = DR - DC

IF $|\Delta| > \epsilon_o$ THEN RUB

ϵ_o = STRUCTURAL CLEARANCE

FR = VECTOR RUB FORCE = $-\frac{\Delta}{|\Delta|}(|\Delta| - \epsilon_o)K$ (NEGLECTING DAMPING)

K = SPRING RATE REPRESENTING THE LOCAL CASE DISTORTION AND BLADE COMPLIANCE

Figure 44. Rub Force Model to Represent the Nonlinear Tip Rub Mechanism That Includes the Dead Band Interval Prior to Closure.

$\frac{\Delta}{|\Delta|}$ = unit vector in the direction of vector Δ.

V_R and V_C are the vector velocities of the rotor and case centers, respectively.

C is the damping rate.

In complex notation, Δ can be written as:

$$\Delta = D_R - D_C = (y_R + jZ_R) - (y_C + jZ_C) = (y_R - y_C) + j(Z_R - Z_C)$$

Where j = unit vector in the z-direction.

$$|\Delta| = \text{amplitude of } \Delta = \sqrt{(y_R-y_C)^2 + (Z_R-Z_C)^2} \tag{22}$$

$$F_r = -\left[(y_R-y_C) + j(Z_R-Z_C)\right]\left[1.0 - \frac{\varepsilon_o}{|\Delta|}\right] K - (V_R-V_C)C$$

$$F_r = -(y_R-y_C)\left[1.0 - \frac{\varepsilon_o}{|\Delta|}\right] K - j(Z_R-Z_C)\left[1.0 - \frac{\varepsilon_o}{|\Delta|}\right] K \tag{23}$$

$$- C\left[(\dot{y}_R-\dot{y}_C)\right] - jC\left[(\dot{Z}_R-\dot{Z}_C)\right]$$

$$\text{Defining } A = \left[1.0 - \frac{\varepsilon_o}{\sqrt{(y_R-y_C)^2 + (Z_R-Z_C)^2}}\right] K \tag{24}$$

as an effective spring coefficient which is dependent on the initial structural clearance and the rotor-case relative displacement and case-blade local spring rate. A stiffness matrix can be defined as follows:

$$\begin{Bmatrix} F_r^Z \\ F_r^y \\ F_C^Z \\ F_C^y \end{Bmatrix} = \begin{bmatrix} -A & 0 & A & 0 \\ 0 & -A & 0 & A \\ A & 0 & -A & 0 \\ 0 & A & 0 & -A \end{bmatrix} \cdot \begin{Bmatrix} Z_R \\ y_R \\ Z_C \\ y_C \end{Bmatrix} \tag{25}$$

Where F_r^z and F_r^y are the forces acting on the rotor center in the z and y directions, repsectively.

F_C^z and F_C^y are the forces acting on the case center in the z and y directions, respectively.

z_R, y_R, z_C, y_C are the absolute displacements of the rotor and case center.

The stiffness matrix in equation (25) is also shown in Figure 45 and represents the $[K_e]^*$ matrix in equation (18). The damping forces can be written in matrix form as:

$$\begin{Bmatrix} F_C^z \\ F_r^y \\ F_C^z \\ F_C^y \end{Bmatrix} = \begin{bmatrix} -C & 0 & 0 & 0 \\ 0 & -C & 0 & C \\ C & 0 & -C & 0 \\ 0 & C & 0 & -C \end{bmatrix} \cdot \begin{Bmatrix} \dot{z}_R \\ \dot{y}_R \\ \dot{z}_C \\ \dot{y}_C \end{Bmatrix} \tag{26}$$

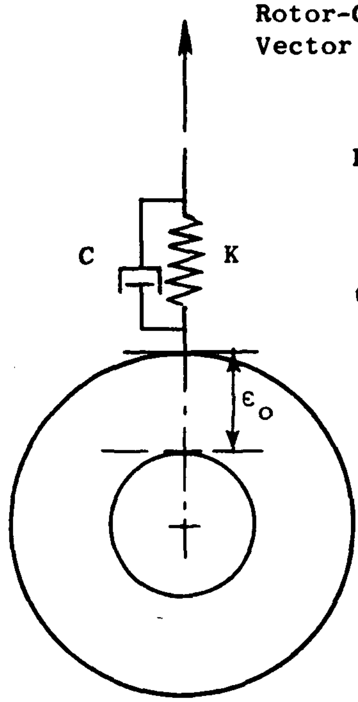
$\dot{z}_R$, $\dot{y}_R$, $\dot{z}_C$, $\dot{y}_C$ are the absolute velocities of the rotor and case centers. The damping matrix in equation (26) represents the $[C_e]^*$ matrix in equation (18).

It will be noted that the rub element defined by equations (25) and (26) can also be used to model rotor-to-rotor rubs as well as rotor-to-case rubs. In this case, the inside rotor is identified with the subscript r and the outside rotor is identified with subscript C.

Engine Support Element (Type 4 Physical Connecting Element)

Real aircraft engine mounting systems are quite complex and must be modeled with three dimensional models if accurate simulation is to be obtained. Figure 46 shows an example of an aircraft engine mounting arrangement where three mounting planes are utilized. The forward mounting plane takes vertical, side, and axial loads. The mid mounting plane takes side and roll loads. The aft mounting plane takes vertical loads only.

*Equations (25) and (26) represent the forces acting on the connecting subsystems and already incorporate the minus signs shown in equation (18). Hence, in this case, the $[K_e]$ and $[C_e]$ matrices shown in equations (25) and (26) should be multiplied by (-1) to conform to the form of equation (18).



$$\begin{bmatrix} F_R^1 \\ F_R^3 \\ F_C^1 \\ F_C^3 \end{bmatrix} = \begin{bmatrix} -A & 0 & A & 0 \\ 0 & -A & 0 & A \\ A & 0 & -A & 0 \\ 0 & A & 0 & -A \end{bmatrix} \cdot \begin{bmatrix} X_R^1 \\ X_R^3 \\ X_C^1 \\ X_C^3 \end{bmatrix}$$

Spring
Rub Forces
Acting on
Rotor and Case
When $/\Delta/ > \varepsilon_o$

$$A = \left[1.0 - \frac{\varepsilon_o}{\sqrt{\left(X_R^1 - X_C^1\right)^2 + \left(X_R^3 - X_C^3\right)^2}} \right] K = \left[1.0 - \frac{\varepsilon_o}{/\Delta/} \right] K$$

Superscripts 1 and 3 Represent Directions Z and Y

Figure 45. Rub Element (Type 3 Physical Connecting Element).

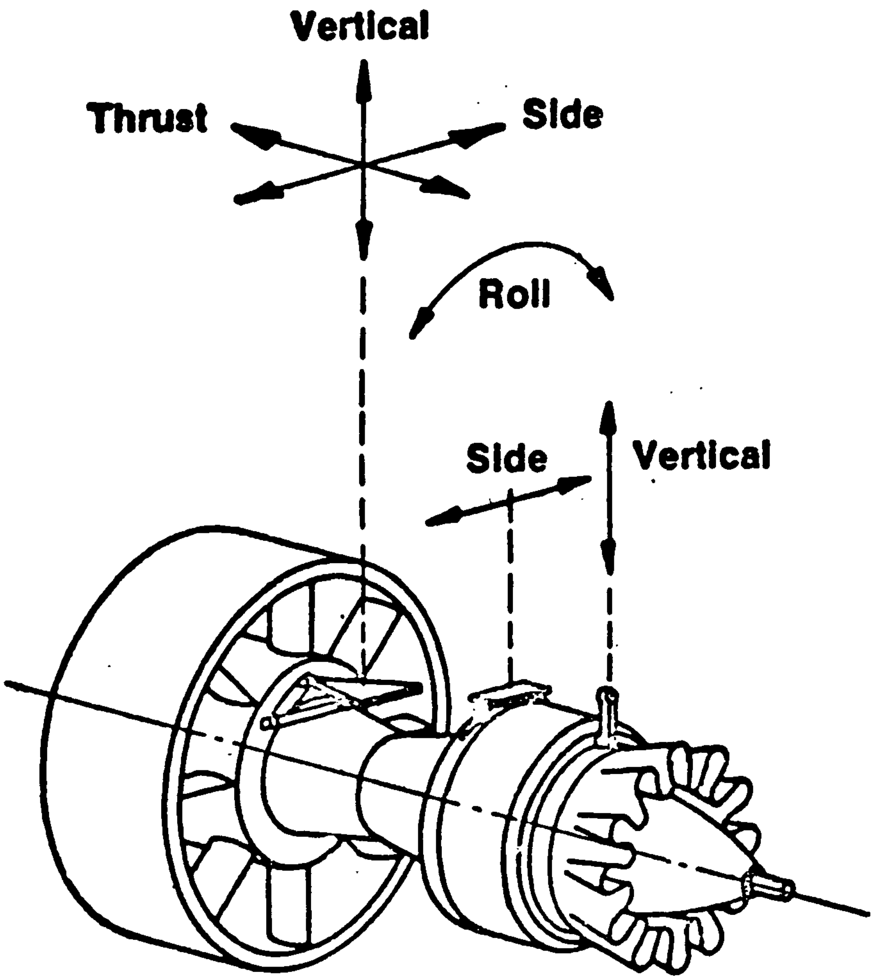
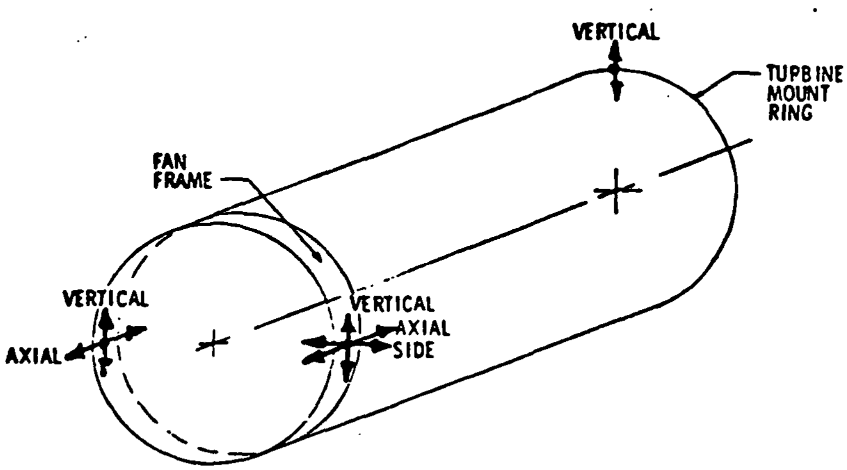


Figure 46. An Example of an Aircraft Engine Mounting Arrangement.

The engine support element is a multipoint, multidirection element that provides the capability to model the complex load paths between the engine case and the pylon and thus allows for the direct modeling of actual engine mount structures. In addition, this element couples the flexible and rigid body-centerline modal subsystems, that represent the engine case, to the support links that comprise the mounting system. Thus, this element is really a combined engine support-case flexibility element that couples the beam-like casing model to the 3D pylon subsystem. Figure 47 shows typical engine case-link attachment points. The loads at these attachment points induce frame/case distortions that increase the effective flexibility that is seen at the engine centerline. In this example, the side direction flexibility at the forward mounting plane would be increased by the fan frame/case ovalization effect and the vertical direction flexibility at the aft mounting plane would be increased by the turbine frame/case ovalization effect.

Figure 48 shows the attachment and centerline points in global space, and the load directions for the two mounting planes corresponding to the typical mounting arrangement shown in Figure 40. At the forward mounting plane, points L, M, and N are the attachment points on the pylon and point I is at the engine centerline. The two attachment points on the engine case are identified by J and K. In this case, the engine support element is represented with the stiffness matrix relating to the points I, L, M, N. The displacement terms associated with points J and K are reduced out. Point I has six degrees-of-freedom and points L, M, and N each have three degrees-of-freedom. It is necessary to eliminate points J and K because the physical connecting elements are only used to define the load paths between modal subsystems or between modal subsystems and ground.

The model definition for the portion of the engine support element that pertains to the case flexibility (flexibility between the engine centerline and the case attach points) is shown in Figure 49. In this representation, all of the case flexibility is lumped at the case attach points (points J and K) and rigid members are used to transfer the loads to the centerline point (point I). The case flexibility is described by three spring rates, K_v, K_h, and K_a. These rates are reciprocals of the case flexibility values obtained by either calculation or measurement. In the former case, a finite



IN THIS ILLUSTRATION, THE LOCAL LOADS AT THE ATTACHMENT POINTS RESULT IN ADDITIONAL MOUNTING FLEXIBILITY AT THE FORWARD PLANE, IN THE SIDE DIRECTION AND AT THE AFT PLANE, IN THE VERTICAL DIRECTION.

Figure 47. Engine Frame/Case Ovalization Effects Increase the Effective Flexibility at the Mounting Planes.

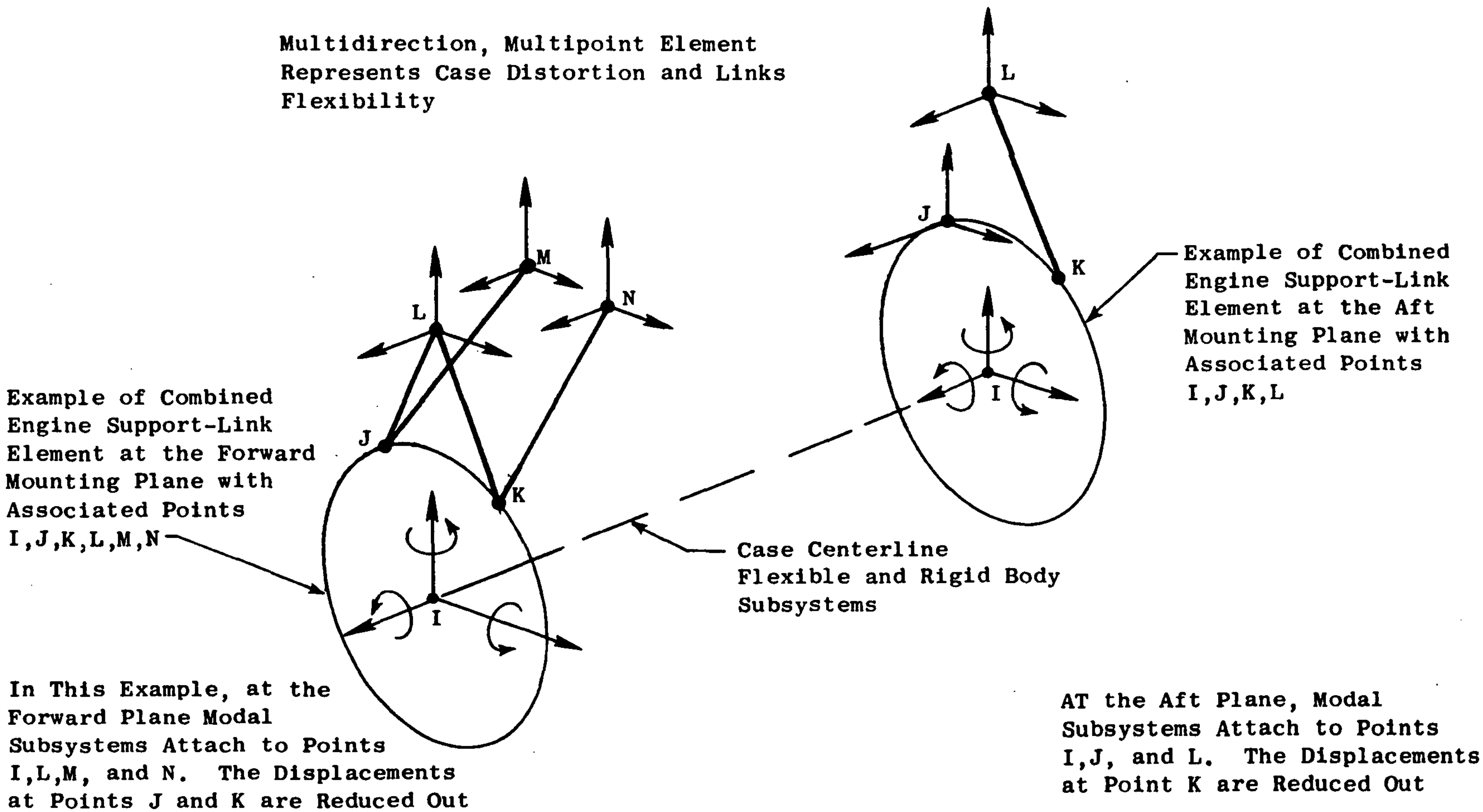


Figure 48. Combined Engine Support-Link Element (Type 4 Physical Connecting Element).

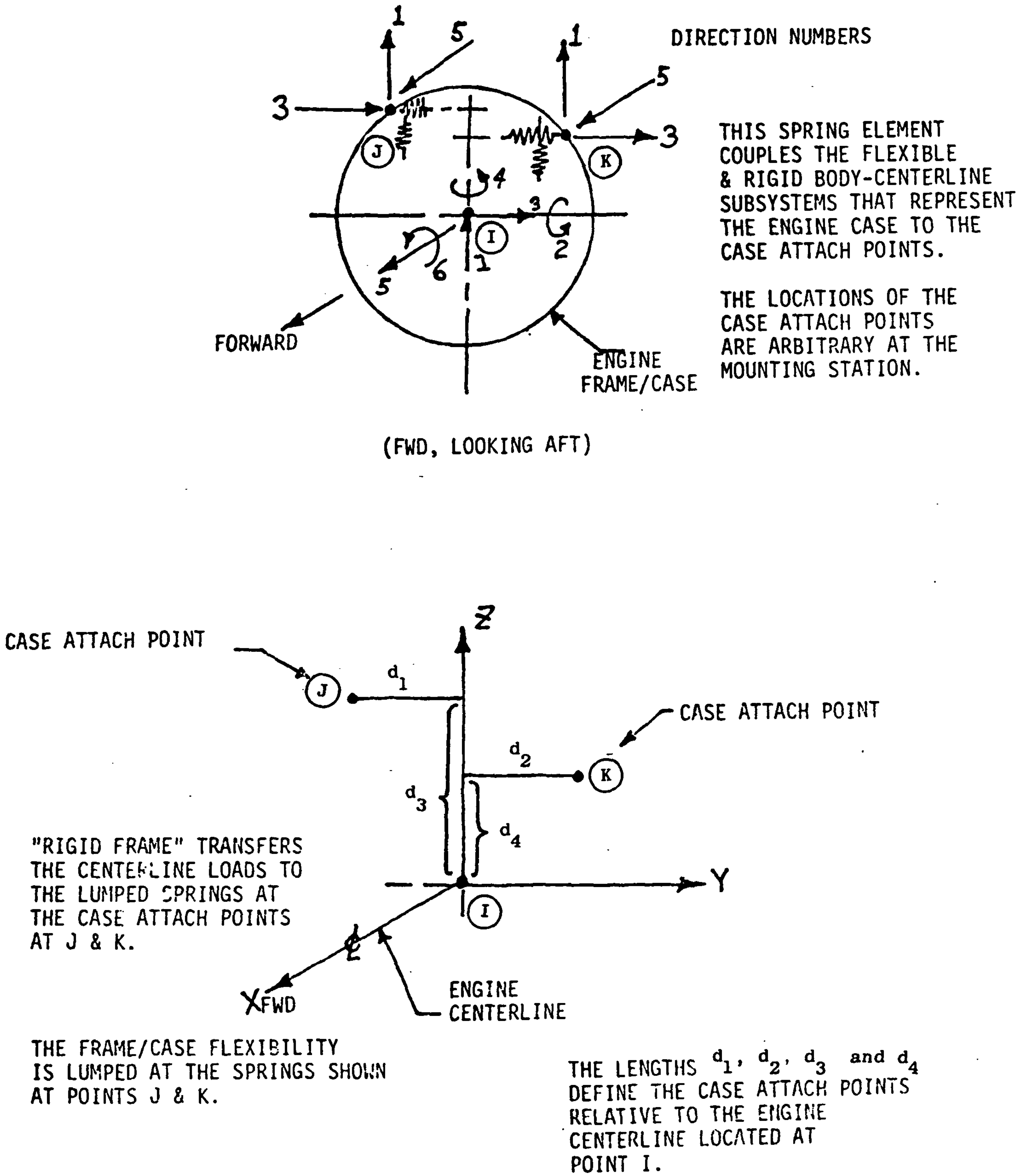


Figure 49. Case Flexibility Represented by Multipoint/Direction Physical Spring Element (Which Defines a Portion of the Engine Support Element).

element model of the frame is typically used to define the flexibility values. For example, K_v would be defined by applying an n = 1 shear flow restraining the frame model at the case attach point locations. The vertical displacement of a horizontal diameter would then be used to establish the spring rate Kv. Figure 50 shows the twelfth order stiffness matrix that describes the case flexibility. The terms, a, b, c, d, e, and f are multipliers used to proportion the spring rates, and the association between the spring rates K_v, K_h, K_a, and the lumped spring location points J and K are shown below.

Multipliers

Spring Rates (lb/in.)	Point J	Point K
Kv	a	c
Kh	b	d
Ka	e	f

Case Distortion Spring Rates

Kv = Vertical Spring Rate

Kh = Horizontal Spring Rate

Ka = Axial Spring Rate

In conjunction with this scheme, the following restraints must be followed.

$$a + c = 1.0$$
$$b + d = 1.0$$
$$e + f = 1.0$$

For symmetrical mounting, a = b = c = d = e = f = .5.

The engine support element is a variable geometry element that is formed by combining the spring element stiffness matrix $[K_f]$ of Figure 50 with the stiffness matrices for connecting link elements. The stiffness matrices for the individual link elments have the same form as the stiffness matrix shown in equation (20).

$$[K_c] = [K_f] + K_l] = \left[\begin{array}{c|c} K_{11} & K_{12} \\ \hline K_{21} & K_{22} \end{array}\right] \tag{27}$$

$$[K_e] = \left[K_{11} - K_{12}\, K_{22}^{-1}\, K_{21}\right] \tag{28}$$

[Kf] = spring element stiffness matrix representing the case

[Kl] = stiffness matrix for the links

	X_I^1	X_I^2	X_I^3	X_I^4	X_I^5	X_I^6	X_J^1	X_J^3	X_J^5	X_K^1	X_K^3	X_K^5
F_I^1	$K_v\ (a+c)$	0	0	0	0	$CK_v\ d_2$ $-AK_vd_1$	$-AK_v$	0	0	$-CKv$	0	0
F_I^2	0	$K_a \cdot$ $(d_4^2f+d_3^2e)$	0	$K_a \cdot$ $(d_1d_3e-d_2d_4f)$	$K_a \cdot$ (d_4f+d_3e)	0	0	0	$-d_3eK_a$	0	0	$-d_4fK_a$
F_I^3	0	0	$K_h(b+d)$	0	0	$-K_h$ (d_3b+d_4d)	0	$-bK_h$	0	0	$-dK_h$	0
F_I^4	0	$K_a \cdot$ $(d_1d_3e-d_2d_4f)$	0	$K_a \cdot$ $(ed_1^2+fd_2^2)$	$K_a \cdot$ (d_1e-d_2f)	0	0	0	$-ed_iK_a$	0	0	fd_2K_a
F_I^5	0	$K_a \cdot$ $(d\ f+d_3e)$	0	$K_a \cdot$ (d_1e-d_2f)	$K_a\ (e+f)$	0	0	0	$-eK_a$	0	0	$-f\ K_a$
F_I^6	CK_vd_2 $-aK_vd_1$	0	$-K_h \cdot$ (d_3b+d_4d)	0	0	$K_v(Cd_2^2+ad_1^2)$ $K_h(bd_3^2+dd_4^2)$	aK_2d_1	bd_3K_h	0	$-Cd_2K_v$	dd_4K_h	0
F_J^1	$-aK_v$	0	0	0	0	ad_1K_v	aK_v	0	0	0	0	0
F_J^3	0	0	$-bK_h$	0	0	bd_3K_h	0	bK_h	0	0	0	0
F_J^5	0	$-d_3\ eK_a$	0	$-ed_1K_a$	$-eK_a$	0	0	0	eK_a	0	0	0
F_K^1	$-CK_v$	0	0	0	0	$-Cd_2K_v$	0	0	0	CK_v	0	0
F_K^3	0	0	$-dK_h$	0	0	dd_4K_h	0	0	0	0	dK_h	0
F_k^5	0	$-d_4fK_a$	0	fd_2K_a	$-fK_a$	0	0	0	0	0	0	fK_a

$= [K_f]$

The subscripts and superscripts for the forces and displacements pertain to the point numbers and the direction numbers, respectively.

Figure 50. Combined In-Plane and Out-of Plane Stiffness Matrix for the Physical Spring Element Shown in Figure 49.

[Kc] = total unreduced stiffness matrix for the assembly

[Ke] = reduced stiffness matrix for the engine support element

The matrix [Kc] in equation (27) represents the total unreduced stiffness matrix which includes the case points J and K. Equation (28) represents the matrix reduction that is performed to eliminate points J and K. Figure 48 shows two examples of engine support element configurations. It will be noted that there are no local moment load paths at points J and K or at the link attachments at the pylon.

The damping matrix [Ce] for the engine support element is defined in terms of proporational damping and has the form of the damping matrix shown in equation (19).

Uncoupled Point Spring-Damper Element (Type 5 Physical Connecting Element)

This element is for connection of two points with an uncoupled spring and damper. Each point has five degrees of freedom, three translational displacements (or velocities) and two rotational displacements (or velocities) (see Figure 51). These elements are typically used to connect the centerlines of beam - like modal subsystems. Because of the lack of load path coupling, good modeling practice infers that the points being connected by this element should be coincident in space.

The equations for the forces at the I and J end points of this element become rather simple due to the lack of coupling:

$$F_x^I = -K_x\left(x^I - x^J\right) - C_x\left(\dot{x}^I - x^J\right)$$

$$F_y^I = -K_y\left(y^I - y^J\right) - C_y\left(\dot{y}^I - \dot{y}^J\right)$$

$$F_z^I = -K_z\left(z^I - z^J\right) - C_z\left(\dot{z}^I - \dot{z}^J\right)$$

$$F_{\theta_y}^I = -K_{\theta_y}\left(\theta_y^I - \theta_y^J\right) - C_{\theta_y}\left(\dot{\theta}_y^I - \dot{\theta}_y^J\right)$$

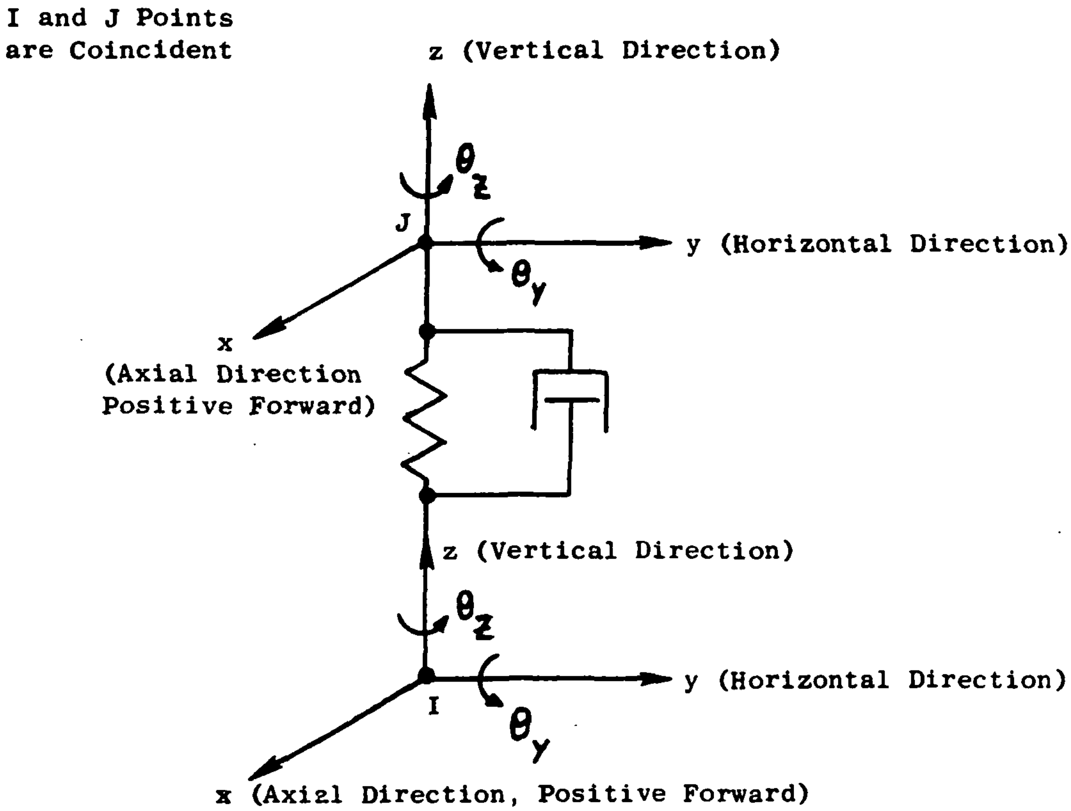


Figure 51. Uncoupled Point Spring - Damper Element (Type 5 Physical Connecting Element).

$$F_{\theta_z}^{I} = -K_{\theta_z}\left(\theta_z^{I} - \theta_z^{J}\right) - C_{\theta_z}\left(\dot{\theta}_z^{I} - \dot{\theta}_z^{J}\right)$$

$$F_x^{J} = F_x^{I}$$

$$F_y^{J} = F_y^{I}$$

$$F_z^{J} = F_z^{I}$$

$$F_{\theta_y}^{J} = F_{\theta_y}^{I}$$

$$F_{\theta_z}^{J} = F_{\theta_z}^{I}$$

where

F_i^j = Force that the element exerts on the modal subsystem or ground. subscript i is for direction (x, y, z, θ_x, or θ_y) and superscript j (I or J) indicates the I-end point or the J-end point.

K_i = Spring constant. Subcript i is for direction (x, y, z, θ_y, or θ_z).

C_i = Damping coefficient. Subscript i is for direction (x, y, z, θ_y, and θ_z).

x^i, y^i, z^i, $\theta_y{}^i$, $\theta_z{}^i$ = Displacements in the x, y, z, θ_y, and θ_z directions, respectively. Superscript i (I or J) indicates the I-end point or the J-end point.

$\dot{x}^i$, $\dot{y}^i$, $\dot{z}^i$, $\dot{\theta}_y{}^i$, $\dot{\theta}_z{}^i$ = Velocities in the x, y, z, θ_y, and θ_z directions respectively. Superscript i (I or J) indicates the I-end point or the J-end point.

As for the generalized spring-damper element (type 1 physical connecting element), the spring constants (K_i) are computed via a finite element program, or with a closed form solution for an idealized model, or are obtained from static or dynamic testing. The damping coefficients (C_i) are computed if analytical expressions are available, or are obtained from dynamic testing, or are based on the assumption that the damping is proportional to the stiffness (see equation 19).

Note that the Type 5 element is a special case of the Type 1 element (generalized spring-damper element). The Type 1 element could always be used instead of the Type 5 element. However, it is recommended that the Type 5 element be used rather than Type 1 wherever possible. The equations for the forces for the Type 5 element are short and simple, but the Type 1 element requires matrix multiplication (see equation 18) (the Type 1 element stiffness and damping matrices are each 12 x 12), which makes the calculation of forces more lengthy. Thus, the program runs more efficiently (and saves on cost) using Type 5 elements instead of Type 1 where possible. The input is also simpler for the Type 5 element than for the Type 1 element.

Gyro Element

The gyro element models the cross-axis forces due to Coliolis acceleration and addresses to general whirl motion defined by the response in two planes. These cross-axis forces are mathematically treated as "Right Hand Side Forces," or externally applied forces, and couple the vertical and horizontal plane rotor subsystem models. Figure 52 shows the damping matrix used to define the gyro forces acting on the connecting subsystems. This matrix represents -1 times the [Ce] matrix in equation (18) and is derived from Euler's equations for rotational motions. For a spinning disk on a whirling shaft, Euler's equations of motion in a fixed frame can be written as:

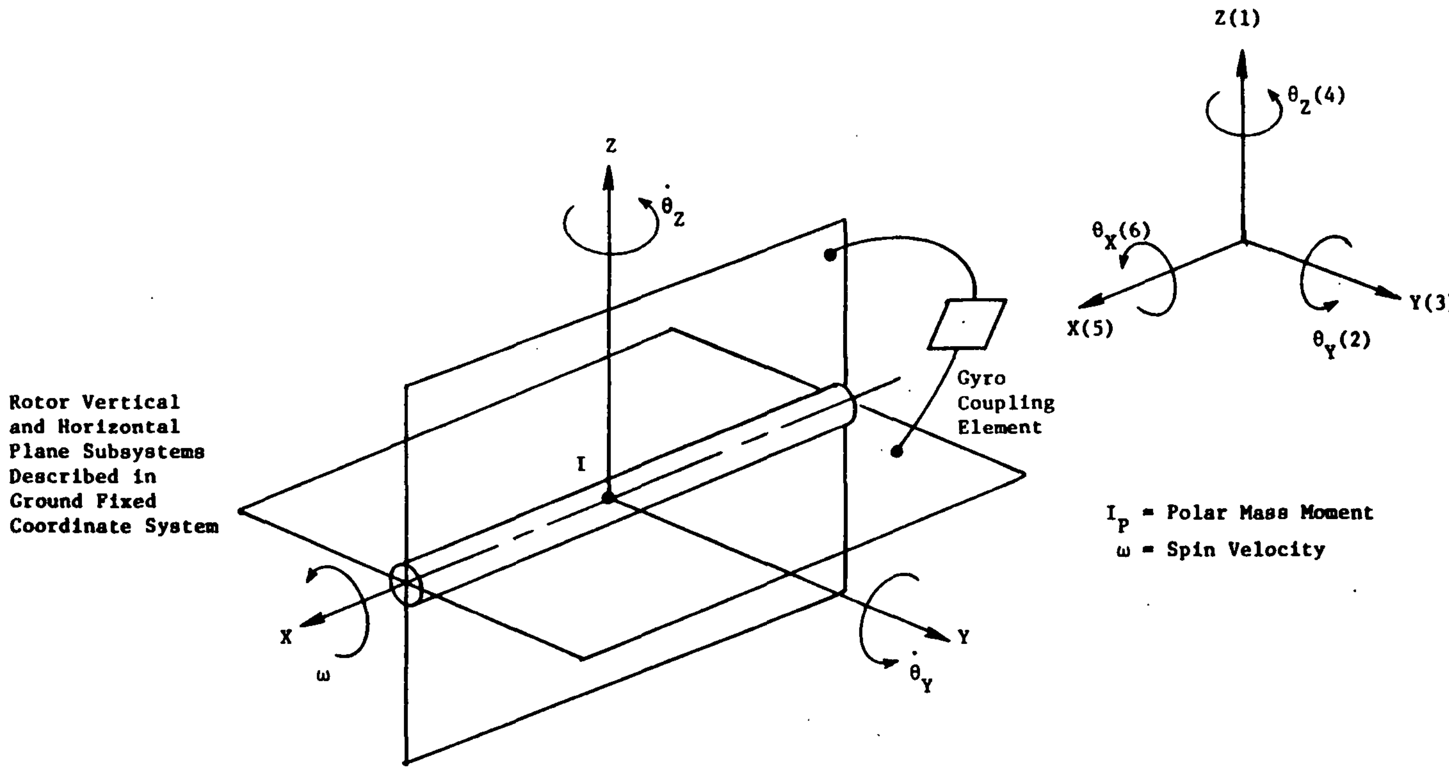
$$\begin{bmatrix} I_y & 0 \\ 0 & Iz \end{bmatrix} \begin{Bmatrix} \ddot{\theta}y \\ \ddot{\theta}z \end{Bmatrix} + \begin{bmatrix} 0 & I_x\omega \\ -I_x\omega & 0 \end{bmatrix} \begin{Bmatrix} \dot{\theta}_y \\ \dot{\theta}_z \end{Bmatrix} = \begin{Bmatrix} My \\ Mz \end{Bmatrix} \tag{29}$$

My and Mz are the applied moments.

$\begin{bmatrix} I_y & 0 \\ 0 & I_z \end{bmatrix}$ = the inertia matrix that defines the uncoupled rotary interia moments acting in the two planes.

$\begin{bmatrix} 0 & I_x\omega \\ -I_x\omega & 0 \end{bmatrix}$ = the damping matrix that defines the coupled-velocity dependent gyroscopic moments.

The affects of the uncoupled rotary inertia are implicitly included in the rotor subsystem modal data and the velocity dependent moments are treated as the applied physical forces shown in Figure 52.



Reversed Effective or D'Alembert Forces

Defined in Ground Fixed Coordinate System

$$\begin{bmatrix} M_Y = F_I^2 \\ M_Z = F_I^4 \end{bmatrix} = \begin{bmatrix} 0 & -I_P\omega \\ I_P\omega & 0 \end{bmatrix} \cdot \begin{bmatrix} \dot{X}_I^2 = \dot{\theta}_Y \\ \dot{X}_I^4 = \dot{\theta}_Z \end{bmatrix}$$

Figure 52. Gyro Element - Gyro Forces are Computed with a Velocity-Dependent Element.

4.0 INPUT AND OUTPUT FILES FOR TETRA

The main input file of the TETRA program consists of namelist input. There are four namelist names - LIST1, LIST2, LIST3, and LIST4 (must be arranged in that order). First must come the LIST1 namelist input (for identifying input and input for points not located on the modal subsystems). There must be one and only one LIST1 section. Next come the LIST2 namelist sections (for the modal subsystems). One LIST2 section is required for each modal subsystem (there must be at least one modal subsystem and at most 11). The LIST3 namelist sections (if any) (for the physical connecting elements) come next. There is one LIST3 section for each physical connecting element. There may be zero physical connecting elements. The current upper limits are a maximum of five Type 1 physical connecting elements, ten of Type 2, ten of Type 3, four of Type 4, and ten of Type 5. Finally, there must be one and only one LIST4 section (which contains the restart input, the time integration input, rotor speed and rate input, unbalance load input, P cos ωt and P sin ωt load input, time-force history load input, gyro load input, and plot file input).

The namelist input for the main input file must always start in Column 2. Within a given namelist section, the input variables can be in any order. The file code for the main input file is the standard 05 file. A listing of the main input file is provided at the beginning of the printed output of TETRA for user convenience.

An interface program has been written to read the output file from the NASTRAN program, and then to automatically generate all or most of the modal subsystem (LIST2) input (see Section 6.0). The modal subsystem input thus generated by the interface program must be merged with the main input file for TETRA in the correct order as explained above.

If the run is a restart run, one additional input file is required, namely, the restart file generated by the original run. This input restart file is read in using file code 22, so the user must assign the input restart file to File 22 (@ ASG control card).

Two output files may be generated by a TETRA run. A plot file (File Code 23) is generated provided the user selects the IPLOT=1 option (see Type P-1 namelist inupt sheet). A listing of all or part of the output plot file contents is provided at the end of each run as an aid for the development of software to plot the TETRA results. (If 21 or less times are written to the output plot file the entire file is listed, but if more than 21 times are written to the output plot file, only the first 21 are listed due to space limitations.) The following pages define the variables which are on the output plot file. An output restart file (File Code 24) is also generated. If the user wishes to save these output files he must assign them (@ ASG control card). Both output files are unformatted output.

The output restart file is always a very short file and would best be saved on disk. The output plot file, however, may be a lengthy file and might be saved on tape or disk.

Plot File Format for TETRA Program

$NP, NRE, NEL, NUMT$
$IPPLOT_1, IDPLOT_1, XPT_1, YPT_1, ZPT_1$
⋮
$IPPLOT_{NP}, IDPLOT_{NP}, XPT_{NP}, ZPT_{NP}$
$ILEM3_1, ILEM3_1, ILEM3_1$
⋮
$ILEM3_{NRE}, ILEM3_{NRE}, ILEM3_{NRE}$
$ILEM_1, IPT_1, IDIR_1$
⋮
$ILEM_{NEL}, IPT_{NEL}, IDIR_{NEL}$
TIME(1), SPEEDI(1), SPEEDD(1), THETAI(1), THETAD(1)
$X_1(1), VEL_1(1), FMOD_1(1)$
⋮
$X_{NP}(1), VEL_{NP}(1), FMOD_{NP}(1)$
$DMAG_1(1), CLEAR_1(1), FMAG_1(1)$
⋮
$DMAG_{NRE}(1), CLEAR_{NRE}(1), FMAG_{NRE}(1)$
$FELEM_1(1), FELEM_1(1), FELEM_1(1)$
⋮
$FELEM_{NEL}(1), FELEM_{NEL}(1), FELEM_{NEL}(1)$
⋮

TIME(NUMT),SPEEDI(NUMT),SPEEDD(NUMT),THETAI(NUMT),THETAD(NUMT)
X_1(NUMT),VEL_1(NUMT),$FMOD_1$(NUMT)
•
•
•
X_{NP}(NUMT),VEL_{NP}(NUMT),$FMOD_{NP}$(NUMT)
$DMAG_1$(NUMT),$CLEAR_1$(NUMT),$FMAG_1$(NUMT)
•
•
•
$DMAG_{NRE}$(NUMT),$CLEAR_{NRE}$(NUMT),$FMAG_{NRE}$(NUMT)
$FELEM_1$(NUMT),FELEM1(NUMT),$FELEM_1$(NUMT)
•
•
•
$FELEM_{NEL}$(NUMT),$FELEM_{NEL}$(NUMT),$FELEM_{NEL}$(NUMT)

Definitions

NP = Number of (global point, global direction) pairs for which the displacement, velocity, and modal force is written on the plot file

NRE = Number of Type 3 physical connecting elements (rub elements) for which the relative displacement magnitude, clearance, and force magnitude are written on the plot file

NEL = Number of (element number, global point, global direction) trios for which the physical connecting element or gyro element force is written on the plot file

NUMT = Number of timne steps on the plot file

$IPPLOT_i$ = Global point number for the i-th (global point, global direction) pair on the plot file

$IDPLOT_i$ = Global direction number for the i-th (global point, global direction) pair on the plot file

XPT_i,YPT_i,ZPT_i = X,Y and Z coordinates (global system) respectively for the i-th (global point, global direction) pair on the plot file

$ILEM3_i$ = Element number for the i-th Type 3 physical connecting element (rub element) for which the displacement magnitude, clearance, and force magnitude are written on the plot file

$ILEM_i$ = Element number for the i-th physical connecting element or gyro element for which the element force is written on the plot file

IPT_i = Global point number for the i-th physical connecting element or gyro element for which the element force is written on the plot file

$IDIR_i$ = Global direction number for the i-th physical connecting element or gyro element for which the element force is written on the plot file

TIME(I) = Time (seconds) for the I-TH time step on the plot file

SPEEDI(I) = Independent rotor speed (rpm) for the I-TH time step on the plot file

SPEEDD(I) = Dependent rotor speed (rpm) for the I-TH time step on the plot file

THETAI(I) = Independent rotor angular displacement (revolutions) for the I-TH time step on the plot file

THETAD(I) = Dependent rotor angular displacement (revolutions) for the I-TH time step on the plot file

X_i(I) = Displacement (inches or radians) for the i-th (global point, global direction) pair and for the i-th time step on the plot file

VEL_i(I) = Velocity (in/sec or rad/sec) for the i-th (global point, global direction) pair and for the I-TH time step on the plot file

$FMOD_i$(I) = Modal force (lb or in-lb) for the i-th (global point, global direction) pair and for the I-TH time step on the plot file

$DMAG_i$(I) = Relative displacement mangitude (inches) for the i-th Type 3 physical connecting element (rub element) and for the I-TH time step on the plot file

$CLEAR_i$(I) = Clearance (inches) for the i-th Type 3 physical connecting element (rub element) and for the I-TH time step on the plot file

$FMAG_i$(I) = Force mangitude (pounds) for the i-th Type 3 physical connecting element (rub element) and for the I-TH time step on the plot file

$FELEM_i$(I) = Force (lb or in-lb) for the i-th (element number, global point number, global direction number) trio and for the I-th time step on the plot file

5.0 INPUT SHEETS

Following is a discussion of the namelist input sheets for the main input file of TETRA. Input data should follow the order given for the input sheets (starting with Type A input, then Type B, etc.). Always begin the namelist input in Column 2 of each line.

Identification Sheet Type A

Each TETRA run, no matter what the engine system or the type of analysis, must have one of these sheets. The four lines are filled in with the information indicated. The last two lines give the user the opportunity to include a descriptive name for the case. All of these lines are reproduced on the output.

TETRA

IDENTIFYING INPUT

▽2
$LIST1
NAME= '______________________ 3 DATE 1 __________ 3 CHARGE 1 ______',
ADDRES= '__________________ 3 MAIL DROP 1 __________ 3 EXT. ______',
IDENT1= '____',
IDENT2= '____',

Maximum of 60 characters enclosed within apostrophes for each of the above variables.

