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NASA CR-121276

FLEXIBLE ROTOR DYNAMICS ANALYSIS

by

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ROCKETDYNE DIVISION, ROCKWELL INTERNATIONAL

prepared for

NATIONAL AERONAUTICS AND SPACE ADMINISTRATION

NASA Lewis Research Center
Contract NAS3-14422
David P. Fleming, Project Manager

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P.O. Box 33
College Park, Md. 20740

1. Report No.	2. Government Accession No.	3. Recipient's Catalog No.
NASA CR-121276		

4. Title and Subtitle	5. Report Date
FLEXIBLE ROTOR DYNAMICS ANALYSIS	September 1973
	6. Performing Organization Code
7. Author(s)	8. Performing Organization Report No.
F. A. Shen	R-9252
	10. Work Unit No.
9. Performing Organization Name and Address	11. Contract or Grant No.
Rocketdyne Division/Rockwell International 6633 Canoga Avenue Canoga Park, California	NAS3-14422
	13. Type of Report and Period Covered
12. Sponsoring Agency Name and Address	Final, Feb 1971 to May 1973
National Aeronautics and Space Administration Washington, D.C. 20546	14. Sponsoring Agency Code

15. Supplementary Notes

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16. Abstract

A digital computer program was developed to analyze the general nonaxisymmetric and nonsynchronous transient and steady-state rotor dynamic performance of a bending- and shear-wise flexible rotor-bearing system under various operating conditions. The effects of rotor material mechanical hysteresis, rotor torsion flexibility, transverse effects of rotor axial and torsional loading and the anisotropic, in-phase and out-of-phase bearing stiffness and damping force and moment coefficients were included in the program to broaden its capability. An optimum solution method was found and incorporated in the computer program. Computer simulation of experimental data was made and qualitative agreements observed. The mathematical formulations, computer program verification, test data simulation, and user instruction was presented and discussed. The contract was a continuation of the work performed under Contract NAS3-13219 which provides a more detailed description in the mathematical analysis.

17. Key Words (Suggested by Author(s))		18. Distribution Statement
Rotor Dynamics	Nonsynchronous Whirl	
Flexible Rotor Dynamics	Anisotropic Stiffness	
Rotor Hysteresis	Out-of-Phase Stiffness	
Torsional Flexibility	Rotor Bearing System	
High-Speed Rotor		

19. Security Classif. (of this report)	20. Security Classif. (of this page)	21. No. of Pages	22. Price*
Unclassified	Unclassified	318	

* For sale by the National Technical Information Service, Springfield, Virginia 22151

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FOREWORD

This report was prepared by Rocketdyne, a division of Rockwell International, under National Aeronautics and Space Administration Contract NAS3-14422.

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SUMMARY

An 11-month study contract, NAS3-14422, was initiated to verify and increase the capability of the digital computer program developed from a previous contract, NAS3-13219. The objective of the present contract was to (1) experimentally verify the computer program developed from Contract NAS3-13219, (2) investigate different solution methods, (3) incorporate additional rotor dynamics parameters and (4) verify the expanded computer program.

The final computer program simulates many important dynamic properties of a real rotor-bearing system. Included in the program are the effects of:

1. Rotor slope coordinates

2. Rotor material mechanical hysteresis in transverse shear and bending and torsional shear mode using viscous and/or Coulomb friction hysteresis coefficients.

3. Torsional flexibility of rotor.

4. Rotor transverse effects due to torsional and axial loading.

5. Bearing in-phase and out-of-phase, anisotropic stiffness and damping force and moment coefficients.

6. Bearing mass.

7. Bearing transverse mass moment of inertia.

8. Mount in-phase, anisotropic stiffness and damping moment coefficients.

The program was written to analyze the general transient responses of nonsynchronous and nonaxisymmetric type rotor motion. The analysis of steady-state, synchronous and axisymmetric rotor motion can also be computed with the "HYSSTA" subroutine as a starting rotor-dynamic configuration.

Evaluation of the digital computer computational speed of several mathematic approaches and integration methods were made. The validity of the computer program and accuracy of results was substantiated.

Graphical (CRT) output capability is incorporated in the program. Detailed user's instructions are included in this report.

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INTRODUCTION

To further broaden the simulation capability and to improve the computational speed of the comptuer pgoram developed during contract NAS3-13219, an 11-month contract (NAS3-14422) was initiated. Extensions to the contract were subsequently made to incorporate additional useful rotor dynamics effects.

The major tasks accomplished in the contract were:

1. Comparison of the initial computer program with the experimental results from Mark-25 test data was made. While only qualitative agreements were observed between the analytical and the test results, the computer results were compared accurately with those from other independently written computer program.

2. Study of various mathematical approaches and integration techniques leading to a solution method which provides an optimum combination of computational speed and the predicted accuracy.

3. Incorporation of the following additional useful rotor dynamics effects:

    a. Generation and application of the rotor slope influence coefficients due to transient force and moment loading.

    b. Rotor mechanical hysteresis effects resulting from transverse shear strain. Viscous and/or Coulomb friction hysteresis coefficients may be applied.

    c. Rotor transverse performance due to torsional and axial loading. (This automatically leads to the torsionally flexible rotor model.)

    d. In-phase and out-of-phase anisotropic bearing stiffness and damping force and moment coefficients.

    e. Bearing mass and transverse mass moment of inertia.

    f. In-phase anisotropic mount stiffness and damping and force and moment coefficients.

4. Final computer program verification.

In Task (1), experimental verification of the computer program using Mark-25 test data was made. The Mark-25 pump rotor is a very rigid rotor that has very small deflections and the calibration of the instrumentation could not be checked at all points due to the limited number of spot faces on the rotor. Therefore only some qualitative agreements between the data and analysis were observed. The computer program results have been compared with those from an independently written steady-state computer program and found to be valid and accurate.

As a result of Task (2), the basic mathematical formulation for the computer program has been completely rewritten to accommodate the increase in new rotor dynamic parameters. Consequently, the size of the program has been substantially enlarged.

The computer program which was written and developed on the G.E. time share computing system was converted to an IBM 360/370 version. Although substantial efforts in checking out the major operation of the program have been made, verification of all details of the program was not practical within the time and cost constraints.

This final report presents the results of the computer program developed from 1 March 1971 through 15 April 1973.

The computer program, developed during this contract contains most of the major useful parameters believed to be required for close simulation of high speed flexible rotors. The program should provide a valuable tool for the analysis, design, and simulation of rotor-dynamic behavior.

Rocketdyne strongly recommends a formal experimental verification of the computer program to further substantiate its validity and to gain confidence in the program use.

THEORY - MATHEMATICAL FORMULATION

The governing mathematical formulation upon which the computer program was based is presented. There are two parts to the mathematical formulation; one is for the HYSSTA subroutine which generates the starting rotor dynamic configuration, and the other is for the computation of the rotor dynamic performance through integration techniques used in subroutine FUND. Each part of the formulation will be separately described; The coordinate systems used are described in Figs. 1 through 4.

I. MATHEMATICAL FORMULATION FOR SUBROUTINE HYSSTA

The mathematical formulation is based on a steady-state, axisymmetric rotor motion of a multiple-station rotor-bearing system having axisymmetric rotor and bearing geometry, elastic modulii, force and moment stiffness and damping characteristics. The basic assumptions in the mathematical formulation are the linear elasticity and small deflections in the elastic rotor. The formulation considers the following parameters:

1. Rotor transverse flexibility in shear and in bending.

2. Rotor masses including transverse and polar mass moments of inertia at each rotor station.

3. Rotor mass eccentricities and their corresponding phase angles.

4. Rotor mass inertial misalignment angles and their corresponding phase angles.

5. Two or more support bearings

6. Linear rotor elastic modulii and bearing and other rotor support stiffness and damping characteristics.

7. Bearing masses and transverse mass moments of inertia.

8. Bearing in-phase and out-of-phase stiffness and damping force and moment coefficients.

9. Mount in-phase stiffness and damping force and moment characteristics.

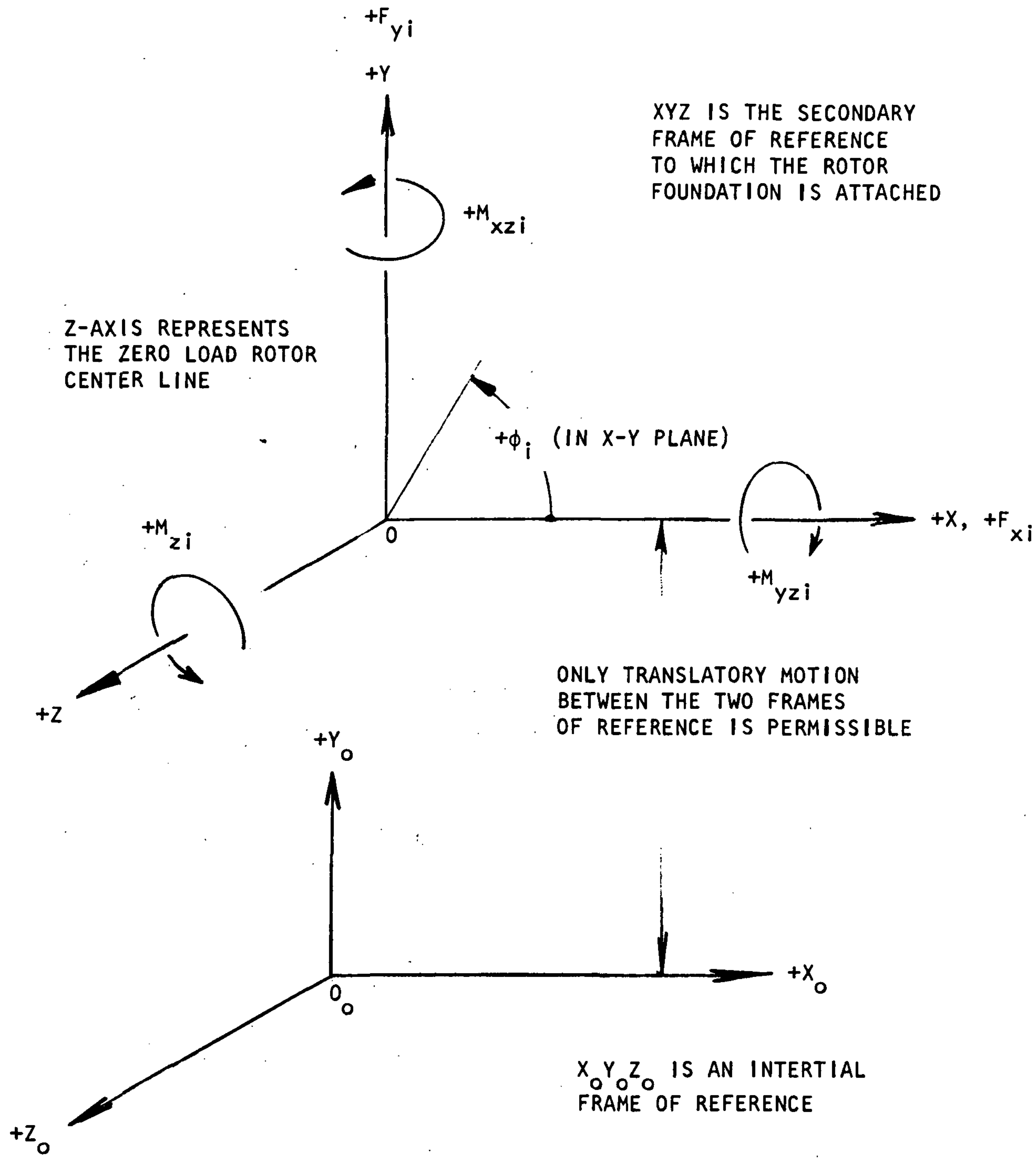


Figure 1. Relation Between the Secondary and an Inertial Frame of Reference

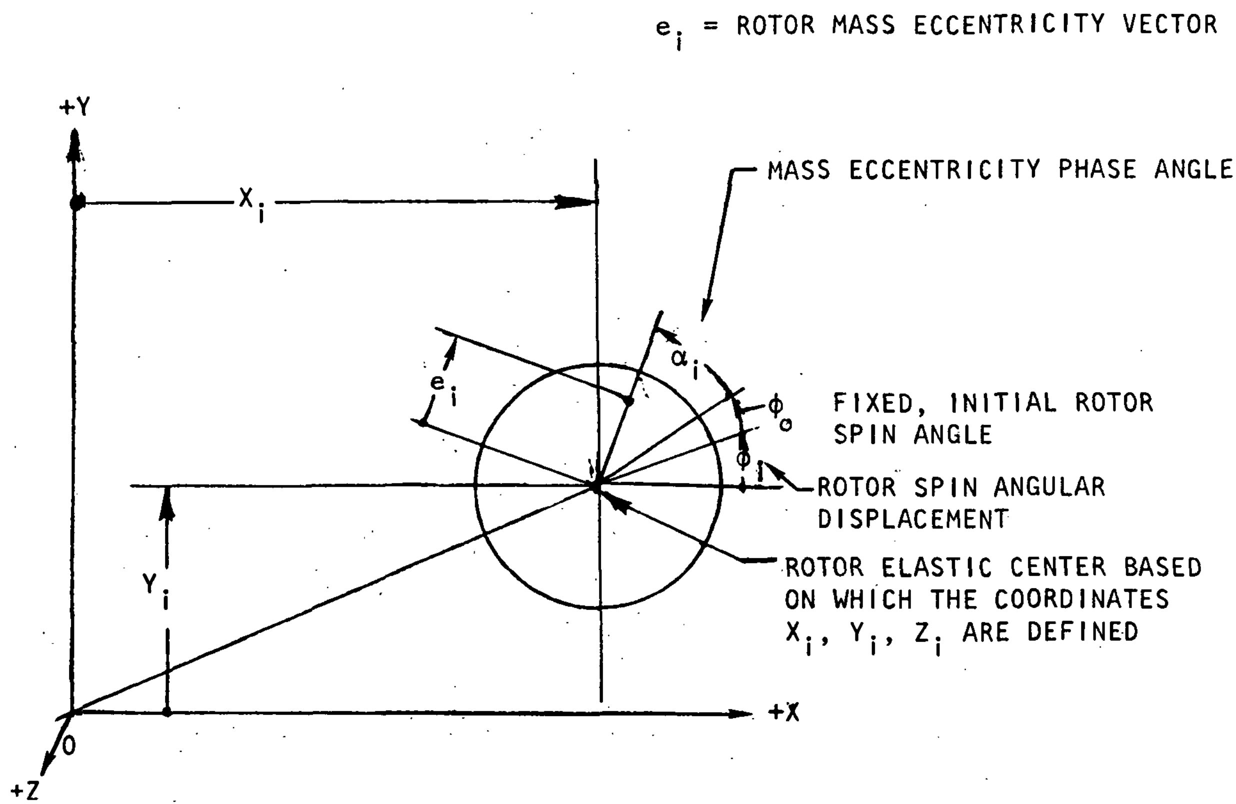


Figure 2. Rotor Transverse Coordinate Designation

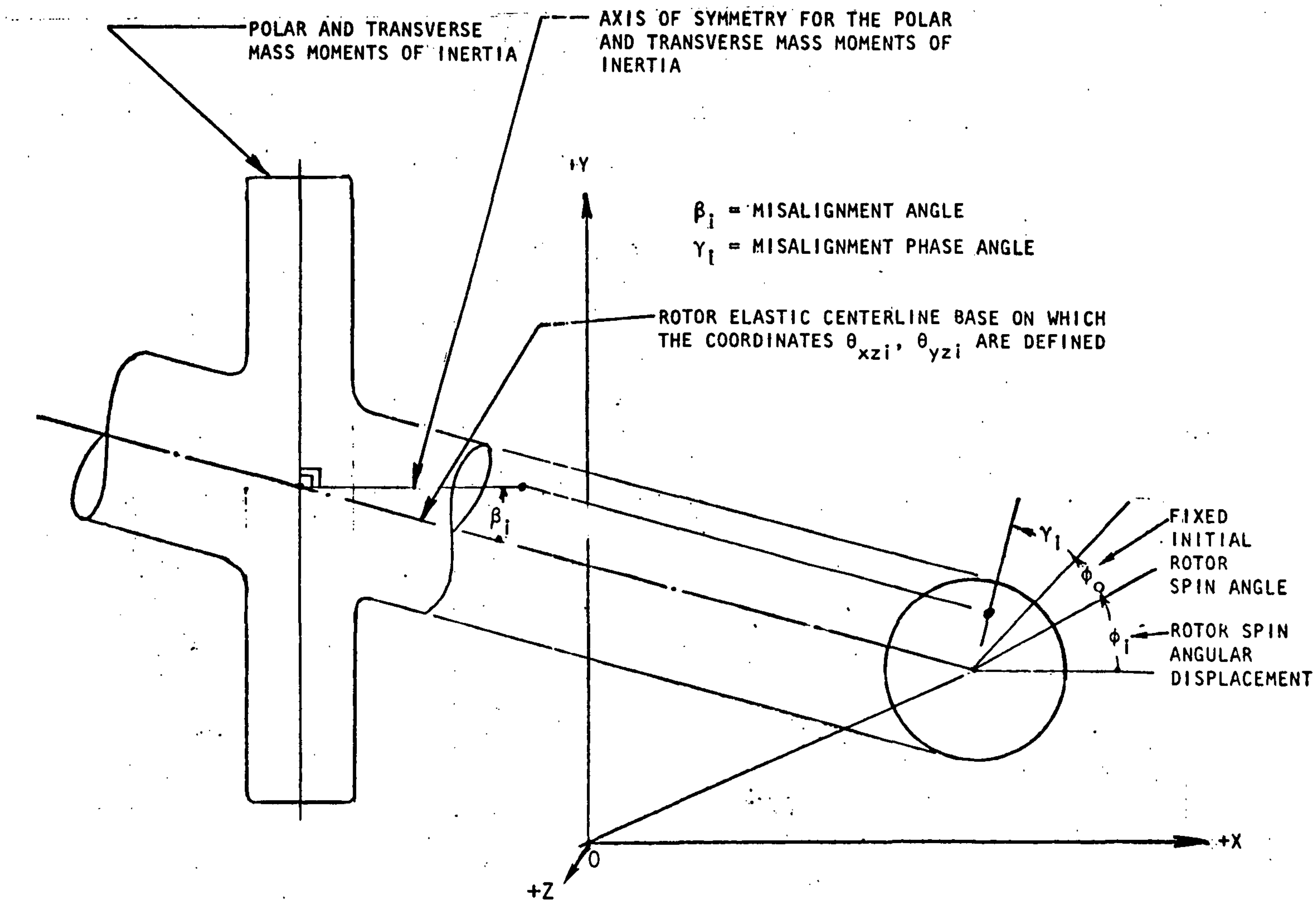
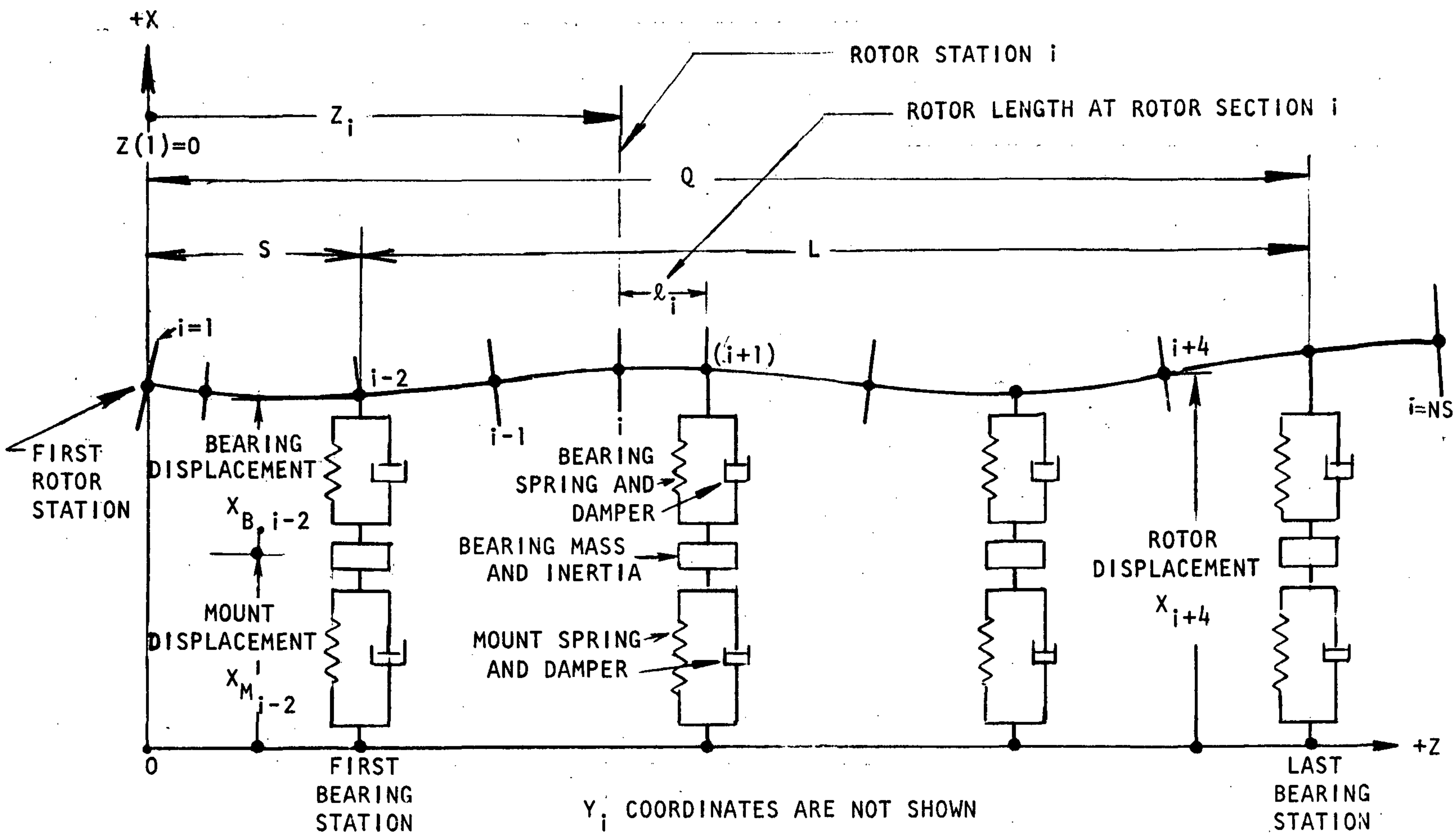


Figure 3. Rotor Slpe Coordinate Designation



THE COORDINATES X_i Y_i X_{Bi} Y_{Bi} X_{Mi} AND Y_{Mi} DO NOT NECESSARILY REPRESENT THE PHYSICAL DISTANCES AS SHOWN. THEY SHOULD BE INTERPRETED AS THE DISPLACEMENT FROM THEIR CORRESPONDING ZERO-LOAD POSITIONS.

Figure 4. Rotor Coordinates and Basic Notations

The following Eqs. (1) through (19) are used in HYSSTA and are solved simultaneously to obtain a starting rotor dynamic configuration, using predetermined ϕ_i values.

$$\ddot{\phi}_i \left[I_{\rho i} + m_i e_i^2 + I_{Di} \beta_i^2\right] +$$

$$m_i e_i \left[\left(\ddot{Y}_i + g_y\right) \cos\left(\phi_i + \alpha_i\right) - \left(\ddot{X}_i + g_x\right) \sin\left(\phi_i + \alpha_i\right)\right] +$$

$$I_{Di}\, \beta_i \left[\ddot{\theta}_{yzi} \cos\left(\phi_i + \gamma_i\right) - \ddot{\theta}_{xzi} \sin\left(\phi_i + \gamma_i\right)\right] -$$

$$I_{\rho i}\, \dot{\phi}_i\, \beta_i \left[\dot{\theta}_{yzi} \sin\left(\phi_i + \gamma_i\right) + \dot{\theta}_{xzi} \cos\left(\phi_i + \gamma_i\right)\right] = 0 \qquad (1)$$

$$
\begin{aligned}
-F_{xi} = m_i & \left\{ \ddot{X}_i + g_x - e_i \left[\ddot{\phi}_i \sin\left(\phi_i + \alpha_i\right) + \left(\dot{\phi}_i\right)^2 \cos\left(\phi_i + \alpha_i\right) \right] \right\} \\
& + \left[K_i X_i + C_i \dot{X}_i + K_{pi} Y_i + C_{pi} \dot{Y}_i \right] \\
& + \left[K_{HDi}\, Y_i \left(\dot{\phi}_i - K_{Fi}\, \omega_{Fi}\right) + C_{HDi}\, \dot{Y}_i \left(\dot{\phi}_i - C_{Fi}\, \omega_{Fi}\right) \right] \\
& + \left\{ \left(\dot{\phi}_i - \dot{\phi}_{oi}\right) \left[N_{BiK} + B_{BiK} \left(\sqrt{X_{Bi}^2 + Y_{Bi}^2} - \rho_{BiK} \right) \right] + K_{BiK} \right\} \left\{ C_{BiK} \left(\sqrt{X_{Bi}^2 + Y_{Bi}^2} - \rho_{BiK} \right)^{H_{BiK}} \right. \\
& \left. + D_{BiK} \left(\sqrt{X_{BiK}^2 + Y_{BiK}^2} - \rho_{BiK} \right) + E_{BiK} \right\} X_{Bi} \\
& + K_{EBxxi}\, X_{Bi} + K_{EBxyi}\, Y_{Bi} + C_{EBxxi}\, \dot{X}_{Bi} + C_{EBxyi}\, \dot{Y}_{Bi}
\end{aligned}
\tag{2}
$$

$$
\begin{aligned}
-F_{yi} = m_i & \left\{ \ddot{Y}_i + g_y + e_i \left[\ddot{\phi}_i \cos\left(\phi_i + \alpha_i\right) - \left(\dot{\phi}_i\right)^2 \sin\left(\phi_i + \alpha_i\right) \right] \right\} \\
& + \left[K_i Y_i + C_i \dot{Y}_i - K_{pi} X_i - C_{pi} \dot{X}_i \right] \\
& - \left[K_{HDi}\, X_i \left(\dot{\phi}_i - K_{Fi}\, \omega_i\right) + C_{HDi}\, \dot{X}_i \left(\dot{\phi}_i - C_{Fi}\, \omega_i\right) \right] \\
& + \left\{ \left(\dot{\phi}_i - \dot{\phi}_{oi}\right) \left[N_{BiK} + B_{BiK} \left(\sqrt{X_{Bi}^2 + Y_{Bi}^2} - \rho_{BiK} \right) \right] + K_{BiK} \right\} \left\{ C_{BiK} \left(\sqrt{X_{Bi}^2 + Y_{Bi}^2} - \rho_{BiK} \right)^{H_{BiK}} \right. \\
& \left. + D_{BiK} \left(\sqrt{X_{BiK}^2 + Y_{BiK}^2} - \rho_{BiK} \right) + E_{BiK} \right\} Y_{Bi} \\
& + K_{EBxxi}\, Y_{Bi} - K_{EBxyi}\, X_{Bi} + C_{EBxxi}\, \dot{Y}_{Bi} - C_{EBxy}\, \dot{X}_{Bi}
\end{aligned}
\tag{3}
$$

where

$$K_{EBxxi} = 1/2\ (K_{Bxxi} + K_{Byyi}) \tag{3a}$$

$$K_{EBxyi} = 1/2\ (K_{Bxyi} + K_{Byxi}) \tag{3b}$$

$$C_{EBxxi} = 1/2\ (C_{Bxxi} + C_{Byyi}) \tag{3c}$$

$$C_{EBxyi} = 1/2\ (C_{Bxyi} + C_{Byxi}) \tag{3d}$$

$$\begin{aligned}
- M_{xzi} = {} & I_{Di}\ddot{\theta}_{xzi} + I_{\rho i}\ \dot{\theta}_{zyi}\ \dot{\phi}_i \\
& + \beta_i\ (I_{\rho i} - I_{Di})\ \left[\ddot{\phi}_i\ \sin\left(\phi_i + \gamma_i\right) + \left(\dot{\phi}_i\right)^2 \cos\left(\phi_i + \gamma_i\right)\right] \\
& + K_{\phi i}\ \theta_{xzi} + C_{\phi i}\ \dot{\theta}_{xzi} + K_{\phi pi}\ \theta_{yzi} + C_{\phi pi}\ \dot{\theta}_{yzi} \\
& + K_{\phi HDi}\ \theta_{yzi}\ \left(\dot{\phi}_i - K_{\phi Mi}\ \omega_{Mi}\right) + C_{\phi HDi}\ \dot{\theta}_{yzi}\ \left(\dot{\phi}_i - C_{\phi Mi}\ \omega_{Mi}\right) \\
& + K_{EB\phi xxi}\ \theta_{Bxzi} + K_{EB\phi xyi}\ \theta_{Byzi} + C_{EB\phi xxi}\ \dot{\theta}_{Bxzi} + C_{EB\phi xyi}\ \dot{\theta}_{Byzi}
\end{aligned} \tag{4}$$

$$\begin{aligned}
- M_{yzi} = {} & I_{Di}\ \ddot{\theta}_{yzi} - I_{\rho i}\ \dot{\theta}_{xzi}\ \dot{\phi}_i \\
& + \beta_i\ \left(I_{\rho i} - I_{Di}\right)\ \left[-\ddot{\phi}_i\ \cos\left(\phi_i + \gamma_i\right) + \left(\dot{\phi}_i\right)^2 \sin\left(\phi_i + \gamma_i\right)\right] \\
& + K_{\phi i}\ \theta_{yzi} + C_{\phi i}\ \dot{\theta}_{yzi} - K_{\phi pi}\ \theta_{xzi} - C_{\phi pi}\ \dot{\theta}_{xzi} \\
& - \left[K_{\phi HDi}\ \theta_{xzi}\ \left(\dot{\phi}_i - K_{\phi Mi}\ \omega_{Mi}\right) + C_{\phi HDi}\ \dot{\theta}_{xzi}\ \left(\dot{\phi}_i - C_{\phi Mi}\ \omega_{Mi}\right)\right] \\
& + K_{EB\phi xxi}\ \theta_{Byzi} - K_{EB\phi xyi}\ \theta_{Bxzi} + C_{EB\phi xxi}\ \dot{\theta}_{Byzi} - C_{EB\phi xyi}\ \dot{\theta}_{Bxzi}
\end{aligned} \tag{5}$$

where

$$K_{EB\phi xxi} = 1/2\ (K_{B\phi xxi} + K_{B\phi yyi}) \tag{5a}$$

$$K_{EB\phi xyi} = 1/2\ (K_{B\phi xyi} + K_{B\phi yxi}) \tag{5b}$$

$$C_{EB\phi xxi} = 1/2\ (C_{B\phi xxi} + C_{B\phi yyi}) \tag{5c}$$

$$C_{EB\phi xyi} = 1/2\ (C_{B\phi xyi} + C_{B\phi yxi}) \tag{5d}$$

$$\sum_{i=1}^{n} \left[F_{xi} C_{ij} + M_{xzi} b_{ij}\right] + X_{b1} + \left(X_{bNB} - X_{b1}\right) \frac{Z_j - S}{L} - X_j = 0 \tag{6}$$

$$\sum_{i=1}^{n} \left[F_{yi} C_{ij} + M_{yzi} b_{ij}\right] + Y_{b1} + \left(Y_{bNB} - Y_{b1}\right) \frac{Z_j - S}{L} - Y_j = 0 \tag{7}$$

$$\sum_{i=1}^{n} \left[F_{xi} T_{Fij} + M_{xzi} T_{Mij}\right] + \frac{X_{bNB} - X_{b1}}{L} - \theta_{Bxzj} = 0 \tag{8}$$

$$\sum_{i=1}^{n} \left[F_{yi} T_{Fij} + M_{yzi} T_{Mij}\right] + \frac{Y_{bNB} - Y_{b1}}{L} - \theta_{Byzj} = 0 \tag{9}$$

$$\sum_{i=1}^{n} \left[\left(Q - Z_i\right) F_{xi} - M_{xzi}\right] = 0 \tag{10}$$

$$\sum_{i=1}^{n} F_{xi} = 0 \tag{11}$$

$$\sum_{i=1}^{n} \left[\left(Q - Z_i\right) F_{yi} - M_{yzi}\right] = 0 \tag{12}$$

$$\sum_{i=1}^{n} F_{yi} = 0 \tag{13}$$

$$K_{EBxxi} X_{Bi} + K_{EBxyi} Y_{Bi} + C_{EBxxi} \dot{X}_{Bi} + C_{EBxyi} \dot{Y}_{Bi} - m_{Bi} \ddot{X}_{Mi} - K_{Mi} X_{Mi} - C_{Mi} \dot{X}_{Mi} = 0 \tag{14}$$

$$K_{EBxxi} Y_{Bi} - K_{EByxi} X_{Bi} + C_{EByyi} \dot{Y}_{Bi} - C_{EByxi} \dot{X}_{Bi} - m_{Bi} \ddot{Y}_{Mi} - K_{Mi} Y_{Mi}$$

$$- C_{Mi} \dot{Y}_{Mi} = 0 \tag{15}$$

$$K_{EB\phi xxi} \theta_{Bxzi} + K_{EB\phi xyi} \theta_{Byzi} + C_{EB\phi xxi} \dot{\theta}_{Bxzi} + C_{EB\phi xyi} \dot{\theta}_{Byzi}$$

$$- I_{Bi} \ddot{\theta}_{Bxyi} - K_{\phi Mi} \theta_{Mxzi} - C_{\phi Mi} \dot{\theta}_{Mxzi} = 0 \tag{16}$$

$$K_{EB\phi yyi} \theta_{Byzi} - K_{EB\phi \quad i} \theta_{Bxzi} - C_{EB\phi \quad i} \dot{\theta}_{Byzi} + C_{EB\phi \quad i} \dot{\theta}_{B \; zi}$$

$$- I_{Bi} \ddot{\theta}_{Byzi} - K_{\phi Mi} \theta_{Myzi} - C_{\phi Mi} \dot{\theta}_{Myzi} = 0 \tag{17}$$

where

$$K_{Mi} = 1/2 \; (K_{Mxi} + K_{Myi}) \tag{17a}$$

$$C_{Mi} = 1/2 \; (C_{Mxi} + C_{Myi}) \tag{17b}$$

$$K_{\phi Mi} = 1/2 \; (K_{\phi Mxi} + K_{\phi Myi}) \tag{17c}$$

$$C_{\phi Mi} = 1/2 \; (C_{\phi Mxi} + C_{\phi Myi}) \tag{17d}$$

$$\omega_{Fi} = \frac{\dot{Y}_i X_i - \dot{X}_i Y_i}{X_i^2 + Y_i^2} \tag{18}$$

$$\omega_{Mi} = \frac{\dot{\theta}_{yzi} \theta_{xzi} - \dot{\theta}_{xzi} \theta_{yzi}}{\theta_{xzi}^2 + \theta_{yzi}^2} \tag{19}$$

II. MATHEMATICAL FORMULATION FOR SUBROUTINE FUND

The subroutine FUND is a time derivative generating subroutine based on the input parameters supplied by integration subroutines RKADAM. Thus the purpose of the mathematical formulation for FUND is to compute the corresponding accelerations from the displacements and velocities furnished by RKADAM.

The formulation used in FUND is the most efficient one selected among various techniques investigated. It is a straight solution method without using simultaneous equations approach that proved to be a more time-consuming method.

The mathematical formulation used in FUND with its nomenclature discribed in Fig. 5 , consists of Eqs. (2) through (5) and (14) through (33).

$$X_{i+1} - X_i = \ell_i \theta_{xzi} - \left(\frac{\alpha'_i \ell_i}{A'_i G_i} + \frac{\ell_i^3}{3E_i I_i} \right) S'_{x,i+1} + \frac{\ell_i^2}{2E_i I_i} M'_{xz,i+1} \tag{20}$$

$$Y_{i+1} - Y_i = \ell_i \theta_{yzi} - \left(\frac{\alpha'_i \ell_i}{A'_i G_i} + \frac{\ell_i^3}{3E_i I_i} \right) S'_{y,i+1} + \frac{\ell_i^2}{2E_i I_i} M'_{yz,i+1} \tag{21}$$

$$\theta_{xz,i+1} - \theta_{xzi} = - \frac{\ell_i^2}{2E_i I_i} S'_{x,i+1} + \frac{\ell_i}{E_i I_i} M'_{xz,i+1} \tag{22}$$

$$\theta_{yz,i+1} - \theta_{yzi} = - \frac{\ell_i^2}{2E_i I_i} S'_{y,i+1} + \frac{\ell_i}{E_i I_i} M'_{yz,i+1} \tag{23}$$

$$F_{xi} = S'_{x,i+1} - S'_{xi} \tag{24}$$

$$F_{yi} = S'_{y,i+1} - S'_{yi} \tag{25}$$

$$M_{xzi} = - M'_{xz,i+1} + M'_{xzi} + S'_{x,i+1} \ell_i \tag{26}$$

$$M_{yzi} = - M'_{yz,i+1} + M'_{yzi} + S'_{y,i+1} \ell_i \tag{27}$$

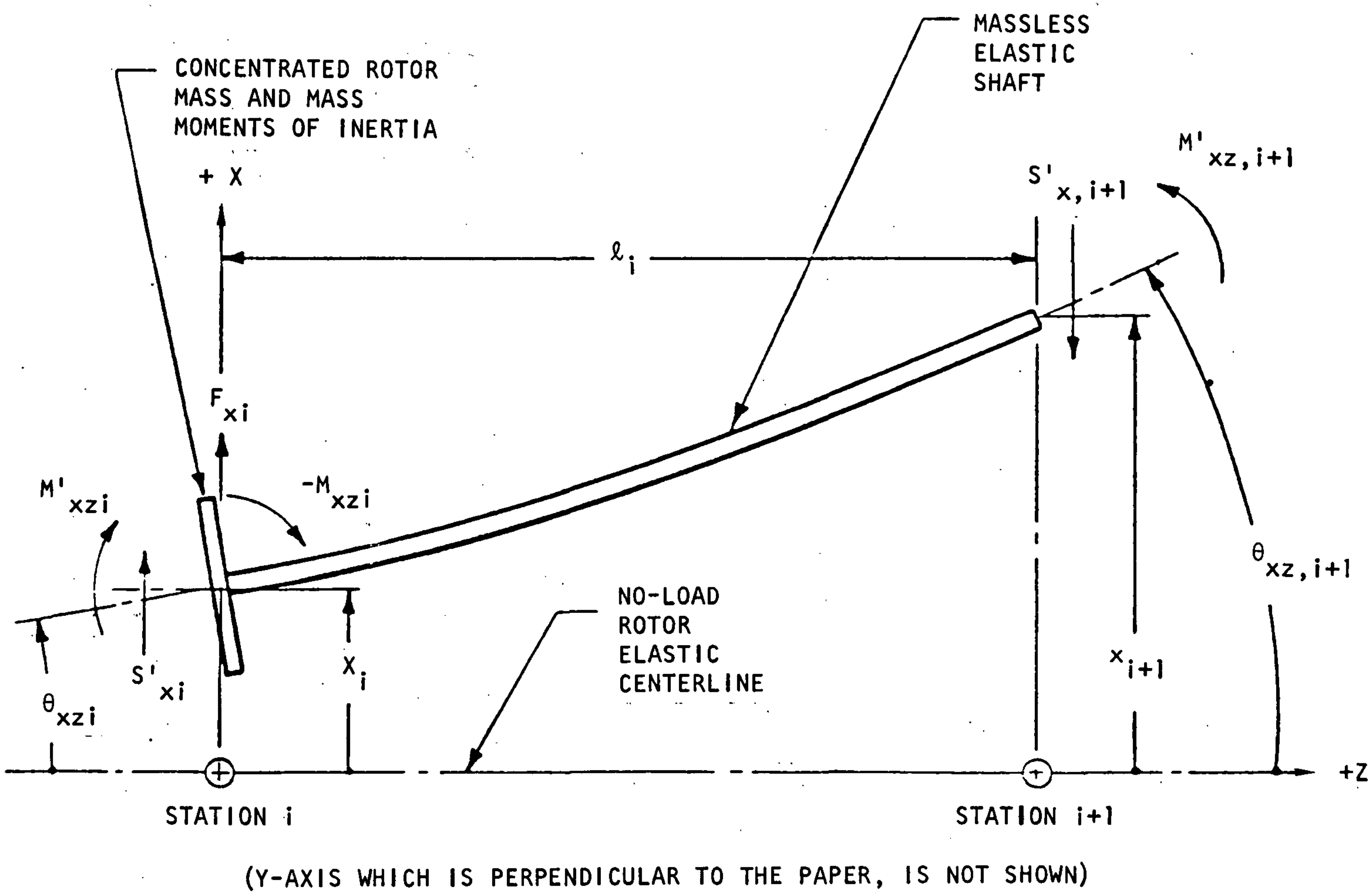


Figure 5. Rotor Dynamic Configuration for the New Solution Method Used in the Computer Program

$$\ddot{\phi}_i \left[I_{\rho i} + m_i e_i^2 + I_{Di}\ \beta_i^2\right] + \quad \text{(a)}$$

$$m_i e_i \left[\left(\ddot{Y}_i + g_y\right) \cos\left(\phi_i + \alpha_i\right) - \left(\ddot{X}_i + g_x\right) \sin\left(\phi_i + \alpha_i\right)\right] + \quad \text{(b)}$$

$$I_{Di}\ \beta_i \left[\ddot{\theta}_{yzi} \cos\left(\phi_i + \gamma_i\right) - \theta_{xzi} \sin\left(\phi_i + \gamma_i\right)\right] - \quad \text{(c)}$$

$$I_{\rho i}\ \dot{\phi}_i\ \beta_i \left[\dot{\theta}_{yzi} \sin\left(\phi_i + \gamma_i\right) + \dot{\theta}_{xzi} \cos\left(\phi_i + \gamma_i\right)\right] \quad \text{(d)}$$

$$+ C_{T1i}\ \dot{\phi}_i^{C_{Ti}} + C_{T2i}\ \dot{\phi}_i \quad \text{(e)}$$

$$- K_{Ti} \left(\phi_{i+1} - \phi_i\right) + K_{T,i-1} \left(\phi_i - \phi_{i-1}\right) \quad \text{(f)}$$

$$- C_{TVi} \left(\dot{\phi}_{i+1} - \dot{\phi}_i\right) + C_{TV,i-1} \left(\dot{\phi}_i - \dot{\phi}_{i-1}\right) \quad \text{(g)}$$

$$- C_{TCi} \frac{\dot{\phi}_{i+1} - \dot{\phi}_i}{|\dot{\phi}_{i+1} - \dot{\phi}_i|} + C_{TC,i-1} \frac{\dot{\phi}_i - \dot{\phi}_{i-1}}{|\dot{\phi}_i - \dot{\phi}_{i-1}|} \quad \text{(h)}$$

$$- \left[M_{T1i}\phi_i^{\ M_{Ti}} + M_{T2i}\phi_i + A_{Ti} + B_{Ti}\ t + D_{Ui}\ t^{H_{Ti}} + E_{Ti}\mathrm{SIN}\left(F_{Ti}t + G_{Ti}\right)\right] \quad \text{(i)}$$

$$- \mathrm{TORHFM}_i \quad \text{(j)}$$

$$= 0 \quad (28)$$

where

$$C_{TVi} = \pi/32\ (D_{oi}^{\ 4} - D_{Ii}^{\ 4})\ \mu_{TVi}/\ell_i \quad \textbf{(29)}$$

$$C_{TCi} = \pi/12\ (D_{oi}^{\ 3} - D_{Ii}^{\ 3})\ \mu_{TCi} \quad (30)$$

$$M_{Txzi} = -\ (\theta_{yz,i+1} - \theta_{yzi})\ T\phi RQ_i \quad (31)$$

$$M_{Tyzi} = (\theta_{xz,i+1} - \theta_{xzi})\ T\phi RQ_i \tag{32}$$

$$T\phi RQ_i = K_{Ti}\ (\phi_{i+1} - \phi_i) + C_{TVi}\ (\dot{\phi}_{i+1} - \dot{\phi}_i) + C_{TCi}\ \frac{(\dot{\phi}_{i+1} - \dot{\phi}_i)}{|\dot{\phi}_{i+1} - \dot{\phi}_i|} \tag{33}$$

The mathematical formulation used for the rotor material mechanical hysteresis effects due to in-plane (in-phase effects) and/or rotational (out-of-phase effects) rotor strain, is presented in Eqs. (34) through (47). Both the viscous and Coulomb friction models representing the hysteresis effects are included as denoted by subscripts V and C, respectively.

$$F_{xHSVi} = \frac{\mu_{SVi}}{G_i} \left[\dot{F}_{xi} + (\dot{\phi}_i - \omega_{Fi})\ F_{yi}\right] \tag{34}$$

$$F_{yHSVi} = \frac{\mu_{SVi}}{G_i} \left[\dot{F}_{yi} - (\dot{\phi}_i - \omega_{Fi})\ F_{xi}\right] \tag{35}$$

$$M_{xHBVi} = \frac{\mu_{BVi}}{E_i} \left[\dot{M}_{xzi} + (\dot{\phi}-\omega_{Mi})\ M_{yzi}\right] \tag{36}$$

$$M_{yHBVi} = \frac{\mu_{BVi}}{E_i} \left[\dot{M}_{yzi} - (\dot{\phi}_i - \omega_{Mi})\ M_{xzi}\right] \tag{37}$$

$$F_{xHBVi} = \frac{\mu_{BVi}}{E_i} \left[\dot{F}_{xi} + (\dot{\phi} - \omega_{Fi})\ F_{yi}\right] \tag{38}$$

$$F_{yHBVi} = \frac{\mu_{BVi}}{E_i} \left[\dot{F}_{yi} - (\dot{\phi} - \omega_{Fi})\ F_{xi}\right] \tag{39}$$

$$F_{xHSCi} = \frac{\mu_{SCi}}{G_i} \left[|F_{xi}|\ \frac{\dot{F}_{xi}}{|\dot{F}_{xi}|} + \frac{\dot{\phi}_i-\omega_{Fi}}{|\dot{\phi}_i-\omega_{Fi}|}\ F_{yi}\right] \tag{40}$$

$$F_{yHSCi} = \frac{\mu_{SCi}}{G_i} \left[|F_{yi}| \frac{\dot{F}_{yi}}{|\dot{F}_{yi}|} - \frac{\dot{\phi}_i - \omega_{Fi}}{|\dot{\phi}_i - \omega_{Fi}|} F_{xi} \right] \tag{41}$$

$$M_{xHBCi} = \frac{\mu_{BCi}}{E_i} \left[|M_{xzi}| \frac{\dot{M}_{xzi}}{|\dot{M}_{xzi}|} + \frac{\dot{\phi}_i - \omega_{Mi}}{|\dot{\phi}_i - \omega_{Mi}|} M_{yzi} \right] \tag{42}$$

$$M_{yHBCi} = \frac{\mu_{BCi}}{E_i} \left[|M_{yzi}| \frac{\dot{M}_{yzi}}{|\dot{M}_{yzi}|} \quad \frac{\dot{\phi}_i - \omega_{Mi}}{|\dot{\phi}_i - \omega_{Mi}|} M_{xzi} \right] \tag{43}$$

$$F_{xHBCi} = \frac{\mu_{BCi}}{E_i} \left[|F_{xi}| \frac{\dot{F}_{xi}}{|\dot{F}_{xi}|} + \frac{\dot{\phi}_i - \omega_{Fi}}{|\dot{\phi}_i - \omega_{Fi}|} F_{yi} \right] \tag{44}$$

$$F_{yHBCi} = \frac{\mu_{BCi}}{E_i} \left[|F_{yi}| \frac{\dot{F}_{yi}}{|\dot{F}_{xi}|} - \frac{\dot{\phi}_i - \omega_{Fi}}{|\dot{\phi} - \omega_{Fi}|} F_{xi} \right] \tag{45}$$

$$P_i = A_{Ai} + B_{Ai}t + D_{Ai}t^{H_A} + E_{Ai}\ \mathrm{SIN}\ (F_A t + G_A) \tag{46}$$

$$\begin{aligned} TORHFM_i = {} & + F_{yHL,i+1} (X_{i+1} - X_i) - F_{xHL,i+1} (Y_{i+1} - Y_i) \\ & - F_{yHR,i-1} (X_i - X_{i-1}) + F_{xHR,i-1} (Y_i - Y_{i-1}) \\ & + M_{yHL,i+1} (\theta_{xz,i+1} - \theta_{xzi}) - M_{xHL,i+1} (\theta_{yz,i+1} - \theta_{yzi}) \\ & - M_{yHR,i-1} (\theta_{yzi} - \theta_{yz,i-1}) + M_{xHR,i-1} (\theta_{xzi} - \theta_{xz,i-1}) \end{aligned} \tag{47}$$

Equations (20) through (47) are used to solve for $\ddot{X}_i$, $\ddot{Y}_i$, $\ddot{\theta}_{xzi}$ and $\ddot{\theta}_{yzi}$ which are required for subroutine RKDAM. The ϕ_i are determined from Eq. (28) using the computed values of $\ddot{X}_i$, $\ddot{Y}_i$, $\ddot{\theta}_{xzi}$ and $\ddot{\theta}_{yzi}$. While not mathematically exact, this procedure for computing $\ddot{\phi}_i$, $\ddot{X}_i$, $\ddot{Y}_i$, $\ddot{\theta}_{xzi}$ and $\ddot{\theta}_{yzi}$ has been demonstrated to give accurate results with substantial time saving over a simultaneous solution method which is a mathematically rigorous procedure.

COMPUTER PROGRAM STUDY AND ITS VERIFICATION

I. VERIFICATION OF THE EXISTING PROGRAM

The computer program developed under contract NAS3-13219 was to be verified by simulating a Mark-25 liquid hydrogen pump rotor dynamic test performance.

The simulation of the balancing data for the Mark 25 pump, without the inducer, was made for four combinations of speed and unbalance conditions. A comparison of the results with the test data indicates approximate agreement as shown in Tables I and II and Figs. 6 through 9 .

The unbalance configurations, designated as I and II, are defined in Table III; the Mark-25 rotor contour, including its balancing and the deflection stations, is described in Fig. 10 .

The comparison of test data with computer results indicates that substantial deviations exist at certain rotor stations. The degree of correlation varies among the four cases. With the exception of the deflection at rotor station 7 for the unbalance configuration I, Fig. 6 , 7 and 9 indicate reasonable agreement in rotor deflection amplitude, while Fig. 7 shows approximate correlation in phase angles between the test data and computer results.

To establish the validity of the computer program, a separate run from a previously written steady-state rotor dynamic response computer program based on a different approach was made. The rotor deflections computed with the steady-state program are within 0.2% and the phase angles within 0.06 degrees of those computed with the present program. The steady-state program has been verified with other experimental data and found to be accurate. Thus, the discrepancies between the Mark-25 test data and the computer results could be due to the inaccuracies of the test data.

In examining the test data, particularly in Figs. 6 and 7 , it was observed that the rotor deflection at station 7 was substantially greater than the deflection at adjacent stations 5 and 12. This would not be realistic since with the large diameter portion of the rotor being sufficiently rigid, the deflection at station 7 should not be much more than that at station 5 or 12 as demonstrated in the computer results. There are several possible causes for the inaccuracy of the test data. In reviewing the data tape, extensive DC drifts of the parameters were observed which may result in amplifier overloading and give rise to invalid scaled data. In the test data acquisition, a calibration spotface on the rotor was provided only at one Bently transducer location near station 17. Hence, it is possible that calibration of the Bently transducers at other stations may deviate from the standard value, thus causing erroneous scaling.

It was also observed on the reduced test data that considerable noise and occasional variations in wave form existed. Difficulties have been experienced in deriving accurate rotor deflection and phase angle data where the magnitude of noise and wave irregularities were substantial in comparison with that of

TABLE I - COMPARISON OF TEST DATA WITH COMPUTER RESULTS (IN SI UNITS)

*UNBALANCE CONFIGURATION	STEADY-STATE OPERATING SPEED, RPM	COMPUTER MODEL ROTOR STATION	COMPUTER RESULTS		TEST DATA	
			ROTOR DEFLECTION VECTOR, 10^{-6} METERS	DEFLECTION VECTOR PHASE ANGLE, RADIANS	ROTOR DEFLECTION VECTOR, 10^{-6} METERS	DEFLECTION VECTOR PHASE ANGLE, RADIANS
I	30,000	5	9.3802	2.9065	10.16	.09
		7	10.2370	2.9016	23.70	4.19
		12	10.0602	2.8946	**INCONSISTENT DATA	
		17	8.2987	2.9533	11.00	3.14
	34,000	5	7.6848	6.03505	10.16	5.94
		7	8.5126	6.0428	22.90	4.54
		12	8.2616	6.0540	10.16	5.76
		17	7.6004	5.9682	5.08	0.122 OR 6.405
II	28,000	5	3.3973	3.2465	12.70	5.59
		7	3.6871	3.2634	6.78	5.94
		12	3.6723	3.2995	7.62	1.75
		17	3.4158	3.3873	12.70	2.44
	30,000	5	8.4099	3.2622	11.85	5.76
		7	9.1857	3.2706	8.46	5.76
		12	9.0594	3.2882	6.78	5.06
		17	8.0795	3.3331	8.46	5.41

*AS DEFINED IN TABLE 3

**A FREQUENCY AT TWICE THE ROTATIVE SPEED WAS OBSERVED AT THIS STATION ONLY

Table II - COMPARISON OF TEST DATA WITH COMPUTER RESULTS
(SECONDARY SYSTEM: INCH AND DEGREE)

*UNBALANCE CONFIGURATION	STEADY-STATE OPERATING SPEED, RPM	COMPUTER MODEL ROTOR STATION NUMBER	COMPUTER RESULTS		TEST DATA	
			ROTOR DEFLECTION VECTOR, INCHES	DEFLECTION VECTOR PHASE ANGLE, DEGREES	ROTOR DEFLECTION VECTOR, INCHES	DEFLECTION VECTOR PHASE ANGLE, DEGREES
I	30,000	5	.00036910	166.53	.00040	5
		7	.00040303	166.25	.000933	240
		12	.00039607	165.85	**INCONSISTENT DATA	
		17	.00032672	169.21	.000433	180
	34,000	5	.00030255	345.783	.0004	340
		7	.00033514	346.228	.0009	260
		12	.00032526	346.869	.0004	330
		17	.00029923	341.953	.0002	7 OR 367
II	28,000	5	.00013375	186.01	.0005	320
		7	.00014516	186.98	.000267	340
		12	.00014458	189.05	.0003	100
		17	.00013448	194.08	.0005	140
	30,000	5	.00033110	186.91	.000467	330
		7	.00036164	187.39	.000333	330
		12	.00035667	188.40	.000267	290
		17	.00031809	190.97	.000333	310

*AS DEFINED IN TABLE 3

**A FREQUENCY AT TWICE THE ROTATIVE SPEED WAS OBSERVED AT THIS STATION ONLY

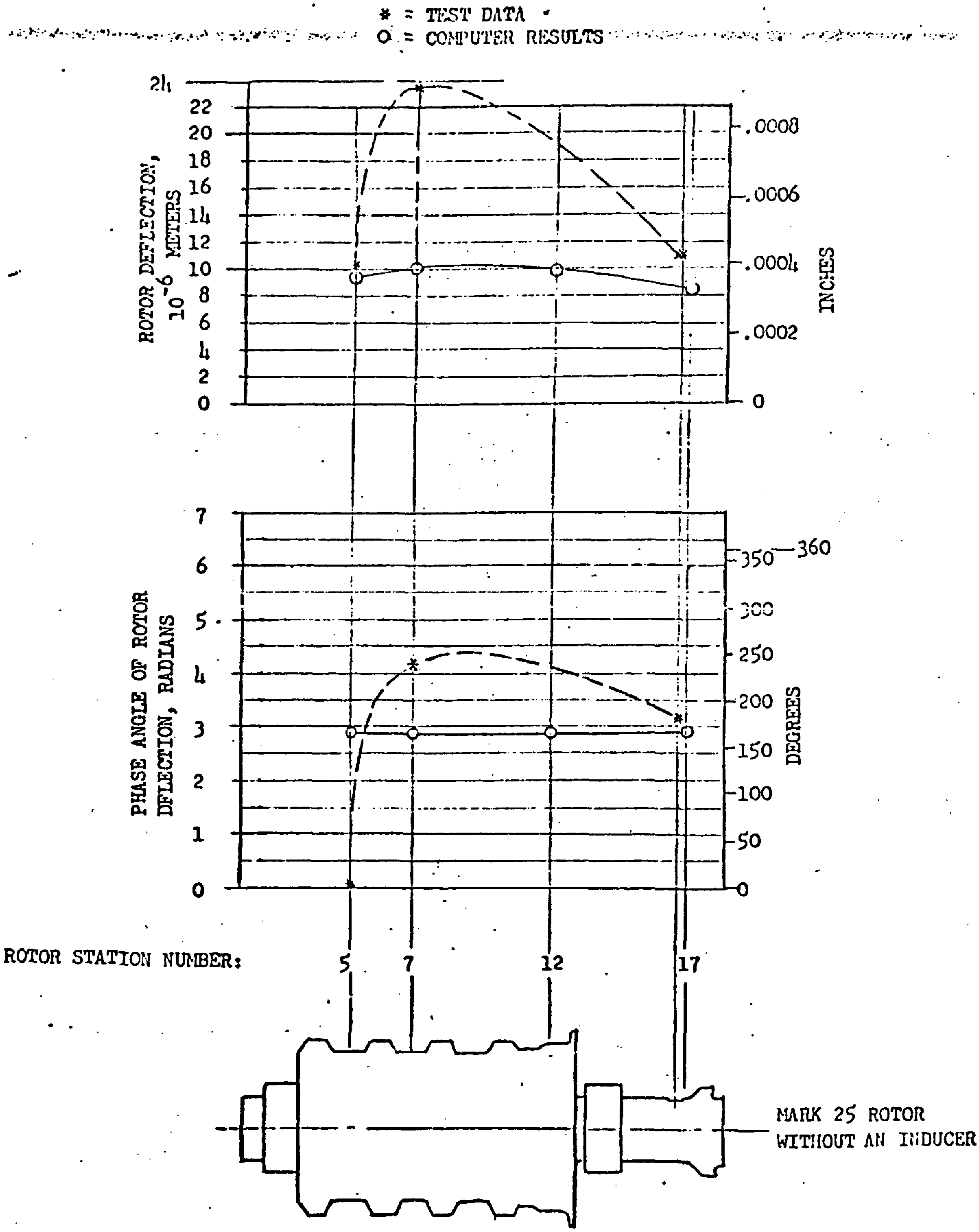


Figure 6. Comparison Between the Test Data and Computer Results for Unbalance Configuration I and the Speed of 30,000 rpm

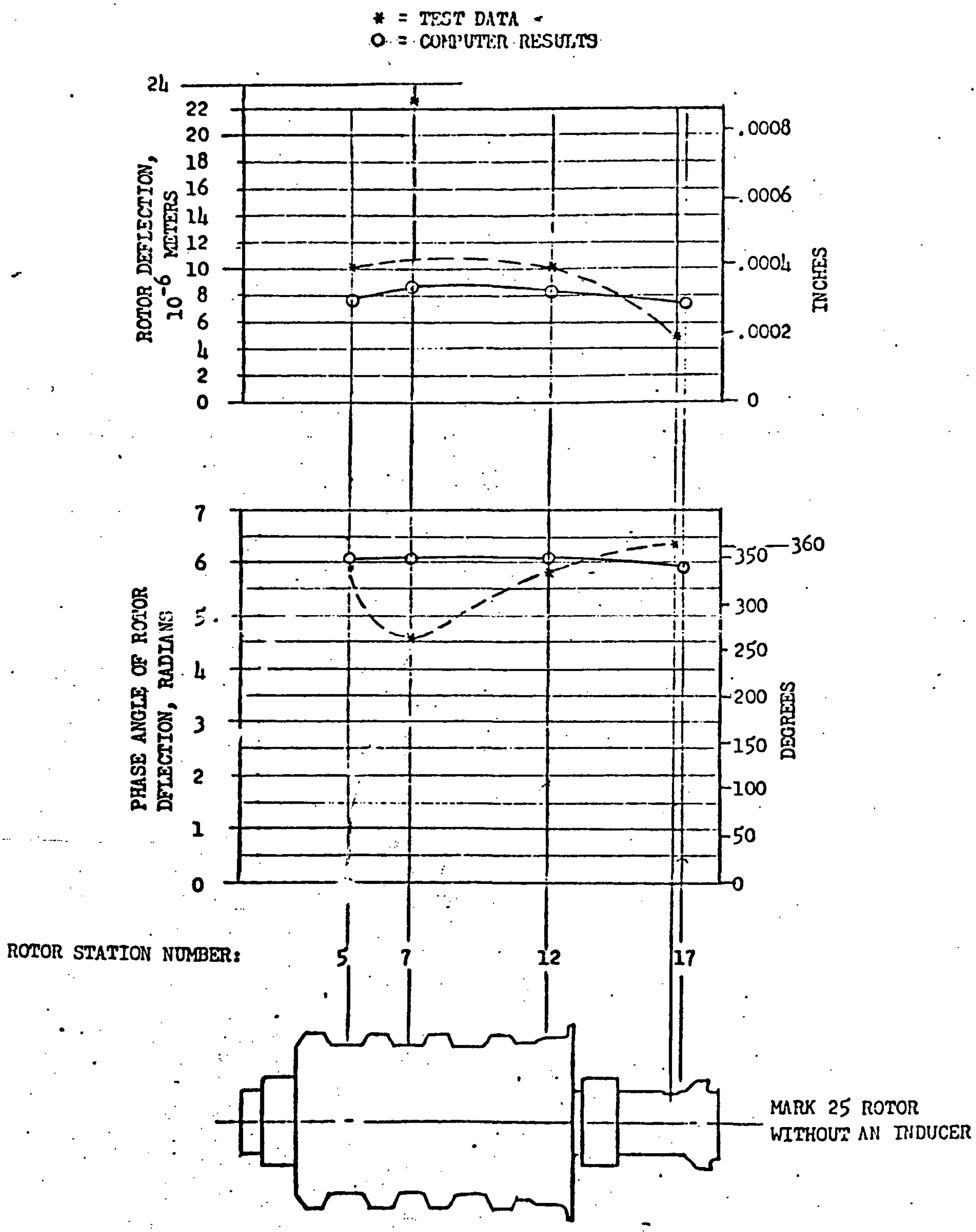


Figure 7. Comparison Between the Test Data and Computer Results for Unbalance Configuration I and the Speed of 34,000 rpm