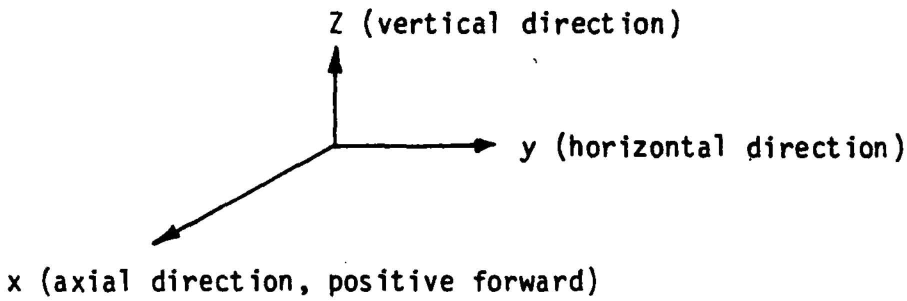
TYPE B INPUT

Physical Points Not Located on Modal Subsystems

This input sheet defines the boundary conditions of the problem. The points which the user desires to ground are defined here. If the code is specified as fixed (CODE=1), then the point is fixed in 6 DOF. If the code is specified as free (CODE=0), then the point is free to move in 6 DOF. The points defined on this sheet may not be located on the modal subsystems but can only be located at ground or at the junctions of links and engine support elements.

TETRA

PHYSICAL POINTS NOT LOCATED ON MODAL SUBSYSTEMS



2

PP(1,1)=

POINT NUMBER NOT ON MODAL SUBSYSTEM *	CODE 0=FREE 1=FIXED	COORDINATES RELATIVE TO GLOBAL SYSTEM		
		X	Y	Z

_______, _______, _______, _______, _______,
_______, _______, _______, _______, _______,
_______, _______, _______, _______, _______,
_______, _______, _______, _______, _______,
_______, _______, _______, _______, _______,
_______, _______, _______, _______, _______,
_______, _______, _______, _______, _______,
_______, _______, _______, _______, _______,
_______, _______, _______, _______, _______,
_______, _______, _______, _______, _______,

* These points include ground points and points between link and engine support elements. It will be noted that points on modal subsystems cannot be attached directly to ground, but can be attached to ground through physical connecting elements.

Modal Subsystem Input (Type C1 Through C-11)

Modal subsystem input is accomplished using the LIST2 namelist section. One LIST 2 namelist section is required for each modal subsystem. The number of modal subsystems present is counted by the program automatically.

The user may input a title (this is optional) for each subsystem using the TITLE='...', variable. Up to 60 characters may be enclosed within the apostrophes.

The subsystem number (ISUB variable) is required. The subsystem number must be an integer number between 1 and 11. The subsystem numbers are not arbitrary - each subsystem number represents a different type of modal subsystem with differing degrees of freedom (see Figure 53). The user chooses which of the modal subsystems to use, and can arrange these modal subsystems in any order. The user must have input for at least one modal subsystem.

Note that Subsystems 1-3 represent "Rotor 1" and Subsystems 4-6 represent "Rotor 2" (see Figure 53). Of course, the user's model may have only one rotor, in which case either Rotor 1 (Subsystems 1-3) or Rotor 2 (Subsystems 4-6) could be used. If the engine is a dual spool engine, however, the user might want to use both "Rotor 1" and "Rotor 2" in his model. In this instance, "Rotor 1" might represent, say, the low pressure system (fan, low pressure compressor, shaft, and low pressure turbine), and Rotor 2 might represent the high pressure system (high pressure compressor, shaft, and high pressure turbine). Or vice-versa - the choice is up to the user. The user has a great deal of flexibility and can model with these subsystems virtually any jet engine configuration.

Each subsystem requires input for points on the subsystem (PTS array) (see input sheets C-2, C-5, C-8 and C-11). Each subsystem must have at least one point. The current upper limits are 10 for the rotor subsystems (Numbers 1-6), 20 for the case (or housing) subsystems (Numbers 7-10), and 10 for the pylon subsystem (Number 11). The rotor and case subsystems (Subsystems 1-10) represent engine centerline models. Thus, if the user chooses his

SUBSYSTEM NUMBER	DESCRIPTION	NUMBER OF DEGREES OF FREEDOM	DIRECTIONS
1	Rotor 1 Vertical Plane	2	Z, θ_Y
2	Rotor 1 Horizontal Plane	2	Y, θ_Z
3	Rotor 1 Rigid Body	5	$X, Y, \theta_Y, Z, \theta_Z$
4	Rotor 2 Vertical Plane	2	Z, θ_Y
5	Rotor 2 Horizontal Plane	2	Y, θ_Z
6	Rotor 2 Rigid Body	5	$X, Y, \theta_Y, Z, \theta_Z$
7	Case Vertical Plane	2	Z, θ_Y
8	Case Horizontal Plane	2	Y, θ_Z
9	Case Rigid Body	6	$X, \theta_X, Y, \theta_Y, Z, \theta_Z$
10	Case Torsional	1	θX
11	Pylon	3	X, Y, Z

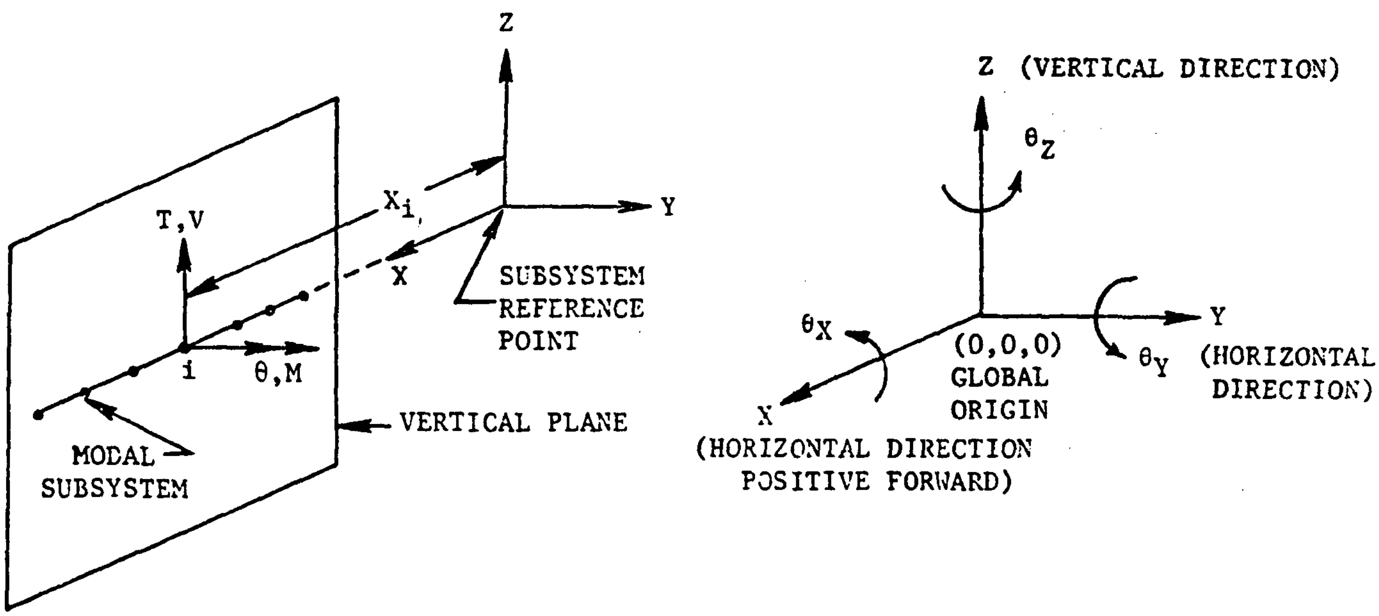
Figure 53. Modal Subsystem Summary.

X-axis (axial direction) to coincide with the engine centerline, then the y and z coordinates for the points on Subsystems 1-10 will all be zero. This is not true for the pylon subystem (Number 11), however. If the subsystem referecne point does not coincide with the global origin, the user should input the coordinates (XREF, YREF and ZREF variables) of the subsystem reference point, so the program can make adjustment.

MODAL SUBSYSTEM INPUT FOR VERTICAL AND HORIZONTAL PLANE SUBSYSTEMS

THIS INPUT SHEET APPLIES FOR THE FOLLOWING MODAL SUBSYSTEMS:

NUMBER 1 (ROTOR 1 VERTICAL PLANE)
NUMBER 2 (ROTOR 1 HORIZONTAL PLANE)
NUMBER 4 (ROTOR 2 VERTICAL PLANE)
NUMBER 5 (ROTOR 2 HORIZONTAL PLANE)
NUMBER 7 (CASE VERTICAL PLANE)
NUMBER 8 (CASE HORIZONTAL PLANE)



NOTE - THE PHYSICAL MODEL (MODAL SOURCE) FOR THE SUBSYSTEM IS ALWAYS A VERTICAL PLANE MODEL.

2
$ END
$LIST2
TITLE= '______________________________',
ISUB=_____, SUBSYSTEM NUMBER (1,2,4,5,7,or 8)

ENTER THE COORDINATES (INCHES) OF THE SUBSYSTEM REFERENCE POINT:
XREF=_____,X COORDINATE (0 ASSUMED)
YREF=_____,Y COORDINATE (0 ASSUMED)
ZREF=_____,Z COORDINATE (0 ASSUMED)

Maximum of 60 characters enclosed within apostrophes for the title.

MODAL SUBSYSTEM INPUT FOR VERTICAL AND HORIZONTAL PLANE SUBSYSTEMS (CONTINUED)

ENTER THE COORDINATES OF THE TETRA POINTS. MAXIMUM OF 10 POINTS FOR SUBSYSTEMS 1,2,4,AND 5. MAXIMUM OF 20 POINTS FOR SUBSYSTEMS 7 AND 8. Y and Z COORDINATES NORMALLY 0.
n=NUMBER OF POINTS IN THE SUBSYSTEM.

TETRA POINT NUMBER	COORDINATES (INCHES) WITH RESPECT TO SUBSYSTEM REFERENCE POINT		
	X	Y	Z

2

PTS(1,1)=

LOCAL POINT NUMBER				
1	________,	________,	________,	________,
2	________,	________,	________,	________,
3	________,	________,	________,	________,
.	.			
.	.			
.	.			
.	.			
.	.			
.	.			
.	.			
.	.			
.	.			
n	________,	________,	________,	________,

ENTER THE VALUES BELOW FOR EACH MODE. MAXIMUM OF 30 MODES.
N=NUMBER OF SUBSYSTEM MODES.

FREQUENCY (RPM)	POTENTIAL ENERGY	Q-FACTOR	MODE TYPE 0=FLEXIBLE 1=RIGID BODY

2

XMODES(1,1)=

LOCAL MODE NUMBER				
1	________,	________,	________,	________,
2	________,	________,	________,	________,
3	________,	________,	________,	________,
.	.			
.	.			
.	.			
.	.			
.	.			
.	.			
.	.			
N	________,	________,	________,	________,

MODAL SUBSYSTEM INPUT FOR VERTICAL AND
HORIZONTAL PLANE SUBSYSTEMS (CONTINUED)

ENTER THE REQUIRED MODE SHAPES BELOW.
n=NUMBER OF POINTS IN THE SUBSYSTEM.
N=NUMBER OF SUBSYSTEM MODES.

TRANSLATION T INCHES	SLOPE θ RADIANS	SHEAR V POUNDS	MOMENT M IN-LB

2

VH(1,1,1)=

LOCAL MODE 1
LOCAL POINT NUMBER

1 ______, ______, ______, ______,
2 ______, ______, ______, ______,
3 ______, ______, ______, ______,
.
.
.
.
.
.
n ______, ______, ______, ______,

VH(1,1,2)=

LOCAL MODE 2
LOCAL POINT NUMBER

1 ______, ______, ______, ______,
2 ______, ______, ______, ______,
3 ______, ______, ______, ______,
.
.
.
.
.
.
n ______, ______, ______, ______,

.
.
.
.
.

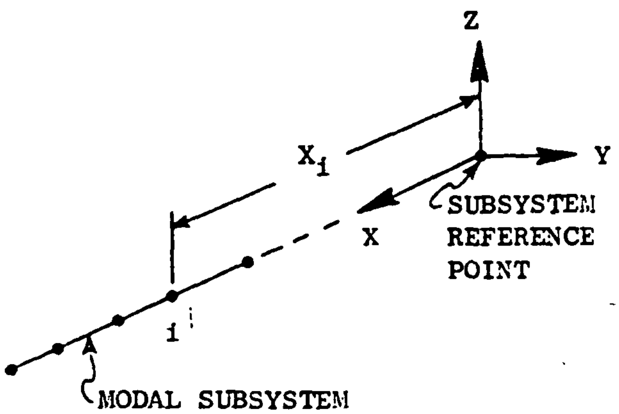
VH(1,1,N)=

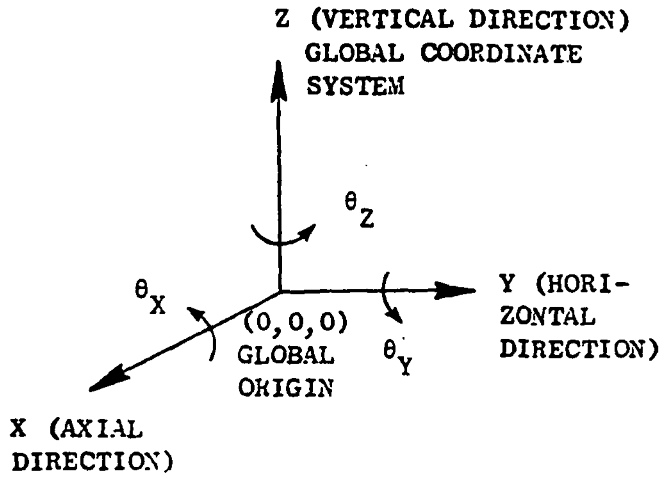
LOCAL MODE N
LOCAL POINT NUMBER

1 ______, ______, ______, ______,
2 ______, ______, ______, ______,
3 ______, ______, ______, ______,
.
.
.
.
.
.
n ______, ______, ______, ______,

MODAL SUBSYSTEM INPUT FOR RIGID BODY SUBSYSTEMS

THIS INPUT SHEET APPLIES FOR MODAL SUBSYSTEM 3 (ROTOR 1 RIGID BODY), MODAL SUBSYSTEM 6 (ROTOR 2 RIGID BODY), AND MODAL SUBSYSTEM 9 (CASE RIGID BODY).





NOTE: MOTION IN THE θX DIRECTION IS NOT CONSIDERED FOR THE ROTOR SUBSYSTEMS (3 AND 6). MOTION IN THIS DIRECTION CAN BE CONSIDERED FOR THE CASE SUBSYSTEM (9), HOWEVER.

2

$ END
$LIST2
TITLE= '____',
ISUB= _______, SUBSYSTEM NUMBER (3,6, OR 9)
ENTER THE COORDINATES (INCHES) OF THE SUBSYSTEM REFERENCE POINT:
XREF=__________, X Coordinate (0 assumed)
YREF=__________, Y Coordinate (0 assumed)
ZREF=__________, Z Coordinate (0 assumed)

Maximum of 60 characters enclosed within apostrophes for the title.

MODAL SUBSYSTEM INPUT FOR RIGID BODY SUBSYSTEMS (CONTINUED)

ENTER COORDINATES OF TETRA POINTS. MAXIMUM OF 10 POINTS FOR SUBSYSTEMS 3 AND 6 AND MAXIMUM OF 20 POINTS FOR SUBSYSTEM 9.
Y AND Z COORDINATES NORMALLY 0.
n= NUMBER OF SUBSYSTEM POINTS.

TETRA POINT NUMBER	COORDINATES (INCHES) WITH RESPECT TO SUBSYSTEM REFERENCE POINT		
	X	Y	Z

PTS(1,1)=

LOCAL POINT NUMBER				
1	________,	________,	________,	________,
2	________,	________,	________,	________,
3	________,	________,	________,	________,
.	.			
.	.			
.	.			
.	.			
.	.			
.	.			
.	.			
n	________,	________,	________,	________,

ENTER THE SUBSYSTEM CENTER OF GRAVITY COORDINATES (INCHES) WITH RESPECT TO SUBSYSTEM REFERENCE POINT:
XCG= ________, X COORDINATE (0 ASSUMED)
YCG= ________, Y COORDINATE (0 ASSUMED)
ZCG= ________, Z COORDINATE (0 ASSUMED)

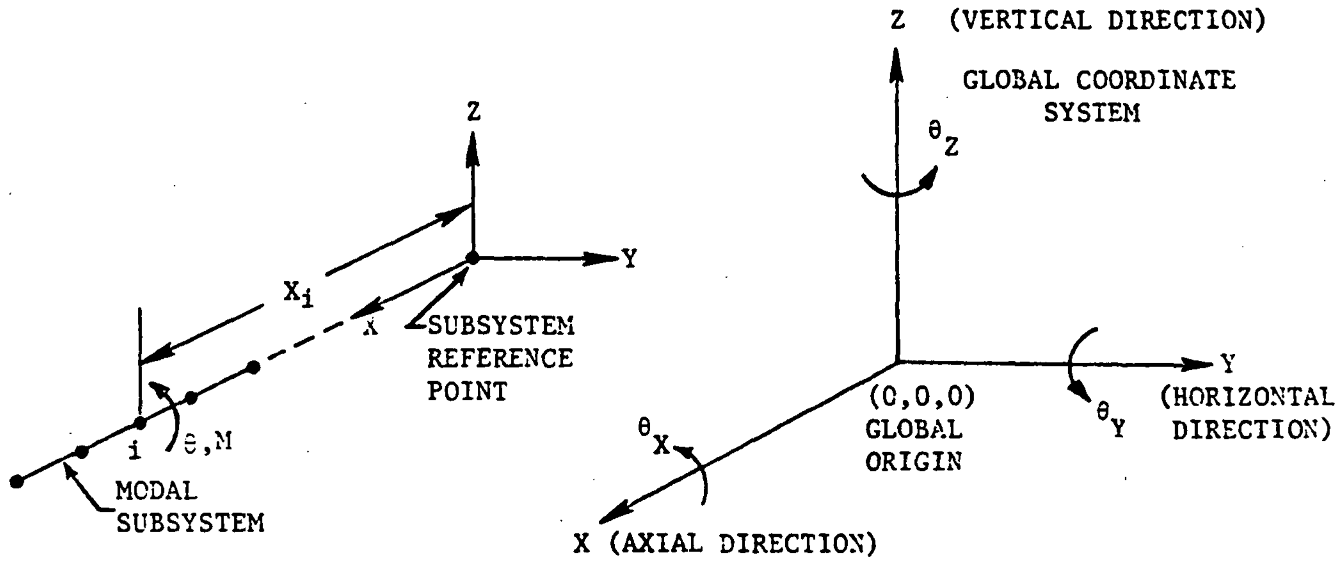
MODAL SUBSYSTEM INPUT FOR RIGID BODY SUBSYSTEMS (CONTINUED)

ENTER THE SUBSYSTEM PHYSICAL WEIGHT PROPERTIES FOR EACH OF THE SIX DIRECTIONS. IF MOTION IN A PARTICULAR DIRECTION IS TO BE NEGLECTED, ENTER ZERO FOR THE PHYSICAL WEIGHT PROPERTY IN THAT DIRECTION. (SINCE THE θX DIRECTION IS ALWAYS NEGLECTED FOR SUBSYSTEMS 3 AND 6, WMIX SHOULD ALWAYS BE SET TO ZERO OR OMITTED FOR SUBSYSTEMS 3 AND 6). AT LEAST ONE OF THE PHYSICAL WEIGHTS MUST BE NON-ZERO.

2

PHYSICAL WEIGHT PROPERTY	DIRECTION		
	X	WX= ________,	WEIGHT, POUNDS (0 ASSUMED)
	Y	WY= ________,	WEIGHT, POUNDS (0 ASSUMED)
	Z	WZ= ________,	WEIGHT, POUNDS (0 ASSUMED)
	θ_X	WMIX= ________,	POLAR MOMENT OF INERTIA, LB-IN^2 (0 ASSUMED)
	θ_Y	WMIY= ________,	MOMENT OF INERTIA ABOUT Y AXIS, LB-IN^2 (0 ASSUMED)
	θ_Z	WMIZ= ________,	MOMENT OF INERTIA ABOUT Z AXIS, LB-IN^2 (0 ASSUMED)

MODAL SUBSYSTEM INPUT FOR SUBSYSTEM 10
(CASE TORSIONAL SUBSYSTEM)



▽2
$END
$LIST2
TITLE='____________________________________',
ISUB=10,

ENTER THE COORDINATES (INCHES) OF THE SUBSYSTEM REFERENCE POINT:
XREF=________,X COORDINATE (0 ASSUMED)
YREF=________,Y COORDINATE (0 ASSUMED)
ZREF=________,Z COORDINATE (0 ASSUMED)

Maximum of 60 characters enclosed within apostrophes for the title.

MODAL SUBSYSTEM INPUT FOR SUBSYSTEM 10
(CASE TORSIONAL SUBSYSTEM) (CONTINUED)

ENTER THE COORDINATES OF THE TETRA POINTS. MAXIMUM OF 20 POINTS.
X AND Y COORDINATES NORMALLY 0
n=NUMBER OF POINTS IN THE SUBSYSTEM

TETRA POINT NUMBER	COORDINATES (INCHES) WITH RESPECT TO SUBSYSTEM REFERENCE POINT		
	X	Y	Z

2

PTS(1,1)=

LOCAL POINT NUMBER				
1	________,	________,	________,	________,
2	________,	________,	________,	________,
3	________,	________,	________,	________,
.	.			
.	.			
.	.			
.	.			
.	.			
.	.			
.	.			
n	________,	________,	________,	________,

ENTER THE VALUES BELOW FOR EACH MODE. MAXIMUM OF 30 MODES.
N=NUMBER OF SUBSYSTEM MODES.

FREQUENCY (RPM)	POTENTIAL ENERGY	Q-FACTOR	MODE TYPE 0=FLEXIBLE 1=RIGID BODY

2

XMODES(1,1)=

LOCAL MODE NUMBER				
1	________,	________,	________,	________,
2	________,	________,	________,	________,
3	________,	________,	________,	________,
.	.			
.	.			
.	.			
.	.			
.	.			
N	________,	________,	________,	________,

MODAL SUBSYSTEM INPUT FOR SUBSYSTEM 10
(CASE TORSIONAL SUBSYSTEM) (CONTINUED)

ENTER THE REQUIRED MODE SHAPES BELOW.
n=NUMBER OF POINTS IN THE SUBSYSTEM.
N=NUMBER OF SUBSYSTEM MODES.

TWIST θ RADIANS	MOMENT IN-LB

2

LOCAL MODE 1 / LOCAL POINT NUMBER

TOR(1,1,1)=

1 ________,________,
2 ________,________,
3 ________,________,
.
.
.
.
.
n ________,________,

LOCAL MODE NUMBER / LOCAL POINT NUMBER

TOR(1,1,2)=

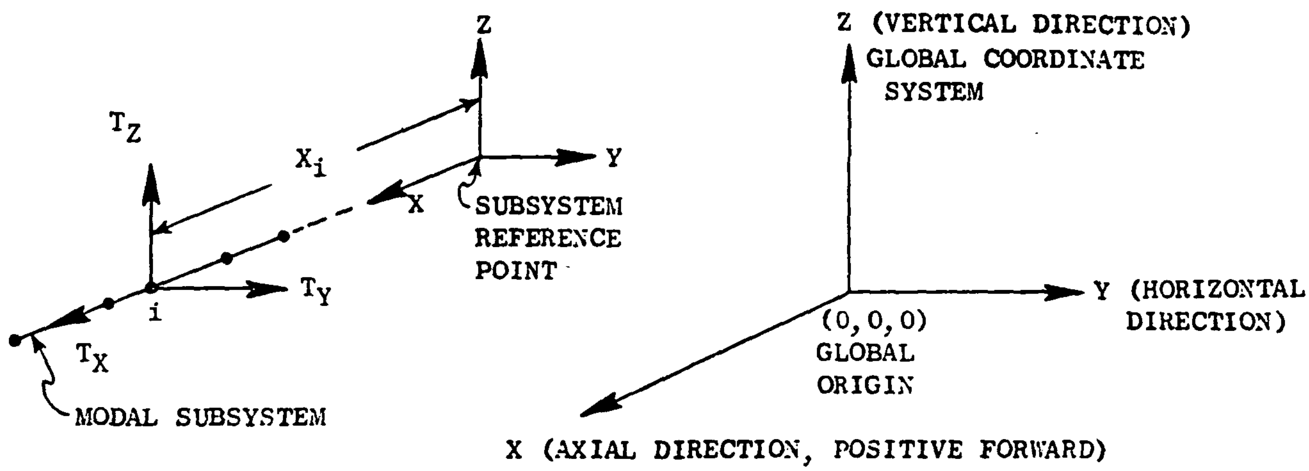
1 ________,________,
2 ________,________,
3 ________,________,
.
.
.
.
.
n ________,________,
.
.
.
.

LOCAL MODE NUMBER / LOCAL POINT NUMBER

TOR(1,1,N)=

1 ________,________,
2 ________,________,
3 ________,________,
.
.
.
.
.
.
n ________,________,

MODAL SUBSYSTEM INPUT FOR SUBSYSTEM 11
PYLON SUBSYSTEM



▽2
$END
$LIST2
TITLE= '____',
ISUB=11,
ENTER THE COORDINATES (INCHES) OF THE SUBSYSTEM REFERENCE POINT:
XREF=____________, X COORDINATE (0 ASSUMED)
YREF=____________, Y COORDINATE (0 ASSUMED)
ZREF=____________, Z COORDINATE (0 ASSUMED)

▽2 Maximum of 60 characters enclosed within apostrophes for the title.

MODAL SUBSYSTEM INPUT FOR SUBSYSTEM 11
(PYLON SUBSYSTEM) (CONTINUED)

ENTER THE COORDINATES OF THE TETRA POINTS. MAXIMUM OF 10 POINTS.
n=NUMBER OF POINTS IN THE SUBSYSTEM

TETRA POINT NUMBER	COORDINATES (INCHES) WITH RESPECT TO SUBSYSTEM REFERENCE POINT		
	X	Y	Z

2

PTS(1,1)=

LOCAL POINT NUMBER

1 ______, ______, ______, ______,
2 ______, ______, ______, ______,
3 ______, ______, ______, ______,
.
.
.
n ______, ______, ______, ______,

ENTER THE VALUES BELOW FOR EACH MODE. MAXIMUM OF 30 MODES.
N=NUMBER OF SUBSYSTEM MODES.

FREQUENCY (RPM)	POTENTIAL ENERGY	Q-FACTOR	MODE TYPE 0=FLEXIBLE 1=RIGID BODY

2

XMODES(1,1)=

LOCAL MODE NUMBER

1 ______, ______, ______, ______,
2 ______, ______, ______, ______,
3 ______, ______, ______, ______,
.
.
.
N ______, ______, ______, ______,

MODAL SUBSYSTEM INPUT FOR SUBSYSTEM 11
PYLON SUBSYSTEM (CONTINUED)

ENTER THE REQUIRED MODE SHAPES BELOW.
n= NUMBER OF POINTS IN THE SUBSYSTEM.
N= NUMBER OF SUBSYSTEM MODES.

TRANSLATION T_X INCHES	TRANSLATION T_Y INCHES	TRANSLATION T_Z INCHES

2

PYL(1,1,1)=

LOCAL MODE 1	LOCAL POINT NUMBER			
	1	___,	___,	___,
	2	___,	___,	___,
	3	___,	___,	___,
	.	.		
	.	.		
	.	.		
	.	.		
	.	.		
	n	___,	___,	___,

PYL(1,1,2)=

LOCAL MODE 2	LOCAL POINT NUMBER			
	1	___,	___,	___,
	2	___,	___,	___,
	3	___,	___,	___,
	.	.		
	.	.		
	.	.		
	.	.		
	.	.		
	n	___,	___,	___,

PYL(1,1,N)=

LOCAL MODE N	LOCAL POINT NUMBER			
	1	___,	___,	___,
	2	___,	___,	___,
	3	___,	___,	___,
	.	.		
	.	.		
	.	.		
	.	.		
	.	.		
	n	___,	___,	___,

Now for a discussion of the modal subsystem input that is particular to certain subsystems. First, consider the vertical and horizontal plane subsystems (Subsystems 1, 2, 4, 5, 7, and 8). Input sheets C-1, C-2, and C-3 apply for these subsystems. The XMODES array (see input sheet C-2) is required to supply data for each mode. These subsystems must have data for at least one and a maximum of 30 modes. The frequency and potential energy for each mode are entered in the XMODES array. These values are used to compute the generalized weight for the mode. Next, Q-factor Q_f is input for the mode. The Q-factor determines the modal damping for the mode (provided the mode type code equals 0) and can be defined as follows:

$$Q_f = \frac{1}{2\left(\frac{C}{C_c}\right)}$$

where C=damping coefficient and C_c=critical damping coefficient. If the user wishes to neglect damping, he should input Qf=0, which is a signal to the computer to neglect damping. Next, the user inputs a code specifying mode type (0=flexible, or 1=rigid body). The code 1 is used for "soft spring" rigid body modes whch are used to approximate the true rigid body modes. If this code equals 1 (rigid body), then the modal stiffness and modal damping are both set to zero (regardless of what was inputted for Q-factor). If, however, the mode type code equals 0 (flexible), the modal stiffness is calculated based on the potential energy, and the modal damping is calculated based on the Q-factor, generalized stiffness, and frequency.

Also the mode shape input (VH array - see page C-3) is required for the vertical and horizontal plane subsystems.

If the user is using the NASTRAN/TETRA interface program to generate input data for the vertical and horizontal plane subsystems, he should make his NASTRAN model a vertical plane model as shown on input sheet C-1. Since the rotors are always rotationally symmetric (and often the case is also), the same vertical plane NASTRAN model can usually be used to generate modal subsystem input for both the vertical and horizontal plane subsystems. In this instance, the only difference in the TETRA modal subsystem input for the vertical and horizontal plane subsystems of a given component will be the title and the subsystem number.

Next, consider the rigid body subsystems (Subsystems 3, 6 and 9). Input sheets C-4, C-5, and C-6 apply for these subsystems. The center of gravity coordinates with respect to the subsystem reference point (XCG, YCG and ZCG variables) are required for these subsystems. In addition, the physical weight properties should be input (see input sheet C-6), but only for those directions for which rigid body motion is to be considered. Generalized coordinates are assigned for each direction for which the physical weight property is non-zero, but are not assigned if the physical weight property was set equal to zero or omitted. Since the θ_x direction is always neglected for Subsystems 3 and 6, WMIX should be set to zero or omitted for Subsystems 3 and 6. At least one of the physical weights must be non-zero.

The user is cautioned to avoid doubling the effect of the rigid body modes, as would happen if the user included the "soft spring" rigid body modes for the vertical and horizontal plane subsystems as obtained from the NASTRAN program and then included the same rigid body modes (that is, rigid body modes for motion in directions Z, θ_y, Y, and θ_z) in the rigid body subsystem. However, the user could model rigid body motion for the Z, θ_y, Y, and θ_z directions using the vertical and horizontal plane subsystems (which cover those four degrees of freedom only) and then use the rigid body subsystem just for motion in the X and θ_x (Subsystem 9 only) directions (the user would zero out or omit the physical weight properties in all but the X and θ_x directions for the rigid body subsystem).

From the above, it is evident that the user has the choice of modeling rigid body motion for the Z, θ_y, Y, and θ_z directions using either "soft spring" rigid body modes in the vertical and horizontal plane subsystems or the rigid body subsystem. Both ways of modeling rigid body motion for these directions give equivalent results. However, it has been found that TETRA runs faster (and thus saves on cost) if the rigid body modes for these directions are included in the vertical and horizontal plane subsystems rather than the rigid body subsystem. This is due to the fact that the rigid body subsystems have more degrees of freedom (five for Subsystems 3 and 6 and six for Subsystem 9) than the vertical and horizontal plane subsystems (which have two degrees of freedom). Also, using the vertical and horizontal plane subsystems for the rigid body modes eliminates the need to input the center of gravity coordinates and the physical weights.

The input for the case torsional subsystem (Number 10) (see input sheets C-7, C-8, and C-9) and the pylon subsystem (Number 11) (see input sheets C-10, C-11, and C-12) is a similar to the input sheets for the vertical and horizontal plane subsystems (Sheets C-1, C-2, and C-3). However, instead of using the VH array to input the mode shapes as is done for the vertical and horizontal subsystems, the TOR array (see input sheet C-9) is used to input the mode shapes for the torsional subsystem and the PYL array (see input sheet C-12) is used to input the mode shapes for the pylon subsystem.

TYPE D1 AND TYPE D2 INPUTS

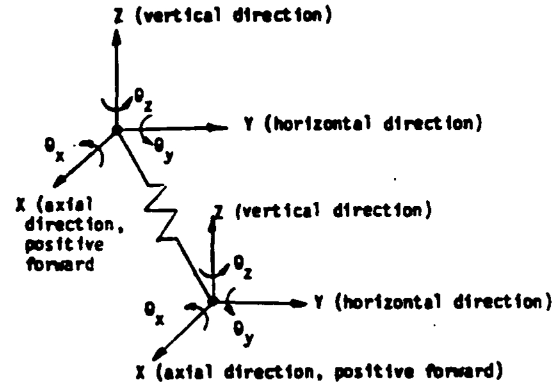
Type 1 Physical Connecting Element (Generalized Spring-Damper Element)

This element is associated with two physical points located at arbitrary locations in global space. Each of these points is assigned six degrees of freedom, three translational displacements (or velocities), and three rotational displacements (or velocities).

A full complement of stiffness and damping coefficients can be input to allow the modeling of fully coupled load paths. The units of the stiffness and damping coefficients are: lb_F/in., lb_F/rad, in.-lb_F/in., in.-lb_F/rad, lb_F-sec/in., lb_F-sec/rad, in.-lb_F-sec/in., and in.-lb_F-sec/rad.

Damping can be specified directly via the coefficient input or can be specified in terms of a structural Q-factor and a selected frequency. For the latter case, the TETRA program computes the damping matrix by multiplying the stiffness matrix by the proportionality term $1/\omega Q_F$, where ω is the selected frequency in radians/sec, and Q_F is the Q-factor. The user inputs the frequency with the units cycles/sec and TETRA converts this to radians/sec.

TYPE 1 PHYSICAL CONNECTING ELEMENT
(GENERALIZED SPRING-DAMPER ELEMENT)



$END
$LIST3
ITYPE=1,

ILEM=__________,element number

I-end point number, J-end point number
JT=___________, ___________,

STIFFNESS MATRIX DEFINITION											
I-END						J-END					
GLOBAL DIRECTION DISPLACEMENT						GLOBAL DIRECTION DISPLACEMENT					
1	2	3	4	5	6	1	2	3	4	5	6
Z	θ_y	Y	θ_z	X	θ_x	Z	θ_y	Y	θ_z	X	θ_x

Global	Dir.	Forces
I-END	1	F_z
	2	$F_{\theta y}$
	3	F_y
	4	$F_{\theta z}$
	5	F_x
	6	$F_{\theta x}$
J-END	1	F_z
	2	$F_{\theta y}$
	3	F_y
	4	$F_{\theta z}$
	5	F_x
	6	$F_{\theta x}$

SPRING(1,1)=

____,____,____,____,____,____,____,____,____,____,____,____,
____,____,____,____,____,____,____,____,____,____,____,____,
____,____,____,____,____,____,____,____,____,____,____,____,
____,____,____,____,____,____,____,____,____,____,____,____,
____,____,____,____,____,____,____,____,____,____,____,____,
____,____,____,____,____,____,____,____,____,____,____,____,

____,____,____,____,____,____,____,____,____,____,____,____,
____,____,____,____,____,____,____,____,____,____,____,____,
____,____,____,____,____,____,____,____,____,____,____,____,
____,____,____,____,____,____,____,____,____,____,____,____,
____,____,____,____,____,____,____,____,____,____,____,____,
____,____,____,____,____,____,____,____,____,____,____,____,

TYPE 1 PHYSICAL CONNECTING ELEMENT

(GENERALIZED SPRING-DAMPER ELEMENT) (Continued)

2

IDAMP= 1=damping / 0=no damping ______________, (0 assumed)

If IDAMP=1, complete the input for one of the following two options:

Option 1: For damping based on Q-factor and selected frequency, enter the following:

QELEM= q-factor ______________,

QFREQ= frequency(hertz) ______________,

Option 2: For damping based on damping matrix definition, enter the following:

DAMPING MATRIX DEFINITION											
I-END						J-END					
GLOBAL DIRECTION VELOCITY						GLOBAL DIRECTION VELOCITY					
1	2	3	4	5	6	1	2	3	4	5	6
$\dot{Z}$	$\dot{\theta}_y$	$\dot{Y}$	$\dot{\theta}_z$	$\dot{X}$	$\dot{\theta}_x$	$\dot{Z}$	$\dot{\theta}_y$	$\dot{Y}$	$\dot{\theta}_z$	$\dot{X}$	$\dot{\theta}_x$

Global Dir. Forces			DAMP(1,1)=
I-END	1	F_z	____, ____, ____, ____, ____, ____, ____, ____, ____, ____, ____, ____,
	2	$F_{\theta y}$	____, ____, ____, ____, ____, ____, ____, ____, ____, ____, ____, ____,
	3	F_y	____, ____, ____, ____, ____, ____, ____, ____, ____, ____, ____, ____,
	4	$F_{\theta z}$	____, ____, ____, ____, ____, ____, ____, ____, ____, ____, ____, ____,
	5	F_x	____, ____, ____, ____, ____, ____, ____, ____, ____, ____, ____, ____,
	6	$F_{\theta x}$	____, ____, ____, ____, ____, ____, ____, ____, ____, ____, ____, ____,
J-END	1	F_z	____, ____, ____, ____, ____, ____, ____, ____, ____, ____, ____, ____,
	2	$F_{\theta y}$	____, ____, ____, ____, ____, ____, ____, ____, ____, ____, ____, ____,
	3	F_y	____, ____, ____, ____, ____, ____, ____, ____, ____, ____, ____, ____,
	4	$F_{\theta z}$	____, ____, ____, ____, ____, ____, ____, ____, ____, ____, ____, ____,
	5	F_x	____, ____, ____, ____, ____, ____, ____, ____, ____, ____, ____, ____,
	6	$F_{\theta x}$	____, ____, ____, ____, ____, ____, ____, ____, ____, ____, ____, ____,

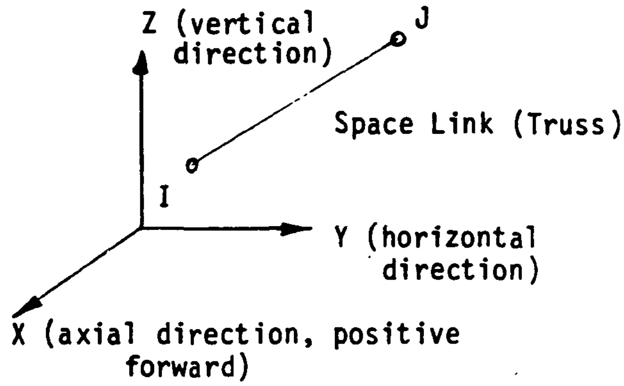
TYPE E INPUT

Type 2 Physical Connecting Element (Space Link - Damper Element)

This element is used to model load paths which have no local moment capability. The load paths are associated with two physical points located at arbitrary locations in global space. Each of these points is assigned three translational degrees of freedom. The user inputs the cross section areas ($in.^2$), and Young's modulus ($lb/in.^2$), and TETRA uses this information along with the coordinates of the two connecting points to calculate the stiffness matrix. The damping can be defined either in terms of translational (dashpot) damping directed along the axis of the link or by proportional damping. In the latter case, the user inputs a structural Q-factor and a selected frequency and the TETRA program computes the damping matrix.

TYPE 2 PHYSICAL CONNECTING ELEMENT

(SPACE LINK-DAMPER ELEMENT)



2

$ END
$LIST3
ITYPE=2,

element number
ILEM=______________,

I-end point number, J-end point number
JT=____________,____________,

Area(in^2)
TAREA=___________,

Young's Modulus (psi)
TYOUNG=______________________,

1=damping
0=no damping
IDAMP=____________, (0 assumed)

If IDAMP=1, complete the input for one of the following two options:

Option 1: For damping based on Q-factor and selected frequency, enter the following:

Q-factor
QELEM=________,

frequency (hertz)
QFREQ=________________,

Option 2: For damping based on the translational damping coefficient c along the axis of the link element, enter the following:

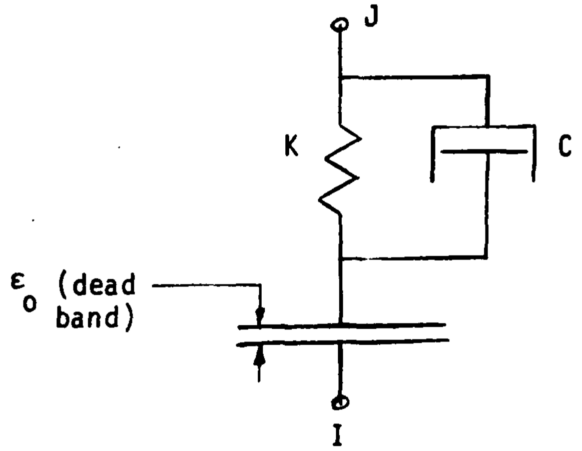
C (lb-sec/in)
TDRATE=______________,

TYPE F INPUT

Type 3 Phsycial Connecting Element (Rub Element)

The rub element allows the mathematical modeling of the nonlinear tip rub that includes the dead band displacement internal prior to closure between the rotor and case (or between rotor and rotor). The user enters the radial spring rate K which represents the local case distortion and the blade compliance, the structural clearance ε_0 (mils), and damping coefficient C (lb-sec/in) if so desired. This element can be used to model rotor-to-case rubs as well as rotor-to-rotor rubs. In the latter case, the I-end must be on the inner rotor and the J-end must be on the outer rotor. In the former case, the I-end must be on the rotor and the J-end on the case.

TYPE 3 PHYSICAL CONNECTING ELEMENT
(RUB ELEMENT)



2

$ END
$LIST3
ITYPE=3,
ILEM=____________,element number
I-end J-end
point number point number
JT=____________,____________,

Note: If rotor-case rub, I-end must be on rotor and J-end must be on case. If rotor-rotor rub, I-end must be on inner rotor and J-end must be on outer rotor.

SK=____________,Case or outer rotor (if rotor-rotor rub) radial spring constant K (lb/in) (becomes active on closure)

DBAND=__________,Radial dead band ε_o (mils) between rotor and case (if rotor-case rub) or between inner rotor and outer rotor (if rotor-rotor rub)

CC=____________,Rub element damping coefficient C (lb-sec/in) (becomes active on closure)

Type 4 Physical Connecting Element (Engine Support-Links Element)

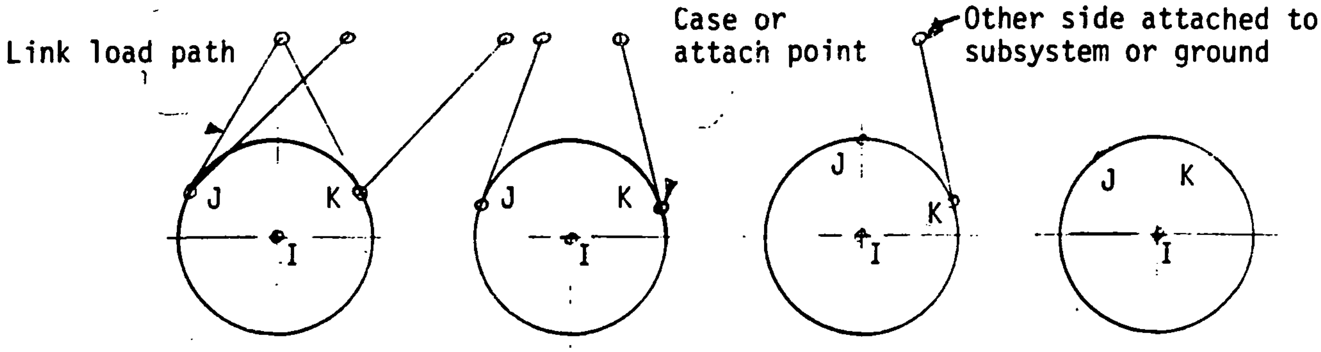
The engine support element is a multipoint, multidirection variable geometry element that provides the capability to model the complex load paths between the engine case and the pylon or ground and thus allows for the direct modeling of actual engine mount structures. In addition, this element couples the flexible and rigid body-centerline modal subsystem that represents the engine case to the support links that comprise the mounting system through the case flexibility. The case flexibility is described by three flexibility rates SKV, SVH and SKA. SKV is the vertical direction case distortion flexibility rate (in./lb).

SVH is the horizontal direction case distortion flexibility rate (in./lb). SKA is the axial direction case distortion flexibility rate (in./lb).

These rates are the reciprocals of the case spring rates that represent local distortion of the engine case under mount reaction loads. Multipliers, defined by the input values AM, BM, CM, DM, EM, and FM, are used to proportion the above flexibility rates per the diagram shown on the Type G-2 input sheet. If it is desired to cut a load path at a case attach point J or K in a given direction, then the applicable multiplier can be set equal to zero. The load paths between the engine case and the pylon or ground can be defined with up to 8 link elements. In defining these load paths, no more than 4 distinct points can be specified on the pylon or ground side. This means that more than a single link may be used to connect a case point to a pylon or ground point. The coordinates for the points that correspond to the J and K points on the case are defined on the Type B input sheet if these points are connected to links. The damping is defined by a structural Q-factor and a selected frequency. These data are used by TETRA to compute the damping matrix based on stiffness matrix proportionality.

TYPE 4 PHYSICAL CONNECTING ELEMENT (ENGINE SUPPORT-LINKS ELEMENT)

Some example configurations that can be modeled with the type 4 element:



(Forward looking aft)

2

```
$END
$LIST3
ITYPE=4,
ILEM=_______________, element number
```

I-end point number (engine centerline)	J-end point number (Case point)	K-end point number (Case point)

JT=__________________, _____________, _______________,

Point I is attached to subsystem. Points J and K can connect to link load paths or subsystems or ground.

SKV=______________, Vertical direction case distortion flexibility rate (in/lb)

SVH=______________, Horizontal direction case distortion flexibility rate (in/lb)

SKA=______________, Axial direction case distortion flexibility rate (in/lb)

TYPE 4 PHYSICAL CONNECTING ELEMENTS (ENGINE SUPPORT-LINKS ELEMENT) (Continued)

Enter multipliers a, b, c, d, e, and f to proportion the spring rates:

2

AM=______________,
BM=______________,
CM=______________,
DM=______________,
EM=______________,
FM=______________,

Rate	POINT J	POINT K
K_V	a	c
K_H	b	d
K_A	e	f

$$\left.\begin{aligned} a + c &= 1.0 \\ b + d &= 1.0 \\ e + f &= 1.0 \end{aligned}\right\}$$

This restraint must be followed (zero values are permissible).

Input one line for each link load path (maximum of 8). If no link load paths, omit this input.

Case side point number (must correspond to case point J or K)	Other side point number (no more than 4 distinct point numbers)	Area (in^2)	Young's Modulus psi

TLP(1,1)=

____________,	____________,	____________,	____________,
____________,	____________,	____________,	____________,
____________,	____________,	____________,	____________,
____________,	____________,	____________,	____________,
____________,	____________,	____________,	____________,
____________,	____________,	____________,	____________,
____________,	____________,	____________,	____________,
____________,	____________,	____________,	____________,

TYPE 4 PHYSICAL CONNECTING ELEMENT (ENGINE SUPPORT-LINKS ELEMENT) (Continued)

Enter the following only if you want damping based on Q-factor and selected frequency. If no damping desired, omit this input.

Q-factor

QELEM=______________,

frequency (herz)

QFREQ=______________,

TYPE H1 AND TYPE H2 INPUTS

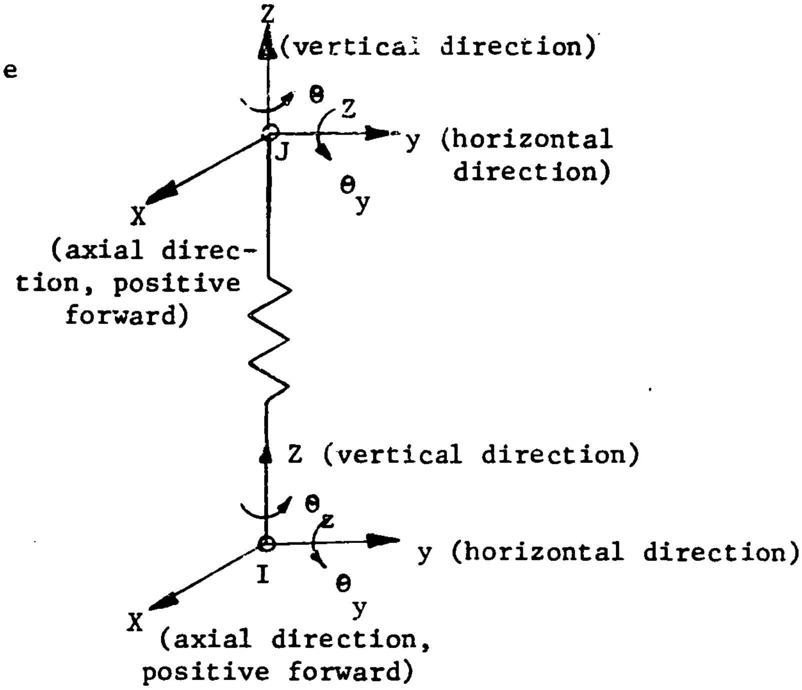
Type 5 Physical Connecting Element (Uncoupled Point Spring - Damper Element)

This input allows the connection of two points with a set of uncoupled springs and dampers. These spring/dampers are typically used to connect the centerlines of beam-like modal subsystems and provide load paths in three translational and two rotational directions. Because of the lack of load path coupling, good modeling practice infers that the points being connected by this element should be coincident in space. Damping can be either specified directly via the coefficient input or can be specified in terms of a structural Q-factor and a selected frequency.

TYPE 5 PHYSICAL CONNECTING ELEMENT

(UNCOUPLED POINT SPRING-DAMPER ELEMENT)

I and J points are coincident.



2

$END
$LIST3
ITYPE=5,

ILEM=____________,element number

I-end point number	J-end point number
JT=_____________,	_____________

Enter the following spring constants:

K_x(lb/in)	XS = ___________,	(0 assumed)
K_y(lb/in)	YS = ___________,	(0 assumed)
K_z(lb/in)	ZS = ___________,	(0 assumed)
$K_{\theta y}(\frac{\text{in-lb}}{\text{rad}})$	TYS = __________,	(0 assumed)
$K_{\theta z}(\frac{\text{in-lb}}{\text{rad}})$	TZS = __________,	(0 assumed)

2 1=damping
0=no damping
IDAMP=________________, (0 assumed)

If IDAMP=1, complete the input for one of the following two options:

Option 1: For damping based on Q-factor and selected frequency, enter the following:

Q-factor
QELEM=___________,
frequency (hertz)
QFREQ=_________________,

Option 2: For damping based on damping coefficient definition, enter the following:

C_x $(\frac{lb\text{-}sec}{in})$	XD = ________________, (0 assumed)
C_y $(\frac{lb\text{-}sec}{in})$	YD = ________________, (0 assumed)
C_z $(\frac{lb\text{-}sec}{in})$	ZD = ________________, (0 assumed)
$C_{\theta x}(\frac{in\text{-}lb\text{-}sec}{rad})$	TYD=_________________, (0 assumed)
$C_{\theta z}(\frac{in\text{-}lb\text{-}sec}{rad})$	TZD=_________________, (0 assumed)

Restart and Time Integration Input (Type I)

If the run is a restart run, the user must input the variable ISTART = 1 (otherwise this variable should be set to zero or omitted). Also, if the run is a restart run, an additional input file is required - namely, the restart file which was generated by the original run. This restart file is read in on file code 22, so the user must assign the restart file to File 22 (@ ASG control card) prior to the run.

The user must choose for this restart time (RTIME input variable) one of the times for which output was printed on the original run (these are the only times for which restart information was written on the restart file). If the user omits the RTIME variable, the program will restart at the final time which was printed out on the original run (provided the original run didn't terminate prematurely).

Next, the user must input the time step (DELTA input variable). The time step should be made equal to about 1/40 of the smallest period of oscillation. The run always begins at time equal zero and then time accumulates. The final time (TFINAL input variable) must also be inputted so that the program knows when to stop. It is recommended that the user choose TFINAL such that the program will do a small number of time steps until the user is sure that his or her input is correct, so as to avoid costly no good runs.

Next, the user must input the print multiple (IPRMUL variable). This value governs the number of time steps that get printed out and the number that gets written onto the output restart file. If IPRMUL = 100, then one out of every 100 time steps computed is printed out and is written onto the restart file. Similarly, the plot multiple (IPLMUL) governs the number of time steps that get written onto the output plot file. If IPLMUL = 10, then one out of every 10 time steps is written onto the plot file.

Example: If DELTA = 0.0001 second, TFINAL = 0.1 second, IPRMUL = 100, and IPLMUL = 5, then computations are made for 1001 times (starting with time = 0 and ending with time = 0.1 second). Eleven times are printed and written onto the restart file (0, 0.01, 0.02, 0.03, 0.04, 0.05, 0.06, 0.07, 0.08, 0.09, and 0.1), and 201 times are written on the output plot file (starting at time = 0 and ending at time = 0.1).

It is recommended that the user pick IPRMUL such that no more than about 10 times are printed, in order to avoid being buried in printed output. The user should pick IPLMUL such that enough times are included to adequately define the curve being plotted (several hundred may be needed). Of course, the larger the value of IPLMUL the smaller the output plot file will be.

RESTART AND TIME INTEGRATION

2

$ END
$LIST4

1=Restart Run
0=New run

ISTART=____________, (0 assumed)

If run is a restart run (ISTART=1), an input restart file (file code 22) must be supplied.

If restart run, enter the restart time. This time must correspond to one of the times for which output was printed on the initial run.

RTIME=____________, Restart time (Program assumes the final time printed for the initial run provided that the initial run didn't terminate prematurely).

DELTA=____________, Time step (seconds)

TFINAL____________, Final time (seconds)

IPRMUL=____________, Print multiple

IPLMUL=____________, Plot multiple

$END (Include if this is the last card of a run, otherwise omit.)

Rotor Speed and Rate Input (Type J)

Rotor speed and rate input is required if unbalance forces or gyroscopic forces are present. If unbalance forces and gyroscopic forces are not present, the rotor speed and rate input is not needed. If rotor speed and rate input is not desired, the user can skip the Type J input sheet altogether.

If rotor speed and rate input is desired, the user must specify which rotor is the "independent" rotor (rotor for which the speed and rate history is specified) by setting IROTI to 1 or 2. (Rotor 1 corresponds to subsystems 1, 2, and 3 and Rotor 2 corresponds to subsystems 4, 5 and 6). Then the user must enter the beginning time (BEGTIM) and beginning speed (BEGRPM) for the first speed segment and the ending time and rate for all the speed segments (TRHIS array). If speed and rate input is present, there must be at least one and no more than ten speed segments.

If another rotor is present, the other rotor is referred to as the "dependent" rotor because its speed is a function of the "independent" rotor speed. If a second rotor is present, the user should input the coefficients A, B, C, and D relating the dependent rotor speed Y to the independent rotor speed X, where

$$Y = AX^3 + BX^2 + C X + D$$

ROTOR SPEED AND RATE INPUT

This sheet is required if unbalance forces or gyroscopic forces are desired.

Enter independent rotor number (rotor for which below ending time/rate table is input). Permissible values are 0 (rotor speed and rate not considered), 1 (rotor corresponding to subsystems 1, 2, and 3), and 2 (rotor corresponding to subsystems 4, 5, and 6).

2

IROTI=______________, (0 assumed)

If IROTI=1 or 2 enter the following:

BEGTIM=____________, Beginning time (seconds) for the first speed segment (applies to independent rotor)
BEGRPM=____________, Beginning speed (rpm) for the first speed segment (applies to independent rotor)

If IROTI=1 or 2 enter the following table in chronological order (applies to independent rotor) (maximum of 10 segments):

	Ending Time (seconds)	Rate (rpm/sec)
	TRHIS(1,1)=	
Segment 1	____________,	____________,
Segment 2	____________,	____________,
Segment 3	____________,	____________,
Segment 4	____________,	____________,
Segment 5	____________,	____________,
Segment 6	____________,	____________,
Segment 7	____________,	____________,
Segment 8	____________,	____________,
Segment 9	____________,	____________,
Segment 10	____________,	____________,

If a second rotor is present, input the following coefficients relating the second (dependent) rotor speed Y to the independent rotor speed X, where $Y=AX^3 + BX^2 + CX + D$:

A=__________, (0 assumed)

B=__________, (0 assumed)

C=__________, (0 assumed)

D=__________, (0 assumed)

$END (Include if this is the last card of a run, otherwise omit.)

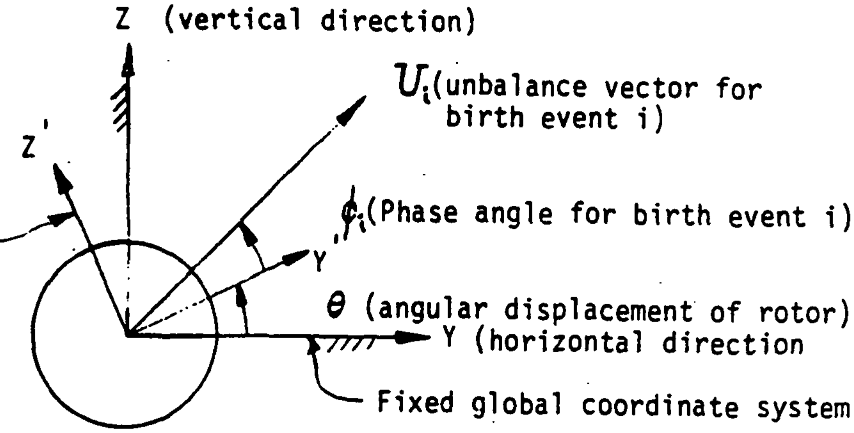
Unbalance Load Input (Type K Input Sheet)

If unbalance load input is not desired, the Type K input sheet can be skipped altogether. To have unbalance load input, rotor speed input (Sheet J) is needed - otherwise the unbalance load input is ignored. If unbalance loads are desired, the unbalance load input (UNBAL array) must be provided. For each unbalance "birth event" four values must be entered - the time of birth (when the unbalance load becomes active), the point number on the unbalanced rotor (the point must lie on Rotor 1 or Rotor 2), the magnitude of the unbalance in gm-in., and the phase angle Ø which gives the position of the unbalance relative to the horizontal (Y) axis at the time of birth. There can be from zero to a maximum of 20 unbalance birth events.

The unbalance load input is quiete flexible. The time of birth can be the same for different birth events. Also, the same point can be referenced more than once if desired. In this way one could model a point (say, the engine fan) which starts out with a nominal unbalance, and later a very much larger unbalance is introduced (fan blade loss). If more than one unbalance birth event is specified for the same points, the unbalance loads for each birth event are added together to get the total unbalance loads.

If the run is a restart run and unbalance loads were present in the original run, then the unbalance load input present in the original run for those birth events that become active prior to the restart time should be left in for the new run. (Otherwise, the unbalance loads would disappear for the new run.) Additional birth events that became active after the start of the restart run may be added to the UNBAL array input for a restart run, however.

APPLIED LOADS
UNBALANCE LOADS



NOTE - to have unbalance loads, must have rotor speed input (type J sheet) - otherwise the unbalance load input is ignored.

If unbalance loads are desired, fill out the following (maximum of 20 lines):

Time of birth (seconds)	Point number on unbalanced rotor	Magnitude (gm-in)	Phase Angle ϕ (degrees)

2

UNBAL(1,1)=

______,	______,	______,	______,
______,	______,	______,	______,
______,	______,	______,	______,
______,	______,	______,	______,
______,	______,	______,	______,
______,	______,	______,	______,
______,	______,	______,	______,
______,	______,	______,	______,
______,	______,	______,	______,

If restart run and the time of birth is less than the restart time, then the unbalance load continues active for the restart run. Time of birth can be the same for different birth events. Also, the same point can be referenced more than once if desired.

$END (Include if this is the last card of the run, otherwise omit.)

P cos ωt and P sin ωt Load Input (Type L Input Sheets)

If P cos ωt and P sin ωt loads are not desired the Type L input sheet can be skipped altogether. If desired, the user must supply six values for each P cos ωt or P sin ωt load (CS array input), as shown on the Type L input sheet. As for the unbalance load input, the same point can be referenced more than once. In this case the loads are added together to get the total load. There can be from zero to a maximum of 20 P sin ωt loads.

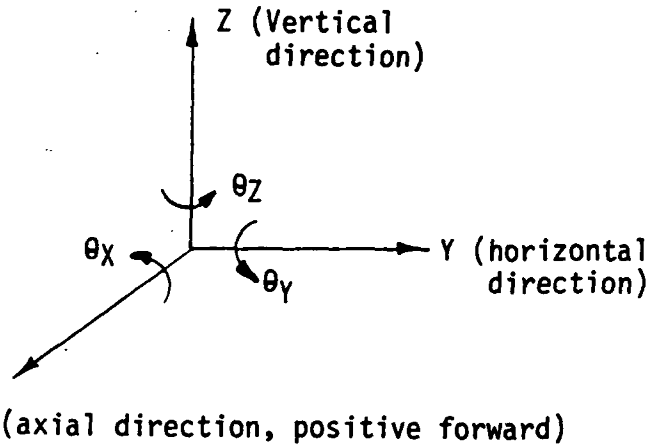
Definitions are as follows:

P = Force Amplitude (lb or in.-lb)

ω = frequency (hertz)

t = time (seconds)

APPLIED LOADS
P*cos (ωt) and P*sin (ωt) LOADS



GLOBAL DIRECTION NUMBER	DIRECTION.
1	Z
2	θY
3	Y
4	θZ
5	X
6	θX

If P*cos (ωt) or P*sin (ωt) loads are desired, enter the following (maximum of 30 lines):

POINT NUMBER	TYPE (1=COS 2=SIN)	AMPLITUDE P (lb or in-lb)	FREQUENCY ω (hertz)	GLOBAL DIRECTION NUMBER

2

CS(1,1)=

_______, _______, _______, _______, _______,
_______, _______, _______, _______, _______,
_______, _______, _______, _______, _______,
_______, _______, _______, _______, _______,
_______, _______, _______, _______, _______,
_______, _______, _______, _______, _______,
_______, _______, _______, _______, _______,
_______, _______, _______, _______, _______,
_______, _______, _______, _______, _______,
_______, _______, _______, _______, _______,

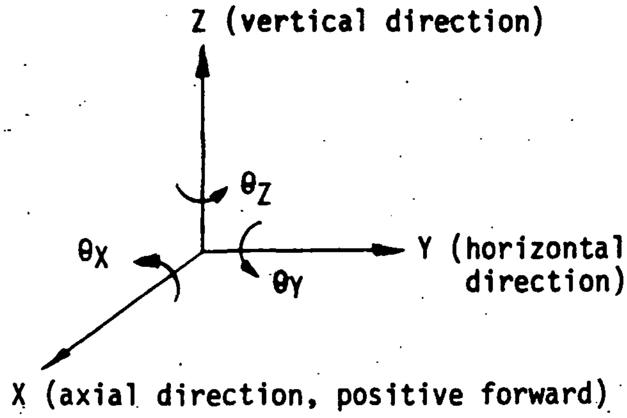
$END (Include if this is the last card of the run, otherwise omit).

Time-Force History Loads (Type M-1 and M-2 Input Sheets)

If time-force history load input is not desired, sheets M-1 and M-2 can be skipped altogether. If desired the user must specify the point number, global direction number, and table number for each time-force history load using the NTF array (see sheet M-1) (values in the NTF array must be integers). The table number must be a value between 1 and 10. There can be from zero to a maximum of 30 time-force history loads entered in the NTF array.

Then, for each table number referenced in the NTF array, the array Table (1, 1, NT) is required, where NT is the table number referenced in the NTF array. If the first time-force pair entry in the table is for a time other than zero, then the force is assumed to be zero up to the time of the first table entry. If the last time-force pair entry in the table is for a time less than the final time of the run, then the force is assumed constant and equal to the force for the last table entry for times greater than the last table entry time. A table may have only one time-force pair entry, in which case the force is zero till the time of the entry and afterward equal to the force given in the entry. There can be a maximum of ten time-force pairs in each table.

APPLIED LOADS
TIME-FORCE HISTORY LOADS



GLOBAL DIRECTION NUMBER	DIRECTION
1	Z
2	θ_Y
3	Y
4	θ_Z
5	X
6	θ_X

If time-force history loads are desired, enter the following (values must be integers) (maximum of 30 lines):

POINT NUMBER	GLOBAL DIRECTION NUMBER	TABLE NUMBER NT (VALUE BETWEEN 1 & 10)

2

NTF(1,1)=

__________,______________,__________________,
__________,______________,__________________,
__________,______________,__________________,
__________,______________,__________________,
__________,______________,__________________,
__________,______________,__________________,
__________,______________,__________________,
__________,______________,__________________,
__________,______________,__________________,
__________,______________,__________________,

APPLIED LOADS
TIME-FORCE HISTORY LOADS (Continued)

For each time-force table, enter the following (substitute actual table number in place of NT in subscript below) (maximum of 10 tables, and maximum of 10 time-force pairs in each table):

TIME (seconds)	FORCE (lb or in-lb)

2

TABLE (1,1,NT)=

____________, ______________,
____________, ______________,
____________, ______________,
____________, ______________,
____________, ______________,
____________, ______________,
____________, ______________,
____________, ______________,
____________, ______________,
____________, ______________,

$ END (Include if this is the last card of the run, otherwise omit.)

Gyroscopic Loads - Type N Input

This input identifies the gyroscopic loading locations. Up to 30 point numbers on the rotors can be entered along with the polar mass moment of intertia ($lb\text{-}in.^2$) values. Since this input models the cross-axis coupling forces associated with Coliolis evaluation, both the vertical and horizontal subsystems must be included for the rotor(s).

GYROSCOPIC LOADS

Note - to have gyroscopic loads, must have rotor speed input (type J sheet) - otherwise the gyroscopic load input is ignored.

Note - for gyroscopic loading, both the vertical and horizontal subsystems must be included for the rotor(s).

If gyroscopic loads are desired, enter the following (maximum of 30 lines):

Point Number On Rotor	Polar Moment of Inertia I_p ($lb\text{-}in^2$)

2

GYRO(1,1)=

____________, ____________________,
____________, ____________________,
____________, ____________________,
____________, ____________________,
____________, ____________________,
____________, ____________________,
____________, ____________________,
____________, ____________________,
____________, ____________________,
____________, ____________________,

$END (Include if this is the last card of the run, otherwise omit.)

Plot File Input (Type P-1 and P-2 Input Sheets)

If no output plot file is wanted, the user should set variable IPLOT to 0 and dispense with the rest of input sheets P-1 and P-2. If, however, IPLOT is set to 1 or omitted, then an output plot file will be produced, and the user should enter the desired input from pages P-1 and P-2.

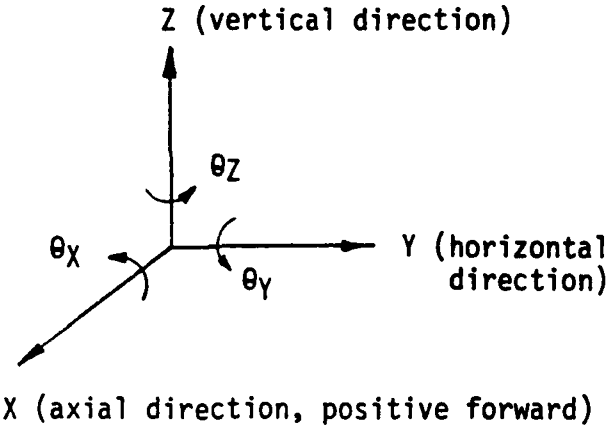
The plot file size would in many cases be excessive if all the data that conceivably might be desired were written onto the plot file. The NTF (see sheet P-1) and the NEPD (see sheet P-2) input arrays were added for this reason.

The NPD array allows the user to select the point and direction pairs for which the coordinates, displacements, velocities, and modal forces are to be written onto the output plot file. If the user doesn't want these values for any point and direction pairs, then the NPD array should be omitted. A maximum of 50 point and direction pairs may be specified.

The NEPD array allows the user to select the physical connecting element number, point number on this element, and direction number for which the physical connecting element forces are to be written onto the output plot file. Again, if the user doesn't want any such output, he should omit this array. A maximum of 50 element, point and direction trios may be specified.

In addition, certain other data is always written to the output plot file (provided an output plot file is generated). This data includes the time, independent and dependent rotor speed (see discussion of Type J input sheet), independent and dependent rotor angular displacement, and the relative displacement magnitude, clearance, and force magnitude for all rub elements (Type 3 physical connecting elements) present (if any).

DATA FOR PLOT FILE



GLOBAL DIRECTION NUMBER	DIRECTION
1	Z
2	θ_Y
3	Y
4	θ_Z
5	X
6	θ_X

0=no plot file
1=plot file produced

IPLOT=______________________, (1 assumed)

Enter the following points and directions (if any) for which the coordinates, displacements, velocities, and modal forces are to be written onto the plot file (values must be integer) (maximum of 50 lines):

POINT NUMBER	GLOBAL DIRECTION NUMBER

NPD(1,1)=

__________,______________,
__________,______________,
__________,______________,
__________,______________,
__________,______________,
__________,______________,
__________,______________,
__________,______________,
__________,______________,
__________,______________,

DATA FOR PLOT FILE (Continued)

Enter the following physical connecting elements, points, and directions (if any) for which the physical connecting element forces are to be written onto the plot file (values must be integer) (maximum of 50 lines):

PHYSICAL CONNECTING ELEMENT NUMBER	POINT NUMBER	GLOBAL DIRECTION NUMBER

2

NEPD(1,1)=

_______________, _______________, _______________,
_______________, _______________, _______________,
_______________, _______________, _______________,
_______________, _______________, _______________,
_______________, _______________, _______________,
_______________, _______________, _______________,
_______________, _______________, _______________,
_______________, _______________, _______________,
_______________, _______________, _______________,
_______________, _______________, _______________,

$END (Include if this is the last card of the run, otherwise omit.)

6.0 NASTRAN/TETRA INTERFACE: MODAL INPUT GENERATOR

The TETRA program was written so that its input information is the type of information readily available to an engineer. As noted in Section 3.0, the required information consists of geometry, frequency, mode shapes and modal potential energy for each of the subsystems considered. Depending on the application, these data can be determined experimentally or obtained from an analysis program. At the General Electric Company, the VAST program is commonly used to provide the information. This program is specifically tailored to analyze vibrations of axisymmetric structures and, as such, it represents a logical choice for the generation of this input data. If a finite element model is needed to provide the mode shapes, the MASS program, which has been developed by General Electric, is used. Both MASS and VAST have postprocessors available to transform the program results into the format required by TETRA. These particular programs have been modified to conform to the TETRA requirements, but their basic structure has been used for many years at General Electric for several postprocessing activities.

One of the terms of this contract was to code a similar postprocessor for NASTRAN level 17.5 as used by NASA on the UNIVAC 1100/42 computer system.

This program has been written, debugged and successfully tested for the TETRA demonstrator case. Instructions on the use of this program are contained later in this section, but an overall description is given at this point.

The information needed for the TETRA modal subsystem input can be found in the NASTRAN output. This fact guided us to write a program which reads this output, stores the variables which will be of interest and then, through a set of user responses in an interactive mode, the program selects the specific data required, formats it correctly, and writes it on another file.

This program can generate TETRA modal subsystem input for the vertical and horizontal plane subsystems (Numbers 1, 2, 4, 5, 7, and 8) (input sheets

C-1, C-2, and C-3) and the case torsional subsystem (Number 10) (input sheets C-7, C-8, and C-9). The program cannot, however, generate modal subsystem input for the rigid body subsystems (Numbers 3, 6, and 9) (input sheets C-4, C-5, and C-6) or for the pylon subsystem (Number 11) (input sheets C-10, C-11, and C-12).

Three fundamental rules were followed during the coding of this program.

1. It was written in time-sharing ASCII for convenience in setting up TETRA files in an interactive fashion. Our experience at General Electric has shown that this method of operation is far more efficient than batch programming for this task. Thus, although NASTRAN runs may require large core and time limits the postprocessor runs will be short.

2. Simple, straight-forward FORTAN coding was used throughout. This decision was enforced as an aid for possible future enhancements. As the program is now written engineers with only moderate programming experience should have no trouble in modifying the routines to suit their own needs. There are only two exceptions to this. In the first part of the program, the NASTRAN output is read and copies directly to another file. This is done only to avoid BACKSPACE problems associated with the UNIVAC system. If the user has copied this file already, he/she need not copy it again. The second area of "awkward logic" is the coding required to read left justified integers in the NASTRAN output. This portion of the code reads the integers twice, once as an integer and once as a character array and actually counts the number of blanks in the field. Outside of these items, all coding is straight-forward.

3. The user response questions were designed to permit a variety of applications. For example, although the NASTRAN run might calculate 20 frequencies, the user might need only Modes 1, 2, and 6. This selection can be easily accomplished.

In summary, the NASTRAN/TETRA interface program represents a working, easily modifiable program based on the approaches we have found most satisfactory at the General Electric Company.

The following section summarizes the NASTRAN 17.5 postprocessor operation in an interactive mode and also includes a sample computer-operator "conversation."

6.1 NASA 17.5 Generated Modal Data File

Below is a sample interactive computer-operator "conversation" initiated by running the NASTRAN/TETRA interface program. From this conversation the interface program knows what values to obtain from the NASTRAN 17.5 output file, and after obtaining these values the interface program generates a file containing TETRA modal subsystem input. The below example demonstrates the use of the interface program to generate modal subsystem input for subsystem 7 (case vertical plane subsystem) and subsystem 8 (case horizontal plane subsystem) for the demonstrator model. Following the below computer-operator "conversation" is a listing of the resulting interface program output file which consists of TETRA modal subsystem input.

```
RUN


     N A S T R A N -- T E T R A INTERFACE PROGRAM

SOME HELPFUL INFORMATION:
   THE ORIGINAL NASTRAN OUPUT MUST BE ASSIGNED
   TO FILE CODE  28

   TO ACCOMODATE THE UNIVAC SYSTEM REQUIREMENTS
   THIS FILE MUST BE COPIED TO ANOTHER ASCII FILE
   THIS FUNCTION CAN BE ACCOMPLISHED BY THIS PROGRAM
   BY RESPONDING WITH A ONE (1) TO THE QUESTION CONCERNING
   WHETHER OR NOT YOU DESIRE AN OUTPUT READ/WRITE

   IF YOU EXERCISE THE READ/WRITE OPTION THE
   ORIGINAL NASTRAN OUTPUT FILE WILL BE COPIED TO
   FILE CODE 27
   THIS FILE CAN BE SAVED OFF ONTO A PERMANENT
   FILE FOR FUTURE USE
   ONCE THE FILE HAS BEEN SAVED THERE IS NO REQUIREMENT
   FOR FUTURE READ/WRITE(S).WHEN FURTHER PROCESSING
   OF THE NASTRAN OUTPUT FILE IS DESIRED

ALL OUTPUT FROM THIS INTERFACE PROGRAM IS ON
TEMPORARY FILE CODE 29
```

```
        G O O D  --  L U C K

TYPE Ø TO SKIP NASTRAN OUTPUT READ/WRITE
>1
INPUT:
 SUBSYSTEM NUMBER
 NUMBER OF FREQUENCIES DESIRED
 Q-FACTOR
>7,3,15
INPUT FREQUENCY NUMBERS DESIRED
>2,3,4
INPUT NUMBER OF GRID POINTS YOU WISH TO ELIMINATE
>7
INPUT THE GRID POINTS TO BE ELIMINATED
>34,35,1ØØ,1Ø1,1Ø2,1Ø3,9ØØØ
INPUT IDENTIFICATION TITLE
>CASE  VERTICAL PLANE SUBSYSTEM FOR DEMONSTRATOR MODEL
THERE WERE    5 JOINTS
THERE WERE    3 EIGENVALUES
THERE WERE    3 EIGENVECTORS
WRITTEN TO THE TETRA INPUT FILE
TYPE 1 TO GENERATE ANOTHER SUBSYSTEM INPUT FILE
>1
INPUT:
 SUBSYSTEM NUMBER
 NUMBER OF FREQUENCIES DESIRED
 Q-FACTOR
>8,3,15
INPUT FREQUENCY NUMBERS DESIRED
>2,3,4
INPUT NUMBER OF GRID POINTS YOU WISH TO ELIMINATE
>7
INPUT THE GRID POINTS TO BE ELIMINATED
>34,35,1ØØ,1Ø1,1Ø2,1Ø3,9ØØØ
INPUT IDENTIFICATION TITLE
>CASE HORIZONTAL PLANE SUBSYSTEM FOR DEMONSTRATOR MODEL
THERE WERE    5 JOINTS
THERE WERE    3 EIGENVALUES
THERE WERE    3 EIGENVECTORS
WRITTEN TO THE TETRA INPUT FILE
TYPE 1 TO GENERATE ANOTHER SUBSYSTEM INPUT FILE
>
```

FOLLOWING IS A LISTING OF THE OUTPUT FILE FROM THIS INTERFACE PROGRAM (FILE CODE 29):

```
 $END
 $LIST2
 TITLE='CASE  VERTICAL PLANE SUBSYSTEM FOR DEMONSTRATOR MODEL
 ISUB= 7,
 XREF=Ø,
 YREF=Ø,
 ZREF=Ø,
 PTS(1,1)=
```

```
   1,      0.    ,       0.    ,       0.    ,
   2,   -10.0000,       0.    ,       0.    ,
   3,   -90.0000,       0.    ,       0.    ,
  33,  -100.0000,       0.    ,       0.    ,
  37,   -50.0000,       0.    ,       0.    ,
XMODES(1,1)=
1.250911E 02, 9.999440E 01,15, 1,
1.588929E 02, 6.399970E 01,15, 1,
3.064352E 04, 2.379934E 06,15, 0,
VH(1,1,1)=
 9.999580E-01, 6.151813E-07,-4.999698E 00,-6.182194E-04,
 9.999628E-01, 6.235140E-07, 2.999931E 01, 9.999146E 01,
 9.999621E-01,-6.431300E-07,-2.999929E 01, 9.999298E 01,
 9.999570E-01,-6.347973E-07, 4.999698E 00, 0.           ,
 1.000000E 00,-9.808070E-09, 3.039837E-06,-1.499972E 03,
VH(1,1,2)=
-9.999996E-01, 2.000014E-02, 8.067115E 00,-4.571677E 01,
-7.999962E-01, 2.000012E-02,-1.095825E 01,-2.984927E 02,
 7.999966E-01, 2.000012E-02,-1.095826E 01, 2.070593E 02,
 1.000000E 00, 2.000014E-02, 8.067120E 00, 0.           ,
 1.945323E-07, 2.000014E-02, 6.715440E-01,-4.571713E 01,
VH(1,1,3)=
 1.000000E 00,-3.121830E-02,-3.000452E 05, 2.654122E 06,
 6.116836E-01,-3.027587E-02,-9.671252E 05, 1.380302E 07,
 6.116836E-01, 3.027587E-02, 9.671252E 05, 8.655026E 06,
 1.000000E 00, 3.121830E-02, 3.000452E 05, 0.           ,
-7.185308E-01,-8.364795E-15, 0.           , 6.802237E 07,
$END
$LIST2
TITLE='CASE HORIZONTAL PLANE SUBSYSTEM FOR DEMONSTRATOR MODEL
ISUB= 8,
XREF=0,
YREF=0,
ZREF=0,
PTS(1,1)=
   1,      0.    ,       0.    ,       0.    ,
   2,   -10.0000,       0.    ,       0.    ,
   3,   -90.0000,       0.    ,       0.    ,
  33,  -100.0000,       0.    ,       0.    ,
  37,   -50.0000,       0.    ,       0.    ,
XMODES(1,1)=
1.250911E 02, 9.999440E 01,15, 1,
1.588929E 02, 6.399970E 01,15, 1,
3.064352E 04, 2.379934E 06,15, 0,
VH(1,1,1)=
 9.999580E-01, 6.151813E-07,-4.999698E 00,-6.182194E-04,
 9.999628E-01, 6.235140E-07, 2.999931E 01, 9.999146E 01,
 9.999621E-01,-6.431300E-07,-2.999929E 01, 9.999298E 01,
 9.999570E-01,-6.347973E-07, 4.999698E 00, 0.           ,
 1.000000E 00,-9.808070E-09, 3.039837E-06,-1.499972E 03,
VH(1,1,2)=
-9.999996E-01, 2.000014E-02, 8.067115E 00,-4.571677E 01,
-7.999962E-01, 2.000012E-02,-1.095825E 01,-2.984927E 02,
 7.999966E-01, 2.000012E-02,-1.095826E 01, 2.070593E 02,
 1.000000E 00, 2.000014E-02, 8.067120E 00, 0.           ,
 1.945323E-07, 2.000014E-02, 6.715440E-01,-4.571713E 01,
VH(1,1,3)=
 1.000000E 00,-3.121830E-02,-3.000452E 05, 2.654122E 06,
 6.116836E-01,-3.027587E-02,-9.671252E 05, 1.380302E 07,
 6.116836E-01, 3.027587E-02, 9.671252E 05, 8.655026E 06,
 1.000000E 00, 3.121830E-02, 3.000452E 05, 0.           ,
-7.185308E-01,-8.364795E-15, 0.           , 6.802237E 07,
```

7.0 DEMONSTRATOR CASE

Input Setup

The results obtained with a demonstrator model that represents the engine system shown in Figure 54 will now be presented. The straight lines shown for the rotor and case in this figure represent segmented beam centerline elements that include both stiffness and mass properties. Free-free modal data for the rotor and case subsystems along with physical spring-damper connecting element data were input to the TETRA time transient computer program and solutions were obtained for various rotor speed and rotor unbalance conditions.

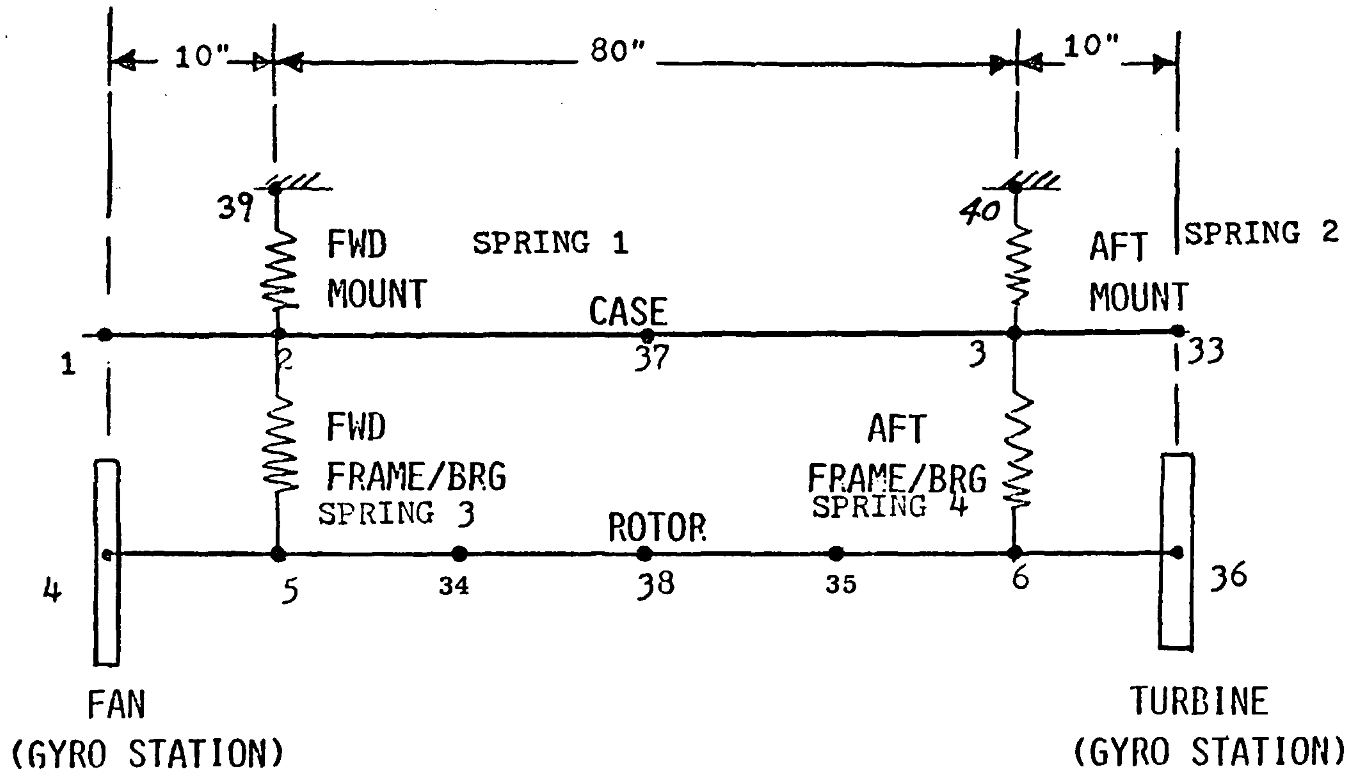
Modal data based on planar finite element models of the total system shown in Figure 54 and on the free-free rotor and casing subsystems was computed with the VAST program. In the former case, a frequency domain modal analysis was used to establish the steady-state frequency response of the total system and in the latter case, the TETRA program was used to synthesize the free-free modal data and the physical connecting element data and to predict the time domain response for the combined system.

Spectral analysis and a comparison of the TETRA and frequency domain solutions indicated that TETRA had correctly synthesized the modal and physical data to predict the time transient response for the combined system.

The frequencies for the free-free subsystem modes used in the TETRA analysis are shown in Table III. Eight generalized coordinates, corresponding to these frequencies, were used to define the time response for the total system, which has 40 degrees-of-freedom. Therefore, the dimensionality of the model has been reduced by 80%.

Inspection of Table III shows that the smallest period of oscillation for the subsystem modes is equal to 1.0/510.62 = 0.001958 sec. Accounting for the stiffening effect of the physical connecting springs, a time step value that is considerably less than 0.001958 second must be used for the numerical integration that will be performed with the TETRA program. In practice, the time step should be made equal to about 1/40 of the smallest period of oscillation for the subsystem modes.

$$1/40 \times .001958 = 4.895 \times 10^{-5}$$



PHYSICAL CONNECTING ELEMENTS

Spring 1	0.5×10^6 lb/in.
Spring 2	0.5×10^6 lb/in.
Spring 3	1.0×10^6 lb/in.
Spring 4	1.0×10^6 lb/in.

POINT 1 IS THE GLOBAL ORIGIN (X=Y=Z=0) FOR THE TETRA MODEL.

PHYSICAL POINT NUMBERS 1,2,37, ETC. IDENTIFIED.

Figure 54. 40 DOF Finite Element Model for Demonstrator.

On this basis a time step of = 50 x 10^{-6} seconds was selected.

Table III. Frequencies* for the Free-Free Modal Subsystems Used in the TETRA Analysis.

Rotor		Case	
cpm	Hz	cpm	Hz
99.3	1.655	125.1	2.085
120.8	2.013	159	2.65
10065	167.75	30367	510.62
16851	280.85		
26425	440.42		

* Free-Free Modal Data Obtained with the Following Boundary Conditions:

Rotor was Supported on Each End by 300 lb/in. Spring and Case was Supported on Each End by 100 lb/in. Spring.

The free-free modal data were used in the TETRA program to respresent both the vertical and horizontal planes and uncoupled springs (in the Z and Y directions) were used to connect the modal subsystems to each other and to the ground to model the configuration shown in Figure 54. The rigid body modes for the rotor and the case were approximated with the "soft spring" rigid body modes at 1.655, 2.013, 2.085, and 2.65 Hz. In addition, they were also defined in subsequent analyses with the true representations that were based on the mass properties. The results obtained with either approach were in excellent agreement. A modal Q-factor equal to 15 (3.33% critical damping) was used to represent the damping of each of the casing subsystem modes. The rotor subsystem modes were undamped. Proportional damping based on a physical Q-factor equal to 15 and a selected frequency of 3624 rpm (a critical speed with gyroscopic stiffening present) was used to represent the damping for the connecting spring elements.