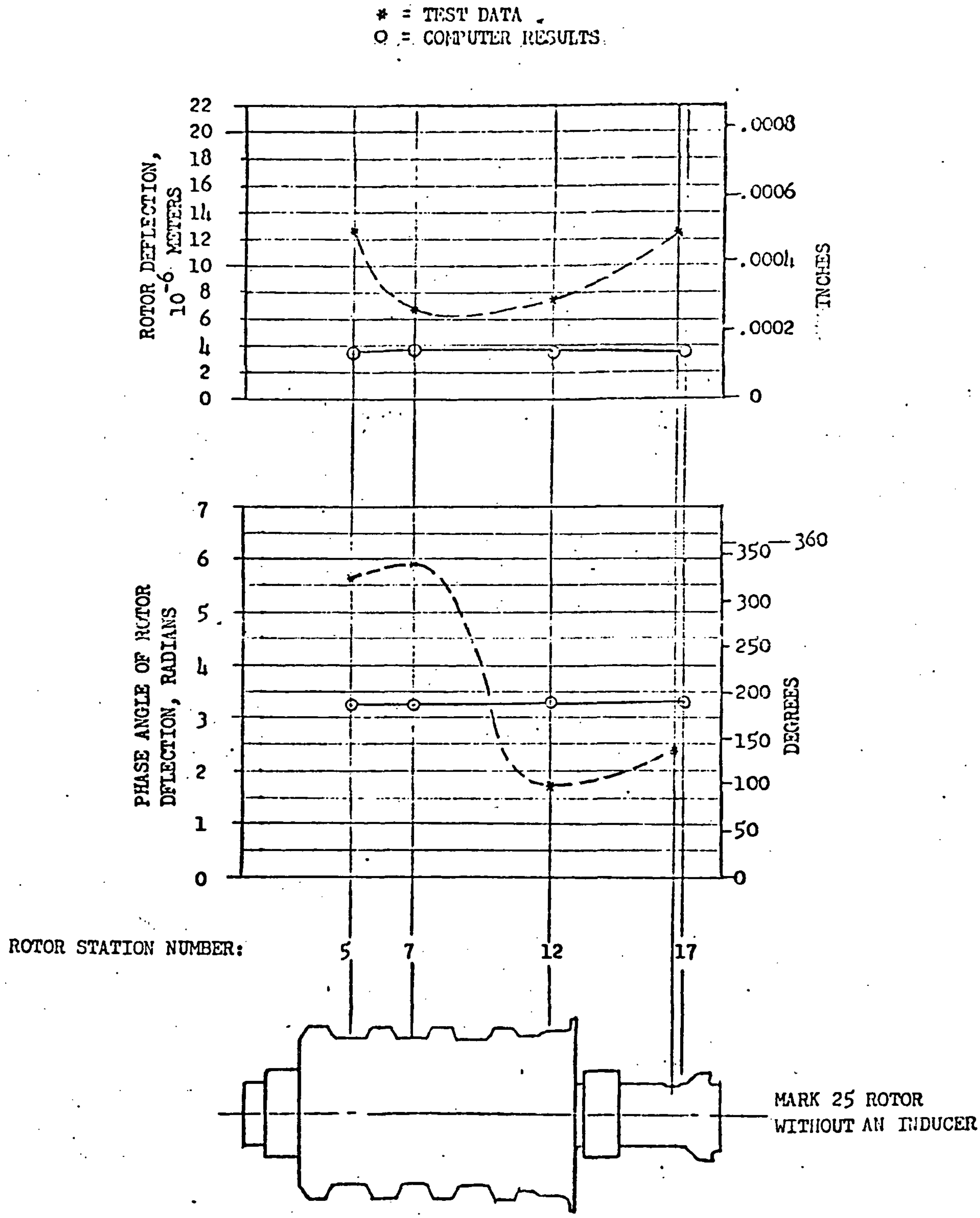


Figure 8. Comparison Between the Test Data and Computer Results for Unbalance Configuration II and the Speed of 28,000 rpm

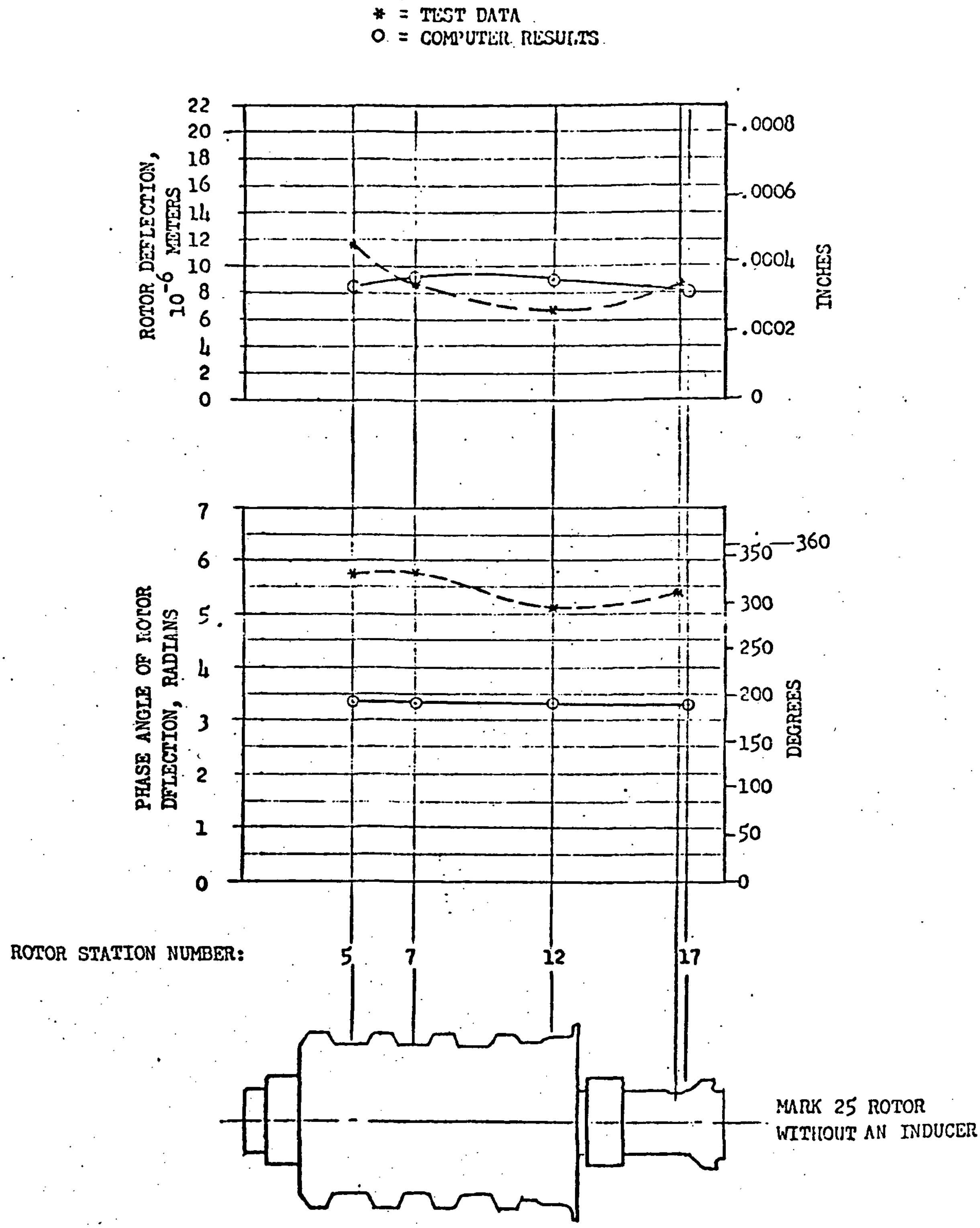


Figure 9. Comparison Between the Test Data and Computer Results for Unbalance Configuration II and the Speed of 30,000 rpm

TABLE III - UNBLANCE CONFIGURATION (SI AND SECONDARY SYSTEM)

UNBALANCE CONFIGURATION	ORIGINATION	UNBALANCE LOCATIONS AT COMPUTER MODEL ROTOR STATIONS					
		3		13		18	
		ROTOR MASS ECCENTRICITY VECTOR, 10^{-6} METERS (INCHES)	ECCENTRICITY VECTOR PHASE ANGLES, RADIANS (DEGREES)	ROTOR MASS ECCENTRICITY VECTOR, 10^{-6} METERS (INCHES)	ECCENTRICITY VECTOR PHASE ANGLES RADIANS (DEGREES)	ROTOR MASS ECCENTRICITY VECTOR, 10^{-6} METERS (INCHES)	ECCENTRICITY VECTOR PHASE ANGLES, RADIANS (DEGREES)
I	SUBTRACTION OF MASS UNBALANCES FOR TEST RUN #1106 FROM THE CORRESPONDING UNBALANCES FOR TEST RUN #1102	6.976590 (.000274 6689)	3.141593 (180)	*4013115. (157.9967)	2.617994 (150)	27.67041 (.001089386)	4.974188 (285)
II	SUBTRACTION OF MASS UNBALANCES FOR TEST RUN #1106 FROM THE CORRESPONDING UNBALANCES FOR TEST RUN #1105	6.976590 (.0002746689)	3.141593 (180)	*2619375. (103.1250)	3.316126 (190)	15.67156 (.0006169905)	3.892433 (223.02)

*THE UNUSUALLY LARGE ECCENTRICITY VALUES ARE THE RESULT OF A VERY SMALL ROTOR MASS OF 0.01 GRAM WHICH WAS ADDED TO THE ROTOR STATION #13 FOR THE PURPOSE OF REPRESENTING REQUIRED UNBALANCES. THE COMPUTER MODEL HAS ZERO MASS AT STATION #13 AND ITS ACTUAL MASS IS SHARED BY THE ADJACENT STATIONS

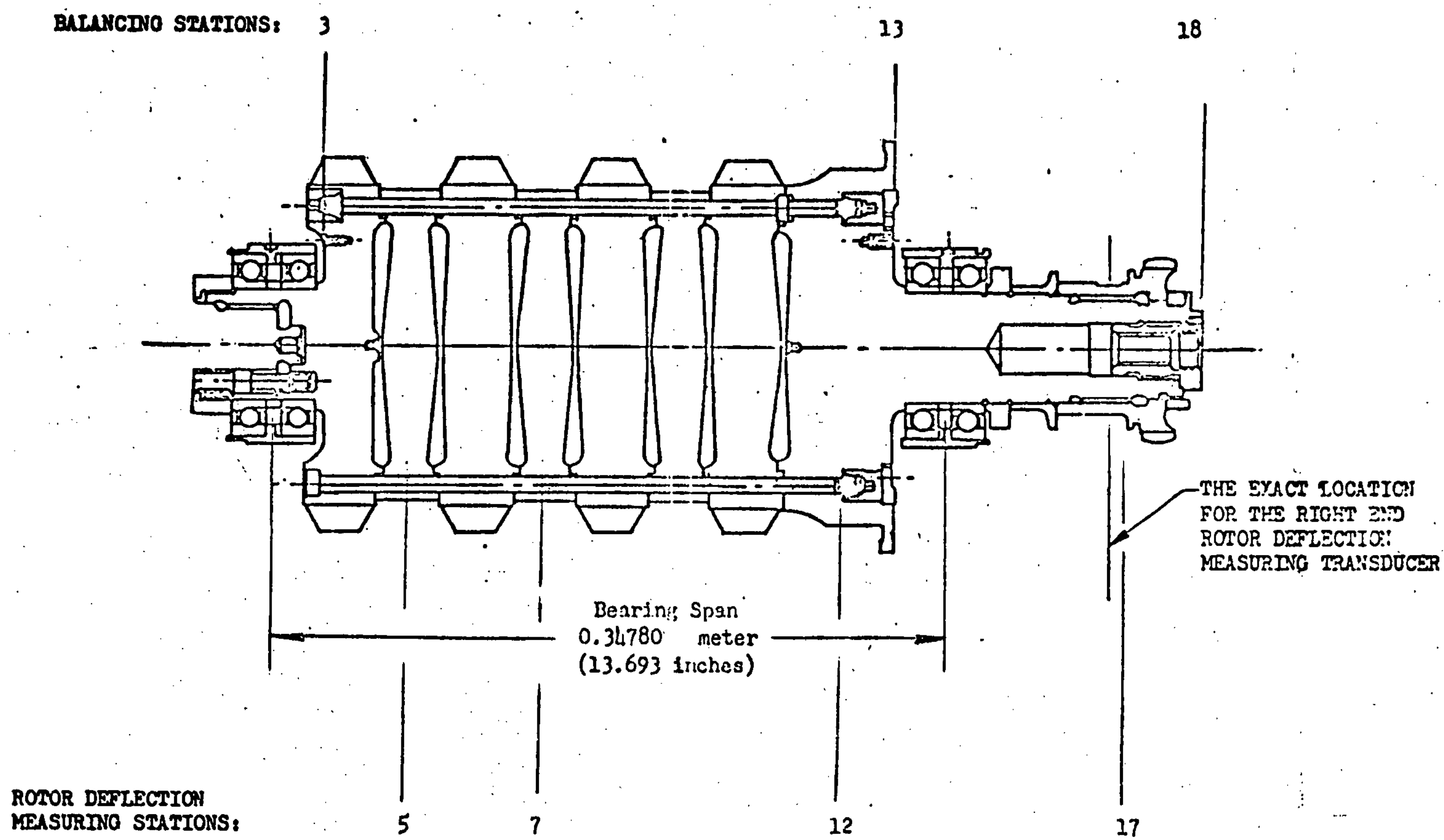


Figure 10. Mark-25 Rotor (Without Inducer) Balancing and Deflection Stations

the useful signal. Thus, it may be tentatively concluded that the discrepancies in the simulation are basically due to the inaccuracies accumulated in the process of test data acquisition.

Experimental test data from Mechanical Technology Incorporated (MTI) was made available by NASA for an additional verification of the computer program.

The test rotor-bearing configuration was modeled for the computer input. The rotor and bearing dimensions and properties used are indicated in Fig. 11. The bearing stiffness and damping coefficients used were interpolated from the values at the speeds furnished by NASA as represented in Fig. 12.

The proximity transducer and the unbalancing plane locations are depicted in Fig. 13. A total of seven sets of test data was simulated with the computer analysis. The test data and corresponding unbalance and speed combinations are compiled in Table IV. The computer results, according to the rotor configurations and operating speeds, are shown in Figs. 14 through 20. Since the computer simulation involves only steady-state operation, a maximum of 0.001 second of real time is used for the purpose of minimizing computation time. The "startup" rotor displacement coordinates are also included as a part of the computer outputs.

Comparison between the computer results and the test data indicates that there are some similarities existing in the displacement and phase angle distribution along the rotor length, but the numerical values are not in close agreement as depicted in Figs. 14 through 20.

To establish some confidence in the computer program, a parallel computer simulation of three sets of rotor test data using an independently written steady-state program was made. Close agreements were achieved between the results from the present transient program and those from the steady-state program.

In an effort to improve the correlation between the computer results and the test data, computer simulations using other than the nominal bearing stiffness and damping coefficients were made. This action was taken assuming that the actual bearing stiffness and damping coefficients could deviate from the nominal computed values furnished by MTI. For simplicity purposes, the same constant ratio is maintained between the stiffness and damping coefficients as between the nominal stiffness and damping coefficients furnished by MTI. The results from this additional computer simulation (shown in Fig. 14) reveal that for some stiffness and damping coefficients used, some improved correlation in the magnitude of the displacement vectors and phase angles between the computer and test data was achieved.

The correlation between the MTI test data and the computer results could probably be substantially improved by using better defined values for some of the system constants in the analytical model.

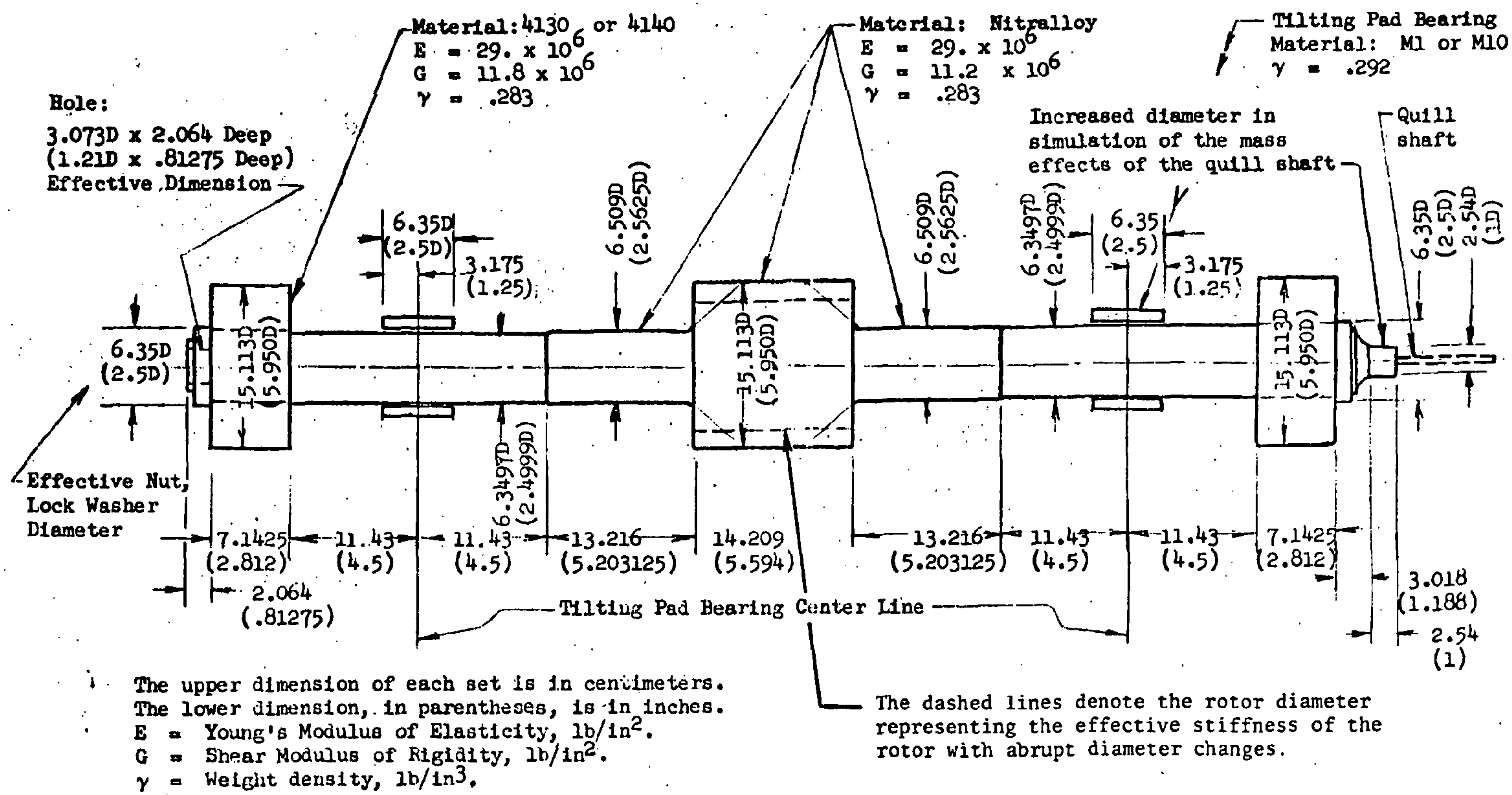


Figure 11. Rotor-Bearing Dimensions and Properties

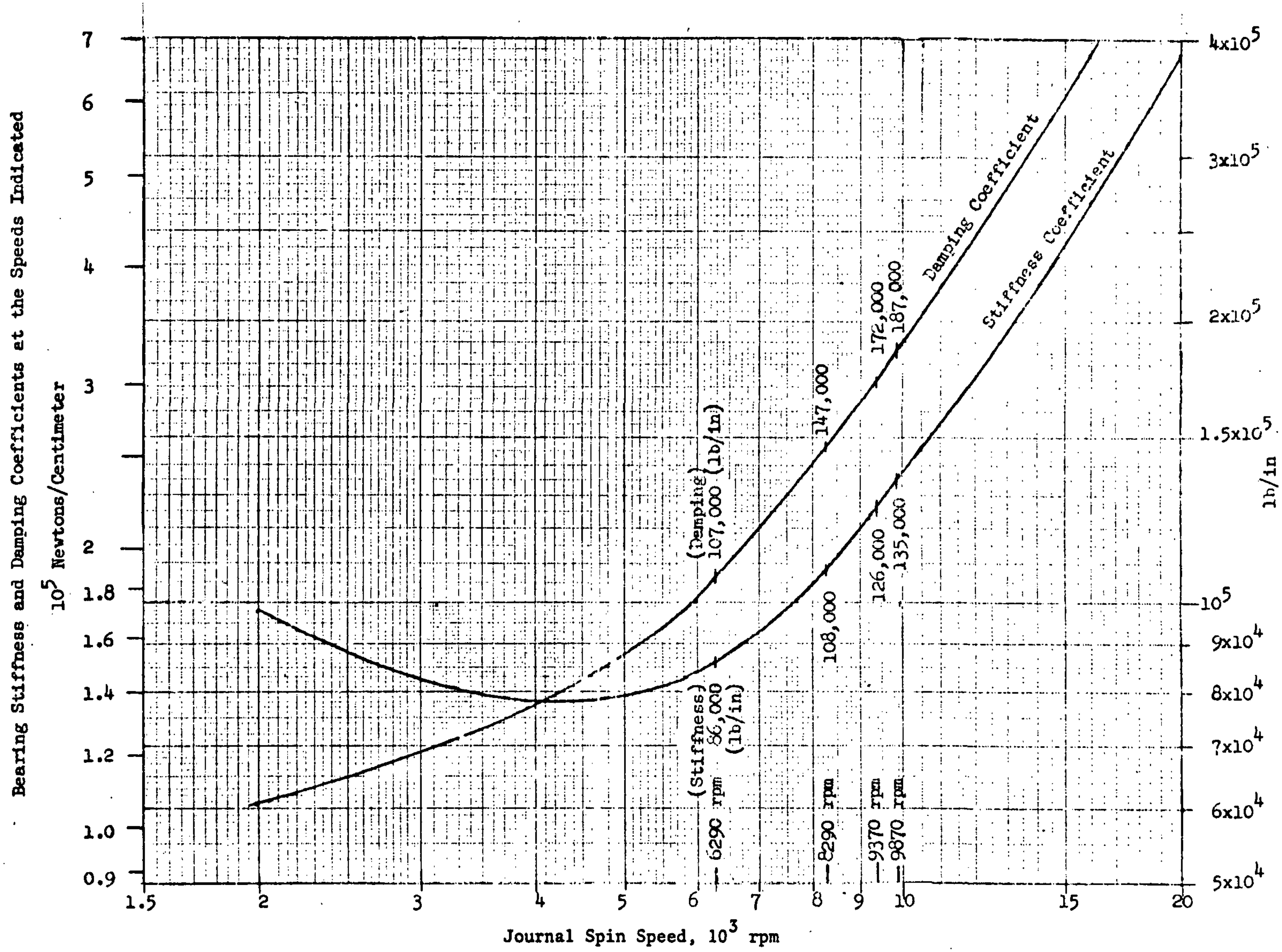


Figure 12. Bearing Stiffness and Damping Coefficients as Functions of Journal Speed

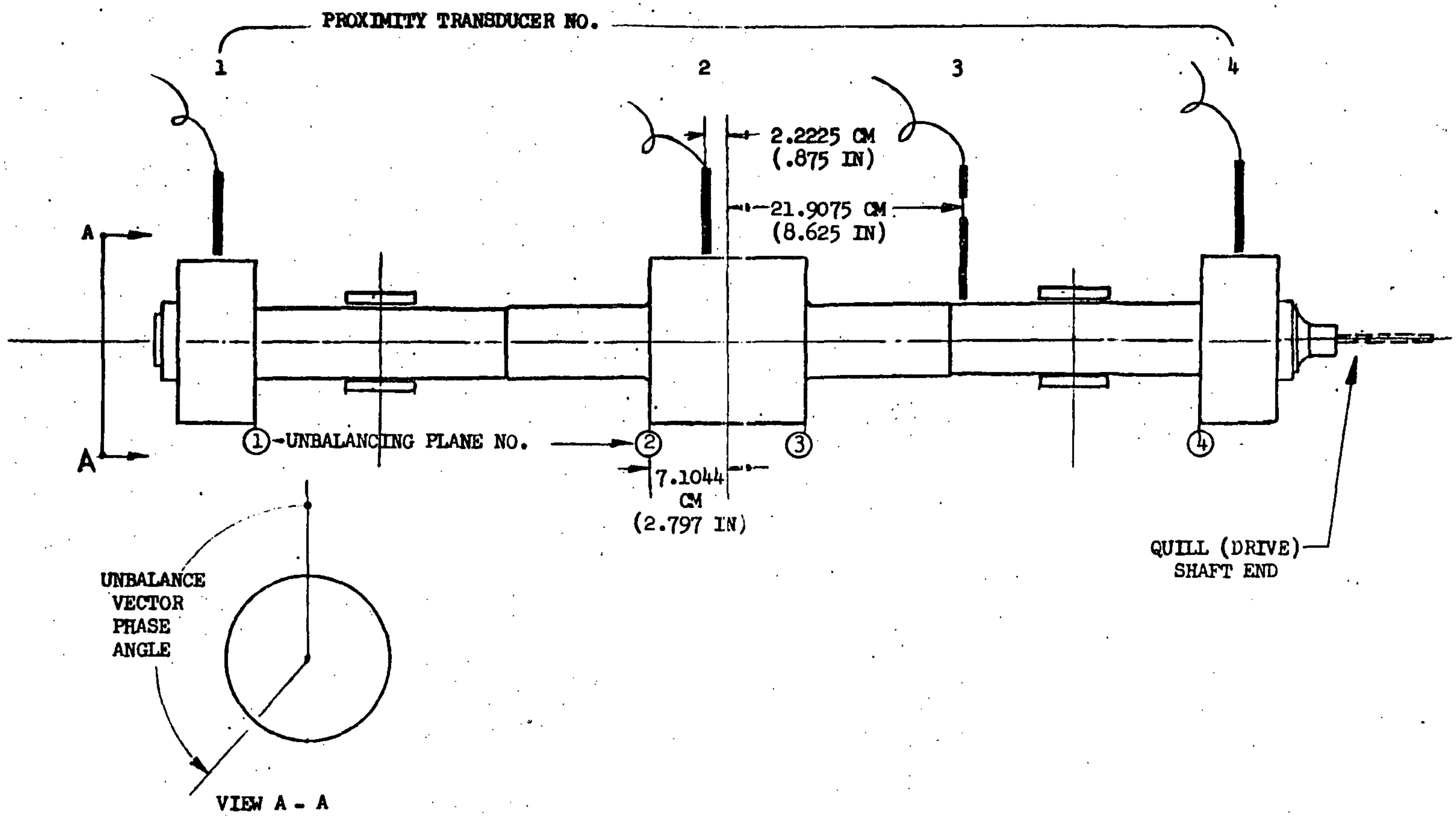


Figure 13. Proximity Transducer and Unbalance Plane Location

TABLE IV. ROTOR TEST DATA AND RELATED UNBALANCE AND SPEED COMBINATIONS

(a) ROTOR UNBALANCE CONFIGURATION

TYPE OF UNBALANCE		IN-LINE				"CORKSCREW"			
UNBALANCE PLANE ACCORDING TO FIG. 3		1	2	3	4	1	2	3	4
UNBALANCE VECTOR	NEWTONS-CM	.261277	.26128	.26128	.26128	.17654	.17654	.08474	.2283
	OZ-IN	.37	.37	.37	.37	.25	.25	.12	.324
PHASE ANGLE	DEGREES	195	195	195	195	90	0	270	180

(b) ROTOR TEST DATA

TYPE OF UNBALANCE			IN-LINE						"CORKSCREW"							
ROTOR SPEED, RPM			6290		8290		9370		6290		8290		9370		9870	
PHASE ANGLE, DEGREES DISPLACEMENT VECTOR			DISPLACEMENT VECTOR	PHASE ANGLE	DISPLACEMENT VECTOR	PHASE ANGLE	DISPLACEMENT VECTOR	PHASE ANGLE	DISPLACEMENT VECTOR	PHASE ANGLE	DISPLACEMENT VECTOR	PHASE ANGLE	DISPLACEMENT VECTOR	PHASE ANGLE	DISPLACEMENT VECTOR	PHASE ANGLE
ROTOR DISPLACEMENT VECTOR AND PHASE ANGLE — PROXIMITY TRANSDUCER STATION, (FIG. 3)	1	.001 CM .001 IN	2.997 1.180	117	3.236 1.274	160	3.513 1.383	152	1.749 .6886	-15	2.583 1.017	-68	5.168 2.035	-75	8.984 3.537	-106
	2	.001 CM .001 IN	4.002 1.576	169	4.064 1.600	160	4.210 1.657	160	1.077 .4242	37.5	2.694 1.061	68	5.310 2.091	62	8.621 3.394	60
	3	.001 CM .001 IN	3.739 1.472	92	3.663 1.442	162	3.777 1.487	160	.9840 .3874	99	1.287 .5066	110	2.951 1.162	80	4.466 1.758	70
	4	.001 CM .001 IN	3.913 1.541	166	4.045 1.593	148	4.458 1.755	159	.2146 .8450	-152	3.306 1.300	-146	5.366 2.113	-138	8.009 3.153	-133
BEARING STIFFNESS COEFFICIENT		NEWTONS/CM LB/IN	150609 86,000		189137 108,000		220660 126,000		150609 86,000		189137 108,000		220660 126,000		236421 135,000	
BEARING DAMPING COEFF. AT SPEED INDICATED		NEWTONS/CM LB/IN	187,386 107,000		257,436 147,000		301,218 172,000		187,386 107,000		257,436 147,000		301,218 172,000		327,487 187,000	

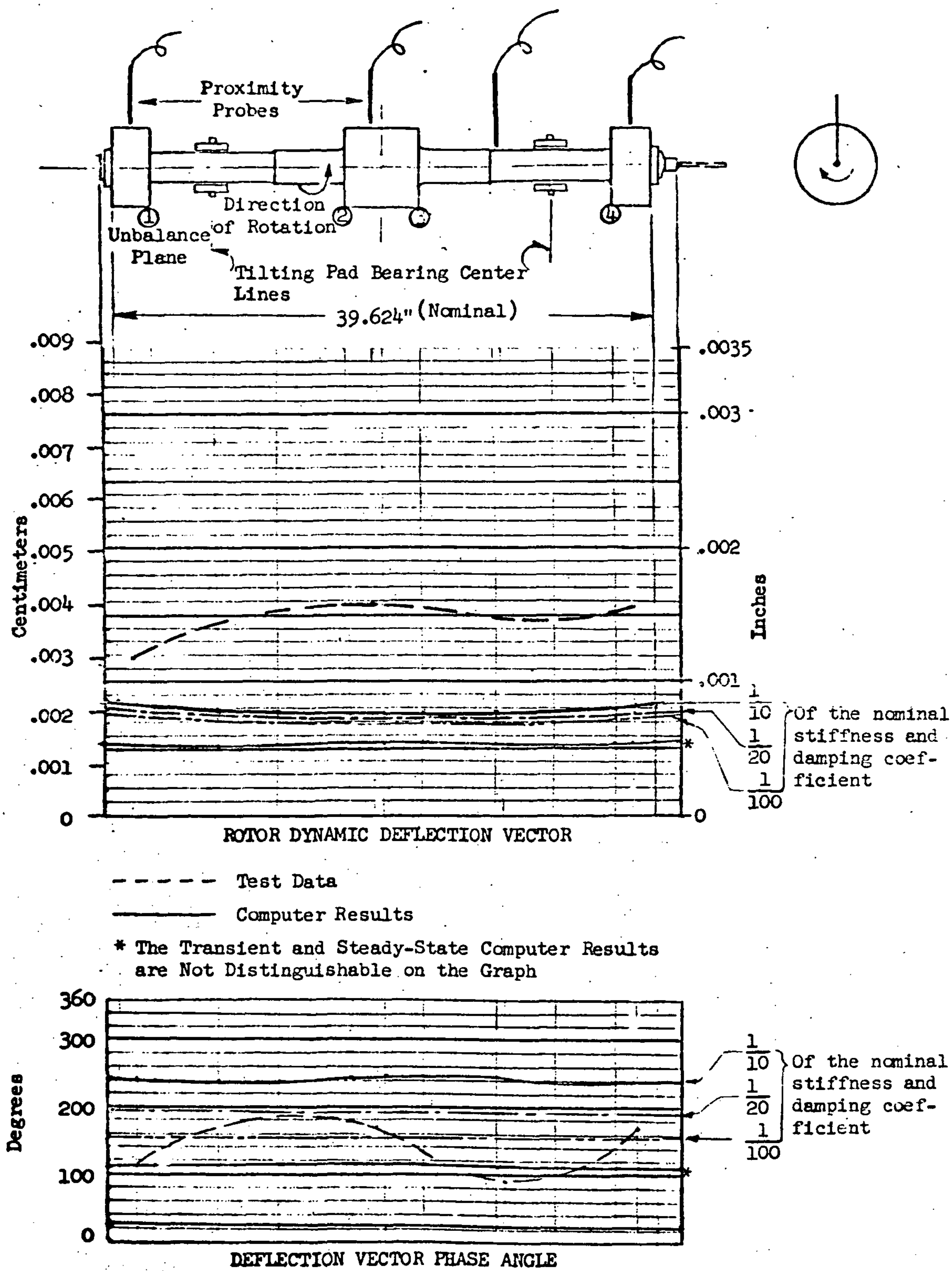


Figure 14. Comparison of the Computer and Test Data for In-Line Unbalance at 6290 rpm

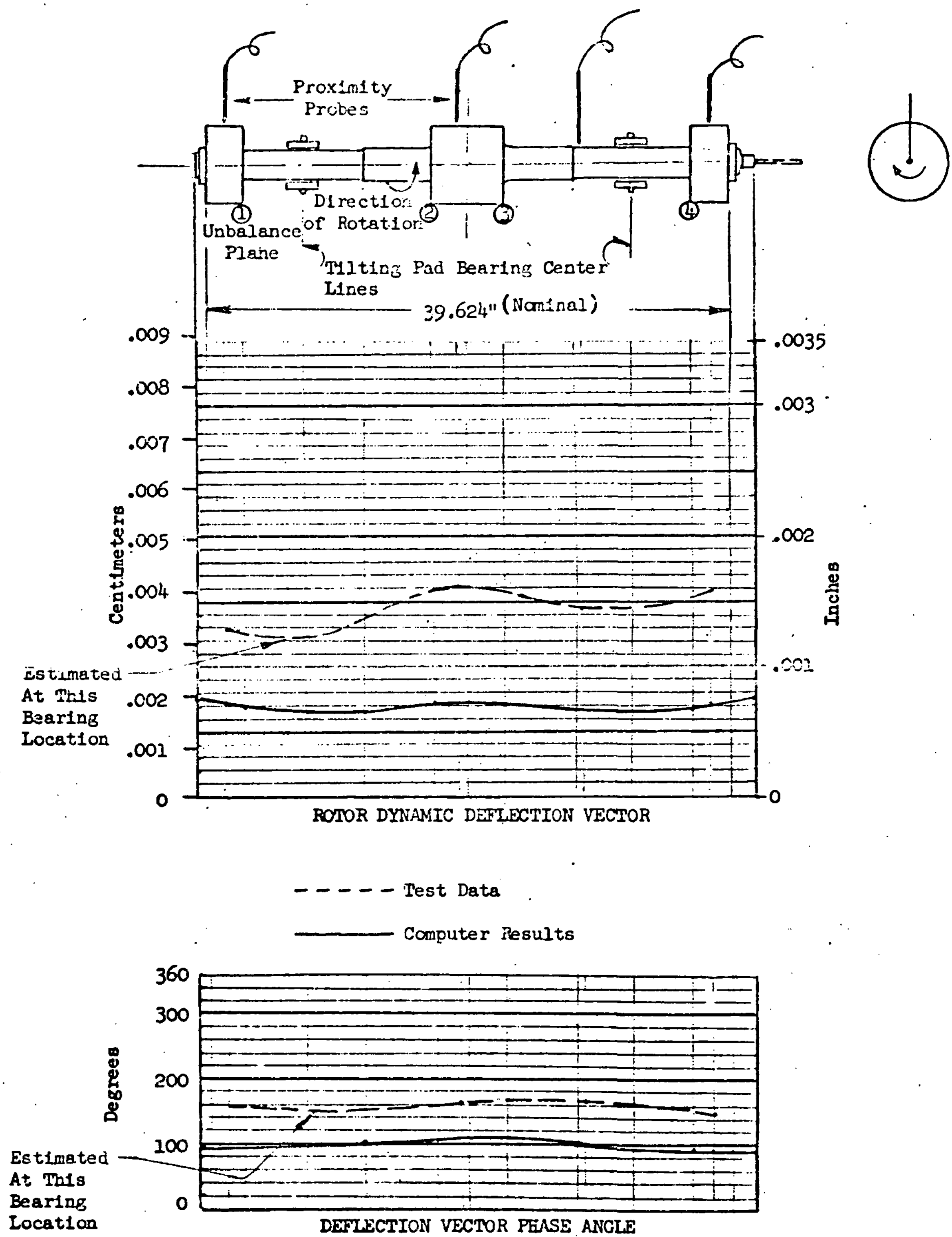


Figure 15. Comparison of the Computer and Test Data for In-Line Unbalance at 8290 rpm

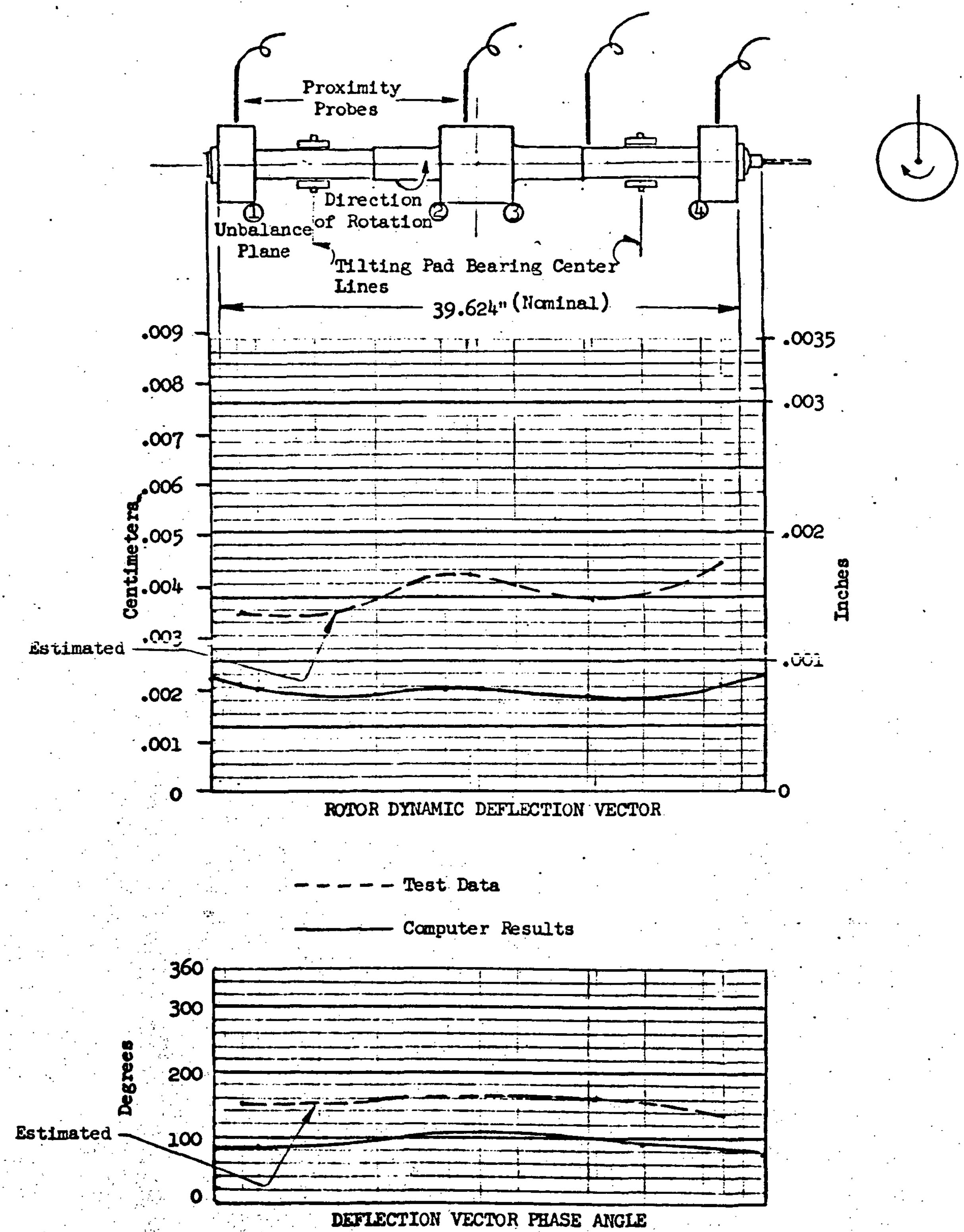


Figure 16. Comparison of the Computer and Test Data for In-Line Unbalance at 9370 rpm

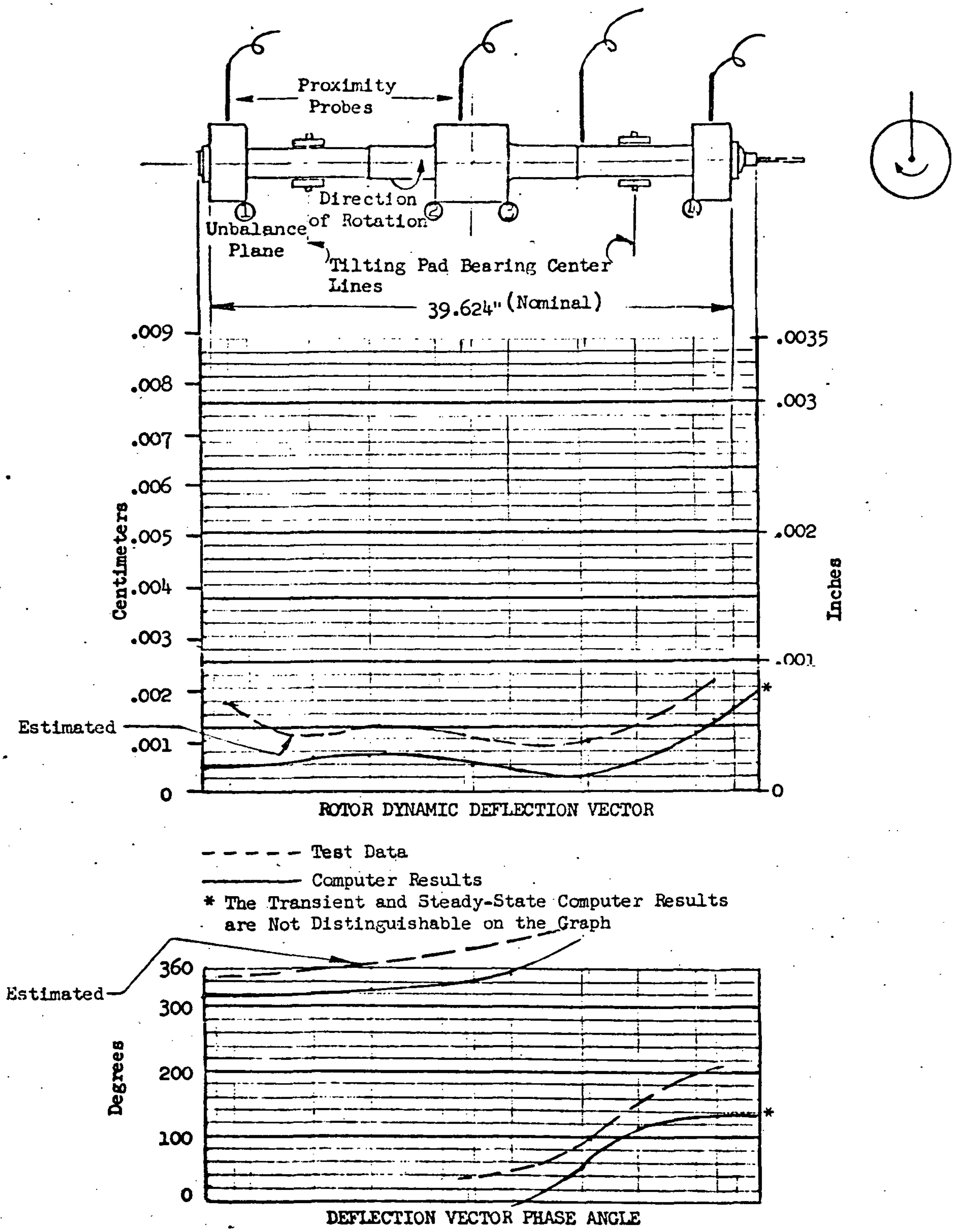


Figure 17. Comparison of the Computer and Test Data for "Corkscrew" Unbalance at 6290 rpm

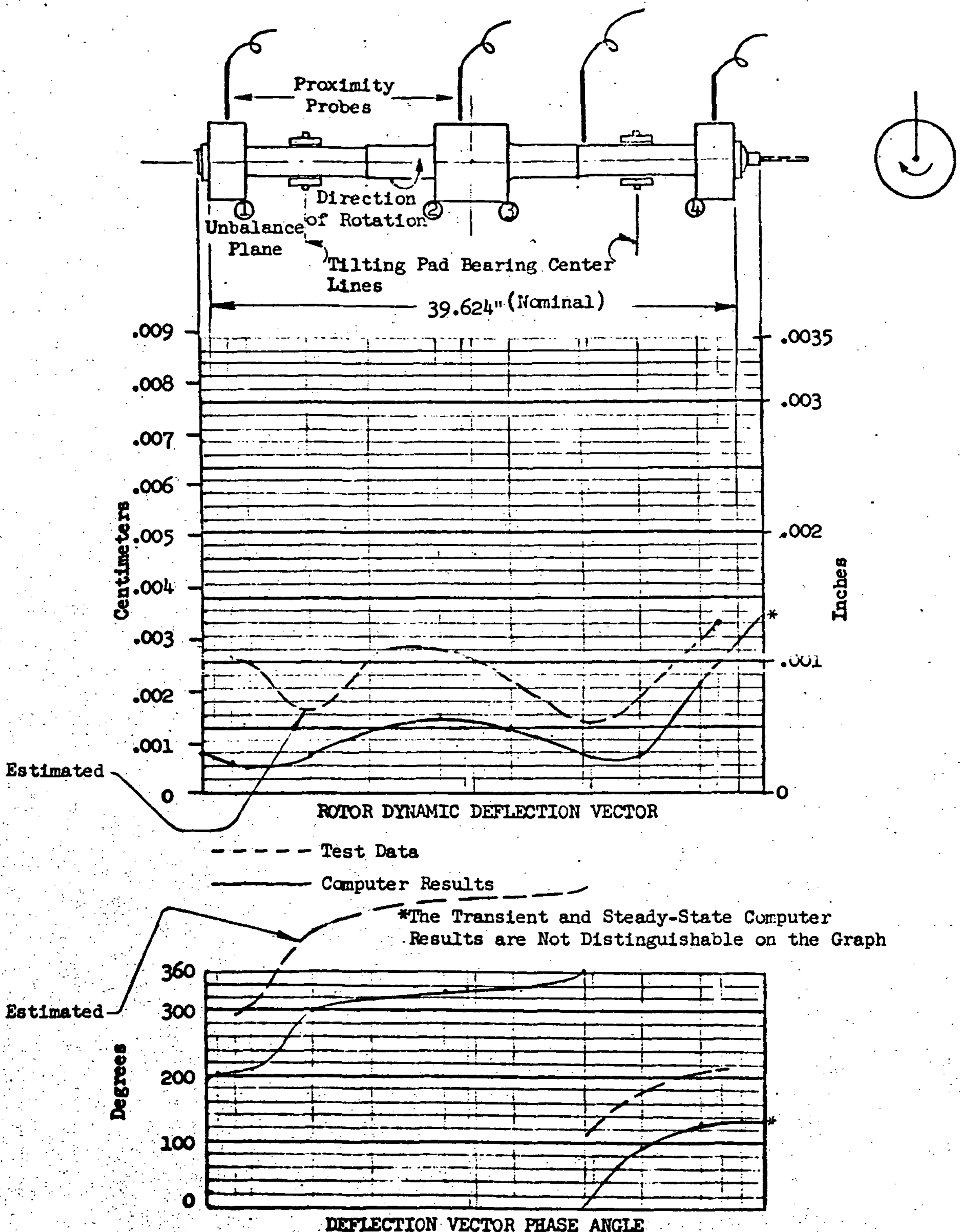


Figure 18. Comparison of the Computer and Test Data for "Corkscrew" Unbalance at 8290 rpm

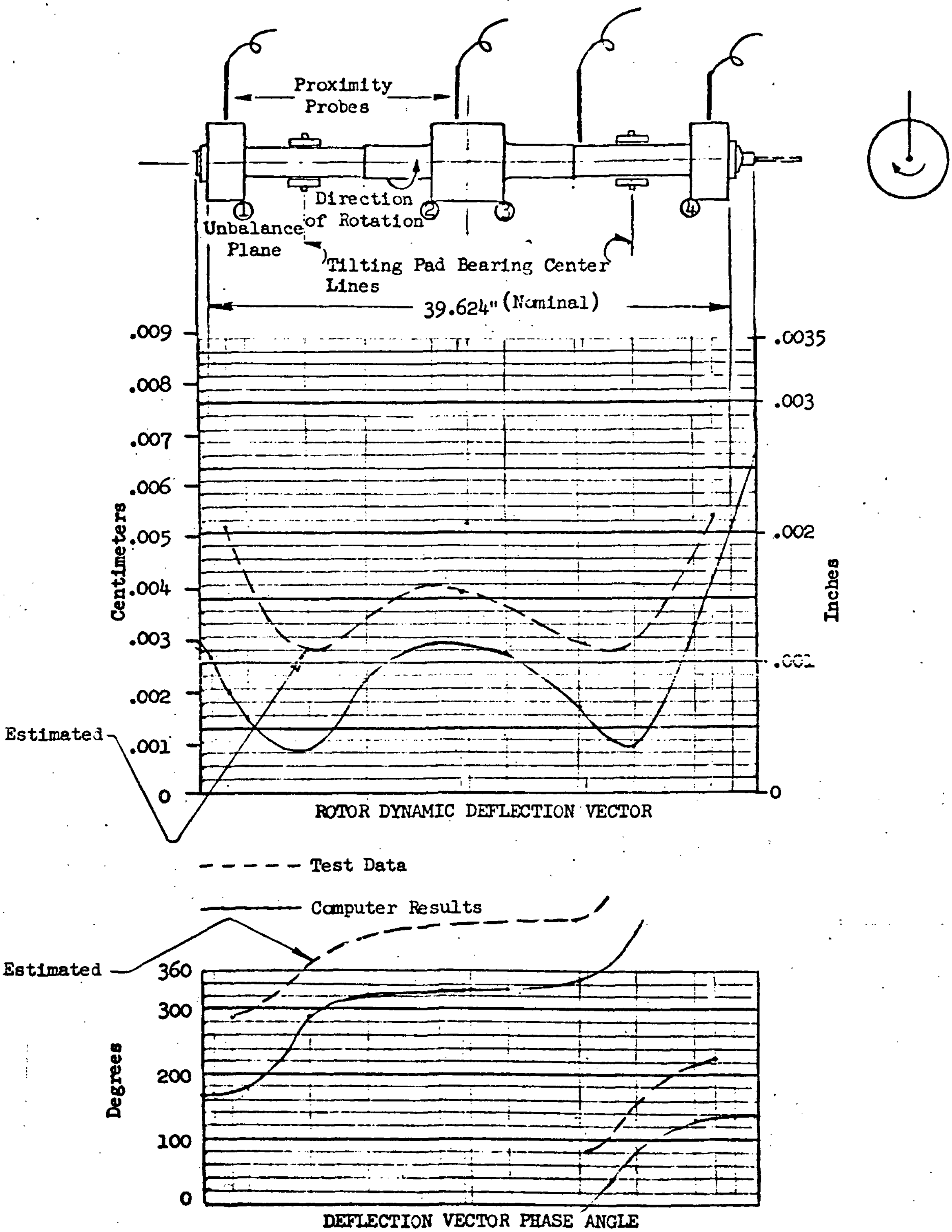


Figure 19. Comparison of the Computer and Test Data for "Corkscrew" Unbalance at 9370 rpm

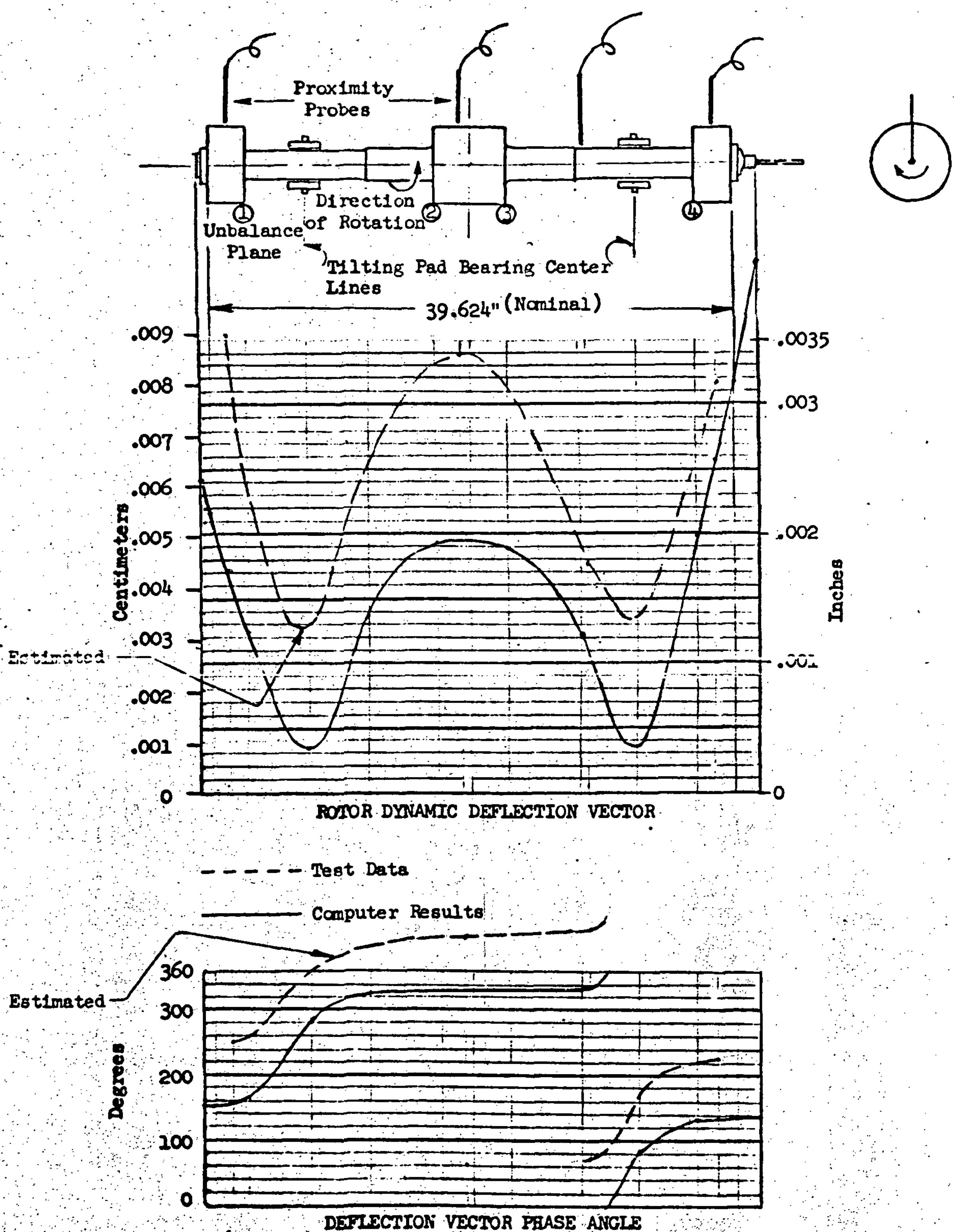


Figure 20. Comparison of the Computer and Test Data for "Corkscrew" Unbalance at 9370 rpm

The aforementioned discrepancies between the computer results and test data could arise from one or more of the several reasons listed below:

1. Accuracy of the test data.

2. Accuracy of the unbalance data.

3. Accuracy of the bearing stiffness and damping coefficients.

4. Accuracy of the rotor modeling.

5. Validity of the computer program.

The first three items are parts of the test data package. No assessment of their accuracies can be made without adequate information concerning these data. The work regarding Items 4 and 5 was performed at Rocketdyne; therefore, their validity and accuracies will be discussed.

Item 4 relates to the modeling of the rotor-bearing configuration. The major portion of the rotor modeling is sufficiently straightforward so that a definite procedure can be followed and accurate results can be predicted. Only at the locations where the rotor diameter changes abruptly, such as that at both sides of the central disk and at the locations of the bolted-on end disks, is special attention in modeling the rotor stiffness required.

For the rotor sections with abrupt change in diameter, the local rotor stiffness is modeled according to that of the dotted lines shown in Fig. 11 to account for the bending stress distribution at the edges of the central rotor. These dotted lines represent the average stiffness of the shaft in the area of enlarged diameter. At the end disks of the rotor, the rotor section stiffness used corresponds to that of a slightly larger diameter shaft (as shown in dotted lines) than the nominal shaft diameter shown in Fig. 11. With the end disk-shaft configuration having a small shoulder and largely relieved shaft-to-hub contact surfaces, this shaft stiffness simulation appears to be reasonable. Furthermore, the end disks being the major end masses of the rotor, the effects of this shaft section stiffness on the rotor dynamic performance is much less than the case of a shaft section at the mid-span of a rotor.

With reference to Item 5, "Validity of the Computer Program," the following may be added. A manual verification of the previous computer results for a 5-station rotor was made under contract NAS3-13219 in Report NASA CR-72740. The computer results were found to be in precise agreement with that from the manual calculation. Additional verifications of the transient computer program, by comparing the results with those from the independently written steady-state rotor response program, was made once under contract NAS3-13219 (Report NASA CR-72740) and twice (March 1971 and NASA Monthly Progress Report No. 10) under the present contract. The steady-state computer program, used in the verifications, was based on a matrix iteration approach and it was shown to give good correlation with other test data.

Further verifications of the transient computer results including various damping parameters were described in the October 1971 monthly report under the current contract.

In conclusion, it may be stated that the transient flexible rotor computer program is believed to be valid and will yield accurate results.

II. STUDY OF VARIOUS SOLUTION METHODS AND INTEGRATION TECHNIQUES

To investigate the relative computational speeds and accuracies, various integration techniques and computation methods were studied and results obtained.

The solution methods studies are:

1. Rotating coordinates using simultaneous equations without rotor slope parameters

2. Stationary coordinates using simultaneous equations without rotor slope parameters

3. Stationary coordinates using matrix inversion without rotor slope parameters

4. Stationary coordinates using independent equations including the rotor slope parameters

The integration techniques used in combination with some of the above solution methods are:

1. Adams-Moulton predictor and corrector integration technique with variable time step

2. Bulirsch-Stoer integration technique

3. Three-time-level solution technique

4. Fixed-step Adams-Moulton integration technique

5. Fixed-step 4th order Runge-Kutta integration technique

6. Fixed-step simple Euler integration technique

7. Several modified, and some tolerance controlled Euler integration techniques

The results in computation time, inverse of computation speed are presented in Fig. 21 through 27. The principles involved in the aforementioned solution methods and integration techniques are described as follows.