7.1 INPUT AND OUTPUT

The TETRA input and representative output follows for constant 3000 rpm speed running with 5000 gm-in. sudden fan unbalance and a 10 mil rub element at the fan. The input listing is a part of the TETRA output and directly follows the cover sheet of the output.

```
TTTTTTTTT  EEEEEEE  TTTTTTTTT  RRRRRRRR      AAAAAA
TTTTTTTTT  EEEEEEE  TTTTTTTTT  RRRRRRRRR    AAAAAAAA
TTTTTTTTT  EEE      TTTTTTTTT  RRR   RRR   AAA    AAA
   TTT     EEE         TTT     RRRRRRRRR  AAA      AAA
   TTT     EEEEEEE     TTT     RRRRRRRR   AAAAAAAAAAAA
   TTT     EEEEEEE     TTT     RRRRRRR    AAAAAAAAAAAA
   TTT     EEE         TTT     RRRRRRRR   AAA      AAA
   TTT     EEE         TTT     RRR RRRRR  AAA      AAA
   TTT     EEEEEEE     TTT     RRR  RRRR  AAA      AAA
   TTT     EEEEEEE     TTT     RRR  RRRR  AAA      AAA
```

G. BLACK   DATE AUGUST 1980   CHARGE 19510

BLDG. 500   MAIL DROP K-190   EXT. 3334

ROTOR AND CASE VERTICAL AND HORIZONTAL MODEL 1

WITH GYRO LOADS AT FAN AND TURBINE

DATE 01/05/81
TIME   16.94

147 XEROX 9700 PS (44)

LISTING OF INPUT FILE-

```
$LIST1
NAME=   'G. BLACK   DATE AUGUST 1980   CHARGE 19510',
ADDRES=  'BLDG. 500   MAIL DROP K-190   EXT. 3334',
IDENT1=  'ROTOR AND CASE VERTICAL AND HORIZONTAL MODEL 1',
IDENT2=  'WITH GYRO LOADS AT FAN AND TURBINE',
PP(1,1)=
39,1,-10,0,0,
40,1,-90,0,0,
$END
$LIST2
TITLE=   'ROTOR VERTICAL PLANE SUBSYSTEM FOR DEMONSTRATOR MODEL 1',
ISUB=1,
PTS(1,1)=
4,0,0,0,
5,-10,0,0,
34,-30,0,0,
38,-50,0,0,
35,-70,0,0,
6,-90,0,0,
38,-100,0,0,
XMODES(1,1)=
99.3,192,0,1,
120.8,300,0,1,
10068,5.38E5,0,0,
16851,9.90E6,0,0,
26425,1.75E6,0,0,
VH(1,1,1)=
-1,.02,0,0,
-.8,.02,0,0,
-.4,.02,0,0,
0,.02,0,0,
.4,.02,0,0,
.8,.02,0,0,
1,.02,0,0,
VH(1,1,2)=
1,0,0,0,
1,0,0,0,
1,0,0,0,
1,0,0,0,
1,0,0,0,
1,0,0,0,
1,0,0,0,
VH(1,1,3)=
.12215,-.034677,0,0,
-.25282,-.029534,-2.073E5,1.176E7,
-.80295,-.016102,-1.021E5,1.568E7,
-1,0,3.519E4,1.711E7,
-.80295,.016102,1.586E5,1.558E7,
-.25282,.029534,2.073E5,1.176E7,
.12215,.034677,0,0,
VH(1,1,4)=
.2748,.1075,0,0,
.8258,.0707,-1.444E6,-6.956E7,
.8584,.0174,-1.892E6,-3.877E7,
0,-.0017,-1.989E6,1.608E4,
-.8584,.0174,-1.723E6,3.846E7,
-.8258,.0707,-1.444E6,6.956E7,
-.2748,.1075,0,0,
VH(1,1,5)=
-.10361,-.01856,0,0,
```

```
.0959,-.00459,1.241E6,2.250E7,
.6966,.00594,6.883E6,-2.488E5,
1,0,-2.426E5,-9.743E6,
.6966,-.00594,-1.026E6,1.768E4,
.0959,.00459,-1.241E6,2.250E7,
-.10361,.01856,0,0,
$END
$LIST2
TITLE=  'ROTOR HORIZONTAL PLANE SUBSYSTEM FOR DEMONSTRATOR MODEL 1',
ISUB=2,
PTS(1,1)=
4,0,0,0,
5,-10,0,0,
34,-30,0,0,
38,-50,0,0,
35,-70,0,0,
6,-90,0,0,
36,-100,0,0,
XMODES(1,1)=
99.3,192,0,1,
120.8,300,0,1,
10065,5.38E5,0,0,
16851,9.90E6,0,0,
26425,1.75E6,0,0,
VH(1,1,1)=
-1,.02,0,0,
-.8,.02,0,0,
-.4,.02,0,0,
0,.02,0,0,
.4,.02,0,0,
.8,.02,0,0,
1,.02,0,0,
VH(1,1,2)=
1,0,0,0,
1,0,0,0,
1,0,0,0,
1,0,0,0,
1,0,0,0,
1,0,0,0,
1,0,0,0,
VH(1,1,3)=
.12215,-.034677,0,0,
-.25282,-.029534,-2.073E5,1.176E7,
-.80295,-.016102,-1.021E5,1.568E7,
-1,0,3.519E4,1.711E7,
-.80295,.016102,1.586E5,1.558E7,
-.25282,.029534,2.073E5,1.176E7,
.12215,.034677,0,0,
VH(1,1,4)=
.2748,.1075,0,0,
.8258,.0707,-1.444E6,-6.956E7,
.8584,.0174,-1.892E6,-3.877E7,
0,-.0017,-1.989E6,1.608E4,
-.8584,.0174,-1.723E6,3.846E7,
-.8258,.0707,-1.444E6,6.956E7,
-.2748,.1075,0,0,
VH(1,1,5)=
-.10361,-.01856,0,0,
.0959,-.00459,1.241E6,2.250E7,
.6966,.00594,6.883E6,-2.488E5,
1,0,-2.426E5,-9.743E6,
.6966,-.00594,-1.026E6,1.768E4,
```

```
.0959,.00459,-1.241E6,2.250E7,
-.10361,.01856,0,0,
$END
$LIST2
TITLE=  'CASE VERTICAL PLANE SUBSYSTEM FOR DEMONSTRATOR MODEL 1',
ISUB=7,
PTS(1,1)=
1,0,0,0,
2,-10,0,0,
37,-50,0,0,
3,-90,0,0,
33,-100,0,0,
XMODES(1,1)=
125.1,100,0,1,
159,64,0,1,
30637,2.38E6,15,0,
VH(1,1,1)=
1,0,0,0,
1,0,0,0,
1,0,0,0,
1,0,0,0,
1,0,0,0,
VH(1,1,2)=
-1,.02,0,0,
-.8,.02,0,0,
0,.02,0,0,
.8,.02,0,0,
1,.02,0,0,
VH(1,1,3)=
1,-.03122,0,0,
.6117,-.03028,-9.6716E5,1.1229E7,
-.7185,0,4.3121E5,6.8026E7,
.6117,.03028,9.6716E5,1.1229E7,
1,.03122,0,0,
$END
$LIST2
TITLE=  'CASE HORIZONTAL PLANE SUBSYSTEM FOR DEMONSTRATOR MODEL 1',
ISUB=8,
PTS(1,1)=
1,0,0,0,
2,-10,0,0,
37,-50,0,0,
3,-90,0,0,
33,-100,0,0,
XMODES(1,1)=
125.1,100,0,1,
159,64,0,1,
30637,2.38E6,15,0,
VH(1,1,1)=
1,0,0,0,
1,0,0,0,
1,0,0,0,
1,0,0,0,
1,0,0,0,
VH(1,1,2)=
-1,.02,0,0,
-.8,.02,0,0,
0,.02,0,0,
.8,.02,0,0,
1,.02,0,0,
VH(1,1,3)=
1,-.03122,0,0,
```

```
.6117,-.03028,-9.6716E5,1.1229E7,
-.7185,0,4.3121E5,6.8026E7,
.6117,.03028,9.6716E5,1.1229E7,
1,.03122,0,0,
$END
$LIST3
ITYPE=5,
ILEM=1,
JT=2,39,
YS=5E5,
ZS=5E5,
IDAMP=1,
QELEM=15,
QFREQ=60.4,
$END
$LIST3
ITYPE=5,
ILEM=2,
JT=3,40,
YS=5E5,
ZS=5E5,
IDAMP=1,
QELEM=15,
QFREQ=60.4,
$END
$LIST3
ITYPE=5,
ILEM=3,
JT=5,2,
YS=1E6,
ZS=1E6,
IDAMP=1,
QELEM=15,
QFREQ=60.4,
$END
$LIST3
ITYPE=5,
ILEM=4,
JT=6,3,
YS=1E6,
ZS=1E6,
IDAMP=1,
QELEM=15,
QFREQ=60.4,
$END
$LIST3
ITYPE=3,
ILEM=5,
JT=4,1,
SK=1E6,
DBAND=10,
CC=0.0,
$END
$LIST4
DELTA=.00005,
TFINAL=.512,
IPRMUL=1000,
IPLMUL=10,
IROTI=1,
BEGTIM=0.,
BEGRPM=3000.,
TRHIS(1,1)=
```

```
 .6,0.,
 UNBAL(1,1)=
 0.4,5000,0.
 GYRO(1,1)=
 4,184205,
 36,184205,
 NPD(1,1)=
 1,1,
 1,3,
 4,1,
 4,3,
 37,1,
 37,3,
 38,1,
 38,3,
 NEPD(1,1)=
 3,2,1,
 3,2,3,
 3,5,1,
 3,5,3,
 4,3,1,
 4,3,3,
 4,6,1,
 4,6,3,
 $END
END OF INPUT FILE
```

INPUT DATA FOR POINTS NOT LOCATED ON THE MODAL SUBSYSTEMS-

POINT NUMBER	RESTRAINT CODE	COORDINATES (INCHES)-GLOBAL SYSTEM X	Y	Z
39	1	-10.000	0.	0.
40	1	-90.000	0.	0.

NUMBER OF PHYSICAL POINTS NOT ON MODAL SUBSYSTEMS= 2

DATA FOR MODAL SUBSYSTEM 1

ROTOR VERTICAL PLANE SUBSYSTEM FOR DEMONSTRATOR MODEL 1

NUMBER OF SUBSYSTEM DIRECTIONS= 2

GLOBAL DIRECTIONS FOR SUBSYSTEM= 1 2

COORDINATES OF REFERENCE POINT RELATIVE TO GLOBAL SYSTEM (IN.)
X= 0. Y= 0. Z= 0.

COORDINATES OF POINTS ON SUBSYSTEM (INCHES)

POINT NUMBER	LOCAL COORDINATE SYSTEM X	Y	Z	GLOBAL COORDINATE SYSTEM X	Y	Z
4	0.	0.	0.	0.	0.	0.
5	-10.000	0.	0.	-10.000	0.	0.
34	-30.000	0.	0.	-30.000	0.	0.
38	-50.000	0.	0.	-50.000	0.	0.
35	-70.000	0.	0.	-70.000	0.	0.
6	-90.000	0.	0.	-90.000	0.	0.
36	-100.000	0.	0.	-100.000	0.	0.

NUMBER OF SUBSYSTEM POINTS= 7

LOCAL MODE NUMBER	GENERALIZED COORDINATE NUMBER	FREQUENCY RPM	POTENTIAL ENERGY	Q FACTOR	MODE TYPE 0=FLEXIBLE 1=RIGID BODY	GENERALIZED WEIGHT-LB	GENERALIZED STIFFNESS LB/IN	GENERALIZED DAMPING VALUE (LB-SEC)/IN
1	1	99.	1.920E 02	0.	1	1.372E 03	0.	0.
2	2	121.	3.000E 02	0.	1	1.449E 03	0.	0.
3	3	10065.	5.380E 05	0.	0	3.743E 02	1.076E 06	0.
4	4	16851.	9.900E 06	0.	0	2.457E 03	1.980E 07	0.
5	5	26425.	1.750E 06	0.	0	1.766E 02	3.500E 06	0.

NUMBER OF SUBSYSTEM MODES= 5

THE MODE SHAPES AND CORRESPONDING FORCES FOR THIS SUBSYSTEM ARE-

LOCAL MODE NUMBER	GENERALIZED COORDINATE NUMBER	POINT NUMBER	MODAL DISPLACEMENTS GLOBAL DIRECTION 1 Z	2 THETA-Y	MODAL FORCES GLOBAL DIRECTION 1 Z	2 THETA-Y
1	1	4	-1.00000	0.02000	0.	0.
1	1	5	-0.80000	0.02000	0.	0.
1	1	34	-0.40000	0.02000	0.	0.
1	1	38	0.	0.02000	0.	0.
1	1	35	0.40000	0.02000	0.	0.
1	1	6	0.80000	0.02000	0.	0.
1	1	36	1.00000	0.02000	0.	0.
2	2	4	1.00000	0.	0.	0.
2	2	5	1.00000	0.	0.	0.
2	2	34	1.00000	0.	0.	0.
2	2	38	1.00000	0.	0.	0.
2	2	35	1.00000	0.	0.	0.
2	2	6	1.00000	0.	0.	0.
2	2	36	1.00000	0.	0.	0.
3	3	4	0.12215	-0.03468	0.	0.

3	3	5	-0.25282	-0.02953	-2.073E 05	1.176E 07
3	3	34	-0.80295	-0.01610	-1.021E 05	1.568E 07
3	3	38	-1.00000	0.	3.519E 04	1.711E 07
3	3	35	-0.80295	0.01610	1.586E 05	1.558E 07
3	3	6	-0.25282	0.02953	2.073E 05	1.176E 07
3	3	36	0.12215	0.03468	0.	0.
4	4	4	0.27480	0.10750	0.	0.
4	4	5	0.82580	0.07070	-1.444E 06	-6.956E 07
4	4	34	0.85840	0.01740	-1.892E 06	-3.877E 07
4	4	38	0.	-0.00170	-1.989E 06	1.608E 04
4	4	35	-0.85840	0.01740	-1.723E 06	3.846E 07
4	4	6	-0.82580	0.07070	-1.444E 06	6.956E 07
4	4	36	-0.27480	0.10750	0.	0.
5	5	4	-0.10361	-0.01856	0.	0.
5	5	5	0.09590	-0.00459	1.241E 06	2.250E 07
5	5	34	0.69660	0.00594	6.883E 06	-2.488E 05
5	5	38	1.00000	0.	-2.426E 05	-9.743E 06
5	5	35	0.69660	-0.00594	-1.026E 06	1.768E 04
5	5	6	0.09590	0.00459	-1.241E 06	2.250E 07
5	5	36	-0.10361	0.01856	0.	0.

DATA FOR MODAL SUBSYSTEM 2

ROTOR HORIZONTAL PLANE SUBSYSTEM FOR DEMONSTRATOR MODEL 1

NUMBER OF SUBSYSTEM DIRECTIONS= 2

GLOBAL DIRECTIONS FOR SUBSYSTEM= 3 4

COORDINATES OF REFERENCE POINT RELATIVE TO GLOBAL SYSTEM (IN.)
X= 0. Y= 0. Z= 0.

COORDINATES OF POINTS ON SUBSYSTEM (INCHES)

POINT NUMBER	LOCAL COORDINATE SYSTEM X	LOCAL COORDINATE SYSTEM Y	LOCAL COORDINATE SYSTEM Z	GLOBAL COORDINATE SYSTEM X	GLOBAL COORDINATE SYSTEM Y	GLOBAL COORDINATE SYSTEM Z
4	0.	0.	0.	0.	0.	0.
5	-10.000	0.	0.	-10.000	0.	0.
34	-30.000	0.	0.	-30.000	0.	0.
38	-50.000	0.	0.	-50.000	0.	0.
35	-70.000	0.	0.	-70.000	0.	0.
6	-90.000	0.	0.	-90.000	0.	0.
36	-100.000	0.	0.	-100.000	0.	0.

NUMBER OF SUBSYSTEM POINTS= 7

LOCAL MODE NUMBER	GENERALIZED COORDINATE NUMBER	FREQUENCY RPM	POTENTIAL ENERGY	Q FACTOR	MODE TYPE 0=FLEXIBLE 1=RIGID BODY	GENERALIZED WEIGHT-LB	GENERALIZED STIFFNESS LB/IN	GENERALIZED DAMPING VALUE (LB-SEC)/IN
1	6	99.	1.920E 02	0.	1	1.372E 03	0.	0.
2	7	121.	3.000E 02	0.	1	1.449E 03	0.	0.
3	8	10065.	5.380E 05	0.	0	3.743E 02	1.076E 06	0.
4	9	16851.	9.900E 06	0.	0	2.457E 03	1.980E 07	0.
5	10	26425.	1.750E 06	0.	0	1.766E 02	3.500E 06	0.

NUMBER OF SUBSYSTEM MODES= 5

THE MODE SHAPES AND CORRESPONDING FORCES FOR THIS SUBSYSTEM ARE-
(SIGNS IN THETA-Z DIRECTION CHANGED TO OBTAIN RIGHT HAND COORDINATE SYSTEM)

LOCAL MODE NUMBER	GENERALIZED COORDINATE NUMBER	POINT NUMBER	MODAL DISPLACEMENTS GLOBAL DIRECTION 3 Y	MODAL DISPLACEMENTS GLOBAL DIRECTION 4 THETA-Z	MODAL FORCES GLOBAL DIRECTION 3 Y	MODAL FORCES GLOBAL DIRECTION 4 THETA-Z
1	6	4	-1.00000	-0.02000	0.	0.
1	6	5	-0.80000	-0.02000	0.	0.
1	6	34	-0.40000	-0.02000	0.	0.
1	6	38	0.	-0.02000	0.	0.
1	6	35	0.40000	-0.02000	0.	0.
1	6	6	0.80000	-0.02000	0.	0.
1	6	36	1.00000	-0.02000	0.	0.
2	7	4	1.00000	0.	0.	0.
2	7	5	1.00000	0.	0.	0.
2	7	34	1.00000	0.	0.	0.
2	7	38	1.00000	0.	0.	0.
2	7	35	1.00000	0.	0.	0.
2	7	6	1.00000	0.	0.	0.
2	7	36	1.00000	0.	0.	0.

3	8	4	0.12215	0.03468	0.	0.
3	8	5	-0.25282	0.02953	-2.073E 05	-1.176E 07
3	8	34	-0.80295	0.01610	-1.021E 05	-1.568E 07
3	8	38	-1.00000	0.	3.519E 04	-1.711E 07
3	8	35	-0.80295	-0.01610	1.586E 05	-1.558E 07
3	8	6	-0.25282	-0.02953	2.073E 05	-1.176E 07
3	8	36	0.12215	-0.03468	0.	0.
4	9	4	0.27480	-0.10750	0.	0.
4	9	5	0.82580	-0.07070	-1.444E 06	6.956E 07
4	9	34	0.85840	-0.01740	-1.892E 06	3.877E 07
4	9	38	0.	0.00170	-1.989E 06	-1.608E 04
4	9	35	-0.85840	-0.01740	-1.723E 06	-3.846E 07
4	9	6	-0.82580	-0.07070	-1.444E 06	-6.956E 07
4	9	36	-0.27480	-0.10750	0.	0.
5	10	4	-0.10361	0.01856	0.	0.
5	10	5	0.09590	0.00459	1.241E 06	-2.250E 07
5	10	34	0.69660	-0.00594	6.883E 06	2.488E 05
5	10	38	1.00000	0.	-2.426E 05	9.743E 06
5	10	35	0.69660	0.00594	-1.026E 06	-1.768E 04
5	10	6	0.09590	-0.00459	-1.241E 06	-2.250E 07
5	10	36	-0.10361	-0.01856	0.	0.

DATA FOR MODAL SUBSYSTEM 7

CASE VERTICAL PLANE SUBSYSTEM FOR DEMONSTRATOR MODEL 1

NUMBER OF SUBSYSTEM DIRECTIONS= 2

GLOBAL DIRECTIONS FOR SUBSYSTEM= 1 2

COORDINATES OF REFERENCE POINT RELATIVE TO GLOBAL SYSTEM (IN.)
X= 0. Y= 0. Z= 0.

COORDINATES OF POINTS ON SUBSYSTEM (INCHES)

POINT NUMBER	LOCAL COORDINATE SYSTEM X	LOCAL Y	LOCAL Z	GLOBAL COORDINATE SYSTEM X	GLOBAL Y	GLOBAL Z
1	0.	0.	0.	0.	0.	0.
2	-10.000	0.	0.	-10.000	0.	0.
37	-50.000	0.	0.	-50.000	0.	0.
3	-90.000	0.	0.	-90.000	0.	0.
33	-100.000	0.	0.	-100.000	0.	0.

NUMBER OF SUBSYSTEM POINTS= 5

LOCAL MODE NUMBER	GENERALIZED COORDINATE NUMBER	FREQUENCY RPM	POTENTIAL ENERGY	Q FACTOR	MODE TYPE 0=FLEXIBLE 1=RIGID BODY	GENERALIZED WEIGHT-LB	GENERALIZED STIFFNESS LB/IN	GENERALIZED DAMPING VALUE (LB-SEC)/IN
1	11	125.	1.000E 02	0.	1	4.503E 02	0.	0.
2	12	159.	6.400E 01	0.	1	1.784E 02	0.	0.
3	13	30637.	2.380E 06	15.	0	1.787E 02	4.760E 06	9.891E 01

NUMBER OF SUBSYSTEM MODES= 3

THE MODE SHAPES AND CORRESPONDING FORCES FOR THIS SUBSYSTEM ARE-

LOCAL MODE NUMBER	GENERALIZED COORDINATE NUMBER	POINT NUMBER	MODAL DISPLACEMENTS GLOBAL DIRECTION 1 Z	MODAL DISPLACEMENTS GLOBAL DIRECTION 2 THETA-Y	MODAL FORCES GLOBAL DIRECTION 1 Z	MODAL FORCES GLOBAL DIRECTION 2 THETA-Y
1	11	1	1.00000	0.	0.	0.
1	11	2	1.00000	0.	0.	0.
1	11	37	1.00000	0.	0.	0.
1	11	3	1.00000	0.	0.	0.
1	11	33	1.00000	0.	0.	0.
2	12	1	-1.00000	0.02000	0.	0.
2	12	2	-0.80000	0.02000	0.	0.
2	12	37	0.	0.02000	0.	0.
2	12	3	0.80000	0.02000	0.	0.
2	12	33	1.00000	0.02000	0.	0.
3	13	1	1.00000	-0.03122	0.	0.
3	13	2	0.61170	-0.03028	-9.672E 05	1.123E 07
3	13	37	-0.71850	0.	4.312E 05	6.803E 07
3	13	3	0.61170	0.03028	9.672E 05	1.123E 07
3	13	33	1.00000	0.03122	0.	0.

DATA FOR MODAL SUBSYSTEM 8

CASE HORIZONTAL PLANE SUBSYSTEM FOR DEMONSTRATOR MODEL 1

NUMBER OF SUBSYSTEM DIRECTIONS= 2

GLOBAL DIRECTIONS FOR SUBSYSTEM= 3 4

COORDINATES OF REFERENCE POINT RELATIVE TO GLOBAL SYSTEM (IN.)

X= O. Y= O. Z= O.

COORDINATES OF POINTS ON SUBSYSTEM (INCHES)

POINT NUMBER	LOCAL COORDINATE SYSTEM X	Y	Z	GLOBAL COORDINATE SYSTEM X	Y	Z
1	O.	O.	O.	O.	O.	O.
2	-10.000	O.	O.	-10.000	O.	O.
37	-50.000	O.	O.	-50.000	O.	O.
3	-90.000	O.	O.	-90.000	O.	O.
33	-100.000	O.	O.	-100.000	O.	O.

NUMBER OF SUBSYSTEM POINTS= 5

LOCAL MODE NUMBER	GENERALIZED COORDINATE NUMBER	FREQUENCY RPM	POTENTIAL ENERGY	Q FACTOR	MODE TYPE O=FLEXIBLE 1=RIGID BODY	GENERALIZED WEIGHT-LB	GENERALIZED STIFFNESS LB/IN	GENERALIZED DAMPING VALUE (LB-SEC)/IN
1	14	125.	1.000E 02	O.	1	4.503E 02	O.	O.
2	15	159.	6.400E 01	O.	1	1.784E 02	O.	O.
3	16	30637.	2.380E 06	15.	0	1.787E 02	4.760E 06	9.891E 01

NUMBER OF SUBSYSTEM MODES= 3

THE MODE SHAPES AND CORRESPONDING FORCES FOR THIS SUBSYSTEM ARE-
(SIGNS IN THETA-Z DIRECTION CHANGED TO OBTAIN RIGHT HAND COORDINATE SYSTEM)

LOCAL MODE NUMBER	GENERALIZED COORDINATE NUMBER	POINT NUMBER	MODAL DISPLACEMENTS GLOBAL DIRECTION 3 Y	4 THETA-Z	MODAL FORCES GLOBAL DIRECTION 3 Y	4 THETA-Z
1	14	1	1.00000	O.	O.	O.
1	14	2	1.00000	O.	O.	O.
1	14	37	1.00000	O.	O.	O.
1	14	3	1.00000	O.	O.	O.
1	14	33	1.00000	O.	O.	O.
2	15	1	-1.00000	-0.02000	O.	O.
2	15	2	-0.80000	-0.02000	O.	O.
2	15	37	O.	-0.02000	O.	O.
2	15	3	0.80000	-0.02000	O.	O.
2	15	33	1.00000	-0.02000	O.	O.
3	16	1	1.00000	0.03122	O.	O.
3	16	2	0.61170	0.03028	-9.672E 05	-1.123E 07
3	16	37	-0.71850	O.	4.312E 05	-6.803E 07
3	16	3	0.61170	-0.03028	9.672E 05	-1.123E 07
3	16	33	1.00000	-0.03122	O.	O.

TOTAL NUMBER OF SUBSYSTEMS= 4

TOTAL NUMBER OF MODES OR GENERALIZED COORDINATES= 16

SUMMARY OF THE MODES OR GENERALIZED COORDINATES-

GENERALIZED COORDINATE NUMBER	GENERALIZED WEIGHT	GENERALIZED STIFFNESS	GENERALIZED DAMPING VALUE
1	1.372E 03	0.	0.
2	1.449E 03	0.	0.
3	3.743E 02	1.076E 06	0.
4	2.457E 03	1.980E 07	0.
5	1.766E 02	3.500E 06	0.
6	1.372E 03	0.	0.
7	1.449E 03	0.	0.
8	3.743E 02	1.076E 06	0.
9	2.457E 03	1.980E 07	0.
10	1.766E 02	3.500E 06	0.
11	4.503E 02	0.	0.
12	1.784E 02	0.	0.
13	1.787E 02	4.760E 06	9.891E 01
14	4.503E 02	0.	0.
15	1.784E 02	0.	0.
16	1.787E 02	4.760E 06	9.891E 01

SUMMARY OF THE COORDINATES FOR THE PHYSICAL POINTS-

POINT NUMBER	COORDINATES (INCHES)-GLOBAL SYSTEM X	Y	Z
1	0.	0.	0.
2	-10.000	0.	0.
3	-90.000	0.	0.
4	0.	0.	0.
5	-10.000	0.	0.
6	-90.000	0.	0.
33	-100.000	0.	0.
34	-30.000	0.	0.
35	-70.000	0.	0.
36	-100.000	0.	0.
37	-50.000	0.	0.
38	-50.000	0.	0.
39	-10.000	0.	0.
40	-90.000	0.	0.

PHYSICAL CONNECTING ELEMENT NUMBER 1

ELEMENT TYPE= 5

NUMBER OF END POINTS= 2

POINT NUMBER AT I END= 2
POINT NUMBER AT J END= 39

NUMBER OF DIRECTIONS FOR POINT AT I END= 5
GLOBAL DIRECTIONS FOR POINT AT I END= 1 2 3 4 5

NUMBER OF DIRECTIONS FOR POINT AT J END= 5
GLOBAL DIRECTIONS FOR POINT AT J END= 1 2 3 4 5

SPRING CONSTANT IN X DIRECTION= 0.
SPRING CONSTANT IN Y DIRECTION= 5.000E 05
SPRING CONSTANT IN Z DIRECTION= 5.000E 05
SPRING CONSTANT IN THETA-Y DIRECTION= 0.
SPRING CONSTANT IN THETA-Z DIRECTION= 0.

Q-FACTOR= 15.0 FREQUENCY= 60.4 HERTZ

DAMPING CONSTANTS (CALCULATED BASED ON ABOVE Q-FACTOR AND FREQUENCY)-

DAMPING CONSTANT IN X DIRECTION= 0.
DAMPING CONSTANT IN Y DIRECTION= 8.783E 01
DAMPING CONSTANT IN Z DIRECTION= 8.783E 01
DAMPING CONSTANT IN THETA-Y DIRECTION= 0.
DAMPING CONSTANT IN THETA-Z DIRECTION= 0.

PHYSICAL CONNECTING ELEMENT NUMBER 2

ELEMENT TYPE= 5

NUMBER OF END POINTS= 2

POINT NUMBER AT I END= 3
POINT NUMBER AT J END= 40

NUMBER OF DIRECTIONS FOR POINT AT I END= 5
GLOBAL DIRECTIONS FOR POINT AT I END= 1 2 3 4 5

NUMBER OF DIRECTIONS FOR POINT AT J END= 5
GLOBAL DIRECTIONS FOR POINT AT J END= 1 2 3 4 5

SPRING CONSTANT IN X DIRECTION= 0.
SPRING CONSTANT IN Y DIRECTION= 5.000E 05
SPRING CONSTANT IN Z DIRECTION= 5.000E 05
SPRING CONSTANT IN THETA-Y DIRECTION= 0.
SPRING CONSTANT IN THETA-Z DIRECTION= 0.

Q-FACTOR= 15.0 FREQUENCY= 60.4 HERTZ

DAMPING CONSTANTS (CALCULATED BASED ON ABOVE Q-FACTOR AND FREQUENCY)-

DAMPING CONSTANT IN X DIRECTION= 0.
DAMPING CONSTANT IN Y DIRECTION= 8.783E 01
DAMPING CONSTANT IN Z DIRECTION= 8.783E 01
DAMPING CONSTANT IN THETA-Y DIRECTION= 0.
DAMPING CONSTANT IN THETA-Z DIRECTION= 0.

PHYSICAL CONNECTING ELEMENT NUMBER 3

ELEMENT TYPE= 5

NUMBER OF END POINTS= 2

POINT NUMBER AT I END= 5
POINT NUMBER AT J END= 2

NUMBER OF DIRECTIONS FOR POINT AT I END= 5
GLOBAL DIRECTIONS FOR POINT AT I END= 1 2 3 4 5

NUMBER OF DIRECTIONS FOR POINT AT J END= 5
GLOBAL DIRECTIONS FOR POINT AT J END= 1 2 3 4 5

SPRING CONSTANT IN X DIRECTION= 0.
SPRING CONSTANT IN Y DIRECTION= 1.000E 06
SPRING CONSTANT IN Z DIRECTION= 1.000E 06
SPRING CONSTANT IN THETA-Y DIRECTION= 0.
SPRING CONSTANT IN THETA-Z DIRECTION= 0.

Q-FACTOR= 15.0 FREQUENCY= 60.4 HERTZ

DAMPING CONSTANTS (CALCULATED BASED ON ABOVE Q-FACTOR AND FREQUENCY)-

DAMPING CONSTANT IN X DIRECTION= 0.
DAMPING CONSTANT IN Y DIRECTION= 1.757E 02
DAMPING CONSTANT IN Z DIRECTION= 1.757E 02
DAMPING CONSTANT IN THETA-Y DIRECTION= 0.
DAMPING CONSTANT IN THETA-Z DIRECTION= 0.

PHYSICAL CONNECTING ELEMENT NUMBER 4

ELEMENT TYPE= 5

NUMBER OF END POINTS= 2

POINT NUMBER AT I END= 6
POINT NUMBER AT J END= 3

NUMBER OF DIRECTIONS FOR POINT AT I END= 5
GLOBAL DIRECTIONS FOR POINT AT I END= 1 2 3 4 5

NUMBER OF DIRECTIONS FOR POINT AT J END= 5
GLOBAL DIRECTIONS FOR POINT AT J END= 1 2 3 4 5

SPRING CONSTANT IN X DIRECTION= 0.
SPRING CONSTANT IN Y DIRECTION= 1.000E 06
SPRING CONSTANT IN Z DIRECTION= 1.000E 06
SPRING CONSTANT IN THETA-Y DIRECTION= 0.
SPRING CONSTANT IN THETA-Z DIRECTION= 0.

Q-FACTOR= 15.0 FREQUENCY= 60.4 HERTZ

DAMPING CONSTANTS (CALCULATED BASED ON ABOVE Q-FACTOR AND FREQUENCY)-

DAMPING CONSTANT IN X DIRECTION= 0.
DAMPING CONSTANT IN Y DIRECTION= 1.757E 02
DAMPING CONSTANT IN Z DIRECTION= 1.757E 02
DAMPING CONSTANT IN THETA-Y DIRECTION= 0.
DAMPING CONSTANT IN THETA-Z DIRECTION= 0.

PHYSICAL CONNECTING ELEMENT NUMBER 5

ELEMENT TYPE= 3

NUMBER OF END POINTS= 2

POINT NUMBER AT I END= 4
POINT NUMBER AT J END= 1

NUMBER OF DIRECTIONS FOR POINT AT I END= 2
GLOBAL DIRECTIONS FOR POINT AT I END= 1 3

NUMBER OF DIRECTIONS FOR POINT AT J END= 2
GLOBAL DIRECTIONS FOR POINT AT J END= 1 3

LOCAL RADIAL SPRING RATE= 1.00E 06 LB/IN
RADIAL DEAD BAND= 10.0 MILS
LOCAL DAMPING COEFFICIENT= 0. (LB-SEC)/IN

NUMBER OF TYPE 1 PHYSICAL CONNECTING ELEMENTS= 0

NUMBER OF TYPE 2 PHYSICAL CONNECTING ELEMENTS= 0

NUMBER OF TYPE 3 PHYSICAL CONNECTING ELEMENTS= 1

NUMBER OF TYPE 4 PHYSICAL CONNECTING ELEMENTS= 0

NUMBER OF TYPE 5 PHYSICAL CONNECTING ELEMENTS= 4

TOTAL NUMBER OF PHYSICAL CONNECTING ELEMENTS= 5

THIS RUN IS NOT A RESTART RUN.

TIME STEP= 0.000050 SECONDS
FINAL TIME= 0.512000 SECONDS
PRINT MULTIPLE= 1000
PLOT MULTIPLE= 10

INDEPENDENT ROTOR NUMBER (ONE FOR WHICH SPEED-TIME HISTORY IS INPUT)= 1

BEGINNING TIME FOR FIRST SEGMENT= 0. SECONDS
BEGINNING SPEED FOR FIRST SEGMENT= 3000. RPM

SEGMENT	ENDING TIME SECONDS	ACCEL RATE RPM/SEC
1	0.600000	0.

TOTAL NUMBER OF SPEED SEGMENTS FOR INDEPENDENT ROTOR SPEED-TIME HISTORY= 1

SUMMARY OF UNBALANCE LOAD INPUT-

BIRTH TIME (SEC.)	POINT NUMBER	MAGNITUDE GM-IN	PHASE ANGLE DEGREES
0.	4	5000.	0.

TOTAL NUMBER OF UNBALANCE BIRTH EVENTS= 1

TOTAL NUMBER OF P*COS(WT) AND P*SIN(WT) LOADS= 0

TOTAL NUMBER OF TIME-FORCE HISTORY LOADS= 0

SUMMARY OF THE GYROSCOPIC LOAD INPUT-

POINT NUMBER	POLAR MOMENT OF INERTIA LB-IN**2
4	184205.
36	184205.

TOTAL NUMBER OF GYRO LOAD LOCATIONS= 2

THIS RUN PRODUCES A PLOT FILE (FILE CODE 23).

TIMES, ROTOR SPEEDS, AND ROTOR ANGULAR DISPLACEMENTS
ARE WRITTEN ONTO THE PLOT FILE.

DISPLACEMENTS, VELOCITIES, MODAL FORCES AND COORDINATES ARE WRITTEN
ONTO THE PLOT FILE FOR THE FOLLOWING POINTS AND DIRECTIONS-

POINT NUMBER	GLOBAL DIRECTION NUMBER	DIRECTION
1	1	Z
1	3	Y
4	1	Z
4	3	Y
37	1	Z
37	3	Y
38	1	Z
38	3	Y

TOTAL NUMBER OF POINTS AND DIRECTIONS FOR DISPLACEMENT, VELOCITY
MODAL FORCE, AND COORDINATE PLOT FILE OUTPUT= 8

THE RELATIVE DISPLACEMENT MAGNITUDE, CLEARANCE, AND FORCE MAGNITUDE
IS WRITTEN TO THE PLOT FILE FOR ALL TYPE 3 PHYSICAL CONNECTING
ELEMENTS (RUB ELEMENTS)(IF ANY).

PHYSICAL CONNECTING ELEMENT FORCES ARE WRITTEN ONTO THE PLOT FILE FOR THE
FOLLOWING PHYSICAL CONNECTING ELEMENTS, POINTS, AND DIRECTIONS-

ELEMENT NUMBER	POINT NUMBER	DIRECTION NUMBER	DIRECTION
3	2	1	Z
3	2	3	Y
3	5	1	Z
3	5	3	Y
4	3	1	Z
4	3	3	Y
4	6	1	Z
4	6	3	Y

TOTAL NUMBER OF ELEMENTS, POINTS, AND DIRECTIONS FOR ELEMENT FORCE PLOT
FILE OUTPUT= 8

SUMMARY OF THE CONNECTIONS BETWEEN THE PHYSICAL CONNECTING ELEMENTS
AND THE MODAL SUBSYSTEMS-

ELEMENT 1 IS CONNECTED TO SUBSYSTEM 7 AT POINT 2
ELEMENT 1 IS CONNECTED TO SUBSYSTEM 8 AT POINT 2
ELEMENT 2 IS CONNECTED TO SUBSYSTEM 7 AT POINT 3
ELEMENT 2 IS CONNECTED TO SUBSYSTEM 8 AT POINT 3
ELEMENT 3 IS CONNECTED TO SUBSYSTEM 1 AT POINT 5
ELEMENT 3 IS CONNECTED TO SUBSYSTEM 2 AT POINT 5
ELEMENT 3 IS CONNECTED TO SUBSYSTEM 7 AT POINT 2
ELEMENT 3 IS CONNECTED TO SUBSYSTEM 8 AT POINT 2
ELEMENT 4 IS CONNECTED TO SUBSYSTEM 1 AT POINT 6
ELEMENT 4 IS CONNECTED TO SUBSYSTEM 2 AT POINT 6
ELEMENT 4 IS CONNECTED TO SUBSYSTEM 7 AT POINT 3
ELEMENT 4 IS CONNECTED TO SUBSYSTEM 8 AT POINT 3
ELEMENT 5 IS CONNECTED TO SUBSYSTEM 1 AT POINT 4
ELEMENT 5 IS CONNECTED TO SUBSYSTEM 2 AT POINT 4
ELEMENT 5 IS CONNECTED TO SUBSYSTEM 7 AT POINT 1
ELEMENT 5 IS CONNECTED TO SUBSYSTEM 8 AT POINT 1

SUMMARY OF THE GYRO LOAD LOCATIONS ON THE MODAL SUBSYSTEMS-

POINT 4 OF SUBSYSTEM 1 IS A GYRO LOAD LOCATION
POINT 4 OF SUBSYSTEM 2 IS A GYRO LOAD LOCATION
POINT 36 OF SUBSYSTEM 1 IS A GYRO LOAD LOCATION
POINT 36 OF SUBSYSTEM 2 IS A GYRO LOAD LOCATION

TIME= 0. SECONDS

SPEED SEGMENT NUMBER= 1

ROTOR PROPERTIES FOR INDEPENDENT ROTOR (ROTOR 1)-

SPEED= 3000. RPM
ACCELERATION= 0. RPM/SEC
ANGULAR DISPLACEMENT= 0. REVOLUTIONS

DISPLACEMENTS IN GIVEN DIRECTION

POINT NUMBER	X INCHES	Y INCHES	Z INCHES	THETA-X RADIANS	THETA-Y RADIANS	THETA-Z RADIANS
1	0.	0.	0.	0.	0.	0.
2	0.	0.	0.	0.	0.	0.
3	0.	0.	0.	0.	0.	0.
4	0.	0.	0.	0.	0.	0.
5	0.	0.	0.	0.	0.	0.
6	0.	0.	0.	0.	0.	0.
33	0.	0.	0.	0.	0.	0.
34	0.	0.	0.	0.	0.	0.
35	0.	0.	0.	0.	0.	0.
36	0.	0.	0.	0.	0.	0.
37	0.	0.	0.	0.	0.	0.
38	0.	0.	0.	0.	0.	0.
39	0.	0.	0.	0.	0.	0.
40	0.	0.	0.	0.	0.	0.

VELOCITIES IN GIVEN DIRECTION

POINT NUMBER	X IN/SEC	Y IN/SEC	Z IN/SEC	THETA-X RAD/SEC	THETA-Y RAD/SEC	THETA-Z RAD/SEC
1	0.	0.	0.	0.	0.	0.
2	0.	0.	0.	0.	0.	0.
3	0.	0.	0.	0.	0.	0.
4	0.	0.	0.	0.	0.	0.
5	0.	0.	0.	0.	0.	0.
6	0.	0.	0.	0.	0.	0.
33	0.	0.	0.	0.	0.	0.
34	0.	0.	0.	0.	0.	0.
35	0.	0.	0.	0.	0.	0.
36	0.	0.	0.	0.	0.	0.
37	0.	0.	0.	0.	0.	0.
38	0.	0.	0.	0.	0.	0.
39	0.	0.	0.	0.	0.	0.
40	0.	0.	0.	0.	0.	0.

FORCES CONTRIBUTED BY THE SUBSYSTEM MODE SHAPES

POINT NUMBER	X POUNDS	Y POUNDS	Z POUNDS	THETA-X IN-LB	THETA-Y IN-LB	THETA-Z IN-LB
1	0.	0.	0.	0.	0.	0.
2	0.	0.	0.	0.	0.	0.
3	0.	0.	0.	0.	0.	0.
4	0.	0.	0.	0.	0.	0.
5	0.	0.	0.	0.	0.	0.
6	0.	0.	0.	0.	0.	0.
33	0.	0.	0.	0.	0.	0.
34	0.	0.	0.	0.	0.	0.
35	0.	0.	0.	0.	0.	0.

36	0.	0.	0.	0.	0.	0.
37	0.	0.	0.	0.	0.	0.
38	0.	0.	0.	0.	0.	0.

THE FOLLOWING VALUES ARE FOR THE TYPE 3 PHYSICAL CONNECTING ELEMENTS.
FORCES ARE THOSE THAT THE ELEMENT EXERTS ON THE ROTOR OR CASE-

ELEMENT NUMBER	RELATIVE DISPLACEMENT INCHES	DEAD BAND INCHES	CLEARANCE INCHES	I-END POINT NUMBER	JEND POINT NUMBER	FORCE IN Y DIRECTION I END POUNDS	FORCE IN Y DIRECTION J END POUNDS	FORCE IN Z DIRECTION I END POUNDS	FORCE IN Z DIRECTION J END POUNDS	FORCE MAGNITUDE POUNDS
5	0.	0.0100	0.0100	4	1	0.	0.	0.	0.	0.

THE FORCES THAT THE TYPE 5 PHYSICAL CONNECTING ELEMENTS (UNCOUPLED POINT SPRING-DAMPER ELEMENTS) EXERT ON THE ENGINE COMPONENTS OR GROUND ARE-

ELEMENT NUMBER	END	POINT NUMBER	FORCE IN GIVEN DIRECTION X POUNDS	Y POUNDS	Z POUNDS	THETA-Y IN-LB	THETA-Z IN-LB
1	I	2	0.	0.	0.	0.	0.
1	J	39	0.	0.	0.	0.	0.
2	I	3	0.	0.	0.	0.	0.
2	J	40	0.	0.	0.	0.	0.
3	I	5	0.	0.	0.	0.	0.
3	J	2	0.	0.	0.	0.	0.
4	I	6	0.	0.	0.	0.	0.
4	J	3	0.	0.	0.	0.	0.

THE GYROSCOPIC FORCES ACTING ON THE ROTOR(S) ARE-

POINT NUMBER	ROTOR NUMBER	POLAR MOMENT OF INERTIA LB-IN**2	Y-AXIS MOMENT IN-LB	Z-AXIS MOMENT IN-LB
4	1	184205.	0.	0.
36	1	184205.	0.	0.

SUMMARY OF UNBALANCE FORCES-

BIRTH TIME SECONDS	POINT NUMBER	ROTOR NUMBER	MAGNITUDE GM-IN	PHASE ANGLE DEGREES	FORCE (LB.) Y-DIRECTION	FORCE (LB.) Z-DIRECTION
0.	4	1	5000.	0.	2815.522	0.

GENERALIZED COORDINATE NUMBER	GENERALIZED FORCE DUE TO APPLIED FORCES ONLY
1	0.
2	0.
3	0.
4	0.
5	0.
6	-2815.522
7	2815.522
8	343.916
9	773.705
10	-291.716
11	0.

12	0.
13	0.
14	0.
15	0.
16	0.

GENERALIZED COORDINATE NUMBER	GENERALIZED DISPLACEMENT	GENERALIZED VELOCITY	GENERALIZED FORCE	GENERALIZED WEIGHT POUNDS	GENERALIZED STIFFNESS LB/IN	GENERALIZED DAMPING VALUE (LB-SEC)/IN	GENERALIZED ACCELERATION
1	0.	0.	0.	1.372E 03	0.	0.	0.
2	0.	0.	0.	1.449E 03	0.	0.	0.
3	0.	0.	0.	3.743E 02	1.076E 06	0.	0.
4	0.	0.	0.	2.457E 03	1.980E 07	0.	0.
5	0.	0.	0.	1.766E 02	3.500E 06	0.	0.
6	0.	0.	-2815.522	1.372E 03	0.	0.	-792.8347
7	0.	0.	2815.522	1.449E 03	0.	0.	750.9274
8	0.	0.	343.916	3.743E 02	1.076E 06	0.	355.0783
9	0.	0.	773.705	2.457E 03	1.980E 07	0.	121.6797
10	0.	0.	-291.716	1.766E 02	3.500E 06	0.	-638.2326
11	0.	0.	0.	4.503E 02	0.	0.	0.
12	0.	0.	0.	1.784E 02	0.	0.	0.
13	0.	0.	0.	1.787E 02	4.760E 06	9.891E 01	0.
14	0.	0.	0.	4.503E 02	0.	0.	0.
15	0.	0.	0.	1.784E 02	0.	0.	0.
16	0.	0.	0.	1.787E 02	4.760E 06	9.891E 01	0.

TIME= 0.0500000 SECONDS

SPEED SEGMENT NUMBER= 1

ROTOR PROPERTIES FOR INDEPENDENT ROTOR (ROTOR 1)-

SPEED= 3000. RPM
ACCELERATION= 0. RPM/SEC
ANGULAR DISPLACEMENT= 2.50000218 REVOLUTIONS

DISPLACEMENTS IN GIVEN DIRECTION

POINT NUMBER	X INCHES	Y INCHES	Z INCHES	THETA-X RADIANS	THETA-Y RADIANS	THETA-Z RADIANS
1	0.	-0.03277097	0.00831543	0.	-0.00023358	-0.00041673
2	0.	-0.02860382	0.00596802	0.	-0.00023343	-0.00041673
3	0.	0.00473958	-0.01233554	0.	-0.00022416	-0.00041685
4	0.	-0.04511452	0.01107266	0.	-0.00031388	-0.00065406
5	0.	-0.03852580	0.00805975	0.	-0.00031162	-0.00064084
6	0.	0.00700484	-0.01765176	0.	-0.00035026	-0.00053106
33	0.	0.00890828	-0.01456402	0.	-0.00022401	-0.00041685
34	0.	-0.02587625	0.00203800	0.	-0.00031369	-0.00060806
35	0.	-0.00327497	-0.01072466	0.	-0.00033705	-0.00054421
36	0.	0.01207768	-0.02122501	0.	-0.00035569	-0.00053139
37	0.	-0.01193478	-0.00338748	0.	-0.00022879	-0.00041679
38	0.	-0.01413032	-0.00416926	0.	-0.00032337	-0.00057262
39	0.	0.	0.	0.	0.	0.
40	0.	0.	0.	0.	0.	0.

VELOCITIES IN GIVEN DIRECTION

POINT NUMBER	X IN/SEC	Y IN/SEC	Z IN/SEC	THETA-X RAD/SEC	THETA-Y RAD/SEC	THETA-Z RAD/SEC
1	0.	-2.308042	-11.006491	0.	0.145031	-0.080491
2	0.	-1.497063	-9.556346	0.	0.145033	-0.080416
3	0.	4.742970	2.051525	0.	0.145164	-0.075585
4	0.	-3.167364	-15.144831	0.	0.224953	-0.113788
5	0.	-2.116223	-12.859901	0.	0.221493	-0.110744
6	0.	6.703062	3.063304	0.	0.194508	-0.115872
33	0.	5.491999	3.503347	0.	0.145166	-0.075510
34	0.	-0.061720	-8.453846	0.	0.211730	-0.108675
35	0.	4.318008	-0.579646	0.	0.193814	-0.114362
36	0.	7.907604	4.907780	0.	0.198268	-0.115298
37	0.	1.729063	-3.755285	0.	0.145098	-0.078000
38	0.	2.053834	-4.363334	0.	0.200898	-0.110877
39	0.	0.	0.	0.	0.	0.
40	0.	0.	0.	0.	0.	0.

FORCES CONTRIBUTED BY THE SUBSYSTEM MODE SHAPES

POINT NUMBER	X POUNDS	Y POUNDS	Z POUNDS	THETA-X IN-LB	THETA-Y IN-LB	THETA-Z IN-LB
1	0.	0.	0.	0.	0.	0.
2	0.	-1.935	-148.119	0.	1719.704	-22.461
3	0.	1.935	148.119	0.	1719.704	-22.461
4	0.	0.	0.	0.	0.	0.
5	0.	420.714	458.600	0.	2368.106	29773.079
6	0.	-952.426	-156.844	0.	-12167.978	4159.596
33	0.	0.	0.	0.	0.	0.
34	0.	1473.846	1196.969	0.	-6570.891	36917.246
35	0.	-860.611	-65.747	0.	-14536.795	22445.777

36	O.	O.	O.	O.	O.	O.
37	O.	0.863	66.039	O.	10418.075	-136.073
38	O.	-490.301	151.269	O.	-12872.401	34733.307

THE FOLLOWING VALUES ARE FOR THE TYPE 3 PHYSICAL CONNECTING ELEMENTS.
FORCES ARE THOSE THAT THE ELEMENT EXERTS ON THE ROTOR OR CASE-

ELEMENT NUMBER	RELATIVE DISPLACEMENT INCHES	DEAD BAND INCHES	CLEARANCE INCHES	I-END POINT NUMBER	JEND POINT NUMBER	FORCE IN Y DIRECTION I END POUNDS	FORCE IN Y DIRECTION J END POUNDS	FORCE IN Z DIRECTION I END POUNDS	FORCE IN Z DIRECTION J END POUNDS	FORCE MAGNITUDE POUNDS
5	0.0126	0.0100	-0.0026	4	1	2584.069	-2584.069	-577.213	577.213	2647.751

THE FORCES THAT THE TYPE 5 PHYSICAL CONNECTING ELEMENTS (UNCOUPLED POINT
SPRING-DAMPER ELEMENTS) EXERT ON THE ENGINE COMPONENTS OR GROUND ARE-

ELEMENT NUMBER	END	POINT NUMBER	FORCE IN GIVEN DIRECTION X POUNDS	Y POUNDS	Z POUNDS	THETA-Y IN-LB	THETA-Z IN-LB
1	I	2	O.	14433.403	-2144.638	O.	O.
1	J	39	O.	-14433.403	2144.638	O.	O.
2	I	3	O.	-2786.382	5987.578	O.	O.
2	J	40	O.	2786.382	-5987.578	O.	O.
3	I	5	O.	10030.745	-1511.401	O.	O.
3	J	2	O.	-10030.745	1511.401	O.	O.
4	I	6	O.	-2609.586	5138.481	O.	O.
4	J	3	O.	2609.586	-5138.481	O.	O.

THE GYROSCOPIC FORCES ACTING ON THE ROTOR(S) ARE-

POINT NUMBER	ROTOR NUMBER	POLAR MOMENT OF INERTIA LB-IN**2	Y-AXIS MOMENT IN-LB	Z-AXIS MOMENT IN-LB
4	1	184205.	17041.671	33690.387
36	1	184205.	17267.804	29693.791

SUMMARY OF UNBALANCE FORCES-

BIRTH TIME SECONDS	POINT NUMBER	ROTOR NUMBER	MAGNITUDE GM-IN	PHASE ANGLE DEGREES	FORCE (LB.) Y-DIRECTION	FORCE (LB.) Z-DIRECTION
O.	4	1	5000.	O.	-2815.522	-0.001

GENERALIZED COORDINATE NUMBER	GENERALIZED FORCE DUE TO APPLIED FORCES ONLY
1	0.001
2	-0.001
3	-0.000
4	-0.000
5	0.000
6	2815.522
7	-2815.522
8	-343.916
9	-773.705
10	291.716
11	O.

12	0.
13	0.
14	0.
15	0.
16	0.

GENERALIZED COORDINATE NUMBER	GENERALIZED DISPLACEMENT	GENERALIZED VELOCITY	GENERALIZED FORCE	GENERALIZED WEIGHT POUNDS	GENERALIZED STIFFNESS LB/IN	GENERALIZED DAMPING VALUE (LB-SEC)/IN	GENERALIZED ACCELERATION
1	-0.01617755	10.053262	6583.309	1.372E 03	0.	0.	1853.8220
2	-0.00497969	-5.039456	3049.866	1.449E 03	0.	0.	813.4293
3	-0.00067527	-0.486346	-979.663	3.743E 02	1.076E 06	0.	-261.2904
4	-0.00010449	0.098095	-1961.822	2.457E 03	1.980E 07	0.	16.8276
5	0.00013516	0.189776	411.839	1.766E 02	3.500E 06	0.	-133.9766
6	0.02864669	5.546710	-11148.495	1.372E 03	0.	0.	-3139.3522
7	-0.01626238	2.338521	7189.706	1.449E 03	0.	0.	1917.5658
8	-0.00189543	0.113431	-1765.899	3.743E 02	1.076E 06	0.	282.4671
9	0.00018411	0.033574	3560.983	2.457E 03	1.980E 07	0.	-13.2750
10	0.00023662	-0.171256	809.847	1.766E 02	3.500E 06	0.	-40.0935
11	-0.00327744	-3.753732	793.073	4.503E 02	0.	0.	680.5414
12	-0.01143973	7.254919	608.654	1.784E 02	0.	0.	1318.2907
13	0.00015315	0.002161	709.255	1.787E 02	4.760E 06	9.891E 01	-43.1302
14	-0.01193335	1.671748	1641.794	4.503E 02	0.	0.	1408.8335
15	0.02083962	3.900020	-1079.494	1.784E 02	0.	0.	-2338.0892
16	0.00000200	-0.079770	0.891	1.787E 02	4.760E 06	9.891E 01	-1.6009

TIME= 0.1000000 SECONDS

SPEED SEGMENT NUMBER= 1

ROTOR PROPERTIES FOR INDEPENDENT ROTOR (ROTOR 1)-

SPEED= 3000. RPM
ACCELERATION= 0. RPM/SEC
ANGULAR DISPLACEMENT= 5.00000525 REVOLUTIONS

DISPLACEMENTS IN GIVEN DIRECTION

POINT NUMBER	X INCHES	Y INCHES	Z INCHES	THETA-X RADIANS	THETA-Y RADIANS	THETA-Z RADIANS
1	0.	0.02746222	-0.00475721	0.	0.00000625	0.00040284
2	0.	0.02343173	-0.00470091	0.	0.00000633	0.00040281
3	0.	-0.00872697	-0.00399713	0.	0.00001127	0.00040115
4	0.	0.03889252	-0.00653721	0.	0.00001866	0.00063848
5	0.	0.03248879	-0.00626488	0.	0.00001916	0.00062634
6	0.	-0.01268604	-0.00566416	0.	-0.00001130	0.00054221
33	0.	-0.01273616	-0.00387748	0.	0.00001134	0.00040113
34	0.	0.02015537	-0.00575915	0.	0.00001542	0.00059776
35	0.	-0.00224095	-0.00542387	0.	-0.00000339	0.00054793
36	0.	-0.01790092	-0.00584569	0.	-0.00001369	0.00054586
37	0.	0.00731590	-0.00445754	0.	0.00000880	0.00040198
38	0.	0.00859837	-0.00544643	0.	0.0000677	0.00056875
39	0.	0.	0.	0.	0.	0.
40	0.	0.	0.	0.	0.	0.

VELOCITIES IN GIVEN DIRECTION

POINT NUMBER	X IN/SEC	Y IN/SEC	Z IN/SEC	THETA-X RAD/SEC	THETA-Y RAD/SEC	THETA-Z RAD/SEC
1	0.	2.001101	8.928284	0.	-0.133852	0.003219
2	0.	1.971567	7.588047	0.	-0.133831	0.003251
3	0.	1.627004	-3.063852	0.	-0.132466	0.005363
4	0.	2.672810	12.745767	0.	-0.214916	0.008544
5	0.	2.560899	10.567732	0.	-0.210981	0.008345
6	0.	2.317475	-4.413607	0.	-0.176755	-0.002897
33	0.	1.570397	-4.386590	0.	-0.132445	0.005395
34	0.	2.362936	6.382647	0.	-0.200439	0.006393
35	0.	2.238117	-1.043631	0.	-0.179594	-0.000572
36	0.	2.373811	-6.090387	0.	-0.178139	-0.003352
37	0.	1.845658	2.232126	0.	-0.133149	0.004307
38	0.	2.246493	2.512109	0.	-0.188636	0.002977
39	0.	0.	0.	0.	0.	0.
40	0.	0.	0.	0.	0.	0.

FORCES CONTRIBUTED BY THE SUBSYSTEM MODE SHAPES

POINT NUMBER	X POUNDS	Y POUNDS	Z POUNDS	THETA-X IN-LB	THETA-Y IN-LB	THETA-Z IN-LB
1	0.	0.	0.	0.	0.	0.
2	0.	-26.521	-78.899	0.	916.040	-307.917
3	0.	26.521	78.899	0.	916.040	-307.917
4	0.	0.	0.	0.	0.	0.
5	0.	-283.498	329.155	0.	-649.495	-26832.642
6	0.	902.907	-215.956	0.	-6102.474	3005.351
33	0.	0.	0.	0.	0.	0.
34	0.	-1353.939	1024.324	0.	-6916.980	-31278.178
35	0.	841.298	-150.948	0.	-9855.739	-14505.715

36	0.	0.	0.	0.	0.	0.
37	0.	11.824	35.177	0.	5549.427	-1865.379
38	0.	534.765	27.539	0.	-10438.742	-27269.947

THE FOLLOWING VALUES ARE FOR THE TYPE 3 PHYSICAL CONNECTING ELEMENTS.
FORCES ARE THOSE THAT THE ELEMENT EXERTS ON THE ROTOR OR CASE-

ELEMENT NUMBER	RELATIVE DISPLACEMENT INCHES	DEAD BAND INCHES	CLEARANCE INCHES	I-END POINT NUMBER	JEND POINT NUMBER	FORCE IN Y DIRECTION I END POUNDS	FORCE IN Y DIRECTION J END POUNDS	FORCE IN Z DIRECTION I END POUNDS	FORCE IN Z DIRECTION J END POUNDS	FORCE MAGNITUDE POUNDS
5	0.0116	0.0100	-0.0016	4	1	-1549.398	1549.398	241.282	-241.282	1568.072

THE FORCES THAT THE TYPE 5 PHYSICAL CONNECTING ELEMENTS (UNCOUPLED POINT SPRING-DAMPER ELEMENTS) EXERT ON THE ENGINE COMPONENTS OR GROUND ARE-

ELEMENT NUMBER	END	POINT NUMBER	FORCE IN GIVEN DIRECTION X POUNDS	Y POUNDS	Z POUNDS	THETA-Y IN-LB	THETA-Z IN-LB
1	I	2	0.	-11889.037	1683.969	0.	0.
1	J	39	0.	11889.037	-1683.969	0.	0.
2	I	3	0.	4220.579	2267.676	0.	0.
2	J	40	0.	-4220.579	-2267.676	0.	0.
3	I	5	0.	-9160.585	1040.527	0.	0.
3	J	2	0.	9160.585	-1040.527	0.	0.
4	I	6	0.	3837.776	1904.136	0.	0.
4	J	3	0.	-3837.776	-1904.136	0.	0.

THE GYROSCOPIC FORCES ACTING ON THE ROTOR(S) ARE-

POINT NUMBER	ROTOR NUMBER	POLAR MOMENT OF INERTIA LB-IN**2	Y-AXIS MOMENT IN-LB	Z-AXIS MOMENT IN-LB
4	1	184205.	-1279.643	-32187.216
36	1	184205.	502.057	-26679.177

SUMMARY OF UNBALANCE FORCES-

BIRTH TIME SECONDS	POINT NUMBER	ROTOR NUMBER	MAGNITUDE GM-IN	PHASE ANGLE DEGREES	FORCE (LB.) Y-DIRECTION	FORCE (LB.) Z-DIRECTION
0.	4	1	5000.	0.	2815.522	0.019

GENERALIZED COORDINATE NUMBER	GENERALIZED FORCE DUE TO APPLIED FORCES ONLY
1	-0.019
2	0.019
3	0.002
4	0.005
5	-0.002
6	-2815.522
7	2815.522
8	343.916
9	773.705
10	-291.716
11	0.

12	0.
13	0.
14	0.
15	0.
16	0.

GENERALIZED COORDINATE NUMBER	GENERALIZED DISPLACEMENT	GENERALIZED VELOCITY	GENERALIZED FORCE	GENERALIZED WEIGHT POUNDS	GENERALIZED STIFFNESS . LB/IN	GENERALIZED DAMPING VALUE (LB-SEC)/IN	GENERALIZED ACCELERATION
1	0.00033499	-9.437936	434.035	1.372E 03	0.	0.	122.2217
2	-0.00611250	3.241049	3185.963	1.449E 03	0.	0.	849.7279
3	-0.00053598	0.599544	-653.211	3.743E 02	1.076E 06	0.	-78.9803
4	-0.00003920	-0.072269	-730.449	2.457E 03	1.980E 07	0.	7.1772
5	0.00013009	-0.129396	290.460	1.766E 02	3.500E 06	0.	-360.7131
6	-0.02845566	-0.148541	10309.892	1.372E 03	0.	0.	2903.2063
7	0.01029312	2.493996	-4056.685	1.449E 03	0.	0.	-1081.9581
8	0.00146076	0.198019	1309.367	3.743E 02	1.076E 06	0.	-270.9261
9	-0.00021448	0.003487	-4057.978	2.457E 03	1.980E 07	0.	29.6704
10	-0.00023399	-0.049484	-743.870	1.766E 02	3.500E 06	0.	164.3333
11	-0.00439892	2.248315	765.700	4.503E 02	0.	0.	657.0524
12	0.00043986	-6.657437	17.361	1.784E 02	0.	0.	37.6020
13	0.00008158	0.022532	374.689	1.787E 02	4.760E 06	9.891E 01	-34.2763
14	0.00733561	1.820610	-796.251	4.503E 02	0.	0.	-683.2680
15	-0.02009919	-0.215352	939.607	1.784E 02	0.	0.	2035.1062
16	0.00002742	-0.034861	114.564	1.787E 02	4.760E 06	9.891E 01	-27.0606

TIME= 0.1500000 SECONDS

SPEED SEGMENT NUMBER= 1

ROTOR PROPERTIES FOR INDEPENDENT ROTOR (ROTOR 1)-

SPEED= 3000. RPM
ACCELERATION= 0. RPM/SEC
ANGULAR DISPLACEMENT= 7.50000840 REVOLUTIONS

DISPLACEMENTS IN GIVEN DIRECTION

POINT NUMBER	X INCHES	Y INCHES	Z INCHES	THETA-X RADIANS	THETA-Y RADIANS	THETA-Z RADIANS
1	0.	-0.02118278	0.00458452	0.	-0.00008039	-0.00028362
2	0.	-0.01835148	0.00378096	0.	-0.00008039	-0.00028369
3	0.	0.00450045	-0.00265931	0.	-0.00008062	-0.00028761
4	0.	-0.03134808	0.00657465	0.	-0.00011985	-0.00048880
5	0.	-0.02641861	0.00538789	0.	-0.00011886	-0.00047714
6	0.	0.00670637	-0.00389174	0.	-0.00011798	-0.00038470
33	0.	0.00738213	-0.00346582	0.	-0.00008062	-0.00028767
34	0.	-0.01702855	0.00304497	0.	-0.00011728	-0.00044832
35	0.	-0.00063050	-0.00157120	0.	-0.00011673	-0.00039385
36	0.	0.01033773	-0.00506509	0.	-0.00011894	-0.00038662
37	0.	-0.00701179	0.00056586	0.	-0.00008050	-0.00028565
38	0.	-0.00844051	0.00073249	0.	-0.00011650	-0.00041756
39	0.	0.	0.	0.	0.	0.
40	0.	0.	0.	0.	0.	0.

VELOCITIES IN GIVEN DIRECTION

POINT NUMBER	X IN/SEC	Y IN/SEC	Z IN/SEC	THETA-X RAD/SEC	THETA-Y RAD/SEC	THETA-Z RAD/SEC
1	0.	-1.522249	-6.562371	0.	0.087676	-0.028574
2	0.	-1.236602	-5.687009	0.	0.087693	-0.028576
3	0.	1.052557	1.372801	0.	0.088802	-0.028653
4	0.	-2.140803	-9.686391	0.	0.152856	-0.039846
5	0.	-1.764106	-8.186424	0.	0.147781	-0.039515
6	0.	1.555216	2.049304	0.	0.119804	-0.046193
33	0.	1.339200	2.262391	0.	0.088820	-0.028655
34	0.	-1.008783	-5.353252	0.	0.137825	-0.040005
35	0.	0.637592	-0.292410	0.	0.122937	-0.044113
36	0.	2.030940	3.205218	0.	0.119439	-0.046959
37	0.	-0.093730	-2.181473	0.	0.088248	-0.028614
38	0.	-0.217100	-2.736721	0.	0.129159	-0.041774
39	0.	0.	0.	0.	0.	0.
40	0.	0.	0.	0.	0.	0.

FORCES CONTRIBUTED BY THE SUBSYSTEM MODE SHAPES

POINT NUMBER	X POUNDS	Y POUNDS	Z POUNDS	THETA-X IN-LB	THETA-Y IN-LB	THETA-Z IN-LB
1	0.	0.	0.	0.	0.	0.
2	0.	-62.729	3.664	0.	-42.538	-728.307
3	0.	62.729	-3.664	0.	-42.538	-728.307
4	0.	0.	0.	0.	0.	0.
5	0.	365.296	29.667	0.	1930.647	26251.171
6	0.	-898.295	46.977	0.	-1761.441	575.686
33	0.	0.	0.	0.	0.	0.
34	0.	1476.109	18.515	0.	1274.031	32342.404
35	0.	-819.840	52.683	0.	-778.288	17864.532

36	0.	0.	0.	0.	0.	0.
37	0.	27.968	-1.634	0.	-257.698	-4412.128
38	0.	-482.042	54.395	0.	308.477	29767.813

THE FOLLOWING VALUES ARE FOR THE TYPE 3 PHYSICAL CONNECTING ELEMENTS.
FORCES ARE THOSE THAT THE ELEMENT EXERTS ON THE ROTOR OR CASE-

ELEMENT NUMBER	RELATIVE DISPLACEMENT INCHES	DEAD BAND INCHES	CLEARANCE INCHES	I-END POINT NUMBER	JEND POINT NUMBER	FORCE IN Y DIRECTION I END POUNDS	FORCE IN Y DIRECTION J END POUNDS	FORCE IN Z DIRECTION I END POUNDS	FORCE IN Z DIRECTION J END POUNDS	FORCE MAGNITUDE POUNDS
5	0.0104	0.0100	-0.0004	4	1	351.603	-351.603	-68.836	68.836	358.278

THE FORCES THAT THE TYPE 5 PHYSICAL CONNECTING ELEMENTS (UNCOUPLED POINT SPRING-DAMPER ELEMENTS) EXERT ON THE ENGINE COMPONENTS OR GROUND ARE-

ELEMENT NUMBER	END	POINT NUMBER	FORCE IN GIVEN DIRECTION X POUNDS	Y POUNDS	Z POUNDS	THETA-Y IN-LB	THETA-Z IN-LB
1	I	2	0.	9284.354	-1390.968	0.	0.
1	J	39	0.	-9284.354	1390.968	0.	0.
2	I	3	0.	-2342.675	1209.079	0.	0.
2	J	40	0.	2342.675	-1209.079	0.	0.
3	I	5	0.	8159.802	-1167.863	0.	0.
3	J	2	0.	-8159.802	1167.863	0.	0.
4	I	6	0.	-2294.221	1113.588	0.	0.
4	J	3	0.	2294.221	-1113.588	0.	0.

THE GYROSCOPIC FORCES ACTING ON THE ROTOR(S) ARE-

POINT NUMBER	ROTOR NUMBER	POLAR MOMENT OF INERTIA LB-IN**2	Y-AXIS MOMENT IN-LB	Z-AXIS MOMENT IN-LB
4	1	184205.	5967.537	22892.702
36	1	184205.	7032.891	17887.896

SUMMARY OF UNBALANCE FORCES-

BIRTH TIME SECONDS	POINT NUMBER	ROTOR NUMBER	MAGNITUDE GM-IN	PHASE ANGLE DEGREES	FORCE (LB.) Y-DIRECTION	FORCE (LB.) Z-DIRECTION
0.	4	1	5000.	0.	-2815.522	-0.037

GENERALIZED COORDINATE NUMBER	GENERALIZED FORCE DUE TO APPLIED FORCES ONLY
1	0.037
2	-0.037
3	-0.004
4	-0.010
5	0.004
6	2815.522
7	-2815.522
8	-343.916
9	-773.705
10	291.716
11	0.

12	0.
13	0.
14	0.
15	0.
16	0.

GENERALIZED COORDINATE NUMBER	GENERALIZED DISPLACEMENT	GENERALIZED VELOCITY	GENERALIZED FORCE	GENERALIZED WEIGHT POUNDS	GENERALIZED STIFFNESS LB/IN	GENERALIZED DAMPING VALUE (LB-SEC)/IN	GENERALIZED ACCELERATION
1	-0.00582716	6.463391	2154.041	1.372E 03	0.	0.	606.5656
2	0.00075243	-3.185382	-123.148	1.449E 03	0.	0.	-32.8447
3	0.00001556	-0.470272	42.252	3.743E 02	1.076E 06	0.	26.3343
4	-0.00002654	0.063997	-505.402	2.457E 03	1.980E 07	0.	3.1560
5	-0.00000437	-0.021611	21.704	1.766E 02	3.500E 06	0.	80.9803
6	0.02089362	2.089969	-6714.912	1.372E 03	0.	0.	-1890.8806
7	-0.01028442	-0.072127	3401.662	1.449E 03	0.	0.	907.2569
8	-0.00160249	0.117351	-1610.352	3.743E 02	1.076E 06	0.	117.6279
9	0.00018456	0.014912	3571.934	2.457E 03	1.980E 07	0.	-12.9405
10	0.00024142	-0.027621	910.685	1.766E 02	3.500E 06	0.	143.7962
11	0.00056314	-2.168310	-58.778	4.503E 02	0.	0.	-50.4378
12	-0.00402517	4.412381	186.041	1.784E 02	0.	0.	402.9487
13	-0.00000379	0.018320	-9.226	1.787E 02	4.760E 06	9.891E 01	15.1248
14	-0.00696519	-0.092807	724.495	4.503E 02	0.	0.	621.6937
15	0.01428245	1.430725	-586.801	1.784E 02	0.	0.	-1270.9598
16	0.00006486	0.001283	306.646	1.787E 02	4.760E 06	9.891E 01	-4.7825

TIME= 0.2000000 SECONDS

SPEED SEGMENT NUMBER= 1

ROTOR PROPERTIES FOR INDEPENDENT ROTOR (ROTOR 1)-

SPEED= 3000. RPM
ACCELERATION= 0. RPM/SEC
ANGULAR DISPLACEMENT= 10.00001156 REVOLUTIONS

DISPLACEMENTS IN GIVEN DIRECTION

POINT NUMBER	X INCHES	Y INCHES	Z INCHES	THETA-X RADIANS	THETA-Y RADIANS	THETA-Z RADIANS
1	0.	0.02728557	-0.00532500	0.	0.00009922	0.00038425
2	0.	0.02344330	-0.00433106	0.	0.00009920	0.00038425
3	0.	-0.00730348	0.00354902	0.	0.00009780	0.00038442
4	0.	0.03863449	-0.00727169	0.	0.00013899	0.00061479
5	0.	0.03247054	-0.00591165	0.	0.00013797	0.00060234
6	0.	-0.01070009	0.00512456	0.	0.00014283	0.00051731
33	0.	-0.01114790	0.00452510	0.	0.00009778	0.00038442
34	0.	0.02062662	-0.00320969	0.	0.00013735	0.00057320
35	0.	-0.00076177	0.00228454	0.	0.00014059	0.00052288
36	0.	-0.01566360	0.00656417	0.	0.00014378	0.00052112
37	0.	0.00807360	-0.00036040	0.	0.00009850	0.00038433
38	0.	0.00957046	-0.00049036	0.	0.00013846	0.00054382
39	0.	0.	0.	0.	0.	0.
40	0.	0.	0.	0.	0.	0.

VELOCITIES IN GIVEN DIRECTION

POINT NUMBER	X IN/SEC	Y IN/SEC	Z IN/SEC	THETA-X RAD/SEC	THETA-Y RAD/SEC	THETA-Z RAD/SEC
1	0.	1.739153	8.663948	0.	-0.122617	0.034446
2	0.	1.393604	7.437793	0.	-0.122617	0.034432
3	0.	-1.326227	-2.372012	0.	-0.122628	0.033564
4	0.	2.364448	12.248238	0.	-0.194153	0.050795
5	0.	1.890633	10.304116	0.	-0.190481	0.049246
6	0.	-1.897122	-3.483391	0.	-0.166855	0.048028
33	0.	-1.660636	-3.598308	0.	-0.122628	0.033550
34	0.	0.974188	6.557749	0.	-0.182016	0.047624
35	0.	-0.907108	-0.274314	0.	-0.167940	0.048144
36	0.	-2.391637	-5.091035	0.	-0.168279	0.047518
37	0.	0.014608	2.533133	0.	-0.122623	0.033998
38	0.	0.052904	3.039241	0.	-0.173656	0.047614
39	0.	0.	0.	0.	0.	0.
40	0.	0.	0.	0.	0.	0.

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FORCES CONTRIBUTED BY THE SUBSYSTEM MODE SHAPES

POINT NUMBER	X POUNDS	Y POUNDS	Z POUNDS	THETA-X IN-LB	THETA-Y IN-LB	THETA-Z IN-LB
1	0.	0.	0.	0.	0.	0.
2	0.	2.686	22.258	0.	-258.418	31.190
3	0.	-2.686	-22.258	0.	-258.418	31.190
4	0.	0.	0.	0.	0.	0.
5	0.	-277.741	-99.857	0.	-1612.481	-27456.883
6	0.	916.022	22.478	0.	2114.988	3290.225
33	0.	0.	0.	0.	0.	0.
34	0.	-1346.020	-298.117	0.	344.260	-31770.476
35	0.	855.404	3.285	0.	2395.501	-14491.698

36	0.	0.	0.	0.	0.	0.
37	0.	-1.198	-9.924	0.	-1565.515	188.953
38	0.	548.401	-41.802	0.	1837.753	-27534.555

THE FOLLOWING VALUES ARE FOR THE TYPE 3 PHYSICAL CONNECTING ELEMENTS.
FORCES ARE THOSE THAT THE ELEMENT EXERTS ON THE ROTOR OR CASE-

ELEMENT NUMBER	RELATIVE DISPLACEMENT INCHES	DEAD BAND INCHES	CLEARANCE INCHES	I-END POINT NUMBER	JEND POINT NUMBER	FORCE IN Y DIRECTION I END POUNDS	FORCE IN Y DIRECTION J END POUNDS	FORCE IN Z DIRECTION I END POUNDS	FORCE IN Z DIRECTION J END POUNDS	FORCE MAGNITUDE POUNDS
5	0.0115	0.0100	-0.0015	4	1	-1492.869	1492.869	256.073	-256.073	1514.672

THE FORCES THAT THE TYPE 5 PHYSICAL CONNECTING ELEMENTS (UNCOUPLED POINT SPRING-DAMPER ELEMENTS) EXERT ON THE ENGINE COMPONENTS OR GROUND ARE-

ELEMENT NUMBER	END	POINT NUMBER	FORCE IN GIVEN DIRECTION X POUNDS	Y POUNDS	Z POUNDS	THETA-Y IN-LB	THETA-Z IN-LB
1	I	2	0.	-11844.054	1512.238	0.	0.
1	J	39	0.	11844.054	-1512.238	0.	0.
2	I	3	0.	3768.227	-1566.169	0.	0.
2	J	40	0.	-3768.227	1566.169	0.	0.
3	I	5	0.	-9114.552	1077.071	0.	0.
3	J	2	0.	9114.552	-1077.071	0.	0.
4	I	6	0.	3496.899	-1380.307	0.	0.
4	J	3	0.	-3496.899	1380.307	0.	0.

THE GYROSCOPIC FORCES ACTING ON THE ROTOR(S) ARE-

POINT NUMBER	ROTOR NUMBER	POLAR MOMENT OF INERTIA LB-IN**2	Y-AXIS MOMENT IN-LB	Z-AXIS MOMENT IN-LB
4	1	184205.	-7607.362	-29077.600
36	1	184205.	-7116.568	-25202.552

SUMMARY OF UNBALANCE FORCES-

BIRTH TIME SECONDS	POINT NUMBER	ROTOR NUMBER	MAGNITUDE GM-IN	PHASE ANGLE DEGREES	FORCE (LB.) Y-DIRECTION	FORCE (LB.) Z-DIRECTION
0.	4	1	5000.	0.	2815.522	0.055

GENERALIZED COORDINATE NUMBER	GENERALIZED FORCE DUE TO APPLIED FORCES ONLY
1	-0.055
2	0.055
3	0.007
4	0.015
5	-0.006
6	-2815.522
7	2815.522
8	343.916
9	773.705
10	-291.716
11	0.

12	0.
13	0.
14	0.
15	0.
16	0.

GENERALIZED COORDINATE NUMBER	GENERALIZED DISPLACEMENT	GENERALIZED VELOCITY	GENERALIZED FORCE	GENERALIZED WEIGHT POUNDS	GENERALIZED STIFFNESS LB/IN	GENERALIZED DAMPING VALUE (LB-SEC)/IN	GENERALIZED ACCELERATION
1	0.00692529	-8.688663	-2516.508	1.372E 03	0.	0.	-708.6342
2	-0.00036806	3.521061	-47.109	1.449E 03	0.	0.	-12.5644
3	0.00008765	0.410984	124.969	3.743E 02	1.076E 06	0.	31.6487
4	0.00002679	-0.069238	516.864	2.457E 03	1.980E 07	0.	-2.1454
5	-0.00003465	-0.070835	-46.509	1.766E 02	3.500E 06	0.	163.5546
6	-0.02720978	-2.381923	9852.111	1.372E 03	0.	0.	2774.2979
7	0.01128086	-0.007515	-4295.000	1.449E 03	0.	0.	-1145.5191
8	0.00147599	0.009714	1447.442	3.743E 02	1.076E 06	0.	-145.2921
9	-0.00022101	-0.014120	-4215.955	2.457E 03	1.980E 07	0.	25.1742
10	-0.00023441	0.070133	-747.694	1.766E 02	3.500E 06	0.	159.1817
11	-0.00037694	2.533002	-6.768	4.503E 02	0.	0.	-5.8078
12	0.00492505	-6.131128	-240.751	1.784E 02	0.	0.	-521.4445
13	-0.00002301	-0.000182	-103.573	1.787E 02	4.760E 06	9.891E 01	12.9511
14	0.00807161	0.024914	-965.306	4.503E 02	0.	0.	-828.3349
15	-0.01921673	-1.699894	907.795	1.784E 02	0.	0.	1966.2032
16	-0.00000278	0.014344	-10.796	1.787E 02	4.760E 06	9.891E 01	2.1765

TIME= 0.2500000 SECONDS

SPEED SEGMENT NUMBER= 1

ROTOR PROPERTIES FOR INDEPENDENT ROTOR (ROTOR 1)-

SPEED= 3000. RPM
ACCELERATION= 0. RPM/SEC
ANGULAR DISPLACEMENT= 12.50001454 REVOLUTIONS

DISPLACEMENTS IN GIVEN DIRECTION

POINT NUMBER	X INCHES	Y INCHES	Z INCHES	THETA-X RADIANS	THETA-Y RADIANS	THETA-Z RADIANS
1	0.	-0.02557192	0.00464358	0.	-0.00006024	-0.00035631
2	0.	-0.02201033	0.00404220	0.	-0.00006025	-0.00035633
3	0.	0.00654277	-0.00081002	0.	-0.00006105	-0.00035750
4	0.	-0.03661259	0.00644784	0.	-0.00009014	-0.00058006
5	0.	-0.03078181	0.00553558	0.	-0.00008945	-0.00056801
6	0.	0.00961086	-0.00121169	0.	-0.00008085	-0.00048042
33	0.	0.01011946	-0.00142170	0.	-0.00006107	-0.00035752
34	0.	-0.01959914	0.00374459	0.	-0.00008727	-0.00053897
35	0.	0.00040890	0.00037883	0.	-0.00008208	-0.00048692
36	0.	0.01419841	-0.00199962	0.	-0.00008081	-0.00048392
37	0.	-0.00775964	0.00163375	0.	-0.00006065	-0.00035691
38	0.	-0.00921793	0.00202322	0.	-0.00008451	-0.00050891
39	0.	0.	0.	0.	0.	0.
40	0.	0.	0.	0.	0.	0.

VELOCITIES IN GIVEN DIRECTION

POINT NUMBER	X IN/SEC	Y IN/SEC	Z IN/SEC	THETA-X RAD/SEC	THETA-Y RAD/SEC	THETA-Z RAD/SEC
1	0.	-1.569837	-8.009648	0.	0.111385	-0.019882
2	0.	-1.371367	-6.896129	0.	0.111389	-0.019886
3	0.	0.230613	2.025686	0.	0.111656	-0.020163
4	0.	-2.160661	-11.500158	0.	0.182766	-0.028637
5	0.	-1.853177	-9.654720	0.	0.178982	-0.029028
6	0.	0.344183	2.970336	0.	0.148627	-0.026855
33	0.	0.432637	3.142621	0.	0.111660	-0.020168
34	0.	-1.241126	-6.120173	0.	0.169400	-0.028751
35	0.	-0.147072	0.133914	0.	0.151217	-0.026578
36	0.	0.593904	4.380524	0.	0.149671	-0.027627
37	0.	-0.576464	-2.441073	0.	0.111523	-0.020025
38	0.	-0.667301	-2.859568	0.	0.159056	-0.027565
39	0.	0.	0.	0.	0.	0.
40	0.	0.	0.	0.	0.	0.

FORCES CONTRIBUTED BY THE SUBSYSTEM MODE SHAPES

POINT NUMBER	X POUNDS	Y POUNDS	Z POUNDS	THETA-X IN-LB	THETA-Y IN-LB	THETA-Z IN-LB
1	0.	0.	0.	0.	0.	0.
2	0.	-18.802	12.840	0.	-149.073	-218.292
3	0.	18.802	-12.840	0.	-149.073	-218.292
4	0.	0.	0.	0.	0.	0.
5	0.	326.207	-54.787	0.	1720.214	26878.249
6	0.	-936.554	80.294	0.	491.465	-2523.240
33	0.	0.	0.	0.	0.	0.
34	0.	1507.079	-200.567	0.	2704.374	32127.619
35	0.	-866.668	69.137	0.	1999.420	15585.857

36	0.	0.	0.	0.	0.	0.
37	0.	8.383	-5.725	0.	-903.096	-1322.425
38	0.	-535.659	29.970	0.	2855.103	28523.552

THE FOLLOWING VALUES ARE FOR THE TYPE 3 PHYSICAL CONNECTING ELEMENTS.
FORCES ARE THOSE THAT THE ELEMENT EXERTS ON THE ROTOR OR CASE-

ELEMENT NUMBER	RELATIVE DISPLACEMENT INCHES	DEAD BAND INCHES	CLEARANCE INCHES	I-END POINT NUMBER	JEND POINT NUMBER	FORCE IN Y DIRECTION I END POUNDS	FORCE IN Y DIRECTION J END POUNDS	FORCE IN Z DIRECTION I END POUNDS	FORCE IN Z DIRECTION J END POUNDS	FORCE MAGNITUDE POUNDS
5	0.0112	0.0100	-0.0012	4	1	1171.579	-1171.579	-191.459	191.459	1187.120

THE FORCES THAT THE TYPE 5 PHYSICAL CONNECTING ELEMENTS (UNCOUPLED POINT
SPRING-DAMPER ELEMENTS) EXERT ON THE ENGINE COMPONENTS OR GROUND ARE-

ELEMENT NUMBER	END	POINT NUMBER	FORCE IN GIVEN DIRECTION X POUNDS	Y POUNDS	Z POUNDS	THETA-Y IN-LB	THETA-Z IN-LB
1	I	2	0.	11125.619	-1415.388	0.	0.
1	J	39	0.	-11125.619	1415.388	0.	0.
2	I	3	0.	-3291.642	227.085	0.	0.
2	J	40	0.	3291.642	-227.085	0.	0.
3	I	5	0.	8856.120	-1008.778	0.	0.
3	J	2	0.	-8856.120	1008.778	0.	0.
4	I	6	0.	-3088.039	235.727	0.	0.
4	J	3	0.	3088.039	-235.727	0.	0.

THE GYROSCOPIC FORCES ACTING ON THE ROTOR(S) ARE-

POINT NUMBER	ROTOR NUMBER	POLAR MOMENT OF INERTIA LB-IN**2	Y-AXIS MOMENT IN-LB	Z-AXIS MOMENT IN-LB
4	1	184205.	4288.872	27372.119
36	1	184205.	4137.657	22415.643

SUMMARY OF UNBALANCE FORCES-

BIRTH TIME SECONDS	POINT NUMBER	ROTOR NUMBER	MAGNITUDE GM-IN	PHASE ANGLE DEGREES	FORCE (LB.) Y-DIRECTION	FORCE (LB.) Z-DIRECTION
0.	4	1	5000.	0.	-2815.522	-0.071

GENERALIZED COORDINATE NUMBER	GENERALIZED FORCE DUE TO APPLIED FORCES ONLY
1	0.071
2	-0.071
3	-0.009
4	-0.020
5	0.007
6	2815.522
7	-2815.522
8	-343.916
9	-773.705
10	291.716
11	0.

12	0.
13	0.
14	0.
15	0.
16	0.

GENERALIZED COORDINATE NUMBER	GENERALIZED DISPLACEMENT	GENERALIZED VELOCITY	GENERALIZED FORCE	GENERALIZED WEIGHT POUNDS	GENERALIZED STIFFNESS LB/IN	GENERALIZED DAMPING VALUE (LB-SEC)/IN	GENERALIZED ACCELERATION
1	-0.00422616	7.958366	1355.665	1.372E 03	0.	0.	381.7474
2	0.00220272	-3.485190	-964.582	1.449E 03	0.	0.	-257.2635
3	0.00015017	-0.528935	166.804	3.743E 02	1.076E 06	0.	5.3916
4	-0.00000883	0.065590	-174.493	2.457E 03	1.980E 07	0.	0.0608
5	-0.00002934	0.096687	-57.098	1.766E 02	3.500E 06	0.	99.7477
6	0.02546358	1.378709	-8907.140	1.372E 03	0.	0.	-2508.1994
7	-0.01099476	-0.771710	4124.138	1.449E 03	0.	0.	1099.9483
8	-0.00152237	-0.045883	-1487.218	3.743E 02	1.076E 06	0.	155.7435
9	0.00021134	0.005192	4059.547	2.457E 03	1.980E 07	0.	-19.6533
10	0.00025447	0.058526	815.480	1.766E 02	3.500E 06	0.	-164.4296
11	0.00162421	-2.437912	-223.793	4.503E 02	0.	0.	-192.0381
12	-0.00303264	5.576134	126.915	1.784E 02	0.	0.	274.8864
13	-0.00001328	0.004399	-62.551	1.787E 02	4.760E 06	9.891E 01	0.4475
14	-0.00774567	-0.573176	894.318	4.503E 02	0.	0.	767.4202
15	0.01784569	1.001237	-806.902	1.784E 02	0.	0.	-1747.6792
16	0.00001944	0.004576	92.130	1.787E 02	4.760E 06	9.891E 01	-1.8524

TIME= 0.3000000 SECONDS

SPEED SEGMENT NUMBER= 1

ROTOR PROPERTIES FOR INDEPENDENT ROTOR (ROTOR 1)-

SPEED= 3000. RPM
ACCELERATION= 0. RPM/SEC
ANGULAR DISPLACEMENT= 15.00001776 REVOLUTIONS

DISPLACEMENTS IN GIVEN DIRECTION

POINT NUMBER	X INCHES	Y INCHES	Z INCHES	THETA-X RADIANS	THETA-Y RADIANS	THETA-Z RADIANS
1	0.	0.02486154	-0.00534319	0.	0.00008801	0.00034511
2	0.	0.02141232	-0.00446294	0.	0.00008801	0.00034513
3	0.	-0.00625826	0.00257237	0.	0.00008788	0.00034663
4	0.	0.03573390	-0.00744054	0.	0.00012886	0.00056692
5	0.	0.03004666	-0.00616757	0.	0.00012758	0.00055433
6	0.	-0.00920327	0.00374897	0.	0.00012573	0.00046534
33	0.	-0.00972668	0.00345095	0.	0.00008787	0.00034665
34	0.	0.01916054	-0.00365991	0.	0.00012556	0.00052474
35	0.	-0.00027704	0.00127204	0.	0.00012460	0.00047251
36	0.	-0.01364711	0.00499987	0.	0.00012662	0.00046823
37	0.	0.00760992	-0.00094243	0.	0.00008794	0.00034588
38	0.	0.00907131	-0.00118867	0.	0.00012452	0.00049461
39	0.	0.	0.	0.	0.	0.
40	0.	0.	0.	0.	0.	0.

VELOCITIES IN GIVEN DIRECTION

POINT NUMBER	X IN/SEC	Y IN/SEC	Z IN/SEC	THETA-X RAD/SEC	THETA-Y RAD/SEC	THETA-Z RAD/SEC
1	0.	1.714370	7.764889	0.	-0.107436	0.028594
2	0.	1.428434	6.691115	0.	-0.107443	0.028594
3	0.	-0.859353	-1.922986	0.	-0.107909	0.028600
4	0.	2.375689	11.143891	0.	-0.176688	0.040666
5	0.	1.968059	9.387116	0.	-0.172278	0.040644
6	0.	-1.263389	-2.823882	0.	-0.144715	0.042179
33	0.	-1.145363	-3.002737	0.	-0.107917	0.028600
34	0.	1.156224	6.030862	0.	-0.162815	0.040563
35	0.	-0.449564	-0.017487	0.	-0.147340	0.041072
36	0.	-1.680513	-4.217023	0.	-0.145026	0.042978
37	0.	0.284667	2.394302	0.	-0.107676	0.028597
38	0.	0.351976	2.905867	0.	-0.153853	0.040604
39	0.	0.	0.	0.	0.	0.
40	0.	0.	0.	0.	0.	0.