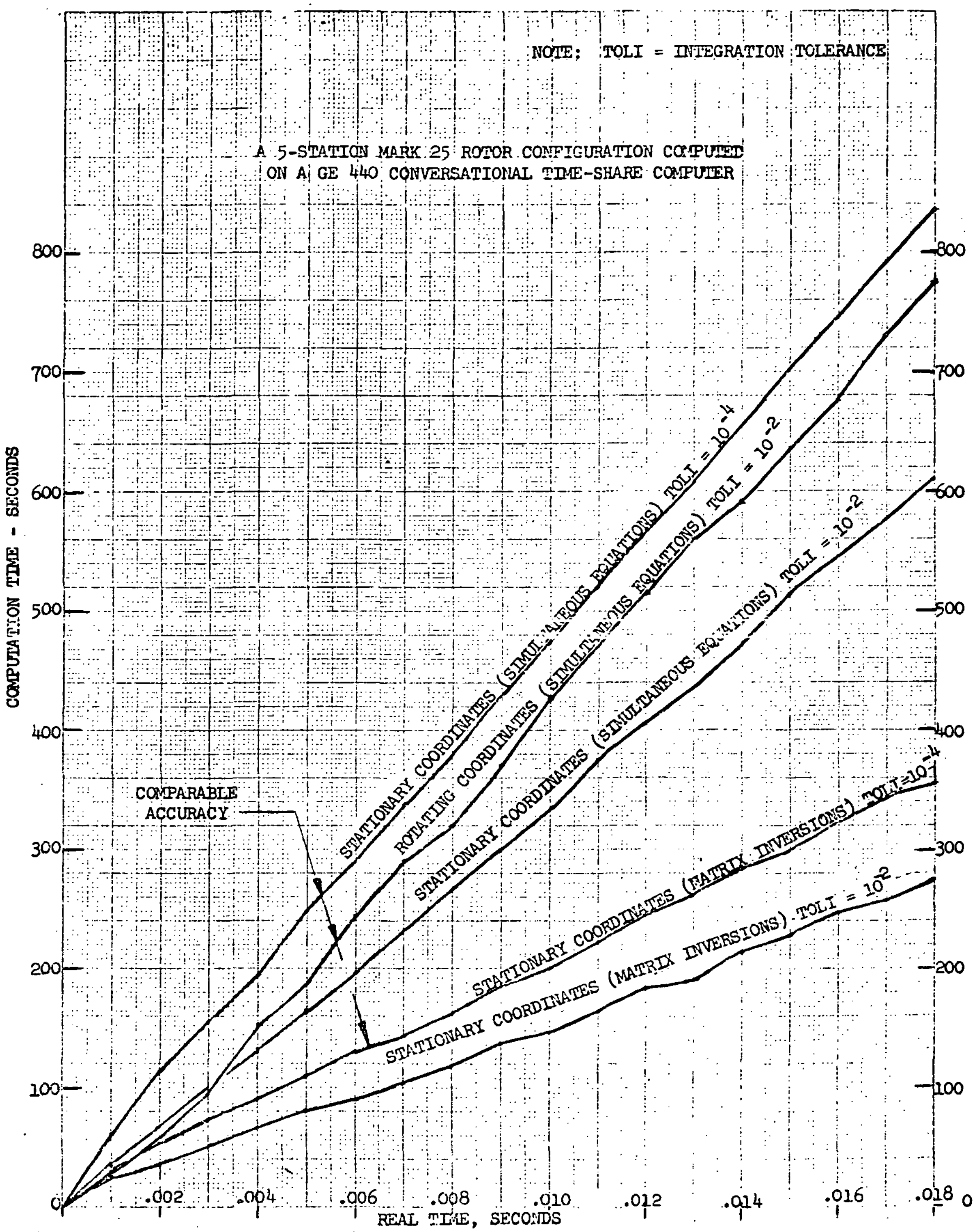


Figure 21. Computation Time Comparison for Steady-State Operating Mode at 34,000 rpm

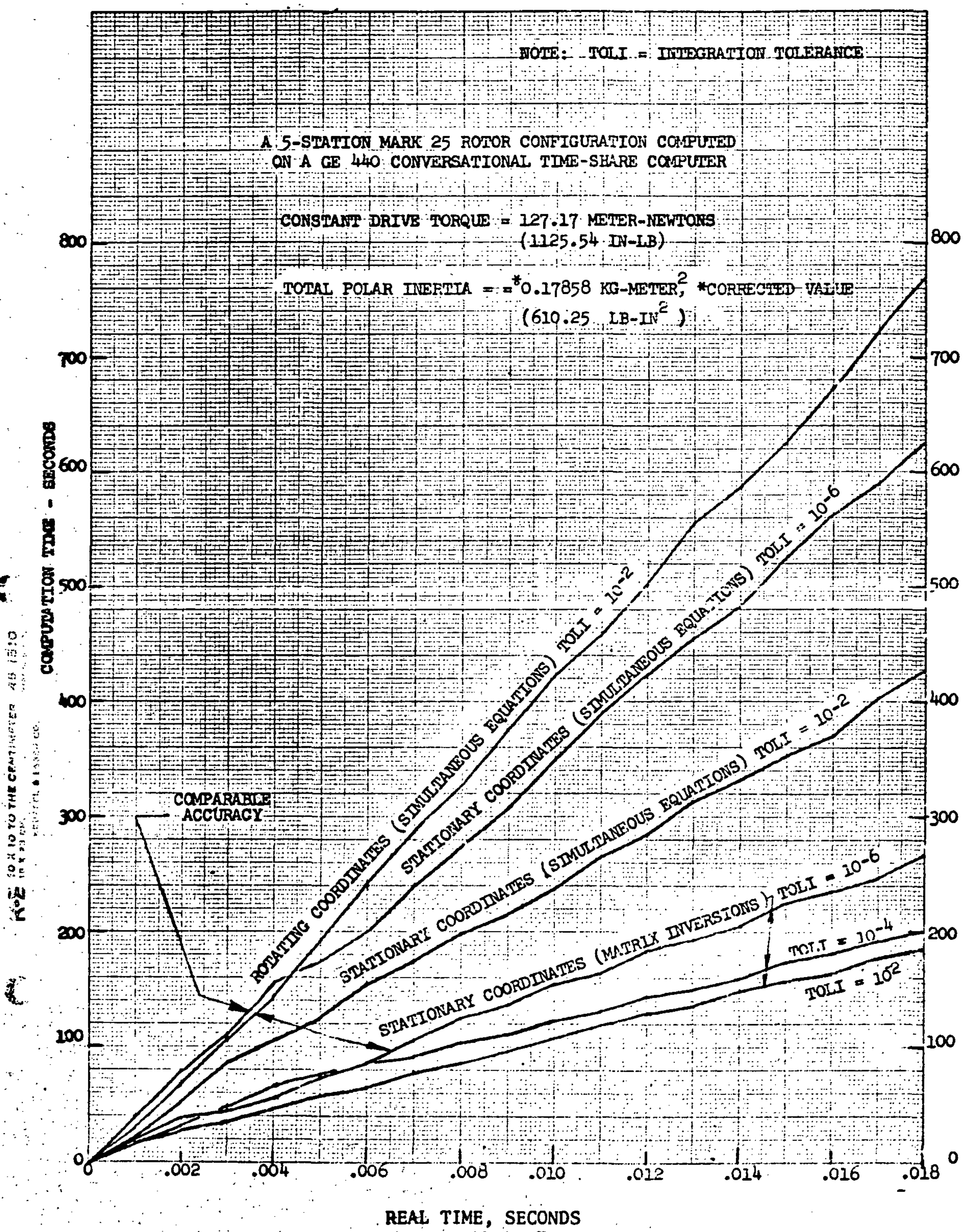


Figure 22. Computation Time Comparison for Accelerated Mode of Operation Starting at 10,000 rpm

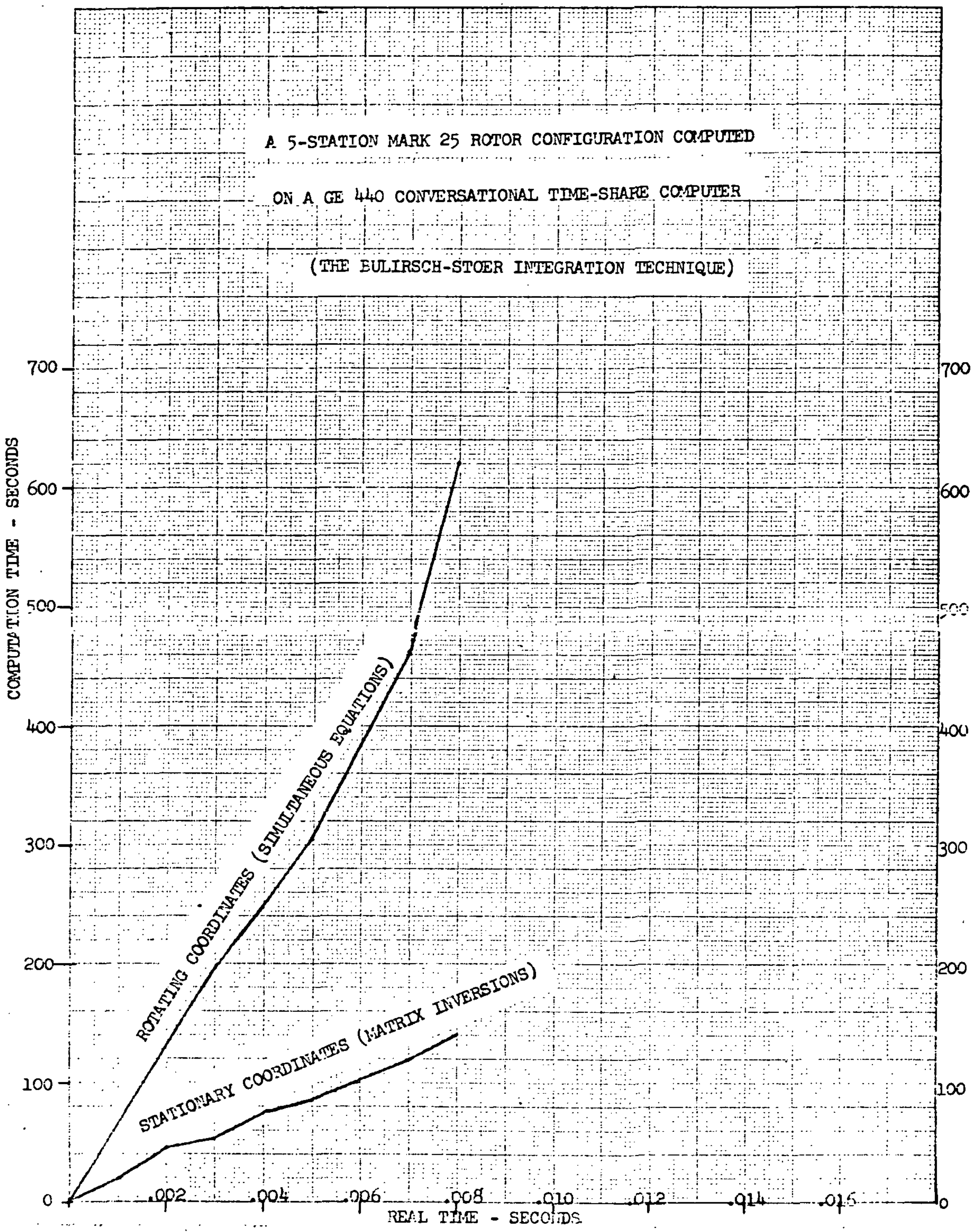


Figure 23. Computation Time Comparison for Steady-State Operating Mode at 34,000 rpm

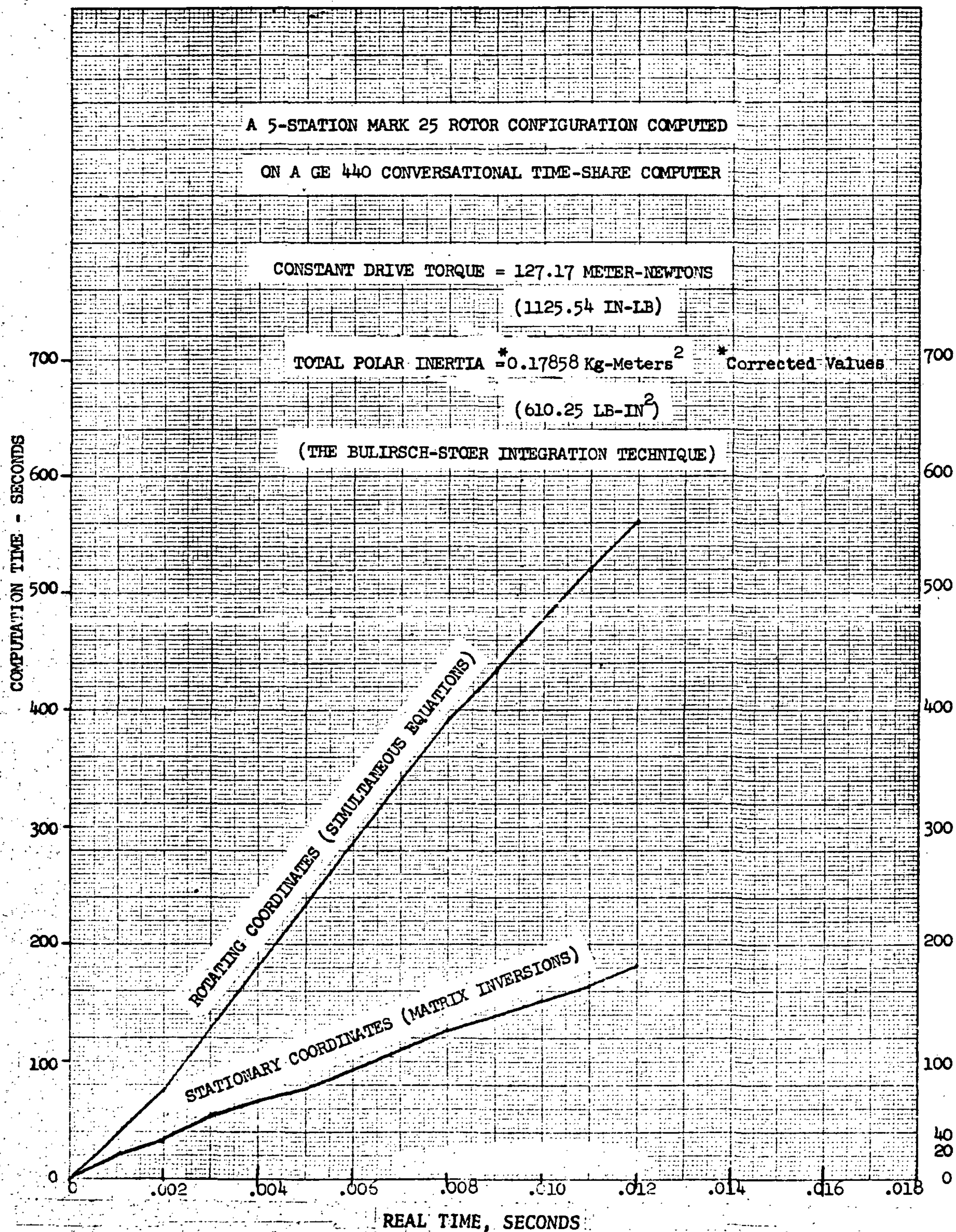


Figure 24. Computation Time Comparison for Accelerated Mode of Operation Starting at 10,000 rpm

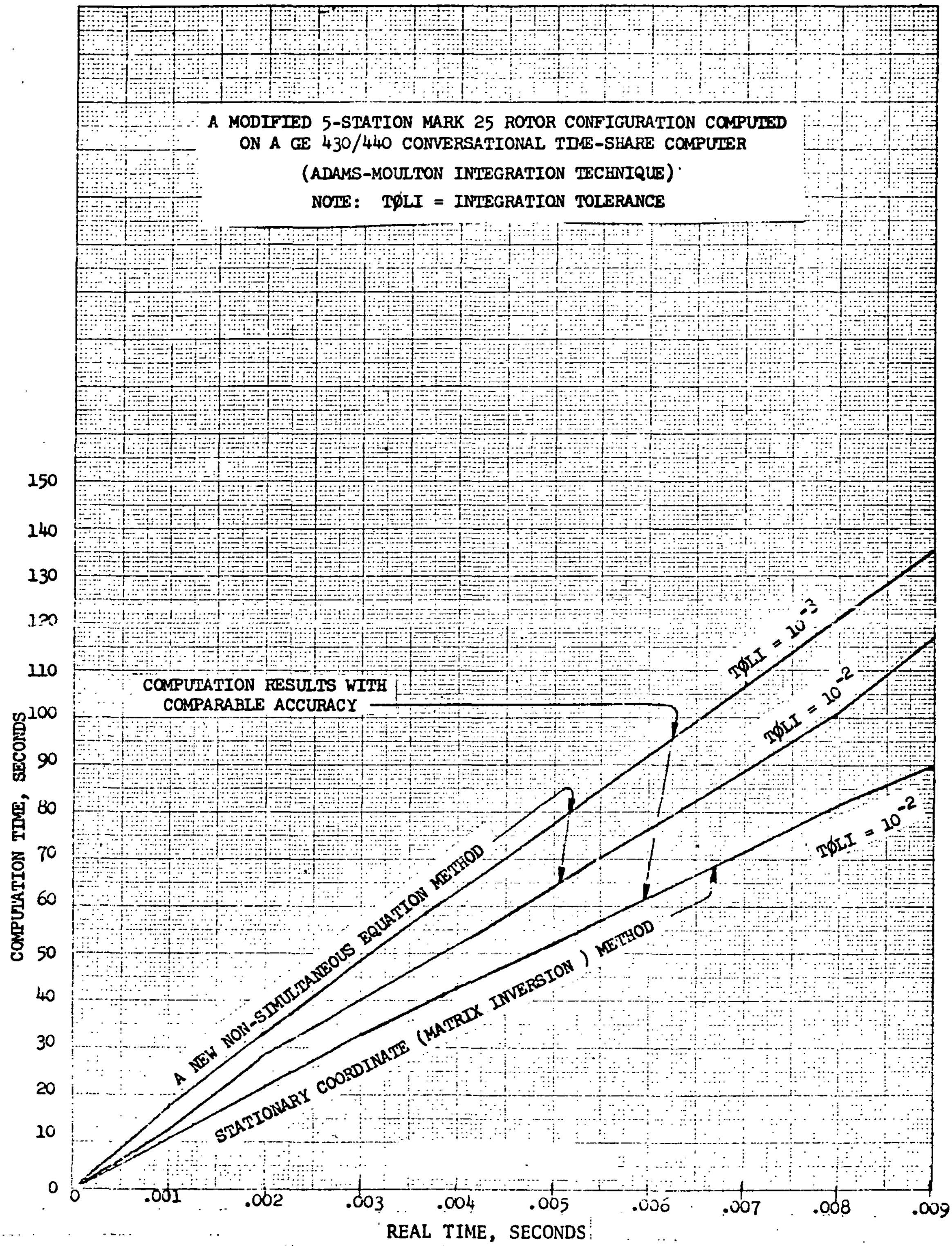


Figure 25. Computation Time Comparison for Steady-State Operating Mode at 34,000 rpm

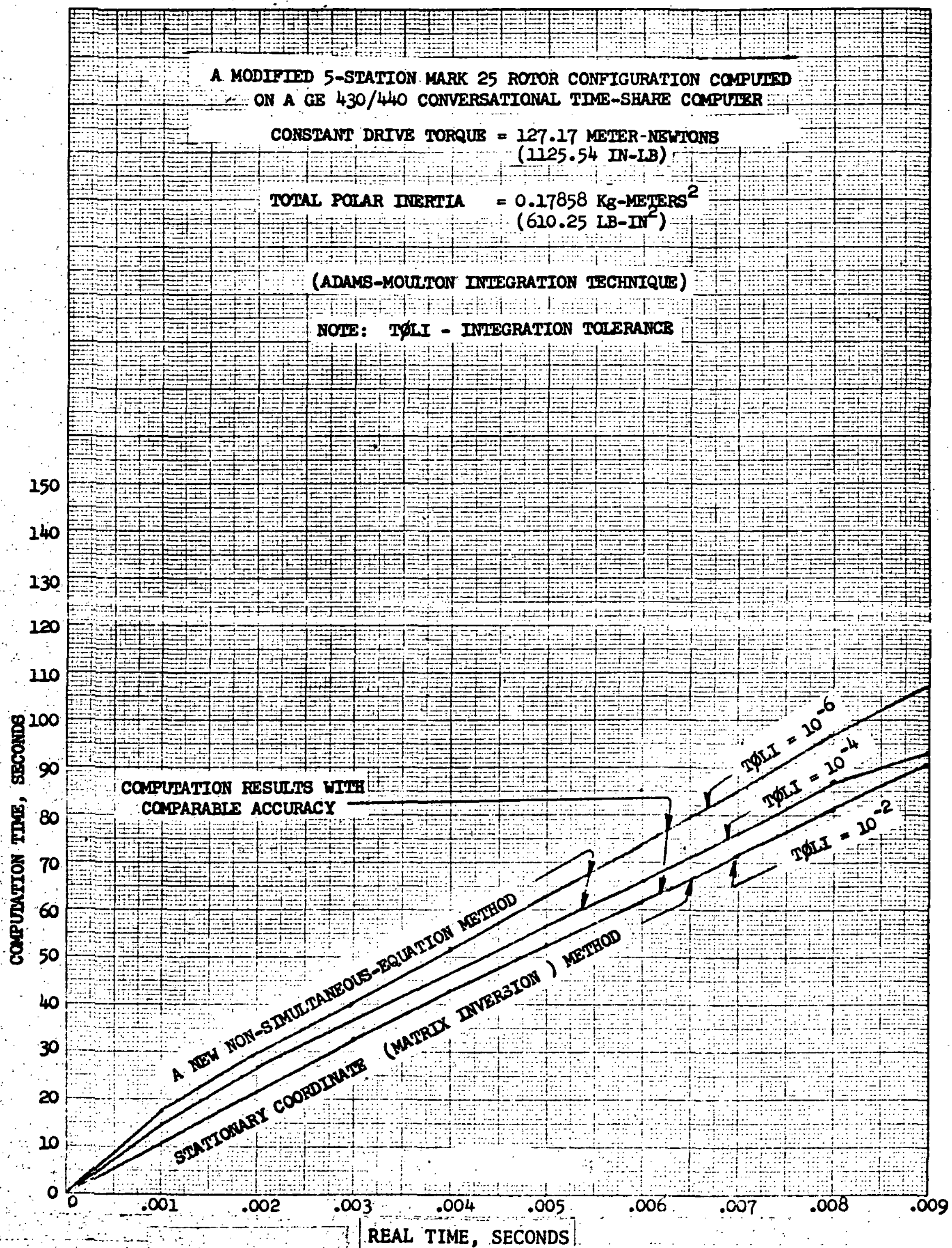


Figure 26. Computation Time Comparison for Accelerated Mode of Operation Starting at 10,000 rpm

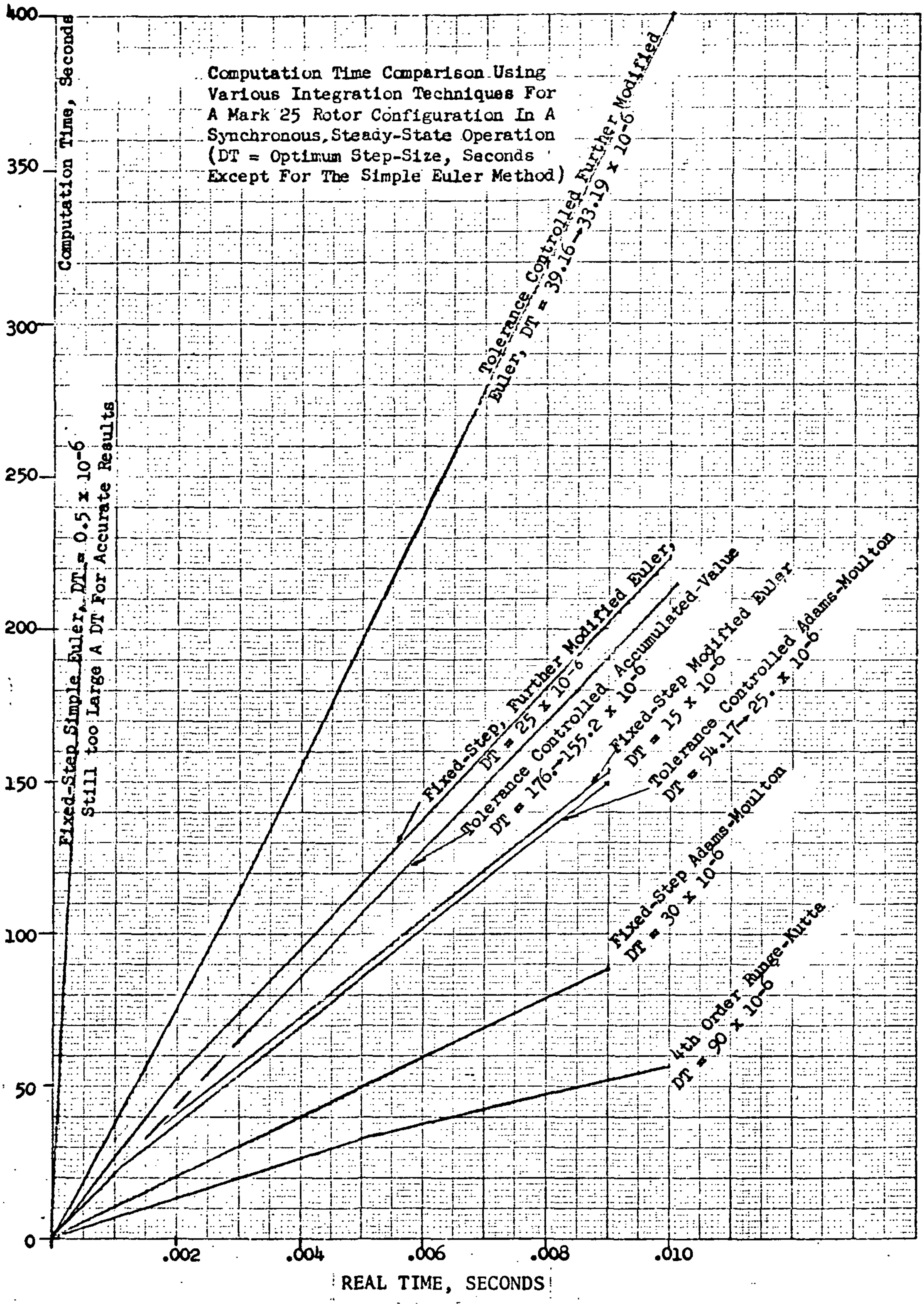


Figure 27. Computation Time Comparison Using Various Integration Techniques

The solution methods are:

1. Rotating coordinates using simultaneous equations without slope parameters. This was the exact solution method developed under contract NAS3-13219. The acceleration of rotor dynamic displacements are solved in rotating coordinates at local rotor whirl frequencies. The purpose of using the rotating coordinates was to minimize the absolute magnitude of the second and third time derivatives of rotor displacements so to promote the computation speeds. This solution method while yielding very accurate computation accuracy, turned out to be a relatively slow process due to the necessary conversion required between rotating and stationary coordinates for each of the simultaneous solution procedures.

2. Stationary coordinates using simultaneous equations without slope parameters. By removing the conversion process between stationary and rotating coordinates from the above rotating coordinates solution method, the computation process for comparable accuracy was found to be faster than using a rotating coordinate method for acceleration runs and slower for steady-state runs.

3. Stationary coordinate method with matrix inversion and without rotor slope parameters. Based on the mathematical formulation (Eqs. (2) through (13)), a set of inverted matrix coefficients using constant ϕ per time step was computed according to the relationships below.

$$\ddot{X}_i = f_{xi}\ (X_i\ Y_i\ \dot{X}_i\ \dot{Y}_i,\ \phi,\ \dot{\phi}\ \ddot{\phi})$$

$$\ddot{Y}_i = f_{yi}\ (X_i\ Y_i\ \dot{X}_i\ \ddot{Y}_i,\ \phi,\ \dot{\phi},\ \ddot{\phi})$$

$$\ddot{\phi} = f_{\phi}\ (X_i\ Y_i\ \dot{X}_i\ \dot{Y},\ \ddot{X}_i\ \ddot{Y}_i,\ \phi,\ \dot{\phi})$$

   Thus the acceleration generating process, used for the rotor dynamics solution, involves only straight algebraic computation. Consequently, the process was substantially expedited.

4. Stationary coordinates without simultaneous solution or matrix inversion, including the rotor slope parameters. The underlying principle of this method is first to compute the elastic and damping forces and moments due to relative displacements of the rotor, bearing and mount, and then apply these elastic damping forces and moments to compute the acceleration of the related masses and mass moments of inertia. This method was incorporated into the final computer program as it possesses an optimum combination of computation speed and additional slope parameters. The slope parameters improve the accuracy of computation results as compared with those of chord parameters developed under contract NAS3-13219. The mathematical formulation for this method is shown as Eqs. (32) through (39).

Several integration techniques were used in combination with the aforementioned solution methods. The basic principle of each of the integration techniques are:

1. Adams-Moulton predictor and corrector integration technique.[1] This integration method makes use of the third differences and a variable increment approach. The incremental time step is controlled by the specified input accuracy tolerance between the predicted and corrected solutions. The 4th order Runge-Kutta solution is used to initiate the computation. The predictor and corrector involves an iterative approach and is suitable for the area of rotor dynamic analysis where the magnitude of second- and third-time derivatives vary widely.

2. Bulirsch-Stoer integration technique.[2] This technique is based on a rational extrapolation in solving ordinary differential equations. According to a published reference, this technique has been demonstrated to be faster than some of the classic techniques. In application to the rotor dynamic analysis, it failed to show any advantage in computational speed over the Adams-Moulton predictor corrector method.

3. Three-time-level solution method.[3] The three-time-level (TTL) solution method is based on the Taylor expansion of a Laplacian type of differential equation with time derivatives and constant terms. The method was first suggested by Dufort and Frankel and subsequently generalized by Rocketdyne to solve multidimensional parabolic, hyperbolic, and elliptic differential equations in an application to transient thermal and related analyses.

   The application of the three-time-level technique has been shown to lead to less accurate results for a rotor without considering polar mass moment of inertia. For rotor including the polar inertia the technique caused computation instability. Therefore, this method was discarded as an integration technique for the computer program.

4. Fixed-Step Adams-Moulton technique. This technique uses the basic formulation applied in the Adams-Moulton predictor-corrector technique except that a fixed-time step is employed. It also uses the 4th order Runge-Kutta method as an integration starter. This method was incorporated into the program as an option of the integration subroutine package which consists of steps

   a. Adams-Moulton predictor-corrector technique

[1] Hildebrand, F. B., "Introduction to Numerical Analysis," McGraw-Hill, New York, 1956, pp. 199-201, 236-237.

[2] Bulirsch, R. and Stoer, J. "Numerical Treatment of Ordinary Differential Equations," Numerische Mathematik 8, 1-13 (1966).

[3] Dufort, E. C. and Frankel, S. P., "Stability Conditions in the Numerical Treatment of Parabolic Differential Equations," Math. Tables Aids Comput., p. 135/152, 7 (1953).

b. Fixed-step Adams-Moulton technique

c. Fixed-step Runge-Kutta technique

5. Fixed-step fourth order Runge-Kutta integration technique. This is the classic fourth order Runge-Kutta technique using a fixed input time step and is incorporated as a part of the program integration package.

6. Fixed-step simple Euler integration technique. This technique was studied only to demonstrate the limitation of a very simple integration technique against a common argument: that the computation accuracy should be achieved by applying a minimum time step but still results in computation time saving due to the simple structure of the Euler integration technique. The computer results using this integration technique has shown extremely slow computational speed for comparable accuracy with the other techniques evaluated such as Runge-Kutta and Adams-Moulton.

7. Several modified and some tolerance controlled Euler integration techniques. The study results demonstrated that the simple Euler technique requires longest computation time and a modified Euler provides shortest computation time among all the versions of Euler techniques investigated. The modified Euler is approximately 22 times faster than the simple Euler technique.

Results of the study in computation speed for various combinations of solution methods and integration techniques are shown in Fig. 21 through 27.

The results of the study have led to the selection of the following method and technique which give the best combination of computation and accuracy.

1. Stationary coordinate solution method using independent equations and including rotor slope parameters.

2. Adams-Moulton predictor-corrector integration technique package which also includes fixed-step 4th order Runge-Kutta and fixed step Adams-Moulton integration technique.

The overall improvement in computer time of the new method over that of the old one for the same program capability and comparable accuracy is substantial. The new computer program solution speed, including the rotor slope parameter, is approximately 2.3 times faster than the old program. The computation-to-real time relationships for various rotor operating conditions are shown in Fig. 21 through 26.

III. INCLUSION OF ROTOR DYNAMICS PARAMETERS

During the contract period several significant and useful rotor dynamics parameters were incorporated in the computer program as follows:

1. Torsional flexibility of rotor
2. Bearing mass
3. Rotor material hysteresis
4. Rotor transverse motion effects due to axial and torsional loading
5. Bearing in-phase and out-of-phase anisotropic stiffness and damping force and moment coefficients
6. Bearing transverse mass moment of inertia
7. Mount in-phase anisotropic stiffness and damping moment characteristics

The mathematical formulations for these parameters are described in this report under the section entitled "Theory - Mathematical Formulation". Computer demonstration of the effects of these included parameters are described in the subsequent sections.

Rotor Torsional Flexibility Verification

The rotor torsional flexibility contribution to the rotor spin drive torque, as defined in part (f) of Eq. (28)

$$\Delta \text{ drive torque}_i = K_{Ti} (\phi_{i+1}-\phi_i) - K_{T,i-1} (\phi_i-\phi_{i-1}) \quad (55)$$

has been demonstrated with the computer program. The computer results were validated with those from the hand calculation.

Figures 28 and 29 contain the intermediate inputs and computer results for a 3-station torsionally flexible rotor with a 10^6 in.-lb drive torque applied only at rotor station 2. No drive torques were applied to stations 1 and 3, which are torsionally connected to station 2 through the elastic shaft sections.

The rotor configuration and properties used in the torsional flexibility computation are described in Fig. 30.

Figures 31 and 32 present the dynamic performance of the torsionally flexible rotor. As shown in the figures, some torsional oscillation exists at all three stations. This torsional oscillation is induced from the suddenly applied drive torque in a nontorsional damping environment.

```
YN 63802
   2.751030E-03   -2.860184E-03    2.751030E-03
   6.357026E-03   -6.705716E-03    6.357026E-03
   6.366534E-04    1.468782E-13   -6.366534E-04
   1.465990E-03    3.052907E-13   -1.465990E-03

  -2.396344E+01    2.598446E+01   -2.396344E+01
   1.036997E+01   -1.105625E+01    1.036997E+01
  -5.436016E+00    1.843964E-09    5.436016E+00
   2.372757E+00    5.857074E-09   -2.372757E+00

   3.771651E-01    4.152487E-01    3.771651E-01
   3.776872E+03    4.528038E+03    3.776872E+03

  -1.308844E-05   -1.308844E-05   -3.024528E-05
  -3.024528E-05    1.140220E-01    1.140220E-01
  -4.934230E-02   -4.934230E-02
```

These YN terms are the Fortran variables YN defined in FUND Table XX Appendix B

```
BD 63805
  -2.159744E+01    2.307404E+01   -2.159744E+01
   1.467776E+01   -1.563286E+01    1.467776E+01
  -4.981118E+00    1.971156E-09    4.981118E+00
   3.386152E+00    3.340203E-09   -3.386152E+00

  -3.904671E+04    4.975964E+04   -3.904671E+04
  -9.037044E+04    9.852171E+04   -9.037044E+04
  -6.659864E+03   -2.363505E-05    6.659864E+03
  -2.075615E+04    3.150476E-05    2.075615E+04

   3.769911E+03    4.155999E+03    3.769911E+03
   1.392250E+05    7.440782E+06    1.392250E+05

   1.027567E-01    1.027567E-01   -6.983368E-02
  -6.983368E-02    1.860197E+02    1.860197E+02
   4.298508E+02    4.298508E+02
```

First time-derivatives of the corresponding terms in YN above

Figure 28. Rotor Displacement, Velocity and Acceleration Data Used in the Computed Results Shown in Fig. 29 for a 10^6 In-Lb Drive Torque Acting at Station 2

```
KT(I-1),F(I),F(I-1) 63925
   -5.316076569E+03    3.771651497E-01    0.000000000E-01
KT(I),F(I+1),F(I) 63927
    1.884955592E+06    4.152486675E-01    3.771651497E-01
CØMB 63955
   -2.969309220E+01
CØMB 64075                              NEGATIVE VALUES INDICATE POSITIVE DRIVE TORQUES, TYPICAL
   -2.969309220E+01
CØMB 64125
   -2.969309220E+01
CØMB 64145
   -7.181543306E+04
TØRS 64175
    7.181543306E+04    9.636132066E+05    1.819498732E+04
```

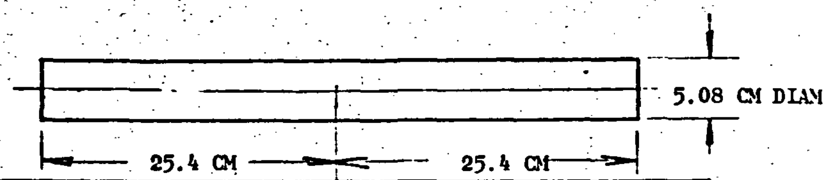
KT(I) = Torsional Stiffness, lb-in/rad

F(I) = ϕ_i

```
KT(I-1),F(I),F(I-1) 63925
    1.884955592E+06    4.152486675E-01    3.771651497E-01
KT(I),F(I+1),F(I) 63927
    1.884955592E+06    3.771651497E-01    4.152486675E-01
CØMB 63955
   -1.392024845E+00
CØMB 64075
   -1.000001392E+06
CØMB 64095
   -9.282156521E+05
CØMB 64115
   -9.282156521E+05
CØMB 64125
   -9.282156521E+05
CØMB 64145
   -8.564299121E+05
TØRS 64175
    7.181543306E+04    8.564299121E+05    1.819498732E+04
```

```
KT(I-1),F(I),F(I-1) 63925
    1.884955592E+06    3.771651497E-01    4.152486675E-01
KT(I),F(I+1),F(I) 63927
    0.000000000E-01    3.776872435E+03    3.771651497E-01
CØMB 63955
   -2.969309247E+01
CØMB 64075
   -2.969309247E+01
CØMB 64095
   -7.181543306E+04
CØMB 64115
   -7.181543306E+04
TØRS 64175
    7.181543306E+04    8.564299121E+05    7.181543306E+04
```

Figure 29. Rotor Drive Torque Step-Computation Results From Data Shown in Fig. 27 for a 10^6 In.-Lb Drive Torque Acting at Station 2 Only



STATION NO.	1	2	3
BEARING STATION NO.	1		2
YOUNG'S MODULUS OF ELASTICITY NEWT/CM^2	20.684×10^6	20.684×10^6	
SHEAR MODULUS OF RIGIDITY NEWT/CM^2	8.2737×10^6	8.2737×10^6	
MASS, Kg	22.6796	22.6796	22.6796
TRANSVERSE MASS MOMENT OF INERTIA Kg CM^2	175.584	175.584	175.584
POLAR MASS MOMENT OF INERTIA, Kg-CM^2	146.320	146.320	146.320
MASS ECCENTRICITY CM	0	.00254	0
ECCENTRICITY PHASE ANGLE, DEGREE	45°	45°	45°
MASS INERTIA MIS-ALIGNMENT, DEGREE	5°	0	−5°
MISALIGNMENT PHASE ANGLE, DEGREE	45°	45°	45°
BEARING STIFFNESS NEWTONS/CM	1.751268×10^6		1.751268×10^6
BEARING MASS, Kg	**2626.90		**2626.90
MOUNT STIFFNESS NEWTONS/CM	3.502537×10^6		3.502537×10^6

**Large Bearing Masses Were Used

Figure 30. Rotor Configuration for the Torsional Analysis

```
THE AVERAGE REAL STEP-TIME FØR THIS PRINTØUT =    5.000E-05 SEC
REAL TIME =   4.500E-04 SEC
REVØLUTIØNS ARRAY:
    2.901E-01     3.540E-01     2.901E-01
SPIN SPEED ARRAY, RPM:
    4.602E+04     4.896E+04     4.602E+04

RØTØR DISPLACEMENT VECTØR ARRAY, IN
    6.933E-03     7.209E-03     6.933E-03

RØTØR VECTØR PHASE ANGLE ARRAY, DEGREES
    1.428E+02     3.275E+02     1.428E+02

RØTØR WHIRL/SPIN FREQ. RATIØ ARRAY
    8.128E-01     8.252E-01     8.128E-01



THE AVERAGE REAL STEP-TIME FØR THIS PRINTØUT =    5.000E-05 SEC
REAL TIME =   1.000E-03 SEC
REVØLUTIØNS ARRAY:
    8.091E-01     7.918E-01     8.091E-01
SPIN SPEED ARRAY, RPM:
    5.887E+04     6.335E+04     5.887E+04

RØTØR DISPLACEMENT VECTØR ARRAY, IN
    5.789E-03     7.495E-03     5.789E-03

RØTØR VECTØR PHASE ANGLE ARRAY, DEGREES
    2.836E+02     1.347E+02     2.836E+02

RØTØR WHIRL/SPIN FREQ. RATIØ ARRAY
    7.856E-01     1.001E+00     7.856E-01



THE AVERAGE REAL STEP-TIME FØR THIS PRINTØUT =    5.000E-05 SEC
REAL TIME =   1.500E-03 SEC
REVØLUTIØNS ARRAY:
    1.329E+00     1.414E+00     1.329E+00
SPIN SPEED ARRAY, RPM:
    7.548E+04     6.677E+04     7.548E+04

RØTØR DISPLACEMENT VECTØR ARRAY, IN
    1.827E-03     8.024E-03     1.827E-03

RØTØR VECTØR PHASE ANGLE ARRAY, DEGREES
    2.399E+02     7.395E+00     2.399E+02

RØTØR WHIRL/SPIN FREQ. RATIØ ARRAY
    6.078E-01     8.512E-01     6.078E-01
```

Figure 31. A Computer Run Relative to the Data in Fig. 28 and Fig. 29 Using a 10^6 In.-Lb Drive Torque Acting at Station 2 but With No Drive Torque at Stations 1 and 3.

```
THE AVERAGE REAL STEP-TIME FØR THIS PRINTØUT =    5.000E-05 SEC
REAL TIME =    2.000E-03 SEC
REVØLUTIØNS ARRAY:
    2.026E+00    1.986E+00    2.026E+00
SPIN SPEED ARRAY, RPM:
    7.974E+04    9.469E+04    7.974E+04

RØTØR DISPLACEMENT VECTØR ARRAY, IN
    6.124E-03    2.769E-03    6.124E-03

RØTØR VECTØR PHASE ANGLE ARRAY, DEGREES
    3.521E+01    1.673E+02    3.521E+01

RØTØR WHIRL/SPIN FREQ. RATIØ ARRAY
    8.081E-01    1.499E+00    8.081E-01
```

```
THE AVERAGE REAL STEP-TIME FØR THIS PRINTØUT =    5.000E-05 SEC
REAL TIME =    2.500E-03 SEC
REVØLUTIØNS ARRAY:
    2.732E+00    2.843E+00    2.732E+00
SPIN SPEED ARRAY, RPM:
    1.046E+05    8.084E+04    1.046E+05

RØTØR DISPLACEMENT VECTØR ARRAY, IN
    2.956E-03    1.897E-02    2.956E-03

RØTØR VECTØR PHASE ANGLE ARRAY, DEGREES
    3.011E+02    9.279E+01    3.011E+02

RØTØR WHIRL/SPIN FREQ. RATIØ ARRAY
    1.127E+00    4.546E-01    1.127E+00
```

Figure 32. Continuation of Fig. 31

Bearing Mass

In verifying the GE computer program, a computation was made which included bearing mass, bearing and mount damping in a synchronous rotor motion. The magnitudes of the bearing mass and damping coefficients used in the computation were such that the computer results were distinct from those without these parameters thus allowing a comparison with accurate hand calculations for verification. The related data used in the computations are,

Bearing Mass	=	175.1 kg	=	1 (lb-sec^2)/in.
Rotor Spin Velocity	=	1000 radians/sec		
Bearing Stiffness	=	3.502×10^6 Newtons/cm	=	2×10^6 lb/in.
Bearing Damping Coefficient	=	1.751×10^4 (Newton-sec)/cm	=	10^4 (lb-sec)/in.
Mount Stiffness	=	3.502×10^6 Newtons/cm	=	2×10^6 lb/in.
Mount Damping Coefficient	=	1.751×10^4 (Newton-sec)/cm	=	10^4 (lb-sec)/in.

Although the bearing damping coefficient is a major parameter in determining the rotor dynamic configuration, it is, however, not directly involved in the bearing mass equilibrium computation. Figure 33 gives the computer results from "STARTUP" computation. Verification of the configuration during the subsequent computation using an integration procedure was not made as it required a precise balanced torque to maintain a steady-state dynamic configuration. However, in a no-damping, steady-state run, the bearing mass coordinates computed from the subsequent integration procedure were found to be in agreement with those from the "STARTUP" computation as shown in Fig. 34.

An axial projection of the bearing and mount dynamic configuration corresponding to the computed results presented in Fig. 33, is shown in Fig. 35.

The individual force components and the force equilibrium conditions, as indicated by the values of relative error, are shown in Table V .

The relative errors result predominantly from the computer printout roundoff errors and the equilibrium among the forces is thus established.

From the results shown in Table V and Fig. 34, it may be concluded that the bearing mass parameter has been correctly formulated in the G.E. computer program.

```
BEARING MASS (LB-SEC^2)/IN
    0.000E+00    1.000E+00    0.000E+00    1.000E+00    0.000E+00
BCB , (LB-SEC)/IN
    0.000E-01    1.000E+04    0.000E-01    1.000E+04    0.000E-01

THE COMPUTED STARTING ROTOR DEFLECTION COORDINATES ARE:

          X ARRAY, IN:
  -1.416E-03   -1.388E-04   -1.933E-03   -1.388E-04   -1.416E-03
          Y ARRAY, IN:
   1.685E-04   -3.486E-04    3.778E-04   -3.486E-04    1.685E-04
          VECTOR ARRAY, IN:
   1.426E-03    3.752E-04    1.970E-03    3.752E-04    1.426E-03
          PHASE ANGLE ARRAY, DEGREES:
   1.732E+02    2.483E+02    1.689E+02    2.483E+02    1.732E+02

XB(2),YB(2),XB(4),YB(4), IN
  -6.724E-05   -3.549E-04   -6.724E-05   -3.549E-04
```

Note: BCB represents bearing damping coefficient. Only the 2nd and 4th bearing mass and damping coefficient are used in the computation. XB(2), YB(2), XB(4) and YB(4) denote the rotor displacements from the bearing center in X- and Y-direction at the 2nd and 4th station, respectively.

Figure 33. Bearing Mass STARTUP Dynamic Configuration

BEARING MASS, $(LB\text{-}SEC^2)/IN$

0.000E+00	1.000E-01	0.000E+00	1.000E-01	0.000E+00

BCB, (LB-SEC)/IN

0.000E-01	0.000E+00	0.000E-01	0.000E+00	0.000E-01

THE COMPUTED STARTING ROTOR DEFLECTION COORDINATES ARE:

X ARRAY, IN:

-4.998E-04	-1.479E-03	-1.976E-03	-1.479E-03	-4.998E-04

Y ARRAY, IN:

1.000E-40	1.000E-40	1.000E-40	1.000E-40	1.000E-40

VECTOR ARRAY, IN:

4.998E-04	1.479E-03	1.976E-03	1.479E-03	4.998E-04

PHASE ANGLE ARRAY, DEGREES:

1.800E+02	1.800E+02	1.800E+02	1.800E+02	1.800E+02

XB(2),YB(2),XB(4),YB(4). IN

-3.321E-04	0.000E+00	-3.321E-04	0.000E+00

MOUNT VECTORS: (2) AND (4), IN.

1.147E-03	1.147E-03

MOUNT VECTOR PHASE ANGLES: (2) AND (4), DEGREES

1.800E+02	1.800E+02

THE AVERAGE REAL STEP-TIME FOR THIS PRINTOUT = 5.000E-05 SEC
REAL TIME = 5.000E-03 SEC
REVOLUTIONS = 3.000E+00 SPEED = 3.600000000E+04 RPM

VECTORS, IN:

4.994E-04	1.480E-03	1.977E-03	1.480E-03	4.994E-04

PHASE, DEGREES:

1.800E+02	1.800E+02	1.800E+02	1.800E+02	1.800E+02

WHIRL/SPIN FREQ. RATIO:

9.999E-01	1.000E+00	1.000E+00	1.000E+00	9.999E-01

MOUNT VECTORS: (2) AND (4), IN.

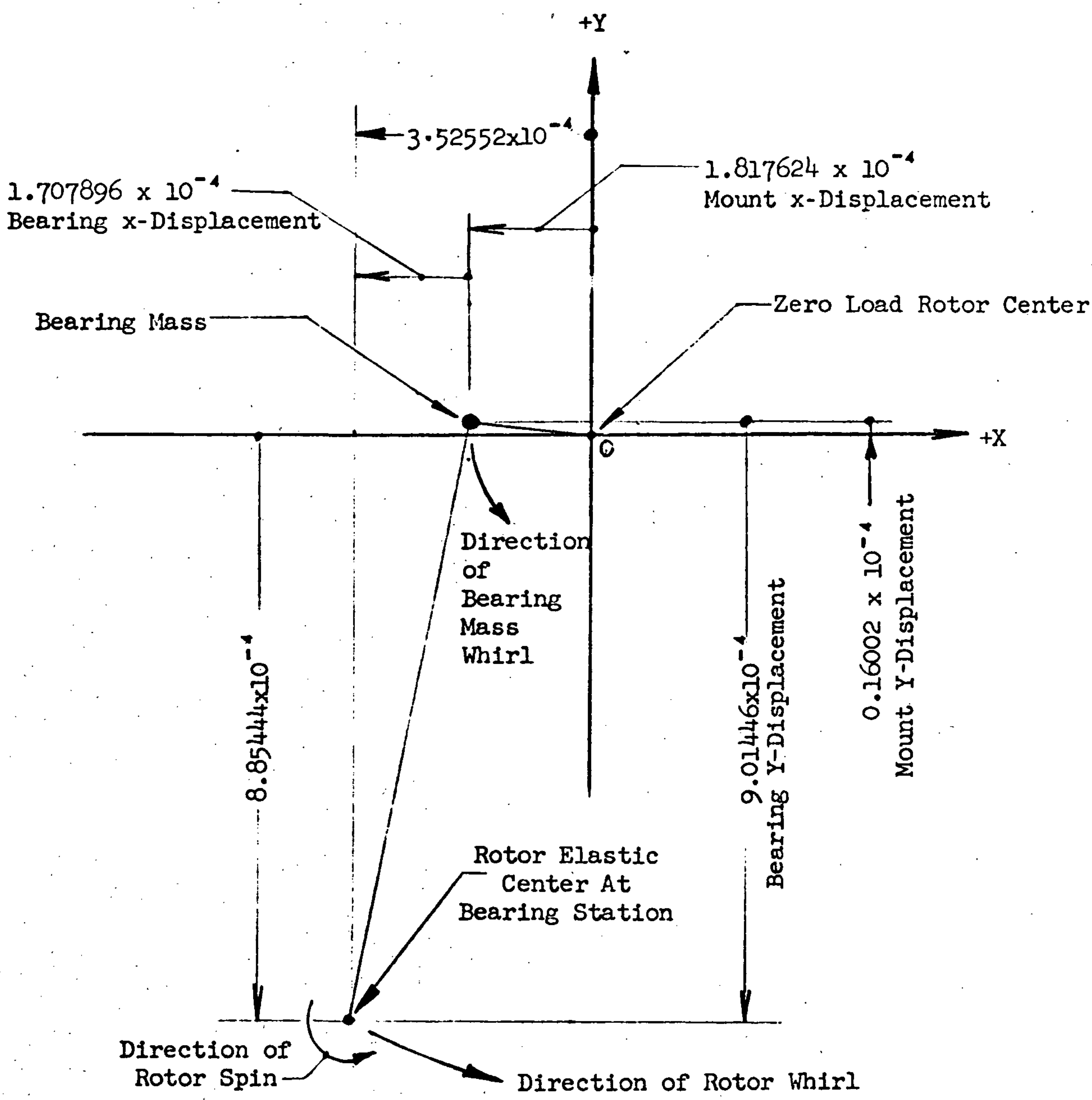
1.147E-03	1.147E-03

MOUNT VECTOR PHASE ANGLES: (2) AND (4), DEGREES

1.800E+02	1.800E+02

Note: Mount vector and mount phase angle represent the polar coordinates of the displaced bearing center.

Figure 34. Bearing Mass Dynamic Configuration From Both "STARTUP" and Subsequent Integration Type of Computation



Note: All dimensions are in centimeters.

Figure 35. Axial Projection of the Bearing-Mount Dynamic Configuration

TABLE V - FORCE EQUILIBRIUM AT BEARING, MASS

Force From	X-Component		Y-Component	
	Newtons	(lb)	Newtons	(lb)
Bearing Stiffness	← 598.2	$(2\times10^6)(0.6724\times10^{-4})$ = 134.48 ←	3157. ↓	$(2\times10^6)(3.549\times10^{-4})$ 709.8 ↓
Bearing Mass	← 318.3	$(1000)^2(0.7156\times10^{-4})$ = 71.56 ←	28. ↑	$(1000)^2(0.063\times10^{-4})$ = 6.3 ↑
Mount Stiffness	→ 636.6	$(2\times10^6)(0.7156\times10^{-4})$ = 143.12 →	56. ↓	$(2\times10^6)(0.063\times10^{-4})$ = 12.6 ↓
Mount Damping	→ 280.2	$(10^4)(10^3)(0.063\times10^{-4})$ = 63. →	3183. ↑	$(10^4)(10^3)(0.7156\times10^{-4})$ = 715.6 ↑
Relative Error	$\dfrac{\sum_1^4 \text{Force}}{0.5\sum_1^4 \lvert\text{Force}\rvert}$ = 0.04%		$\dfrac{\sum_1^4 \text{Force}}{0.5\sum_1^4 \lvert\text{Force}\rvert}$ = 0.07%	

Hysteresis

In the verification of the hysteresis formulation in the computer program, a hysteresis moment computation was made by using an artificial value of $\dot{\phi}-\omega_{ci}$. The resulting hysteresis moments generated has been verified to be correct.

Rotor Transverse Motion Effects

In both the axial and torsional loading computations, a 3-station symmetric rotor-bearing configuration was used for each loading. The two configurations, shown in Fig. 36 , were identical except for different polar mass moments of inertia. No basic reasons for using different rotor configurations exist, they simply represent alternate rotor designs.

Axial Loading Effects on Rotor Transverse Motion. In the computer analysis, various combinations of axial loading, rotor spin speed, and damping parameter were included in the computer runs, as presented in Table VI .

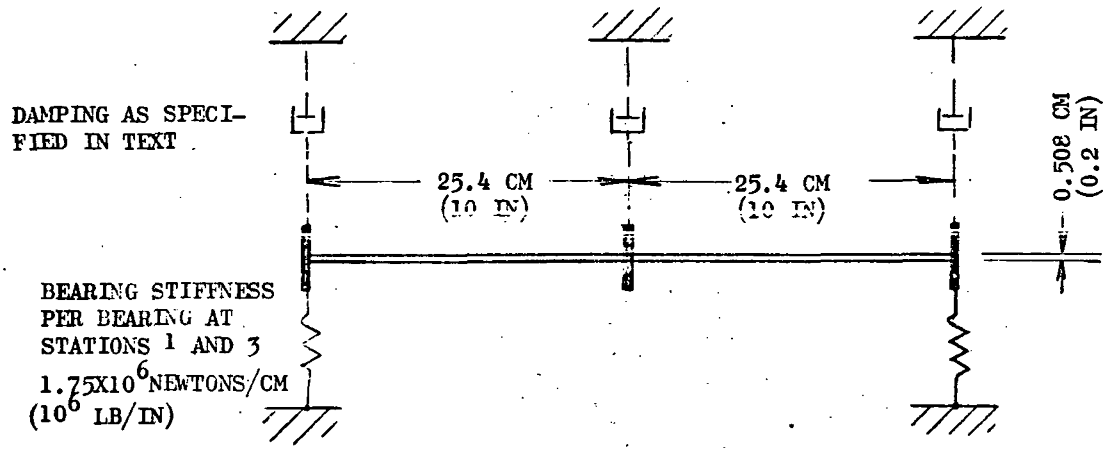
Three 1-rpm rotor spin speed runs (Runs 1 through 3) were first made to simulate the static performance of an axially loaded, hinged-end, uniform cross-section column having an initial elastic deflection. In Run 1, a 44,482 Newtons (10^4 lb) axial compressive loading was used. The midspan (Rotor Station 2) rotor deflections are depicted in Fig. 37 . In Run 2, the same operating conditions were maintained except that a 44,482 Newtons axial tensile loading was applied, instead of the compressive one. The corresponding computer results are shown in Fig. 38 , which indicates a reduction of rotor deflections leading to stable operation as expected. Run 3 is similar to Run 1, except that a smaller axial loading of 222 Newtons (50 pounds) was used. The results are presented in the lower portion of Fig. 38 . Although the rotor deflection magnitude in Run 3 is much reduced from that in Run 1, the general trend of monotonically increasing deflection remains the same as in Run 1 as shown in Fig. 37.

The critical buckling load for the hinged-end, uniform cross-section column was computed from the Euler formulation ($P_{critical} = \pi^2 EI/L^2$) to be 259 Newtons (58 pounds). The reasons for the instability trend observed in Run 3 with below the critical compressive loading are twofold; first, a sectional linear moment axial loading model was used in the analysis, as compared with the actual nonlinear moment-axial loading function, and second, the inherent instability effects of the mass-unbalance rotor dynamic loading considered in the analysis. For a rotor having a reasonable number of stations, the computer analysis will closely approximate the exact non-linear moment-axial loading function of an axially loaded rotor.

In Run 4 through 9, a moderately high rotor spin speed of 36,000 rpm in combination with different axial loadings and damping coefficients was used. The rotor deflection results for these runs are depicted in Fig. 39 through 41.