FORCES CONTRIBUTED BY THE SUBSYSTEM MODE SHAPES

POINT NUMBER	X POUNDS	Y POUNDS	Z POUNDS	THETA-X IN-LB	THETA-Y IN-LB	THETA-Z IN-LB
1	0.	0.	0.	0.	0.	0.
2	0.	23.911	2.073	0.	-24.071	277.610
3	0.	-23.911	-2.073	0.	-24.071	277.610
4	0.	0.	0.	0.	0.	0.
5	0.	-289.025	-39.589	0.	-2477.952	-27794.224
6	0.	896.396	-45.704	0.	1630.753	1463.907
33	0.	0.	0.	0.	0.	0.
34	0.	-1275.207	-71.258	0.	-1628.371	-22368.677
35	0.	832.686	-53.020	0.	654.873	-15913.777

36	0.	0.	0.	0.	0.	0.
37	0.	-10.661	-0.924	0.	-145.825	1681.780
38	0.	525.952	-59.175	0.	-501.461	-28505.856

THE FOLLOWING VALUES ARE FOR THE TYPE 3 PHYSICAL CONNECTING ELEMENTS.
FORCES ARE THOSE THAT THE ELEMENT EXERTS ON THE ROTOR OR CASE-

ELEMENT NUMBER	RELATIVE DISPLACEMENT INCHES	DEAD BAND INCHES	CLEARANCE INCHES	I-END POINT NUMBER	JEND. POINT NUMBER	FORCE IN Y DIRECTION I END POUNDS	FORCE IN Y DIRECTION J END POUNDS	FORCE IN Z DIRECTION I END POUNDS	FORCE IN Z DIRECTION J END POUNDS	FORCE MAGNITUDE POUNDS
5	0.0111	0.0100	-0.0011	4	1	-1053.380	1053.380	203.204	-203.204	1072.801

THE FORCES THAT THE TYPE 5 PHYSICAL CONNECTING ELEMENTS (UNCOUPLED POINT SPRING-DAMPER ELEMENTS) EXERT ON THE ENGINE COMPONENTS OR GROUND ARE-

			FORCE IN GIVEN DIRECTION				
ELEMENT NUMBER	END	POINT NUMBER	X POUNDS	Y POUNDS	Z POUNDS	THETA-Y IN-LB	THETA-Z IN-LB
1	I	2	0.	-10831.625	1643.765	0.	0.
1	J	39	0.	10831.625	-1643.765	0.	0.
2	I	3	0.	3204.609	-1117.283	0.	0.
2	J	40	0.	-3204.609	1117.283	0.	0.
3	I	5	0.	-8729.129	1231.021	0.	0.
3	J	2	0.	8729.129	-1231.021	0.	0.
4	I	6	0.	3015.988	-1018.337	0.	0.
4	J	3	0.	-3015.988	1018.337	0.	0.

THE GYROSCOPIC FORCES ACTING ON THE ROTOR(S) ARE-

POINT NUMBER	ROTOR NUMBER	POLAR MOMENT OF INERTIA LB-IN**2	Y-AXIS MOMENT IN-LB	Z-AXIS MOMENT IN-LB
4	1	184205.	-6090.348	-26461.887
36	1	184205.	-6436.726	-21719.919

SUMMARY OF UNBALANCE FORCES-

BIRTH TIME SECONDS	POINT NUMBER	ROTOR NUMBER	MAGNITUDE GM-IN	PHASE ANGLE DEGREES	FORCE (LB.) Y-DIRECTION	FORCE (LB.) Z-DIRECTION
0.	4	1	5000.	0.	2815.522	0.089

GENERALIZED COORDINATE NUMBER	GENERALIZED FORCE DUE TO APPLIED FORCES ONLY
1	-0.089
2	0.089
3	0.011
4	0.025
5	-0.009
6	-2815.522
7	2815.522
8	343.916
9	773.705
10	-291.716
11	0.

12	0.
13	0.
14	0.
15	0.
16	0.

GENERALIZED COORDINATE NUMBER	GENERALIZED DISPLACEMENT	GENERALIZED VELOCITY	GENERALIZED FORCE	GENERALIZED WEIGHT POUNDS	GENERALIZED STIFFNESS LB/IN	GENERALIZED DAMPING VALUE (LB-SEC)/IN	GENERALIZED ACCELERATION
1	0.00622832	-7.698082	-2253.322	1.372E 03	0.	0.	-634.5224
2	-0.00121685	3.403180	415.977	1.449E 03	0.	0.	110.9452
3	-0.00003087	0.470751	-40.950	3.743E 02	1.076E 06	0.	-7.9858
4	0.00002953	-0.064140	566.725	2.457E 03	1.980E 07	0.	-2.8370
5	-0.00000269	-0.026562	-7.096	1.766E 02	3.500E 06	0.	5.0933
6	-0.02474829	-2.031166	8597.588	1.372E 03	0.	0.	2421.0314
7	0.01083237	0.348386	-3951.000	1.449E 03	0.	0.	-1053.7708
8	0.00154083	-0.022973	1495.205	3.743E 02	1.076E 06	0.	-168.0105
9	-0.00021031	-0.011151	-4035.337	2.457E 03	1.980E 07	0.	20.2520
10	-0.00022022	-0.019383	-818.477	1.766E 02	3.500E 06	0.	-104.3555
11	-0.00094397	2.388772	110.595	4.503E 02	0.	0.	94.9023
12	0.00439707	-5.383813	-206.147	1.784E 02	0.	0.	-446.4968
13	-0.00000214	-0.007696	-11.253	1.787E 02	4.760E 06	9.891E 01	-0.6230
14	0.00759215	0.284599	-860.495	4.503E 02	0.	0.	-738.3959
15	-0.01729411	-1.429867	779.514	1.784E 02	0.	0.	1688.3584
16	-0.00002472	-0.000095	-117.337	1.787E 02	4.760E 06	9.891E 01	0.7615

TIME= 0.3500000 SECONDS

SPEED SEGMENT NUMBER= 1

ROTOR PROPERTIES FOR INDEPENDENT ROTOR (ROTOR 1)-

SPEED= 3000. RPM
ACCELERATION= 0. RPM/SEC
ANGULAR DISPLACEMENT= 17.50002074 REVOLUTIONS

DISPLACEMENTS IN GIVEN DIRECTION

POINT NUMBER	X INCHES	Y INCHES	Z INCHES	THETA-X RADIANS	THETA-Y RADIANS	THETA-Z RADIANS
1	0.	-0.02588359	0.00504401	0.	-0.00008165	-0.00036335
2	0.	-0.02225120	0.00422724	0.	-0.00008164	-0.00036337
3	0.	0.00685484	-0.00229398	0.	-0.00008139	-0.00036428
4	0.	-0.03696257	0.00696776	0.	-0.00011831	-0.00058882
5	0.	-0.03105714	0.00580273	0.	-0.00011711	-0.00057645
6	0.	0.01005826	-0.00333814	0.	-0.00011598	-0.00049084
33	0.	0.01049896	-0.00310752	0.	-0.00008139	-0.00036430
34	0.	-0.01972735	0.00350565	0.	-0.00011540	-0.00054742
35	0.	0.00063819	-0.00104252	0.	-0.00011502	-0.00049687
36	0.	0.01475840	-0.00449619	0.	-0.00011661	-0.00049434
37	0.	-0.00771828	0.00096108	0.	-0.00008152	-0.00036383
38	0.	-0.00918230	0.00123256	0.	-0.00011473	-0.00051803
39	0.	0.	0.	0.	0.	0.
40	0.	0.	0.	0.	0.	0.

VELOCITIES IN GIVEN DIRECTION

POINT NUMBER	X IN/SEC	Y IN/SEC	Z IN/SEC	THETA-X RAD/SEC	THETA-Y RAD/SEC	THETA-Z RAD/SEC
1	0.	-1.584295	-8.123706	0.	0.113962	-0.025912
2	0.	-1.324966	-6.984489	0.	0.113967	-0.025910
3	0.	0.741222	2.145690	0.	0.114288	-0.025745
4	0.	-2.189696	-11.601606	0.	0.184148	-0.038727
5	0.	-1.817932	-9.748956	0.	0.180531	-0.037852
6	0.	1.075170	3.151010	0.	0.154176	-0.035903
33	0.	0.998440	3.289017	0.	0.114292	-0.025742
34	0.	-1.094759	-6.189541	0.	0.171704	-0.036725
35	0.	0.344830	0.200908	0.	0.155879	-0.036197
36	0.	1.438521	4.624574	0.	0.155476	-0.035604
37	0.	-0.288257	-2.426440	0.	0.114127	-0.025827
38	0.	-0.379043	-2.877580	0.	0.162515	-0.036312
39	0.	0.	0.	0.	0.	0.
40	0.	0.	0.	0.	0.	0.

FORCES CONTRIBUTED BY THE SUBSYSTEM MODE SHAPES

POINT NUMBER	X POUNDS	Y POUNDS	Z POUNDS	THETA-X IN-LB	THETA-Y IN-LB	THETA-Z IN-LB
1	0.	0.	0.	0.	0.	0.
2	0.	-14.614	-4.030	0.	46.793	-169.669
3	0.	14.614	4.030	0.	46.793	-169.669
4	0.	0.	0.	0.	0.	0.
5	0.	281.308	50.279	0.	2257.960	27300.832
6	0.	-904.161	21.904	0.	-1219.185	-2703.071
33	0.	0.	0.	0.	0.	0.
34	0.	1323.651	143.675	0.	1230.356	31703.978
35	0.	-842.655	31.119	0.	-697.810	14838.167

36	0.	0.	0.	0.	0.	0.
37	0.	6.516	1.797	0.	283.476	-1027.868
38	0.	-536.916	46.849	0.	149.768	27642.124

THE FOLLOWING VALUES ARE FOR THE TYPE 3 PHYSICAL CONNECTING ELEMENTS.
FORCES ARE THOSE THAT THE ELEMENT EXERTS ON THE ROTOR OR CASE-

ELEMENT NUMBER	RELATIVE DISPLACEMENT INCHES	DEAD BAND INCHES	CLEARANCE INCHES	I-END POINT NUMBER	JEND POINT NUMBER	FORCE IN Y DIRECTION I END POUNDS	FORCE IN Y DIRECTION J END POUNDS	FORCE IN Z DIRECTION I END POUNDS	FORCE IN Z DIRECTION J END POUNDS	FORCE MAGNITUDE POUNDS
5	0.0112	0.0100	-0.0012	4	1	1226.405	-1226.405	-212.953	212.953	1244.756

THE FORCES THAT THE TYPE 5 PHYSICAL CONNECTING ELEMENTS (UNCOUPLED POINT SPRING-DAMPER ELEMENTS) EXERT ON THE ENGINE COMPONENTS OR GROUND ARE-

			FORCE IN GIVEN DIRECTION				
ELEMENT NUMBER	END	POINT NUMBER	X POUNDS	Y POUNDS	Z POUNDS	THETA-Y IN-LB	THETA-Z IN-LB
1	I	2	0.	11241.978	-1500.143	0.	0.
1	J	39	0.	-11241.978	1500.143	0.	0.
2	I	3	0.	-3492.524	958.528	0.	0.
2	J	40	0.	3492.524	-958.528	0.	0.
3	I	5	0.	8892.535	-1089.867	0.	0.
3	J	2	0.	-8892.535	1089.867	0.	0.
4	I	6	0.	-3262.083	867.553	0.	0.
4	J	3	0.	3262.083	-867.553	0.	0.

THE GYROSCOPIC FORCES ACTING ON THE ROTOR(S) ARE-

POINT NUMBER	ROTOR NUMBER	POLAR MOMENT OF INERTIA LB-IN**2	Y-AXIS MOMENT IN-LB	Z-AXIS MOMENT IN-LB
4	1	184205.	5799.931	27579.121
36	1	184205.	5332.254	23285.045

SUMMARY OF UNBALANCE FORCES-

BIRTH TIME SECONDS	POINT NUMBER	ROTOR NUMBER	MAGNITUDE GM-IN	PHASE ANGLE DEGREES	FORCE (LB.) Y-DIRECTION	FORCE (LB.) Z-DIRECTION
0.	4	1	5000.	0.	-2815.522	-0.107

GENERALIZED COORDINATE NUMBER	GENERALIZED FORCE DUE TO APPLIED FORCES ONLY
1	0.107
2	-0.107
3	-0.013
4	-0.029
5	0.011
6	2815.522
7	-2815.522
8	-343.916
9	-773.705
10	291.716
11	0.

12	0.
13	0.
14	0.
15	0.
16	0.

GENERALIZED COORDINATE NUMBER	GENERALIZED DISPLACEMENT	GENERALIZED VELOCITY	GENERALIZED FORCE	GENERALIZED WEIGHT POUNDS	GENERALIZED STIFFNESS LB/IN	GENERALIZED DAMPING VALUE (LB-SEC)/IN	GENERALIZED ACCELERATION
1	-0.00573884	8.131451	2001.640	1.372E 03	0.	0.	563.6503
2	0.00123520	-3.423439	-435.375	1.449E 03	0.	0.	-116.1188
3	0.00001689	-0.459588	13.963	3.743E 02	1.076E 06	0.	-4.3517
4	-0.00002499	0.066817	-478.276	2.457E 03	1.980E 07	0.	2.6110
5	0.00001425	0.086271	-7.925	1.766E 02	3.500E 06	0.	-126.4897
6	0.02591975	1.816256	-9151.860	1.372E 03	0.	0.	-2577.1112
7	-0.01089690	-0.375441	4041.335	1.449E 03	0.	0.	1077.8641
8	-0.00148504	-0.028073	-1468.696	3.743E 02	1.076E 06	0.	133.3965
9	0.00021567	0.007815	4132.696	2.457E 03	1.980E 07	0.	-21.6331
10	0.00022956	-0.031675	784.307	1.766E 02	3.500E 06	0.	-41.9198
11	0.00096408	-2.422637	-106.348	4.503E 02	0.	0.	-91.2577
12	-0.00407576	5.706362	188.048	1.784E 02	0.	0.	407.2944
13	0.00000417	0.005293	17.637	1.787E 02	4.760E 06	9.891E 01	-5.8872
14	-0.00770742	-0.290209	892.597	4.503E 02	0.	0.	765.9433
15	0.01819128	1.291367	-837.503	1.784E 02	0.	0.	-1813.9572
16	0.00001511	-0.002718	69.789	1.787E 02	4.760E 06	9.891E 01	-4.0345

TIME= 0.4000000 SECONDS

SPEED SEGMENT NUMBER= 1

ROTOR PROPERTIES FOR INDEPENDENT ROTOR (ROTOR 1)-

SPEED= 3000. RPM
ACCELERATION= 0. RPM/SEC
ANGULAR DISPLACEMENT= 20.00002408 REVOLUTIONS

DISPLACEMENTS IN GIVEN DIRECTION

POINT NUMBER	X INCHES	Y INCHES	Z INCHES	THETA-X RADIANS	THETA-Y RADIANS	THETA-Z RADIANS
1	0.	0.02541246	-0.00503269	0.	0.00007793	0.00035327
2	0.	0.02188145	-0.00425343	0.	0.00007793	0.00035329
3	0.	-0.00643449	0.00198239	0.	0.00007796	0.00035461
4	0.	0.03640190	-0.00699374	0.	0.00011467	0.00057624
5	0.	0.03061435	-0.00585301	0.	0.00011359	0.00056402
6	0.	-0.00945753	0.00289451	0.	0.00010953	0.00047636
33	0.	-0.00998246	0.00276208	0.	0.00007796	0.00035463
34	0.	0.01952040	-0.00360907	0.	0.00011148	0.00053486
35	0.	-0.00032740	0.00074312	0.	0.00010905	0.00048300
36	0.	-0.01400781	0.00397735	0.	0.00011023	0.00047967
37	0.	0.00775255	-0.00113625	0.	0.00007795	0.00035395
38	0.	0.00922351	-0.00141531	0.	0.00010980	0.00050490
39	0.	0.	0.	0.	0.	0.
40	0.	0.	0.	0.	0.	0.

VELOCITIES IN GIVEN DIRECTION

POINT NUMBER	X IN/SEC	Y IN/SEC	Z IN/SEC	THETA-X RAD/SEC	THETA-Y RAD/SEC	THETA-Z RAD/SEC
1	0.	1.586089	7.962738	0.	-0.110448	0.024349
2	0.	1.342701	6.858897	0.	-0.110456	0.024350
3	0.	-0.608431	-1.998010	0.	-0.110966	0.024428
4	0.	2.202479	11.416348	0.	-0.180144	0.035118
5	0.	1.844659	9.595497	0.	-0.176662	0.035140
6	0.	-0.888825	-2.939413	0.	-0.148619	0.034614
33	0.	-0.852826	-3.108395	0.	-0.110974	0.024430
34	0.	1.134515	6.100765	0.	-0.167682	0.034834
35	0.	-0.225318	-0.108612	0.	-0.150651	0.034093
36	0.	-1.226124	-4.351037	0.	-0.149935	0.035207
37	0.	0.368861	2.441652	0.	-0.110711	0.024389
38	0.	0.443878	2.868068	0.	-0.157921	0.034315
39	0.	0.	0.	0.	0.	0.
40	0.	0.	0.	0.	0.	0.

FORCES CONTRIBUTED BY THE SUBSYSTEM MODE SHAPES

POINT NUMBER	X POUNDS	Y POUNDS	Z POUNDS	THETA-X IN-LB	THETA-Y IN-LB	THETA-Z IN-LB
1	0.	0.	0.	0.	0.	0.
2	0.	21.137	-0.530	0.	6.152	245.411
3	0.	-21.137	0.530	0.	6.152	245.411
4	0.	0.	0.	0.	0.	0.
5	0.	-309.821	-4.998	0.	-2237.058	-27153.837
6	0.	919.629	-64.930	0.	1131.500	2221.680
33	0.	0.	0.	0.	0.	0.
34	0.	-1415.958	46.394	0.	-2049.314	-32103.534
35	0.	852.587	-65.591	0.	-168.965	-15579.815

36	O.	O.	O.	O.	O.	O.
37	O.	-9.424	0.236	O.	37.267	1486.715
38	O.	532.036	-53.642	O.	-1328.414	-28379.419

THE FOLLOWING VALUES ARE FOR THE TYPE 3 PHYSICAL CONNECTING ELEMENTS.
FORCES ARE THOSE THAT THE ELEMENT EXERTS ON THE ROTOR OR CASE-

ELEMENT NUMBER	RELATIVE DISPLACEMENT INCHES	DEAD BAND INCHES	CLEARANCE INCHES	I-END POINT NUMBER	JEND POINT NUMBER	FORCE IN Y DIRECTION I END POUNDS	FORCE IN Y DIRECTION J END POUNDS	FORCE IN Z DIRECTION I END POUNDS	FORCE IN Z DIRECTION J END POUNDS	FORCE MAGNITUDE POUNDS
5	0.0112	0.0100	-0.0012	4	1	-1144.962	1144.962	204.317	-204.317	1163.049

THE FORCES THAT THE TYPE 5 PHYSICAL CONNECTING ELEMENTS (UNCOUPLED POINT
SPRING-DAMPER ELEMENTS) EXERT ON THE ENGINE COMPONENTS OR GROUND ARE-

ELEMENT NUMBER	END	POINT NUMBER	FORCE IN GIVEN DIRECTION X POUNDS	Y POUNDS	Z POUNDS	THETA-Y IN-LB	THETA-Z IN-LB
1	I	2	O.	-11058.660	1524.269	O.	O.
1	J	39	O.	11058.660	-1524.269	O.	O.
2	I	3	O.	3270.683	-815.704	O.	O.
2	J	40	O.	-3270.683	815.704	O.	O.
3	I	5	O.	-8821.072	1118.851	O.	O.
3	J	2	O.	8821.072	-1118.851	O.	O.
4	I	6	O.	3072.299	-746.747	O.	O.
4	J	3	O.	-3072.299	746.747	O.	O.

THE GYROSCOPIC FORCES ACTING ON THE ROTOR(S) ARE-

POINT NUMBER	ROTOR NUMBER	POLAR MOMENT OF INERTIA LB-IN**2	Y-AXIS MOMENT IN-LB	Z-AXIS MOMENT IN-LB
4	1	184205.	-5259.468	-26979.465
36	1	184205.	-5272.765	-22455.169

SUMMARY OF UNBALANCE FORCES-

BIRTH TIME SECONDS	POINT NUMBER	ROTOR NUMBER	MAGNITUDE GM-IN	PHASE ANGLE DEGREES	FORCE (LB.) Y-DIRECTION	FORCE (LB.) Z-DIRECTION
O.	4	1	5000.	O.	2815.522	0.125

GENERALIZED COORDINATE NUMBER	GENERALIZED FORCE DUE TO APPLIED FORCES ONLY
1	-0.125
2	0.125
3	0.015
4	0.034
5	-0.013
6	-2815.522
7	2815.522
8	343.916
9	773.705
10	-291.716
11	O.

12	0.
13	0.
14	0.
15	0.
16	0.

GENERALIZED COORDINATE NUMBER	GENERALIZED DISPLACEMENT	GENERALIZED VELOCITY	GENERALIZED FORCE	GENERALIZED WEIGHT POUNDS	GENERALIZED STIFFNESS LB/IN	GENERALIZED DAMPING VALUE (LB-SEC)/IN	GENERALIZED ACCELERATION
1	0.00549220	-7.901605	-1907.565	1.372E 03	0.	0.	-537.1593
2	-0.00149829	3.462017	576.546	1.449E 03	0.	0.	153.7706
3	-0.00007063	0.490791	-69.564	3.743E 02	1.076E 06	0.	6.6436
4	0.00002421	-0.065184	464.576	2.457E 03	1.980E 07	0.	-2.3351
5	0.00001235	-0.103159	14.256	1.766E 02	3.500E 06	0.	-63.3680
6	-0.02526288	-1.716432	8832.830	1.372E 03	0.	0.	2487.2741
7	0.01098620	0.483799	-4078.214	1.449E 03	0.	0.	-1087.7001
8	0.00152150	0.013084	1500.575	3.743E 02	1.076E 06	0.	-140.9936
9	-0.00021115	-0.007754	-4048.253	2.457E 03	1.980E 07	0.	20.8482
10	-0.00024119	-0.026837	-808.365	1.766E 02	3.500E 06	0.	78.3281
11	-0.00113585	2.435598	132.144	4.503E 02	0.	0.	113.3940
12	0.00389739	-5.535567	-175.183	1.784E 02	0.	0.	-379.4313
13	0.00000055	-0.008426	1.497	1.787E 02	4.760E 06	9.891E 01	-0.6004
14	0.00773685	0.367929	-894.241	4.503E 02	0.	0.	-767.3538
15	-0.01769746	-1.219457	803.816	1.784E 02	0.	0.	1740.9946
16	-0.00002186	-0.001297	-102.418	1.787E 02	4.760E 06	9.891E 01	3.7633

TIME= 0.4500000 SECONDS

SPEED SEGMENT NUMBER= 1

ROTOR PROPERTIES FOR INDEPENDENT ROTOR (ROTOR 1)-

SPEED= 3000. RPM
ACCELERATION= 0. RPM/SEC
ANGULAR DISPLACEMENT= 22.49989796 REVOLUTIONS

DISPLACEMENTS IN GIVEN DIRECTION

POINT NUMBER	X INCHES	Y INCHES	Z INCHES	THETA-X RADIANS	THETA-Y RADIANS	THETA-Z RADIANS
1	0.	-0.02538712	0.00523581	0.	-0.00008409	-0.00035406
2	0.	-0.02184803	0.00439483	0.	-0.00008409	-0.00035408
3	0.	0.00652519	-0.00232857	0.	-0.00008400	-0.00035526
4	0.	-0.03636473	0.00726953	0.	-0.00012296	-0.00057776
5	0.	-0.03056947	0.00605131	0.	-0.00012180	-0.00056524
6	0.	0.00958412	-0.00339448	0.	-0.00011949	-0.00047720
33	0.	0.01007941	-0.00316844	0.	-0.00008400	-0.00035527
34	0.	-0.01946490	0.00365181	0.	-0.00011982	-0.00053583
35	0.	0.00042362	-0.00104597	0.	-0.00011847	-0.00048409
36	0.	0.01414736	-0.00458040	0.	-0.00012041	-0.00048023
37	0.	-0.00768733	0.00103122	0.	-0.00008404	-0.00035467
38	0.	-0.00915290	0.00129327	0.	-0.00011861	-0.00050592
39	0.	0.	0.	0.	0.	0.
40	0.	0.	0.	0.	0.	0.

VELOCITIES IN GIVEN DIRECTION

POINT NUMBER	X IN/SEC	Y IN/SEC	Z IN/SEC	THETA-X RAD/SEC	THETA-Y RAD/SEC	THETA-Z RAD/SEC
1	0.	-1.641356	-7.968073	0.	0.111035	-0.026378
2	0.	-1.377564	-6.858186	0.	0.111041	-0.026378
3	0.	0.732146	2.039868	0.	0.111410	-0.026365
4	0.	-2.280028	-11.405145	0.	0.181249	-0.038402
5	0.	-1.897346	-9.594643	0.	0.177093	-0.038138
6	0.	1.069723	2.994161	0.	0.149686	-0.037594
33	0.	0.995781	3.154495	0.	0.111416	-0.026365
34	0.	-1.141672	-6.128393	0.	0.167766	-0.037623
35	0.	0.334277	0.107195	0.	0.151977	-0.037202
36	0.	1.441705	4.430858	0.	0.150388	-0.037957
37	0.	-0.322439	-2.417278	0.	0.111226	-0.026371
38	0.	-0.399426	-2.902432	0.	0.158611	-0.037250
39	0.	0.	0.	0.	0.	0.
40	0.	0.	0.	0.	0.	0.

ORIGINAL PAGE IS OF POOR QUALITY

FORCES CONTRIBUTED BY THE SUBSYSTEM MODE SHAPES

POINT NUMBER	X POUNDS	Y POUNDS	Z POUNDS	THETA-X IN-LB	THETA-Y IN-LB	THETA-Z IN-LB
1	0.	0.	0.	0.	0.	0.
2	0.	-18.837	-1.386	0.	16.092	-218.707
3	0.	18.837	1.386	0.	16.092	-218.707
4	0.	0.	0.	0.	0.	0.
5	0.	286.090	25.167	0.	2299.156	27642.973
6	0.	-896.338	56.233	0.	-1621.987	-1753.708
33	0.	0.	0.	0.	0.	0.
34	0.	1281.743	9.046	0.	1720.860	32157.419
35	0.	-833.369	60.894	0.	-461.446	15626.812

36	0.	0.	0.	0.	0.	0.
37	0.	8.399	0.618	0.	97.486	-1324.940
38	0.	-527.725	58.884	0.	740.263	28247.012

THE FOLLOWING VALUES ARE FOR THE TYPE 3 PHYSICAL CONNECTING ELEMENTS.
FORCES ARE THOSE THAT THE ELEMENT EXERTS ON THE ROTOR OR CASE-

ELEMENT NUMBER	RELATIVE DISPLACEMENT INCHES	DEAD BAND INCHES	CLEARANCE INCHES	I-END POINT NUMBER	JEND POINT NUMBER	FORCE IN Y DIRECTION I END POUNDS	FORCE IN Y DIRECTION J END POUNDS	FORCE IN Z DIRECTION I END POUNDS	FORCE IN Z DIRECTION J END POUNDS	FORCE MAGNITUDE POUNDS
5	0.0112	0.0100	-0.0012	4	1	1144.928	-1144.928	-212.110	212.110	1164.410

THE FORCES THAT THE TYPE 5 PHYSICAL CONNECTING ELEMENTS (UNCOUPLED POINT SPRING-DAMPER ELEMENTS) EXERT ON THE ENGINE COMPONENTS OR GROUND ARE-

			FORCE IN GIVEN DIRECTION				
ELEMENT NUMBER	END	POINT NUMBER	X POUNDS	Y POUNDS	Z POUNDS	THETA-Y IN-LB	THETA-Z IN-LB
1	I	2	0.	11045.011	-1595.033	0.	0.
1	J	39	0.	-11045.011	1595.033	0.	0.
2	I	3	0.	-3326.904	985.114	0.	0.
2	J	40	0.	3326.904	-985.114	0.	0.
3	I	5	0.	8812.753	-1175.773	0.	0.
3	J	2	0.	-8812.753	1175.773	0.	0.
4	I	6	0.	-3118.223	898.274	0.	0.
4	J	3	0.	3118.223	-898.274	0.	0.

THE GYROSCOPIC FORCES ACTING ON THE ROTOR(S) ARE-

POINT NUMBER	ROTOR NUMBER	POLAR MOMENT OF INERTIA LB-IN**2	Y-AXIS MOMENT IN-LB	Z-AXIS MOMENT IN-LB
4	1	184205.	5751.313	27144.989
36	1	184205.	5684.619	22523.112

SUMMARY OF UNBALANCE FORCES-

BIRTH TIME SECONDS	POINT NUMBER	ROTOR NUMBER	MAGNITUDE GM-IN	PHASE ANGLE DEGREES	FORCE (LB.) Y-DIRECTION	FORCE (LB.) Z-DIRECTION
0.	4	1	5000.	0.	-2815.521	2.142

GENERALIZED COORDINATE NUMBER	GENERALIZED FORCE DUE TO APPLIED FORCES ONLY
1	-2.142
2	2.142
3	0.262
4	0.589
5	-0.222
6	2815.521
7	-2815.521
8	-343.916
9	-773.705
10	291.716
11	0.

12	0.
13	0.
14	0.
15	0.
16	0.

GENERALIZED COORDINATE NUMBER	GENERALIZED DISPLACEMENT	GENERALIZED VELOCITY	GENERALIZED FORCE	GENERALIZED WEIGHT POUNDS	GENERALIZED STIFFNESS LB/IN	GENERALIZED DAMPING VALUE (LB-SEC)/IN	GENERALIZED ACCELERATION
1	-0.00593271	7.936141	2097.925	1.372E 03	0.	0.	590.7635
2	0.00133908	-3.424323	-487.467	1.449E 03	0.	0.	-130.0123
3	0.00003997	-0.471788	42.197	3.743E 02	1.076E 06	0.	-0.8325
4	-0.00002819	0.066009	-541.084	2.457E 03	1.980E 07	0.	2.6712
5	-0.00000584	0.050102	-6.095	1.766E 02	3.500E 06	0.	31.3885
6	0.02531411	1.863206	-8867.550	1.372E 03	0.	0.	-2497.0512
7	-0.01089946	-0.417135	4023.938	1.449E 03	0.	0.	1073.2240
8	-0.00152487	-0.010356	-1483.481	3.743E 02	1.076E 06	0.	162.3856
9	0.00021130	0.008513	4054.201	2.457E 03	1.980E 07	0.	-20.3865
10	0.00022168	0.007352	804.978	1.766E 02	3.500E 06	0.	63.6412
11	0.00103225	-2.412892	-120.310	4.503E 02	0.	0.	-103.2387
12	-0.00420212	5.561284	192.770	1.784E 02	0.	0.	417.5234
13	0.00000143	0.006103	8.769	1.787E 02	4.760E 06	9.891E 01	2.9060
14	-0.00767333	-0.322585	878.649	4.503E 02	0.	0.	753.9741
15	0.01773326	1.318569	-807.823	1.784E 02	0.	0.	-1749.6741
16	0.00001948	-0.000203	92.894	1.787E 02	4.760E 06	9.891E 01	0.4400

TIME= 0.5000000 SECONDS

SPEED SEGMENT NUMBER= 1

ROTOR PROPERTIES FOR INDEPENDENT ROTOR (ROTOR 1)-

SPEED= 3000. RPM
ACCELERATION= 0. RPM/SEC
ANGULAR DISPLACEMENT= 24.99974918 REVOLUTIONS

DISPLACEMENTS IN GIVEN DIRECTION

POINT NUMBER	X INCHES	Y INCHES	Z INCHES	THETA-X RADIANS	THETA-Y RADIANS	THETA-Z RADIANS
1	0.	0.02551177	-0.00512239	0.	0.00008136	0.00035611
2	0.	0.02195211	-0.00430869	0.	0.00008136	0.00035613
3	0.	-0.00658546	0.00219568	0.	0.00008125	0.00035731
4	0.	0.03651526	-0.00710485	0.	0.00011906	0.00057969
5	0.	0.03069712	-0.00592832	0.	0.00011781	0.00056740
6	0.	-0.00967227	0.00320016	0.	0.00011522	0.00048053
33	0.	-0.01016019	0.00300808	0.	0.00008125	0.00035733
34	0.	0.01954141	-0.00361285	0.	0.00011578	0.00053832
35	0.	-0.00045457	0.00092791	0.	0.00011443	0.00048703
36	0.	-0.01426733	0.00434566	0.	0.00011591	0.00048383
37	0.	0.00770913	-0.00105427	0.	0.00008130	0.00035672
38	0.	0.00917577	-0.00133505	0.	0.00011461	0.00050863
39	0.	0.	0.	0.	0.	0.
40	0.	0.	0.	0.	0.	0.

VELOCITIES IN GIVEN DIRECTION

POINT NUMBER	X IN/SEC	Y IN/SEC	Z IN/SEC	THETA-X RAD/SEC	THETA-Y RAD/SEC	THETA-Z RAD/SEC
1	0.	1.599841	8.012369	0.	-0.111856	0.025413
2	0.	1.345630	6.894241	0.	-0.111861	0.025412
3	0.	-0.684586	-2.068456	0.	-0.112206	0.025344
4	0.	2.220163	11.470458	0.	-0.182110	0.037864
5	0.	1.854763	9.641096	0.	-0.178289	0.037109
6	0.	-0.995855	-3.038490	0.	-0.150824	0.035598
33	0.	-0.937930	-3.191003	0.	-0.112211	0.025343
34	0.	1.141820	6.133135	0.	-0.169155	0.036132
35	0.	-0.276457	-0.147535	0.	-0.152884	0.035734
36	0.	-1.355066	-4.479548	0.	-0.151886	0.035424
37	0.	0.329037	2.420463	0.	-0.112034	0.025378
38	0.	0.436063	2.875520	0.	-0.159752	0.035782
39	0.	0.	0.	0.	0.	0.
40	0.	0.	0.	0.	0.	0.

FORCES CONTRIBUTED BY THE SUBSYSTEM MODE SHAPES

POINT NUMBER	X POUNDS	Y POUNDS	Z POUNDS	THETA-X IN-LB	THETA-Y IN-LB	THETA-Z IN-LB
1	0.	0.	0.	0.	0.	0.
2	0.	18.762	1.626	0.	-18.877	217.830
3	0.	-18.762	-1.626	0.	-18.877	217.830
4	0.	0.	0.	0.	0.	0.
5	0.	-295.807	-33.684	0.	-2426.568	-27209.151
6	0.	907.485	-42.419	0.	1239.421	2256.436
33	0.	0.	0.	0.	0.	0.
34	0.	-1357.509	-71.050	0.	-1700.477	-31897.414
35	0.	843.077	-48.460	0.	337.975	-15327.313

36	O.	O.	O.	O.	O.	O.
37	O.	-8.365	-0.725	O.	-114.357	1319.631
38	O.	530.845	-53.035	O.	-705.069	-28050.409

THE FOLLOWING VALUES ARE FOR THE TYPE 3 PHYSICAL CONNECTING ELEMENTS.
FORCES ARE THOSE THAT THE ELEMENT EXERTS ON THE ROTOR OR CASE-

ELEMENT NUMBER	RELATIVE DISPLACEMENT INCHES	DEAD BAND INCHES	CLEARANCE INCHES	I-END POINT NUMBER	JEND POINT NUMBER	FORCE IN Y DIRECTION I END POUNDS	FORCE IN Y DIRECTION J END POUNDS	FORCE IN Z DIRECTION I END POUNDS	FORCE IN Z DIRECTION J END POUNDS	FORCE MAGNITUDE POUNDS
5	0.0112	0.0100	-0.0012	4	1	-1161.945	1161.945	209.344	-209.344	1180.653

THE FORCES THAT THE TYPE 5 PHYSICAL CONNECTING ELEMENTS (UNCOUPLED POINT SPRING-DAMPER ELEMENTS) EXERT ON THE ENGINE COMPONENTS OR GROUND ARE-

ELEMENT NUMBER	END	POINT NUMBER	FORCE IN GIVEN DIRECTION X POUNDS	Y POUNDS	Z POUNDS	THETA-Y IN-LB	THETA-Z IN-LB
1	I	2	O.	-11094.245	1548.797	O.	O.
1	J	39	O.	11094.245	-1548.797	O.	O.
2	I	3	O.	3352.860	-916.161	O.	O.
2	J	40	O.	-3352.860	916.161	O.	O.
3	I	5	O.	-8834.451	1137.095	O.	O.
3	J	2	O.	8834.451	-1137.095	O.	O.
4	I	6	O.	3141.491	-834.069	O.	O.
4	J	3	O.	-3141.491	834.069	O.	O.

THE GYROSCOPIC FORCES ACTING ON THE ROTOR(S) ARE-

POINT NUMBER	ROTOR NUMBER	POLAR MOMENT OF INERTIA LB-IN**2	Y-AXIS MOMENT IN-LB	Z-AXIS MOMENT IN-LB
4	1	184205.	-5670.702	-27273.964
36	1	184205.	-5305.378	-22747.371

SUMMARY OF UNBALANCE FORCES-

BIRTH TIME SECONDS	POINT NUMBER	ROTOR NUMBER	MAGNITUDE GM-IN	PHASE ANGLE DEGREES	FORCE (LB.) Y-DIRECTION	FORCE (LB.) Z-DIRECTION
O.	4	1	5000.	O.	2815.517	-4.809

GENERALIZED COORDINATE NUMBER	GENERALIZED FORCE DUE TO APPLIED FORCES ONLY
1	4.809
2	-4.809
3	-0.587
4	-1.321
5	0.498
6	-2815.517
7	2815.517
8	343.915
9	773.704
10	-291.716
11	O.

12	0.
13	0.
14	0.
15	0.
16	0.

GENERALIZED COORDINATE NUMBER	GENERALIZED DISPLACEMENT	GENERALIZED VELOCITY	GENERALIZED FORCE	GENERALIZED WEIGHT POUNDS	GENERALIZED STIFFNESS LB/IN	GENERALIZED DAMPING VALUE (LB-SEC)/IN	GENERALIZED ACCELERATION
1	0.00573250	-7.993238	-2000.988	1.372E 03	0.	0.	-563.4668
2	-0.00137468	3.429242	507.561	1.449E 03	0.	0.	135.3714
3	-0.00004335	0.476910	-38.959	3.743E 02	1.076E 06	0.	7.9380
4	0.00002635	-0.066357	504.065	2.457E 03	1.980E 07	0.	-2.7821
5	-0.00000372	-0.076811	14.649	1.766E 02	3.500E 06	0.	60.5520
6	-0.02544950	-1.789783	8927.608	1.372E 03	0.	0.	2513.9631
7	0.01091575	0.432514	-4039.388	1.449E 03	0.	0.	-1077.3447
8	0.00150688	0.021673	1484.309	3.743E 02	1.076E 06	0.	-141.5476
9	-0.00021180	-0.007892	-4058.038	2.457E 03	1.980E 07	0.	21.3253
10	-0.00023309	0.025221	-801.295	1.766E 02	3.500E 06	0.	31.7929
11	-0.00105548	2.416374	120.267	4.503E 02	0.	0.	103.2016
12	0.00406523	-5.601686	-185.691	1.784E 02	0.	0.	-402.1903
13	-0.00000168	-0.005691	-7.721	1.787E 02	4.760E 06	9.891E 01	1.8247
14	0.00769519	0.329839	-886.480	4.503E 02	0.	0.	-760.6942
15	-0.01783598	-1.268885	814.985	1.784E 02	0.	0.	1765.1854
16	-0.00001940	0.001117	-91.077	1.787E 02	4.760E 06	9.891E 01	2.4907

OUTPUT PLOT FILE IS A BINARY SEQUENTIAL FILE

LISTING OF AT LEAST PART OF OUTPUT PLOT FILE-

```
  8    1     8     1025
   1   1          0.              0.             0.
   1   3          0.              0.             0.
   4   1          0.              0.             0.
   4   3          0.              0.             0.
  37   1     -50.000              0.             0.
  37   3     -50.000              0.             0.
  38   1     -50.000              0.             0.
  38   3     -50.000              0.             0.
   5   5     5
  3    2   1
  3    2   3
  3    5   1
  3    5   3
  4    3   1
  4    3   3
  4    6   1
  4    6   3
  0.                 3000.0          0.        0.                 0.
       0.                      0.                      0.
       0.                      0.                      0.
       0.                      0.                      0.
       0.                      0.                      0.
       0.                      0.                      0.
       0.                      0.                      0.
       0.                      0.                      0.
       0.                      0.                      0.
     0.              0.01000           0.
            0.                0.              0.
            0.                0.              0.
            0.                0.              0.
            0.                0.              0.
            0.                0.              0.
            0.                0.              0.
            0.                0.              0.
            0.                0.              0.
  0.0005000          3000.0           0.      0.02500000         0.
       0.00000094          0.007831               0.
       0.00002663          0.167883               0.
       0.00001077          0.064133               0.
       0.00020520          0.804002               0.
      -0.00000000          0.000040               0.118
       0.00000018          0.003689               3.194
      -0.00000132         -0.006846               0.222
      -0.00002222         -0.053297              -7.959
     0.00018         0.00982              0.
           15.004            15.004           15.004
          230.258           230.258          230.258
          -15.004           -15.004          -15.004
         -230.258          -230.258         -230.258
           -1.264            -1.264           -1.264
          -21.225           -21.225          -21.225
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           21.225            21.225           21.225
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       0.00022502          0.657962               0.
       0.00008429          0.247373               0.
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0.00069202	1.197454	0.		
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0.00011922	0.346955	41.671		
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0.00097	0.00903	0.		
175.670	175.670	175.670		
869.411	869.411	869.411		
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0.00604	0.00396	0.		
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0.00564388	-0.304323	264.154		