A comparison study of the undamped axial loading results (Runs 1 through 5 and run 8) suggests that a high rotor spin speed tends to resist buckling instability even under large axial compressive loading. While a larger than critical

ROTOR STATION NO.	1		2		3	
MASS: Kg (LB)	22.68	(50)	22.68	(50)	22.68	(50)
TRANSVERSE INERTIA						
Kg-CM^2(LB-IN^2)	176	(60)	176	(60)	176	(60)
POLAR INERTIA						
Kg-CM^2(LB-IN^2)						
FOR AXIAL LOADING	146	(50)	146	(50)	146	(50)
FOR TORSIONAL LOADING	205	(70)	205	(70)	205	(70)
MASS ECCENTRICITY CM (IN) AT 45 DEG PHASE ANGLE	0.000762 (0.0003)		0.00254 (0.001)		0.000762 (0.0003)	
INERTIA MISALIGNMENT	0		0		0	



ROTOR MATERIAL PROPERTIES:

DENSITY	0
YOUNG MODULUS OF ELASTICITY	2.068X10^7 NEWTON/CM^2 (3 x 10^7 PSI)
SHEAR MODULUS OF RIGIDITY	0.793X10^7 NEWTON/CM^2 (1.15x10^7 PSI)
POISSON'S RATIO	0.3

Figure 36. Rotor Configuration

TABLE VI - AXIAL LOADING RUNS

RUN NO.	PARAMETER INCLUDED		
	ROTOR SPIN SPEED RPM	AXIAL LOADING NEWTONS (LB)	DISPLACEMENT DAMPING COEFFICIENT NEWTONS-SEC/CM (LB-SEC/IN)
1	1	44,482 *C (10^4 C)	0
2	1	44,482 *T (10^4 T)	0
3	1	222. C (50 C)	0
4	36,000	222. C (50 C)	0
5	36,000	44,482 C (10^4 C)	0
6	36,000	44,482 C (10^4 C)	1,751. (10^3)
7	36,000	444,822 C (10^5 C)	1,751 (10^3)
8	36,000	444,822 C (10^5 C)	0

***C = Compressive Axial Loading**
***T = Tensile Axial Loading**

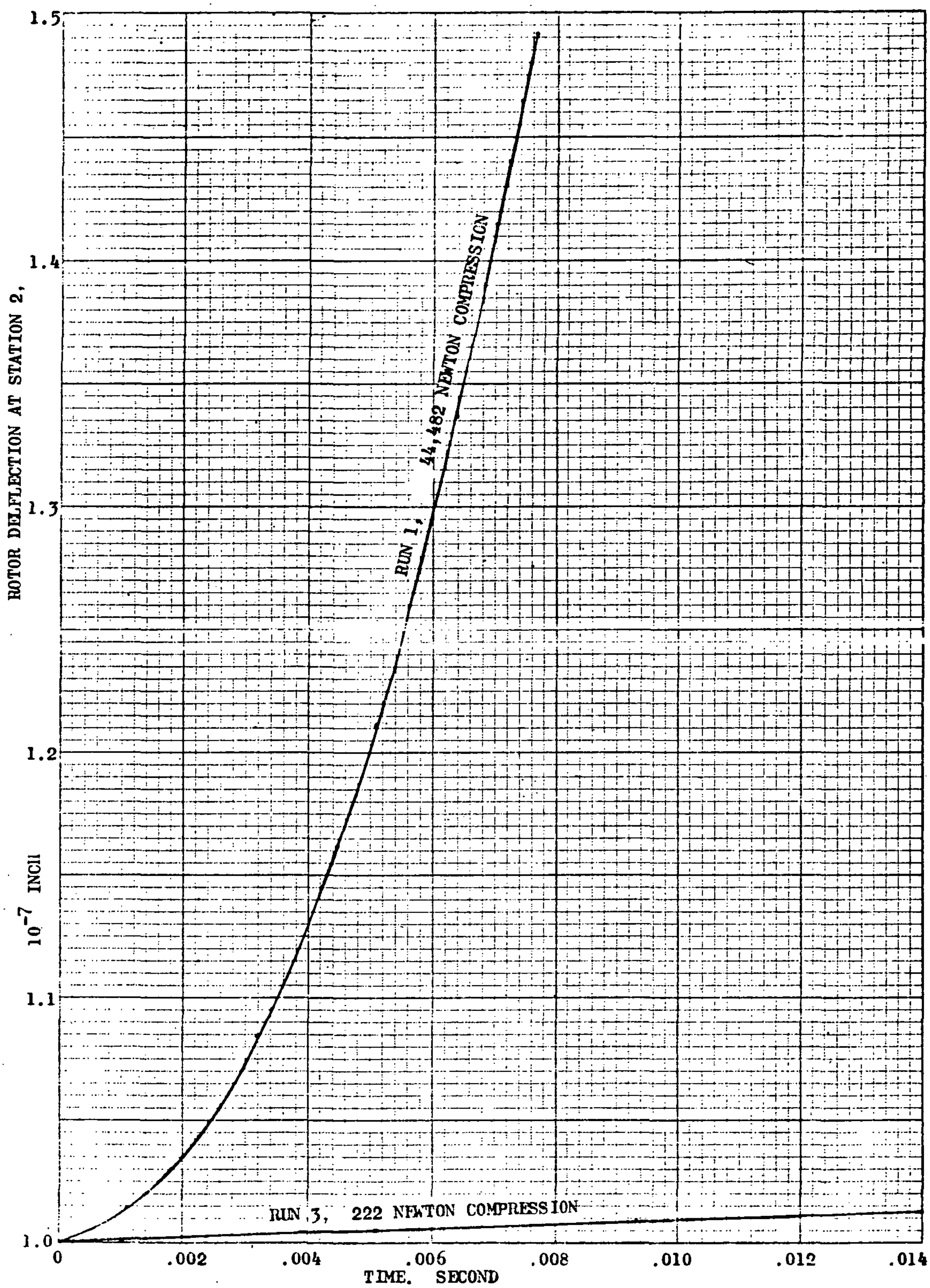


Figure 37. Axial Loading Effects at 1 rpm, Runs 1 and 3

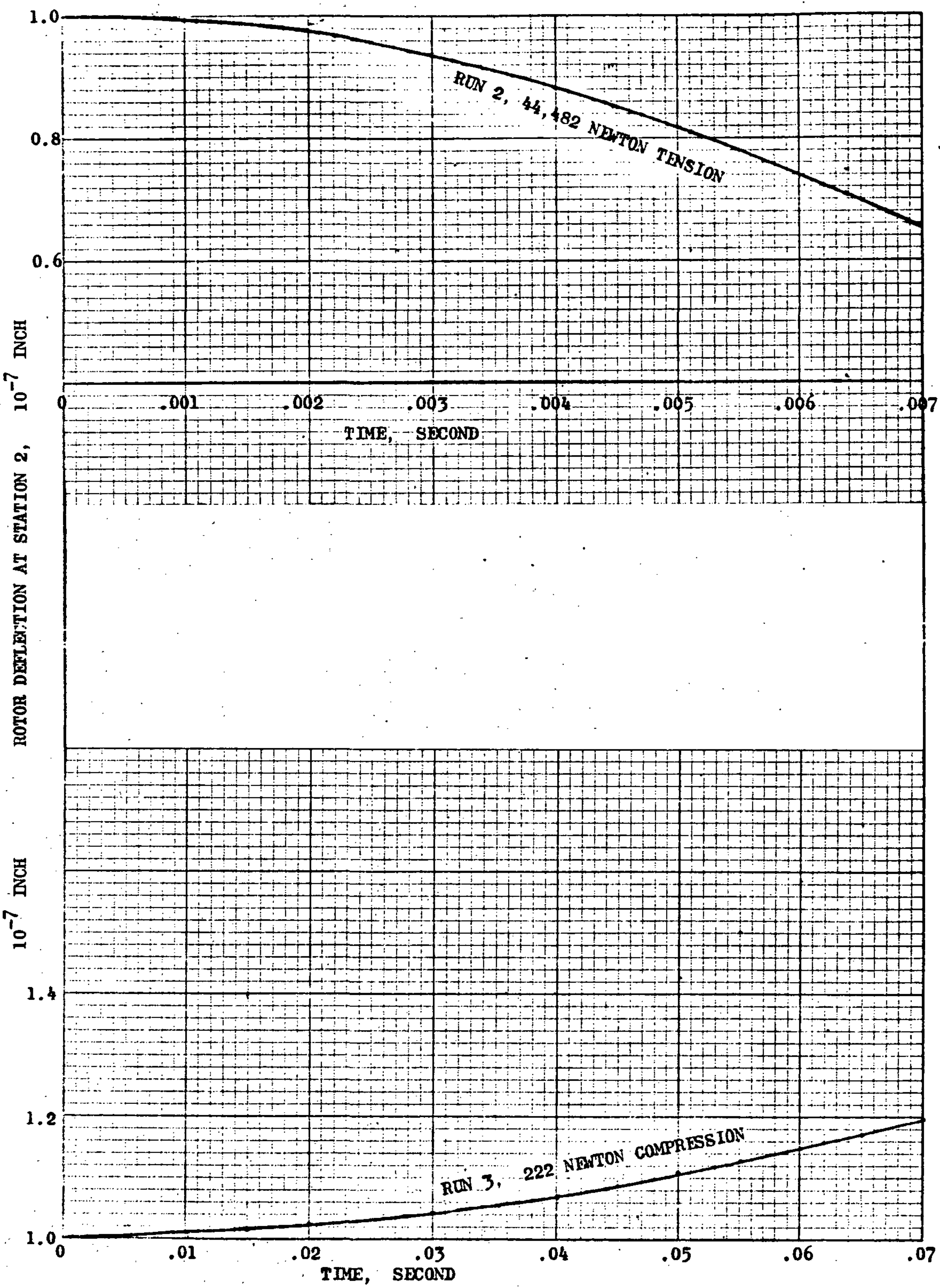


Figure 38. Axial Loading Effects at 1 rpm, Runs 2 and 3

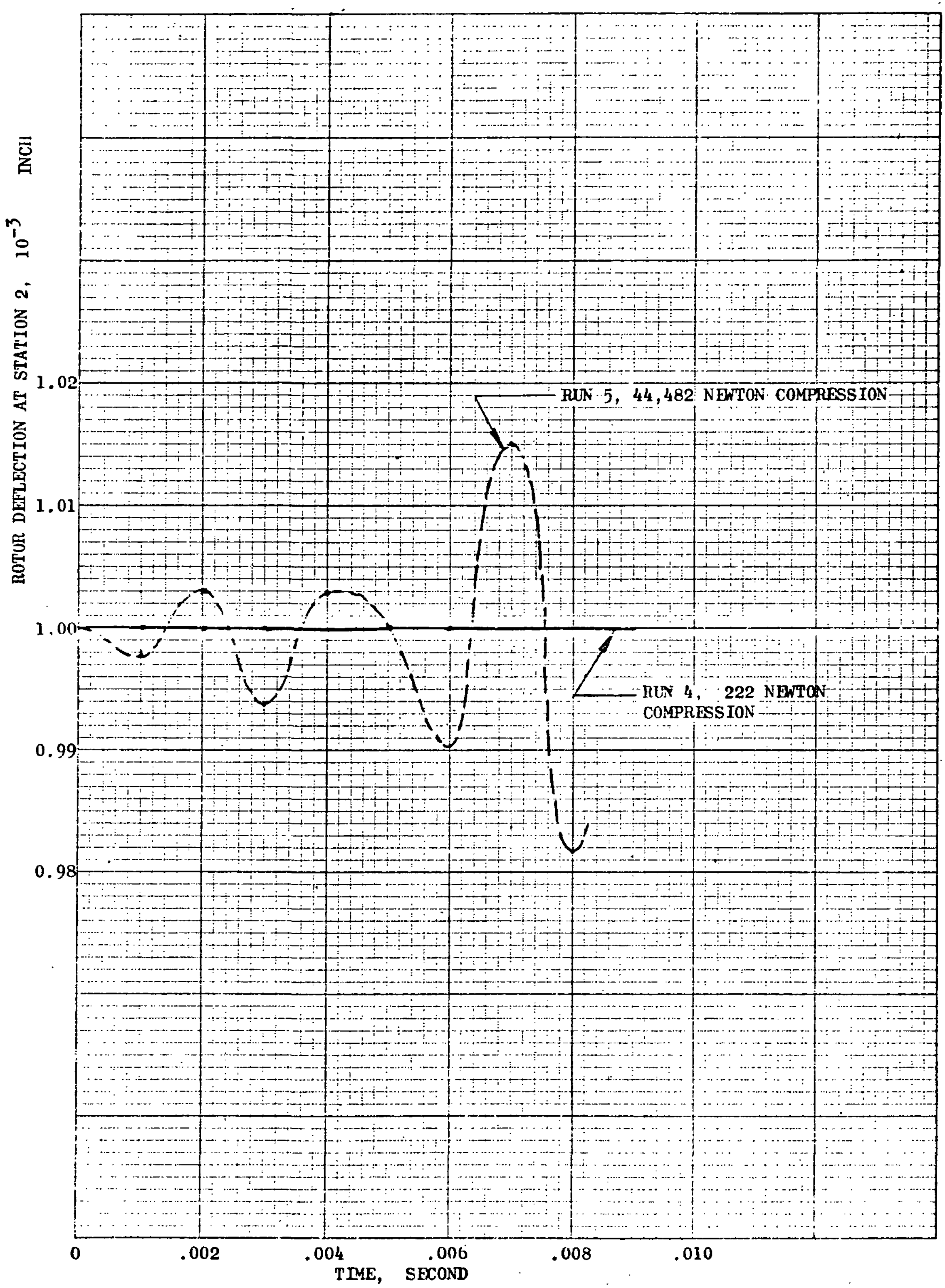


Figure 39. Axial Loading Effects at 36,000 rpm, Runs 4 and 5

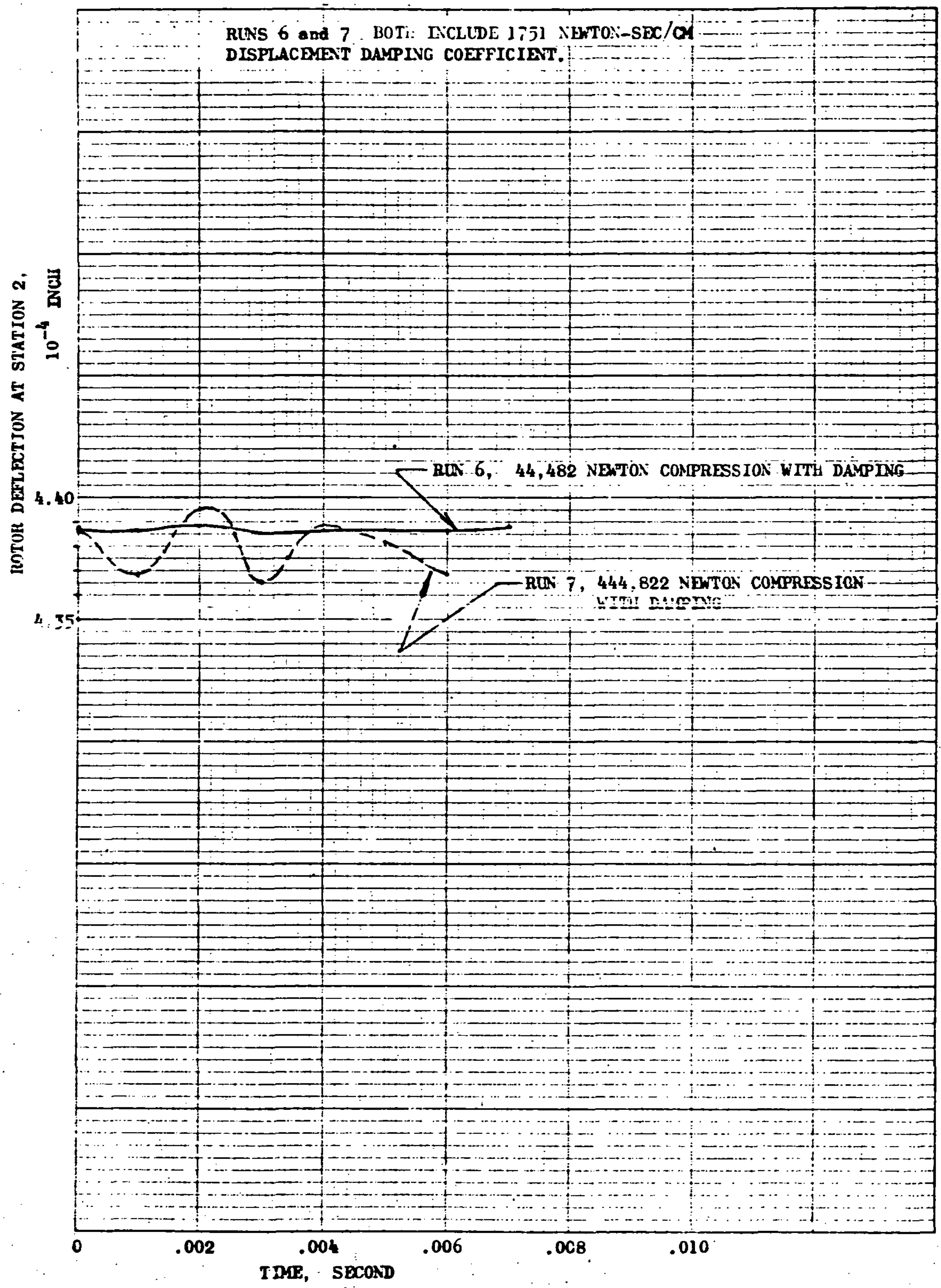


Figure 40. Axial Loading Effects at 36,000 rpm

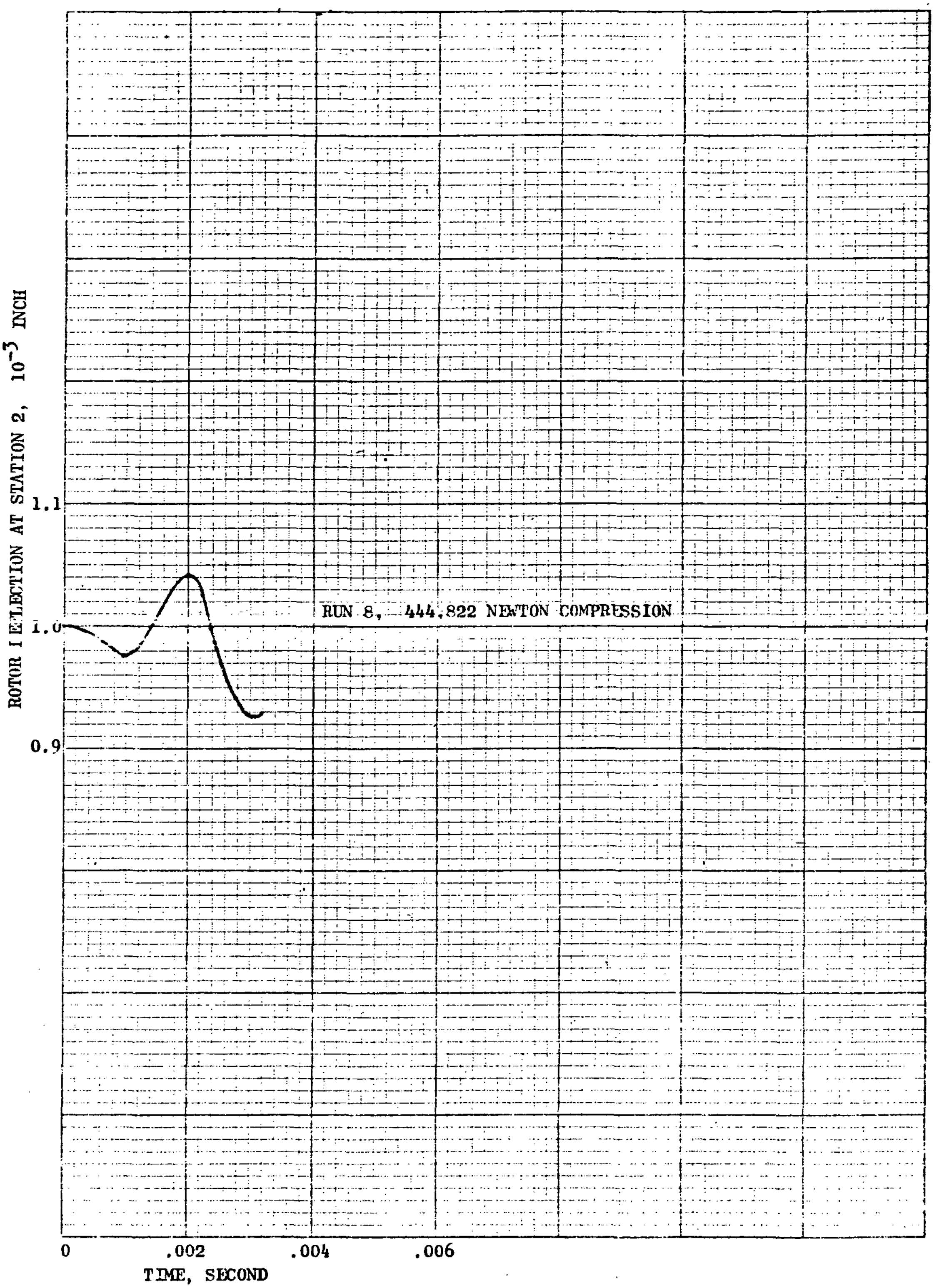


Figure 41. Axial Loading Effects at 36,000 rpm, Run 8

loading would definitely result in rotor instability under a non-rotating, static condition, a high speed rotor system of the same design may operate without exhibiting an unstable trend. The mechanism for the apparently more stable motion with a high speed rotor under compressive axial loading appears to be similar to that causing the stable motion for a super-resonant rotor speed operation. In such a super-resonant rotor speed operation, the mass acceleration stiffness exceeds that of the combined rotor-bearing stiffness which would lead to instability if not for the dynamic effects of rotation.

Runs 6 and 7 included viscous damping in the rotor-bearing system under a large axial compressive load. The corresponding rotor deflections are plotted in Fig. 40, which indicates a substantial reduction in rotor deflection and oscillation compare with those in Run 5, Fig. 39, and Run 8, Fig. 41, where damping was absent.

Figure 41 depicts the results from Run 8 which was conducted under the same operating conditions as Run 7, except without damping. In Fig. 41, Run 8 exhibits a trend of larger rotor deflection over that in Run 5 (Fig. 39) due to larger axial loading and a much stronger oscillation as compared with Run 7 due to the absence of damping.

A review of the rotor dynamic deflection performance of the eight computer runs suggests that the rotor rotation, particularly at high rotational speed, and damping are stabilizing factors against the buckling effects of an axial compressive loading. The stabilizing effects include the minimization of deflections as well as oscillations induced by axial loading.

Torsional Loading Effects on Rotor Transverse Motion. In the analytical demonstration of the torsional loading effects, eight computer runs (Runs 9 through 16), which include various combinations of rotor speed, torsional loading and damping coefficient, were made as stated in Table VII. The computer results are depicted in Fig. 42 through 44. The rotor bearing configuration used in this analysis is defined in Fig. 36.

For each of the computer runs, positive drive torque was applied at Rotor Station 3 (rotor right end) balanced with an equal and opposite drive torque at Station 1 (rotor left end). Thus, the rotor spin acceleration at the mid-rotor station (Station 2) will remain zero and the average speed at the ends of rotor will be that of the initial starting rotor speed. Using the opposite drive torques at the ends of the rotor, the rotor transverse effects due to torsion without those due to the average rotor acceleration caused by unbalanced torque application may be clearly observed.

To simulate the torsional loading effects under the nonrotating, static conditions, two 1-rpm and two 10-rpm runs were included; Runs 9 and 10 are those at 1-rpm and Runs 11 and 12 were made at 10-rpm. The computed rotor deflections at rotor ends (Stations 1 and 3) or the rotor deflections at Station 1 when they approximate those at Station 3, are depicted in Fig. 42 through 44, in the torsional loading analysis.

TABLE VII - TORSIONAL LOADING RUNS

RUN NO.	PARAMETERS INCLUDED			
	ROTOR SPIN SPEED RPM	*BALANCED DRIVE TORQUE NEWTON-CM (LB-IN)	DISPLACEMENT DAMPING COEFFICIENT NEWTON-SEC/CM (LB-SEC/IN)	SLOPE DAMPING COEFFICIENT NEWTON-CM-SEC/RADIAN (LB-IN-SEC/RADIAN)
9	1	7909 (700)	0	0
10	1	11.2985×10^6 (10^6)	0	0
11	10	7909 (700)	0	0
12	10	11.2985×10^6 (10^6)	0	0
13	36,000	7909 (700)	0	0
14	36,000	11.2985×10^6 (10^6)	0	0
15	36,000	11.2985×10^6 (10^6)	17513 (10^4)	0
16	36,000	11.2985×10^6 (10^6)	0	11.2985×10^4 (10^4)

*Positive Drive Torque at Station 3 and An Equal and Opposite Drive Torque at Station 1.

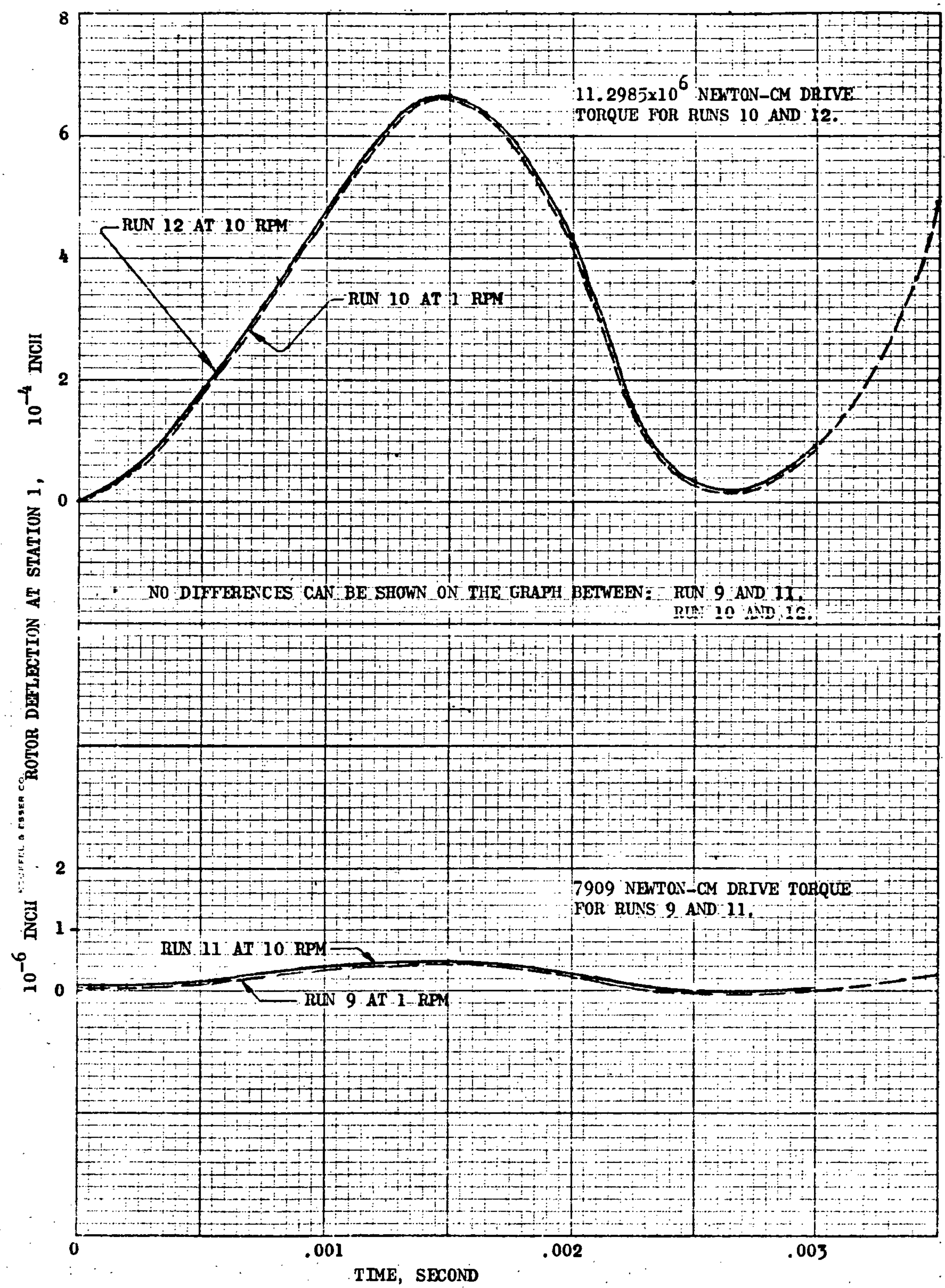


Figure 42. Torsional Loading Effects, Runs 9 Through 12

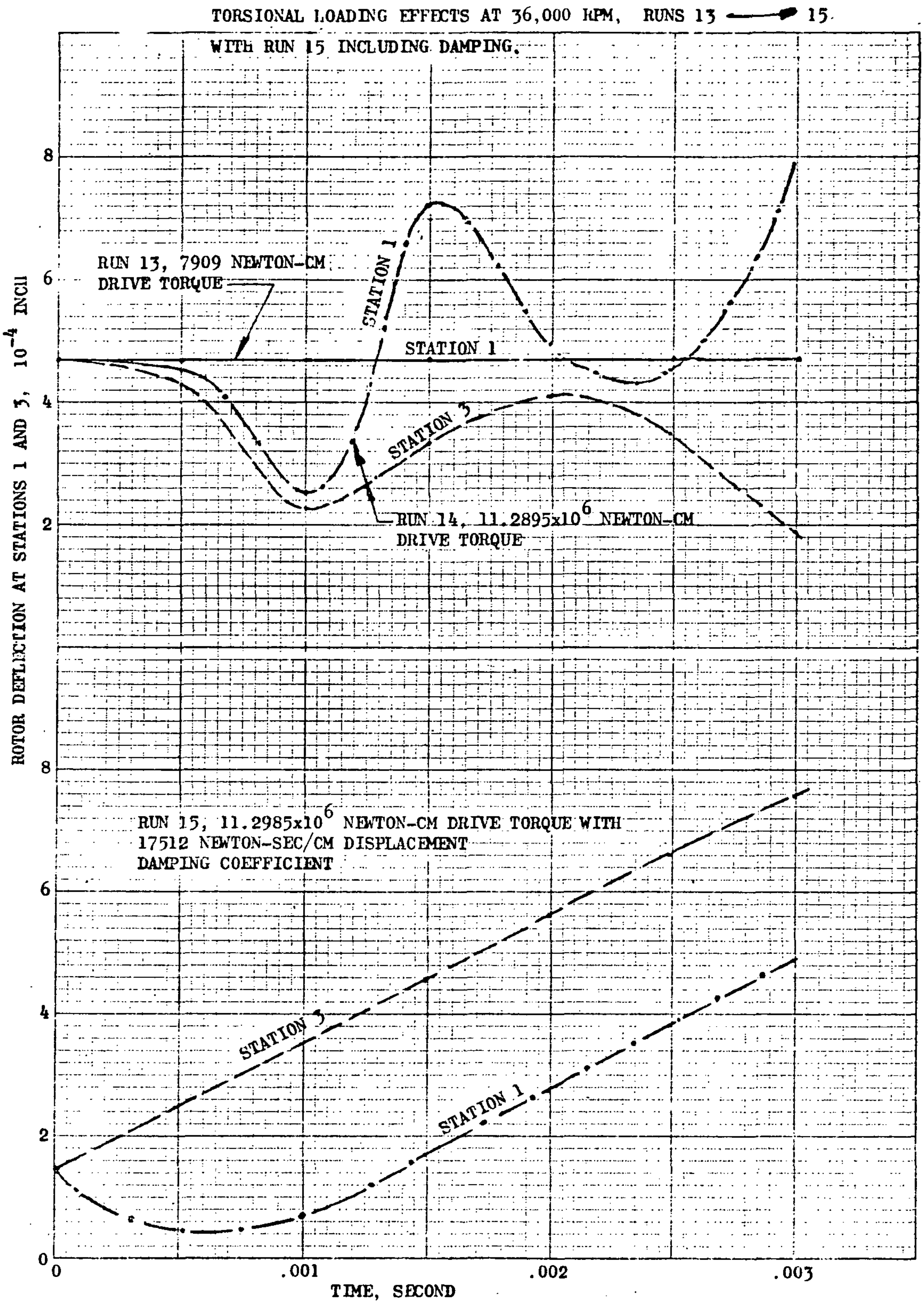


Figure 43. Torsional Loading Effects at 36,000 rpm,

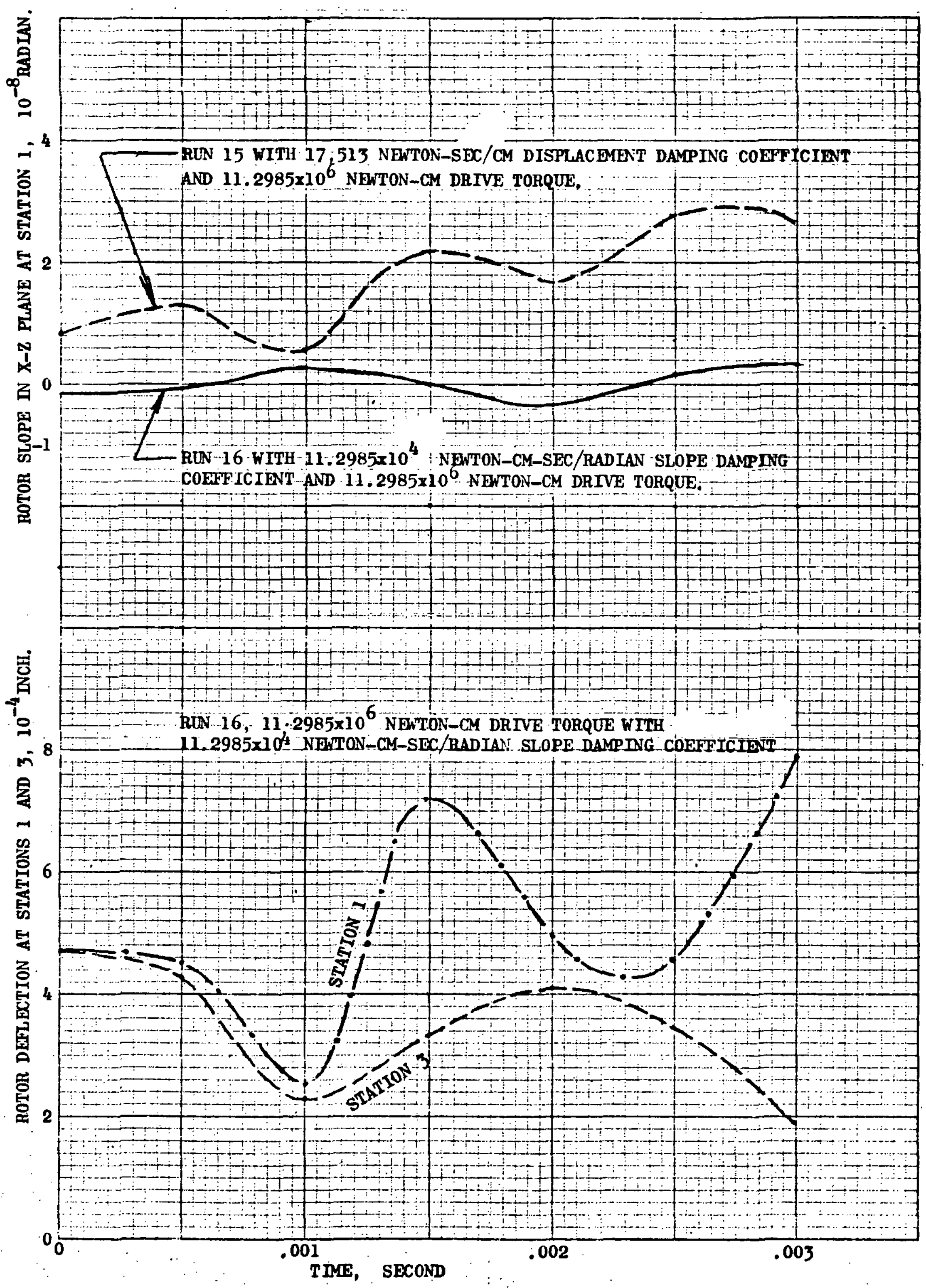


Figure 44. Torsional Loading Effects Including Damping at 36,000 rpm

The midrotor deflections remain basically constant in all the runs under the balanced torque conditions. In Fig. 42 large oscillations are observed for the 11.2985×10^6 Newton-cm (10^6 lb-in.) torque runs, while for a 7909 Newton-cm (700 lb-in.) torque loading, the oscillation in rotor deflections are drastically reduced. The effects of a small change of rotor speed from 1 to 10 rpm is minimal as expected. The results presented in the upper portion of Fig. 42 suggest a trend of instability, while the lower portion may lead to stable operation.

For the static, nonrotating, uniform cross-section rotor, the critical torsional buckling load is computed to be 8363 Newton-cm (740 lb-in.) from the classic formulation; $\text{torque}_{\text{critical}} = 2\pi EI/L$. The value of smaller torsional loading (7909 Newton-cm) used in the analysis is below the static critical buckling loading, where the larger torque loading far exceeds the critical value.

Runs 13 through 16 were made at a moderately high operating speed of 36,000 rpm. A lower torsional loading of 7909 Newton-cm was used in Run 13 and the higher loading of 11.2985×10^6 Newton-cm was applied in Run 14. No rotor damping was included in Runs 13 and 14. The computer results are depicted in Fig. 43 . Run 13, shown in the upper portion of Fig. 43, indicates a high degree of stability, while Run 14, which used large torsional loading, shows oscillations and a divergence in rotor deflection versus time relationship.

Runs 15 and 16 included displacement and slope damping, respectively. In both the runs the high torsional loading of 11.2985×10^6 Newton-cm was used. Rotor deflection data for Run 15 are depicted in the lower portion of Fig. 43 which indicates a modification of the deflection versus time characteristic from a divergently oscillatory in the no-damping case of Run 14 to a monotonically increasing behavior, except near zero time point. The explanation for the performance in Run 15 versus Run 14 is that although the oscillation energy has been dissipated through damping, the divergent, unstable factor induced by the super-critical buckling torsion still persists.

Run 16 was computed under the effects of slope damping which acts against the change of slopes, but not against the change of deflection. Clearly no noticeable damping effects on rotor deflections are observed, as shown in the lower portion of Fig. 44. However, a comparison of the rotor slope versus time functions between Run 15 and 16, as shown in the upper portion of Fig. 44, indicates that the slope damping was demonstrated to be substantially effective in minimizing the slope oscillation in Run 16.

The study of the torsional loading computer results revealed that the application of a below critical buckling torque would not cause rotor oscillation or instability in the high speed rotor operation, particularly in the presence of rotor damping. High speed rotation and damping parameters are, therefore, considered to have a substantial stabilizing effect for rotors under torsional loading.

Bearing and Mount Parameters

These added parameters include:

1. Bearing in-phase and out-of-phase stiffness and damping forces,
2. Bearing in-phase and out-of-phase stiffness and damping moments,
3. Bearing transverse mass moments of inertia, and
4. Mount in-phase stiffness and damping moments.

To demonstrate the validity of the GE coding of these parameters, sample rotor dynamic performance computations were made. Figures 45 through 53 represent the rotor dynamic performance according to the input parameters defined in Fig. 54. Each of the computer runs consists of two parts; part a is the startup rotor dynamic configuration generated in subroutine STARUP and part b represents the integration results computed in subroutine RKADAM. The agreements between the rotor performance from STARUP and RKADAM of each of the computer runs indicate that the coding in RKADAM is consistent with that in STARUP. The validity of the startup rotor configuration has been demonstrated in three ways:

1. Force and moment equilibrium among those due to the displacements and slopes of the bearings and mounts and bearing masses and mass moments of inertia as follows:

   Bearing force + bearing mass force = mount force (along X and Y axes)

   Bearing moment + bearing inertia moment = mount moment (in X-Z and Y-Z planes)
2. Displacement and slope consistency among those of the rotor, bearings and mounts (i.e., the vectorial sum of displacements or slopes of bearings and mounts equal those of the corresponding rotor displacements or rotations).
3. The bearing and mount forces and moments correspond to the products of their displacements and slopes, their first time derivatives and the stiffness and damping coefficients.

Since there is a unique solution to a rotor system at a set of operating conditions, other than those unstable rotor dynamic configurations due to nonlinear bearing stiffness, etc., the consistent solutions represented in Figures 45 through 53 are the only valid ones.

In the aforementioned computer runs, axisymmetric bearing and mount stiffness and damping coefficients were used although the general nonisotropic coefficient capability is included in the RKADAM subroutine. The reason for the use of axisymmetric coefficients was to provide an exact comparison of rotor performance between that generated from RKADAM and that from STARUP which is limited to axisymmetric coefficients as planned.

The other rotor design and operating conditions which are not contained in Fig. 36, but common to all the 9 computer runs, are described in Fig. 55.

```
THE COMPUTED STARTING ROTOR DEFLECTION COORDINATES ARE:

          VECTOR ARRAY, IN:
   1.1409E-04   9.3123E-05   1.1409E-04
          PHASE ANGLE ARRAY, DEGREES:
   2.2500E+02   2.2500E+02   2.2500E+02

BEARING DISPLACEMENT VECTOR,IN
   1.3801E-04   1.3801E-04
BEARING DISPLACEMENT PHASE ANGLE, DEGREES
   2.2500E+02   2.2500E+02
MOUNT VECTORS, IN
   2.3918E-05   2.3918E-05
MOUNT VECTOR PHASE ANGLES, DEGREES
   4.5000E+01   4.5000E+01

ROTOR SLOPE VECTORS
   1.2827E-04   9.5349E-14   1.2827E-04
ROTOR SLOPE VECTOR PHASE ANGLE, DEGREES
   2.2500E+02   2.2060E+02   4.5000E+01
BEARING SLOPE VECTORS
   0.0000E+00   0.0000E+00
BEARING SLOPE PHASE ANGLE , DEGREES
   4.5000E+01   4.5000E+01
MOUNT SLOPE VECTORS
   1.2827E-04   1.2827E-04
MOUNT SLOPE PHASE ANGLE, DEGREES
   2.2500E+02   4.5000E+01

BEARING FORCE IN X-DIRECTION
  -9.7590E+01  -9.7590E+01
BEARING FORCE IN Y-DIRECTION
  -9.7590E+01  -9.7590E+01
BEARING MOMENT IN X-Z PLANE
   0.0000E+00   0.0000E+00
BEARING MOMENT IN Y-Z PLANE
   0.0000E+00   0.0000E+00

MOUNT FORCE IN X-DIRECTION
   3.3825E+01   3.3825E+01
MOUNT FORCE IN Y-DIRECTION
   3.3825E+01   3.3825E+01
MOUNT MOMENT IN X-Z PLANE
   0.0000E+00   0.0000E+00
MOUNT MOMENT IN Y-Z PLANE
   0.0000E+00   0.0000E+00

BEARING MASS FORCE IN X-DIRECTION
   1.3142E+02   1.3142E+02
BEARING MASS FORCE IN Y-DIRECTION
   1.3142E+02   1.3142E+02
BEARING INERTIA MOMENT IN X-Z PLANE
   0.0000E+00   0.0000E+00
BEARING INERTIA MOMENT IN Y-Z PLANE
   0.0000E+00   0.0000E+00
```

NOTE: FOR FIG. 45 THROUGH 53 THE UNITS USED IN THE COMPUTER RUN ARE:

DISPLACEMENT	=	INCHES
SLOPE	=	RADIANS
FORCE	=	LB
MOMENT	=	IN-LB

Figure 45. Computed Starting Rotor Deflection Coordinates Run 2

```
THE AVERAGE REAL STEP-TIME FØR THIS PRINTØUT =    2.500E-05 SEC
REAL TIME =    1.000E-03 SEC
REVØLUTIØNS ARRAY:
   1.5915E+00    1.5915E+00    1.5915E+00
SPIN SPEED ARRAY, RPM:
   9.5493E+04    9.5493E+04    9.5493E+04

RØTØR DISPLACEMENT VECTØR ARRAY, IN
   1.1409E-04    9.3124E-05    1.1409E-04
RØTØR VECTØR PHASE ANGLE ARRAY, DEGREES
   7.7958E+01    7.7959E+01    7.7958E+01
BEARING DISPLACEMENT VECTØRS
   1.3801E-04    1.3801E-04
BEARING DISPLACEMENT PHASE ANGLES, DEGREES
   7.7958E+01    7.7958E+01
MØUNT DISPLACEMENT VECTØR ARRAY, IN
   2.3914E-05    2.3914E-05
MØUNT VECTØR PHASE ANGLE ARRAY, DEGREES
   2.5796E+02    2.5796E+02

RØTØR WHIRL/SPIN FREQ.RATIØ ARRAY
   1.0000E+00    1.0000E+00    1.0000E+00

RØTØR SLØPE VECTØRS
   1.2825E-04    1.1498E-13    1.2825E-04
RØTØR SLØPE PHASE ANGLES, DEGREES
   7.7958E+01    3.4306E+02    2.5796E+02
BEARING SLØPE VECTØRS
   3.3399E-15    2.2888E-15
BEARING SLØPE PHASE ANGLES, DEGREES
   1.9542E+02    3.3717E+02
MØUNT SLØPE VECTØRS
   1.2825E-04    1.2825E-04
MØUNT SLØPE VECTØR PHASE ANGLES, DEGREES
   7.7958E+01    2.5796E+02
```

Figure 45. Concluded

```
THE CØMPUTED STARTING RØTØR DEFLECTIØN CØØRDINATES ARE:

          VECTØR ARRAY, IN:
   1.0167E-04    9.3438E-05    1.0167E-04
          PHASE ANGLE ARRAY, DEGREES:
   2.2072E+02    2.2512E+02    2.2072E+02

BEARING DISPLACEMENT VECTØR,IN
   1.0018E-04    1.0018E-04
BEARING DISPLACEMENT PHASE ANGLE, DEGREES
   2.1088E+02    2.1088E+02
MØUNT VECTØRS, IN
   1.7362E-05    1.7362E-05
MØUNT VECTØR PHASE ANGLES, DEGREES
   3.0088E+02    3.0088E+02

RØTØR SLØPE VECTØRS
   1.2723E-04    2.3270E-14    1.2723E-04
RØTØR SLØPE VECTØR PHASE ANGLE, DEGREES
   2.2472E+02    2.4623E-25    4.4719E+01
BEARING SLØPE VECTØRS
   0.0000E+00    0.0000E+00
BEARING SLØPE PHASE ANGLE , DEGREES
   4.5000E+01    4.5000E+01
MØUNT SLØPE VECTØRS
   1.2723E-04    1.2723E-04
MØUNT SLØPE PHASE ANGLE, DEGREES
   2.2472E+02    4.4719E+01

BEARING FØRCE IN X-DIRECTIØN
  -5.1425E+01   -5.1425E+01
BEARING FØRCE IN Y-DIRECTIØN
   8.5980E+01    8.5980E+01
BEARING MØMENT IN X-Z PLANE
   0.0000E+00    0.0000E+00
BEARING MØMENT IN Y-Z PLANE
   0.0000E+00    0.0000E+00

MØUNT FØRCE IN X-DIRECTIØN
   1.7824E+01    1.7824E+01
MØUNT FØRCE IN Y-DIRECTIØN
  -2.9801E+01   -2.9801E+01
MØUNT MØMENT IN X-Z PLANE
   0.0000E+00    0.0000E+00
MØUNT MØMENT IN Y-Z PLANE
   0.0000E+00    0.0000E+00

BEARING MASS FØRCE IN X-DIRECTIØN
   6.9249E+01    6.9249E+01
BEARING MASS FØRCE IN Y-DIRECTIØN
  -1.1578E+02   -1.1578E+02
BEARING INERTIA MØMENT IN X-Z PLANE
   0.0000E+00    0.0000E+00
BEARING INERTIA MØMENT IN Y-Z PLANE
   0.0000E+00    0.0000E+00
```

Figure 46. Computer Starting Rotor Deflection Coordinates Run 3

```
THE AVERAGE REAL STEP-TIME FØR THIS PRINTØUT =    2.500E-05
REAL TIME =    1.000E-03 SEC                      SEC
REVØLUTIØNS ARRAY:
   1.5915E+00   1.5915E+00   1.5915E+00
SPIN SPEED ARRAY, RPM:
   9.5493E+04   9.5493E+04   9.5493E+04

RØTØR DISPLACEMENT VECTØR ARRAY, IN
   1.0167E-04   9.3439E-05   1.0167E-04
RØTØR VECTØR PHASE ANGLE ARRAY, DEGREES
   7.3673E+01   7.8074E+01   7.3673E+01
BEARING DISPLACEMENT VECTØRS
   1.0018E-04   1.0018E-04
BEARING DISPLACEMENT PHASE ANGLES, DEGREES
   6.3839E+01   6.3839E+01
MØUNT DISPLACEMENT VECTØR ARRAY, IN
   1.7365E-05   1.7365E-05
MØUNT VECTØR PHASE ANGLE ARRAY, DEGREES
   1.5385E+02   1.5385E+02

RØTØR WHIRL/SPIN FREQ.RATIØ ARRAY
   1.0000E+00   1.0000E+00   1.0000E+00

RØTØR SLØPE VECTØRS
   1.2721E-04   2.8000E-14   1.2721E-04
RØTØR SLØPE PHASE ANGLES, DEGREES
   7.7677E+01   9.7561E+01   2.5768E+02
BEARING SLØPE VECTØRS
   2.2888E-15   1.9860E-15
BEARING SLØPE PHASE ANGLES, DEGREES
   2.0283E+02   3.3343E+02
MØUNT SLØPE VECTØRS
   1.2721E-04   1.2721E-04
MØUNT SLØPE VECTØR PHASE ANGLES, DEGREES
   7.7677E+01   2.5768E+02
```

Figure 46. Concluded

```
THE COMPUTED STARTING ROTOR DEFLECTION COORDINATES ARE:

          VECTOR ARRAY, IN:
   1.1050E-04   9.3231E-05   1.1050E-04
          PHASE ANGLE ARRAY, DEGREES:
   2.3173E+02   2.2480E+02   2.3173E+02

BEARING DISPLACEMENT VECTOR,IN
   1.3083E-04   1.3083E-04
BEARING DISPLACEMENT PHASE ANGLE, DEGREES
   2.4357E+02   2.4357E+02
MOUNT VECTORS, IN
   3.2064E-05   3.2064E-05
MOUNT VECTOR PHASE ANGLES, DEGREES
   1.0857E+02   1.0857E+02

ROTOR SLOPE VECTORS
   1.2791E-04   8.6063E-14   1.2791E-04
ROTOR SLOPE VECTOR PHASE ANGLE, DEGREES
   2.2548E+02   2.3726E+02   4.5476E+01
BEARING SLOPE VECTORS
   0.0000E+00   0.0000E+00
BEARING SLOPE PHASE ANGLE , DEGREES
   4.5000E+01   4.5000E+01
MOUNT SLOPE VECTORS
   1.2791E-04   1.2791E-04
MOUNT SLOPE PHASE ANGLE, DEGREES
   2.2548E+02   4.5476E+01

BEARING FORCE IN X-DIRECTION
   5.8926E+01   5.8926E+01
BEARING FORCE IN Y-DIRECTION
  -1.7538E+02  -1.7538E+02
BEARING MOMENT IN X-Z PLANE
   0.0000E+00   0.0000E+00
BEARING MOMENT IN Y-Z PLANE
   0.0000E+00   0.0000E+00

MOUNT FORCE IN X-DIRECTION
  -2.0424E+01  -2.0424E+01
MOUNT FORCE IN Y-DIRECTION
   6.0789E+01   6.0789E+01
MOUNT MOMENT IN X-Z PLANE
   0.0000E+00   0.0000E+00
MOUNT MOMENT IN Y-Z PLANE
   0.0000E+00   0.0000E+00

BEARING MASS FORCE IN X-DIRECTION
  -7.9350E+01  -7.9350E+01
BEARING MASS FORCE IN Y-DIRECTION
   2.3617E+02   2.3617E+02
BEARING INERTIA MOMENT IN X-Z PLANE
   0.0000E+00   0.0000E+00
BEARING INERTIA MOMENT IN Y-Z PLANE
   0.0000E+00   0.0000E+00
```

Figure 47. Computed Starting Rotor Deflection Coordinates Run 4

```
THE AVERAGE REAL STEP-TIME FØR THIS PRINTØUT =    2.500E-05
REAL TIME =   1.000E-03 SEC                       SEC
REVØLUTIØNS ARRAY:
   1.5915E+00   1.5915E+00   1.5915E+00
SPIN SPEED ARRAY, RPM:
   9.5493E+04   9.5493E+04   9.5493E+04

RØTØR DISPLACEMENT VECTØR ARRAY, IN
   1.1050E-04   9.3233E-05   1.1050E-04
RØTØR VECTØR PHASE ANGLE ARRAY, DEGREES
   8.4689E+01   7.7762E+01   8.4689E+01
BEARING DISPLACEMENT VECTØRS
   1.3082E-04   1.3082E-04
BEARING DISPLACEMENT PHASE ANGLES, DEGREES
   9.6528E+01   9.6528E+01
MØUNT DISPLACEMENT VECTØR ARRAY, IN
   3.2061E-05   3.2061E-05
MØUNT VECTØR PHASE ANGLE ARRAY, DEGREES
   3.2153E+02   3.2153E+02

RØTØR WHIRL/SPIN FREQ.RATIØ ARRAY
   1.0000E+00   1.0000E+00   1.0000E+00

RØTØR SLØPE VECTØRS
   1.2790E-04   1.1185E-13   1.2790E-04
RØTØR SLØPE PHASE ANGLES, DEGREES
   7.8434E+01   3.5890E+02   2.5843E+02
BEARING SLØPE VECTØRS
   3.2196E-15   3.3307E-15
BEARING SLØPE PHASE ANGLES, DEGREES
   1.8000E+02   1.7202E-24
MØUNT SLØPE VECTØRS
   1.2790E-04   1.2790E-04
MØUNT SLØPE VECTØR PHASE ANGLES, DEGREES
   7.8434E+01   2.5843E+02
```

Figure 47. Concluded

```
THE CØMPUTED STARTING RØTOR DEFLECTIØN CØØRDINATES ARE:

          VECTØR ARRAY, IN:
   1.3581E-04   9.2585E-05   1.3581E-04
          PHASE ANGLE ARRAY, DEGREES:
   2.2500E+02   2.2500E+02   2.2500E+02

BEARING DISPLACEMENT VECTØR,IN
   2.0785E-04   2.0785E-04
BEARING DISPLACEMENT PHASE ANGLE, DEGREES
   2.2500E+02   2.2500E+02
MØUNT VECTØRS, IN
   7.2041E-05   7.2041E-05
MØUNT VECTØR PHASE ANGLES, DEGREES
   4.5000E+01   4.5000E+01

RØTØR SLØPE VECTØRS
   1.3005E-04   2.0684E-14   1.3005E-04
RØTØR SLØPE VECTØR PHASE ANGLE, DEGREES
   2.2500E+02   9.0000E+01   4.5000E+01
BEARING SLØPE VECTØRS
   0.0000E+00   0.0000E+00
BEARING SLØPE PHASE ANGLE , DEGREES
   4.5000E+01   4.5000E+01
MØUNT SLØPE VECTØRS
   1.3005E-04   1.3005E-04
MØUNT SLØPE PHASE ANGLE, DEGREES
   2.2500E+02   4.5000E+01

BEARING FØRCE IN X-DIRECTIØN
  -2.9394E+02  -2.9394E+02
BEARING FØRCE IN Y-DIRECTIØN
  -2.9394E+02  -2.9394E+02
BEARING MØMENT IN X-Z PLANE
   0.0000E+00   0.0000E+00
BEARING MØMENT IN Y-Z PLANE
   0.0000E+00   0.0000E+00

MØUNT FØRCE IN X-DIRECTIØN
   1.0188E+02   1.0188E+02
MØUNT FØRCE IN Y-DIRECTIØN
   1.0188E+02   1.0188E+02
MØUNT MØMENT IN X-Z PLANE
   0.0000E+00   0.0000E+00
MØUNT MØMENT IN Y-Z PLANE
   0.0000E+00   0.0000E+00

BEARING MASS FØRCE IN X-DIRECTIØN
   3.9582E+02   3.9582E+02
BEARING MASS FØRCE IN Y-DIRECTIØN
   3.9582E+02   3.9582E+02
BEARING INERTIA MØMENT IN X-Z PLANE
   0.0000E+00   0.0000E+00
BEARING INERTIA MØMENT IN Y-Z PLANE
   0.0000E+00   0.0000E+00
```

Figure 48. Computed Starting Rotor Deflection Coordinates
Run 5

```
THE AVERAGE REAL STEP-TIME FOR THIS PRINTØUT =    2.500E-05 SEC
REAL TIME =    1.000E-03 SEC
REVØLUTIONS ARRAY:
   1.5915E+00   1.5915E+00   1.5915E+00
SPIN SPEED ARRAY, RPM:
   9.5493E+04   9.5493E+04   9.5493E+04

RØTØR DISPLACEMENT VECTØR ARRAY, IN
   1.3580E-04   9.2587E-05   1.3580E-04
RØTØR VECTØR PHASE ANGLE ARRAY, DEGREES
   7.7958E+01   7.7959E+01   7.7958E+01
BEARING DISPLACEMENT VECTØRS
   2.0783E-04   2.0783E-04
BEARING DISPLACEMENT PHASE ANGLES, DEGREES
   7.7957E+01   7.7957E+01
MØUNT DISPLACEMENT VECTØR ARRAY, IN
   7.2027E-05   7.2027E-05
MØUNT VECTØR PHASE ANGLE ARRAY, DEGREES
   2.5796E+02   2.5796E+02

RØTØR WHIRL/SPIN FREQ.RATIØ ARRAY
   1.0000E+00   1.0000E+00   1.0000E+00

RØTØR SLØPE VECTØRS
   1.3003E-04   2.7882E-14   1.3003E-04
RØTØR SLØPE PHASE ANGLES, DEGREES
   7.7957E+01   1.9796E+02   2.5796E+02
BEARING SLØPE VECTØRS
   5.1837E-15   4.0943E-15
BEARING SLØPE PHASE ANGLES, DEGREES
   2.2326E+02   3.1940E+02
MØUNT SLØPE VECTØRS
   1.3003E-04   1.3003E-04
MØUNT SLØPE VECTØR PHASE ANGLES, DEGREES
   7.7957E+01   2.5796E+02
```

Figure 48. Concluded

```
THE CØMPUTED STARTING RØTØR DEFLECTION CØØRDINATES ARE:

          VECTØR ARRAY, IN:
   1.1047E-04    9.0418E-05    1.1047E-04
          PHASE ANGLE ARRAY, DEGREES:
   2.2500E+02    2.2500E+02    2.2500E+02

BEARING DISPLACEMENT VECTØR,IN
   7.3652E-05    7.3652E-05
BEARING DISPLACEMENT PHASE ANGLE, DEGREES
   2.2500E+02    2.2500E+02
MØUNT VECTØRS, IN
   3.6826E-05    3.6826E-05
MØUNT VECTØR PHASE ANGLES, DEGREES
   2.2500E+02    2.2500E+02

RØTØR SLØPE VECTØRS
   1.8239E-04    1.1243E-14    1.8239E-04
RØTØR SLØPE VECTØR PHASE ANGLE, DEGREES
   2.2500E+02    2.6069E+02    4.5000E+01
BEARING SLØPE VECTØRS
   2.2062E-04    2.2062E-04
BEARING SLØPE PHASE ANGLE , DEGREES
   2.2500E+02    4.5000E+01
MØUNT SLØPE VECTØRS
   3.8234E-05    3.8234E-05
MØUNT SLØPE PHASE ANGLE, DEGREES
   4.5000E+01    2.2500E+02

BEARING FØRCE IN X-DIRECTIØN
  -5.2080E+01   -5.2080E+01
BEARING FØRCE IN Y-DIRECTIØN
  -5.2080E+01   -5.2080E+01
BEARING MØMENT IN X-Z PLANE
  -1.5600E+02    1.5600E+02
BEARING MØMENT IN Y-Z PLANE
  -1.5600E+02    1.5600E+02

MØUNT FØRCE IN X-DIRECTIØN
  -5.2080E+01   -5.2080E+01
MØUNT FØRCE IN Y-DIRECTIØN
  -5.2080E+01   -5.2080E+01
MØUNT MØMENT IN X-Z PLANE
   5.4072E+01   -5.4072E+01
MØUNT MØMENT IN Y-Z PLANE
   5.4072E+01   -5.4072E+01

BEARING MASS FØRCE IN X-DIRECTIØN
   0.0000E+00    0.0000E+00
BEARING MASS FØRCE IN Y-DIRECTIØN
   0.0000E+00    0.0000E+00
BEARING INERTIA MØMENT IN X-Z PLANE
   2.1008E+02   -2.1008E+02
BEARING INERTIA MØMENT IN Y-Z PLANE
   2.1008E+02   -2.1008E+02
```

Figure 49. Computed Starting Rotor Deflection Coordinates
Run 6

```
THE AVERAGE REAL STEP-TIME FØR THIS PRINTØUT =   2.500E-05
REAL TIME =    1.000E-03 SEC                     SEC
REVØLUTIONS ARRAY:
   1.5915E+00   1.5915E+00   1.5915E+00
SPIN SPEED ARRAY, RPM:
   9.5493E+04   9.5493E+04   9.5493E+04

RØTØR DISPLACEMENT VECTØR ARRAY, IN
   1.1047E-04   9.0420E-05   1.1047E-04
RØTØR VECTØR PHASE ANGLE ARRAY, DEGREES
   7.7958E+01   7.7959E+01   7.7958E+01
BEARING DISPLACEMENT VECTØRS
   7.3651E-05   7.3651E-05
BEARING DISPLACEMENT PHASE ANGLES, DEGREES
   7.7958E+01   7.7958E+01
MØUNT DISPLACEMENT VECTØR ARRAY, IN
   3.6826E-05   3.6826E-05
MØUNT VECTØR PHASE ANGLE ARRAY, DEGREES
   7.7958E+01   7.7958E+01

RØTØR WHIRL/SPIN FREQ.RATIØ ARRAY
   1.0000E+00   1.0000E+00   1.0000E+00

RØTØR SLØPE VECTØRS
   1.8236E-04   7.9395E-15   1.8236E-04
RØTØR SLØPE PHASE ANGLES, DEGREES
   7.7952E+01   4.5579E+01   2.5795E+02
BEARING SLØPE VECTØRS
   2.2058E-04   2.2058E-04
BEARING SLØPE PHASE ANGLES, DEGREES
   7.7951E+01   2.5795E+02
MØUNT SLØPE VECTØRS
   3.8224E-05   3.8224E-05
MØUNT SLØPE VECTØR PHASE ANGLES, DEGREES
   2.5795E+02   7.7946E+01
```

Figure 49. Concluded

```
THE COMPUTED STARTING ROTOR DEFLECTION COORDINATES ARE:

          VECTOR ARRAY, IN:
   1.0867E-04    9.3546E-05    1.0867E-04
          PHASE ANGLE ARRAY, DEGREES:
   2.2461E+02    2.2585E+02    2.2461E+02

BEARING DISPLACEMENT VECTOR,IN
   7.2453E-05    7.2453E-05
BEARING DISPLACEMENT PHASE ANGLE, DEGREES
   2.2461E+02    2.2461E+02
MOUNT VECTORS, IN
   3.6226E-05    3.6226E-05
MOUNT VECTOR PHASE ANGLES, DEGREES
   2.2461E+02    2.2461E+02

ROTOR SLOPE VECTORS
   1.1960E-04    1.2668E-14    1.1960E-04
ROTOR SLOPE VECTOR PHASE ANGLE, DEGREES
   2.1202E+02    3.2791E+02    3.2025E+01
BEARING SLOPE VECTORS
   1.1785E-04    1.1785E-04
BEARING SLOPE PHASE ANGLE , DEGREES
   2.0219E+02    2.2193E+01
MOUNT SLOPE VECTORS
   2.0424E-05    2.0424E-05
MOUNT SLOPE PHASE ANGLE, DEGREES
   2.9219E+02    1.1219E+02

BEARING FORCE IN X-DIRECTION
  -5.1577E+01   -5.1577E+01
BEARING FORCE IN Y-DIRECTION
  -5.0884E+01   -5.0884E+01
BEARING MOMENT IN X-Z PLANE
  -4.4515E+01    4.4515E+01
BEARING MOMENT IN Y-Z PLANE
   1.0912E+02   -1.0912E+02

MOUNT FORCE IN X-DIRECTION
  -5.1577E+01   -5.1577E+01
MOUNT FORCE IN Y-DIRECTION
  -5.0884E+01   -5.0884E+01
MOUNT MOMENT IN X-Z PLANE
   1.5429E+01   -1.5429E+01
MOUNT MOMENT IN Y-Z PLANE
  -3.7822E+01    3.7822E+01

BEARING MASS FORCE IN X-DIRECTION
   0.0000E+00    0.0000E+00
BEARING MASS FORCE IN Y-DIRECTION
   0.0000E+00    0.0000E+00
BEARING INERTIA MOMENT IN X-Z PLANE
   5.9945E+01   -5.9945E+01
BEARING INERTIA MOMENT IN Y-Z PLANE
  -1.4694E+02    1.4694E+02
```

Figure 50. Computed Starting Rotor Deflection Coordinates
Run 7

```
THE AVERAGE REAL STEP-TIME FØR THIS PRINTØUT =   2.500E-05
                                                 SEC
REAL TIME =   1.000E-03 SEC
REVØLUTIØNS ARRAY:
   1.5915E+00   1.5915E+00   1.5915E+00
SPIN SPEED ARRAY, RPM:
   9.5493E+04   9.5493E+04   9.5493E+04

RØTØR DISPLACEMENT VECTØR ARRAY, IN
   1.0867E-04   9.3848E-05   1.0867E-04
RØTØR VECTØR PHASE ANGLE ARRAY, DEGREES
   7.7571E+01   7.8809E+01   7.7571E+01
BEARING DISPLACEMENT VECTØRS
   7.2452E-05   7.2452E-05
BEARING DISPLACEMENT PHASE ANGLES, DEGREES
   7.7571E+01   7.7571E+01
MØUNT DISPLACEMENT VECTØR ARRAY, IN
   3.6226E-05   3.6226E-05
MØUNT VECTØR PHASE ANGLE ARRAY, DEGREES
   7.7571E+01   7.7571E+01

RØTØR WHIRL/SPIN FREQ.RATIØ ARRAY
   1.0000E+00   9.9999E-01   1.0000E+00

RØTØR SLØPE VECTØRS
   1.1959E-04   1.7485E-14   1.1959E-04
RØTØR SLØPE PHASE ANGLES, DEGREES
   6.4989E+01   9.2657E+01   2.4499E+02
BEARING SLØPE VECTØRS
   1.1783E-04   1.1783E-04
BEARING SLØPE PHASE ANGLES, DEGREES
   5.5161E+01   2.3516E+02
MØUNT SLØPE VECTØRS
   2.0412E-05   2.0412E-05
MØUNT SLØPE VECTØR PHASE ANGLES, DEGREES
   1.4515E+02   3.2515E+02
```

Figure 50. Concluded

```
THE CØMPUTED STARTING RØTØR DEFLECTIØN CØØRDINATES ARE:

         VECTØR ARRAY, IN:
   1.0699E-04   9.7030E-05   1.0699E-04
         PHASE ANGLE ARRAY, DEGREES:
   2.2526E+02   2.2446E+02   2.2526E+02

BEARING DISPLACEMENT VECTØR,IN
   7.1331E-05   7.1331E-05
BEARING DISPLACEMENT PHASE ANGLE, DEGREES
   2.2526E+02   2.2526E+02
MØUNT VECTØRS, IN
   3.5665E-05   3.5665E-05
MØUNT VECTØR PHASE ANGLES, DEGREES
   2.2526E+02   2.2526E+02

RØTØR SLØPE VECTØRS
   5.7831E-05   2.1740E-14   5.7831E-05
RØTØR SLØPE VECTØR PHASE ANGLE, DEGREES
   2.4266E+02   2.5045E+02   6.2656E+01
BEARING SLØPE VECTØRS
   3.0118E-05   3.0118E-05
BEARING SLØPE PHASE ANGLE , DEGREES
   3.0715E+02   1.2715E+02
MØUNT SLØPE VECTØRS
   5.2456E-05   5.2456E-05
MØUNT SLØPE PHASE ANGLE, DEGREES
   2.1144E+02   3.1443E+01

BEARING FØRCE IN X-DIRECTIØN
  -5.0212E+01  -5.0212E+01
BEARING FØRCE IN Y-DIRECTIØN
  -5.0664E+01  -5.0664E+01
BEARING MØMENT IN X-Z PLANE
   2.5824E+02  -2.5824E+02
BEARING MØMENT IN Y-Z PLANE
   1.5790E+02  -1.5790E+02

MØUNT FØRCE IN X-DIRECTIØN
  -5.0212E+01  -5.0212E+01
MØUNT FØRCE IN Y-DIRECTIØN
  -5.0664E+01  -5.0664E+01
MØUNT MØMENT IN X-Z PLANE
  -8.9507E+01   8.9507E+01
MØUNT MØMENT IN Y-Z PLANE
  -5.4728E+01   5.4728E+01

BEARING MASS FØRCE IN X-DIRECTIØN
   0.0000E+00   0.0000E+00
BEARING MASS FØRCE IN Y-DIRECTIØN
   0.0000E+00   0.0000E+00
BEARING INERTIA MØMENT IN X-Z PLANE
  -3.4775E+02   3.4775E+02
BEARING INERTIA MØMENT IN Y-Z PLANE
  -2.1262E+02   2.1262E+02 WHAT?
```

Figure 51. Computed Starting Rotor Deflection Coordinates
Run 8

```
THE AVERAGE REAL STEP-TIME FOR THIS PRINTØUT =   2.500E-
REAL TIME =    1.000E-03 SEC                      05 SEC
REVØLUTIØNS ARRAY:
   1.5915E+00   1.5915E+00   1.5915E+00
SPIN SPEED ARRAY, RPM:
   9.5493E+04   9.5493E+04   9.5493E+04

RØTØR DISPLACEMENT VECTØR ARRAY, IN
   1.0699E-04   9.7031E-05   1.0699E-04
RØTØR VECTØR PHASE ANGLE ARRAY, DEGREES
   7.8215E+01   7.7421E+01   7.8215E+01
BEARING DISPLACEMENT VECTØRS
   7.1330E-05   7.1330E-05
BEARING DISPLACEMENT PHASE ANGLES, DEGREES
   7.8215E+01   7.8215E+01
MØUNT DISPLACEMENT VECTØR ARRAY, IN
   3.5665E-05   3.5665E-05
MØUNT VECTØR PHASE ANGLE ARRAY, DEGREES
   7.8215E+01   7.8215E+01

RØTØR WHIRL/SPIN FREQ.RATIØ ARRAY
   1.0000E+00   1.0000E+00   1.0000E+00

RØTØR SLØPE VECTØRS
   5.7828E-05   2.7954E-14   5.7828E-05
RØTØR SLØPE PHASE ANGLES, DEGREES
   9.5616E+01   3.5497E+02   2.7562E+02
BEARING SLØPE VECTØRS
   3.0120E-05   3.0120E-05
BEARING SLØPE PHASE ANGLES, DEGREES
   1.6011E+02   3.4011E+02
MØUNT SLØPE VECTØRS
   5.2454E-05   5.2454E-05
MØUNT SLØPE VECTØR PHASE ANGLES, DEGREES
   6.4400E+01   2.4440E+02
```

Figure 51. Concluded

```
THE COMPUTED STARTING ROTOR DEFLECTION COORDINATES ARE:

          VECTOR ARRAY, IN:
   1.0636E-04   9.8228E-05   1.0636E-04
          PHASE ANGLE ARRAY, DEGREES:
   2.2500E+02   2.2500E+02   2.2500E+02

BEARING DISPLACEMENT VECTOR,IN
   7.0908E-05   7.0908E-05
BEARING DISPLACEMENT PHASE ANGLE, DEGREES
   2.2500E+02   2.2500E+02
MOUNT VECTORS, IN
   3.5454E-05   3.5454E-05
MOUNT VECTOR PHASE ANGLES, DEGREES
   2.2500E+02   2.2500E+02

ROTOR SLOPE VECTORS
   3.1959E-05   1.1607E-14   3.1959E-05
ROTOR SLOPE VECTOR PHASE ANGLE, DEGREES
   2.2500E+02   3.0220E+02   4.5000E+01
BEARING SLOPE VECTORS
   3.5262E-05   3.5262E-05
BEARING SLOPE PHASE ANGLE , DEGREES
   4.5000E+01   2.2500E+02
MOUNT SLOPE VECTORS
   6.7222E-05   6.7222E-05
MOUNT SLOPE PHASE ANGLE, DEGREES
   2.2500E+02   4.5000E+01

BEARING FORCE IN X-DIRECTION
  -5.0139E+01  -5.0139E+01
BEARING FORCE IN Y-DIRECTION
  -5.0139E+01  -5.0139E+01
BEARING MOMENT IN X-Z PLANE
   2.7428E+02  -2.7428E+02
BEARING MOMENT IN Y-Z PLANE
   2.7428E+02  -2.7428E+02

MOUNT FORCE IN X-DIRECTION
  -5.0139E+01  -5.0139E+01
MOUNT FORCE IN Y-DIRECTION
  -5.0139E+01  -5.0139E+01
MOUNT MOMENT IN X-Z PLANE
  -9.5066E+01   9.5066E+01
MOUNT MOMENT IN Y-Z PLANE
  -9.5066E+01   9.5066E+01

BEARING MASS FORCE IN X-DIRECTION
   0.0000E+00   0.0000E+00
BEARING MASS FORCE IN Y-DIRECTION
   0.0000E+00   0.0000E+00
BEARING INERTIA MOMENT IN X-Z PLANE
  -3.6934E+02   3.6934E+02
BEARING INERTIA MOMENT IN Y-Z PLANE
  -3.6934E+02   3.6934E+02
```

Figure 52. Computed Starting Rotor Deflection Coordinates
Run 9

```
THE AVERAGE REAL STEP-TIME FOR THIS PRINTOUT = 2.500E-05 SE
REAL TIME =    1.000E-03 SEC
REVOLUTIONS ARRAY:
   1.5915E+00   1.5915E+00   1.5915E+00
SPIN SPEED ARRAY, RPM:
   9.5493E+04   9.5493E+04   9.5493E+04

ROTOR DISPLACEMENT VECTOR ARRAY, IN
   1.0636E-04   9.8228E-05   1.0636E-04
ROTOR VECTOR PHASE ANGLE ARRAY, DEGREES
   7.7958E+01   7.7958E+01   7.7958E+01
BEARING DISPLACEMENT VECTORS
   7.0907E-05   7.0907E-05
BEARING DISPLACEMENT PHASE ANGLES, DEGREES
   7.7958E+01   7.7958E+01
MOUNT DISPLACEMENT VECTOR ARRAY, IN
   3.5454E-05   3.5454E-05
MOUNT VECTOR PHASE ANGLE ARRAY, DEGREES
   7.7958E+01   7.7958E+01

ROTOR WHIRL/SPIN FREQ.RATIO ARRAY
   1.0000E+00   1.0000E+00   1.0000E+00

ROTOR SLOPE VECTORS
   3.1955E-05   1.5493E-14   3.1955E-05
ROTOR SLOPE PHASE ANGLES, DEGREES
   7.7965E+01   4.3144E+01   2.5796E+02
BEARING SLOPE VECTORS
   3.5267E-05   3.5267E-05
BEARING SLOPE PHASE ANGLES, DEGREES
   2.5795E+02   7.7948E+01
MOUNT SLOPE VECTORS
   6.7222E-05   6.7222E-05
MOUNT SLOPE VECTOR PHASE ANGLES, DEGREES
   7.7956E+01   2.5796E+02
```

Figure 52. Concluded

```
THE COMPUTED STARTING ROTOR DEFLECTION COORDINATES ARE:

          VECTOR ARRAY, IN:
   8.8108E-05   9.9668E-05   8.8108E-05
          PHASE ANGLE ARRAY, DEGREES:
   2.6033E+02   2.2282E+02   2.6033E+02

BEARING DISPLACEMENT VECTOR,IN
   5.1619E-05   5.1619E-05
BEARING DISPLACEMENT PHASE ANGLE, DEGREES
   3.0571E+02   3.0571E+02
MOUNT VECTORS, IN
   6.3544E-05   6.3544E-05
MOUNT VECTOR PHASE ANGLES, DEGREES
   2.2501E+02   2.2501E+02

ROTOR SLOPE VECTORS
   5.6783E-05   1.3875E-14   5.6783E-05
ROTOR SLOPE VECTOR PHASE ANGLE, DEGREES
   2.9533E+02   2.8458E+02   1.1533E+02
BEARING SLOPE VECTORS
   3.3267E-05   3.3267E-05
BEARING SLOPE PHASE ANGLE , DEGREES
   3.4071E+02   1.6071E+02
MOUNT SLOPE VECTORS
   4.0953E-05   4.0953E-05
MOUNT SLOPE PHASE ANGLE, DEGREES
   2.6001E+02   8.0012E+01

BEARING FORCE IN X-DIRECTION
   7.0864E+02   7.0864E+02
BEARING FORCE IN Y-DIRECTION
  -1.8988E+02  -1.8988E+02
BEARING MOMENT IN X-Z PLANE
   4.4431E+02  -4.4431E+02
BEARING MOMENT IN Y-Z PLANE
   1.6169E+02  -1.6169E+02

MOUNT FORCE IN X-DIRECTION
   3.5959E+02   3.5959E+02
MOUNT FORCE IN Y-DIRECTION
  -5.3911E+02  -5.3911E+02
MOUNT MOMENT IN X-Z PLANE
   3.8912E+02  -3.8912E+02
MOUNT MOMENT IN Y-Z PLANE
  -1.5170E+02   1.5170E+02

BEARING MASS FORCE IN X-DIRECTION
  -3.4905E+02  -3.4905E+02
BEARING MASS FORCE IN Y-DIRECTION
  -3.4922E+02  -3.4922E+02
BEARING INERTIA MOMENT IN X-Z PLANE
  -5.5194E+01   5.5194E+01
BEARING INERTIA MOMENT IN Y-Z PLANE
  -3.1339E+02   3.1339E+02
```

Figure 53. Computed Starting Rotor Deflection Coördinates
Run 10

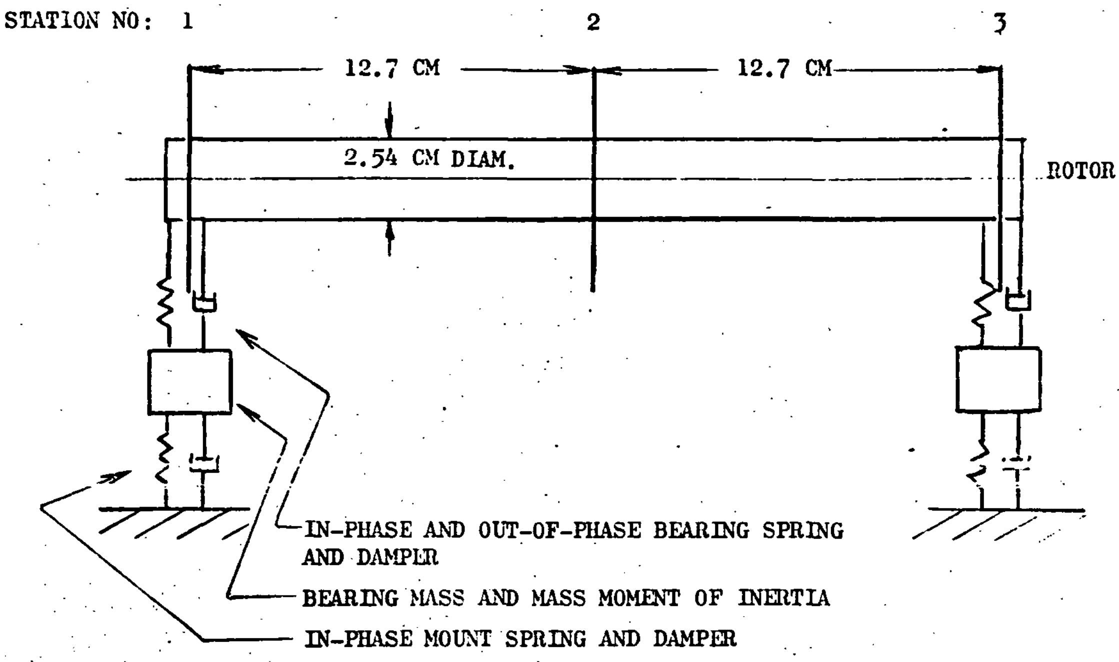
```
THE AVERAGE REAL STEP-TIME FØR THIS PRINTØUT = 2.500E-05
REAL TIME =    4.000E-03 SEC                          SEC
REVØLUTIONS ARRAY:
   6.3662E+00   6.3662E+00   6.3662E+00
SPIN SPEED ARRAY, RPM:
   9.5493E+04   9.5493E+04   9.5493E+04

RØTØR DISPLACEMENT VECTØR ARRAY, IN
   8.8108E-05   9.9668E-05   8.8108E-05
RØTØR VECTØR PHASE ANGLE ARRAY, DEGREES
   3.2167E+01   3.5465E+02   3.2167E+01
BEARING DISPLACEMENT VECTØRS
   5.1623E-05   5.1623E-05
BEARING DISPLACEMENT PHASE ANGLES, DEGREES
   7.7545E+01   7.7545E+01
MØUNT DISPLACEMENT VECTØR ARRAY, IN
   6.3547E-05   6.3547E-05
MØUNT VECTØR PHASE ANGLE ARRAY, DEGREES
   3.5684E+02   3.5684E+02

RØTØR WHIRL/SPIN FREQ.RATIØ ARRAY
   9.9995E-01   1.0000E+00   9.9995E-01
BEARING MASS WHIRL/RØTØR SPIN FREQ. RATIØ ARRAY:
   1.0001E+00   1.0001E+00

RØTØR SLØPE VECTØRS
   5.6785E-05   1.2678E-14   5.6785E-05
RØTØR SLØPE PHASE ANGLES, DEGREES
   6.7162E+01   3.4538E+02   2.4716E+02
BEARING SLØPE VECTØRS
   3.3270E-05   3.3270E-05
BEARING SLØPE PHASE ANGLES, DEGREES
   1.1253E+02   2.9254E+02
MØUNT SLØPE VECTØRS
   4.0954E-05   4.0954E-05
MØUNT SLØPE VECTØR PHASE ANGLES, DEGREES
   3.1837E+01   2.1184E+02
```

Figure 53. Concluded

FIGURE NUMBER (COM-PUTER RUN)	BEARING AND MOUNT FORCE COEFFICIENT AND MASS PER BEARING							BEARING AND MOUNT MOMENT COEFFICIENT AND BEARING MASS MOMENT OF INERTIA PER BEARING						
	BEARING				BEARING MASS Kg (LB)	MOUNT		BEARING				BEARING INERTIA $Kg\text{-}CM^2$ ($LB\text{-}IN^2$)	MOUNT	
	IN-PHASE		OUT-OF-PHASE			IN-PHASE		IN-PHASE		OUT-OF-PHASE			IN-PHASE	
	*STIFF.	DAMP.	STIFF.	DAMP.		STIFF.	DAMP.	STIFF.	DAMP.	STIFF.	DAMP.		STIFF.	DAMP.
2	1.75×10^{6} (10^{6})	**			13.61 (30.)	3.50×10^{6} (2×10^{6})								
3			1.75×10^{6} (10^{6})		13.61 (30.)	3.50×10^{6} (2×10^{6})								
4	1.75×10^{6} (10^{6})	175. (10^{2})			13.61 (30.)	3.50×10^{6} (2×10^{6})								
5	1.75×10^{6} (10^{6})			175. (10^{2})	13.61 (30.)	3.50×10^{6} (2×10^{6})								
6	1.75×10^{6} (10^{6})					3.50×10^{6} (2×10^{6})		11.3×10^{6} (10^{6})				87.8 (30.)	22.6×10^{6} (2×10^{6})	
7	1.75×10^{6} (10^{6})					3.50×10^{6} (2×10^{6})				11.3×10^{6} (10^{6})		87.8 (30.)	22.6×10^{6} (2×10^{6})	
8	1.75×10^{6} (10^{6})					3.50×10^{6} (2×10^{6})		11.3×10^{6} (10^{6})	11300. (10^{3})			87.8 (30.)	22.6×10^{6} (2×10^{6})	
9	1.75×10^{6} (10^{6})					3.50×10^{6} (2×10^{6})	3.50×10^{6} (2×10^{6})	11.3×10^{6} (10^{6})			11300 (10^{3})	87.8 (30.)	22.6×10^{6} (2×10^{6})	22.6×10^{6} (2×10^{6})
10	1.75×10^{6} (10^{6})	1751. (10^{3})	1.75×10^{6} (10^{6})	1751. (10^{3})	13.61 (30.)	3.50×10^{6} (2×10^{6})	1751. (1000.)	11.3×10^{6} (10^{6})	11300. (10^{3})	11.3×10^{6} (10^{6})	11300. (10^{3})	87.8 (30.)	22.6×10^{6} (2×10^{6})	11300. (1000.)

*STIFF. = STIFFNESS COEFFICIENT IN NEWTON/CM (LB/IN); DAMP. = DAMPING COEFFICIENT IN NEWTON-SEC/CM (LB-SEC/IN)
**BLANK REPRESENTS ZERO VALUE IN THE APPROPRIATE LOCATION

Figure 54. Specification of the Stiffness and Damping Data Used in Computer Runs 2 Through 10



ROTOR PROPERTIES:

YOUNG'S MODULUS	= 20.68×10^6 NEWTONS/CM^2 (30×10^6 psi)
SHEAR MODULUS	= 8.27×10^6 NEWTONS/CM^2 ($12. \times 10^6$ psi)
POISSON'S RATIO	= 0.3
MATERIAL DENSITY	= 0
ROTOR MASS	= 22.68 Kg (50 LB)/STATION
ROTOR TRANSVERSE MASS INERTIA	= 146.3 Kg-CM^2 (50 LB-IN^2)/STATION
ROTOR POLAR MASS INERTIA	= 87.8 Kg-CM^2 (30 LB-IN^2)/STATION
ROTOR ECCENTRICITY	=0.000254 CM/STATION
ECCENTRICITY PHASE ANGLE	= 45°/STATION
ROTOR INERTIA INERTIA MISALIGNMENT	= 0.0057°, 0°, -0.0057°
MISALIGNMENT PHASE ANGLE	= 45°/STATION
ROTOR SPIN SPEED	= 95493. RPM

Figure 53. Schematic Representation of the Rotor System and Properties Used in the Computer Runs

IV. FINAL VERIFICATION OF IBM 360/370 COMPUTER PROGRAM

After conversion of the GE computer program to an IBM 360/370 version, the IBM program was checkout in five different runs:

1. Steady-state run in English units
2. Transient spin speed run in English units
3. Steady-state run in international units
4. Transient spin speed run in international units (Appendix F, Table XXIII)
5. A 15-rotor station and 6 bearing station run using the current maximum computer program capacity (Appendix F, Table XXIV)

Runs from 1 through 4 were also made on the GE computer version using identical inputs. Basically identical results, except round off errors, were observed for both computer versions.

The same physical rotor design and operation data were used in the computer runs involving English and international units. Equivalent computation results were obtained for the two different systems of units. The IBM computer results for the final computer checkout using Runs 4 and 5 are attached as Appendix F (Tables XXIII and XXIV, respectively). In all the IBM 360/370 runs, the Runge-Kutta integration technique was used instead of the Adams-Moulton technique. For reasonably smooth rotor acceleration function, the former technique is faster than the latter. In the case where the rotor acceleration function is unpredictable, the Adams-Moulton predictor-corrector technique will be applied.

CONCLUSIONS AND RECOMMENDATIONS

During the contract period, extensive efforts to update and broaden the capability of the computer program have been made. An optimum integration technique and solution method have been established and included in the program. The computational speed over that from the previous contractual study has been substantially improved by a factor of 2970. The CPU to real-time ratio for a 15-station and 6-bearing program is 5050. The input/output time versus real-time ratio will vary according to the frequency of input/output for a computer run. For this run, the input/output (channel) to real-time ratio is 5123. Several useful rotor dynamics parameters such as hysteresis, general in-phase and out-of-phase bearing force and moment characteristics, transverse effects of torsional and axial loading, and bearing mass and inertia effects have been included in the program. To facilitate computation processing, flexibility in optionally selecting some of the rotor parameters was provided. Program input/output may be performed in international or English units system as a user's option. Although the program does not include all possible rotor dynamics parameters at present, it should cover most rotor designs where the application requires stringent design and stable operation.

Future efforts in experimental verification and updating of the computer program will be of great interest in keeping pace with the demands in rotor dynamics technology. Experimental effort to verify the various applications of the transient rotor dynamics analysis computer program is recommended as a follow-on to the analytical effort completed in this contract. Periodic updating of the transient rotor dynamics program should be under taken to keep pace with the future technologocal demands and advances in the field of rotor dynamics. Accordingly, specific recommendations are delineated below:

1. Experimental verification of the validity and accuracy of the various simulation options in the computer model. This could include rotor hysteresis effects simulation.

2. Rotor casing mass and mass moment of inertia. The rotor casing can be rigid or flexible, rotating or nonrotating. There can be several rotor casings with or without coupling between them. A rotating casing will in effect be a multiple concentric rotating rotor system.

3. Rotor casing support. The rotor casing can be supported on a foundation attached to an inertial frame of reference or the foundation may experience an angular velocity or acceleration such as space vehicle borne rotating machinery. The rotor casing may be floating or attached to a floating mass.

4. Axial elasticity of rotor and resulting axial rotor dynamics.

5. Compute and writeout rotor dynamic stresses at specified locations.

6. Design a simplified computer model to include a minimum number of basic parameters to be used for quick preliminary exploration analysis in a new design or study.

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APPENDIX A

COMPUTER PROGRAM USER'S INSTRUCTION

DESCRIPTION OF THE COMPUTER PROGRAM

The transient analysis computer program, written in Fortran IV, consists of one main program, 11 subroutines, and one Fortran function. Their names and the basic flow path are depicted in Fig. 56. The functions of the main program, the subroutines, and the Fortran function are delineated as follows.

Main Program

The main program is used as the basic calling program to coordinate the operation of the subroutines and the function so as to perform the various prescribed calculations. The other important function performed within the main program is to provide English unit output of the computed results in the printout and graphical output as required. In addition, it also prints out the following nondimensional output which are common to both English unit and International unit outputs:

1. Average real time-step for this printout
2. Real time
3. Rotor spin revolution array.

Subroutine HYSREA

The subroutine HYSREA reads all of the input data. It will also read punched cards when CØNTIN = 1. The namelist read procedure is basically used in HYSREA except for (1) a title card which precedes the namelist read statement and (2) the punch cards following the namelists. There are two namelists defined, MUST and OPTION, with MUST namelist proceeding the OPTION namelist. Every Fortran variable except ID is required input in the MUST namelist. ID is included only for the purpose of punching card sequence numbers and is not used in the computations. The variables included in the OPTION namelist may be read at the user's option. For this reason, a set of default values for the OPTION namelist variables are stored in HYSREA which can be overwritten by the desired OPTION input data.

Subroutine HYSWRI

HYSWRI is a subroutine that prints out the input data including the built-in data in HYSREA if it is not overwritten by actual input. The data writeout in HYSWRI will include the values of general, nondimensional data and the remainder of the input data when English units are specified.

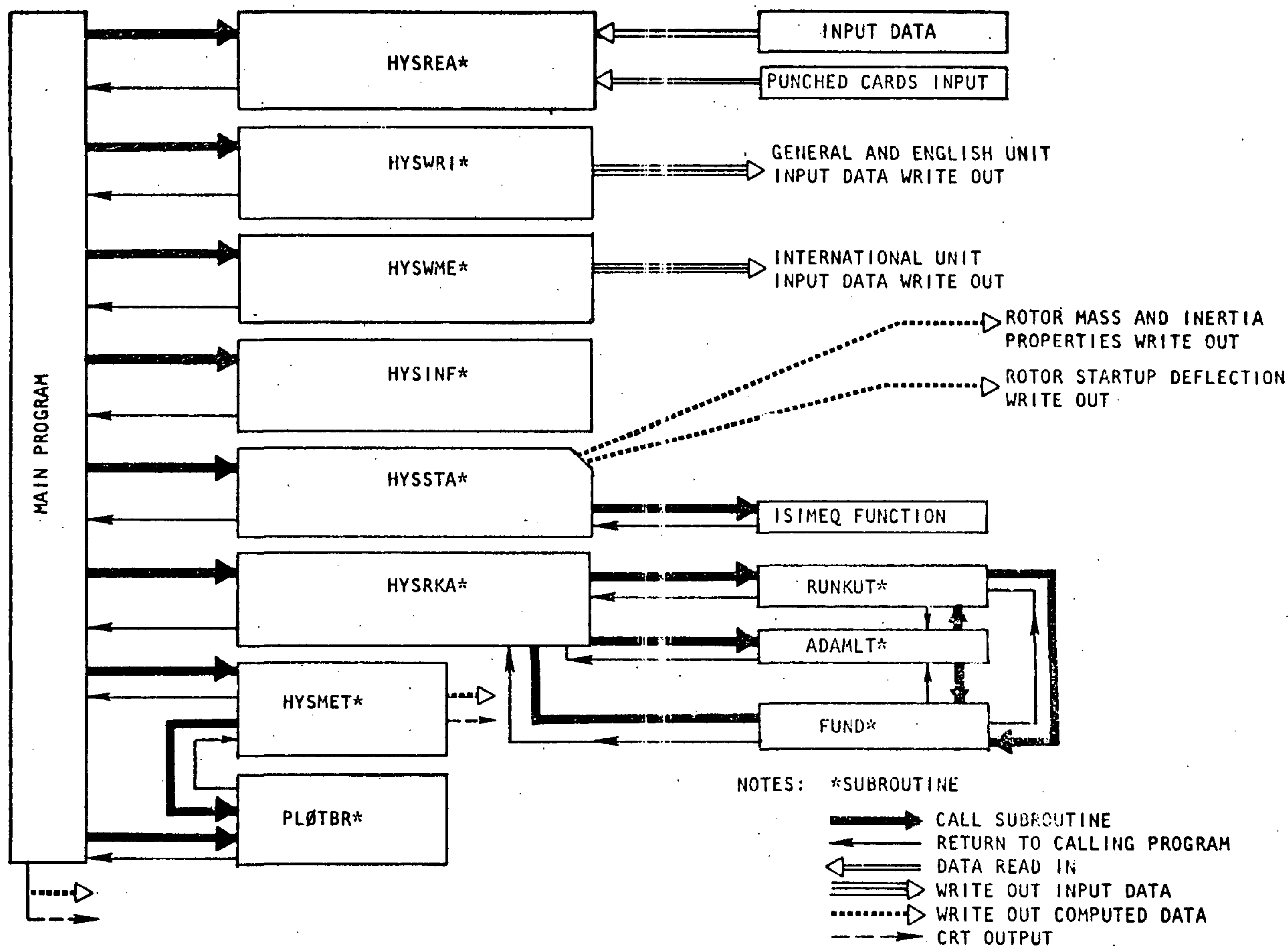


Figure 56. Computer Program Components and Flow Path

Subroutine HYSWME

HYSWME is another subroutine that prints out the data following the general, nondimensional data which are printed out in HYSWRI. HYSWME is used when input and output are required in International units.

Subroutine HYSMET

HYSMET will write out computed results and produce graphical output when input and output are required in International units.

Subroutine HYSINF

HYSINF is used to generate rotor displacement and slope deflection influence coefficients due to applied unit forces and moments. The influence coefficients are referred to a straight line joining the centers of the first and last bearings.

Subroutine HYSSTA

HYSSTA will compute startup rotor dynamic deflections based on a steady-state and axisymmetric rotor-bearing system design. Influence coefficients provided by HYSINF will be used in generating the startup rotor configuration through the use of the simultaneous equation solution Fortran function. Rotor mass and inertial properties are also computed in HYSSTA.

Subroutines HYSRKA, RUNKUT and ADAMLT

These are the Adams-Moulton and Runge-Kutta integration subroutines. HYSRKA is called by MAIN program and in turn RUNKUT and ADAMLT are called by HYSRKA. FUND is called by these subroutines to return with derivatives corresponding to the calling variables. There are three optional integration techniques to be selected for use according to the value assigned to the Fortran variable, IND, the options are:

- IND = 0 Uses Adams-Moulton predictor-corrector variable step integration technique. TOLI is used in determining the time steps applied for a desired accuracy.
- IND = 1 Uses 4th order Runge-Kutta fixed step integration technique
- IND = 2 Uses Adams-Moulton fixed step integration technique

Subroutine FUND

FUND is used to generate time derivatives of the incoming variables from the calling program. From the incoming variables, the rotor and bearing reactional forces and moments are first determined and the time derivatives are computed from the mass properties and the reactional loads.

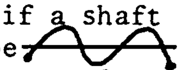
Function ISIMEQ

ISIMEQ is a simultaneous equation solution function called by HYSSTA in computing the startup rotor deflection configuration.

Subroutine PLOTBR

PLOTBR is called by MAIN or HYSMET for graphical plotting of bearing force and displacement versus rotor spin speed function.

INPUT PROCEDURE

The computer program is written to simulate a continuous rotor mass distribution by a discrete-mass rotor model with an appropriate mass-less elastic shaft. In general, the minimum number of discrete masses used should be such that the desired rotor dynamic mode shape can be sustained. For instance, if a shaft operates in a bending critical speed range, the mode shape could be  to sustain this mode shape a minimum of 5 masses is required. In general, to obtain good accuracy several times the minimum number of mass requirements are used. For rotor motion predominately influenced by mass eccentricity and damping and stiffness function, the mode shape in a critical speed range may be substantially modified from that of a pure critical speed mode shape. Judgement must hence be exercised in selecting the number of discrete masses to adequately represent a rotor configuration.

The rotor to be studied is first divided into consecutively numbered stations. The total number of stations may vary from 3 to 15, inclusively. Rotor sections between adjacent rotor stations are labeled with the same numbers as that of the left adjacent stations. The rotor property input data are appropriately subscripted according to the rotor station or section numbers. For nonlinear stiffness bearing data, two-dimensional subscripts are used. The first subscript defines their bearing station location and the second defines the nonlinear bearing stiffness sections.

A complete input data writeout is provided for each computer run. A detailed description of the input, output, and usage of the program appears in the following sections.

Input

A namelist input procedure is used as the basic input format due to its flexibility in selecting input parameters and the liberal use of built-in input data when appropriate. For preliminary analysis, by making use of built-in data, the input data volume, particularly for a large number of rotor stations, can be drastically reduced.

The complete input data must include the following sections in the sequence listed.

1. Title. One 80-column card, with the first 72 columns available for a descriptive title and columns 73 through 80 reserved for card identification, must be provided.

2. Namelist/MUST/. This namelist data section consists of variable names which, except for the variable name ID, must be read in. The input variables are defined as follows:

   a. Integration step (real) time (DT), seconds

   b. Maximum run (real) time (TMAX), seconds

   c. Minimum printing (real) time interval (DP), seconds

   d. Total number of rotor stations (NS)

   e. Total number of bearing stations (NB)

   f. Startup whirl and spin speed (FDOTI), rpm

   g. Bearing location rotor stations (IB(K))

   h. Rotor section outside diameters (DD(I)), inches

   i. Rotor section length (QL(I)), inches

   j. MET = Input/output English or international unit control variable

   k. ID, not a part of rotor dynamics analysis input data. ID is includ included for the purpose of allowing data cards to be numbered in order to maintain their proper sequence.

   The namelist/MUST/ pertains to rotor geometry and bearing arrangement data. It is not possible to provide built-in values to approximate the input rotor and bearing information. The physical input of these data is necessary.

3. Namelist/ØPTION/. This input data included in this section may be applied at the user's option, although a blank card, shown at top of next page, is necessary even if no optional input is desired. The user needs only to include the data different from built-in values. The complete list of namelist/ØPTION/ is shown on the following page and the data built-in values are described in subroutine HYSREA in Appendix C.

1	&OPTION	
13		
25		
37		
49		
61	&END	
	IDENTIFICATION 73	80

4. Punched Card Read In (Conditional Input Data). For a continued analysis from a previous study punched cards generated from the previous analysis must be provided. Concurrently the data variable CONTIN = 1, in namelist/OPTION/ must be entered. In addition, the data entered in namelist/MUST/ and namelist/OPTION/ must be identical to those from the previous study.

   If CONTIN = 0, or no entry of CONTIN is made in namelist/OPTION, punched cards must not be included.

   Although the startup rotor dynamic configuration is not used in a continued analysis, the startup configuration will still be generated. The startup configuration may be used as a verification for the input data which must be the same as those for the original run.

Data names included in namelist/MUST/ and namelist/OPTION/ are as follows.

```
NAMELIST/MUST/DT,TMAX,DP,NS,NB,FDOT1,IB,DD,QL,MET, ID

 NAMELIST/OPTION/     IND,TOLI,T,CONTIN,ITORQ,IPP,IMT,RIG,CRT,MOSHA,
&NPOINT,NOORPM,IASIGN,INPRPM,D,DN,P,EE,GG,EI,GAK,AM,ECC,AID,AIRO,BE
&TA,GAMMA,BKMX,BKMY,BCMX,BCMY,XKMM,YKMM,XCMM,YCMM,BM,BI,QKXX,QKXY,Q
&KYY,QKYX,QCXX,QCXY,QCYY,QCYX,XXMK,XYMK,YYMK,YXMK,XXMC,XYMC,YYMC,YX
&MC,KK,FDDFIX,BBB,BDB,BEB,BHB,BKB,BNB,BROB, QK,QC,QKP,QCP, QKF,QCF,
&QKPF,QCPF, XKF,XCF,XKFF,XCFF, QKHD,QCHD,QKHDG,QCHDF,  CT1,CT,CT2,
&MT,MT1,MT2,AT,BT,DU,ET,HT,FT,GT, AA,BA,DA,EA.HA,FA,GA,  GX,GY,
&USV,USC,UBV,UBC,UTV,UTC,F1,ALFA,BCB,IPRINT, ID
```

For data name description and units used, refer to Appendix B, Table XIV. Definition of Fortran Variables in Common Block. All namelist names except ID which is for input card identification only, may be found in the common block Fortran variable definition.

COMPUTER PROGRAM CAPABILITY AS
CONTROLLED BY INPUT VARIABLES

The values of certain input variables determine which area of computer capability will be activated or bypassed. The following is a description of the computer optional capability and related control varialbes.

Rotor Mechanical Hysteresis Effects

The hysteresis effects include

1. In-phase transverse damping hysteresis forces and moments

2. Out-of-phase transverse driving and damping hysteresis forces and moments

3. In-phase damping torque

There are six hysteresis coefficients which lead to the above hysteresis effects. These coefficients are:

1. Transverse shear viscous hysteresis coefficient

2. Transverse shear Coulomb friction hysteresis coefficient

3. Transverse bending viscous hysteresis coefficient

4. Transverse bending Coulomb friction hysteresis coefficient

5. Torsional shear viscous hysteresis coefficient

6. Torsional shear Coulomb hysteresis coefficient.

Only by including any of the above coefficients for certain rotor sections (or all rotor sections) in namelist/OPTION/, will the related hysteresis portion of the computer program be activated. By inputing a hysteresis coefficient (or hysteresis coefficients), the hysteresis load as well as the dissipative hysteresis torque will be computed and their effects on the rotor dynamic performance included.

Torsional Flexibility and its Control

This parameter is used to simulate the torsional dynamic performance of a rotor. The incorporation of rotor torsional flexibility also makes it possible to include the torsional hysteresis effects of the rotor.

The optimum time step size used in a stable computation varies according to the absolute magnitude of local mass acceleration. The stable time step size is dominated by the maximum local acceleration in the rotor bearing system. To achieve a low computer time to real time ratio, it is desirable to have reasonable uniform acceleration rates among all local mass-load components. A large local peak acceleration magnitude which may be caused by a very stiff, torsional rotor section among other sections results in a time consuming slow computation. Converting this very stiff section into a rigid section will in general lead to a computer time saving without affecting much of the computation accuracy. For this reason a rigid torsional section control parameter was incorporated in the program. With this parameter, the user can eliminate the torsional elasticity of certain rotor sections whose configurations are substantially stiffer than those of the others. An integer variable RIG (J), is used to assign an artificial rigidity of rotor section J by letting RIG (J) = 1. If RIG (J) is not input, the built-in values of RIG (J) = 0, which considers actual torsional flexibility, will be used.

Rotor Transverse Effects Due to Rotor Torsion

For rotor sections having slope deflection, torsional loading will result in rotor transverse motion. For computations where this effect is desired, set IMT = 1 which overrides the builtin value of IMT = 0.

Rotor Transverse Effects Due To Axial Loading

The current rotor model does not have axial elasticity parameters, and the only dynamic effect of the axial loading is the rotor transverse motion. When IPP = 1 the rotor transverse motion effect due to axial loading is included. When the IPP value is not read in, the built-in value of IPP = 0 will be used to instruct the program to bypass the effects.

Bearing In-Phase and Out-of-Phase Anisotropic Stiffness and Damping Force and Moment Coefficients

In a specific rotor dynamics analysis, the effects of the coefficients can be included or deleted by using the appropriate input or the built-in default values of the coefficients.

Mount In-Phase Anisotropic Stiffness and Damping Force and Moment Coefficients

Similar treatment in applying or deleting the effects of the coefficients as stated in the bearing coefficient above may be used.

Bearing Mass and Transverse Mass Moment of Inertia

Choice of including or deleting the bearing mass and inertia effects may be exercised for the same reason discussed above for torsional flexibility. For a comparatively small bearing mass (or inertia) to bearing load ratio, use BM (K) = 0, or BI (K) = 0 (built-in value). This will instruct the program to bypass the bearing acceleration computation while maintaining reasonable computation accuracy. When a substantial BK (K) or BI (K) to bearing load ratio exists, use their actual values.

Additional Control Parameters

There are other input control parameters such

MET = 1 For using international units input and output

MET = 0 For using English units input and output

A complete list of input control parameters may be found in Section IV Final Verification of IBM 360/370 computer program.

Other capability such as automatic restart, when the assigned integration time step (DT) is too large that the initial computation results in journal displacements exceeding the bearing clearance. The computation is limited at present to a total of five restarts. In each restart, DT is reduced to one-fourth its previous value.

COMPUTER PROGRAM OUTPUT AND ITS CONTROL

The computer program output is in the form of printed output and graphic (CRT) plots as discussed below. The units of the input-output data may be selected by inputting MET = 1 for international units and MET = 0 for English units.

Printout

The printed output includes the following:

1. Input Data Write-Out. Except that which is input through punched cards.

2. Input Rotor Mass Data. Includes rotor local masses, transverse and polar mass moments of inertia, total rotor mass and polar mass moment of inertia, and location of the rotor mass center.

3. Rotor Dynamic Startup Configuration. Includes deflections and loads for all rotor and bearing components.

4. Computation Results Write-Out. The printout time interval can be approximately specified by the product of the values DP and IPRINT in seconds.

5. Graphic (CRT) Output. This is an optional output controlled by CRT = 1, or 0, and partially controlled by MOSHA = 1, or 0. When CRT = 1 graphic output will be produced; CRT = 0 suppresses graphic output. The only type of graphic output control by MOSHA, in addition to CRT control variable, is the rotor mode-shape plot. When MOSHA = 1 and CRT = 1 the rotor mode shape will be plotted, otherwise there will be no mode shape graphic output. A total of eight types of CRT graphs

are provided where each presents a pictorial summary of certain rotor dynamic performance in supplementing the printed output. The time interval between successive points on the graph will be equal to the value of DP in seconds. The types of the graphic output are:

a. Rotor mode shape graphs, one at or near each of the INPRPM (I). The phase angles of rotor deflection vectors are labelled at each rotor station.

b. Rotor spin speed at station IASIGN versus time with the maximum time interval per graph equal to the product of DP and NPOINT.

c. Rotor displacement whirl to spin velocity ratio versus time at rotor station IASIGN. NPOINT number of points will be included in each graph.

d. Bearing force versus rotor spin speed for each of the support bearings. NPOINT number of points will be included in each graph.

e. Bearing displacement versus rotor spin speed for each of the support bearings. NPOINT number of points will be included in each graph.

f. Maximum rotor deflection versus rotor spin speed, with the corresponding rotor station number labeled in the graph. NPOINT number of points will be included in each graph.

g. Rotor deflection at station IASIGN versus rotor spin speed. NPOINT number of points will be included in each graph.

h. Rotor orbital path for rotor station IASIGN. NPOINT number of points will be included in each graph

The incorporation of graphic output capability in the computer program was provided. This output operation was not verified due to the absence of the specific graphic output facilities at Rocketdyne.

NONLINEAR BEARING STIFFNESS INPUT COEFFICIENTS DETERMINATION

The nonlinear stiffness coefficients are provided to simulate a known or predicted bearing stiffness characteristic. The steps in determining their coefficients are as follows:

1. Load versus bearing displacement vector characteristic at a journal spin speed value $\dot{\phi}_{oi}$ may be represented as in Fig. 57.

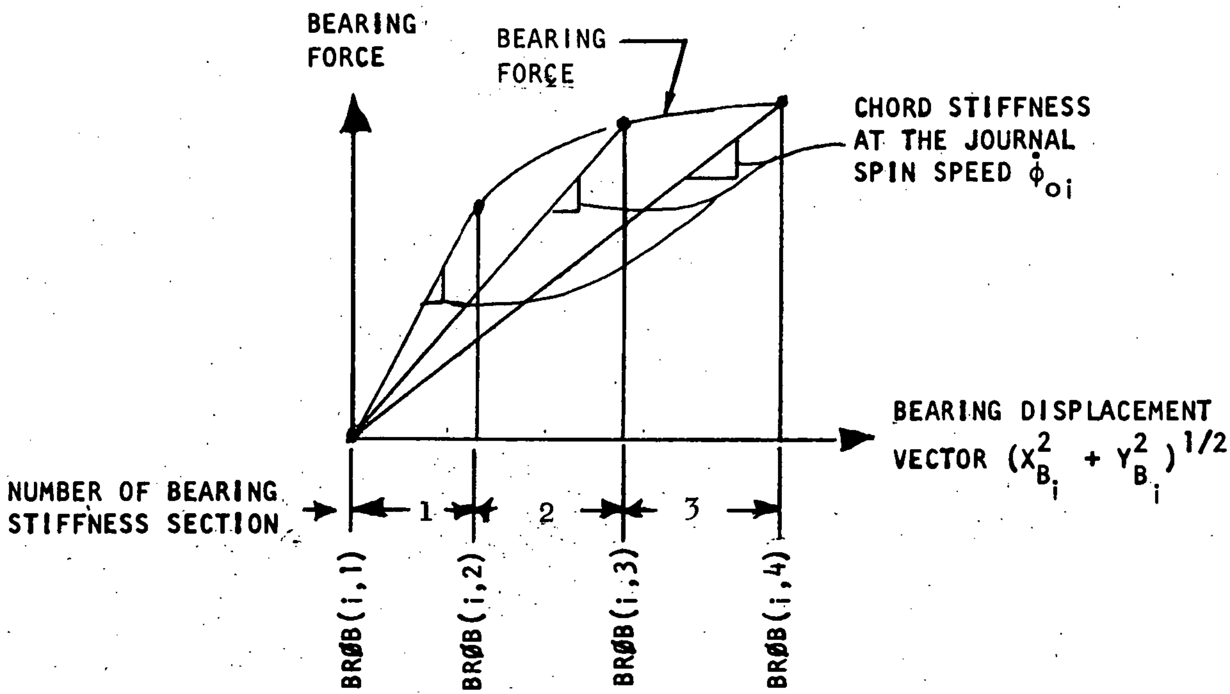


Figure 57. A Bearing Force Versus Displacement Characteristics

2. The bearing-load displacement characteristic for bearing stiffness, section K is now transformed into a corresponding chord stiffness as indicated by the dashed line (cd) in Fig. 58,

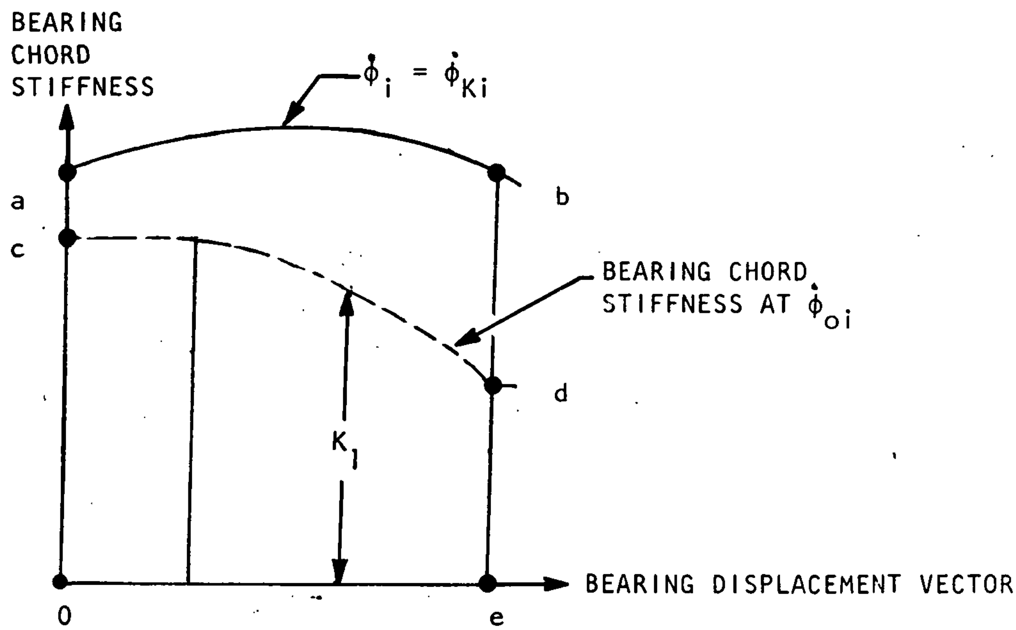


Figure 58 . Bearing Stiffness vs Displacement Characteristics

where (in Fig. 58) K is to be curve fitted by the formulation below, which is a displacement function of the nonlinear stiffness characteristics:

$$K_{BiK}\left[C_{BiK}\left(\sqrt{X_{Bi}^2+Y_{Bi}^2}-\rho_{BiK}\right)^{H_{BiK}}+D_{BiK}\left(\sqrt{X_{Bi}^2+Y_{Bi}^2}-\rho_{BiK}\right)+E_{BiK}\right]$$

To determine the remaining constants, N_{BiK} and B_{BiK} in the nonlinear bearing formulation, an overall bearing chord stiffness curve ab for $\dot{\phi}_i = \dot{\phi}_{Ki}$ must be provided either from analytical prediction or experimental results. With this stiffness addition ac and bd for the spin speed $\dot{\phi}_i = \dot{\phi}_{Ki}$, the speed sensitive constant N_{BiK} and B_{BiK} can now be determined as follows

$$\frac{N_{BiK}\,(\dot{\phi}_{Ki}-\dot{\phi}_{oi})}{K_{BiK}} = \frac{ac}{co}$$

$$\frac{(\phi_{Ki}-\phi_{oi})\left[N_{BiK}+B_{BiK}\left(\sqrt{X_{Bi}^2+Y_{Bi}^2}-\rho_{BiK}\right)\right]}{K_{BiK}} = \frac{bd}{de}$$

where

$$\sqrt{X_{Bi}^2 + Y_{Bi}^2} = Oe$$

Thus a combination of speed and displacement sensitive nonlinear bearing stiffness characteristic may be represented in various stiffness sections of a support bearing.

PROGRAM SIZE CAPACITY

The current computer program dimension size is compatible with the following maximums

Rotor Stations (NS)	= 15
Bearing Stations (NB)	= 6
Nonlinear Bearing Stiffness sections (KK(K))	= 3

The current object program size including all necessary library and auxiliary requirements is approximately 199 K bytes. When the enlargement of the computer program capacity is required, the rule in adjusting the size of the dimension statement as indicated in Table VIII may be used.

TABLE VIII - RULES FOR MODIFYING COMPUTER PROGRAM CAPACITY

Subscripted Variable Name or Group	Dimension Size	
	Current Computer Program Capacity NS = 15 NB = 6 KK(K) = 3	Enlarged Computer Program Capacity, NS, NB, KK(K)
Pertaining to Rotor Stations	QM(15)	QM(NS)
	C(15,15)	C(NS,NS)
	Etc.	Etc.
Pertaining to Rotor Section	DD(14)	DD(NS-1)
	EE(14)	EE(NS-1)
	USV(14)	USV(NS-1)
	RIG(14)	RIG(NS-1)
	Etc.	Etc.
Pertaining to Bearing Station	QKXX(6)	QKXX(NB)
	BCB(6,3)	BCB(NB,KK(K))
	BRØB(6,4)	BRØB(NB,KK(K)+1)
	Etc.	Etc.
AA_{ij}, in HYSSTA	AA(84,84)	AA(4(NS+NB),4(NS+NB)
CC_i in HYSSTA	CC(84)	CC(4*(NS+NB))
YN_i in MAIN	YN(84)	YN(4*(NS+NB))
YN in FUND	YN(198)	YN(NNS)
BD in FUND	BD(198)	BD(NNS)
	Etc.	Etc.
Dimensioned Variables in HYSRKA, RUNKUT, ADAMLT	Data NN/198/	Data NN/NNS/
	Y(198)	Y(NNS)
	F(198,7)	F(NNS,7)
	A(198,4)	A(NNS,4)
	YP(198)	YP(NNS)
	Etc.	Etc.

*NNS = 10NS+8NB

APPENDIX B

DEFINITION OF FORTRAN VARIABLES

The input Fortran variables definitions including their default values are described in Appendix C (Table XXI) and the Fortran variable except those in function ISIMEQ and subroutine PLØTBR are described and their units defined. ISIMEQ is a library subroutine in IBM 360/370. Its function is to solve a set of linear algebraic equations by inputting the coefficients and constants of the equation. The variables contained in ISIMEQ are purely mathematical notations which are not directly related to rotor dynamics analysis programming. The meaning of the variable names in PLØTBR are the same as those in MAIN and HYSMET.

Fortran variable definitions in CØMMØN are described in Table IX. The variables in each of the subroutines not covered in the CØMMØN table are defined in Tables X through XX according to the sequence they appear in each of the subroutines. All successive Fortran variable tables will only contain those variables not defined in the preceding tables.

TABLE IX - DESCRIPTION OF ALL FORTRAN VARIABLES LISTED

IN COMMON BLOCKS

Variable	Definition	Units
NS2	= 2*NS	
NS3	= 3*NS	
NS4	= 4*NS	
NS5	= 5*NS	
NS6	- 6*NS	
NS7	= 7*NS	
NS8	= 8*NS	
NS9	= 9*NS	
NS10	= 10*NS	
NSM1	= NS-1	
NSP1	= NS+1	
NS2P1	= NS*2+1	
NS4P1	= NS*4+1	
IP (or IQ	Computer results printout frequency control	
IPRINT	IPRINT x DP = computer output printout real time interval	
NN	8*NB+10*NS; MM spacer in "common" in "fund"	
IB1	Station number for the first bearing location	
IBNB	Station number for the last bearing location	
INT	Computation cycle indicator and control INT = 0 first time "fund" is called INT = 2 during "fund" calling process	
ITIM	Startup control for integration ITIM = +1 restart with forward integration ITIM = -1 restart with backward integration ITIM = 0 continuing integration	
IUSE	Interaction process and indicator IUSE = 1 completion of an integration process IUSE = 0 during integration	
G	Gravitational constant G = 386.088	in./sec
PI	π = 3.14159265358979324	

TABLE IX -(Continued)

Variable	Definition	Units
Q	Axial length between rotor station I and the last bearing station	cm (inches)
S	Axial length between rotor station I and the first bearing station	cm (inches
QLL	Axial length between the first and last bearing station	cm (inches)
QMLØV	Negative reciprocal of QLL	cm^{-1} ($in.^{-1}$)
KKSPA(K)	Number of nonlinear bearing stiffness sections for bearing station K, KKSPA(K) is used as a spacer for KK(K) in the program where KK(K) is not used, while KK is used for other function	dimensionless
JBI(I)	Bearing number at rotor station I JBI(I) = 0 for rotor station where no bearing exists	dimensionless
F(I)	Starting rotor angular position for rotor station I	degrees
FDØT(I)	Starting rotor angular spin speed for rotor station I	rpm
SHK(J)	Average shear strain to actual shear strain ratio for rotor section J	dimensionless
QM(I)	Total rotor mass at rotor station I	($kg\text{-}sec^2$)/cm (($lb\text{-}sec^2$)/in.)
QID(I)	Total rotor transverse mass moment of inertia at rotor station I	$kg\text{-}cm\text{-}sec^2$ ($lb\text{-}in.\text{-}sec^2$)
QIRØ(I)	Total rotor polar mass moment of inertia at rotor station I	$kg\text{-}cm\text{-}sec^2$ ($lb\text{-}in.\text{-}sec^2$)
QME(I)	Product of QM(I) and ECC(I) at rotor	$kg\text{-}sec^2$ ($lb\text{-}sec^2$)
FØSTIFF(K)	Nonlinear bearing stiffness at bearing station K	kg/cm (lb/in.)
Z(I)	Rotor axial length measured from rotor stations 1 to (I)	cm (inches)
QZ(I)	Q less the amount Z(I)	cm (inches)
QK(I)	Rotor-to-casing in-phase stiffness force coefficient at rotor station I	Newtons/cm (lb/in.)

TABLE IX - (Concluded)

Variable	Definition	Units
QC(I)	Rotor-to-casing in-phase damping force coefficient at rotor station I	(Newton-sec)/cm (lb-sec)/in.
YN(M)	Startup rotor and bearing displacement and slope array M = 4*(NS + NB)	inches, radians
YNSPA(M)	"Common" spacer for YN(M)	
INPRPM(N)	Number of rotor spin-speed rpm one for each rotor mode shape CRT plot	
C(I,I1)	Rotor linear deflection at station I1 from the straight line joining the first and last bearing centers due to unit transverse loading at station I	in./lb
B(I,I1)	Rotor linear deflection at station I1 from the straight line joining the first and last bearing centers due to unit transverse moment loading at station I	in./lb-in.
TF(I,I1)	Rotor slope deflection at station I1 from the straight line joining the first and last bearing centers due to unit transverse loading at station I	radians/lb
TM(I,I1)	Rotor slope deflection at station I1 from the straight line joining the first and last bearing centers due to unit transverse moment loading at station I	radians/lb-in.

TABLE X - DEFINITION OF FORTRAN VARIABLES USED IN MAIN PROGRAM

Variable	Definition	Units
A	180/π conversion factor between angular degrees and radians	degrees/radian
H	30/π conversion factor between rpm and radians/sec	$\frac{\text{rev-sec}}{\text{radian-min}}$
I,J,M	Subscripts used in dimensioned variable	
V	0.5/π conversion constant	
IC	CRT variable accumulator subscript	
II	CRT mode shape plot counter	
IP	Printing interval counter	
IS	Output printing interval counter	
KA	Punch card ID sequence specification	
KB	Punch card block ID sequence specification	
RØ(I)	Rotor displacement vector	inches
SP(N)	Transfer of YNN(I) to punch 6 values per card	inch, in./sec
TT(N1)	Subscripted T for CRT data accumulation	seconds
XB(K)	Bearing X-displacement at bearing station K	inches
XX(I)	Rotor X-displacement at rotor station I	inches
YB(K)	Bearing Y-displacement at bearing station K	inches
YY(I)	Rotor Y-displacement at rotor station I	inches
DDA	Printing interval control variable	seconds
INS,JNS,MNS	Subscripts	
REV(I)	Rotor spin revolution at rotor station I	

TABLE X - (Continued)

Variable	Definition	Units
RPM(I)	Rotor spin speed at rotor station I	rpm
TSA	Initial "T" saved for restart with 10 percent DT	seconds
XBM(K)	Bearing slope in XZ-plane at bearing station K	radians
XXT(N)	Rotor X-displacement component printing time-step accumulation (IC) array at rotor station "IASIGN," for CRT use	inches
YBM(K)	Bearing slope in YZ-plane at bearing station K	radians
YYT(N)	Rotor Y-displacement component printing time-step accumulation (IC) array at rotor station "IASIGN," for CRT use	inches
BRGR(IC,K)	Bearing displacement vector printing time-step accumulation (IC) array at bearing station K, for CRT use	inches
FØRC(IC,K)	Bearing force vector printing time-step accumulation (IC) array at bearing station K, for CRT use	pounds
IERR	Indicator from subroutine HYSRKA IERR = 0 solution is valid IERR = 1 solution is invalid or integration time step reaches zero	
I1OS,I2NS I3NS,I4Ns I5NS,I6NS I7NS,I8NS I9NS,J2NS J3NS,J4NS J5NS,J6NS J7NS,J9NS	Subscripts used in dimensioned variable	
MØRØ(I)	Mount displacement vector	inches
MØSQ	Square of mount displacement vector	$in.^2$
M2NS,M3NS, M5M1	Subscripts used in dimensioned variables	

TABLE X - (Continued)

Variable	Definition	Units
RØMM(I)	Mount slope vector	inches
RØSQ	Square of rotor displacement at a rotor station	$in.^2$
RPMM(IC)	Rotor spin speed array at rotor station IASIGN for A series of time step; A CRT plotting variable	rpm
SLØP(I)	Rotor slope vector at rotor station I	radians
XMØM(I)	Mount moment in XZ-plane at rotor station I	lb-in.
YMØM(I)	Mount moment in YZ-plane at rotor station I	lb-in.
BRGRØ(K)	Bearing displacement vector at bearing station K	inches
BSLRØ(K)	Bearing slope vector at bearing station K	radians
DTAVE	Average integration step time	seconds
I1OSB	A subscript used in dimensioned variables	
MØFØR(K)	Mount force vector at station K	pounds
PHARØ(I)	Rotor displacement vector phase angle	degrees
ROMAX(IC)	Rotor maximum displacement vector printing time-step accumulation (IC) array at rotor station "IASIGN" for CRT use	inches
RØSTA(IC)	Rotor displacement vector printing time-step accumulation (IC) array at rotor station "IASIGN" for CRT use	inches
TSAVE	Time saved for computing average integration	seconds
WHIRR(I)	Rotor displacement whirl frequency	rpm
XBDOT(K)	Bearing displacement X-velocity at bearing station K	in./sec
XBFOR(K)	Bearing Y-force at bearing station K	pounds
XBMON(K)	Bearing moment in XZ-plane at bearing station K	lb-in.

TABLE X - (Continued)

Variable	Definition	Units
XMFØR(K)	Mount X-force at bearing K	pounds
YBDØT(K)	Bearing displacement Y-velocity at bearing station K	in./sec
YBFØR(K)	Bearing Y-force at bearing station K	pounds
YBMOM(K)	Bearing YZ-plane moment at bearing station K	lb-in.
YMFØR(K)	Mount Y-force at bearing station I	pounds
BGPHAS(K)	Bearing displacement vector phase angle at bearing station K	degrees
BRFOPH(K)	Bearing force vector phase angle at bearing station K	degrees
BRGFOR(K)	Bearing force vector at bearing station K	pounds
BSPHAS(K)	Bearing slope vector phase angle at bearing station K	degrees
ISTATN(IC)	Rotor station time-step array for maximum rotor displace at each time-step for CRT graph	
I10S2B, I10S3B I10S4B, I10S5B I10S6B, I10S7B 14NSNB 14NS2B 14NS3B	Subscripts used in dimensioned variables	
MØFØPH(K)	Mount force vector phase angle at bearing station K	degrees
MØPHAS(K)	Mount displacement vector-phase angle at bearing station K	degrees
MØWHIR(K)	Mount displacement (bearing mass) whirl frequency also mount whirl to rotor spin speed (bearing mass) whirl frequency ratio at bearing station K	radians/sec dimensionless
PHARØS(I)	Rotor slope vector phase angle at rotor station I	degrees
PHASMM(K)	Mount slope vector phase angle at bearing station K	degrees
SLOPSQ	Rotor slope vector square at a rotor station	$(\text{radians})^2$
WHRATI(IC)	Rotor displace whirl to rotor spin velocity ratio time-step array at rotor station "IASIGN"	dimensionless

TABLE X - (Concluded)

Variable	Definition	Units
WHRATØ(I)	Rotor displacement whirl-to-rotor spin velocity ratio at rotor station I	
WHRVLØ(I)	Rotor displacement whirl velocity at rotor station I	radians/sec
WHSLØP(I)	Rotor slope whirl velocity at rotor station I	rpm
XBMDØT(K)	Bearing slope velocity in XZ-plane at bearing station K	radians/sec
YBMDØT(K)	Bearing slope velocity in YZ-plane at bearing station K	radians/sec
YNNSAV(I)	Saved YNN(I) data from a continued run when "CONTIN=1"	
IR	Number of restart control variables	
K1,K4	Subscripts used in dimensioned variables	
ACA	Journal displacement vector at a bearing station	inches

TABLE XI - DEFINITION OF FORTRAN VARIABLES USED IN SUBROUTINE HYSREA

Variable	Definition	Units
I,J,K	Subscripts used in dimensioned variables	
AP1, AP2, AP3, AP4	Variables for detecting the axial load unbalance with dimension corresponding to that of AA(I), BA(I), DA(I) and EA(I)	
NB4	Four times number of bearing	
MUST	Name of one of the two name lists used to read input data. Variables contained in this namelist must be input to the program at all times	
ØPTIØN	Name of one of the two namelists used to read input data. The variables contained in this namelist may be read in total or in part as desired.	