```
    -0.00086808        -2.410120          -25.258
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     -1075.227        -1075.227       -1075.227
     -4659.599        -4659.599       -4659.599
      1075.227         1075.227        1075.227
      -602.613         -602.613        -602.613
      -421.136         -421.136        -421.136
       602.613          602.613         602.613
       421.136          421.136         421.136
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    -0.00322667        -4.459796            0.
     0.01716310        -1.839483            0.
    -0.00543095        -6.775127            0.
     0.00458282        -0.489883          -36.265
    -0.00188405        -2.098889           -8.360
     0.00545011        -0.438829          253.132
    -0.00212024        -2.570246         -102.125
    0.00609      0.00391          0.
      4407.801         4407.801        4407.801
     -1988.320        -1988.320       -1988.320
     -4407.801        -4407.801       -4407.801
      1988.320         1988.320        1988.320
      -677.563         -677.563        -677.563
      -419.970         -419.970        -419.970
       677.563          677.563         677.563
       419.970          419.970         419.970
OUTPUT PLOT FILE LONGER BUT STOP LISTING HERE
```

7.2 COMPUTED RESULTS

For the plotted results that are presented, the following computing strategy was used for constant speed running.

ΔT = 50 microseconds

Number of time integration points = 10,240

Time frame = 10,240 x 50 x 10^{-6} = 0.512 second.

Figure 55 shows the TETRA computed displacement-time history at the middle of the rotor (point 38) in the vertical direction corresponding to a sudden 100 gm-in. fan unbalance at a constant 12,000 rpm speed. The number of computed values were decimated so that 1,024 points are shown and the time increment between points is equal to 50 x 10^{-5} seconds. The 12,000 rpm speed corresponds to super critical speed operation relative to a rotor dominated mode computed at 9,908 rpm for the total system. Overshoot is clearly in evidence for the transient response shown in Figure 55. The Fast Fourier Transform of this time history response that is shown in Figure 56 indicates that four modes are contributing to the response. The peak at 200 Hz (12,000 rpm) is associated with the driving force. The VAST predicted mode shapes for the total system sketched in Figure 57 show that the modes at 3617 rpm, 9908 rpm, 13,983 rpm, and 26,473 rpm should be responsive at the middle of the rotor for fan unbalance. This indicates that TETRA has correctly synthesized the modal and physical data to predict the time transient response for the total system. Figure 58 shows the displacement-time history at the middle of the rotor in the vertical direction corresponding to a sudden 100 gm-in. fan unbalance at 9908 rpm critical speed operation. In this case, there is no overshoot and the transient response builds up to the steady-state level. This response behavior is characteristic of operation at a critical speed.

The results presented in Figures 55 and 58 do not include gyroscopic stiffening. Figure 59 shows the off-resonant response in two planes at the fan that reflects the effects of gyroscopic stiffening at both the fan and turbine. Figure 60 shows orbit plots of the data presented in Figure 59. Inspection of Figure 60 shows that the initial response is a noncircular

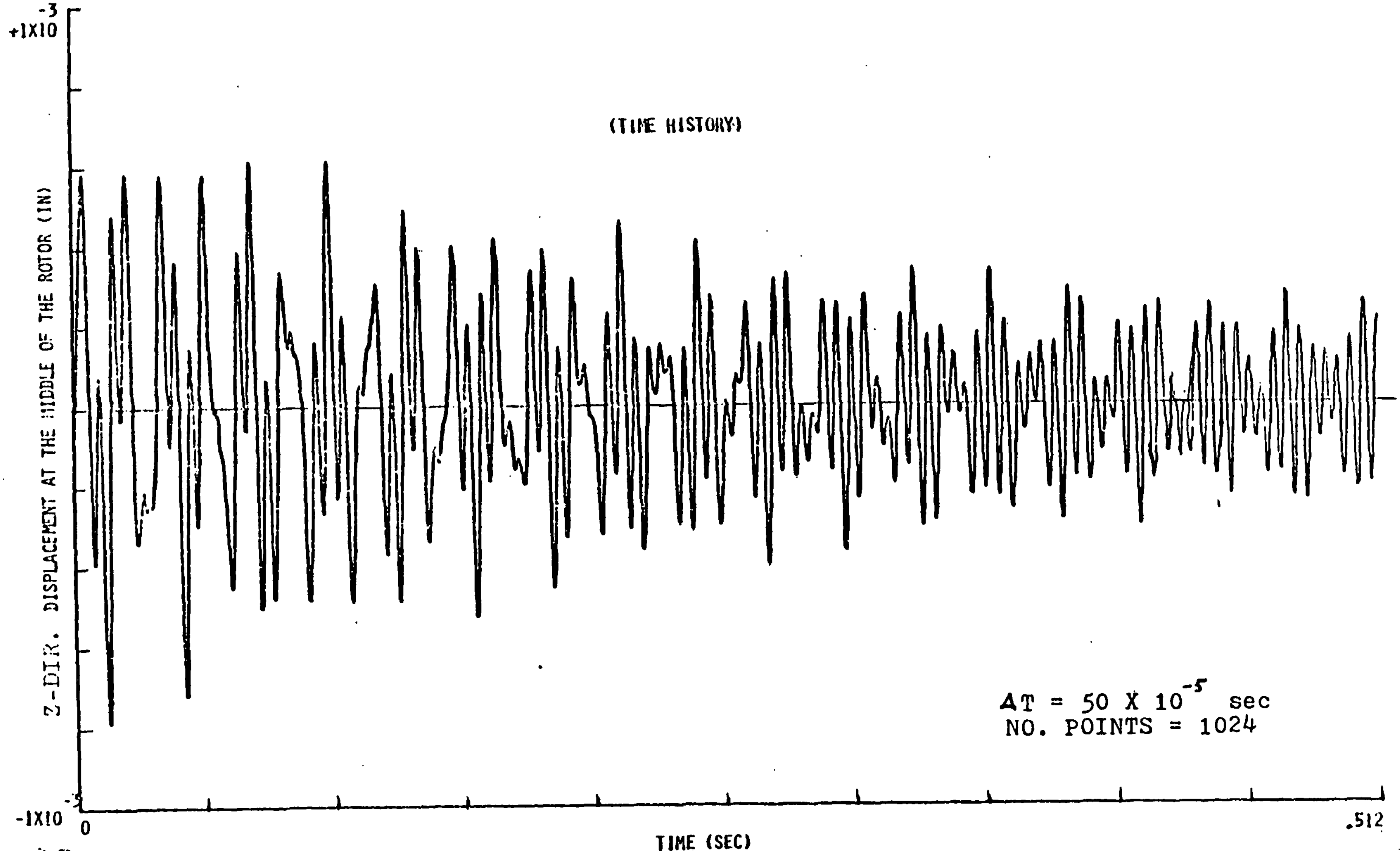


Figure 55. Demonstrator Model - 100 gm-in. Sudden Unbalance at the Fan at 12,000 rpm.

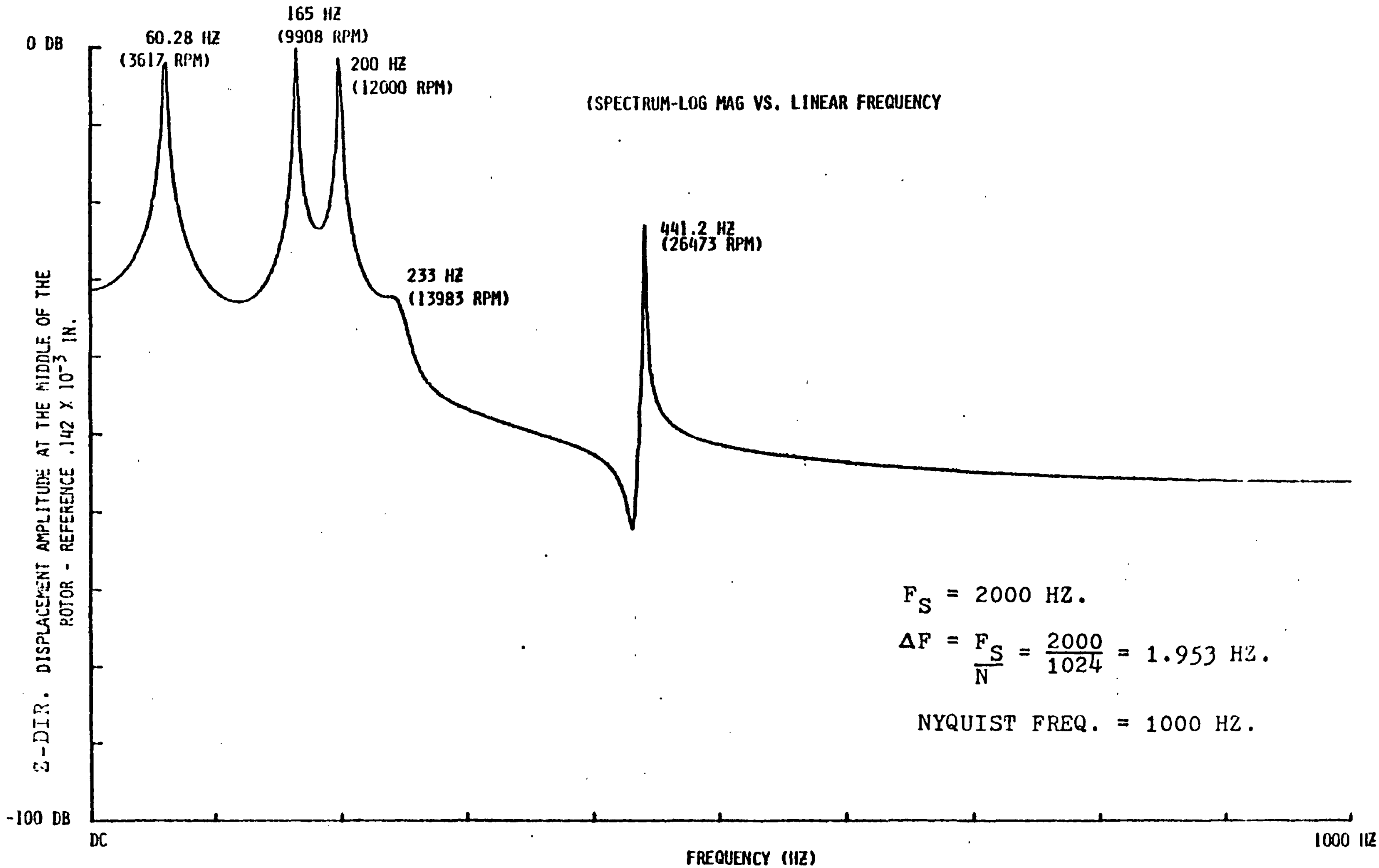


Figure 56. Demonstrator Model - 100 gm-in. Sudden Unbalance at the Fan at 12,000 rpm.

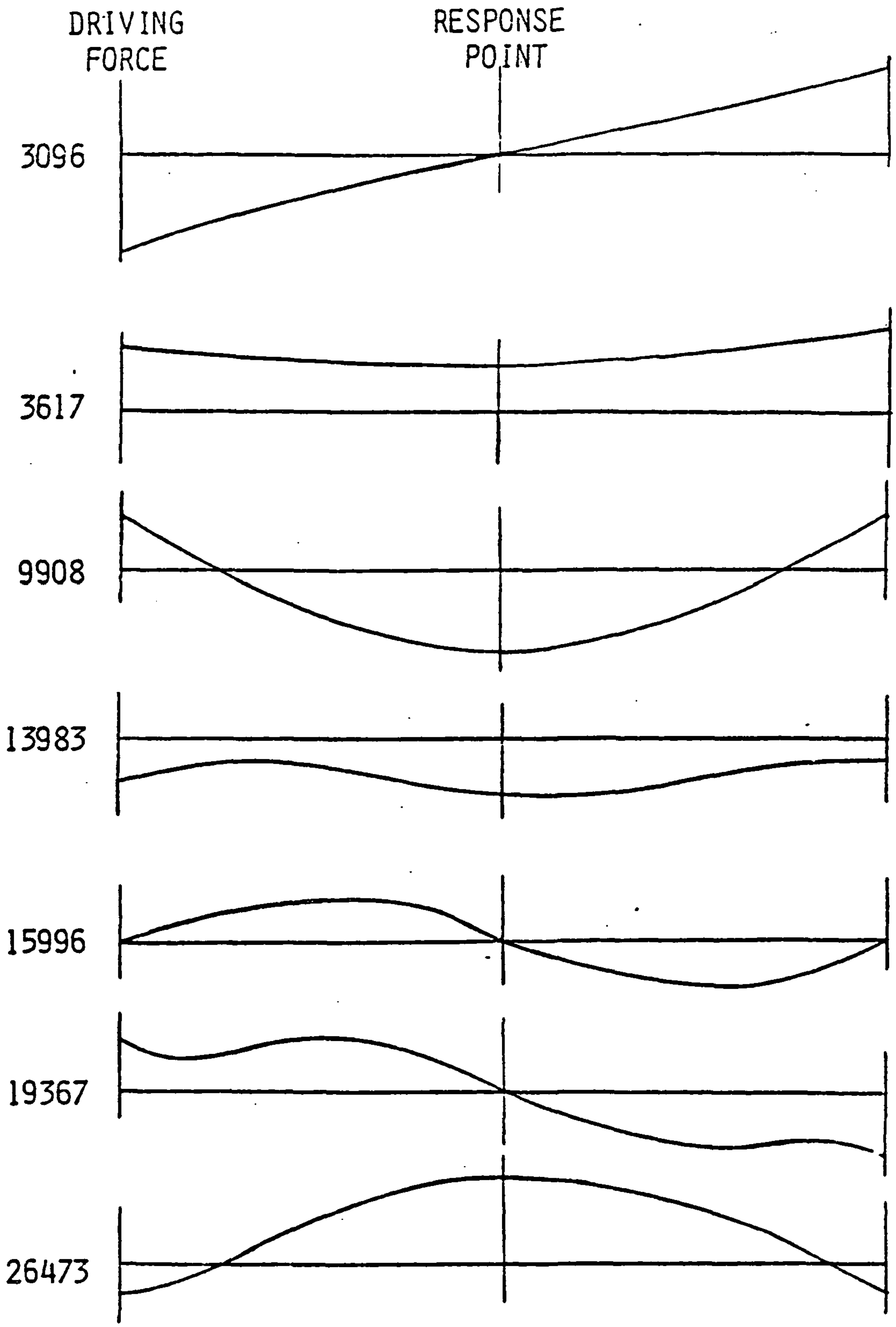
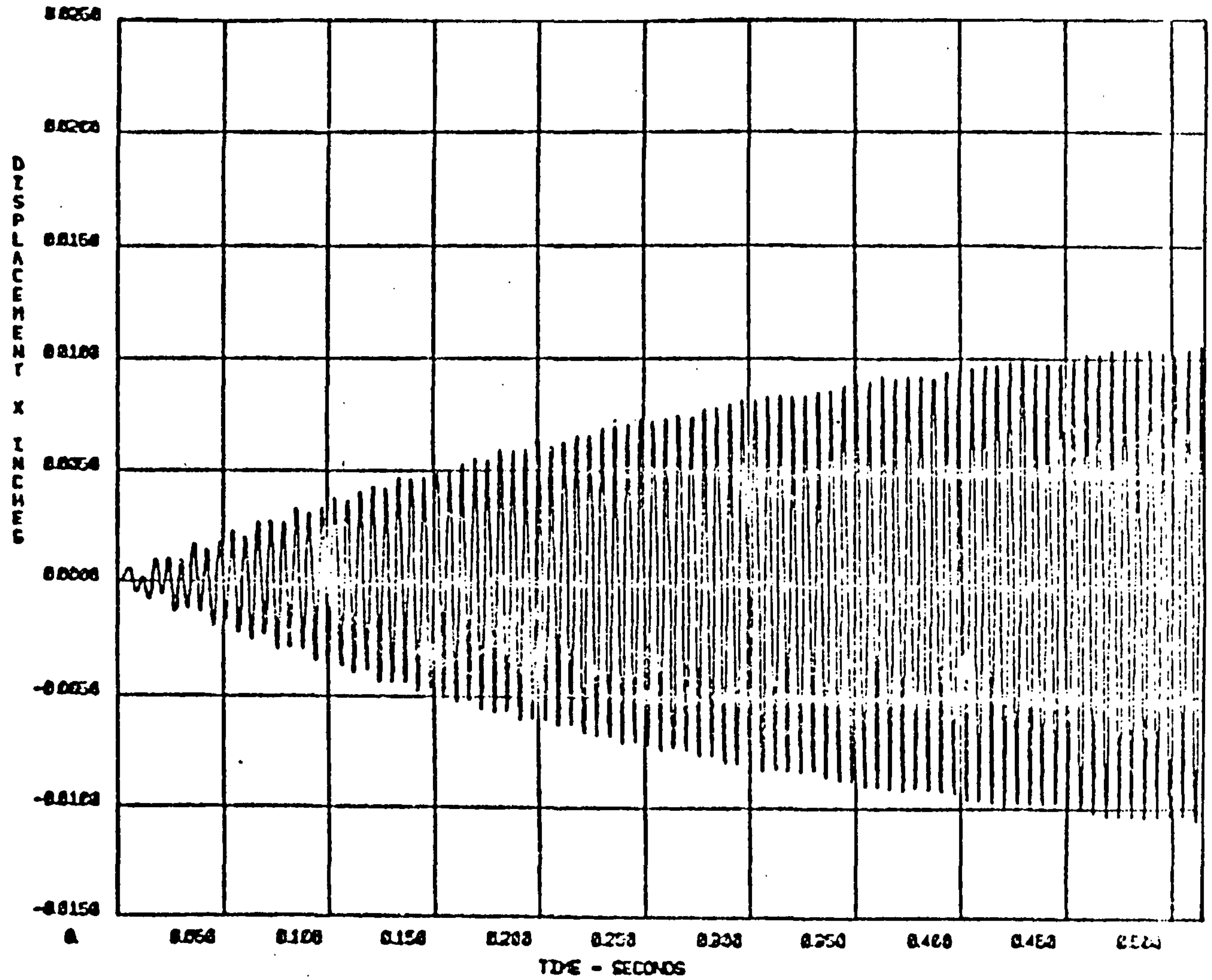


Figure 57. Total System - Rotor Mode Shapes.

Z - DIR.
AT MIDDLE
OF ROTOR



$\Delta T = 50 \times 10^{-5}$ SEC.
NO. POINTS = 1024

Figure 58. Demonstrator Model - 100 gm-in. Sudden Unbalance at the Fan at 9908 rpm.

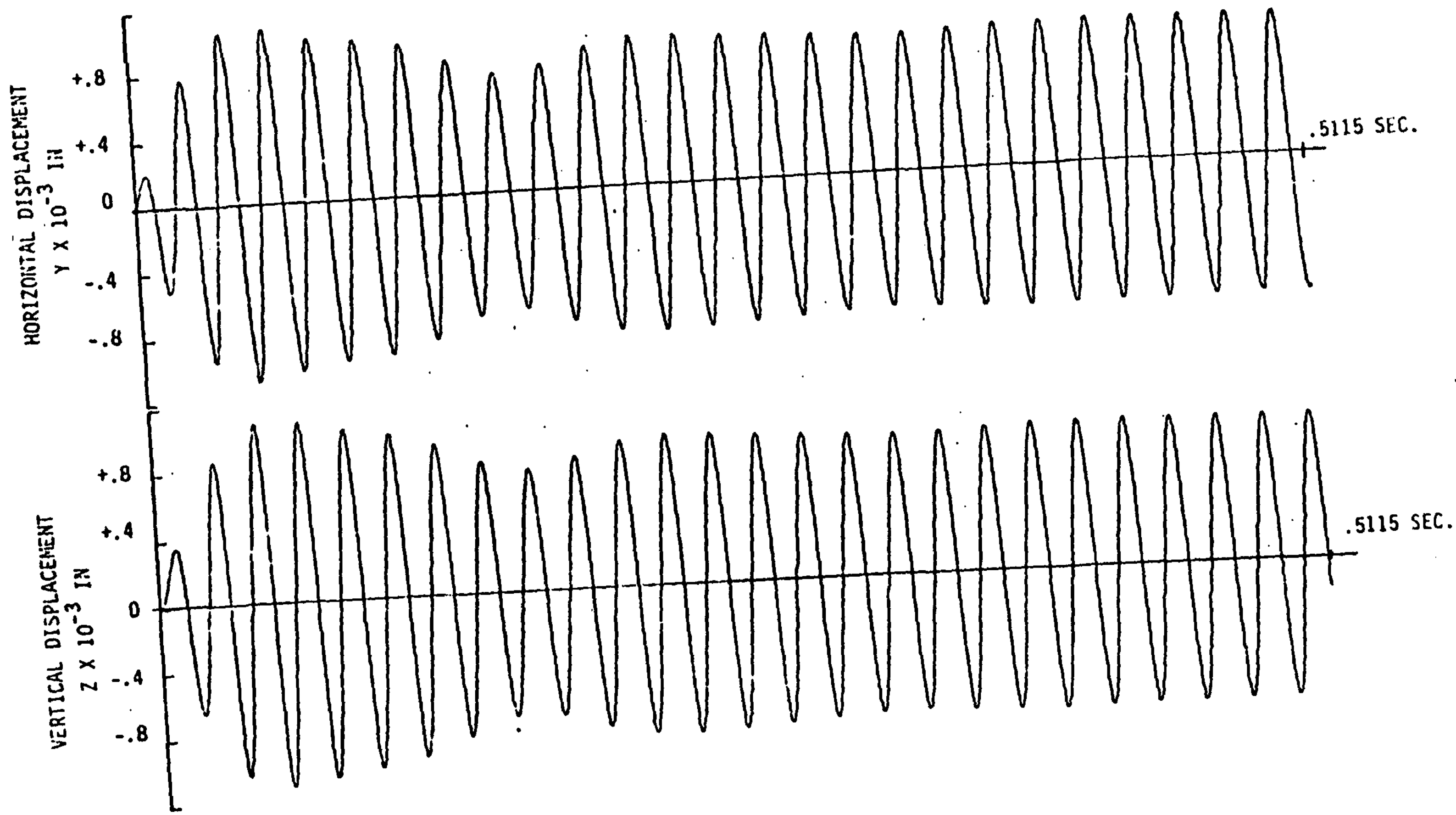


Figure 59. Fan Response in Two Planes for NASA Demonstrator Model with Gyro 100 gm-in. Sudden Fan Unbalance at 3000 rpm.

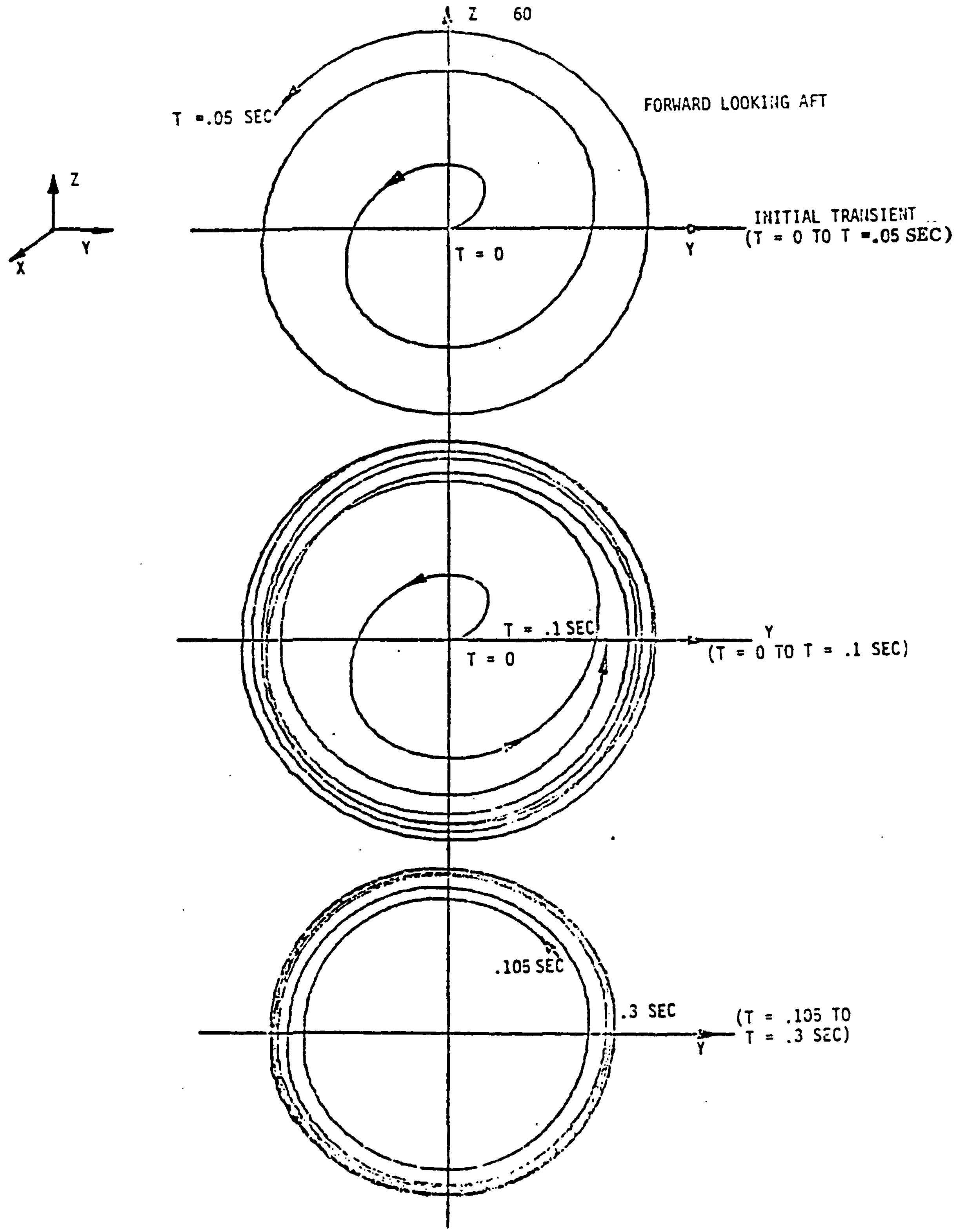


Figure 60. Orbit Plots at the Fan for NASA Demonstrator Model with Gyro 100 gm-in. Sudden Fan Unbalance at 3000 rpm.

whirl. This noncircular whirl transitions into a circular whirl after steady-state conditions are reached. Figures 61 through 66 show response plots at the fan and case that include both the effects of gyroscopic stiffening and the rub load path. Figures 67 through 70 show the steady-state frequency response for the total system with and without gyroscopic stiffening at the fan and the turbine locations. Comparison of the time response, once steady-state conditions have been reached, with the frequency response shows good agreement.

Figures 71 through 76 show the results of analyses for a 2,000 rpm/sec accel rate that reflects use of the TETRA restart option. The restart option allows the utilization of the results obtained from a previous analysis to continue the analysis out to future time without the introduction of pseudo transients. For several different times (those for which output was printed) the TETRA program writes to a restart file data including values for each of the generalized coordinates for the current time step, for one time step earlier, and for two time steps earlier. The user chooses one of the times for which output was printed on the original run (usually the last such time) as the restart time for the new run. The data for that time from the restart file is then utilized to provide the initial data needed to continue the analysis. The process can be repeated any number of times.

The computing strategy used to generate the response data shown in Figures 71 through 76 was as follows. The maximum speed for the accel was selected as 5,000 rpm so as to encompass the two gyro stiffened critical speeds located at 3292 rpm and 3624 rpm for steady-state operation. Modal Q-factor values of 15 were used for each of the casing subsystem modes and the rotor subsystem modes were undamped. Physical damping for the connecting springs based on a Q-factor equal to 15 and a 60.4 Hz frequency, corresponding to the 3624 rpm mode, was used.

The analysis was accompanished with three restart segments for the following cases.

a. Large fan-case radial clearance (200 mils)

b. Small fan-case radial clearance (10 mils)

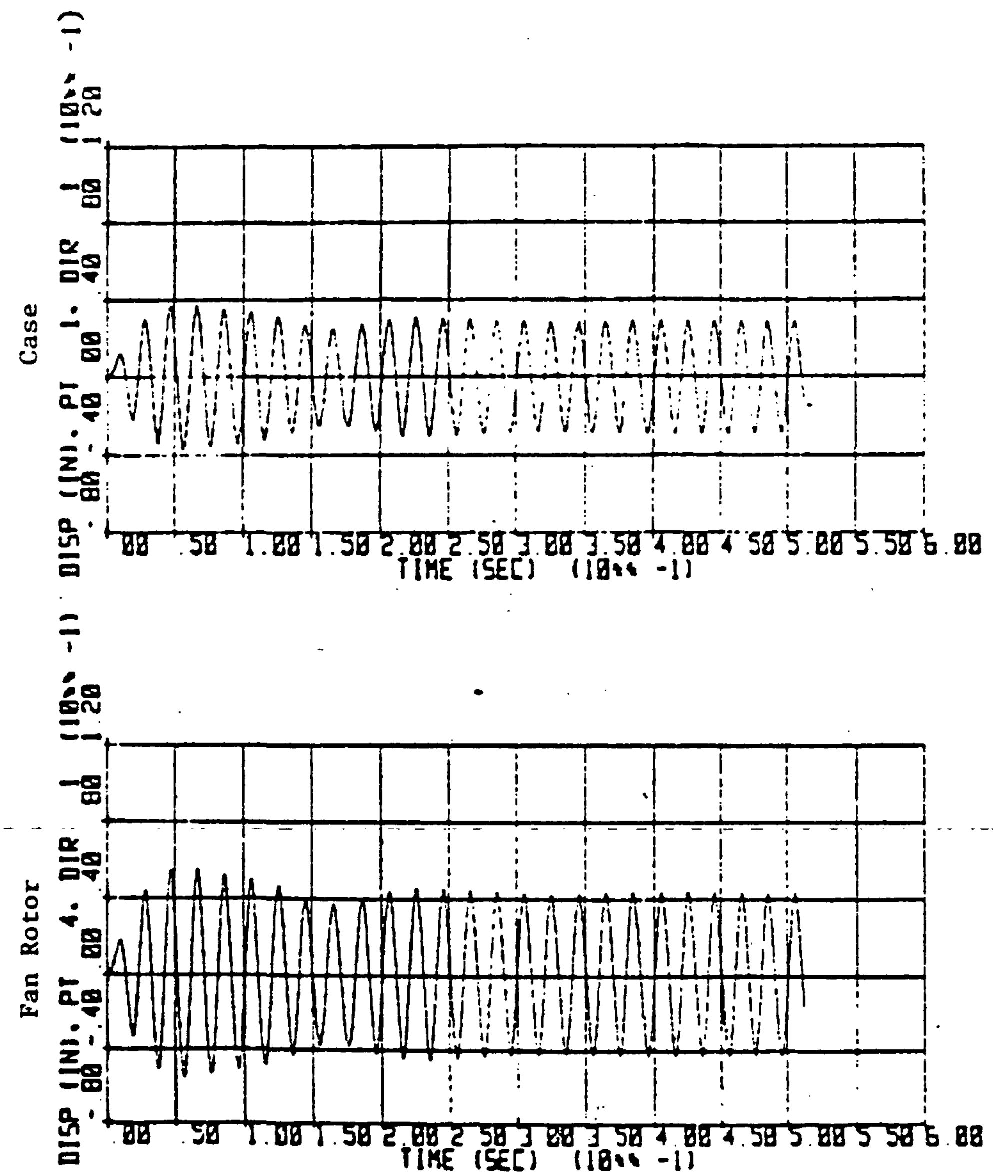


Figure 61. Response in the Vertical Direction at the Case and Fan Rotor for the NASA Demonstrator Model for 5000 Gm-In. Sudden Fan Unbalance at 3000 RPM (No Rub).

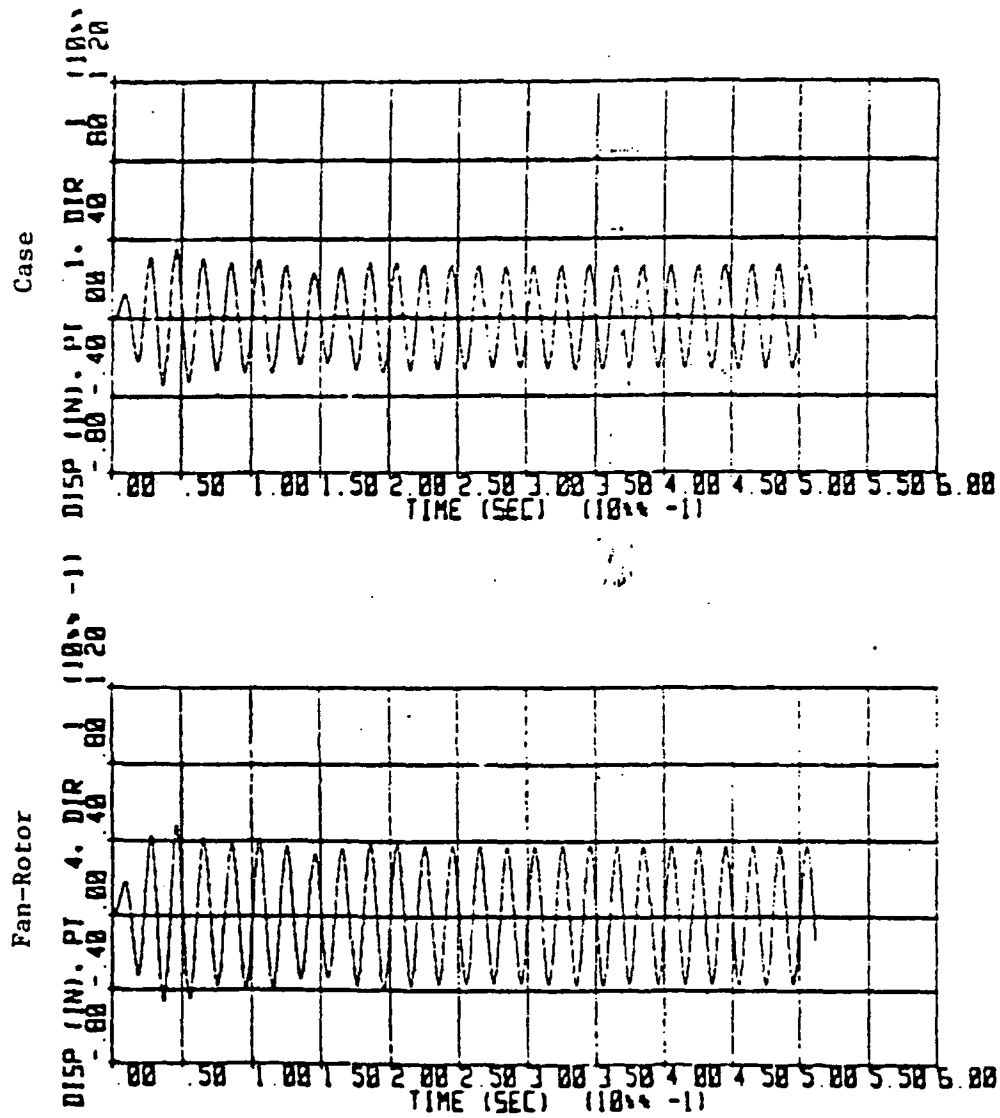


Figure 62. Response in the Vertical Direction at the Case and Fan Rotor for the NASA Demonstrator Model for 5000 Gm-In. Sudden Fan Unbalance at 3000 RPM (With Rub).

Shown to time 0.05 second. Radial displacement dead band exceeds the fan rotor-case relative displacement.

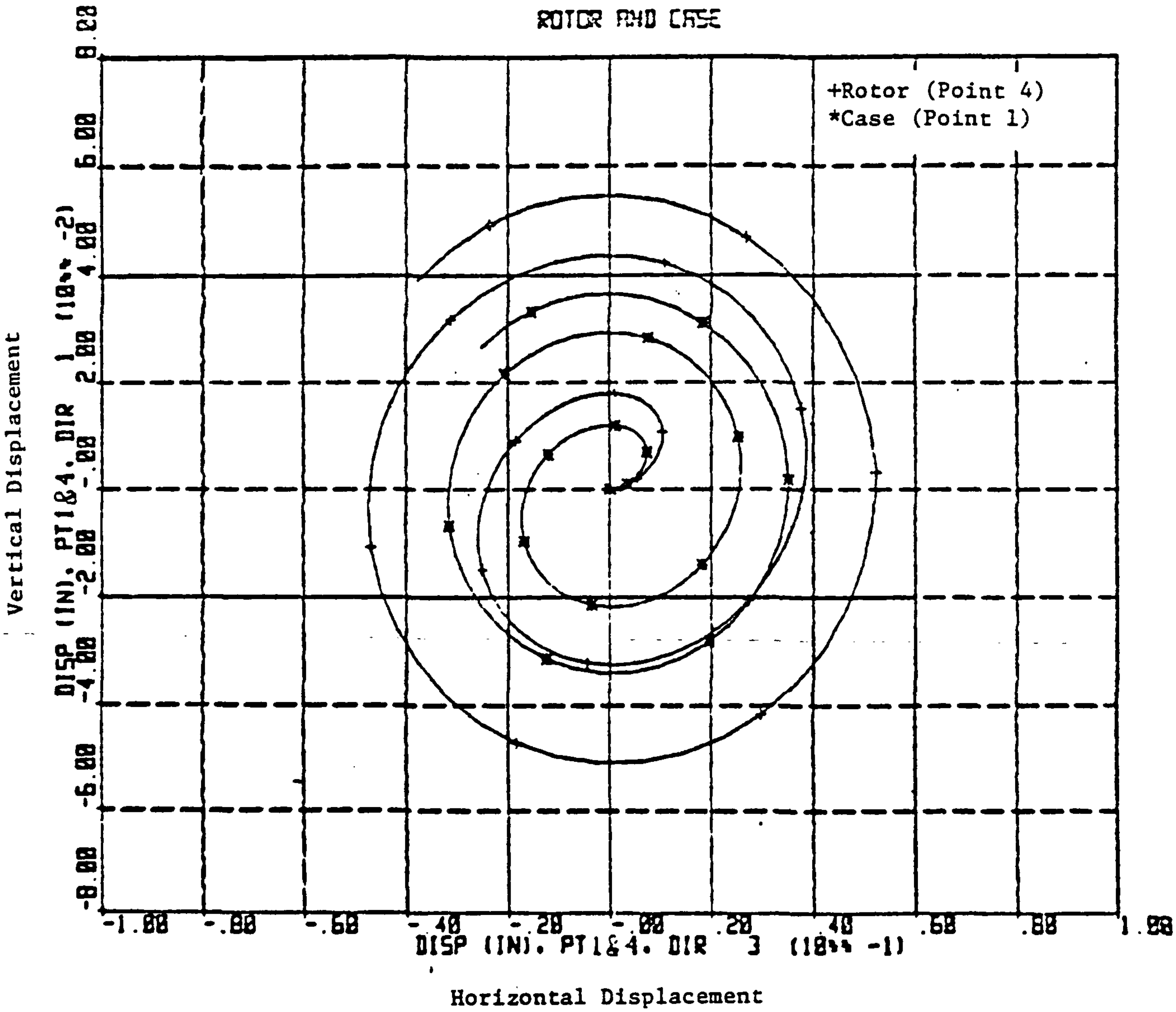


Figure 63. Rotor and Case Orbit Plot for the NASA Demonstrator Model for 5000 Gm-In. Sudden Fan Unbalance at 3000 RPM (No Rub).

Shown to time 0.05 second. 10 mil radial displacement dead band and 1×10^6 lb/in. rub spring at the fan rotor-case.

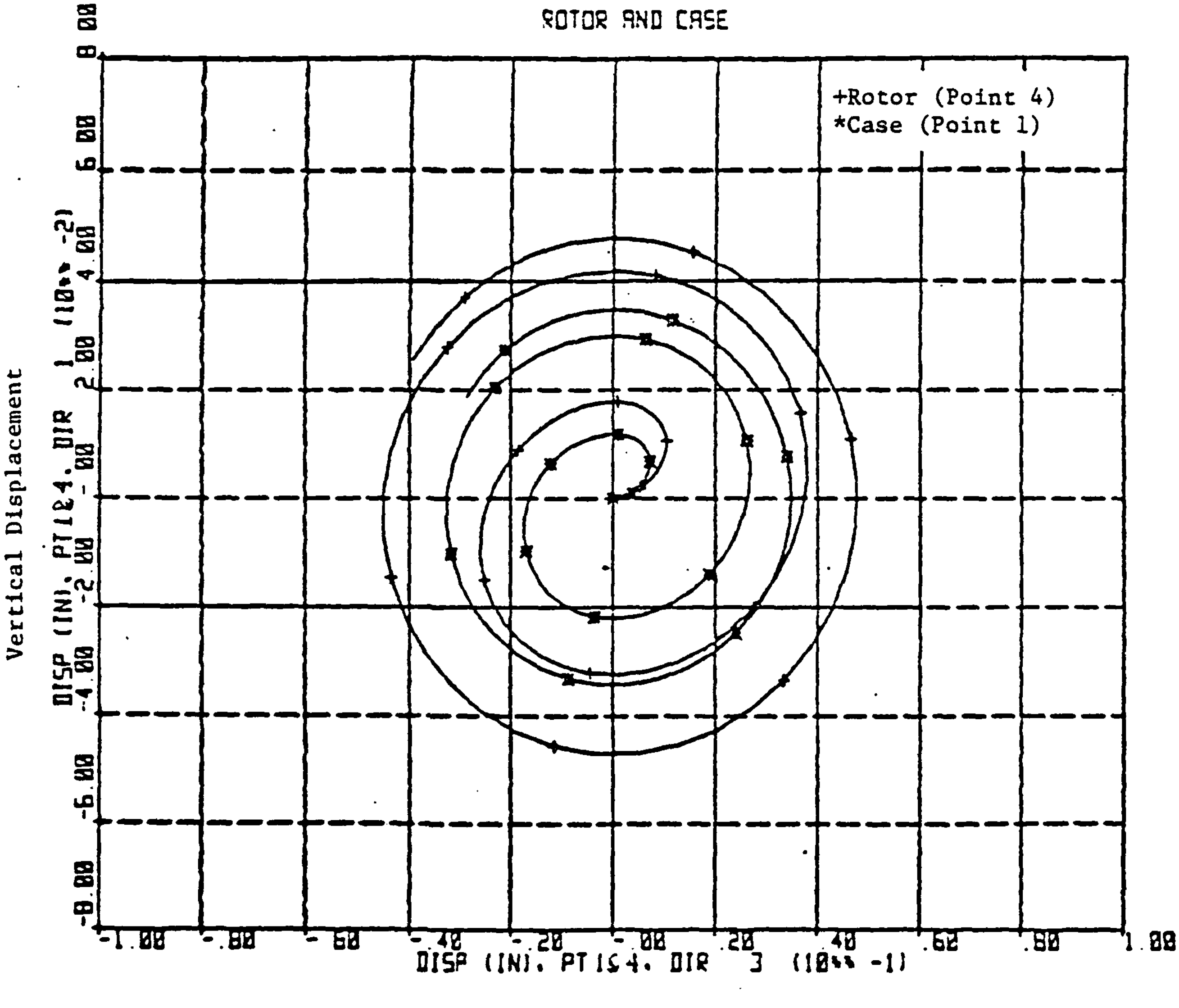


Figure 64. Rotor and Case Orbit Plot for the NASA Demonstrator Model for 5000 Gm-In. Sudden Fan Unbalance at 3000 RPM (With Rub).

Shown to time 0.512 second. Radial displacement dead band exceeds the fan rotor-case relative displacement.

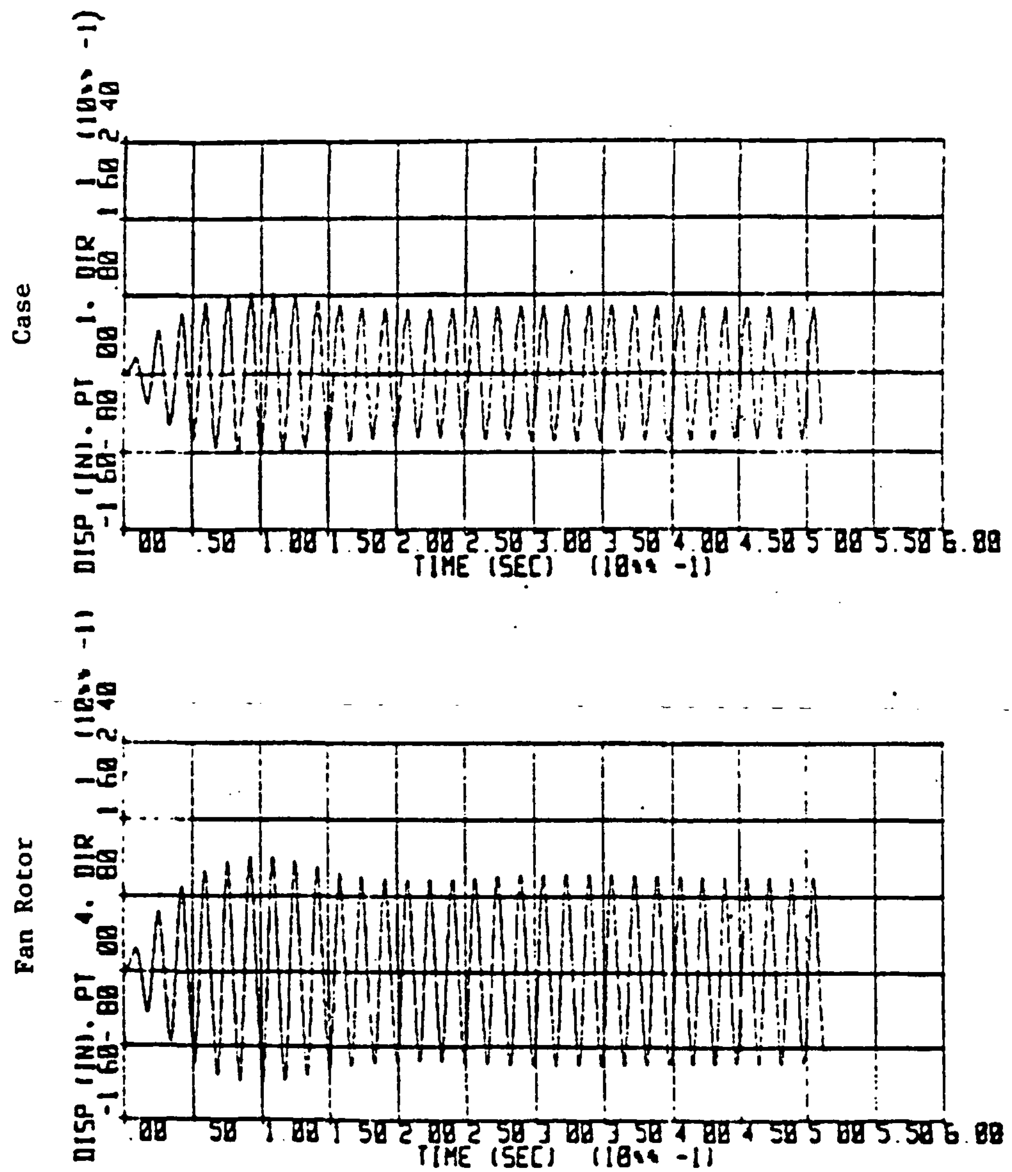


Figure 65. Response in the Vertical Direction at the Case and Fan Rotor for the NASA Demonstrator Model for 5000 Gm-In. Sudden Fan Unbalance at 3624 RPM (No Rub).

Shown to time 0.512 second. 10 mil radial displacement dead band and 1×10^6 lb/in. rub spring at the fan rotor-case.

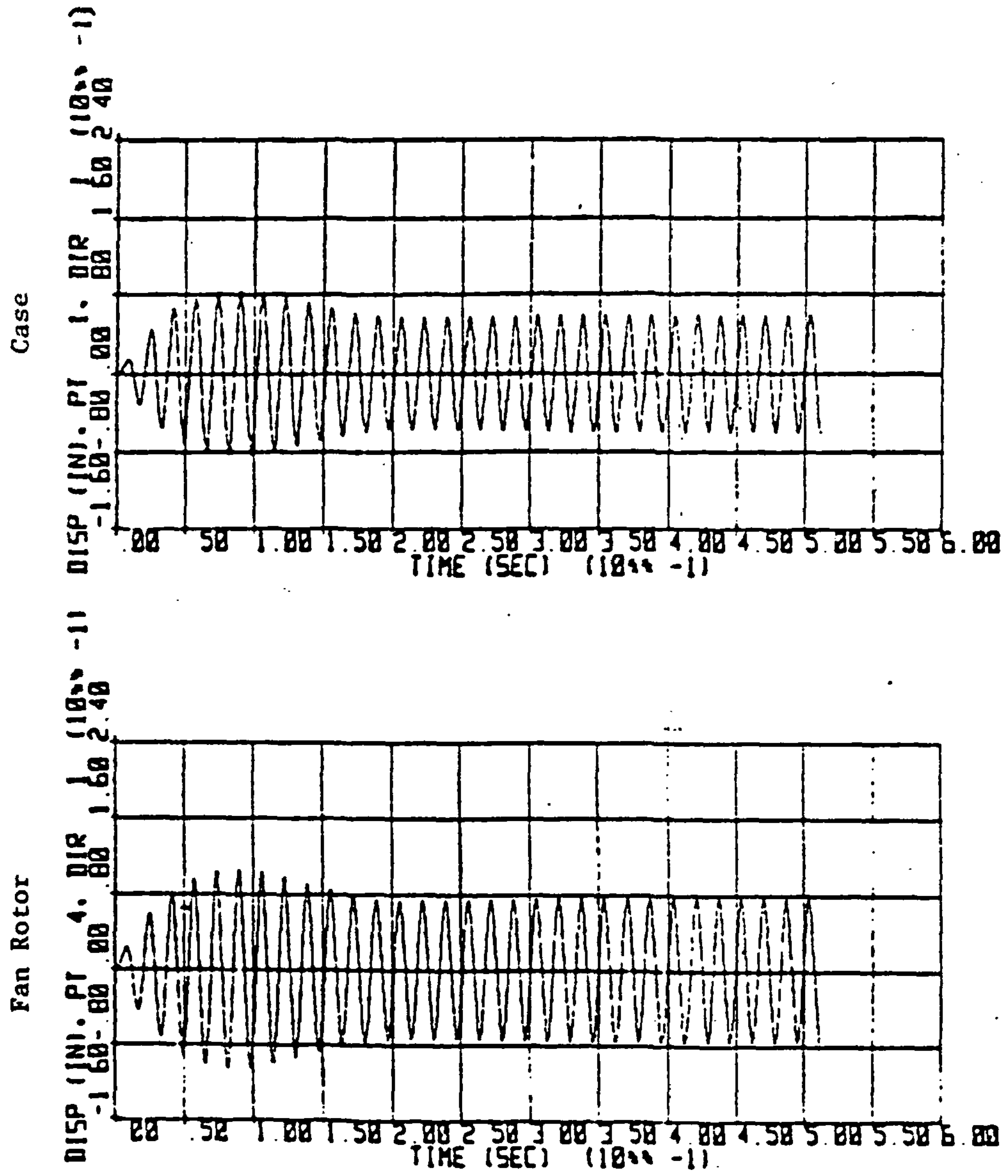


Figure 66. Response in the Vertical Direction at the Case and Fan Rotor for the NASA Demonstrator Model for 5000 Gm-In. Sudden Fan Unbalance at 3624 RPM (With Rub).

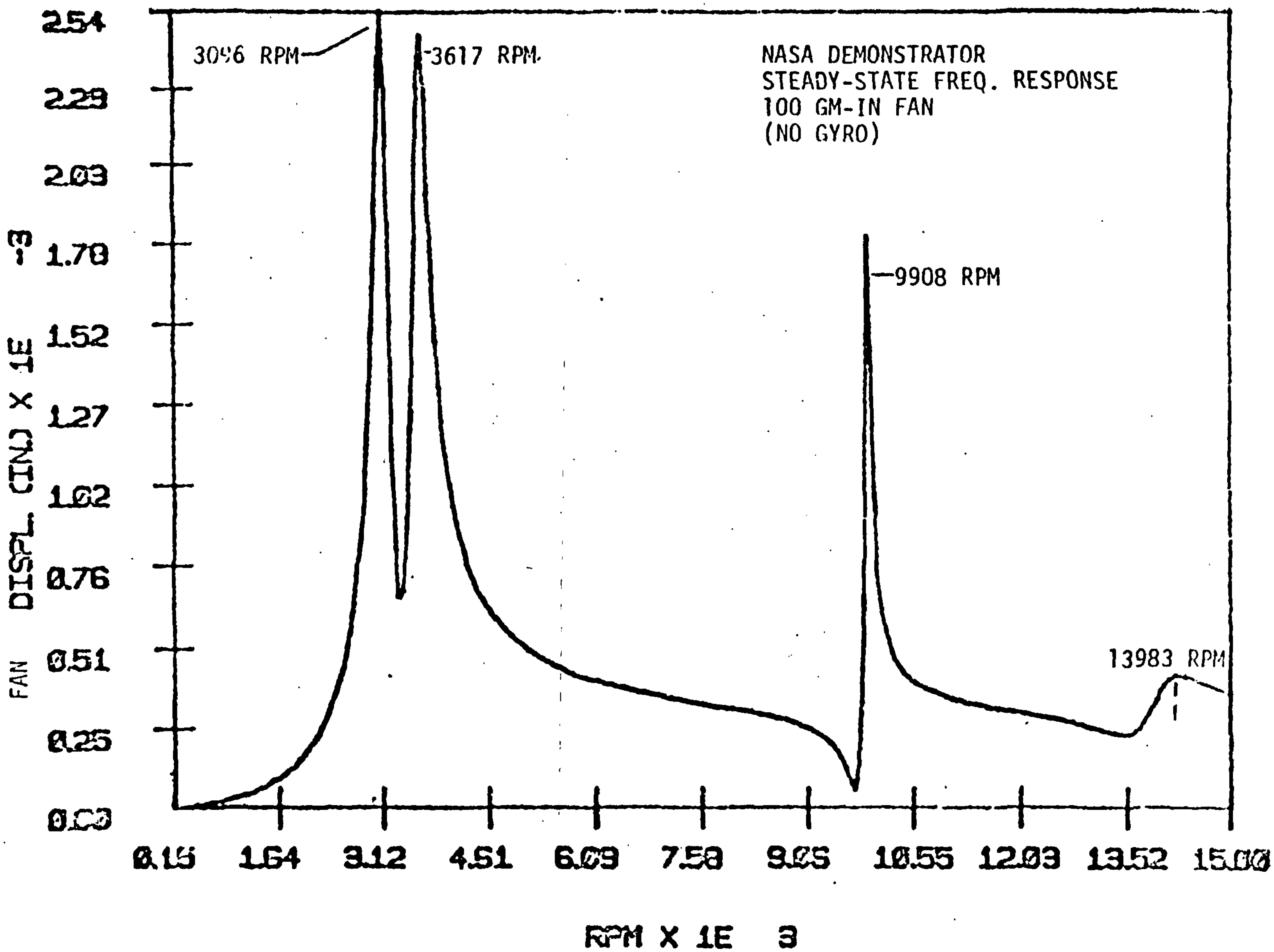


Figure 67. NASA Demonstrator - Steady-State Frequency Response, 100 gm-in. Fan (No Gyro).

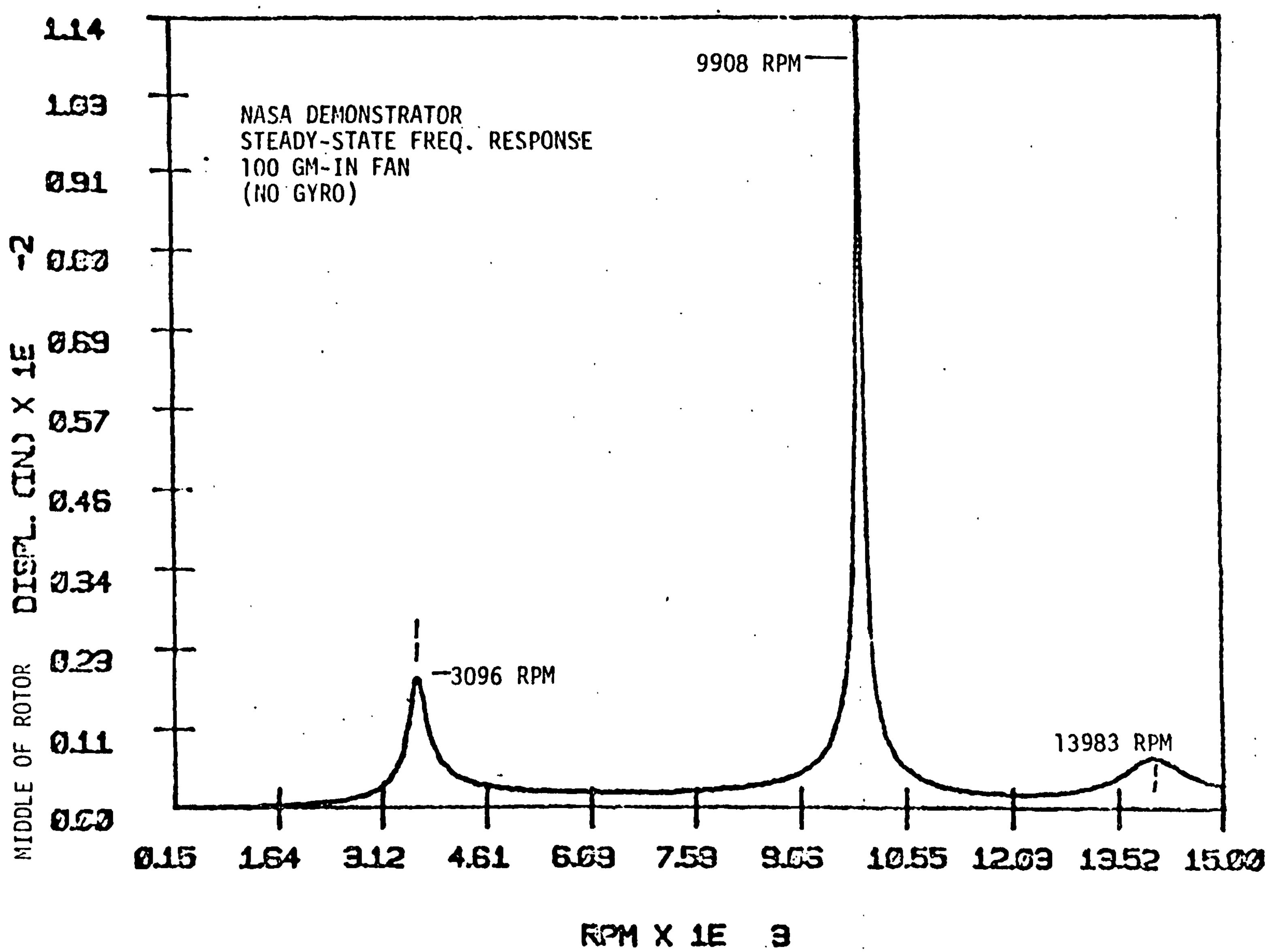


Figure 68. NASA Demonstrator - Steady-State Frequency Responce, 100 gm-in. Fan (No Gyro).

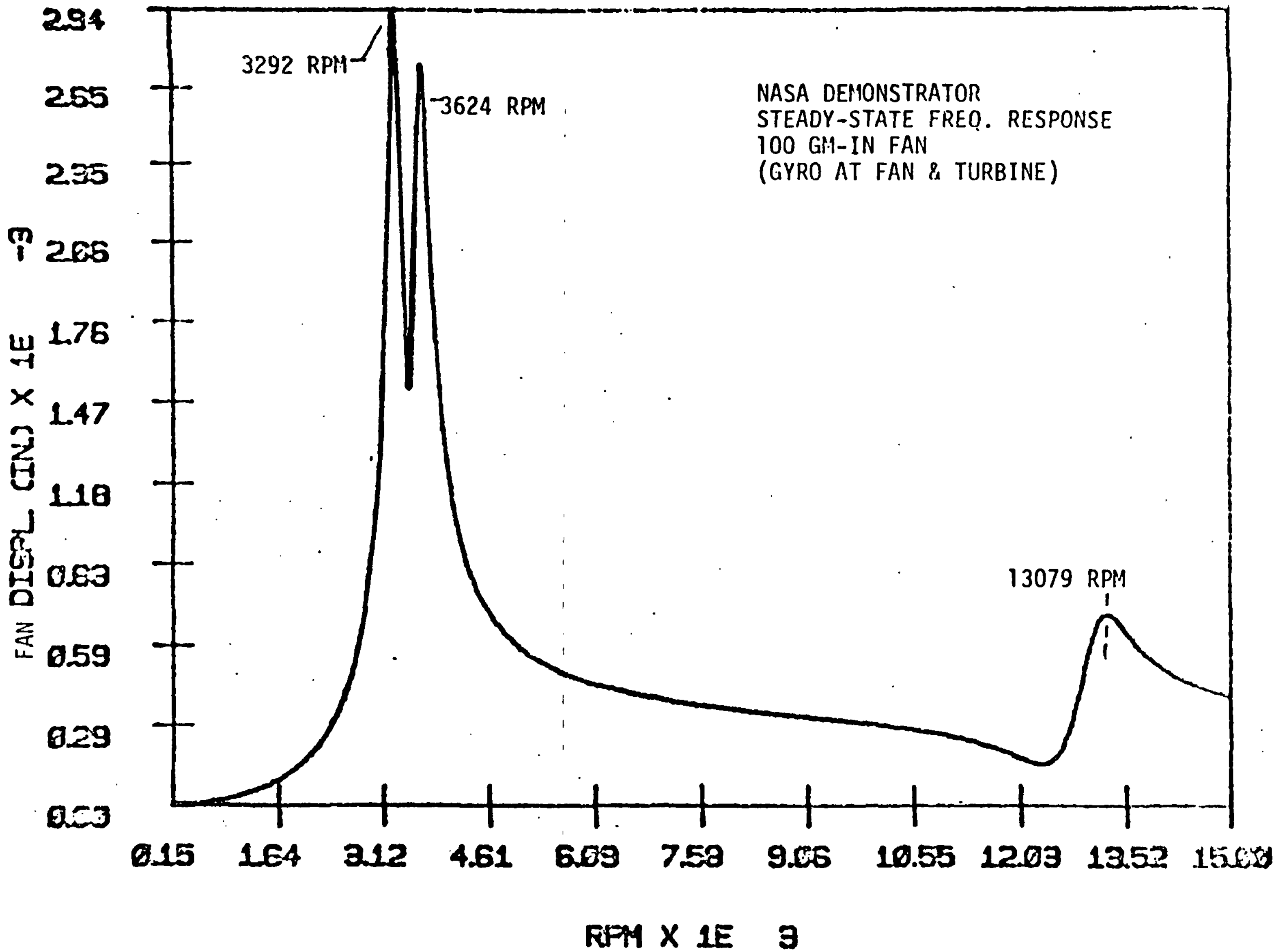


Figure 69. NASA Demonstrator - Steady-State Frequency Response, 100 gm-in. Fan (Gyro at Fan and Turbine).

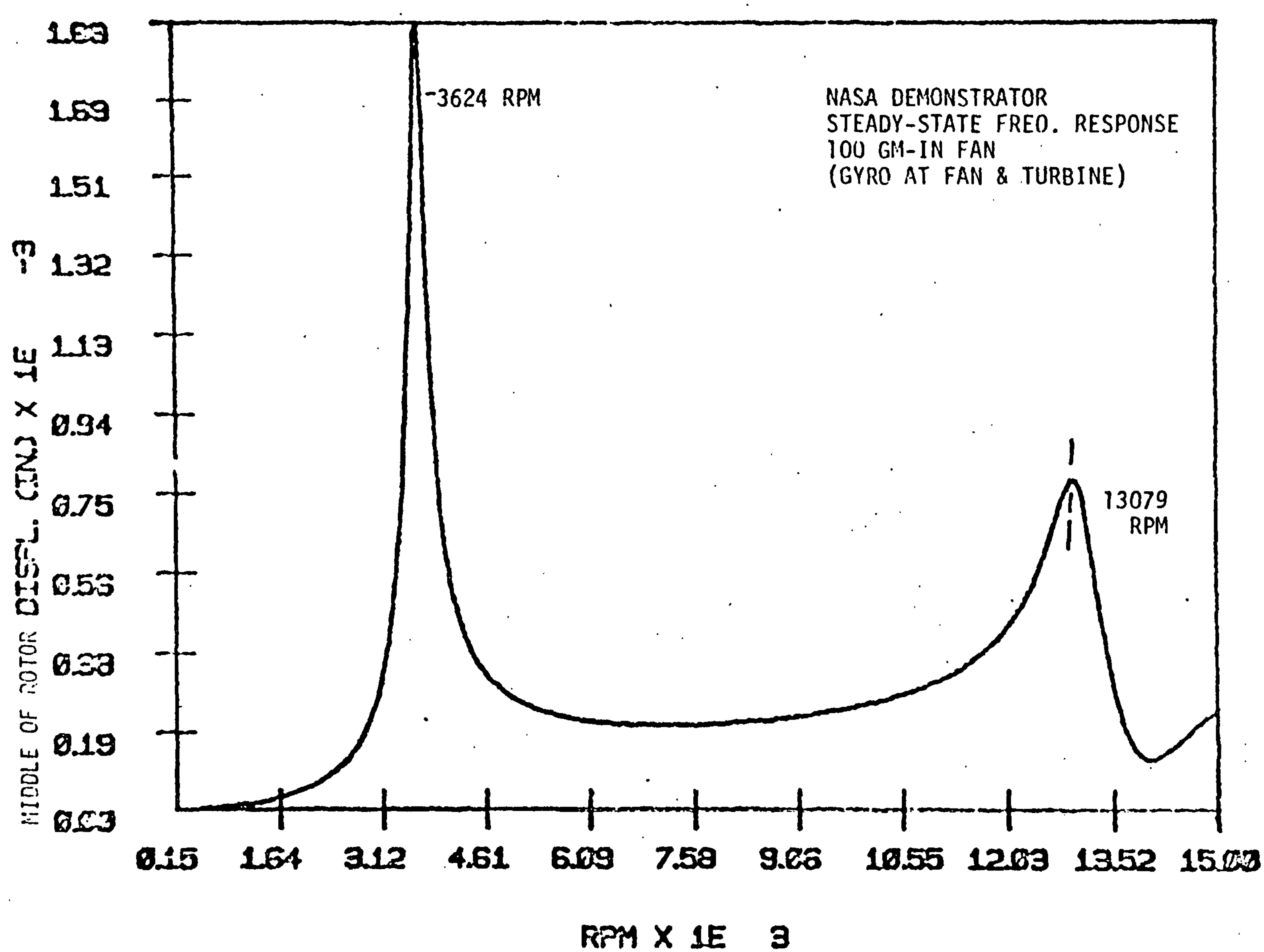


Figure 70. NASA Demonstrator - Steady-State Frequency Response, 100 gm-in. Fan (Gyro at Fan and Turbine).

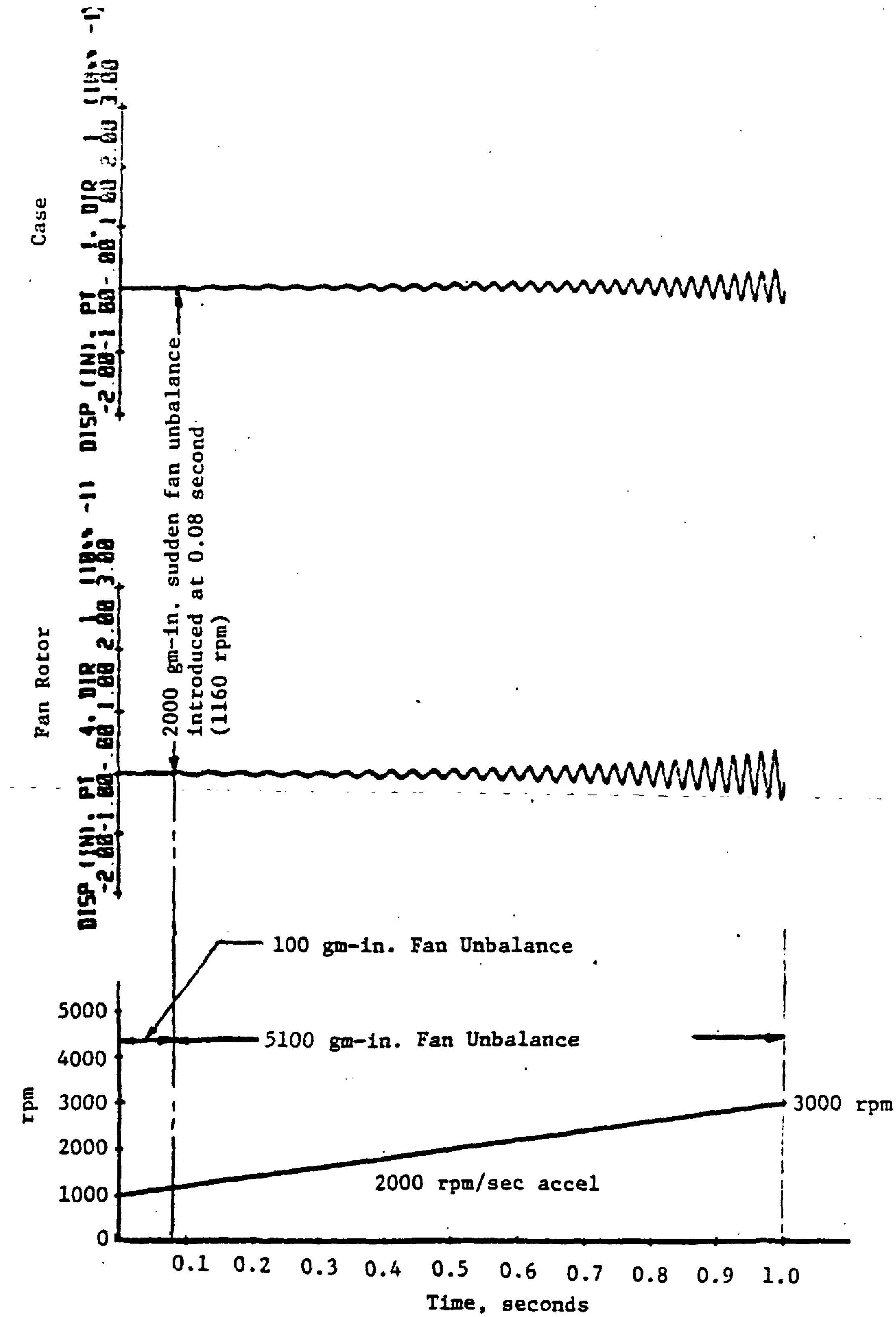


Figure 71. Response in the Vertical Direction of the Case and Fan Rotor for the NASA Demonstrator Model for 1000 to 3000 RPM Accel Segment. Radial Displacement Dead Band Exceeds the Fan-Case Relative Displacement (No Rub).

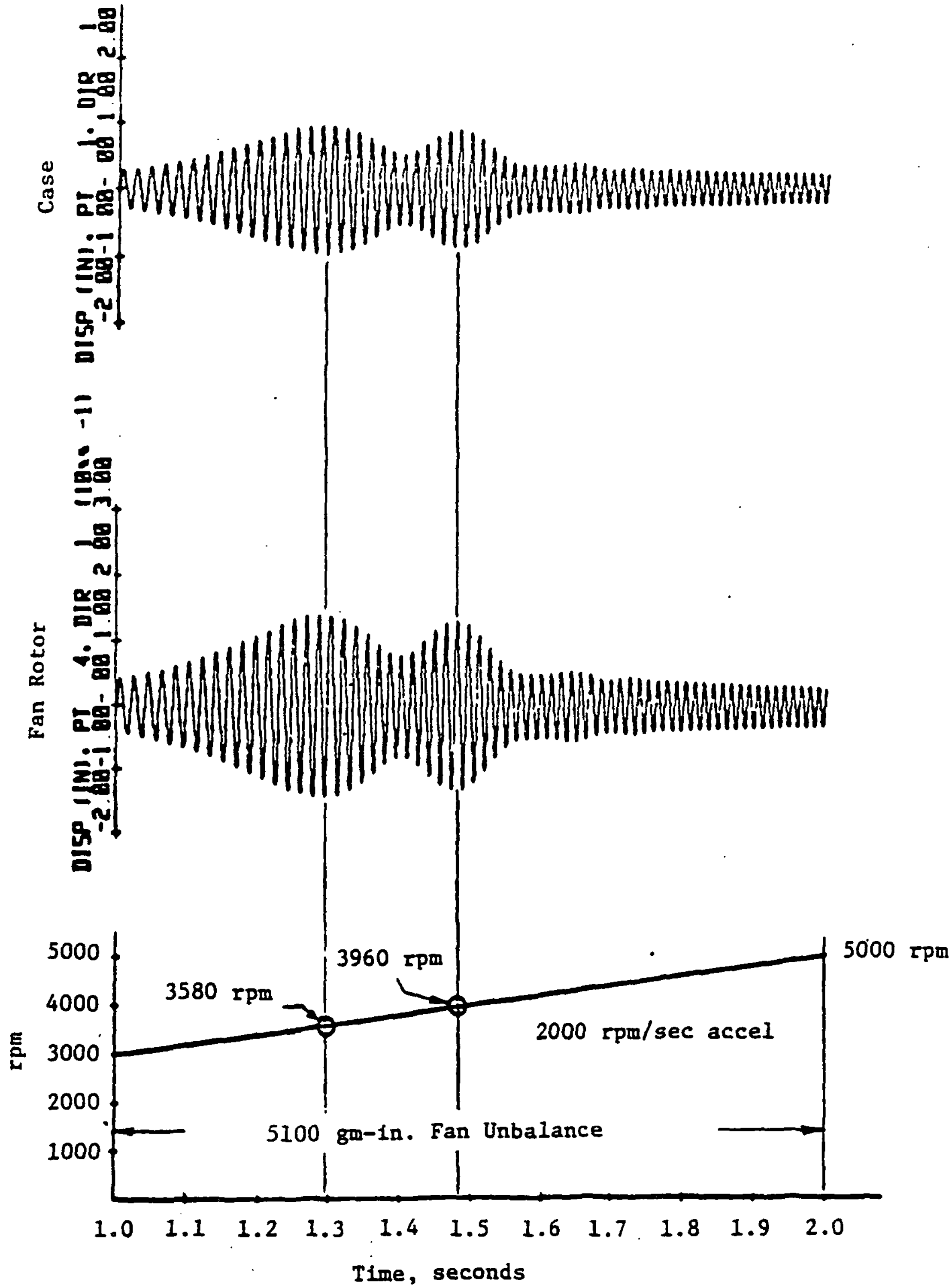


Figure 72. Response in the Vertical Direction at the Case and Fan Rotor for the NASA Demonstrator Model for 3000 to 5000 RPM Accel Segment. Radial Displacement Dead Band Exceeds the Fan-Case Relative Displacement (No Rub).

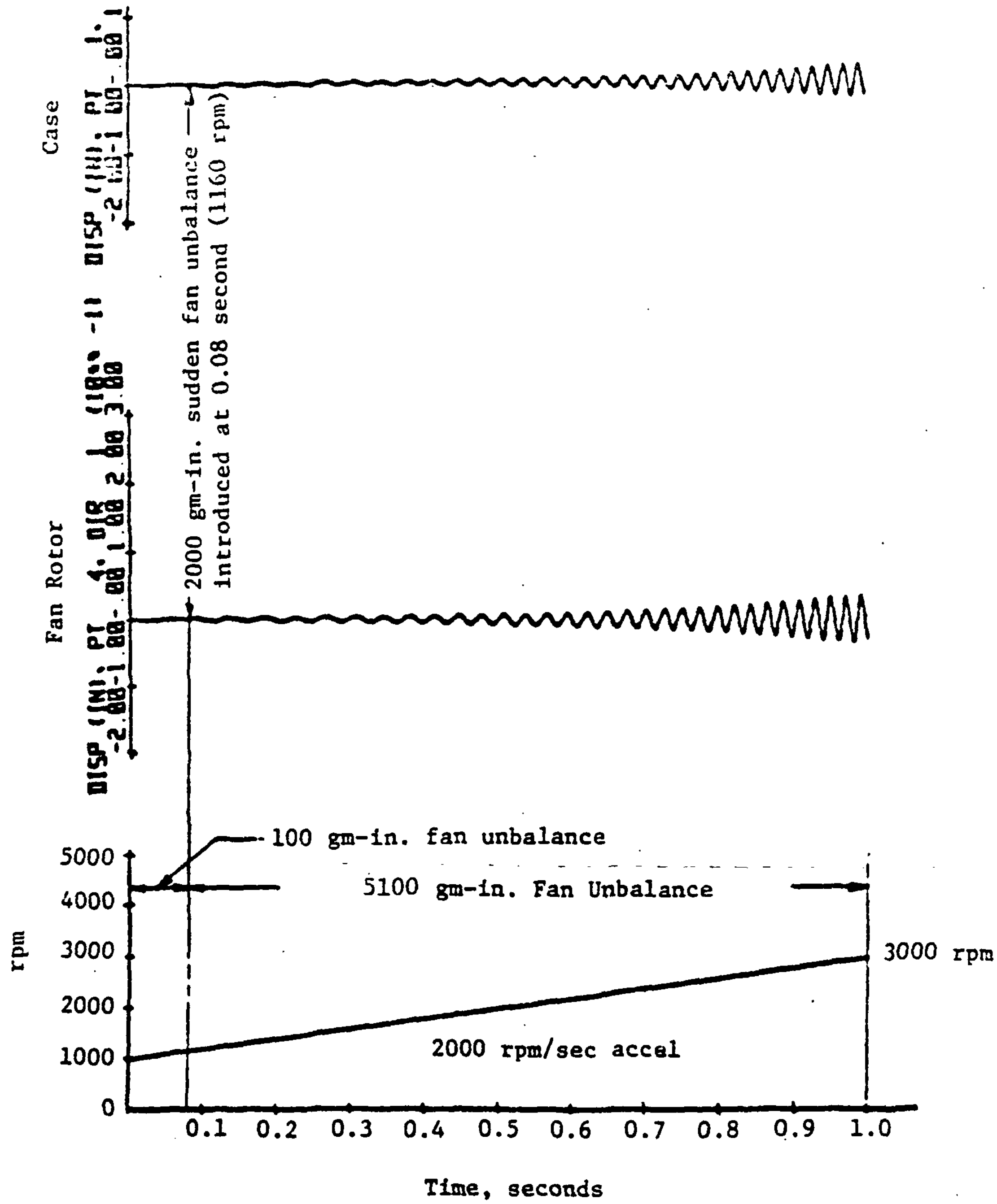


Figure 73. Response in the Vertical Direction at the Case and Fan Rotor for NASA Demonstrator Model for 1000 to 3000 RPM Accel Segment. 10 Mil Radial Displacement Dead Band and 1×10^6 Lb/In. Rub Spring at the Fan Rotor-Case (With Rub).

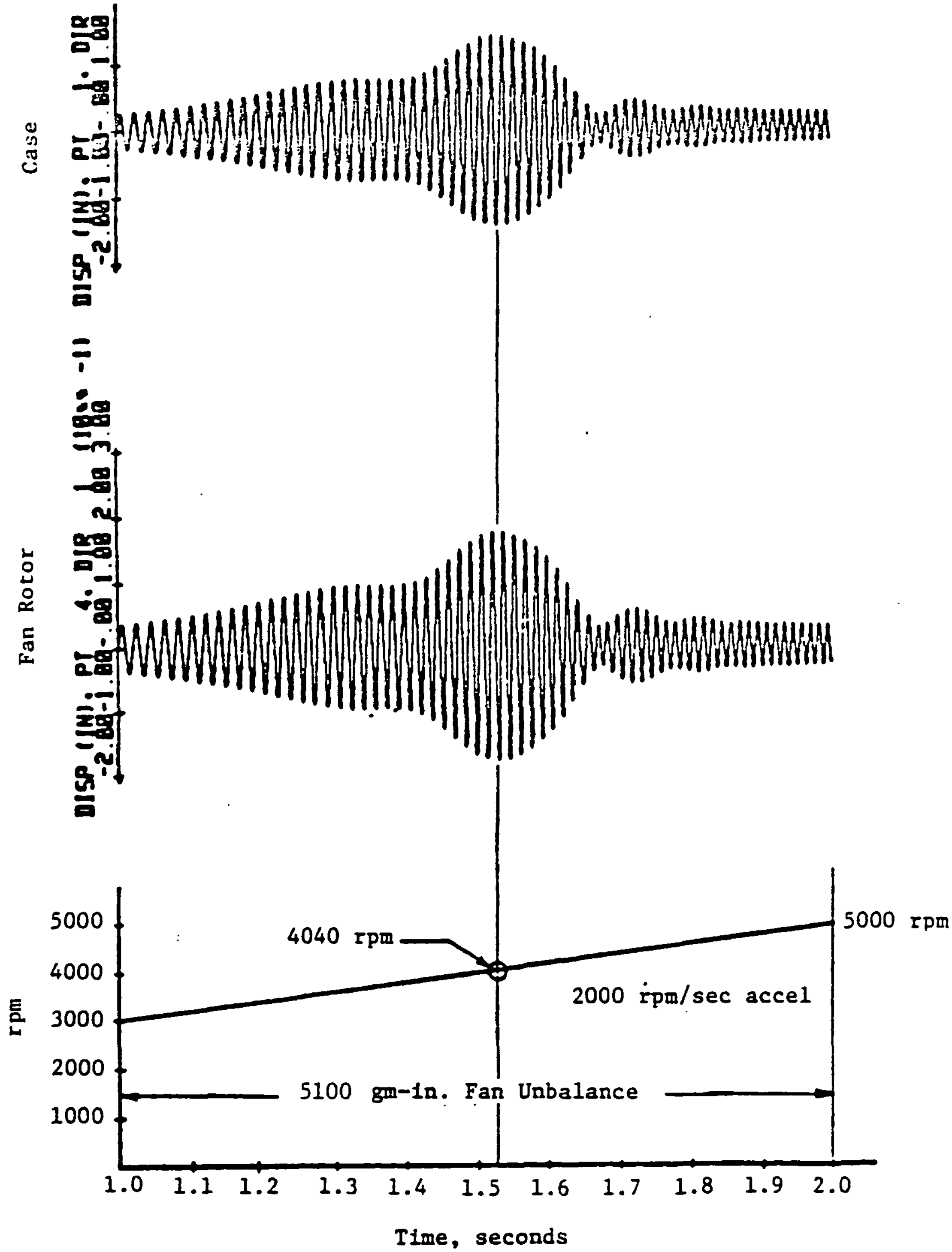


Figure 74. Response in the Vertical Direction at the Case and Fan Rotor for the NASA Demonstrator Model for 3000 to 5000 RPM Accel Segment. 10 Mil Radial Displacement Dead Band and 1 x 10^6 Lb/In. Rub Spring at the Fan Rotor-Case (With Rub).

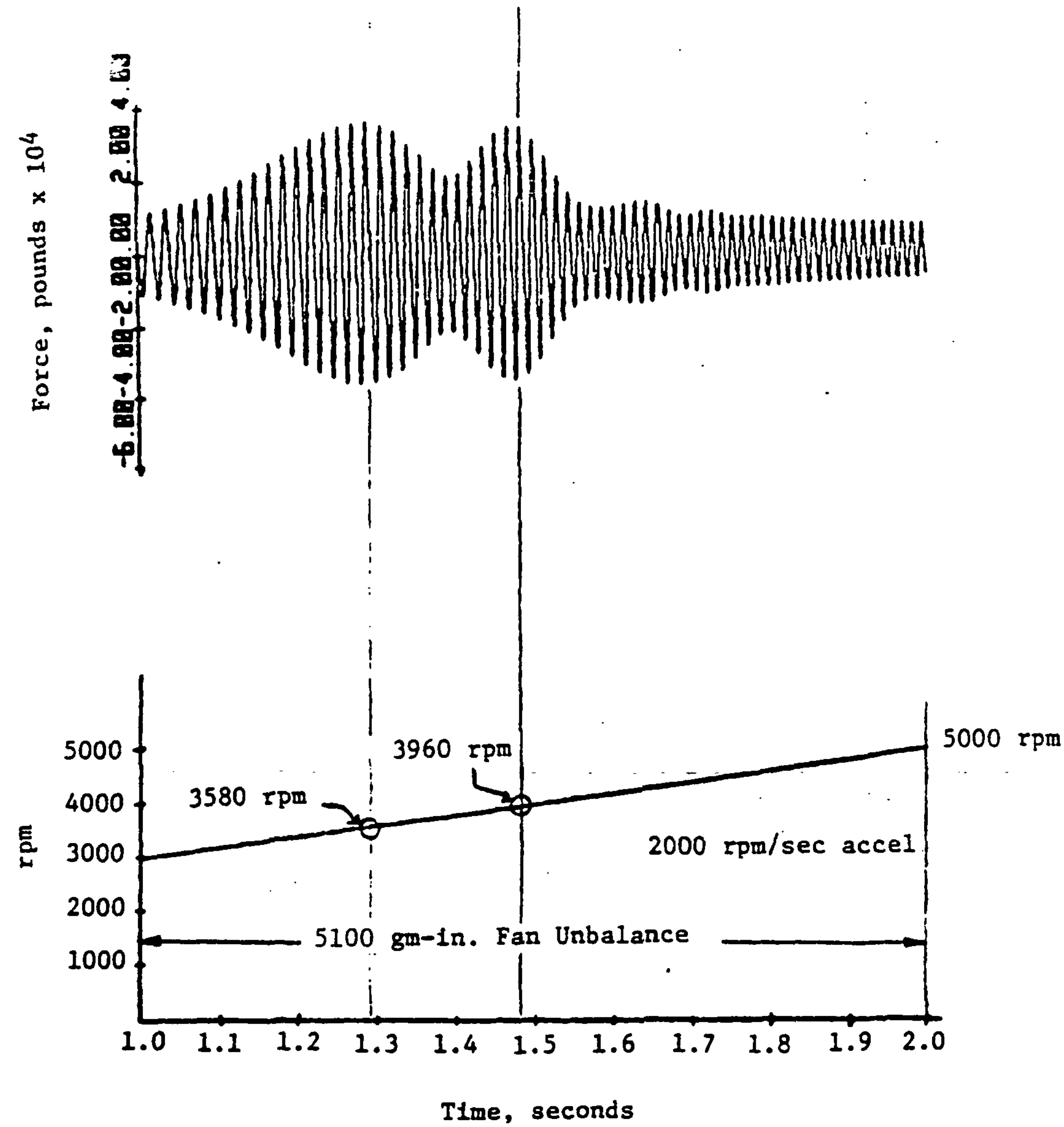


Figure 75. Force Exerted by the Forward Frame/Bearing (Spring 3) on the Rotor at Point 5 in the Vertical Direction for the NASA Demonstrator Model for 3000 to 5000 RPM Accel Segment. Radial Displacement Dead Band Exceeds the Fan Rotor-Case Relative Displacement (No Rub).

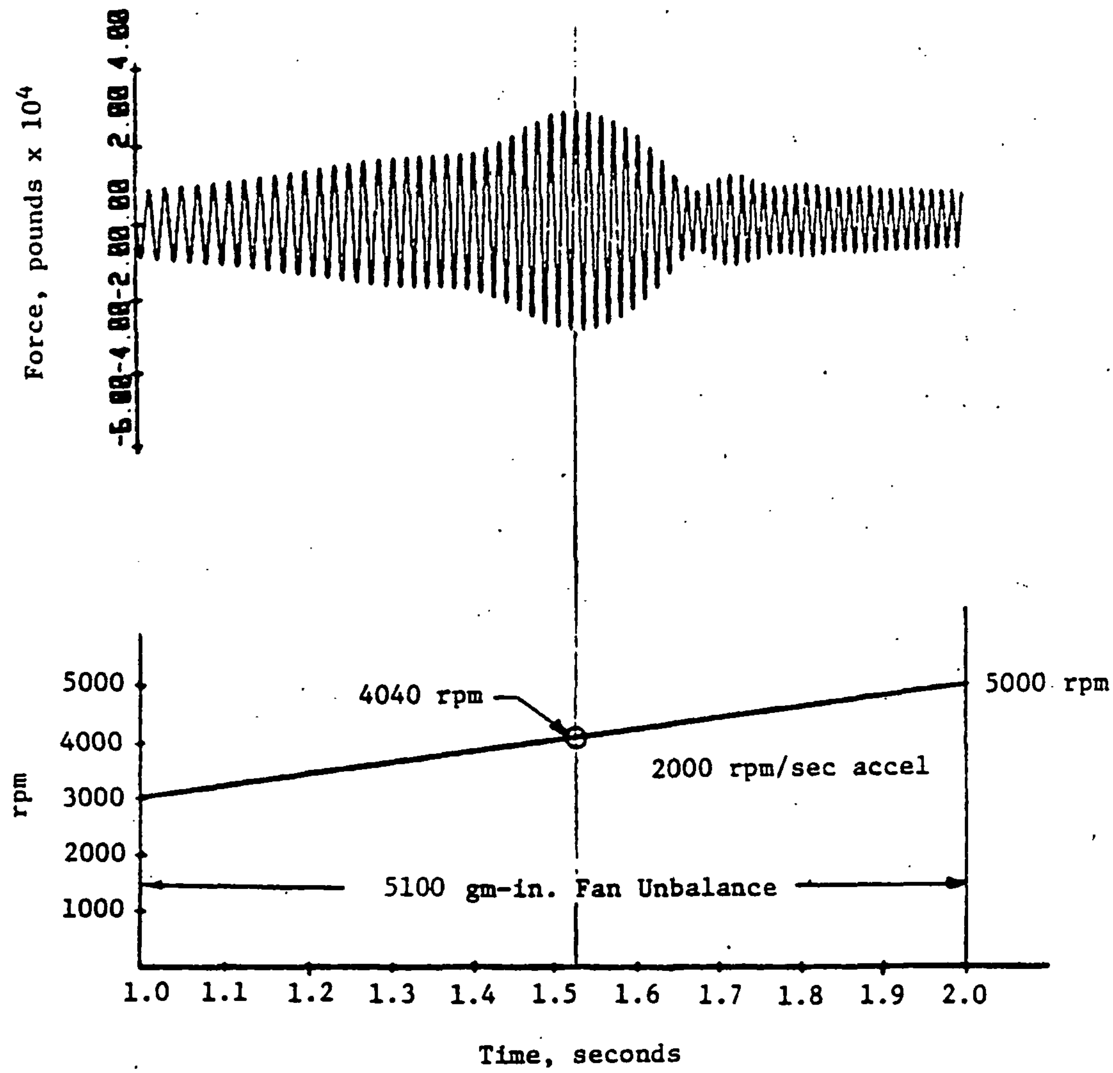


Figure 76. Force Exerted by the Forward Frame/Bearing (Spring 3) on the Rotor at Point 5 in the Vertical Direction for the NASA Demonstrator Model for 3000 to 5000 RPM Accel Segment. 10 Mil Radial Displacement Dead Band and 1×10^6 Lb/In. Rub Spring at the Fan Rotor Case (With Rub).

Initial constant speed runs were made for 0.520 second of simulated time with the rotor speed set at 1,000 rpm and with 100 gm-in. fan unbalance to establish steady-state conditions. For the 2,000 rpm/sec accel rate, the time required to accel from 1,000 to 5,000 rpm is

$$\frac{(5000-1000)\text{rpm}}{2000\text{ rpm/sec}} = 2\text{ seconds.}$$

With an integration time step of ΔT = 50 microseconds, the number of time steps required is equal to

$$\frac{2\text{ seconds}}{50 \times 10^{-6}\ \frac{\text{seconds}}{\text{time step}}} = 40{,}000\text{ time steps.}$$

For both cases a and b, two restart segments of 20,000 integration points each were used to compute the response for the 2 second accel from 1,000 to 5,000 rpm. For plotting purposes, the computed data were decimated so that each of the restart segment plots represents 2,000 points with a time increment between points equal to 50×10^{-5} seconds. This means that there are at least $(60/5000) \times 1/(50 \times 10^{-5}) = 24$ plotted points per cycle at the highest rotor speed (5,000 rpm). Although the plots are labeled 0 to 1.0 second for the accel from 1,000 to 3,000 rpm, the 0 time actually corresponds to 0.52 second. At a time of 0.6 second (labeled as 0.6 - 0.52 = 0.08 second), a large unbalance increment of 5000 gm-in. is added to represent sudden unbalance. It will be noted that the apparent critical speeds for the large clearance case (i.e., no rub) occur at higher rotor speeds than the steady-state values. The 3580 rpm speed corresponds to the 3292 rpm speed and the 3960 rpm corresponds to the 3624 rpm speed. The shifting of the peak response speeds is caused by the accel rate and this phenomenon is discussed in the literature.[1] The fan rub which is present for the small clearance case causes a stiffening effect that shifts the peak response to a higher speed.

(1) Vibration During Acceleration Through a Critical Speed, F.M. Lewis: Trans. ASME, Vol. 54, pp253-261, 1932.