TABLE XII - DEFINITION OF FORTRAN VARIABLES USED IN SUBROUTINE HYSWRI

Variable	Definition	Units
I,J,K	Subscripts used in dimensioned variables	
U	π divided by 30. A conversion constant between rotational speed in rpm and that in radians/sec	$\frac{\text{radians-min}}{\text{rev-sec}}$
V	π divided by 180. A conversion constant between angular displacement in degrees and radians	radians/degree
K1	Maximum value of the subscript KI for BRØB(K,KI) for each of the nonlinear stiffness bearings	

TABLE XIII - DEFINITION OF FORTRAN VARIABLES USED IN SUBROUTINE HYSWME

Variable	Definition	Units
I,J,K,	Subscripts used in dimensioned variables	
U,V	Same as those defined in Table XII	
AF	Conversion constant from pounds to Newtons	Newtons/lb
IC,II	Same as those defined in Table X	
KI	KI=KK(K) Number of stiffness sections for each of the nonlinear stiffness bearings	
K1,K2	Maximum value of the subscript KI for BROB(K,KI) for each of the nonlinear stiffness bearings	
ADN	Material weight density conversion constant from lb/in.^{3} to kg/cm^3	
AIN	Equivalent of cm to inch	
AFIN	Conversion constant from lb-in. to Newton-cm	
AFIN^2	Conversion constant from lb-in.^{2} to Newton-cm^2	
AFØIN	Conversion constant from lb/in. to Newtons/cm	
AINER	Conversion constant from lb-in.^{2} to kg-cm^2	
AMASS	Conversion constant from pounds to kg	
AFØIN2	Conversion constant from lb/in.^{2} to Newtons/cm^2	

TABLE XIV - DEFINITION OF FORTRAN VARIABLES USED IN SUBROUTINE HYSMET

Variable	Definition	Units
A,H	Same as that defined in Table X	
I,J	Subscripts used in dimensioned variables	
V	Same as that defined in Table X	
AIN	Same as that defined in Table XIII	
REV(I)	Same as that defined in Table X	
XXT(IC)	Rotor X-displacement component printing time-step accumulation (IC) array at rotor station "IASIGN," for CRT use	cm
YYT(IC)	Rotor Y-displacement component printing time-step accumulation (IC) array at rotor station "IASIGN," for CRT use	cm
FØRC(IC,K)	Bearing force vector printing time-step accumulation (IC) array at bearing station K, for CRT use	Newton
BRGR(IC,K)	Bearing displacement vector printing time-step accumulation (IC) array at bearing station K, for CRT use	cm
RØSQ, RPMM, SLØP, SQRT, I10SB	Same as that defined in Table X	
BRGRØ(K)	Bearing displacement vector at bearing station K	inches
ROMAX(IC)	Maximum rotor displacement vector (at a time point) printing time-step accumulation (IC) array for CRT use	cm
RØSTA(IC)	Rotor displacement vector printing time-step accumulation (IC) array at rotor station "IASIGN" for CRT use	cm

TABLE XIV - (Concluded)

Variable	Definition	Units
XBDØT,XBFØR, XBMØM,XMFØR, XBDØT,YBFØR, YBMØM,YMFØR, BRGFØR,BSPHAS, ISTATN	Same as those defined in Table X	
I10S2B,I10S3B, I10S4B,I10S5B, I10S6B,I10S7B,		
MØFØPH,MØPHAS, MØWHIR,PHARØS, PHASMM,SLØPSQ		
WHRATI WHRVLØ WHSLØP XBMDØT YBMDØT		

TABLE XV - DEFINITION OF FORTRAN VARIABLES USED IN SUBROUTINE HYSINF

Variable	Definition	Units
I,J,K	Subscripts used in dimensioned variables	
RA(J)	Rotor outside diameter to inside diameter ratio for rotor section (J)	dimensionless
SZ(I)	Z-coordinate (axial) value from Ith rotor station to first bearing station	inches
ZQ(I)	Z-coordinate of rotor station I less that at the last bearing station	inches
FØF(I,I1)	Reactional transverse rotor force at station I1 due to unit force application at rotor station I	pounds
FØM(I,I1)	Reactional transverse rotor force at rotor station I1 due to unit moment application at rotor station I	lb-in.
IB2	Last bearing rotor station number	
MØF(I,I1)	Reactional rotor transverse moment at rotor station I due to unit force application at rotor station I	pounds
MØM(I,I1)	Reactional rotor transverse moment at rotor station I1 due to unit moment application at rotor station I	lb-in.
RØF(I,J)	Rotor transverse deflection at rotor station J relative to the straight line joining first and last bearing centers due to load at rotor station I	in./lb
RØM(I,J)	Rotor transverse deflection at rotor station J relative to the straight line joining first and last bearing centers due to moment at rotor station I	in./(lb-in.)
OLEI(J)	Rotor sectional length divided by the product of Young's modulus of elasticity and sectional area moment of inertia for rotor section J	1/lb-in.)
QZØL(I)	Negative of ZA(I) divided by the span between first and last bearing	dimensionless

TABLE XV - (Concluded)

Variable	Definition	Units
SZØL(I)	SZ(I) divided by the span between first and last bearing	dimensionless
ZQØL(I)	ZA(I) divided by the span between first and last bearing	dimensionless
AFALEI(I)	Sum of SHERGA(J) and cube of rotor sectional length divided by three times EI(J) for rotor section J	in./lb
SHERGA(J)	Rotor sectional length divided by the product of modulus of shear rigidity, cross-sectional area and inverse of shear strain factor (GAK(J)) for rotor section J	in./lb
SQLZEI(J)	Rotor sectional length square divided by 2EI(J) for rotor section J	lb^{-1}

TABLE XVI - DEFINITION OF FORTRAN VARIABLES USED IN SUBROUTINE HYSSTA

Variable	Definition	Units
I,J,K,M	Subscripts	
U	4/3, a constant	dimensionless
V	180 divided by π, radian to angular degrees conversion constant	degrees/radian
W	π divided by the product of 128* gravitational constant	$sec^2/in.$
AA(I,I1)	Matrix coefficients for solution of startup rotor deflection configuration	dimensionless
CC(I)	Matrix coefficient constant terms for solution of startup rotor deflection configuration	inches,radians
CF(I)	Square of initial rotor spin speed times rotor mass at rotor station I	lb/in.
CG	Center of rotor mass from rotor station 1	inches, cm
CM	Square of initial rotor spin speed times the difference of rotor transverse mass moment of inertia less the polar mass inertia at a rotor station	lb-in.
FC	Product of rotor mass eccentricity vector, square of initial rotor spin speed and rotor mass at a rotor station	pounds
FF	A variable whose value is used as a scale factor for determinant evaluation in the "ISIMEQ" library function FF=0 is used here	
FG	Sum of initial rotor spin angular position and rotor eccentricity phase angle at a rotor station	radians
F1	Initial rotor spin angular position	radians
IA	A variable having one-dimensional erasable array at least equal to the number of rows of matrix AA(I,I1) for library function "ISIMEQ" use	

TABLE XVI - (Continued)

Variable	Definition	Units
IK,JK,JS	Subscripts used in dimensioned variables	
KL	Integer variable name for the library function "ISIMEQ". In return to the calling program KL serves as an indicator of the status of solution, i.e., KL=1 successful solution KL=3 singular matrix detected	
MC	Product of square of initial rotor spin speed, value of rotor transverse mass moment of inertia less polar mass moment of inertia and the misalignment angle of the rotor mass moment of inertia	lb-in.
QW(I)	Rotor mass at rotor station I	pounds, kg
RØ(I)	Rotor displacement vector at rotor station I	inches, cm
XB(K)	Bearing X-displacement at bearing station K	inches
XM(K)	Mount X-displacement at bearing station.K	
XS(I)	Rotor slope in XZ-plane at rotor station I	radians
XX(I)	Rotor X-displacement at rotor station I	inches
YB(K)	Bearing Y-displacement at bearing station K	inches
YM(K)	Mount Y-displacement at bearing station K	inches
YN(N)	Computed rotor and bearing startup displacements and slopes	inches,radians
YS(I)	Rotor slope in YZ-plane at rotor station I	radians
YY(I)	Rotor Y-displacement at rotor station I	
CØN(N,1)	Computed rotor and bearing startup displacements and slopes	inches,radians
DDL(J)	Sum of square of rotor outside diameter, square of rotor inside diameter and four thirds square of rotor sectional length for rotor station J	$in.^2$

TABLE XVI - (Continued)

Variable	Definition	Units
DD2(J)	Square of rotor outside diameter for rotor section (J)	$in.^2$
FAA	Sum of the rotor initial starting spin angular displacement and rotor mass eccentricity phase angle at a rotor station	radians
FXC(I)	Negative of cosine of eccentricity vector angular displacement times "FC" at rotor station I	pounds
FXX(I)	X-force gradient for X-displacement due to mass and related nonbearing stiffness and damping coefficients at rotor station I	lb/in.
FXY(I)	X-force gradient for Y-displacement due to related nonbearing stiffness and damping coefficients at rotor station I	lb/in.
FYC(I)	Negative of sine of eccentricity vector angular displacement times "FC" at rotor station I	pounds
INB,JKS,JNB, JNS,J2S,J3S, MNS	Subscripts used in dimensioned variables	
MXC(I)	Negative cosine of misalignment vector angular displacement times MC	lb-in.
MXX(I)	XZ-plane moment gradient for XZ-plane slope due to mass inertia and related nonbearing stiffness and damping coefficients at rotor station I	lb-in./radian
MXY(I)	XZ-plane moment gradient for YZ-plane slope due to related nonbearing stiffness and damping coefficients at rotor station I	lb-in./radian
MYC(I)	Negative sine of misalignment vector angular displacement times MC	lb-in.
QKB(K)	Startup nonlinear bearing stiffness at bearing station K	lb/in.

TABLE XVI - (Continued)

Variable	Definition	Units
QL2(J)	Square of rotor sectional length for rotor section J	$in.^2$
SIN(A)	Sine function with argument "A" in radians	
SUM	Total rotor mass moment about rotor station I	lb-in.
SBM(K)	Bearing slope at bearing station K	radians
XMM(K)	Mount slope at bearing station K	radians
XXC(K)	Average in-phase bearing damping force coefficient of the corresponding nonisotropic X- and Y-components at bearing station K for startup computation purpose	lb-sec/in.
XXK(K)	Average in-phase bearing stiffness force coefficient of the corresponding nonisotropic X- and Y-components at bearing station K for startup computation purpose	lb/in.
XYC(K)	Average out-of-phase bearing damping force coefficient of the corresponding nonisotropic X- and Y-components at bearing station K for startup computation purpose	lb-sec/in.
XYK(K)	Average out-of-phase bearing stiffness for coefficient of the corresponding nonisotropic X- and Y-components at bearing station K for startup computation purpose	lb/in.
YBM(K)	Bearing slope in YZ-plane at bearing station K	radians
AFIN	A conversion constant from lb-in. to Newton-cm	Newton-cm/ lb-in.
BCMM(K)	Mount damping moment coefficient at bearing station K	lb-in.-sec/ radian
BKMM(K)	Mount stiffness moment coefficient at bearing station K	lb-in./radian

TABLE XVI - (Continued)

Variable	Definition	Units
I2NB,I2NS, I3NB,I3NS, I4NS,JK2S JK3S,J2NB, J2NS,J3NB, J3NS,M2NS, M3NS	Subscripts used in dimensioned variables	
NS41	One plus four times number of rotor stations, used as a DØ LØØP index	
QIDW(I)	Rotor transverse mass moment of inertia at rotor station I	lb-in.^2 kg-cm^2
RØMM(K)	Mount slope vector at bearing station K	radians
RØSL(I)	Rotor slope vector at rotor station I	radians
WEIT	Total rotor mass	pounds, kg
XBDØ(K)	Bearing linear X-velocity at bearing station K	in./sec
XMDØ(K)	Mount linear X-velocity at bearing station K	in./sec
XXCM	Average in-phase bearing damping moment coefficient of the corresponding nonisotropic X- and Y-components at bearing station K for startup computation purpose	(lb-in.-sec)/ radian
XXKM	Average in-phase bearing stiffness moment coefficient of the corresponding nonisotropic X- and Y-components at bearing station K for startup computation purpose	(lb-in.)/ radian
XYCM	Average out-of-phase bearing damping moment coefficient of the corresponding nonisotropic X- and Y-components at bearing station K for startup computation purpose	(lb-in.-sec)/ radian
XYKM	Average out-of-phase bearing stiffness moment coefficient of the corresponding nonisotropic X- and Y-components at the bearing station K for startup computation purpose	(lb-in.)/sec

TABLE XVI - (Continued)

Variable	Definition	Units
YBDØ	Bearing linear Y-velocity at bearing station K	in./sec
YMDØ	Mount linear Y-velocity at bearing station K	in./sec
ZSØL	The value of rotor axial (Z) coordinate less that of the first bearing then divided by the span between first and last bearing	dimensionless
AMASS	Conversion constant from pounds to kg	kg/lb
AMIN2	Conversion constant from lb-in.^{2} to kg-cm^2	kg-cm^2/lb-in.^{2}
ATAN2(Y,X)	Arc tangent function using Y, and X argument	radians
BRGRØ(K)	Bearing displacement vector at bearing station K	inches, cm
BSLRØ(K)	Bearing slope vector at bearing station K	radians
COSFA	Cosine of rotor mass eccentricity vector displacement angle at a rotor station	dimensionless
COSFG	Cosine of rotor mass inertia misalignment displacement angle at a rotor station	dimensionless
DDPLD(J)	Sum of the square of rotor outside diameters and square of rotor inside diameter for rotor section J	in.^{2}
IBINS,I4NSB	Subscripts used for dimensioned variables	
NS4NB	Total number of bearings plus four times total number of rotor stations	dimensionless
QIRØW(I)	Rotor polar mass moment of inertia at rotor station I	lb-in^2 kg-cm^2
QMASS	Total rotor mass	lb-sec^2/in.
SINFA	Sine of rotor mass eccentricity vector displacement angle at a rotor station	dimensionless
SINFG	Sine of rotor mass inertia misalignment displacement angle at a rotor station	

TABLE XVI - (Continued)

Variable	Definition	Units
XBFØR(K)	Bearing X-force at bearing station K	pounds,Newtons
XBIMØ(K)	Bearing mass moment of inertia XZ-plane moment at bearing station K	lb-in., Newton-cm
XBMDØ(K)	Bearing slope XZ-plane velocity at bearing station K	radians/sec
XBMFØ(K)	Bearing mass inertia X-force at bearing station K	pounds,Newtons
XBMØM(K)	XZ-plane bearing moment at bearing station K	lb-in., Newton-cm
XMFØR(K)	Mount X-force at bearing station K	pounds,Newtons
XMMDØ(K)	Mount XZ-plane slope velocity at bearing station K	radians/sec
XMMOM(K)	Mount XZ-plane moment at bearing station K	lb-in., Newton-cm
YBFØR(K)	Bearing Y-force at bearing station K	pounds,Newtons
YBIMØ(K)	Bearing mass moment of inertia YZ-plane moment at bearing station K	lb-in., Newton-cm
YBMDØ(K)	Bearing slope ZY-plane velocity at bearing station K	radian/sec
YBMFØ(K)	Bearing mass inertia Y-force at bearing station K	pounds,Newtons
YBMØM(K)	YZ-plane bearing moment at bearing station K	lb-in., Newton-cm
YBFØR(K)	Bearing Y-force at bearing station K	pounds,Newtons
YMMDØ(K)	Mount YZ-plane slope velocity at bearing staion K	radians/sec
YMMØM(K)	Mount YZ-plane moment at bearing station K	lb-in., Newton-cm
BRPHAS(K)	Bearing displacement vector phase angle at bearing station K	degrees

TABLE XVI - (Continued)

Variable	Definition	Units
BSPHAS(K)	Bearing slope vector phase angle at bearing station K	degrees
FDØTSQ	Square of starting rotor spin speed	radians/sec
IBNBNS	A subscript used in dimensioned variables	
ISIMEQ	Library function name for solution of simultaneous equations	
I4NS2B,I4NS3B	Subscripts used in dimensioned variables	
MOPHAS(K)	Mount displacement vector phase angle at bearing station K	degrees
MØUNRØ(K)	Mount displacement vector at bearing station K	inches, cm
NS42NB	Sum of four times total number of rotor stations and two times total number of bearing stations	
NS43NB	Sum of four times total number of rotor stations and three times total number of bearing stations	
NS44NB	Sum of four times total number of rotor stations and four times total number of bearing stations	
PHARØØ(I)	Rotor displacement vector phase angle at rotor station I	degrees
PHARØS(I)	Rotor slope vector phase angle at rotor station I	degrees
PHASMM(K)	Mount slope vector phase angle at bearing station K	degrees
PØLARA	Total rotor polar mass moment of inertia	$lb\text{-}in.^2$ $lb\text{-}in.sec^2$ $kg\text{-}cm\text{-}sec^2$

TABLE XVI - (Concluded)

Variable	Definition	Units
PRIMAS	Printout of rotor mass properties control variable PRIMAS=0, delete printing PRIMAS=1, print the properties	
PRISTA	Print of startup rotor dynamic deflection control variable PRISTA=0, delete printing PRISTA=1, print the deflection	
QLDNDD	$4/\pi$ times the rotor section mass for a rotor section	pounds
Q1LDND(J)	Rotor sectional mass divided by 2 * 386.088 for rotor section J	$lb\text{-}sec^2/in.$
Q6LDND(J)	Rotor sectional mass divided by 32 * 386.088 for rotor section J	$lb\text{-}sec^2/in.$

TABLE XVII - DEFINITION OF FORTRAN VARIABLES USED IN SUBROUTINE HYSRKA

Variable	Definition	Units
A(NN,I1),	Integration processing variables First Subscript = number of input and output variables to be integrated Second Subscript = number of internal processing steps	
H	Integration time step could have time or other units	
I,J	Subscripts used for dimensioned variables	
K	Indicator for overflow conditions	
L	A flow procedure control constant	
N	Total number of variables to be integrated	
NN	Maximum allowable number of variables to be integrated	
NS	A flow control variable	
XB	Substitute time variable	
YB	Substitute variable for Y(NN)	
NERR	Integration validity indicator NERR = 0 solution is valid NERR = 1 solution is invalid either due to N is invalid or H has gone to zero	
ISTFLG	A flow process control variable	
OVERFL	A library subroutine which provides for testing for an exponent overflow or underflow in real (floating point) operations	

TABLE XVIII - DEFINITION OF FORTRAN VARIABLES USED IN SUBROUTINE RUNKUT

Variable	Definition	Units
A(NN,I3)	Derivatives supplied by "FUND" for integrating variables. Their units vary according to the units used for dependent and independent variables.	
H	Time step or step of other type of independent variable used	
I	A subscript for a dimensioned variable	
N	Number of variables to be integrated	
V(I)	An integration variable array	
X	An integration time or other independent variables	
Y	Variables to be integrated	
X1	Alternate time (or other variable) step variable	
X2, X3	Alternate time (or other variable) in integration	
YY(NN)	Solution of integration variable at end of time (or other variable) step	

TABLE XIX - DEFINITION OF FORTRAN VARIABLES USED IN SUBROUTINE ADAMLT

Variable	Definition	Units
A(NN,I1) F(NN,I2)	An integrating variable array in the process of computation, NN = number of integration variable I1 = number of internal processing levels	
H	Time (or other variable) step	
I,K	Subscripts used in dimensioned variables	
N	Number of integration variables	
S	A flow control variable	
T,U,V,W	Equivalent variable names for testing intermediate integration variables	
X	Time or other independent variables in integration	
Y	Integration variables	
HH	One-twenty-fourth of time (or other variables) step	
IC	A flow process control variable	
YC(NN,I3)	Corrector integration solution variables	
YP(NN,I4)	Predictor integration solution variables	
NERR	Same as that defined in Table	
ISTFLG	A flow control flag	
OVERFL	Same as that defined in Table	

TABLE XX - DEFINITION OF FORTRAN VARIABLES USED IN SUBROUTINE FUND

Variable	Definition	Units
I,J,K	Subscripts used in dimensioned variables	
AR(I)	Equivalent polar mass moment of inertia at rotor station I	$lb\text{-}in.^2$
EX	Rotor XZ-plane slope differential for a rotor section	radians
EY	Rotor YZ-plane slope differential for a rotor section	
FG	Rotor mass inertia misalignment angular displacement angle at a rotor station	radians
FX(I)	Combined rotor transverse elastic and hysteresis X-force at rotor station I	pounds
FY(I)	Combined rotor transverse elastic and hysteresis Y-force at rotor station I	pounds
HX	Product of rotor sectional length and its XZ-plane slope less XMX for a rotor section	inches
HY	Product of rotor section length and its YZ-plane slope less YMY for a rotor section	inches
IJ	Subscript for a dimensioned variable	
IQ	Dummy spacer in common	
IR	A variable in torsional rigid section control	
JJ,K1	A subscript used in dimensioned variables	
K4	Number of stiffness sections for a nonlinear stiffness bearing	
MX(I)	Combined rotor transverse elastic and hysteresis XZ-plane moment at rotor station I	lb-in.
MY(I)	Combined rotor transverse elastic and hysteresis YZ-plane moment at rotor station I	lb-in.
PP(I)	Total axes loading at rotor station I	pounds
UE	Viscous rotor bending hysteresis coefficient divided by rotor Young's modulus of elasticity for a rotor section	seconds

TABLE XX - (Continued)

Variable	Definition	Units
UG	Coulomb friction rotor shear hysteresis coefficient divided by rotor shear modulus of rigidity at a rotor section	dimensionless
XB(K)	Bearing X-displacement at bearing station K	inches
YB(K)	Bearing Y-displacement at bearing station K	
YN(NN)	Incoming variables into "fund" from which the derivatives are generated	inches, in./sec, radians, radians/sec
ACA	Bearing displacement vector at a bearing station	inches
BXL(I),BXR(I)	Combine rotor transverse XZ-plane, viscous and Coulomb friction hysteresis bending moment at the immediate left and right of rotor station I, respectively	lb-in.
BYL(I),BYR(I)	Combined rotor transverse YZ-plane, viscous and Coulomb friction hysteresis bending moment at the immediate left and right of rotor station I, respectively	lb-in.
FAA	Rotor mass eccentricity vector angular displacement	radians
FDD(I)	Rotor spin acceleration at rotor station I	radians/sec^2
FDL,FDR	Absolute value of the rotor transverse force whirl to rotor spin velocity ratio at the immediate left and right of a rotor station, respectively	dimensionless
FHX(I),FHY(I)	Combined rotor transverse viscous and Coulomb friction hysteresis X- and Y-force at rotor station I, respectively	pounds
FLS,FRS	Rotor transverse elastic force vector at the immediate left and right of a rotor station, respectively	pounds

TABLE XX - (Continued)

Variable	Definition	Units
FWL,FWR	Rotor force spin-whirl velocity difference to its absolute value ratio at the immediate left and right of a rotor station, respectively	dimensionless
FXL(I),FXR(I)	Rotor elastic X-force to the immediate left and right of a rotor station I, respectively	pounds
FXX	An X-force function	
FYL(I),FYR(I)	Rotor elastic Y-force to the immediate left and right of a rotor station I, respectively	pounds
FYY	A Y-force function	
GAL	Combined shear rigidity	
IBI,INS	Subscripts used in dimensioned variables	
IR1	A rotor section torsional rigidity variable	
KNS	Subscript used in a dimensioned variable	
MDL,MDR	Absolute value of the rotor transverse moment whirl to rotor spin velocity ratio at the immediate left and right of a rotor station, respectively	
MHX(I),MHY(I)	Combined rotor transverse viscons and Coulomb friction hysteresis XZ-plane and YZ-plane moment at rotor station I, respectively	lb-in.
MLS,MRS	Rotor transverse elastic moment vector at the immediate left and right of a rotor station, respectively	lb-in.
MWL,MWR	Rotor moment spin-whirl velocity difference to its absolute value ratio at the immediate left and right of a rotor station	dimensionless
MXL(I),MXR(I)	Rotor XZ-plane elastic moment at the immediate left and right of rotor station I	lb-in.
MYL(I),MYR(I)	Rotor YZ-plane elastic moment at the immediate left and right of rotor station I	lb-in.

TABLE XX - (Continued)

Variable	Definition	Units
NB4	Four times total number of bearings	
PPL		
SXL	=SVXL+SCXL	
SXR	=XVXR+SCXR	
SYL	=SVYL+SCYL	
SYR	=SVYR+SCYR	
THH	T to the power HA	
TØL	Tolerance used in limiting the computation round off error from generating unrealistic Coulomb friction induced hysteresis effect	dimensionless
TØR	Net externally applied rotor drive and damping torque in an assumed rigid rotor sections	lb-in.
XBM(K)	Bearing XZ-plane slope at bearing station K	radians
XMX	Rotor X-displacement differential between the end stations of a rotor section	inches
XPL		
YBM	Bearing YZ-plane slope at bearing station K	radians
YMY	Rotor Y-displacement differential between the end stations of a rotor section	inches
YPL		
BCXL,BCXR	Rotor Conlomb friction induced hysteresis bending moment in XZ-plane at the immediate left and right of a rotor station	lb-in.
BCYL,BCYR	Rotor Conlomb friction induced hysteresis bending moment in YZ-plane at the immediate left and right of a rotor station	lb-in

TABLE XX - (Continued)

Variable	Definition	Units
BVXL,BVXR	Rotor viscous hysteresis coefficient induced XZ-plane bending moment at the immediate left and right of a rotor station	lb-in.
BVYL,BVYR	Rotor viscous hysteresis coefficient induced YZ-plane bending moment at the immediate left and right of a rotor station	
COMB	Combined torque	
EI1L,EI2L, EI3L	Bending sectional rigidity variables	
FDØD	Rotor acceleration variable	
FWIL,FWIR	The magnitude of rotor force spin-whirl velocity difference at the immediate left and right of a rotor station	radians/sec
FXLD	Rotor force left X-velocity	lb/sec
FXRD	Rotor force right X-velocity	lb/sec
FYLD	Rotor force left Y-velocity	lb/sec
FYRD	Rotor force right Y-velocity	lb/sec
IBNS		
I10S,I2NS, I3NS,I4NS I5NS,I6NS I7NS,I8NS I9NS,K2NS K3NS,K4NS K5NS,K6NS K7NS	Subscripts	
MBVC MSVC MTVC	Indicators for hysterisis input conditions	

TABLE XX - (Continued)

Variable	Definition	Units
MTXZ(I),MTYZ(I)	Transverse torque XZ-plane and YZ-plane moment, respectively	lb-in.
MWIL,MWIR	The magnitude of rotor whirl spin-whirl velocity difference at the immediate left and right of a rotor station	
MXLD(I), MXRD(I)	Rotor elastic XZ-plane moment at the immediate left and right of the rotor station I	
MYLD(I), MYRD(2)	Rotor elastic YZ-plane moment at the immediate left and right of the rotor station I	
NST1	An index in torsionally rigid rotor section control	
SCXL,SCXR	Rotor Coulomb friction induced hysteresis shear force along X-axis at the immediate left and right of a rotor station	pounds
SCYL,SCYR	Rotor Coulomb friction induced hysteresis shear force along Y-axis at the immediate left and right of a rotor station	pounds
SQRT	Square root library function	
SVXL,SVXR	Rotor viscons coefficient induced hysteresis shear force along X-axis at the immediate left and right of a rotor station	pounds
SVYL,SVYR	Rotor viscons coefficient induced hysteresis shear force along Y-axis at the immediate left and right of a rotor station	pounds
TMTX(I), TMTY(I)	Transverse torsion moment loading in XZ- and YZ-plane, respectively	pounds
TØRQ(J)	Internal torque transmission including elastic torque hysteresis torque at rotor section J for computing the transverse loading effects of torsion	lb-in.
TØRS(I)	Externally applied net rotor drive and damping torque at rotor station I	lb-in.

TABLE XX - (Continued)

Variable	Definition	Units
WHIR	Rotor displacement whirl velocity	radians/sec
XFØR	Rotor Y-force	pounds
XMØM	Rotor XZ moment	lb-in.
YFØR	Rotor Y-force	pound
YMØM	Rotor YZ-moment	lb-in.
CØSFA	Cosine of eccentricity angle	
CØSFG	Cosine of misalignment angle	
EICØM	Rotor section rigidity	lb-in.^{-1}
FDØAB,FDØCT	Spin velocity variable	dimensionless, radians/sec
FDØMT	A spin-speed variable	$\text{radians/sec}^{MT(I)}$
FDØRA	A spin-speed ratio	dimensionless
FDØTM,FDØTN FDØTP	Spin-speed differences	radians/sec
FXLD1,FXLD2 FXRD1,FXRD2	Rotor X-force velocities at the immediate left and right of a rotor station, respectively	lb/sec
FYLD1,FYLD2 FYRD1,FYRD2	Rotor Y-force velocities at the immediate left and right of a rotor station, respectively	lb/sec
IB2NS,IB3NS, IB4NS,IB5NS IB6NS,IB7NS	Subscripts	
ISTAR ISTØP	Rotor torsional rigidity variables	
I10SB	Subscript	
MXLD1,MXLD2 MXRD1,MXRD2	Rotor XZ-plane moment velocities at the immediate left and right of a rotor station	lb-in./sec

TABLE XX - (Concluded)

Variable	Definition	Units
MYLD1 MYLD2 MYRD1 MYRD2	Rotor YZ-plane moment velocities at the immediate left and right of a rotor station	lb-in./sec
NSTØT	Torsion rigidity variable	
SINFA	Sine of eccentricity angle	
SINFG	Sine of misalignment angle	
WHIRM	Rotor moment whirl velocity	radians/sec
XBDØT(I)	Bearing X-velocity	in./sec
XBFØR(I)	Bearing X-force	pounds
XBMDØ	Bearing XZ-plane slope velocity	radians/sec
XBMØM	Bearing XZ-plane moment	lb-in.
YBDØT	Bearing Y-velocity	in./sec
YBFØR	Bearing Y-force	pounds
YBMDØ	Bearing YZ-plane slope velocity	radians/sec
YBMØM	Bearing YZ-plane moment	lb-in.
FDØMAB FDØMRA FDØNAB FDØNRA	Rotor spin velocity ratios	
FDØTSQ	Square of rotor spin velocity	$radians/sec^2$
GALEI3	Rotor section rigidity variable	in./lb
I10S2B,I10S3B I10S4B,I10S5B I10S6B,I10S7B	Subscripts used in dimensioned variables	
TORHFM	Hysteresis torque	lb-in.

APPENDIX C

PROGRAM INPUT VARIABLES

Appendix C consists of two sets of program input variables

(a) NAMELIST/MUST - These variables must be input (Table XXI)

(b) NAMELIST/ØPTIØN - The input of these variables is optional. The default values of the variables are as shown in Table XXII.

TABLE XXI. PROGRAM INPUT VARIABLES (NAMELIST/MUST)

Variables	Description	Unit	Symbol Used and Eq. No.
Title	A description card consisting of 72 characters and ID field		
DT	Initial integration step For Runge-Kutta and Adams-Moulton fixed-step techniques, DT will be used for the entire computation For predictor and corrector Adams-Moulton variable step technique, the input DT will be used only when the integration tolerance requirement is met	sec	
TMAX	Maximum run real time	sec	
DP	Output printing real time interval	sec	
NS	Number of rotor stations of the rotor model		"n" 6-13
NB	Number of bearing stations		
FDØTI	Initial rotor spin and whirl velocity	rpm	$\dot{\phi}_i$ 1-5
IB(I)	Rotor station number for each bearing		
DD(J)	Outside diameter for rotor sections	cm	D_{oi} 29-30
QL(J)	Rotor section length	cm	ℓ_i 20-29
MET	Unit system selector 1 = international units 0 = English units		
ID	Not used in computation. It is a way to punch ID on cards for namelist input, so that the cards sequence can be defined		

TABLE XXII - PROGRAM INPUT VARIABLES (NAMELIST/ØPTIØN)

Variable	Description	Default Value	Unit	Symbols Used and Eq. No.
IND	Integration technique selector 0 = using Adams-Moulton predictor-corrector variable step technique 1 = using 4th order Runge-Kutta fixed-step technique 2 = using Adams-Moulton fixed-step technique	1		
TØLI	Computation accuracy control tolerance for Adams-Moulton variable step integration technique	0.0001		
T	Starting computation real time	0	sec	t 28(i),46
CØNTIN	Specification for cold start or continued analysis from a previous un 0 = cold start 1 = continued analysis in which punch cards for T, DT, YNN(I) from a previous analysis must be included in addition to the input required for cold start. T, DT value in the punched cards will be used to override that from the key punch input.	0		
ITØRQ	Input driving and damping torque control ITØRQ = 0 means no driving or damping torque effect will not be considered in computation ITØRQ = 1 means the torque effects will be considered in computation This is to bypass certain computation when ITØRQ = 0, to better computation efficiency	0		
IPP	Axial loading transverse effects control IPP = 1 including the effects IPP = 0 excluding the effects	0		
IMT	Torsional transverse effects control IMT = 1 including the effects IMT = 0 excluding the effects	0		
RIG(J)	Rotor section torsional flexibility indicator RIG(I) = 1 rotor section (I) is rigid in torsion RIG(I) = 0 rotor section (I) is torsionally flexible	0		
CRT	CRT graphs requirement specification CRT = 1 requires CRT CRT = 0 no CRT required	0		
MØSHA	Rotor mode shape CRT generation control	1		
NPØINT	Number of points per CRT graph range from 1 to 50	25		
NØØRPM	Number of rotor spin speeds one for each rotor mode shape CRT plot	1		
IASIGN	Rotor station number for which the related CRT graph will be plotted	1		
INPRPM(M)	The values of input rotor spin speeds at or near which rotor mode shape CRT will be plotted	0	rpm	
D(J)	Rotor section inside diameter	0	cm	D_{Ii} 29-30

TABLE XXII - (Continued)

Variable	Description	Default Value	Unit	Symbols Used and Eq. No.
DN(J)	Rotor mass density	0.008304	kg/cm^3	
P(J)	Rotor section Poisson's ratio	0.3		
EE(J)	Rotor section Young's modulus of elasticity	2.0684×10^7	$Newtons/cm^2$	E_i 20-23,36-39,42-45
GG(J)	Rotor section shear modulus of rigidity	0.7929×10^7	$Newtons/cm^2$	G_i 20,21,34,35,40,41
EI(J)	Product of rotor modulus of elasticity and area moment of inertia	0	$Newton/cm^2$	
GAK(J)	Product of rotor shear modulus, cross-sectional area and shear strain over average shear strain ratio	0	Newtons	
AM(I)	Additional (nonstructural) rotor masses	0	kg	
ECC(I)	Rotor mass eccentricity	0.000254	cm	e_i 1,2,3
ALFA(I)	Rotor mass eccentricity phase angle	0	degrees	α_i 1,2,3
AIRØ(I)	Additional (nonstructural) rotor polar mass moments of inertia	0	$kg\text{-}cm^2$	
AID(I)	Additional (nonstructural) rotor transverse mass moments of inertia	0	$kg\text{-}cm^2$	
BETA(I)	Rotor inertia axis misalignment	0	degrees	β_i 4,5
GAMMA(I)	Rotor inertia axis misalignment phase angle	0	degrees	γ_i 4,5
BKMX(K) BKMY(K)	Mount in-phase anisotropic stiffness force coefficient along x- and y-axis, respectively	3.5025×10^6 each	N/cm	K_{Mxi} K_{Myi} 17a
BCMX(K) BCMY(K)	Mount in-phase anisotropic damping force coefficients along x- and y-axis, respectively	0	(N-cm-sec)/cm	C_{Mxi} C_{Myi} 17b
XKMM(K) XKMM(K)	Mount in-phase anisotropic stiffness moment coefficients in xz- and yz-plane, respectively	22.59697×10^6 each	(N-cm)/radian	$K_{\phi Myi}$ $K_{\phi Myi}$ 17c
XCMM(K) YCMM(K)	Mount in-phase anisotropic damping moment coefficients in xz- and yz-plane, respectively	22.59697×10^6 each	(N-cm-sec)/radian	$C_{\phi Mxi}$ $C_{\phi Myi}$ 17d
BM(K)	Bearing mass	0	kg	M_{Bi} 14,15
BI(K)	Bearing transverse mass moment of inertia	0	$kg\text{-}cm^2$	I_{Bi} 16,17
QKXX(K) QKYY(K)	Bearing in-phase anisotropic stiffness force coefficients along x- and y-axis, respectively	1.7513×10^6 each	Newtons/cm	K_{Bxxi} K_{Byyi} 3a
QKXY(K)	Bearing out-of-phase anisotropic stiffness x-force due to y-displacement coefficient	0	Newton/cm	K_{Bxyi} 3a
QKYX(K)	Bearing out-of-phase anisotropic stiffness y-axis due to x-displacement coefficient	0	Newton/cm	K_{Byxi} 3a
QCXX(K) QCYY(K)	Bearing in-phase anisotropic damping force coefficients along x- and y-axis, respectively	0	(Newton-sec)/cm	C_{Bxxi} C_{Byyi} 3a

TABLE XXII - (Continued)

Variable	Description	Default Value	Unit	Symbols Used and Eq. No.
QCXY(K)	Bearing out-of-phase anisotropic damping x-force due to y-velocity coefficient	0	(Newton-sec)/ cm	C_{Bxyi} 3a
QCYX(K)	Bearing out-of-phase anisotropic damping y-force due to x-velocity coefficient	0	(Newton-sec)/ cm	C_{Byxi} 3a
XXMK(K) YYMK(K)	Bearing in-phase anisotropic stiffness moment coefficients in xz- and yz-plane, respectively	11.29848 x 10^6 each	(Newton-cm)/ radian	$K_{B\phi xxi}$ $K_{B\phi yyi}$ 5a
XYMK(K)	Bearing out-of-phase anisotropic stiffness xz-plane moment due to yz-plane slope coefficient	0	(Newton-cm)/ radian	$K_{B\phi xyi}$ 5b
YXMK(K)	Bearing out-of-phase anisotropic stiffness yz-plane moment due to xz-plane slope coefficient	0	(Newton-cm)/ radian	$K_{B\phi yxi}$ 5b
XXMC(K) YYMC(K)	Bearing in-phase anisotropic damping moment coefficients in xz- and yz-plane, respectively	0	(Newton-cm-sec)/radian	$C_{B\phi xxi}$ $C_{B\phi yyi}$ 5c
XYMC(K)	Bearing out-of-phase anisotropic damping xz-plane moment due to yz-plane slope velocity coefficient	0	(Newton-cm-sec)/radian	$C_{B\phi xyi}$ 5d
YXMC(K)	Bearing out-of-phase anisotropic damping yz-plane moment due to xz-plane slope velocity coefficient	0	(Newton-cm-sec)/radian	$C_{B\phi yxi}$ 5d
KK(K)	Number of nonlinear bearing stiffness sections	1		
FDØFIX(I)	Nonlinear stiffness bearing rotor spin-speed factor	0	radians/sec	$\dot{\phi}_{oi}$ 2,3
BBB(K,K1)	Nonlinear stiffness bearing spin-speed, journal displacement coefficient	0	(Newton-sec)/ radian	B_{Bik} 2,3
BCB(K,K1)	Nonlinear stiffness bearing journal displacement power coefficient	0	$1/(cm)^{BHB(K,K1)}$	C_{Bik} 2,3
BDB(K,K1)	Nonlinear stiffness bearing journal displacement coefficient	0	cm^{-1}	D_{Bik} 2,3
BEB(K,K1)	Nonlinear stiffness bearing constant	0	dimensionless	E_{Bik} 2,3
BHB(K,K1)	Nonlinear stiffness bearing displacement exponent	1.0	dimensionless	H_{Bik} 2,3
BKB(K,K1)	Nonlinear stiffness bearing coefficient	0	Newtons/cm	K_{Bik} 2,3
BNB(K,K1)	Nonlinear stiffness bearing spin-speed coefficient	0	(Newton-sec)/ (cm-radian)	N_{Bik} 2,3
BRØB(K,KZ)	Nonlinear stiffness bearing stiffness lower limit bearing displacement for a stiffness section	BRØB(K,1) =0 BRØB(K,2) =.0127	cm	P_{Bik} 2,3
QK(I)	Rotor-to-casing in-phase stiffness force coefficient	0	Newtons/cm	K_i 2,3
QC(I)	Rotor-to-casing in-phase damping force coefficient	0	(Newton-sec)/ cm	C_i 2,3
QKP(I)	Rotor-to-casing out-of-phase stiffness force coefficient	0	Newtons/cm	K_{pi} 2,3

TABLE XXII - (Continued)

Variable	Description	Default Value	Unit	Symbols Used and Eq. No.
QCP(I)	Rotor-to-casing out-of-phase damping force coefficient	0	(Newton-sec)/cm	C_{pi} 2,3
QKF(I)	Rotor-to-casing in-phase stiffness moment coefficient	0	(Newton-cm)/radian	$K_{\phi i}$ 4,5
QCF(I)	Rotor-to-casing in-phase damping moment coefficient	0	(Newton-cm-sec)/radian	$C_{\phi i}$ 4,5
QKPF(I)	Rotor-to-casing out-of-phase stiffness moment coefficient	0	(Newton-cm)/radian	$K_{\phi pi}$ 4,5
QCPF(I)	Rotor-to-casing out-of-phase damping moment coefficient	0	(Newton-cm-sec)/radian	$C_{\phi pi}$ 4,5
XKF(I)	Rotor-to-casing whirl stiffness force factor	0	dimensionless	K_{Fi} 2,3
XCF(I)	Rotor-to-casing whirl damping force factor	0	dimensionless	C_{Fi} 2,3
XKFF(I)	Rotor-to-casing whirl stiffness moment factor	0	dimensionless	$K_{\phi Mi}$ 4,5
XCFF(I)	Rotor-to-casing whirl damping moment factor	0	dimensionless	$C_{\phi Mi}$ 4,5
QKHD(I)	Rotor-to-casing out-of-phase whirl-spin stiffness force coefficient	0	(Newton-sec)/cm	K_{HDi} 2,3
QCHD(I)	Rotor-to-casing out-of-phase, whirl-spin damping force coefficient	0	(Newton-sec^2)/radian	C_{HDi} 2,3
QKHDF(I)	Rotor-to-casing out-of-phase, whirl-spin stiffness moment coefficient	0	(Newton-cm-sec)/radian	$K_{\phi HDi}$ 4,5
QCHDF(I)	Rotor-to-casing out-of-phase, whirl-spin damping moment coefficient	0	(Newton-cm-sec^2)/radian	$C_{\phi HDi}$ 4,5
CT1(I)	Rotor damping torque spin-speed power coefficient	0	(Newton-cm)(sec/radian)$^{CT(I)}$	C_{T1i} 28
CT(I)	Rotor damping torque spin-speed	0	dimensionless	C_{Ti} 28
CI2(I)	Rotor damping torque spin-speed coefficient	0	(Newton-cm-sec)/radian	C_{T2i} 28
MT(I)	Rotor drive torque spin-speed exponent	0	dimensionless	M_{Ti} 28
MT1(I)	Rotor drive torque spin-speed power coefficient	0	(Newton-cm)(sec/radian)$^{MT(I)}$	M_{T1i} 28
MT2(I)	Rotor drive torque spin-speed coefficient	0	(Newton-cm-sec)/radian	M_{T2i} 28
AT(I)	Constant rotor drive torque	0	Newton-cm	A_{Ti} 28
BT(I)	Rotor drive torque time coefficient	0	(Newton-cm)/sec	B_{Ti} 28
DU(I)	Rotor drive torque time power coefficient	0	(Newton-cm)/(sec)$^{HT(I)}$	D_{Ui} 28
ET(I)	Rotor drive torque sine coefficient	0	Newton-cm	E_{Ti} 28
HT(I)	Rotor drive torque time power exponent	0	dimensionless	H_{Ti} 28
FT(I)	Rotor drive torque time coefficient sine function	0	radians/sec	F_{Ti} 28

TABLE XXII - (Concluded)

Variable	Description	Default Value	Unit	Symbols Used and Eq. No.	
GT(I)	Rotor drive torque constant argument for sine function	0	radians	G_{Ti}	28
AA(I)	Rotor axial loading constant	0	Newtons	A_{Ai}	46
BA(I)	Rotor axial loading time coefficient	0	Newtons/sec	B_{Ai}	46
DA(I)	Rotor axial loading time power coefficient	0	Newton/(sec)^{HA}	D_{Ai}	46
EA(I)	Rotor axial loading sine coefficient	0	Newtons	E_{Ai}	46
FA	Rotor axial loading sine function time coefficient	0	radians/sec	FA	46
HA	Rotor axial loading time power exponent	0	dimensionless	HA	46
GA	Rotor axial loading since function constant argument	0	radians	GA	46
GX GY	Acceleration or gravity loading along negative x- and y-axis, respectively	0 0	cm/sec^2	g_x g_y	2 3
USV(J)	Rotor transverse shear viscous hysteresis coefficient	0	(Newton-sec)/ cm^2	μ_{SVi}	34,35
USC(J)	Rotor transverse shear Coulomb friction hysteresis coefficient	0	Newtons/cm^2	μ_{SCi}	40,41
UBV(J)	Rotor transverse bending viscous hysteresis coefficient	0	(Newton-sec)/ cm^2	μ_{BVi}	36-39
UBC(J)	Rotor transverse bending Coulomb friction hysteresis coefficient	0	Newtons/cm^2	μ_{BCi}	40-43
UTV(J)	Rotor torsional shear viscous hysteresis coefficient	0	Newton-sec/ cm^2	μ_{TVi}	29
UTC(J)	Rotor torsional shear Coulomb friction coefficient	0	Newtons/cm^2	μ_{TCi}	30
F1	Initial rotor spin angular position	1.0 x 10^{-20}	degrees	ϕ_i	2-5
IPRINT	IPRINT x DP = computer output printout real time interval	1	sec		
ID	Not used in computation, it is a way to punch ID on cards for namelist input, so that the card sequence can be defined				

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APPENDIX D

SYMBOLS LIST FOR THE MATHEMATICAL FORMULATION

A_{Ai}	=	rotor axial loading constant force, Newtons
A'_i	=	rotor cross-sectional area, cm^2
A_{Ti}	=	rotor constant drive torque, Newton-cm
b_{ij}	=	rotor displacement (j)-moment(i) influence coefficient, cm/(Newton-cm)
B_{Ai}	=	rotor axial loading time coefficient, Newtons/sec
B_{BiK}	=	nonlinear stiffness bearing spin-speed and journal displacement coefficient, Newton-sec/radian
B_{Ti}	=	rotor drive torque time coefficient, (Newton-cm)/sec
$C_i, C_{\phi i}$	=	in-phase force and moment damping coefficient, respectively, (Newton-sec)/cm, (Newton-cm-sec)/radian
C_{ij}	=	rotor displacement (j)-force (i) influence coefficient, cm/Newton
C_{BiK}	=	nonlinear stiffness bearing displacement power coefficient, $(1/cm)^{H_{BiK}}$
C_{Bxxi} C_{Byyi}	=	in-phase anisotropic bearing damping force coefficients along x- and y-axis, respectively, (Newton-sec)/cm
C_{Bxyi} C_{Byxi}	=	out-of-phase anisotropic bearing damping coefficients along x- and y-axis due to velocities along y- and x-axis, respectively (Newton-sec)/cm
$C_{B\phi xxi}$ $C_{B\phi yyi}$	=	in-phase anisotropic bearing damping moment coefficients in xz- and yz-plane, respectively, (Newton-cm-sec)/radian
$C_{B\phi xyi}$ $C_{B\phi yxi}$	=	out-of-phase anisotropic bearing damping moments in xz- and yz-plane due to rotations in yz- and xz-plane, respectively, (Newton-cm-sec)/radian
C_{Mxi}, C_{Myi}	=	mount in-phase damping force coefficients along x- and y-axis, respectively, (Newton-sec)/cm
$C_{Pi}, C_{\phi Pi}$	=	out-of-phase force and moment damping coefficients, respectively, (Newton-sec)/cm, (Newton-cm-sec)/radian
C_{Ti}	=	rotor torsion spin-speed damping spin-speed power coefficient exponent, dimensionless
C_{T1i}	=	rotor torsion spin-speed damping spin-speed power coefficient, $(\text{Newton-cm})(\text{sec/radian})^{C_{Ti}}$
C_{T2i}	=	rotor torsion spin-speed damping coefficient, (Newton-cm-sec)/radian

C_{HDi}, $C_{\phi HD_i}$	=	out-of-phase whirl and spin speed sensitive force and moment damping coefficients, respectively, (Newton-sec^2)/(cm-radian), (Newton-cm-sec^2)/radian^2
$C_{Fi}, C_{\phi Fi}$	=	rotor-to-casing whirl damping force and moment factor, respectively, dimensionless
$C_{\phi Mxi}$, $C_{\phi Myi}$	=	mount in-phase damping moment coefficients in xz- and yz-plane, respectively, (Newton-dm-sec)/radian
D_{Ai}	=	rotor axial loading time power coefficient, Newton/(sec)^{H_A}
D_{BiK}	=	nonlinear stiffness bearing journal displacement coefficient, 1/cm
D_{Ii}, D_{oi}	=	rotor section inside and outside diameter, respectively, cm
D_{Ui}	=	rotor drive torque time power coefficient, (Newton-cm)/(sec)$^{H_{Ti}}$
e_i	=	rotor mass eccentricity, cm
E_{Ai}	=	rotor axial loading sinussoidal function coefficient, Newtons
E_i	=	rotor Young's modulus of elasticity, Newtons/cm^2
E_{BiK}	=	nonlinear stiffness bearing constant, dimensionless
E_{Ti}	=	rotor drive torque sinusoidal function coefficient, Newton-cm
F_A	=	rotor axial loading sinusoidal function constant argument, radians
F_{Ti}	=	rotor drive torque sinusoidal function argument time coefficient, radians/sec
F_{xi}, F_{yi}	=	force loading on rotor along +x- and +y-axis, respectively, Newtons
g_x, g_y	=	gravitational or g-loading along -x- and -y-axis, respectively, cm/sec^2
G_i	=	rotor shear modulus of rigidity, Newton/cm^2
G_{Ti}	=	rotor drive torque sinusoidal function constant argument, radians
G_A	=	axial loading sinusoidal function constant argument, radians
H_A	=	rotor axial loading time power exponent, dimensionless
H_{BiK}	=	nonlinear stiffness bearing displacement exponent, dimensionless
HL,HR	=	subscripts pertaining to rotor hysteresis force or moment at left or right of a rotor station
HSC,HSV	=	subscripts pertaining to the shear Coulomb friction and viscous hysteresis force coefficient, respectively
HBC,HBV	=	subscripts pertaining to the bending Coulomb friction and viscous hysteresis moment coefficient, respectively
H_{Ti}	=	rotor drive torque time power exponent, dimensionless

i	=	subscript pertaining to ith rotor station or section as appropriate
I_i	=	rotor area moment of inertia, cm^2
I_{Bi}	=	bearing transverse mass moment of inertia, $kg\text{-}cm^2$
I_{Di}, I_{Pi}	=	equivalent discrete rotor transverse and polar mass moment of inertia, respectively, $kg\text{-}cm^2$
k	=	subscript pertaining to kth stiffness section for nonlinear stiffness bearing
K_{Bxxi} K_{Byyi}	=	in-phase anisotropic bearing stiffness force coefficients along x- and y-axis, respectively, Newton/cm
K_{Bxyi} K_{Byxi}	=	out-of-phase anisotropic bearing stiffness force along x- and y-axis due to displacements coefficients along y- and x-axis, respectively, Newtons/cm
$K_{B\phi xxi}$ $K_{B\phi yyi}$	=	in-phase anisotropic bearing stiffness moment coefficients in xz- and yz-plane, respectively, (Newton-cm)/radian
$K_{B\phi xyi}$ $K_{B\phi yxi}$	=	out-of-phase anisotropic bearing stiffness moment in xz- and yz-phase due to yz- and xz-plane rotations coefficients, respectively, (Newtons-cm)/radian
K_{BiK}	=	nonlinear stiffness bearing coefficient, Newton/cm
K_{Fi}	=	rotor-to-casing whirl stiffness force factor, dimensionless
$K_i, K_{\phi i}$	=	in-phase force and moment stiffness coefficient, respectively, Newton/cm, (Newton-cm)/radian
K_{HDi} $K_{\phi HDi}$	=	out-of-phase force and moment stiffness coefficient, respectively, (Newton-sec)/(cm-radian), (Newton-cm-sec)/radian^2
K_{Ii} $K_{\phi Mi}$	=	rotor-to-casing whirl stiffness force and moment factor, respectively, dimensionless
K_{Mxi} K_{Myi}	=	mount in-phase stiffness force coefficients along x- and y-axis, respectively, Newtons/cm
K_{Pi} $K_{\Phi Pi}$	=	out-of-phase force and moment stiffness coefficients, respectively, Newtons/cm
K_{Ti}	=	rotor sectional torsional stiffness, (Newton-cm)/radian
$K_{\phi Mxi}$ $K_{\phi Myi}$	=	mount in-phase stiffness moment coefficients in xz- and yz-plane, respectively, (Newton-cm)/radian

ℓ_i	=	rotor section length between stations i and i+1, cm
L	=	z-distance between first and last bearing stations, cm
M_i	=	equivalent discrete rotor mass, kg
M_{Bi}	=	bearing mass, kg
M_{xzi} M_{yzi}	=	moment rotor loading in x_iz_i and y_iz_i plane, respectively, Newton-cm
M'_{xzi} M'_{yzi}	=	rotor transverse elastic moment as defined in Fig. 5
M_{Ti}	=	rotor torsional drive torque spin-speed power exponent, dimensionless
M_{T1i}	=	rotor torsional drive torque spin-speed power coefficient, Newton-cm-$(\text{sec/radian})^{M_{Ti}}$
M_{T2i}	=	rotor torsional drive torque spin-speed coefficient, (Newton-cm-sec)/radian
N_{BiK}	=	nonlinear stiffness bearing spin-speed coefficient, (Newton-sec)/(cm-radian)
Q	=	z-coordinate of the last bearing station, cm
S	=	z-coordinate of the first bearing station, cm
S'_{xi}, S'_{yi}	=	rotor transverse elastic shear as defined in Fig. 5
T_{Fij}	=	rotor slope rotation (j)-force (i) influence coefficient, radian/Newton
T_{Mij}	=	rotor slope rotation (j)-moment (i) influence coefficient, radian/(Newton-cm)
X_i, Y_i, Z_i	=	a right-hand rotor system displacement coordinates with X_i and Y_i defined in Fig.
$\dot{X}_i, \dot{Y}_i, \dot{Z}_i$	=	first time derivations of X_i, Y_i, Z_i, cm/sec
$\ddot{X}_i, \ddot{Y}_i, \ddot{Z}_i$	=	second time derivatives of X_i, Y_i, Z_i, cm/sec^2
X_{B1}, Y_{B1}	=	bearing displacements at the first bearing station along x- and y-axis, respectively, cm
$\dot{X}_{Bi}, \dot{Y}_{Bi}$	=	journal x- and y-displacement with respect the bearing, respectively, cm
X_{Bi}, Y_{Bi}	=	first time derivatives of X_{Bi}, Y_{Bi}, respectively, cm/sec
X_{bNB} Y_{bNB}	=	bearing displacement at the last bearing station along x- and y-axis, respectively, cm

X_{Mi}, Y_{Mi}	=	mount displacements along x- and y-axis, respectively
$\dot{X}_M, \dot{Y}_{Mi}$	=	first time derivatives of x_{Mi} and Y_{Mi}, respectively, cm/sec
$\ddot{X}_M, \ddot{Y}_{Mi}$	=	second time derivatives of X_{Mi} and Y_{Mi}, respectively, cm/sec^2
Z_i	=	z-coordinate of rotor station i, cm

Greek Symbols

α_i	=	phase angle for e_i, radians
α_i'	=	shear deflection correction factor, dimensionless
β_i	=	rotor mass moments of inertia misalignment, radians
γ_i	=	rotor mass moments of inertia misalignment phase angle, radians
θ_{Bxzi}, θ_{Byzi}	=	journal slopes with respect to the bearing in xz- and yz-planes, respectively, radians
$\dot{\theta}_{Bxzi}$, $\dot{\theta}_{Byzi}$	=	first derivatives of θ_{Bxzi} and θ_{Byzi}, respectively, radians/sec
θ_{xzi}, θ_{yzi}	=	angular displacements of rotor elastic centerline in xz- and yz-plane, respectively, radians
$\dot{\theta}_{xzi}$, $\dot{\theta}_{yzi}$	=	first time derivatives of θ_{xzi}, θ_{yzi}, radians/sec
$\ddot{\theta}_{xzi}$, $\ddot{\theta}_{yzi}$	=	second time derivatives of θ_{xzi}, θ_{yzi}, radians/sec^2
μ_{BCi} μ_{BVi}	=	rotor transverse bending Coulomb friction and viscous hysteresis coefficient, respectively, (Newton-sec)/cm^2, Newtons/cm^2
μ_{SCi}, μ_{SVi}	=	rotor transverse shear Coulomb friction and viscous hysteresis coefficient, respectively, (Newton-sec)/cm^2, Newtons/cm^2
μ_{TCi}, μ_{TVi}	=	rotor torsional shear Coulomb friction and viscous hysteresis coefficient, respectively, Newtons/cm^2, (Newton-sec)/(radians-cm^2)
ρ_{BiK}	=	**nonlinear stiffness** bearing initial displacement, cm
$\phi_i, \dot{\phi}_i$ $\ddot{\phi}_i$	=	rotor spin angular displacement, velocity, and acceleration, respectively, radians, radians/sec, and radians/sec^2
$\dot{\phi}_{oi}$	=	nonlinear bearing speed sensitive coefficient, radians/sec
ω_{Fi}, ω_{Mi}	=	force and moment whirl velocity, respectively, radians/sec

APPENDIX E

COMPUTER PROGRAM LISTING

The rotor dynamics computer program listing, including the CDC system graphic plotting portions, is herewith attached. The graphic plotting portions in MAIN and in HYSMET, have not been checked out in accordance with contractual agreements.

Five sets of namelist data used in obtaining the final computer verification are also attached for reference.

```
C     THIS TRANSIENT SPEED FLEXIBLE ROTOR DYNAMICS ANALYSIS COMPUTER
C     PROGRAM EXCEPT THE THREE INTEGRATION SUBROUTINES (HYSRKA, RUNKUT,
C     AND ADAMLT), IS BASED ON THE THEORY DEVELOPED BY AND WRITTEN
C     BY FRED. A. SHEN OF ROCKETDYNE DIVISION OF ROCKWELL INTERNATIONAL
C     CORPORATION, CANOGA PARK, CALIFCRNIA,  APRIL 4, 1973.
      INTEGER       CONTIN,RIG,CT,CRT
      REAL INPRPM,   MT1,MT2,MCSQ,MOWHIR,MCRO,MOPHAS,MOFOR,MOFOPH
      DIMENSION TT(50),RPMM(50),WHRATI(50),FORC(50,6),BRGR(50,6),ROMAX(5
     &0),ROSTA(50),ISTATN(50),XXT(50),YYT(50)
      DIMENSION SP(6),WHIRR(15),WHSLOP(15),SLOP(15)
     &,                        PHAROS(15),BSLRO(6),BSPHAS(6),ROMM(6),
     &PHASMM(6),BGPHAS(6),YNNSAV(198)
      DIMENSION XBM(6),YBM(6),XBMOM(6),YBMOM(6),
     &XMOM(6),YMOM(6)
     &,XX(15),YY(15),RO(15)          ,PHARO(15),WHRVLO(15),WHRATO(15),
     &           XB(6),YB(6),XBDOT(6),YBDOT(6),BRGRO(6),XBFOR(6),
     &YBFOR(6),BRGFOR(6),BRFGPH(6),MORO(6),MOPHAS(6),MOFOR(6),MOFOPH(6),
     &MOWHIR(6),
     &XMFOR(6),YMFOR(6),REV(15),RPM(15),YNN(198)
      COMMON NS,NS2,NS3,NS4,NS5,NS6,NS7,NS8,NS9,NS10,NSM1,NSP1,NS2P1,
     &NS4P1,IP,IPRINT,
     &NN,NB,IB1,IBNB,NNT,ITIM,IUSE,CRT,CONTIN,NOORPM,IASIGN,NPOINT,
     &MOSHA,MET,IND,IPP,ITORQ,IMT,G
      COMMON PI, T,DT,TMAX,DP,      TOLI,GX,GY,Q,S,QLL,QMLOV,HA,FA,GA
      COMMON IB(6),KK(6),RIG(14),JBI(15),CT(15),MT(15)
     &,TITLE(18),F(15),FDOT(15),FDOFIX(6),DD(14),D(14),QL(14),P(14),
     &DN(14),EE(14),GG(14),EI(14),GAK(14),SHK(14),AM(15),AID(15),
     &AIRO(15),QM(15),QID(15),QIRO(15),ECC(15),ALFA(15),BETA(15),
     &GAMMA(15),QME(15),FOSTIF(6),Z(15),QZ(15),QK(15),QC(15),QKP(15),
     &QCP(15),QKHD(15),QCHD(15),QKF(15),QCF(15),QKPF(15),QCPF(15),
     &QKHDF(15),QCHDF(15),XKF(15),XCF(15),XKFF(15),XCFF(15),
     &QKXX(6),QKXY(6),QKYY(6),QKYX(6),QCXX(6),QCXY(6),QCYY(6),QCYX(6),
     &XXMK(6),XYMK(6),YYMK(6),YXMK(6),XXMC(6),XYMC(6),YYMC(6),YXMC(6),
     &BI(6),XKMM(6),YKMM(6),XCMM(6),YCMM(6),
     &BKMX(6),BKMY(6),BCMX(6),BCMY(6),BM(6),USV(14),USC(14),
     &UBV(14),UBC(14),UTV(14),UTC(14),CT1(15),CT2(15),CTV(14),CTC(14),
     &MT1(15),MT2(15),AT(15),BT(15),DU(15),HT(15),ET(15),FT(15),GT(15),
     &AA(15),BA(15),DA(15),EA(15),YN(84),INPRPM(50),C(15,15),B(15,15),
     &TF(15,15),TM(15,15),BBB(6,3),BDB(6,3),BEB(6,3),
     &BCB(6,3),BHB(6,3),BKB(6,3),BNB(6,3),BROB(6,4)
404   FORMAT(1PE21.4,1P4E13.4)
      KB=0
100   CALL HYSREA(YNN)
```

```
      IR=0
      TSA=T
      F1=F(1)
      FDOT1=FDOT(1)
      IF(CONTIN.EQ.0) GO TO 12
      DO 11 I=1,NN
   11 YNNSAV(I)=YNN(I)
   12 KB=KB+10000
      KA=KB+1
      DDA=DP-DT
      A=180./PI
      H=A/6.
      V=.5/PI
      CALL HYSWRI
      IF(MET.EQ.0) GO TO 47
      CALL HYSWME
 47   ITIM=1
      NNT=0
      IUSE=1
      IC=0
      II=1
      IP=0
      CALL HYSINF
      CALL HYSSTA
      IF(CONTIN.EQ.0) GO TO 5
      IF(CONTIN.EQ.1) GO TO 6
    7 IF(IR.GE.6) STOP
      ITIM=1
      T=TSA
      F(1)=F1
      FDOT(1)=FDOT1
      IUSE=1
      IC=0
      II=1
      IP=0
      DT=0.25*DT
      IF(CONTIN.EQ.1) GO TO 6
    5 DO 911 I=1,NB
      M=IB(I)
      MNS=M+NS
```

```
      M2NS=M+NS2
      M3NS=M+NS3
      I4NS=I+NS4
      I4NSNB=I4NS+NB
      I4NS2B=I4NSNB+NB
      I4NS3B=I4NS2B+NB
      I10S=I+NS10
      I10SB=I10S+NB
      I10S2B=I10SB+NB
      I10S3B=I10S2B+NB
      I10S4B=I10S3B+NB
      I10S5B=I10S4B+NB
      I10S6B=I10S5B+NB
      I10S7B=I10S6B+NB
      YNN(I10S)=YN(M)-YN(I4NS)
      YNN(I10SB)=YN(MNS)-YN(I4NSNB)
      YNN(I10S2B)=YN(M2NS)-YN(I4NS2B)
      YNN(I10S3B)=YN(M3NS)-YN(I4NS3B)
      YNN(I10S4B)=-FDOT(1)*YNN(I10SB)
      YNN(I10S5B)= FDOT(1)*YNN(I10S)
      YNN(I10S6B)=-FDOT(1)*YNN(I10S3B)
911   YNN(I10S7B)=FDOT(1)*YNN(I10S2B)
      DO 95 I=1,NS4
95    YNN(I)=YN(I)
      DO 99  I=1,NS
      INS=I+NS
      I2NS=INS+NS
      I3NS=I2NS+NS
      I4NS=I3NS+NS
      I5NS=I4NS+NS
      I6NS=I5NS+NS
      I7NS=I6NS+NS
      I8NS=I+NS8
      I9NS=I+NS9
      YNN(I4NS)=-FDOT(1)*YN(INS)
      YNN(I5NS)=FDOT(1)*YN(I)
      YNN(I6NS)=-FDOT(1)*YN(I3NS)
      YNN(I7NS)=FDOT(1)*YN(I2NS)
      YNN(I8NS)=F(1)
99    YNN(I9NS)=FDOT(1)
      GO TO 109
    6 DO 10 I=1,NN
```

```
   10 YNN(I)=YNNSAV(I)
109    IS=0
       TSAVE=T
107    CALL HYSRKA(NN,T,YNN,DT,IND,ITIM,TOLI,IERR)
       IF(IERR.EQ.0) GO TO 34
       WRITE(6,301)
301    FORMAT(' THE SOLUTION IS INVALID DUE TO INPUT ERROR AND ',
      &'THE RUN'/' IS DISCONTINUED, PLEASE VERIFY THE INPUT AND RERUN',
      &' THE PROGRAM.')
       STOP
34     IUSE=1
       IS=IS+1
       ITIM=0
       IF(T.LT.DDA) GO TO 107
       IF(T.LT.TMAX) GO TO 105
805    FORMAT(1P2E12.5,48X,I8)
806    FORMAT(1P6E12.5,I8)
       PUNCH 805, T,DT,KA
       DO 803 I=1,NN,6
       KA=KA+1
       DO 801 J=1,6
801    SP(J)=YNN(I+J-1)
803    PUNCH 806, SP,KA
105    DTAVE=(T-TSAVE)/IS
       DDA=DDA+DP
       GO TO 77
79     WRITE(6,302)
  302 FORMAT(///
      &       ' AT LEAST ONE OF THE JOURNAL DISPLACEMENTS HAS EXCEEDED TH
      &E ALLOWABLE BEARING CLEARANCE,'/' HENCE THE COMPUTATION WAS INTERR
      &UPTED.'/' THE COMPUTATION IS RESTARTED FROM THE BEGINNING BY USING
      & A SMALLER INTEGRATION TIME STEP(DT) EQUAL TO'/' 1/4 OF THE PREVIO
      &US TIME STEP.  A MAXIMUM OF 5 RESTARTS IS ALLOWED.  AT THE END OF
      &UNSUCCESSFUL 5TH RESTART'/' COMPUTATION WILL BE DISCONTINUED.')
       IR=IR+1
       GO TO 7
77     DO 32 I=1,NS
       INS=I+NS
       I2NS=I+NS2
       I3NS=I+NS3
       I4NS=I+NS4
       I5NS=I+NS5
```

```
      I6NS=I+NS6
      I7NS=I+NS7
      ROSQ=YNN(I)**2+YNN(INS)**2
      RO(I)=SQRT(ROSQ)
      XX(I)=YNN(I)
      YY(I)=YNN(INS)
      IF(YY(I).EQ.0) YY(I)=1.E-20
      IF(XX(I).EQ.0) XX(I)=1.E-20
      PHARO(I)=ATAN2(YY(I),XX(I))*A
      IF(PHARO(I).LT.0) PHARO(I)=360.+PHARO(I)
      WHRVLO(I)=(YNN(I5NS)*YNN(I)-YNN(I4NS)*YNN(INS))/ROSQ
      SLOPSQ=YNN(I2NS)**2+YNN(I3NS)**2
      WHSLOP(I)=(YNN(I7NS)*YNN(I2NS)-YNN(I6NS)*YNN(I3NS))/SLOPSQ*H
      SLOP(I)=SQRT(SLOPSQ)
      IF(YNN(I2NS).EQ.0) YNN(I2NS)=1.E-20
      IF(YNN(I3NS).EQ.0) YNN(I3NS)=1.E-20
      PHAROS(I)=ATAN2(YNN(I3NS),YNN(I2NS))*A
   32 IF(PHAROS(I).LT.0) PHAROS(I)=360.+PHAROS(I)
      DO 224 I=1,NB
      I10S=I+NS10
      I10SB=I10S+NB
      I10S2B=I10SB+NB
      I10S3B=I10S2B+NB
      I10S4B=I10S3B+NB
      I10S5B=I10S4B+NB
      I10S6B=I10S5B+NB
      I10S7B=I10S6B+NB
      J=IB(I)
      JNS=J+NS
      J2NS=J+NS2
      J3NS=J+NS3
      J4NS=J+NS4
      J5NS=J+NS5
      J6NS=J+NS6
      J7NS=J+NS7
      J9NS=J+NS9
      XB(I)=YNN(J)-YNN(I10S)
      YB(I)=YNN(JNS)-YNN(I10SB)
      ACA=SQRT(XB(I)**2+YB(I)**2)
      K4=KK(I)
      DO 3 K=1,K4
      K1=K+1
```

```
      IF(ACA.LE.BROB(I,K1)) GO TO 4                                     01004220
      IF(K.GE.K4) GO TO 79                                              01004240
    3 CONTINUE                                                          01004260
    4 XBDOT(I)= YNN(J4NS)-YNN(I10S2B)                                   01004280
      YBDOT(I)= YNN(J5NS)-YNN(I10S3B)                                   01004300
      IF(XB(I).EQ.0) XB(I)=1.E-20                                       01004320
      IF(YB(I).EQ.0) YB(I)=1.E-20                                       01004340
      BRGRO(I)=SQRT(XB(I)**2+YB(I)**2)                                  01004360
      BGPHAS(I)=ATAN2(YB(I),XB(I))*A                                    01004380
      IF(BGPHAS(I).LT.0) BGPHAS(I)=360.+BGPHAS(I)                       01004400
      XBFOR(I)=FOSTIF(I)*XB(I)                                          01004420
     &+QKXX(I)*XB(I)+QKXY(I)*YB(I)+QCXX(I)*XBDOT(I)+QCXY(I)*YBDOT(I)    01004440
      YBFOR(I)=FOSTIF(I)*YB(I)                                          01004460
     &+QKYY(I)*YB(I)-QKYX(I)*XB(I)+QCYY(I)*YBDOT(I)-QCYX(I)*XBDOT(I)    01004480
      IF(XBFOR(I).EQ.0) XBFOR(I)=1.E-20                                 01004500
      IF(YBFOR(I).EQ.0) YBFOR(I)=1.E-20                                 01004520
      BRGFOR(I)=SQRT(XBFOR(I)**2+YBFOR(I)**2)                           01004540
      BRFOPH(I)=ATAN2(YBFOR(I),XBFOR(I))*A                              01004560
      IF(BRFOPH(I).LT.0) BRFOPH(I)=BRFOPH(I)+360.                       01004580
      MOSQ=YNN(I10S)**2+YNN(I10SB)**2                                   01004600
      MOWHIR(I)=(YNN(I10S5B)*YNN(I10S)-YNN(I10S4B)*YNN(I10SB))/MOSQ     01004620
      MOWHIR(I)=MOWHIR(I)/YNN(J9NS)                                     01004640
      MORO(I)=SQRT(MOSQ)                                                01004660
      IF(YNN(I10S).EQ.0) YNN(I10S)=1.E-20                               01004680
      IF(YNN(I10SB).EQ.0) YNN(I10SB)=1.E-20                             01004700
      MOPHAS(I)=ATAN2(YNN(I10SB),YNN(I10S))*A                           01004720
      IF(MOPHAS(I).LT.0) MOPHAS(I)=MOPHAS(I)+360.                       01004740
      XBM(I)=YNN(J2NS)-YNN(I10S2B)                                      01004760
      YBM(I)=YNN(J3NS)-YNN(I10S3B)                                      01004780
      IF(1.NE.2) GO TO 2                                                01004800
C     THE LOAD COMPUTATIONS SKIPPED BY "GO TO 2" ARE NOT NEEDED IN WRITE01004820
C     -OUT, HOWEVER THEY ARE RETAINED FOR POSSIBLE FUTURE USE.          01004840
      XMFOR(I)=BKMX(I)*YNN(I10S)+BCMX(I)*YNN(I10S4B)                    01004860
      YMFOR(I)=BKMY(I)*YNN(I10SB)+BCMY(I)*YNN(I10S5B)                   01004880
      IF(XMFOR(I).EQ.0) XMFOR(I)=1.E-20                                 01004900
      IF(YMFOR(I).EQ.0) YMFOR(I)=1.E-20                                 01004920
      MOFOR(I)=SQRT(XMFOR(I)**2+YMFOR(I)**2)                            01004940
      MOFOPH(I)=ATAN2(YMFOR(I),XMFOR(I))*A                              01004960
      IF(MOFOPH(I).LT.0) MOFOPH(I)=MOFOPH(I)+360.                       01004980
      XBMDOT=YNN(J6NS)-YNN(I10S6B)                                      01005000
      YBMDOT=YNN(J7NS)-YNN(I10S7B)                                      01005020
      XBMOM(I)=XXMK(I)*XBM(I)+XYMK(I)*YBM(I)+XXMC(I)*XBMDOT+XYMC(I)     01005040
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```
     &*YBMDOT                                                              01005060
      YBMOM(I)=YYMK(I)*YBM(I)-YXMK(I)*XBM(I)+YYMC(I)*YBMDOT-YXMC(I)        01005080
     &*XBMDOT                                                              01005100
      XMOM(I)=XKMM(I)*YNN(I10S2B)+XCMM(I)*YNN(I10S6B)                      01005120
      YMOM(I)=YKMM(I)*YNN(I10S3B)+YCMM(I)*YNN(I10S7B)                      01005140
    2 IF(XBM(I).EQ.0) XBM(I)=1.E-20                                        01005160
      IF(YBM(I).EQ.0) YBM(I)=1.E-20                                        01005180
      BSLRO(I)=SQRT(XBM(I)**2+YBM(I)**2)                                   01005200
      BSPHAS(I)=ATAN2(YBM(I),XBM(I))*A                                     01005220
      IF(BSPHAS(I).LT.0) BSPHAS(I)=360.+BSPHAS(I)                          01005240
      IF(YNN(I10S2B).EQ.0) YNN(I10S2B)=1.E-20                              01005260
      IF(YNN(I10S3B).EQ.0) YNN(I10S3B)=1.E-20                              01005280
      ROMM(I)=SQRT(YNN(I10S2B)**2+YNN(I10S3B)**2)                          01005300
      PHASMM(I)=ATAN2(YNN(I10S3B),YNN(I10S2B))*A                           01005320
224   IF(PHASMM(I).LT.0) PHASMM(I)=360.+PHASMM(I)                          01005340
      DO 225 I=1,NS                                                        01005360
      I8NS=I+NS8                                                           01005380
      I9NS=I+NS9                                                           01005400
      REV(I)=YNN(I8NS)*V                                                   01005420
      WHIRR(I)=WHRVLO(I)*H                                                 01005440
      RPM(I)=YNN(I9NS)*H                                                   01005460
225   WHRATO(I)=WHRVLO(I)/YNN(I9NS)                                        01005480
      IP=IP+1                                                              01005500
      IF(IP.LT.IPRINT) GO TO 165                                           01005520
      WRITE(6,9)                                                           01005540
    9 FORMAT(1H1///)                                                       01005560
      WRITE(6,23) DTAVE                                                    01005580
23    FORMAT(' THE AVERAGE REAL STEP-TIME FOR THIS PRINTOUT ='1PE12.4,     01005600
     &' SEC')                                                              01005620
      WRITE(6,51) T                                                        01005640
51    FORMAT(' REAL TIME ='1PE12.4,' SEC')                                 01005660
  165 IF(MET.EQ.0) GO TO 161                                               01005680
      CALL HYSMET(YNN,IC,II)                                               01005700
      GO TO 162                                                            01005720
  161 IF(IP.LT.IPRINT)GO TO 164                                            01005740
      IP=0                                                                 01005760
      WRITE(6,304)                                                         01005780
304   FORMAT('      ROTOR SPIN REVOLUTION ARRAY')                          01005800
      WRITE(6,404) (REV(I),I=1,NS)                                         01005820
      WRITE(6,305)                                                         01005840
305   FORMAT('      ROTOR DISPLACEMENT ARRAY, IN')                         01005860
      WRITE(6,404) (RO(I),I=1,NS)                                          01005880
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      WRITE(6,386)                                                    01005900
386   FORMAT('    ROTOR DISPLACEMENT PHASE ANGLE ARRAY, DEGREES')     01005920
      WRITE(6,404) (PHARO(I),I=1,NS)                                  01005940
      WRITE(6,306)                                                    01005960
306   FORMAT('    ROTOR SLOPE ARRAY, RADIANS')                        01005980
      WRITE(6,404) (SLOP(I),I=1,NS)                                   01006000
      WRITE(6,307)                                                    01006020
307   FORMAT('    ROTOR SLOPE PHASE ANGLE ARRAY, DEGREES')            01006040
      WRITE(6,404) (PHAROS(I),I=1,NS)                                 01006060
      WRITE(6,308)                                                    01006080
308   FORMAT('    ROTOR SPIN SPEED ARRAY, RPM')                       01006100
      WRITE(6,404) (RPM(I),I=1,NS)                                    01006120
      WRITE(6,309)                                                    01006140
309   FORMAT('    ROTOR DISPLACEMENT WHIRL FREQUENCY ARRAY, RPM')     01006160
      WRITE(6,404) (WHIRR(I),I=1,NS)                                  01006180
      WRITE(6,310)                                                    01006200
310   FORMAT('    ROTOR SLOPE WHIRL FREQUENCY ARRAY, RPM')            01006220
      WRITE(6,404) (WHSLOP(I),I=1,NS)                                 01006240
      WRITE(6,311)                                                    01006260
311   FORMAT('    BEARING DISPLACEMENT ARRAY, IN')                    01006280
      WRITE(6,404) (BRGRO(I),I=1,NB)                                  01006300
      WRITE(6,312)                                                    01006320
312   FORMAT('    BEARING DISPLACEMENT PHASE ANGLE ARRAY, DEGREES')   01006340
      WRITE(6,404) (BGPHAS(I),I=1,NB)                                 01006360
      WRITE(6,313)                                                    01006380
313   FORMAT('    MOUNT DISPLACEMENT ARRAY, IN')                      01006400
      WRITE(6,404) (MORO(I),I=1,NB)                                   01006420
      WRITE(6,314)                                                    01006440
314   FORMAT('    MOUNT DISPLACEMENT PHASE ANGLE ARRAY, DEGREES')     01006460
      WRITE(6,404) (MOPHAS(I),I=1,NB)                                 01006480
      WRITE(6,315)                                                    01006500
315   FORMAT('    BEARING MASS WHIRL/ROTOR SPIN FREQUENCY RATIO ARRAY')01006520
      WRITE(6,404) (MOWHIR(I),I=1,NB)                                 01006540
      WRITE(6,316)                                                    01006560
316   FORMAT('    BEARING SLOPE ARRAY, RADIANS')                      01006580
      WRITE(6,404) (BSLRO(I),I=1,NB)                                  01006600
      WRITE(6,317)                                                    01006620
317   FORMAT('    BEARING SLOPE PHASE ANGLE ARRAY, DEGREES')          01006640
      WRITE(6,404) (BSPHAS(I),I=1,NB)                                 01006660
      WRITE(6,388)                                                    01006680
388   FORMAT('    MOUNT SLOPE ARRAY, RADIANS')                        01006700
318   FORMAT('    MOUNT SLOPE ARRAY, RADIANS')                        01006720
```

```
      WRITE(6,404) (ROMM(I),I=1,NB)
      WRITE(6,319)
319   FORMAT('      MOUNT SLOPE PHASE ANGLE ARRAY, DEGREES')
      WRITE(6,404) (PHASMM(I),I=1,NB)
  164 IF(CRT.EQ.0) GO TO 162
      IC=1+IC
      TT(IC)=T
      RPMM(IC)=RPM(IASIGN)
      WHRATI(IC)=WHIRR(IASIGN)/RPM(IASIGN)
      XXT(IC)=XX(IASIGN)
      YYT(IC)=YY(IASIGN)
      DO 500 I=1,NB
      FORC(IC,I)=BRGFOR(I)
  500 BRGR(IC,I)=BRGRO(I)
      J=1
      DO 510 I=1,NS
      IF(RO(J).LT.RO(I))J=I
  510 CONTINUE
      ROMAX(IC)=RO(J)
      ISTATN(IC)=J
      ROSTA(IC)=RO(IASIGN)
      IF(MOSHA.EQ.0)GOTO163
      IF(II.GT.NOORPM)GOTO163
      II=1+II
      IF(RPM(IASIGN).LT.INPRPM(II))GOTO163
C     PLOT 1
      REAL CHAR11(21),CHAR21(7),CHAR31(8),CHARSS(4),SYMBOL/'*'/
      DATA CHAR11/'ROTOR 3-DIMENSIONAL MODE SHAPE WITH PHASE ANGLES (DEG
     1REES) LABELED AS SHOWN, AT RPM='/,CHAR21/'ROTOR AXIAL LENGTH,  INC
     2HES '/,CHAR31/'ROTOR DEFLECTION VECTOR, INCHES '/
      CALL LRLEGN(TITLE,72,0,1.15,9.99,0.)
      CALL LRLEGN(CHAR11,84,0,1.463,9.67,0.)
      CALL LRCNVT(RPMM(IC),3,CHARSS,4,13,5)
      CALL LRLEGN(CHARSS,13,0,8.6,9.67,0.)
      CALL LRLEGN(CHAR21,27,0,4.31,0.,0.)
      CALL LRCURV(Z,RO,NS,2,SYMBOL,0.)
      DO 1005 I=1,NS
      CALL LRCNVT(PHARO(I),3,CHARSS,3,4,0)
      CALL LRLABL(CHARSS,4,0,Z(I),RO(I),0.)
 1005 CONTINUE
      CALL LRLEGN(CHAR31,31,1,0.,4.6,1.)
  163 IF(T.GE.TMAX) GO TO 1040
```

```
      IF(IC.LT.NPOINT) GO TO 162
 1040 NPOINT =IC
      IC=0
C     PLOT 2
      CALL LRLEGN(TITLE,72,0,1.15,9.99,0.)
      REAL CHAR12(7)/'ROTOR SPIN SPEED VERSUS TIME'/,CHAR22(4)/'TIME, SE
     1CONDS   '/,CHAR32(6)/'ROTOR SPIN SPEED, RPM   '/
      CALL LRCURV(TT,RPM,NPOINT,2,SYMBOL,0.)
      CALL LRCURV(TT,RPM,NPOINT,3,SYMBOL,0.)
      CALL LRLEGN(CHAR12,28,0,3.50,9.67,0.)
      CALL LRLEGN(CHAR22,13,0,4.86,0.,0.)
      CALL LRLEGN(CHAR32,21,1,0.,4.95,1.)
C     PLOT 3
      CALL LRLEGN(TITLE,72,0,1.15,9.99,0.)
      REAL CHAR13(19)/'ROTOR WHIRL-TO-SPIN FREQUENCY RATIO VERSUS ROTOR
     1SPIN SPEED AT ROTOR STATION'/
      CALL LRCURV(RPM,WHRATI,NPOINT,2,SYMBOL,0.)
      CALL LRCURV(RPM,WHRATI,NPOINT,3,SYMBOL,0.)
      CALL LRCNVT(IASIGN,1,CHARSS,1,3,0)
      CALL LRLEGN(CHARSS,3,0,7.85,9.67,0.)
      CALL LRLEGN(CHAR13,76,0,1.795,9.67,0.)
      CALL LRLEGN(CHAR13,35,1,0.,3.47,0.)
      CALL LRLEGN(CHAR32,21,0,4.55,0.,1.)
C     PLOT 4
C     PLOT RPM VS FORC FUNCTIONS
      CALL PLOTBR(FORC)
      CALL LRLEGN(TITLE,72,0,1.15,9.99,0.)
      REAL CHAR14(24)/'BEARING REACTIONS VERSUS ROTOR SPIN SPEED WITH BE
     1ARING LOCATION STATION NUMBERS LABELED AS SHOWN'/,CHAR24(7)/'BEARI
     2NG REACTIONS, POUNDS   '/
      CALL LRLEGN(CHAR14,96,0,1.385,9.67,0.)
      CALL LRLEGN(CHAR32,21,0,4.55,0.,0.)
      CALL LRLEGN(CHAR24,25,1,0.,4.37,1.)
C     PLOT 5
C     PLOT RPM VS BRGR FUNCTIONS
      CALL PLOTBR(BRGR)
      CALL LRLEGN(TITLE,72,0,1.15,9.99,0.)
      REAL CHAR15(25)/'JOURNAL DISPLACEMENT VERSUS ROTOR SPIN SPEED WITH
     1 BEARING LOCATION STATION NUMBERS LABELED AS SHOWN '/,CHAR25(8)/
     2'JOURNAL DISPLACEMENTS, INCHES   '/
      CALL LRLEGN(CHAR15,99,0,1.21,9.67,0.)
      CALL LRLEGN(CHAR32,21,0,4.55,0.,0.)
```

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      CALL LRLEGN(CHAR25,29,1,0.,4.52,1.)                              01008400
C     PLOT 6                                                           01008420
      CALL LRANGE(0.,0.,0.,0.)                                         01008440
      REAL CHAR16(13)/'MAXIMUM ROTOR DEFLECTIONS VERSUS ROTOR SPIN SPEED01008460
     1    '/,CHAR26(22)/'(THE STATION NUMBERS WHERE THE MAXIMUM DEFLECTIO01008480
     2NS OCCUR ARE SHOWN) '/,CHAR36(9)/'MAXIMUM ROTOR DEFLECTIONS, INCHE01008500
     3S    '/                                                          01008520
      CALL LRCURV(RPM,ROMAX,NPOINT,2,SYMBOL,0.)                        01008540
      DO 1006 I=1,NPOINT                                               01008560
      CALL LRCNVT(ISTATN(I),1,CHARSS,1,3,0)                            01008580
 1006 CALL LRLABL(CHARSS,3,0,RPM(I),ROMAX(I),0.)                       01008600
      CALL LRLEGN(TITLE,72,0,1.15,9.99,0.)                             01008620
      CALL LRLEGN(CHAR16,49,0,3.45,9.756,0.)                           01008640
      CALL LRLEGN(CHAR26,67,0,2.75,9.639,0.)                           01008660
      CALL LRLEGN(CHAR32,21,0,4.55,0.,0.)                              01008680
      CALL LRLEGN(CHAR36,33,1,0.,4.52,1.)                              01008700
C     PLOT 7                                                           01008720
      REAL CHAR17(17)/'(THE STATION NUMBER WHERE THE ROTOR DEFLECTIONS O01008740
     1CCUR IS SHOWN)'/                                                 01008760
      CALL LRCURV(RPM,ROSTA,NPOINT,2,SYMBOL,0.)                        01008780
      DO 1007 I=1,NPOINT                                               01008800
      CALL LRCNVT(IASIGN,1,CHARSS,1,3,0)                               01008820
 1007 CALL LRLABL(CHARSS,3,0,RPM(I),ROSTA(I),0.)                       01008840
      CALL LRLEGN(TITLE,72,0,1.15,9.99,0.)                             01008860
      CALL LRLEGN(CHAR16(3),41,0,3.45,9.756,0.)                        01008880
      CALL LRLEGN(CHAR17,63,0,2.75,9.639,0.)                           01008900
      CALL LRLEGN(CHAR32,21,0,4.55,0.,0.)                              01008920
      CALL LRLEGN(CHAR36(3),25,1,0.,4.25,1.)                           01008940
C     PLOT 8                                                           01008960
      REAL CHAR18( 8)/'ROTOR ORBIT X-Y PLOT AT STATION '/,             01008980
     1CHAR28( 4)/'X-AXIS INCHES   '/,                                  01009000
     2CHAR38( 4)/'Y-AXIS INCHES   '/                                   01009020
 2000 CALL LRLEGN(TITLE,72,0,1.15,9.99,0.)                             01009040
      CALL LRLEGN(CHAR18,32,0,3.45,9.67,0.)                            01009060
      CALL LRCNVT(IASIGN,1,CHARSS,1,2,0)                               01009080
      CALL LRLEGN(CHARSS,2,0,9.25,9.67 ,0.)                            01009100
      CALL LRLEGN(CHAR28,16,0,4.31,0.,0.)                              01009120
      CALL LRLEGN(CHAR38,16,1,0.,5.,0.)                                01009140
      XMIN=1E70                                                        01009160
      YMIN=1E70                                                        01009180
      XMAX=-1E70                                                       01009200
      YMAX=-1E70                                                       01009220
```

```
      DO 2010 I=1,NPOINT
      XMIN=AMIN1(XMIN,XXT(I))
      YMIN=AMIN1(YMIN,YYT(I))
      XMAX=AMAX1(XMAX,XXT(I))
 2010 YMAX=AMAX1(YMAX,YYT(I))
      CALL LRANGE(XMIN,XMAX,YMIN,YMAX)
      CALL LRCURVE(XX,YY,NPOINT,2,SYMBOL,1.)
  162 IF(T.GE.TMAX) GO TO 100
      GO TO 109
      END
      SUBROUTINE HYSREA(YNN)
      INTEGER        CONTIN,RIG,CT,CRT
      REAL INPRPM,    MT1,MT2
      DIMENSION YNN(198)
      COMMON NS,NS2,NS3,NS4,NS5,NS6,NS7,NS8,NS9,NS10,NSM1,NSP1,NS2P1,
     &NS4P1,IP,IPRINT,
     &NN,NB,IB1,IBNB,NNT,ITIM,IUSE,CRT,CONTIN,NOORPM,IASIGN,NPOINT,
     &MOSHA,MET,IND,IPP,ITORQ,IMT,G
      COMMON PI, T,DT,TMAX,DP,      TOLI,GX,GY,Q,S,QLL,QMLOV,HA,FA,GA
      COMMON IB(6),KK(6),RIG(14),JBI(15),CT(15),MT(15)
      COMMON TITLE(18),F(15),FDOT(15),FDOFIX(6),DD(14),D(14),QL(14),
     &P(14),
     &DN(14),EE(14),GG(14),EI(14),GAK(14),SHK(14),AM(15),AID(15),
     &AIRO(15),QM(15),
     &QID(15),QIRO(15),ECC(15),ALFA(15),BETA(15),GAMMA(15),QME(15),
     &FOSTIF(6),Z(15),QZ(15),QK(15),QC(15),QKP(15),QCP(15),QKHD(15),
     &QCHD(15),QKF(15),QCF(15),QKPF(15),QCPF(15),QKHDF(15),QCHDF(15),
     &XKF(15),XCF(15),XKFF(15),XCFF(15),
     &QKXX(6),QKXY(6),QKYY(6),QKYX(6),QCXX(6),QCXY(6),QCYY(6),QCYX(6),
     &XXMK(6),XYMK(6),YYMK(6),YXMK(6),XXMC(6),XYMC(6),YYMC(6),YXMC(6),
     &BI(6),XKMM(6),YKMM(6),XCMM(6),YCMM(6),
     &BKMX(6),BKMY(6),BCMX(6),BCMY(6),BM(6),USV(14),USC(14),
     &UBV(14),UBC(14),UTV(14),UTC(14),CT1(15),CT2(15),CTV(14),CTC(14),
     &MT1(15),MT2(15),AT(15),BT(15),DU(15),HT(15),ET(15),FT(15),GT(15),
     &AA(15),BA(15),DA(15),EA(15),YN(84),INPRPM(50),C(15,15),B(15,15),
     &TF(15,15),TM(15,15),BBB(6,3),BDB(6,3),BEB(6,3),
     &BCB(6,3),BHB(6,3),BKB(6,3),BNB(6,3),BROB(6,4)
      NAMELIST/MUST/DT,TMAX,DP,NS,NB,FDOT1,IB,DD,QL,MET,        ID
      NAMELIST/OPTION/    IND,TOLI,T,CONTIN,ITORQ,IPP,IMT,RIG,CRT,MOSHA,
     &NPOINT,NOORPM,IASIGN,INPRPM,D,DN,P,EE,GG,EI,GAK,AM,ECC,AID,AIRO,BE
     &TA,GAMMA,BKMX,BKMY,BCMX,BCMY,XKMM,YKMM,XCMM,YCMM,BM,BI,QKXX,QKXY,Q
     &KYY,QKYX,QCXX,QCXY,QCYY,QCYX,XXMK,XYMK,YYMK,YXMK,XXMC,XYMC,YYMC,YX
```

```
     &MC,KK,FDOFIX,BBB,BDB,BEB,BHB,BKB,BNB,BROB, QK,QC,QKP,QCP, QKF,QCF,02000640
     &QKPF,QCPF, XKF,XCF,XKFF,XCFF, QKHD,QCHD,QKHDF,QCHDF,  CT1,CT,CT2, 02000660
     &MT,MT1,MT2,AT,BT,DU,ET,HT,FT,GT, AA,BA,DA,EA,HA,FA,GA,  GX,GY,    02000680
     &USV,USC,UBV,UBC,UTV,UTC,F1,ALFA,BCB,IPRINT,              ID       02000700
  200 FORMAT(18A4)                                                      02000720
 404  FORMAT(6E12.8)                                                    02000740
      PI=3.14159265358979324                                            02000760
      G=386.088                                                         02000780
      MET=1                                                             02000800
      IND=1                                                             02000820
      TOLI=.0001                                                        02000840
      T=0                                                               02000860
      CONTIN=0                                                          02000880
      F1=1.E-20                                                         02000900
      CRT=0                                                             02000920
      MOSHA=1                                                           02000940
      NPOINT=25                                                         02000960
      NOORPM=1                                                          02000980
      IASIGN=1                                                          02001000
      INPRPM(1)=0                                                       02001020
      IPRINT=1                                                          02001040
      READ(5,200,END=100)TITLE                                          02001060
      READ(5,MUST)                                                      02001080
      FDOT(1)=FDOT1                                                     02001100
      NS2=NS*2                                                          02001120
      NS3=NS*3                                                          02001140
      NS4=NS*4                                                          02001160
      NS5=NS*5                                                          02001180
      NS6=NS*6                                                          02001200
      NS7=NS*7                                                          02001220
      NS8=NS*8                                                          02001240
      NS9=NS*9                                                          02001260
      NS10=NS*10                                                        02001280
      NB4=NB*4                                                          02001300
      NN=NS10+NB4                                                       02001320
      NSM1=NS-1                                                         02001340
      NSP1=NS+1                                                         02001360
      NS2P1=NS2+1                                                       02001380
      NS4P1=NS4+1                                                       02001400
      NN=NS10+NB*8                                                      02001420
      DO 1 I=1,NB                                                       02001440
 1    KK(I)=1                                                           02001460
```

```
      IB1=IB(1)
      IBNB=IB(NB)
      DO 789 J=1,NS
789   JBI(J)=0
      DO 790 I=1,NB
      K=IB(I)
      JBI(K)=I
      FDOFIX(I)=0
      BM(I)=0
      BI(I)=0
      BBB(I,1)=0
      BCB(I,1)=0
      BDB(I,1)=0
      BEB(I,1)=0
      BHB(I,1)=1.
      BKB(I,1)=0
      BNB(I,1)=0
      BROB(I,1)=0
      BROB(I,2)=.005
      BKMX(I)=2.E6
      BKMY(I)=2.E6
      IF(MET.EQ.1) BROB(I,2)=.0127
      IF(MET.EQ.1) BKMX(I)=3.5025E6
      IF(MET.EQ.1) BKMY(I)=3.5025E6
      BCMX(I)=0
      BCMY(I)=0
      XKMM(I)=2.E6
      YKMM(I)=2.E6
      IF(MET.EQ.1) XKMM(I)=22.59697E6
      IF(MET.EQ.1) YKMM(I)=22.59697E6
      XCMM(I)=0
      YCMM(I)=0
      QKXX(I)=1.E6
      IF(MET.EQ.1) QKXX(I)=1.7513E6
      QKXY(I)=0
      QKYY(I)=1.E6
      IF(MET.EQ.1) QKYY(I)=1.7513E6
      QKYX(I)=0
      QCXX(I)=0
      QCXY(I)=0
      QCYY(I)=0
      QCYX(I)=0
```

```
      XXMK(I)=1.E6
      IF(MET.EQ.1) XXMK(I)=11.29848E6
      XYMK(I)=0
      YYMK(I)=1.E6
      IF(MET.EQ.1) YYMK(I)=11.29848E6
      YXMK(I)=0
      XXMC(I)=0
      XYMC(I)=0
      YYMC(I)=0
      YXMC(I)=0
790   CONTINUE
      DO 22 I=1,NSM1
      RIG(I)=0
      D(I)=0
      DN(I)=.3
      EE(I)=3.E7
      GG(I)=1.15E7
      IF(MET.EQ.1) DN(I)=.008304
      IF(MET.EQ.1) EE(I)=2.0684E7
      IF(MET.EQ.1) GG(I)=.7929E7
      P(I)=.3
      EI(I)=0
      GAK(I)=0
      USV(I)=0
      USC(I)=0
      UBV(I)=0
      UBC(I)=0
      UTV(I)=0
      UTC(I)=0
22    CONTINUE
      DO 23 I=1,NS
      AM(I)=0
      AID(I)=0
      AIRO(I)=0
      ECC(I)=.0001
      IF(MET.EQ.1) ECC(I)=.000254
      ALFA(I)=0
      BETA(I)=0
      GAMMA(I)=0
      QK(I)=0
      QC(I)=0
      QKP(I)=0
```

```
      QCP(I)=0                                                          02003160
      QKF(I)=0                                                          02003180
      QCF(I)=0                                                          02003200
      QKPF(I)=0                                                         02003220
      QCPF(I)=0                                                         02003240
      XKF(I)=0                                                          02003260
      XCF(I)=0                                                          02003280
      XKFF(I)=0                                                         02003300
      XCFF(I)=0                                                         02003320
      QKHD(I)=0                                                         02003340
      QCHD(I)=0                                                         02003360
      QKHDF(I)=0                                                        02003380
      QCHDF(I)=0                                                        02003400
      CT(I)=1                                                           02003420
      CT1(I)=0                                                          02003440
      CT2(I)=0                                                          02003460
      MT(I)=1                                                           02003480
      MT1(I)=0                                                          02003500
      MT2(I)=0                                                          02003520
      HT(I)=1.0                                                         02003540
      AT(I)=0                                                           02003560
      BT(I)=0                                                           02003580
      DU(I)=0                                                           02003600
      ET(I)=0                                                           02003620
      FT(I)=0                                                           02003640
      GT(I)=0                                                           02003660
      AA(I)=0                                                           02003680
      BA(I)=0                                                           02003700
      DA(I)=0                                                           02003720
      EA(I)=0                                                           02003740
   23 CONTINUE                                                          02003760
      FA=0                                                              02003780
      GA=0                                                              02003800
      HA=1.0                                                            02003820
      GX=0                                                              02003840
      GY=0                                                              02003860
      ITORQ=0                                                           02003880
      IPP=0                                                             02003900
      IMT=0                                                             02003920
      READ(5,OPTION)                                                    02003940
      F(1)=F1                                                           02003960
      IF(HA.LE.0) GO TO 52                                              02003980
```

```
      DO 51 I=1,NS
      IF(CT(I).LE.0) GO TO 52
      IF(MT(I).LE.0) GO TO 52
      IF(HT(I).LE.0) GO TO 52
51    CONTINUE
      GO TO 54
   52 WRITE(6,210)
  210 FORMAT(/' ZERO OR NEGATIVE VALUES OF CT(I), MT(I), HT(I) AND/OR HA
     & HAVE BEEN DETECTED.'/' CT(I) AND MT(I) MUST BE POSITIVE INTEGERS,
     & AND HT(I) AND HA MUST BE POSITIVE NUMBERS.' /' PLEASE VERIFY THE
     &INPUT DATA AND RERUN THE PROGRAM.')
      STOP
   54 DO  10 I=1,NS
      IF(HT(I).LE.0) GO TO 11
10    CONTINUE
      GO TO 12
   11 WRITE(6,220)
  220 FORMAT('-THE INPUT VALUE OF HT(I) MUST BE LARGER THAN ZERO.'/
     1' PLEASE REINPUT THE CORRECT RANGE OF HT(I) VALUES AND RERUN THE P
     2ROGRAM.')
      STOP
   12 AP1=0
      AP2=0
      AP3=0
      AP4=0
      DO 24 I=1,NS
      AP1=AP1+AA(I)
      AP2=AP2+BA(I)
      AP3=AP3+DA(I)
24    AP4=AP4+EA(I)
      IF(AP1.EQ.0.AND.AP2.EQ.0.AND.AP3.EQ.0.AND.AP4.EQ.0) GO TO 26
      WRITE(6,230)
  230 FORMAT('-UNBALANCED AXIAL LOADING INPUT HAS BEEN DETECTED AND HENC
     1E, THE COMPUTATION IS DISCONTINUED.'/' PLEASE VERIFY THE INPUT DAT
     2A AND RERUN THE PROGRAM.')
      STOP
   26 IF(CONTIN.EQ.0) GO TO 17
      READ(5,404) T,DT
      READ(5,404) (YNN(I),I=1,NN)
17    DO 15 I=1,NSM1
      IF(EI(I).NE.0)   EE(I)=0
      IF(GAK(I).NE.0)  GG(I)=0
```

```
15    CONTINUE                                                             02004840
      GO TO 101                                                            02004860
  100 WRITE(6,240)                                                         02004880
  240 FORMAT('-THIS IS THE END OF COMPUTED DATA FOR ALL THE INPUT DATA G02004900
     &ROUPS.'/' THE LAST SETS OF COMPUTED T, DT, AND YNN FOR EACH INPUT 02004920
     &DATA GROUP HAVE BEEN PUNCHED OUT ON CARDS'/' FOR CONTINUED ANALYSI02004940
     &S IN THE FUTURE.')                                                   02004960
      STOP                                                                 02004980
101   RETURN                                                               02005000
      END                                                                  02005020
      SUBROUTINE HYSWRI                                                    03000000
      INTEGER       CONTIN,RIG,CT,CRT                                      03000020
      REAL INPRPM,   MT1,MT2                                               03000040
      COMMON NS,NS2,NS3,NS4,NS5,NS6,NS7,NS8,NS9,NS10,NSM1,NSP1,NS2P1,      03000060
     &NS4P1,IP,IPRINT,                                                     03000080
     &NN,NB,IB1,IBNB,NNT,ITIM,IUSE,CRT,CONTIN,NOORPM,IASIGN,NPOINT,        03000100
     &MOSHA,MET,IND,IPP,ITORQ,IMT,G                                        03000120
      COMMON PI, T,DT,TMAX,DP,      TOLI,GX,GY,Q,S,QLL,QMLOV,HA,FA,GA      03000140
      COMMON IB(6),KK(6),RIG(14),JBI(15),CT(15),MT(15)                     03000160
      COMMON TITLE(18),F(15),FDOT(15),FDOFIX(6),DD(14),D(14),QL(14),       03000180
     &P(14),                                                               03000200
     &DN(14),EE(14),GG(14),EI(14),GAK(14),SHK(14),AM(15),AID(15),          03000220
     &AIRO(15),QM(15),                                                     03000240
     &QID(15),QIRO(15),ECC(15),ALFA(15),BETA(15),GAMMA(15),QME(15),        03000260
     &FOSTIF(6),                                                           03000280
     &Z(15),QZ(15),QK(15),QC(15),QKP(15),QCP(15),QKHD(15),QCHD(15),        03000300
     &QKF(15),QCF(15),                                                     03000320
     &QKPF(15),QCPF(15),QKHDF(15),QCHDF(15),XKF(15),XCF(15),XKFF(15),      03000340
     &XCFF(15),                                                            03000360
     &QKXX(6),QKXY(6),QKYY(6),QKYX(6),QCXX(6),QCXY(6),QCYY(6),QCYX(6),     03000380
     &XXMK(6),XYMK(6),YYMK(6),YXMK(6),XXMC(6),XYMC(6),YYMC(6),YXMC(6),     03000400
     &BI(6),XKMM(6),YKMM(6),XCMM(6),YCMM(6),                               03000420
     &BKMX(6),BKMY(6),BCMX(6),BCMY(6),BM(6),USV(14),USC(14),               03000440
     &UBV(14),UBC(14),UTV(14),UTC(14),CT1(15),CT2(15),CTV(14),CTC(14),     03000460
     &MT1(15),MT2(15),AT(15),BT(15),DU(15),HT(15),ET(15),FT(15),GT(15),    03000480
     &AA(15),                                                              03000500
     &BA(15),DA(15),EA(15),  YN(84),  INPRPM(50)                           03000520
      COMMON C(15,15),B(15,15),TF(15,15),TM(15,15),BBB(6,3),BDB(6,3),      03000540
     &BEB(6,3),                                                            03000560
     &BCB(6,3),BHB(6,3),BKB(6,3),BNB(6,3),BROB(6,4)                        03000580
   40 FORMAT(I8,4I13)                                                      03000600
404   FORMAT(1PE21.5,1P4E13.5)                                             03000620
```

```
      WRITE(6,9)                                                          03000640
    9 FORMAT(1H1//' THE FOLLOWING ARE THE VALUES OF INPUT DATA USED IN T03000660
     1HIS RUN WITH TITLE DESCRIPTION ON THE NEXT LINE.'/)                 03000680
      WRITE(6,5) TITLE                                                    03000700
    5 FORMAT(15X,(18A4),//)                                               03000720
      IF(IND.EQ.0) GO TO 10                                               03000740
      IF(IND.EQ.1) GO TO 11                                               03000760
      IF(IND.EQ.2) GO TO 12                                               03000780
   10 WRITE(6,13)                                                         03000800
      GO TO 16                                                            03000820
   11 WRITE(6,14)                                                         03000840
      GO TO 16                                                            03000860
   12 WRITE(6,15)                                                         03000880
   13 FORMAT(' ADAMS-MOULTON PREDICTOR-CORRECTOR INTEGRATION TECHNIQUE I03000900
     1S USED FOR THIS RUN.')                                              03000920
   14 FORMAT(' 4TH ORDER RUNGE-KUTTA FIXED STEP INTEGRATION TECHNIQUE IS03000940
     1 USED FOR THIS RUN.')                                               03000960
   15 FORMAT(' FIXED STEP ADAMS-MOULTON INTEGRATION TECHNIQUE IS USED FO03000980
     1R THIS RUN.')                                                       03001000
   16 WRITE(6,17)                                                         03001020
   17 FORMAT('- I. GENERAL PARAMETERS'/)                                  03001040
      WRITE(6,4) IND                                                      03001060
    4 FORMAT(4X'IND ='I4,',''7X'0=USING ADAMS-MOULTON PREDICTOR-CORRECTOR03001080
     & VARIABLE STEP INTEGRATION TECHNIQUE'/21X'1=USING 4TH ORDER RUNGE-03001100
     &KUTTA FIXED STEP INTEGRATION TECHNIQUE'/21X'2=USING ADAMS-MOULTON 03001120
     &FIXED STEP INTEGRATION TECHNIQUE')                                  03001140
      WRITE(6,18) MET,CONTIN,T,DT,TMAX,DP,IPRINT,IPRINT                   03001160
   18 FORMAT( 4X'MET ='I4,',''7X'1=INTERNATIONAL UNITS,   0=ENGLISH UNITS03001180
     &,'/4X'CONTIN='I1,',''6X'  1=CONTINUATION FROM A PREVIOUS RUN,   0=A03001200
     & NEW RUN'/21X'WHEN CONTIN=1 ADDITIONAL INPUT OF PUNCHED CARDS MUST03001220
     & BE PROVIDED,'/21X'AND THE DT VALUE ON THE PUNCHED CARD WILL OVERR03001240
     &IDE THE DT VALUE ON THE SECOND LINE BELOW.'/4X'T ='1PE13.5,' SEC. 03001260
     &STARTING TIME'/                                                     03001280
     34X'DT='E13.5, ' SEC. SUGGESTED INTEGRATION TIME STEP'/              03001300
     44X'TMAX ='E13.5,' SEC. MAXIMUM RUN TIME'/                           03001320
     54X'DP='1PE13.5,' SEC,  COMPUTED RESULTS MIMIMUM PRINTING TIME INTE03001340
     6RVALS'/4X'IPRINT ='I4,',''4X'PRINTING FREQUENCY 1 PER'I4,' MINIMUM 03001360
     7PRINTING INTERVALS (DP)')                                           03001380
      WRITE(6,211)  CRT,MOSHA,NPOINT,NOORPM,IASIGN                        03001400
  211 FORMAT(4X'CRT = 'I1,',''9X'1=CRT PRODUCED,   0=NO CRT'/4X'MOSHA = '03001420
     1I1,',''7X'1=ROTOR MODE SHAPE CRT WILL BE PRODUCED PROVIDED THAT CRT03001440
     2=1,'/ 21X'0=THE CRT WILL NOT BE PRODUCED.'/                         03001460
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   34X'NPOINT ='I3,',' 5X'THE NUMBER OF POINTS (ONE PER MIMIMUM PRINTOU03001480
   4T STEP) PER CRT GRAPH,'/21X'THE RANGE OF NPOINT IS 1 THROUGH 50.'/03001500
   54X'NOORPM ='I3,',' 5X'THE NUMBER OF ROTOR SPIN SPEEDS AT OR NEAR AN03001520
   6D ABOVE WHICH'/21X'THE ROTOR MODE SHAPE CRT WILL BE PRODUCED PROVI03001540
   7DED THAT MOSHA=1 AND CRT=1.'/    4X'IASIGN ='I3,',' 5X'THE ROTOR ST03001560
   7ATION NUMBER AT WHICH THE ROTOR SPIN SPEED VERSUS TIME CRT, DISPLA03001580
   8CEMENT'/ 21X'WHIRL/SPIN SPEED FREQUENCY RATIO CRT AND ROTOR ORBIT 03001600
   9X-Y PLOT CRT WILL BE PRODUCED.')                                  03001620
    WRITE(6,212)                                                      03001640
212 FORMAT(4X'INPRPM ARRAY'  5X'INPUT RPM ARRAY AT OR ABOVE EACH OF WH03001660
   &ICH A 3-DIMENSION ROTOR MODEL SHAPE WILL BE'/21X'PRODUCED.')      03001680
    WRITE(6,404) (INPRPM(I),I=1,NOORPM)                               03001700
    WRITE(6,19) NS,NB                                                 03001720
 19 FORMAT(/4X'NS ='I3,',' 9X'NUMBER OF ROTOR STATIONS'/4X'NB ='I3,',' 903001740
   1X'NUMBER OF BEARING STATIONS'/)                                   03001760
    WRITE(6,20)                                                       03001780
 20 FORMAT(4X'BEARING STATION LOCATION ARRAY (IB(K),K=1,NB):')        03001800
    WRITE(6,40) (IB(I),I=1,NB)                                        03001820
    WRITE(6,21)                                                       03001840
 21 FORMAT('0   NUMBER OF NONLINEAR BEARING STIFFNESS SECTIONS FOR EAC03001860
   1H OF THE BEARING STATIONS (KK(K),K=1,NB)')                        03001880
    WRITE(6,40) (KK(I),I=1,NB)                                        03001900
    WRITE(6,22) F(1),FDOT(1)                                          03001920
 22 FORMAT('0   F(1) ='1PE13.5,' DEGREES,   STARTING ROTOR SPIN ANGULA03001940
   1R POSITION'/4X'FDOT(1) ='1PE13.5,' RPM,    STARTING ROTOR SPIN AND03001960
   2 WHIRL SPEED'/)                                                   03001980
    WRITE(6,152)                                                      03002000
152 FORMAT(4X'ROTOR SECTION TORSIONAL ELASTICITY CONTROL VARIABLE (RIG03002020
   1(J),J=1,NS-1)'/21X'1=TORSIONALLY RIGID ROTOR SECTION IS ASSUMED'/203002040
   21X'0=ACTUAL TORSIONALLY ELASTIC ROTOR SECTION IS USED')           03002060
    WRITE(6,40) (RIG(I),I=1,NSM1)                                     03002080
    IF(MET.EQ.1) GO TO 200                                            03002100
    WRITE(6,23)                                                       03002120
 23 FORMAT(1H1/////'  II. ROTOR GEOMETRY AND MECHANICAL PROPERTIES (J=03002140
   11,NS-1),(I=1,NS)'/)                                               03002160
    WRITE(6,24)                                                       03002180
 24 FORMAT(5X'OUTSIDE DIAMETER ARRAY (DD(J)), IN.')                   03002200
    WRITE(6,404) (DD(I),I=1,NSM1)                                     03002220
    WRITE(6,25)                                                       03002240
 25 FORMAT(5X'INSIDE DIAMETER ARRAY (D(J)), IN.')                     03002260
    WRITE(6,404) (D(I),I=1,NSM1)                                      03002280
    WRITE(6,26)                                                       03002300
```

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   26 FORMAT(5X'SECTION LENGTH ARRAY (QL(J)), IN.')                     03002320
      WRITE(6,404) (QL(I),I=1,NSM1)                                     03002340
      WRITE(6,27)                                                       03002360
   27 FORMAT(  5X'MASS DENSITY ARRAY (DN(J)), LB/IN**3')                03002380
      WRITE(6,404) (DN(I),I=1,NSM1)                                     03002400
      WRITE(6,28)                                                       03002420
   28 FORMAT(5X'ELASTICITY MODULUS ARRAY (EE(J)), LB/IN**2')            03002440
      WRITE(6,404) (EE(I),I=1,NSM1)                                     03002460
      WRITE(6,29)                                                       03002480
   29 FORMAT(5X'SHEAR MODULUS ARRAY (GG(J)), LB/IN**2')                 03002500
      WRITE(6,404) (GG(I),I=1,NSM1)                                     03002520
      WRITE(6,30)                                                       03002540
   30 FORMAT(5X'POISSON''S RATIO ARRAY (P(J))')                         03002560
      WRITE(6,404) (P(I),I=1,NSM1)                                      03002580
      WRITE(6,31)                                                       03002600
   31 FORMAT(5X'PRODUCT OF ELASTICITY AND AREA INERTIA ARRAY (EI(J)), LB03002620
     1*IN**2')                                                          03002640
      WRITE(6,404) (EI(I),I=1,NSM1)                                     03002660
      WRITE(6,32)                                                       03002680
   32 FORMAT(5X'PRODUCT OF SHEAR MODULUS, AREA AND SHEAR FACTOR ARRAY (G03002700
     1AK(J)), LB')                                                      03002720
      WRITE(6,404) (GAK(I),I=1,NSM1)                                    03002740
      WRITE(6,33)                                                       03002760
   33 FORMAT(5X'ADDITIONAL MASS ARRAY (AM(I)), LB')                     03002780
      WRITE(6,404) (AM(I),I=1,NS)                                       03002800
      WRITE(6,34)                                                       03002820
   34 FORMAT(5X'ADDITIONAL TRANSVERSE MASS MOMENT OF INERTIA ARRAY (AID(03002840
     1I)), LB*IN**2')                                                   03002860
      WRITE(6,404) (AID(I),I=1,NS)                                      03002880
      WRITE(6,35)                                                       03002900
   35 FORMAT(5X'ADDITIONAL POLAR MASS MOMENT OF INERTIA ARRAY (AIRO(I)),03002920
     1 LB*IN**2')                                                       03002940
      WRITE(6,404) (AIRO(I),I=1,NS)                                     03002960
      WRITE(6,36)                                                       03002980
   36 FORMAT(5X'MASS ECCENTRICITY ARRAY (ECC(I)), IN.')                 03003000
      WRITE(6,404) (ECC(I),I=1,NS)                                      03003020
      WRITE(6,37)                                                       03003040
   37 FORMAT(5X'ECCENTRICITY PHASE ANGLE ARRAY (ALFA(I)), DEGREES')     03003060
      WRITE(6,404) (ALFA(I),I=1,NS)                                     03003080
      WRITE(6,38)                                                       03003100
   38 FORMAT(5X'MASS INERTIA MISALIGNMENT ANGLE ARRAY (BETA(I)), DEGREES03003120
     1')                                                                03003140
```

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      WRITE(6,404) (BETA(I),I=1,NS)                                     03003160
      WRITE(6,39)                                                       03003180
   39 FORMAT(5X'MISALIGNMENT PHASE ANGLE ARRAY (GAMMA(I)), DEGREES')    03003200
      WRITE(6,404) (GAMMA(I),I=1,NS)                                    03003220
      WRITE(6,6)                                                        03003240
    6 FORMAT(/////'  III. LINEAR SUPPORT BEARING AND MOUNT PARAMETERS (K03003260
     1=1,NB)'/)                                                         03003280
      WRITE(6,41)                                                       03003300
   41 FORMAT(5X'MOUNT X-FORCE STIFFNESS COEFFICIENT ARRAY (BKMX(K)), LB/03003320
     1IN')                                                              03003340
      WRITE(6,404) (BKMX(I),I=1,NB)                                     03003360
      WRITE(6,42)                                                       03003380
   42 FORMAT(5X'MOUNT Y-FORCE STIFFNESS COEFFICIENT ARRAY (BKMY(K)), LB/03003400
     1IN')                                                              03003420
      WRITE(6,404)(BKMY(I),I=1,NB)                                      03003440
      WRITE(6,43)                                                       03003460
   43 FORMAT(5X'MOUNT X-FORCE DAMPING COEFFICIENT ARRAY (BCMX(K)), LB*SE03003480
     1C/IN')                                                            03003500
      WRITE(6,404) (BCMX(I),I=1,NB)                                     03003520
      WRITE(6,44)                                                       03003540
   44 FORMAT(5X'MOUNT Y-FORCE DAMPING COEFFICIENT ARRAY (BCMY(K)), LB*SE03003560
     1C/IN')                                                            03003580
      WRITE(6,404) (BCMY(I),I=1,NB)                                     03003600
      WRITE(6,153)                                                      03003620
  153 FORMAT(5X'MOUNT XZ-PLANE STIFFNESS MOMENT COEFFICIENT ARRAY (XKMM(03003640
     1K)), LB*IN/RADIAN')                                               03003660
      WRITE(6,404) (XKMM(I),I=1,NB)                                     03003680
      WRITE(6,154)                                                      03003700
  154 FORMAT(5X'MOUNT YZ-PLANE STIFFNESS MOMENT COEFFICIENT ARRAY (YKMM(03003720
     1K)), LB*IN/RADIAN')                                               03003740
      WRITE(6,404) (YKMM(I),I=1,NB)                                     03003760
      WRITE(6,155)                                                      03003780
  155 FORMAT(5X'MOUNT XZ-PLANE DAMPING MOMENT COEFFICIENT ARRAY (XCMM(K)03003800
     1), LB*IN*SEC/RADIAN')                                             03003820
      WRITE(6,404) (XCMM(I),I=1,NB)                                     03003840
      WRITE(6,156)                                                      03003860
  156 FORMAT(5X'MOUNT YZ-PLANE DAMPING MOMENT COEFFICIENT ARRAY (YCMM(K)03003880
     1), LB*IN*SEC/RADIAN')                                             03003900
      WRITE(6,404) (YCMM(I),I=1,NB)                                     03003920
      WRITE(6,45)                                                       03003940
   45 FORMAT(5X'BEARING MASS ARRAY (BM(K)), LB')                        03003960
      WRITE(6,404) (BM(I),I=1,NB)                                       03003980
```

```
      WRITE(6,46)
   46 FORMAT(5X'BEARING TRANSVERSE MASS MOMENT OF INERTIA ARRAY (BI(K)),
     1 LB*IN**2')
      WRITE(6,404) (BI(I),I=1,NB)
      WRITE(6,47)
   47 FORMAT(5X'BEARING IN-PHASE STIFFNESS X-FORCE COEFFICIENT ARRAY (QK
     1XX(K)), LB/IN')
      WRITE(6,404) (QKXX(I),I=1,NB)
      WRITE(6,48)
   48 FORMAT(5X'BEARING IN-PHASE STIFFNESS Y-FORCE COEFFICIENT ARRAY (QK
     1YY(K)), LB/IN')
      WRITE(6,404) (QKYY(I),I=1,NB)
      WRITE(6,49)
   49 FORMAT(5X'BEARING OUT-OF-PHASE STIFFNESS X-FORCE FROM Y-DISPLACEME
     1NT COEFFICIENT ARRAY (QKXY(K)), LB/IN')
      WRITE(6,404) (QKXY(I),I=1,NB)
      WRITE(6,50)
   50 FORMAT(5X'BEARING OUT-OF-PHASE STIFFNESS Y-FORCE FROM X-DISPLACEME
     1NT COEFFICIENT ARRAY (QKYX(K)), LB/IN')
      WRITE(6,404) (QKYX(I),I=1,NB)
      WRITE(6,51)
   51 FORMAT(5X'BEARING IN-PHASE DAMPING X-FORCE COEFFICIENT ARRAY (QCXX
     1(K)), LB*SEC/IN')
      WRITE(6,404) (QCXX(I),I=1,NB)
      WRITE(6,52)
   52 FORMAT(5X'BEARING IN-PHASE DAMPING Y-FORCE COEFFICIENT ARRAY (QCYY
     1(K)), LB*SEC/IN')
      WRITE(6,404) (QCYY(I),I=1,NB)
      WRITE(6,53)
   53 FORMAT(5X'BEARING OUT-OF-PHASE DAMPING X-FORCE FROM Y-VELOCITY COE
     1FFICIENT ARRAY (QCXY(K)), LB*SEC/IN')
      WRITE(6,404) (QCXY(I),I=1,NB)
      WRITE(6,54)
   54 FORMAT(5X'BEARING OUT-OF-PHASE DAMPING Y-FORCE FROM X-VELOCITY COE
     1FFICIENT ARRAY (QCYX(K)), LB*SEC/IN')
      WRITE(6,404) (QCYX(I),I=1,NB)
      WRITE(6,55)
   55 FORMAT(5X'BEARING IN-PHASE STIFFNESS XZ-PLANE MOMENT COEFFICIENT A
     1RRAY (XXMK(K)), LB*IN/RADIAN')
      WRITE(6,404) (XXMK(I),I=1,NB)
      WRITE(6,56)
   56 FORMAT(5X'BEARING IN-PHASE STIFFNESS YZ-PLANE MOMENT COEFFICIENT A
```

```
      1RRAY (YYMK(K)), LB*IN/RADIAN')                                    03004840
       WRITE(6,404) (YYMK(I),I=1,NB)                                     03004860
       WRITE(6,57)                                                       03004880
57     FORMAT('      BEARING OUT-OF-PHASE STIFFNESS XZ-PLANE MOMENT FROM Y03004900
      1Z-PLANE'/5X'SLOPE ROTATICN COEFFICIENT ARRAY (XYMK(K)), LB*IN/RADI03004920
      2AN')                                                              03004940
       WRITE(6,404) (XYMK(I),I=1,NB)                                     03004960
       WRITE(6,58)                                                       03004980
    58 FORMAT('      BEARING OUT-OF-PHASE STIFFNESS YZ-PLANE MOMENT FROM X03005000
      1Z-PLANE'/5X'SLOPE ROTATION COEFFICIENT ARRAY (YXMK(K)), LB*IN/RADI03005020
      2AN')                                                              03005040
       WRITE(6,404) (YXMK(I),I=1,NB)                                     03005060
       WRITE(6,59)                                                       03005080
59     FORMAT('      BEARING IN-PHASE DAMPING XZ-PLANE MOMENT'1X         03005100
      1'COEFFICIENT ARRAY (XXMC(K)), LB*IN*SEC/RADIAN')                  03005120
       WRITE(6,404) (XXMC(I),I=1,NB)                                     03005140
       WRITE(6,60)                                                       03005160
60     FORMAT('      BEARING IN-PHASE DAMPING YZ-PLANE MOMENT COEFFICIENT'03005180
      1, ' ARRAY (YYMC(K)), LB*IN*SEC/RADIAN')                           03005200
       WRITE(6,404) (YYMC(I),I=1,NB)                                     03005220
       WRITE(6,61)                                                       03005240
61     FORMAT('      OUT-OF-PHASE DAMPING XZ-PLANE MOMENT FROM YZ-PLANE'/ 03005260
      15X'SLOPE VELOCITY COEFFICIENT ARRAY (XYMC(K)), LB*IN*SEC/RADIAN') 03005280
       WRITE(6,404) (XYMC(I),I=1,NB)                                     03005300
       WRITE(6,62)                                                       03005320
62     FORMAT('      BEARING OUT-OF-PHASE DAMPING YZ-PLANE MOMENT FROM XZ-03005340
      1PLANE'/5X'SLOPE VELOCITY COEFFICIENT ARRAY (YXMC(K)), LB*IN*SEC/RA03005360
      2DIAN')                                                            03005380
       WRITE(6,404) (YXMC(I),I=1,NB)                                     03005400
       WRITE(6,63)                                                       03005420
    63 FORMAT(/////'  IV. NONLINEAR BEARING PARAMETERS (K=1,NB), (L=1,KK(03005440
      1K))'/)                                                            03005460
       WRITE(6,65)                                                       03005480
    65 FORMAT(5X'SPIN SPEED PARAMETER ARRAY (FDOFIX(K)), RADIANS/SEC')   03005500
       WRITE(6,404) (FDOFIX(I),I=1,NB)                                   03005520
       DO 201 I=1,NB                                                     03005540
       K=KK(I)                                                           03005560
       WRITE(6,64) I                                                     03005580
64     FORMAT(/  5X'THE NONLINEAR STIFFNESS COEFFICIENTS FOR STIFFNESS SE03005600
      &CTIONS 1,2,3, ETC. FOR THE',I2,'TH BEARING ARE:'/)                03005620
       WRITE(6,160)                                                      03005640
   160 FORMAT(5X'BBB(K,L), LB*SEC/(RADIAN*IN**2)')                       03005660
```

```
      WRITE(6,404) (BBB(I,J),J=1,K)                                     03005680
      WRITE(6,66)                                                       03005700
   66 FORMAT(5X'BCB(K,L), 1./IN**BHB(I,L)')                             03005720
      WRITE(6,404) (BCB(I,J),J=1,K)                                     03005740
      WRITE(6,161)                                                      03005760
  161 FORMAT(5X'BDB(K,L), 1./IN')                                       03005780
      WRITE(6,404) (BDB(I,J),J=1,K)                                     03005800
      WRITE(6,67)                                                       03005820
   67 FORMAT(5X'BEB(K,L), DIMENSIONLESS')                               03005840
      WRITE(6,404) (BEB(I,J),J=1,K)                                     03005860
      WRITE(6,68)                                                       03005880
   68 FORMAT(5X'BKB(K,L), LB/IN')                                       03005900
      WRITE(6,404) (BKB(I,J),J=1,K)                                     03005920
      WRITE(6,69)                                                       03005940
   69 FORMAT(5X'BNB(K,L), (LB*SEC)/(IN*RADIAN)')                        03005960
      WRITE(6,404) (BNB(I,J),J=1,K)                                     03005980
      WRITE(6,71)                                                       03006000
   71 FORMAT(5X'BHB(K,L), DIMENSIONLESS')                               03006020
      WRITE(6,404) (BHB(I,J),J=1,K)                                     03006040
      K1=K+1                                                            03006060
      WRITE(6,70)                                                       03006080
   70 FORMAT(5X'BROB(K,L+1), IN')                                       03006100
      WRITE(6,404) (BROB(I,J),J=1,K1)                                   03006120
201   CONTINUE                                                          03006140
      WRITE(6,72)                                                       03006160
   72 FORMAT(/////'  V. ROTOR-TO-CASING GENERAL STIFFNESS AND DAMPING FO03006180
     1RCE AND MOMENT COEFFICIENTS (I=1,NS)'/)                           03006200
      WRITE(6,73)                                                       03006220
   73 FORMAT(5X'IN-PHASE STIFFNESS FORCE COEFFICIENT ARRAY (QK(I)), LB/I03006240
     1N')                                                               03006260
      WRITE(6,404) (QK(I),I=1,NS)                                       03006280
      WRITE(6,74)                                                       03006300
   74 FORMAT(5X'OUT-OF-PHASE STIFFNESS FORCE COEFFICIENT ARRAY (QKP(I)),03006320
     1 LB/IN')                                                          03006340
      WRITE(6,404) (QKP(I),I=1,NS)                                      03006360
      WRITE(6,75)                                                       03006380
   75 FORMAT(5X'IN-PHASE DAMPING FORCE COEFFICIENT ARRAY (QC(I)), LB*SEC03006400
     1/IN')                                                             03006420
      WRITE(6,404) (QC(I),I=1,NS)                                       03006440
      WRITE(6,76)                                                       03006460
   76 FORMAT(5X'OUT-OF-PHASE DAMPING FORCE COEFFICIENT ARRAY (QCP(I)), L03006480
     1B*SEC/IN')                                                        03006500
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      WRITE(6,404) (QCP(I),I=1,NS)                                      03006520
      WRITE(6,77)                                                       03006540
   77 FORMAT(5X'IN-PHASE STIFFNESS MOMENT COEFFICIENT ARRAY (QKF(I)), LB03006560
     1*IN/RADIAN')                                                      03006580
      WRITE(6,404) (QKF(I),I=1,NS)                                      03006600
      WRITE(6,78)                                                       03006620
   78 FORMAT(5X'OUT-OF-PHASE STIFFNESS MOMENT COEFFICIENT ARRAY (QKPF(I)03006640
     1), LB*IN/RADIAN')                                                 03006660
      WRITE(6,404) (QKPF(I),I=1,NS)                                     03006680
      WRITE(6,79)                                                       03006700
   79 FORMAT(5X'IN-PHASE DAMPING MOMENT COEFFICIENT ARRAY (QCF(I)), LB*I03006720
     1N*SEC/RADIAN')                                                    03006740
      WRITE(6,404) (QCF(I),I=1,NS)                                      03006760
      WRITE(6,80)                                                       03006780
   80 FORMAT(5X'OUT-OF-PHASE DAMPING MOMENT COEFFICIENT ARRAY (QCPF(I)),03006800
     1 LB*IN*SEC/RADIAN')                                               03006820
      WRITE(6,404) (QCPF(I),I=1,NS)                                     03006840
      WRITE(6,81)                                                       03006860
   81 FORMAT(5X'WHIRL STIFFNESS FORCE FACTOR ARRAY (XKF(I)), DIMENSIONLE03006880
     1SS')                                                              03006900
      WRITE(6,404) (XKF(I),I=1,NS)                                      03006920
      WRITE(6,82)                                                       03006940
   82 FORMAT(5X'WHIRL DAMPING FORCE FACTOR ARRAY (XCF(I)), DIMENSIONLESS03006960
     1')                                                                03006980
      WRITE(6,404) (XCF(I),I=1,NS)                                      03007000
      WRITE(6,83)                                                       03007020
   83 FORMAT(5X'WHIRL STIFFNESS MOMENT FACTOR ARRAY (XKFF(I)), DIMENSION03007040
     1LESS')                                                            03007060
      WRITE(6,404) (XKFF(I),I=1,NS)                                     03007080
      WRITE(6,84)                                                       03007100
   84 FORMAT(5X'WHIRL DAMPING MOMENT FACTOR ARRAY (XCFF(I)), DIMENSIONLE03007120
     1SS')                                                              03007140
      WRITE(6,404) (XCFF(I),I=1,NS)                                     03007160
      WRITE(6,85)                                                       03007180
85    FORMAT('      OUT-OF-PHASE STIFFNESS FORCE WHIRL-SPIN'1X          03007200
     1'COEFFICIENT ARRAY (QKHD(I)), LB*SEC/IN')                         03007220
      WRITE(6,404) (QKHD(I),I=1,NS)                                     03007240
      WRITE(6,86)                                                       03007260
86    FORMAT('      OUT-OF-PHASE DAMPING FORCE WHIRL-SPIN'1X            03007280
     1'COEFFICIENT ARRAY (QCHD(I)), LB*SEC**2/IN')                      03007300
      WRITE(6,404) (QCHD(I),I=1,NS)                                     03007320
      WRITE(6,87)                                                       03007340
```

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87     FORMAT('     OUT-OF-PHASE STIFFNESS MOMENT WHIRL-SPIN'1X         03007360
      1'COEFFICIENT ARRAY (QKHDF(I)), LB*IN*SEC/RADIAN')                03007380
       WRITE(6,404) (QKHDF(I),I=1,NS)                                   03007400
       WRITE(6,88)                                                      03007420
88     FORMAT('     OUT-OF-PHASE DAMPING MOMENT WHIRL-SPIN'1X           03007440
      1'COEFFICIENT ARRAY (QCHDF(I)), LB*IN*SEC**2/RADIAN')             03007460
       WRITE(6,404) (QCHDF(I),I=1,NS)                                   03007480
       WRITE(6,89)                                                      03007500
   89 FORMAT(/////'  VI. ROTOR DRIVE AND DAMPING TORQUE PARAMETERS (I=1,03007520
      1NS)'/)                                                           03007540
       WRITE(6,120) ITORQ                                               03007560
120    FORMAT('     TORQUE CONTROL VARIABLE  (ITORQ) = ',I1,/           03007580
      121X'1=INCLUDING DRIVE AND DAMPING TORQUE IN COMPUTATION'/        03007600
      221X'0=EXCLUDING THE TORQUE'/)                                    03007620
       WRITE(6,121) IMT                                                 03007640
121    FORMAT('     TORQUE TRANSVERSE EFFECT CONTROL VARIABLE  (IMT) = ',03007660
      1I1/21X'1=INCLUDING THE EFFECTS'/ 21X'0=EXCLUDING THE EFFECTS'/)  03007680
       WRITE(6,98)                                                      03007700
   98 FORMAT(5X'CT(I) ARRAY (CT(I) MUST BE POSITIVE INTEGERS), DIMENSION03007720
      1LESS')                                                           03007740
       WRITE(6,40 ) (CT(I),I=1,NS)                                      03007760
       WRITE(6,99)                                                      03007780
   99 FORMAT(5X'CT1(I) ARRAY, LB*IN/(RADIANS/SEC)**CT(I)')              03007800
       WRITE(6,404) (CT1(I),I=1,NS)                                     03007820
       WRITE(6,100)                                                     03007840
  100 FORMAT(5X'CT2(I) ARRAY, LB*IN/(RADIANS/SEC)')                     03007860
       WRITE(6,404) (CT2(I),I=1,NS)                                     03007880
       WRITE(6,90)                                                      03007900
   90 FORMAT(5X'MT(I) ARRAY (MT(I) MUST BE POSITIVE INTEGERS), DIMENSION03007920
      1LESS')                                                           03007940
       WRITE(6,40 ) (MT(I),I=1,NS)                                      03007960
       WRITE(6,91)                                                      03007980
   91 FORMAT(5X'MT1(I) ARRAY, LB*IN/(RADIANS/SEC)**MT(I)')              03008000
       WRITE(6,404) (MT1(I),I=1,NS)                                     03008020
       WRITE(6,92)                                                      03008040
   92 FORMAT(5X'MT2(I) ARRAY, LB*IN/(RADIANS/SEC)')                     03008060
       WRITE(6,404) (MT2(I),I=1,NS)                                     03008080
       WRITE(6,93)                                                      03008100
   93 FORMAT(5X'AT(I) ARRAY, LB*IN')                                    03008120
       WRITE(6,404) (AT(I),I=1,NS)                                      03008140
       WRITE(6,94)                                                      03008160
   94 FORMAT(5X'BT(I) ARRAY, LB*IN/SEC')                                03008180
```

```
      WRITE(6,404) (BT(I),I=1,NS)
      WRITE(6,95)
   95 FORMAT(5X'DU(I) ARRAY, LB*IN/SEC**HT(I)')
      WRITE(6,404) (DU(I),I=1,NS)
      WRITE(6,96)
   96 FORMAT(5X'ET(I) ARRAY, LB*IN')
      WRITE(6,404) (ET(I),I=1,NS)
      WRITE(6,97)
   97 FORMAT(5X'HT(I) ARRAY (HT(I) MUST BE POSITIVE NUMBER), DIMENSIONLE
     1SS')
      WRITE(6,404) (HT(I),I=1,NS)
      WRITE(6,101)
  101 FORMAT(5X'FT(I) ARRAY, RADIANS/SEC')
      WRITE(6,404) (FT(I),I=1,NS)
      WRITE(6,102)
  102 FORMAT(5X'GT(I) ARRAY, RADIANS')
      WRITE(6,404) (GT(I),I=1,NS)
      WRITE(6,103)
  103 FORMAT(/////'  VII. ROTOR AXIAL LOADING PARAMETERS (I=1,NS)'/)
      WRITE(6,122) IPP
122   FORMAT('     AXIAL LOADING CONTROL VARIABLE (IPP) = ',I1,/
     121X'1=INCLUDING AXIAL LOADING TRANSVERSE EFFECTS'/21X'0=EXCLUDING
     2THE EFFECTS'/)
      WRITE(6,104)
  104 FORMAT(5X'AA(I) ARRAY, LB')
      WRITE(6,404) (AA(I),I=1,NS)
      WRITE(6,105)
  105 FORMAT(5X'BA(I) ARRAY, LB/SEC')
      WRITE(6,404) (BA(I),I=1,NS)
      WRITE(6,106)
  106 FORMAT(5X'DA(I) ARRAY, LB/SEC**HA')
      WRITE(6,404) (DA(I),I=1,NS)
      WRITE(6,107)
  107 FORMAT(5X'EA(I) ARRAY, LB')
      WRITE(6,404) (EA(I),I=1,NS)
      WRITE(6,108)
  108 FORMAT(5X'HA DIMENSIONLESS,  FA RADIANS/SEC,  GA RADIANS (HA MUST
     &BE A POSITIVE NUMBER.)')
      WRITE(6,404) HA,FA,GA
      WRITE(6,109)
  109 FORMAT(/////'  VIII. ROTOR SYSTEM G-LOADING PARAMETERS'/)
      WRITE(6,110)
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110   FORMAT('      TRANSVERSE ACCELERATION OR GRAVITY LOADING IN MINUS X03009040
     1-DIRECTION (GX), IN/SEC**2')                                      03009060
      WRITE(6,404) GX                                                   03009080
      WRITE(6,111)                                                      03009100
111   FORMAT('      TRANSVERSE ACCELERATION OR GRAVITY LOADING IN MINUS Y03009120
     1-DIRECTION (GY), IN/SEC**2')                                      03009140
      WRITE(6,404) GY                                                   03009160
      WRITE(6,112)                                                      03009180
  112 FORMAT(/////'  IX. ROTOR MATERIAL MECHANICAL HYSTERESIS PARAMETERS03009200
     1 (J=1,NS-1)'/)                                                    03009220
      WRITE(6,113)                                                      03009240
  113 FORMAT(5X'TRANSVERSE SHEAR VISCOUS COEFFICIENT ARRAY (USV(J)), LB*03009260
     1SEC/IN**2')                                                       03009280
      WRITE(6,404) (USV(I),I=1,NSM1)                                    03009300
      WRITE(6,114)                                                      03009320
114   FORMAT('      TRANSVERSE SHEAR COULOMB FRICTION COEFFICIENT'1X    03009340
     1'ARRAY (USC(J)), LB/IN**2')                                       03009360
      WRITE(6,404) (USC(I),I=1,NSM1)                                    03009380
      WRITE(6,115)                                                      03009400
  115 FORMAT(5X'TRANSVERSE BENDING VISCOUS COEFFICIENT ARRAY (UBV(J)), L03009420
     1B*SEC/IN**2')                                                     03009440
      WRITE(6,404) (UBV(I),I=1,NSM1)                                    03009460
      WRITE(6,116)                                                      03009480
116   FORMAT('      TRANSVERSE BENDING COULOMB FRICTION COEFFICIENT'    03009500
     11X'ARRAY (UBC(J)), LB/IN**2')                                     03009520
      WRITE(6,404) (UBC(I),I=1,NSM1)                                    03009540
      WRITE(6,117)                                                      03009560
  117 FORMAT(5X'TORSIONAL SHEAR VISCOUS COEFFICIENT ARRAY (UTV(J)), LB*S03009580
     1EC/IN**2')                                                        03009600
      WRITE(6,404) (UTV(I),I=1,NSM1)                                    03009620
      WRITE(6,118)                                                      03009640
118   FORMAT('      TORSIONAL SHEAR COULOMB FRICTION COEFFICIENT'1X     03009660
     1'ARRAY (UTC(J)), LB/IN**2')                                       03009680
      WRITE(6,404) (UTC(I),I=1,NSM1)                                    03009700
      WRITE(6,119)                                                      03009720
  119 FORMAT(//'  *** THIS IS THE END OF INPUT DATA. ***'////)          03009740
      V=PI/180.                                                         03009760
      U=V*6.                                                            03009780
      F(1)=F(1)*V                                                       03009800
      FDOT(1)=FDOT(1)*U                                                 03009820
      DO 7 I=1,NS                                                       03009840
      ALFA(I)=ALFA(I)*V                                                 03009860
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      GAMMA(I)=GAMMA(I)*V                                               03009880
      BETA(I)=BETA(I)*V                                                 03009900
      AM(I)=AM(I)/G                                                     03009920
      AIRO(I)=AIRO(I)/G                                                 03009940
    7 AID(I)=AID(I)/G                                                   03009960
      DO 8 I=1,NB                                                       03009980
      BI(I)=BI(I)/G                                                     03010000
    8 BM(I)=BM(I)/G                                                     03010020
  200 RETURN                                                            03010040
      END                                                               03010060
      SUBROUTINE HYSWME                                                 04000000
      INTEGER       CONTIN,RIG,CT,CRT                                   04000020
      REAL INPRPM,   MT1,MT2                                            04000040
      COMMON NS,NS2,NS3,NS4,NS5,NS6,NS7,NS8,NS9,NS10,NSM1,NSP1,NS2P1,   04000060
     &NS4P1,IP,IPRINT,                                                  04000080
     &NN,NB,IB1,IBNB,NNT,ITIM,IUSE,CRT,CONTIN,NOORPM,IASIGN,NPOINT,     04000100
     &MOSHA,MET,IND,IPP,ITORQ,IMT,G                                     04000120
      COMMON PI, T,DT,TMAX,DP,       TOLI,GX,GY,Q,S,QLL,QMLOV,HA,FA,GA  04000140
      COMMON IB(6),KK(6),RIG(14),JBI(15),CT(15),MT(15)                  04000160
      COMMON TITLE(18),F(15),FDOT(15),FDOFIX(6),DD(14),D(14),QL(14),    04000180
     &P(14),                                                            04000200
     &DN(14),EE(14),GG(14),EI(14),GAK(14),SHK(14),AM(15),AID(15),       04000220
     &AIRO(15),QM(15),                                                  04000240
     &QID(15),QIRO(15),ECC(15),ALFA(15),BETA(15),GAMMA(15),QME(15),     04000260
     &FOSTIF(6),                                                        04000280
     &Z(15),QZ(15),QK(15),QC(15),QKP(15),QCP(15),QKHD(15),QCHD(15),     04000300
     &QKF(15),QCF(15),                                                  04000320
     &QKPF(15),QCPF(15),QKHDF(15),QCHDF(15),XKF(15),XCF(15),XKFF(15),   04000340
     &XCFF(15),                                                         04000360
     &QKXX(6),QKXY(6),QKYY(6),QKYX(6),QCXX(6),QCXY(6),QCYY(6),QCYX(6),  04000380
     &XXMK(6),XYMK(6),YYMK(6),YXMK(6),XXMC(6),XYMC(6),YYMC(6),YXMC(6),  04000400
     &BI(6),XKMM(6),YKMM(6),XCMM(6),YCMM(6),                            04000420
     &BKMX(6),BKMY(6),BCMX(6),BCMY(6),BM(6),USV(14),USC(14),            04000440
     &UBV(14),UBC(14),UTV(14),UTC(14),CT1(15),CT2(15),CTV(14),CTC(14),  04000460
     &MT1(15),MT2(15),AT(15),BT(15),DU(15),HT(15),ET(15),FT(15),GT(15), 04000480
     &AA(15),                                                           04000500
     &BA(15),DA(15),EA(15),  YN(84),  INPRPM(50)                        04000520
      COMMON C(15,15),B(15,15),TF(15,15),TM(15,15),BBB(6,3),BDB(6,3),   04000540
     &BEB(6,3),                                                         04000560
     &BCB(6,3),BHB(6,3),BKB(6,3),BNB(6,3),BROB(6,4)                     04000580
   40 FORMAT(I8,4I13)                                                   04000600
  404 FORMAT(1PE21.5,1P4E13.5)                                          04000620
```

```
      WRITE(6,23)                                                       04000640
   23 FORMAT(1H1/////'  II. ROTOR GEOMETRY AND MECHANICAL PROPERTIES (J=04000660
     11,NS-1),(I=1,NS)'/)                                               04000680
      WRITE(6,24)                                                       04000700
   24 FORMAT(5X'OUTSIDE DIAMETER ARRAY (DD(J)), CM' )                   04000720
      WRITE(6,404) (DD(I),I=1,NSM1)                                     04000740
      WRITE(6,25)                                                       04000760
   25 FORMAT(5X'INSIDE DIAMETER ARRAY (D(J)), CM')                      04000780
      WRITE(6,404) (D(I),I=1,NSM1)                                      04000800
      WRITE(6,26)                                                       04000820
   26 FORMAT(5X'SECTION LENGTH ARRAY (QL(J)), CM')                      04000840
      WRITE(6,404) (QL(I),I=1,NSM1)                                     04000860
      WRITE(6,27)                                                       04000880
   27 FORMAT(  5X'MASS DENSITY ARRAY (DN(J)), KG/CM**3')                04000900
      WRITE(6,404) (DN(I),I=1,NSM1)                                     04000920
      WRITE(6,28)                                                       04000940
   28 FORMAT(5X'ELASTICITY MODULUS ARRAY (EE(J)), NEWTON/CM**2')        04000960
      WRITE(6,404) (EE(I),I=1,NSM1)                                     04000980
      WRITE(6,29)                                                       04001000
   29 FORMAT(5X'SHEAR MODULUS  ARRAY (GG(J)), NEWTON/CM**2')            04001020
      WRITE(6,404) (GG(I),I=1,NSM1)                                     04001040
      WRITE(6,30)                                                       04001060
   30 FORMAT(5X'POISSON''S RATIO ARRAY (P(J))')                         04001080
      WRITE(6,404) (P(I),I=1,NSM1)                                      04001100
      WRITE(6,31)                                                       04001120
   31 FORMAT(5X'PRODUCT OF ELASTICITY AND AREA INERTIA ARRAY (EI(J)), NE04001140
     1WTON*CM**2')                                                      04001160
      WRITE(6,404) (EI(I),I=1,NSM1)                                     04001180
      WRITE(6,32)                                                       04001200
   32 FORMAT(5X'PRODUCT OF SHEAR MODULUS, AREA AND SHEAR FACTOR ARRAY (G04001220
     1AK(J)), NEWTONS')                                                 04001240
      WRITE(6,404) (GAK(I),I=1,NSM1)                                    04001260
      WRITE(6,33)                                                       04001280
   33 FORMAT(5X'ADDITIONAL MASS ARRAY (AM(I)), KG')                     04001300
      WRITE(6,404) (AM(I),I=1,NS)                                       04001320
      WRITE(6,34)                                                       04001340
   34 FORMAT(5X'ADDITIONAL TRANSVERSE MASS MOMENT OF INERTIA ARRAY (AID(04001360
     1I)), KG*CM**2')                                                   04001380
      WRITE(6,404) (AID(I),I=1,NS)                                      04001400
      WRITE(6,35)                                                       04001420
   35 FORMAT(5X'ADDITIONAL POLAR MASS MOMENT OF INERTIA ARRAY (AIRO(I)),04001440
     1 KG*CM**2')                                                       04001460
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      WRITE(6,404) (AIRO(I),I=1,NS)
      WRITE(6,36)
   36 FORMAT(5X'MASS ECCENTRICITY ARRAY (ECC(I)), CM' )
      WRITE(6,404) (ECC(I),I=1,NS)
      WRITE(6,37)
   37 FORMAT(5X'ECCENTRICITY PHASE ANGLE ARRAY (ALFA(I)), DEGREES')
      WRITE(6,404) (ALFA(I),I=1,NS)
      WRITE(6,38)
   38 FORMAT(5X'MASS INERTIA MISALIGNMENT ANGLE ARRAY (BETA(I)), DEGREES
     1')
      WRITE(6,404) (BETA(I),I=1,NS)
      WRITE(6,39)
   39 FORMAT(5X'MISALIGNMENT PHASE ANGLE ARRAY (GAMMA(I)), DEGREES')
      WRITE(6,404) (GAMMA(I),I=1,NS)
      WRITE(6,6)
    6 FORMAT(/////'  III. LINEAR SUPPORT BEARING AND MOUNT PARAMETERS (K
     1=1,NB)'/)
      WRITE(6,41)
   41 FORMAT(5X'MOUNT X-FORCE STIFFNESS COEFFICIENT ARRAY (BKMX(K)), NEW
     1TON/CM')
      WRITE(6,404) (BKMX(I),I=1,NB)
      WRITE(6,42)
   42 FORMAT(5X'MOUNT Y-FORCE STIFFNESS COEFFICIENT ARRAY (BKMY(K)), NEW
     1TON/CM')
      WRITE(6,404)(BKMY(I),I=1,NB)
      WRITE(6,43)
   43 FORMAT(5X'MOUNT X-FORCE DAMPING COEFFICIENT ARRAY (BCMX(K)), NEWTO
     1N*SEC/CM')
      WRITE(6,404) (BCMX(I),I=1,NB)
      WRITE(6,44)
   44 FORMAT(5X'MOUNT Y-FORCE DAMPING COEFFICIENT ARRAY (BCMY(K)), NEWTO
     1N*SEC/CM')
      WRITE(6,404) (BCMY(I),I=1,NB)
      WRITE(6,153)
  153 FORMAT(5X'MOUNT XZ-PLANE STIFFNESS MOMENT COEFFICIENT ARRAY (XKMM(
     1K)), NEWTON*CM/RADIAN')
      WRITE(6,404) (XKMM(I),I=1,NB)
      WRITE(6,154)
  154 FORMAT(5X'MOUNT YZ-PLANE STIFFNESS MOMENT COEFFICIENT ARRAY (YKMM(
     1K)), NEWTON*CM/RADIAN')
      WRITE(6,404) (YKMM(I),I=1,NB)
      WRITE(6,155)
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155 FORMAT(5X'MOUNT XZ-PLANE DAMPING MOMENT COEFFICIENT ARRAY (XCMM(K)
   1), NEWTON*CM*SEC/RADIAN')
    WRITE(6,404) (XCMM(I),I=1,NB)
    WRITE(6,156)
156 FORMAT(5X'MOUNT YZ-PLANE DAMPING MOMENT COEFFICIENT ARRAY (YCMM(K)
   1), NEWTON*CM*SEC/RADIAN')
    WRITE(6,404) (YCMM(I),I=1,NB)
    WRITE(6,45)
 45 FORMAT(5X'BEARING MASS ARRAY (BM(K)), KG')
    WRITE(6,404) (BM(I),I=1,NB)
    WRITE(6,46)
 46 FORMAT(5X'BEARING TRANSVERSE MASS MOMENT OF INERTIA ARRAY (BI(K)),
   1 KG*CM**2')
    WRITE(6,404) (BI(I),I=1,NB)
    WRITE(6,47)
 47 FORMAT(5X'BEARING IN-PHASE STIFFNESS X-FORCE COEFFICIENT ARRAY (QK
   1XX(K)), NEWTON/CM')
    WRITE(6,404) (QKXX(I),I=1,NB)
    WRITE(6,48)
 48 FORMAT(5X'BEARING IN-PHASE STIFFNESS Y-FORCE COEFFICIENT ARRAY (QK
   1YY(K)), NEWTON/CM')
    WRITE(6,404) (QKYY(I),I=1,NB)
    WRITE(6,49)
 49 FORMAT(5X'BEARING OUT-OF-PHASE STIFFNESS X-FORCE FROM Y-DISPLACEME
   1NT COEFFICIENT ARRAY (QKXY(K)), NEWTON/CM')
    WRITE(6,404) (QKXY(I),I=1,NB)
    WRITE(6,50)
 50 FORMAT(5X'BEARING OUT-OF-PHASE STIFFNESS Y-FORCE FROM X-DISPLACEME
   1NT COEFFICIENT ARRAY (QKYX(K)), NEWTON/CM')
    WRITE(6,404) (QKYX(I),I=1,NB)
    WRITE(6,51)
 51 FORMAT(5X'BEARING IN-PHASE DAMPING X-FORCE COEFFICIENT ARRAY (QCXX
   1(K)), NEWTON*SEC/CM')
    WRITE(6,404) (QCXX(I),I=1,NB)
    WRITE(6,52)
 52 FORMAT(5X'BEARING IN-PHASE DAMPING Y-FORCE COEFFICIENT ARRAY (QCYY
   1(K)), NEWTON*SEC/CM')
    WRITE(6,404) (QCYY(I),I=1,NB)
    WRITE(6,53)
 53 FORMAT(5X'BEARING OUT-OF-PHASE DAMPING X-FORCE FROM Y-VELOCITY COE
   1FFICIENT ARRAY (QCXY(K)), NEWTON*SEC/CM')
    WRITE(6,404) (QCXY(I),I=1,NB)
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      WRITE(6,54)                                                        04003160
   54 FORMAT(5X'BEARING OUT-OF-PHASE DAMPING Y-FORCE FROM X-VELOCITY COE04003180
     1FFICIENT ARRAY (QCYX(K)), NEWTON*SEC/CM')                          04003200
      WRITE(6,404) (QCYX(I),I=1,NB)                                      04003220
      WRITE(6,55)                                                        04003240
   55 FORMAT(5X'BEARING IN-PHASE STIFFNESS XZ-PLANE MOMENT COEFFICIENT A04003260
     1RRAY (XXMK(K)), NEWTON*CM/RADIAN')                                 04003280
      WRITE(6,404) (XXMK(I),I=1,NB)                                      04003300
      WRITE(6,56)                                                        04003320
   56 FORMAT(5X'BEARING IN-PHASE STIFFNESS YZ-PLANE MOMENT COEFFICIENT A04003340
     1RRAY (YYMK(K)), NEWTON*CM/RADIAN')                                 04003360
      WRITE(6,404) (YYMK(I),I=1,NB)                                      04003380
      WRITE(6,57)                                                        04003400
57    FORMAT('      BEARING OUT-OF-PHASE STIFFNESS XZ-PLANE MOMENT FROM Y04003420
     1Z-PLANE'/5X'SLOPE ROTATION COEFFICIENT ARRAY (XYMK(K)), NEWTON*CM/04003440
     2RADIAN')                                                           04003460
      WRITE(6,404) (XYMK(I),I=1,NB)                                      04003480
      WRITE(6,58)                                                        04003500
58    FORMAT('      BEARING OUT-OF-PHASE STIFFNESS YZ-PLANE MOMENT FROM X04003520
     1Z-PLANE'/5X'SLOPE ROTATION COEFFICIENT ARRAY (YXMK(K)), NEWTON*CM/04003540
     2RADIAN')                                                           04003560
      WRITE(6,404) (YXMK(I),I=1,NB)                                      04003580
      WRITE(6,59)                                                        04003600
59    FORMAT('      BEARING IN-PHASE DAMPING XZ-PLANE MOMENT'1X          04003620
     1'COEFFICIENT ARRAY (XXMC(K)), NEWTON*CM*SEC/RADIAN')               04003640
      WRITE(6,404) (XXMC(I),I=1,NB)                                      04003660
      WRITE(6,60)                                                        04003680
60    FORMAT('      BEARING IN-PHASE DAMPING YZ-PLANE MOMENT COEFFICIENT 04003700
     1ARRAY (YYMC(K)), NEWTON*CM*SEC/RADIAN')                            04003720
      WRITE(6,404) (YYMC(I),I=1,NB)                                      04003740
      WRITE(6,61)                                                        04003760
   61 FORMAT('      BEARING OUT-OF-PHASE DAMPING XZ-PLANE MOMENT FROM YZ-04003780
     1PLANE'/5X'SLOPE VELOCITY COEFFICIENT ARRAY (XYMC(K)), NEWTON*CM*SE04003800
     2C/RADIAN')                                                         04003820
      WRITE(6,404) (XYMC(I),I=1,NB)                                      04003840
      WRITE(6,62)                                                        04003860
62    FORMAT('      BEARING OUT-OF-PHASE DAMPING YZ-PLANE MOMENT FROM XZ-04003880
     1PLANE'/5X'SLOPE VELOCITY COEFFICIENT ARRAY (YXMC(K)), NEWTON*CM*SE04003900
     2C/RADIAN')                                                         04003920
      WRITE(6,404) (YXMC(I),I=1,NB)                                      04003940
      WRITE(6,63)                                                        04003960
   63 FORMAT(/////'  IV. NONLINEAR BEARING PARAMETERS (K=1,NB), (L=1,KK(04003980
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     1K))'/)                                                            04004000
      WRITE(6,65)                                                       04004020
   65 FORMAT(5X'SPIN SPEED PARAMETER ARRAY (FDOFIX(K)), RADIANS/SEC')   04004040
      WRITE(6,404) (FDOFIX(I),I=1,NB)                                   04004060
      DO 201 I=1,NB                                                     04004080
      K=KK(I)                                                           04004100
      WRITE(6,64) I                                                     04004120
64    FORMAT(/  5X'THE NONLINEAR STIFFNESS COEFFICIENTS FOR STIFFNESS SE04004140
     &CTIONS 1,2,3, ETC. FOR THE',I2,'TH BEARING ARE:'/)                04004160
      WRITE(6,160)                                                      04004180
  160 FORMAT(5X'BBB(K,L), NEWTON*SEC/(RADIAN*CM**2)')                   04004200
      WRITE(6,404) (BBB(I,J),J=1,K)                                     04004220
      WRITE(6,66)                                                       04004240
   66 FORMAT(5X'BCB(K,L), 1./CM**BHB(I,L)')                             04004260
      WRITE(6,404) (BCB(I,J),J=1,K)                                     04004280
      WRITE(6,161)                                                      04004300
  161 FORMAT(5X'BDB(K,L), 1./CM')                                       04004320
      WRITE(6,404) (BDB(I,J),J=1,K)                                     04004340
      WRITE(6,67)                                                       04004360
   67 FORMAT(5X'BEB(K,L), DIMENSIONLESS')                               04004380
      WRITE(6,404) (BEB(I,J),J=1,K)                                     04004400
      WRITE(6,68)                                                       04004420
   68 FORMAT(5X'BKB(K,L), NEWTON/CM')                                   04004440
      WRITE(6,404) (BKB(I,J),J=1,K)                                     04004460
      WRITE(6,69)                                                       04004480
   69 FORMAT(5X'BNB(K,L), (NEWTON*SEC)/(CM*RADIAN)')                    04004500
      WRITE(6,404) (BNB(I,J),J=1,K)                                     04004520
      WRITE(6,71)                                                       04004540
   71 FORMAT(5X'BHB(K,L), DIMENSIONLESS')                               04004560
      WRITE(6,404) (BHB(I,J),J=1,K)                                     04004580
      K1=K+1                                                            04004600
      WRITE(6,70)                                                       04004620
   70 FORMAT(5X'BROB(K,L+1), CM')                                       04004640
      WRITE(6,404) (BROB(I,J),J=1,K1)                                   04004660
201   CONTINUE                                                          04004680
      WRITE(6,72)                                                       04004700
   72 FORMAT(/////'  V. ROTOR-TO-CASING GENERAL STIFFNESS AND DAMPING FO04004720
     1RCE AND MOMENT COEFFICIENTS (I=1,NS)'/)                           04004740
      WRITE(6,73)                                                       04004760
   73 FORMAT(5X'IN-PHASE STIFFNESS FORCE COEFFICIENT ARRAY (QK(I)), NEWT04004780
     1ON/CM')                                                           04004800
      WRITE(6,404) (QK(I),I=1,NS)                                       04004820
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      WRITE(6,74)                                                       04004840
   74 FORMAT(5X'OUT-OF-PHASE STIFFNESS FORCE COEFFICIENT ARRAY (QKP(I)),04004860
     1 NEWTON/CM')                                                      04004680
      WRITE(6,404) (QKP(I),I=1,NS)                                      04004900
      WRITE(6,75)                                                       04004920
   75 FORMAT(5X'IN-PHASE DAMPING FORCE COEFFICIENT ARRAY (QC(I)), NEWTON04004940
     1*SEC/CM')                                                         04004960
      WRITE(6,404) (QC(I),I=1,NS)                                       04004980
      WRITE(6,76)                                                       04005000
   76 FORMAT(5X'OUT-OF-PHASE DAMPING FORCE COEFFICIENT ARRAY (QCP(I)), N04005020
     1EWTON*SEC/CM')                                                    04005040
      WRITE(6,404) (QCP(I),I=1,NS)                                      04005060
      WRITE(6,77)                                                       04005080
   77 FORMAT(5X'IN-PHASE STIFFNESS MOMENT COEFFICIENT ARRAY (QKF(I)), NE04005100
     1WTON*CM/RADIAN')                                                  04005120
      WRITE(6,404) (QKF(I),I=1,NS)                                      04005140
      WRITE(6,78)                                                       04005160
   78 FORMAT(5X'OUT-OF-PHASE STIFFNESS MOMENT COEFFICIENT ARRAY (QKPF(I)04005180
     1), NEWTON*CM/RADIAN')                                             04005200
      WRITE(6,404) (QKPF(I),I=1,NS)                                     04005220
      WRITE(6,79)                                                       04005240
   79 FORMAT(5X'IN-PHASE DAMPING MOMENT COEFFICIENT ARRAY (QCF(I)), NEWT04005260
     1ON*CM*SEC/RADIAN')                                                04005280
      WRITE(6,404) (QCF(I),I=1,NS)                                      04005300
      WRITE(6,80)                                                       04005320
   80 FORMAT(5X'OUT-OF-PHASE DAMPING MOMENT COEFFICIENT ARRAY (QCPF(I)),04005340
     1 NEWTON*CM*SEC/RADIAN')                                           04005360
      WRITE(6,404) (QCPF(I),I=1,NS)                                     04005380
      WRITE(6,81)                                                       04005400
   81 FORMAT(5X'WHIRL STIFFNESS FORCE FACTOR ARRAY (XKF(I)), DIMENSIONLE04005420
     1SS')                                                              04005440
      WRITE(6,404) (XKF(I),I=1,NS)                                      04005460
      WRITE(6,82)                                                       04005480
   82 FORMAT(5X'WHIRL DAMPING FORCE FACTOR ARRAY (XCF(I)), DIMENSIONLESS04005500
     1')                                                                04005520
      WRITE(6,404) (XCF(I),I=1,NS)                                      04005540
      WRITE(6,83)                                                       04005560
   83 FORMAT(5X'WHIRL STIFFNESS MOMENT FACTOR ARRAY (XKFF(I)), DIMENSION04005580
     1LESS')                                                            04005600
      WRITE(6,404) (XKFF(I),I=1,NS)                                     04005620
      WRITE(6,84)                                                       04005640
   84 FORMAT(5X'WHIRL DAMPING MOMENT FACTOR ARRAY (XCFF(I)), DIMENSIONLE04005660
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      1SS')                                                             04005680
       WRITE(6,404) (XCFF(I),I=1,NS)                                    04005700
       WRITE(6,85)                                                      04005720
 85    FORMAT('      OUT-OF-PHASE STIFFNESS FORCE WHIRL-SPIN'1X         04005740
      1'COEFFICIENT ARRAY (QKHD(I)), NEWTON*SEC/CM')                    04005760
       WRITE(6,404) (QKHD(I),I=1,NS)                                    04005780
       WRITE(6,86)                                                      04005800
 86    FORMAT('      OUT-OF-PHASE DAMPING FORCE WHIRL-SPIN'1X           04005820
      1'COEFFICIENT ARRAY (QCHD(I)), NEWTON*SEC**2/CM')                 04005840
       WRITE(6,404) (QCHD(I),I=1,NS)                                    04005860
       WRITE(6,87)                                                      04005880
 87    FORMAT('      OUT-OF-PHASE STIFFNESS MOMENT WHIRL-SPIN'1X        04005900
      1'COEFFICIENT ARRAY (QKHDF(I)), NEWTON*CM*SEC/RADIAN')            04005920
       WRITE(6,404) (QKHDF(I),I=1,NS)                                   04005940
       WRITE(6,88)                                                      04005960
 88    FORMAT('      OUT-OF-PHASE DAMPING MOMENT WHIRL-SPIN'1X          04005980
      1'COEFFICIENT ARRAY (QCHDF(I)), NEWTON*CM*SEC**2/RADIAN')         04006000
       WRITE(6,404) (QCHDF(I),I=1,NS)                                   04006020
       WRITE(6,89)                                                      04006040
    89 FORMAT(/////'  VI. ROTOR DRIVE AND DAMPING TORQUE PARAMETERS (I=1,04006060
      1NS)'/)                                                           04006080
       WRITE(6,120) ITORQ                                               04006100
 120   FORMAT('      TORQUE CONTROL VARIABLE  (ITORQ) = ',I1,/          04006120
      &       21X'1=INCLUDING DRIVE AND DAMPING TORQUE IN COMPUTATION'/ 04006140
      &       21X'0= EXCLUDING THE TORQUE'/)                            04006160
       WRITE(6,121) IMT                                                 04006180
 121   FORMAT('      TORQUE TRANSVERSE EFFECT CONTROL VARIABLE  (IMT) = ',04006200
      &I1,/         21X'1=INCLUDING THE EFFECTS'/                       04006220
      &       21X'0=EXCLUDING THE EFFECTS'/)                            04006240
       WRITE(6,98)                                                      04006260
    98 FORMAT(5X'CT(I) ARRAY (CT(I) MUST BE POSITIVE INTEGERS), DIMENSION04006280
      1LESS')                                                           04006300
       WRITE(6,40 ) (CT(I),I=1,NS)                                      04006320
       WRITE(6,99)                                                      04006340
    99 FORMAT(5X'CT1(I) ARRAY, (NEWTON*CM)/(RADIANS/SEC)**CT(I)')       04006360
       WRITE(6,404) (CT1(I),I=1,NS)                                     04006380
       WRITE(6,100)                                                     04006400
   100 FORMAT(5X'CT2(I) ARRAY, (NEWTON*CM)/(RADIANS/SEC)')              04006420
       WRITE(6,404) (CT2(I),I=1,NS)                                     04006440
       WRITE(6,90)                                                      04006460
    90 FORMAT(5X'MT(I) ARRAY (MT(I) MUST BE POSITIVE INTEGERS), DIMENSION04006480
      1LESS')                                                           04006500
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      WRITE(6,40 ) (MT(I),I=1,NS)
      WRITE(6,91)
   91 FORMAT(5X'MT1(I) ARRAY, (NEWTON*CM)/(RADIANS/SEC)**MT(I)')
      WRITE(6,404) (MT1(I),I=1,NS)
      WRITE(6,92)
   92 FORMAT(5X'MT2(I) ARRAY, NEWTON*CM/(RADIANS/SEC)')
      WRITE(6,404) (MT2(I),I=1,NS)
      WRITE(6,93)
   93 FORMAT(5X'AT(I) ARRAY, NEWTON*CM')
      WRITE(6,404) (AT(I),I=1,NS)
      WRITE(6,94)
   94 FORMAT(5X'BT(I) ARRAY, (NEWTON*CM)/SEC')
      WRITE(6,404) (BT(I),I=1,NS)
      WRITE(6,95)
   95 FORMAT(5X'DU(I) ARRAY, (NEWTON*CM)/SEC**HT(I)')
      WRITE(6,404) (DU(I),I=1,NS)
      WRITE(6,96)
   96 FORMAT(5X'ET(I) ARRAY, NEWTON*CM')
      WRITE(6,404) (ET(I),I=1,NS)
      WRITE(6,97)
   97 FORMAT(5X'HT(I) ARRAY (HT(I) MUST BE POSITIVE NUMBER), DIMENSIONLE
     1SS')
      WRITE(6,404) (HT(I),I=1,NS)
      WRITE(6,101)
  101 FORMAT(5X'FT(I) ARRAY, RADIANS/SEC')
      WRITE(6,404) (FT(I),I=1,NS)
      WRITE(6,102)
  102 FORMAT(5X'GT(I) ARRAY, RADIANS')
      WRITE(6,404) (GT(I),I=1,NS)
      WRITE(6,103)
  103 FORMAT(/////'  VII. ROTOR AXIAL LOADING PARAMETERS (I=1,NS)'/)
      WRITE(6,122) IPP
122   FORMAT('      AXIAL LOADING CONTROL VARIABLE  (IPP) = ',I1,/
     &       21X'1=INCLUDING AXIAL LOADING TRANSVERSE EFFECTS'/
     &       21X'0=EXCLUDING THE EFFECTS'/)
      WRITE(6,104)
  104 FORMAT(5X'AA(I) ARRAY, NEWTONS')
      WRITE(6,404) (AA(I),I=1,NS)
      WRITE(6,105)
  105 FORMAT(5X'BA(I) ARRAY, NEWTONS/SEC')
      WRITE(6,404) (BA(I),I=1,NS)
      WRITE(6,106)
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  106 FORMAT(5X'DA(I) ARRAY, NEWTONS/SEC**HA')                         04007360
      WRITE(6,404) (DA(I),I=1,NS)                                      04007380
      WRITE(6,107)                                                     04007400
  107 FORMAT(5X'EA(I) ARRAY, NEWTONS')                                 04007420
      WRITE(6,404) (EA(I),I=1,NS)                                      04007440
      WRITE(6,108)                                                     04007460
  108 FORMAT(5X'HA DIMENSIONLESS,  FA RADIANS/SEC,  GA RADIANS (HA MUST 04007480
     &BE A POSITIVE NUMBER.)')                                         04007500
      WRITE(6,404) HA,FA,GA                                            04007520
      WRITE(6,109)                                                     04007540
  109 FORMAT(/////'  VIII. ROTOR SYSTEM G-LOADING PARAMETERS'/)        04007560
      WRITE(6,110)                                                     04007580
110   FORMAT('      TRANSVERSE ACCELERATION OR GRAVITY LOADING IN'     04007600
     11X'MINUS X-DIRECTION (GX), CM/SEC**2')                           04007620
      WRITE(6,404) GX                                                  04007640
      WRITE(6,111)                                                     04007660
111   FORMAT('      TRANSVERSE ACCELERATION OR GRAVITY LOADING IN'     04007680
     11X'MINUS Y-DIRECTION (GY), CM/SEC**2')                           04007700
      WRITE(6,404) GY                                                  04007720
      WRITE(6,112)                                                     04007740
  112 FORMAT(/////'  IX. ROTOR MATERIAL MECHANICAL HYSTERESIS PARAMETERS04007760
     1 (J=1,NS-1)'/)                                                   04007780
      WRITE(6,113)                                                     04007800
  113 FORMAT(5X'TRANSVERSE SHEAR VISCOUS COEFFICIENT ARRAY (USV(J)), NEW04007820
     1TON*SEC/CM**2')                                                  04007840
      WRITE(6,404) (USV(I),I=1,NSM1)                                   04007860
      WRITE(6,114)                                                     04007880
114   FORMAT('      TRANSVERSE SHEAR COULOMB FRICTION COEFFICIENT'1X   04007900
     1'ARRAY (USC(J)), NEWTON/CM**2')                                  04007920
      WRITE(6,404) (USC(I),I=1,NSM1)                                   04007940
      WRITE(6,115)                                                     04007960
  115 FORMAT(5X'TRANSVERSE BENDING VISCOUS COEFFICIENT ARRAY (UBV(J)), N04007980
     1EWTON*SEC/CM**2')                                                04008000
      WRITE(6,404) (UBV(I),I=1,NSM1)                                   04008020
      WRITE(6,116)                                                     04008040
116   FORMAT('      TRANSVERSE BENDING COULOMB FRICTION COEFFICIENT'   04008060
     11X'ARRAY (UBC(J)), NEWTON/CM**2')                                04008080
      WRITE(6,404) (UBC(I),I=1,NSM1)                                   04008100
      WRITE(6,117)                                                     04008120
  117 FORMAT(5X'TORSIONAL SHEAR VISCOUS COEFFICIENT ARRAY (UTV(J)), NEWT04008140
     1ON*SEC/CM**2')                                                   04008160
      WRITE(6,404) (UTV(I),I=1,NSM1)                                   04008180
```

```
      WRITE(6,118)
118   FORMAT('     TORSIONAL SHEAR COULOMB FRICTION COEFFICIENT'1X
     1'ARRAY (UTC(J)), NEWTON/CM**2')
      WRITE(6,404) (UTC(I),I=1,NSM1)
      WRITE(6,119)
  119 FORMAT(//'  *** THIS IS THE END OF INPUT DATA. ***'////)
      AIN=2.54
      AF=4.4482216152605
      AFIN=11.298482902761
      AFIN2=28.69814657
      AFOIN=1.7512683521146
      AFOIN2=.6894757293168
      AMASS=.45359237
      AINER=2.926396534292
      ADN=.0276799047101
      DO 298 I=1,NB
      KI=KK(I)
      DO 299 J=1,KI
      BNB(I,J)=BNB(I,J)/AFOIN
      BKB(I,J)=BKB(I,J)/AFOIN
      BBB(I,J)=BBB(I,J)*AIN/AFOIN
      BCB(I,J)=BCB(I,J)*AIN
  299 BDB(I,J)=BDB(I,J)*AIN
      K2=1+KK(I)
      DO 300 K=2,K2
  300 BROB(I,K)=BROB(I,K)/AIN
  298 CONTINUE
      DO 301 I=1,NSM1
      DD(I)=DD(I)/AIN
      D(I)=D(I)/AIN
      QL(I)=QL(I)/AIN
      DN(I)=DN(I)/ADN
      EE(I)=EE(I)/AFOIN2
      GG(I)=GG(I)/AFOIN2
      EI(I)=EI(I)/AFIN2
      GAK(I)=GAK(I)/AF
      USV(I)=USV(I)/AFOIN2
      USC(I)=USC(I)/AFOIN2
      UBV(I)=UBV(I)/AFOIN2
      UBC(I)=UBC(I)/AFOIN2
      UTV(I)=UTV(I)/AFOIN2
301   UTC(I)=UTC(I)/AFOIN2
```

```
      DO 302 I=1,NS                                                     04009040
      AM(I)=AM(I)/AMASS                                                 04009060
      AID(I)=AID(I)/AINER                                               04009080
      AIRO(I)=AIRO(I)/AINER                                             04009100
      ECC(I)=ECC(I)/AIN                                                 04009120
      QK(I)=QK(I)/AFOIN                                                 04009140
      QC(I)=QC(I)/AFOIN                                                 04009160
      QKP(I)=QKP(I)/AFOIN                                               04009180
      QCP(I)=QCP(I)/AFOIN                                               04009200
      QKF(I)=QKF(I)/AFIN                                                04009220
      QCF(I)=QCF(I)/AFIN                                                04009240
      QKPF(I)=QKPF(I)/AFIN                                              04009260
      QCPF(I)=QCPF(I)/AFIN                                              04009280
      QKHD(I)=QKHD(I)/AFOIN                                             04009300
      QCHD(I)=QCHD(I)/AFOIN                                             04009320
      QKHDF(I)=QKHDF(I)/AFIN                                            04009340
      QCHDF(I)=QCHDF(I)/AFIN                                            04009360
      CT1(I)=CT1(I)/AFIN                                                04009380
      CT2(I)=CT2(I)/AFIN                                                04009400
      MT1(I)=MT1(I)/AFIN                                                04009420
      MT2(I)=MT2(I)/AFIN                                                04009440
      AT(I)=AT(I)/AFIN                                                  04009460
      BT(I)=BT(I)/AFIN                                                  04009480
      DU(I)=DU(I)/AFIN                                                  04009500
      ET(I)=ET(I)/AFIN                                                  04009520
      AA(I)=AA(I)/AF                                                    04009540
      BA(I)=BA(I)/AF                                                    04009560
      DA(I)=DA(I)/AF                                                    04009580
      EA(I)=EA(I)/AF                                                    04009600
  302 CONTINUE                                                          04009620
      GX=GX/AIN                                                         04009640
      GY=GY/AIN                                                         04009660
      DO 303 I=1,NB                                                     04009680
      BKMX(I)=BKMX(I)/AFOIN                                             04009700
      BKMY(I)=BKMY(I)/AFOIN                                             04009720
      BCMX(I)=BCMX(I)/AFOIN                                             04009740
      BCMY(I)=BCMY(I)/AFOIN                                             04009760
      XKMM(I)=XKMM(I)/AFIN                                              04009780
      YKMM(I)=YKMM(I)/AFIN                                              04009800
      XCMM(I)=XCMM(I)/AFIN                                              04009820
      YCMM(I)=YCMM(I)/AFIN                                              04009840
      BM(I)=BM(I)/AMASS                                                 04009860
```

```
      BI(I)=BI(I)/AINER
      QKXX(I)=QKXX(I)/AFOIN
      QKXY(I)=QKXY(I)/AFOIN
      QKYY(I)=QKYY(I)/AFOIN
      QKYX(I)=QKYX(I)/AFOIN
      QCXX(I)=QCXX(I)/AFOIN
      QCXY(I)=QCXY(I)/AFOIN
      QCYY(I)=QCYY(I)/AFOIN
      QCYX(I)=QCYX(I)/AFOIN
      XXMK(I)=XXMK(I)/AFIN
      XYMK(I)=XYMK(I)/AFIN
      YYMK(I)=YYMK(I)/AFIN
      YXMK(I)=YXMK(I)/AFIN
      XXMC(I)=XXMC(I)/AFIN
      XYMC(I)=XYMC(I)/AFIN
      YYMC(I)=YYMC(I)/AFIN
  303 YXMC(I)=YXMC(I)/AFIN
      V=PI/180.
      U=V*6.
      G=386.088
      F(1)=F(1)*V
      FDOT(1)=FDOT(1)*U
      DO 7 I=1,NS
      ALFA(I)=ALFA(I)*V
      GAMMA(I)=GAMMA(I)*V
      BETA(I)=BETA(I)*V
      AM(I)=AM(I)/G
      AIRO(I)=AIRO(I)/G
    7 AID(I)=AID(I)/G
      DO 8 I=1,NB
      BI(I)=BI(I)/G
    8 BM(I)=BM(I)/G
      RETURN
      END
      SUBROUTINE HYSINF
      INTEGER       CONTIN,RIG,CT,CRT
      REAL INPRPM,   MT1,MT2,MOF,MOM
      DIMENSION SHERGA(14),ROF(15,15),ROM(15,15),AFALEI(14),QLEI(14),
     &SQL2EI(14),FOF(15,15),MOF(15,15),FOM(15,15),MOM(15,15)
      DIMENSION  SZ(15),ZQ(15),QZOL(15),SZOL(15),ZQOL(15),ZSOL(15)
      COMMON NS,NS2,NS3,NS4,NS5,NS6,NS7,NS8,NS9,NS10,NSM1,NSP1,NS2P1,
     &NS4P1,IP,IPRINT,
```

```
     &NN,NB,IB1,IBNB,NNT,ITIM,IUSE,CRT,CONTIN,NOORPM,IASIGN,NPOINT,
     &MOSHA,MET,IND,IPP,ITORQ,IMT,G
      COMMON PI, T,DT,TMAX,DP,       TOLI,GX,GY,Q,S,QLL,QMLOV,HA,FA,GA
      COMMON IB(6),KKSPA(6),RIG(14),JBI(15),CT(15),MT(15)
      COMMON TITLE(18),F(15),FDOT(15),FDOFIX(6),DD(14),D(14),QL(14),
     &P(14),
     &DN(14),EE(14),GG(14),EI(14),GAK(14),SHK(14),AM(15),AID(15),
     &AIRO(15),QM(15),
     &QID(15),QIRO(15),ECC(15),ALFA(15),BETA(15),GAMMA(15),QME(15),
     &FOSTIF(6),Z(15),QZ(15),QK(15),QC(15),QKP(15),QCP(15),QKHD(15),
     &QCHD(15),QKF(15),QCF(15),QKPF(15),QCPF(15),QKHDF(15),QCHDF(15),
     &XKF(15),XCF(15),XKFF(15),XCFF(15),
     &QKXX(6),QKXY(6),QKYY(6),QKYX(6), QCXX(6),QCXY(6),QCYY(6),QCYX(6),
     &XXMK(6),XYMK(6),YYMK(6),YXMK(6),XXMC(6),XYMC(6),YYMC(6),YXMC(6),
     &BI(6),XKMM(6),YKMM(6),XCMM(6),YCMM(6),
     &BKMX(6),BKMY(6),BCMX(6),BCMY(6),BM(6),USV(14),USC(14),
     &UBV(14),UBC(14),UTV(14),UTC(14),CT1(15),CT2(15),CTV(14),CTC(14),
     &MT1(15),MT2(15),AT(15),BT(15),DU(15),HT(15),ET(15),FT(15),GT(15),
     &AA(15),BA(15),DA(15),EA(15),YN(84),INPRPM(50),C(15,15),B(15,15),
     &TF(15,15),TM(15,15),BBB(6,3),BDB(6,3),BEB(6,3),
     &BCB(6,3),BHB(6,3),BKB(6,3),BNB(6,3),BROB(6,4)
      Z(1)=0
      DO 105  I=2,NS
105   Z(I)=Z(I-1)+QL(I-1)
      Q=Z(IBNB)
      S=Z(IB1)
      DO 103 I=1,NS
      SZ(I)=Z(IB1)-Z(I)
      ZQ(I)=Z(I)-Z(IBNB)
103   QZ(I)=-ZQ(I)
      QLL=Z(IBNB)-Z(IB1)
      QMLOV=-1./QLL
      DO 104  I=1,NS
      SZOL(I)=SZ(I)/QLL
      ZSOL(I)=-SZOL(I)
      QZOL(I)=QZ(I)/QLL
104   ZQOL(I)=-QZOL(I)
      IB2=IBNB
      DO 200 I=1,NSM1
      RA=D(I)/DD(I)
      SHK(I)=((7.+6.*P(I))*(1.+RA**2)**2+(20.+12.*P(I))*RA**2)/
     &(6.*(1.+P(I))*(1.+RA**2)**2)
```

```
      QLEI(I)=QL(I)/(EE(I)*PI/64.*(DD(I)**4-D(I)**4)+EI(I))
      SQL2EI(I)=.5*QL(I)*QLEI(I)
      SHERGA(I)=QL(I)/(GG(I)*PI/4.*(DD(I)**2-D(I)**2)/SHK(I)+GAK(I))
  200 AFALEI(I)=SHERGA(I)+2./3.*QL(I)*SQL2EI(I)
      DO 400 I=1,NS
      DO 400 J=1,NS
      FOF(I,J)=0.
      MOF(I,J)=0.
      FOM(I,J)=0.
      MOM(I,J)=0.
      C(I,J)=0
  400 B(I,J)=0
      DO 140      I=1,IB1
      IF(IB1.EQ.1) GO TO 122
      K=I+1
      DO 120 J=K,IB1
      FOF(I,J) =-1.0
      MOF(I,J) =Z(J)-Z(I)
  120 MOM(I,J) = -1.0
  122 K=IB1+1
      DO 130   J=K,IB2
      FOF(I,J)= SZOL(I)
      MOF(I,J)=QZ(J)*SZOL(I)
      FOM(I,J)=QMLOV
  130 MOM(I,J)=ZQOL(J)
  140 CONTINUE
      KK=IB1+1
      DO 440    I=KK,   IB2
      K=IB1+1
      DO 420   J=K,I
      FOF(I,J) = QZOL(I)
      MOF(I,J)=SZ(J)*QZOL(I)
      FOM(I,J) =QMLOV
  420 MOM(I,J)  =ZSOL(J)
      K=I+1
      IF(K.GT.IB2) GO TO 440
      DO 430   J=K,   IB2
      FOF(I,J) =SZOL(I)
      MOF(I,J)=-ZQ(J)*SZOL(I)
      FOM(I,J)=QMLOV
  430 MOM(I,J)=ZQOL(J)
  440 CONTINUE
```

```
      IF (IB2.EQ.NS)GO TO 542                                           06001860
      KK=IB2+1                                                          06001880
      DO  540     I=KK,    NS                                           06001900
      K=IB1+1                                                           06001920
      DO 520    J=K,     IB2                                            06001940
      FOF(I,J) =QZOL(I)                                                 06001960
      MOF(I,J)=SZ(J)*QZOL(I)                                            06001980
      FOM(I,J)=QMLOV                                                    06002000
520   MOM(I,J) =ZSOL(J)                                                 06002020
      K=IB2+1                                                           06002040
      DO 530     J=K,     I                                             06002060
      FOF(I,J) =1.                                                      06002080
      MOF(I,J) =Z(I)-Z(J)                                               06002100
530   MOM(I,J) =1.0                                                     06002120
540   CONTINUE                                                          06002140
542   DO 600  I=1,NS                                                    06002160
      ROF(I,1)=0.                                                       06002180
      ROM(I,1)=0.                                                       06002200
      TF(I,1)=0                                                         06002220
      TM(I,1)=0                                                         06002240
      DO 600     J=2,NS                                                 06002260
      ROF(I,J)=ROF(I,J-1)+QL(J-1)*TF(I,J-1)+AFALEI(J-1)*FOF(I,J)        06002280
     &+MOF(I,J)*SQL2EI(J-1)                                             06002300
      ROM(I,J)=ROM(I,J-1)+QL(J-1)*TM(I,J-1)+AFALEI(J-1)*FOM(I,J)        06002320
     &+MOM(I,J)*SQL2EI(J-1)                                             06002340
      TF(I,J)=TF(I,J-1)+SQL2EI(J-1)*FOF(I,J)+QLEI(J-1)*MOF(I,J)         06002360
600   TM(I,J)=TM(I,J-1)+SQL2EI(J-1)*FOM(I,J)+QLEI(J-1)*MOM(I,J)         06002380
      DO 700     I=1,NS                                                 06002400
      DO 700     J=1,NS                                                 06002420
      TF(I,J)=TF(I,J)-(ROF(I,IB2)-ROF(I,IB1))/QLL                       06002440
      TM(I,J)=TM(I,J)-(ROM(I,IB2)-ROM(I,IB1))/QLL                       06002460
      C(I,J)=ROF(I,J)-ROF(I,IB1)+SZOL(J)*(ROF(I,IB2)-ROF(I,IB1))        06002480
700   B(I,J)=ROM(I,J)-ROM(I,IB1)+SZOL(J)*(ROM(I,IB2)-ROM(I,IB1))        06002500
      RETURN                                                            06002520
      END                                                               06002540
      SUBROUTINE HYSSTA                                                 07000000
      INTEGER        CONTIN,RIG,CT,CRT                                  07000020
      INTEGER PRISTA,PRIMAS                                             07000040
      REAL INPRPM,   MT1,MT2,MC,MYC,MXY,MXX,MXC,MOUNRO,MOPHAS           07000060
      DIMENSION XS(15),YS(15),ROSL(15),PHAROS(15),XBDO(6),YBDO(6),      07000080
     &XBMDO(6),QW(15),QIDW(15),QIROW(15),IA(84),                        07000100
     &YBMDO(6),XMDO(6),YMDO(6),XMMDO(6),YMMDO(6),BSLRO(6),BSPHAS(6),    07000120
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     &ROMM(6),PHASMM(6),XBFOR(6),YBFOR(6),XBMOM(6),YBMOM(6),XMFOR(6),    07000140
     &YMFOR(6),XMMOM(6),YMMOM(6),XBMFO(6),YBMFO(6),XBIMO(6),YBIMO(6)     07000160
      DIMENSION BKM(6),BCM(6),BKMM(6),BCMM(6),XBM(6),YBM(6),XMM(6),      07000180
     &YMM(6),                                                            07000200
     &XXK(6),XYK(6),XXC(6),XYC(6),XXKM(6),XYKM(6),XXCM(6),XYCM(6)        07000220
      DIMENSION XM(6),YM(6),MOUNRO(6),MOPHAS(6),BRGRO(6),BRPHAS(6),      07000240
     &QKB(6),DDL(14),Q1LDND(14),Q6LDND(14),DDPLD(14),                    07000260
     &ZSOL(15),FXX(15),FXY(15),FXC(15),FYC(15),MXX(15),MXY(15),MXC(15), 07000280
     &MYC(15),                                                           07000300
     &XX(15),YY(15),XB(15),YB(15),RO(15),PHAROO(15),                     07000320
     &CC(84),           AA(84,84)                                        07000340
      COMMON NS,NS2,NS3,NS4,NS5,NS6,NS7,NS8,NS9,NS10,NSM1,NSP1,NS2P1,    07000360
     &NS4P1,IP,IPRINT,                                                   07000380
     &NN,NB,IB1,IBNB,NNT,ITIM,IUSE,CRT,CONTIN,NOORPM,IASIGN,NPOINT,      07000400
     &MOSHA,MET,IND,IPP,ITORQ,IMT,G                                      07000420
      COMMON PI, T,DT,TMAX,DP,       TOLI,GX,GY,Q,S,QLL,QMLOV,HA,FA,GA   07000440
      COMMON IB(6),KK(6),RIG(14),JBI(15),CT(15),MT(15)                   07000460
      COMMON TITLE(18),F(15),FDOT(15),FDOFIX(6),DD(14),D(14),QL(14),     07000480
     &P(14),                                                             07000500
     &DN(14),EE(14),GG(14),EI(14),GAK(14),SHK(14),AM(15),AID(15),        07000520
     &AIRO(15),QM(15),                                                   07000540
     &QID(15),QIRO(15),ECC(15),ALFA(15),BETA(15),GAMMA(15),QME(15),      07000560
     &FOSTIF(6),                                                         07000580
     &Z(15),QZ(15),QK(15),QC(15),QKP(15),QCP(15),QKHD(15),QCHD(15),      07000600
     &QKF(15),QCF(15),                                                   07000620
     &QKPF(15),QCPF(15),QKHDF(15),QCHDF(15),XKF(15),XCF(15),XKFF(15),    07000640
     &XCFF(15),                                                          07000660
     &QKXX(6),QKXY(6),QKYY(6),QKYX(6),QCXX(6),QCXY(6),QCYY(6),QCYX(6),   07000680
     &XXMK(6),XYMK(6),YYMK(6),YXMK(6),XXMC(6),XYMC(6),YYMC(6),YXMC(6),   07000700
     &BI(6),XKMM(6),YKMM(6),XCMM(6),YCMM(6),                             07000720
     &BKMX(6),BKMY(6),BCMX(6),BCMY(6),BM(6),USV(14),USC(14),             07000740
     &UBV(14),UBC(14),UTV(14),UTC(14),CT1(15),CT2(15),CTV(14),CTC(14),   07000760
     &MT1(15),MT2(15),AT(15),BT(15),DU(15),HT(15),ET(15),FT(15),GT(15), 07000780
     &SPA(15),                                                           07000800
     &BA(15),DA(15),EA(15),   YN(84),   INPRPM(50)                       07000820
      COMMON C(15,15),B(15,15),TF(15,15),TM(15,15),BBB(6,3),BDB(6,3),    07000840
     &BEB(6,3),                                                          07000860
     &BCB(6,3),BHB(6,3),BKB(6,3),BNB(6,3),BROB(6,4)                      07000880
 40   FORMAT(6I12)                                                       07000900
 404  FORMAT(1PE21.4,1P4E13.4)                                           07000920
      NS4P2=NS4P1+1                                                      07000940
      NS4NB=NS4+NB                                                       07000960
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      NS42NB=NS4NB+NB                                                   07000980
      NS43NB=NS42NB+NB                                                  07001000
      NS44NB=NS43NB+NB                                                  07001020
      U=4./3.                                                           07001040
      V=180./PI                                                         07001060
      W=PI/(128.*G)                                                     07001080
      E=PI/(8.*G)                                                       07001100
      DO 5 I=1,NS                                                       07001120
    5 ZSOL(I)=(Z(I)-S)/QLL                                              07001140
      DO 90 I=1,NB                                                      07001160
90    QKB(I)=((FDOT(1)-FDOFIX(I))*BNB(I,1)+BKB(I,1))*BDB(I,1)          07001180
      SUM=0                                                             07001200
      DO 50 I=1,NSM1                                                    07001220
      DD2    = DD(I)**2                                                 07001240
      D2     = D(I)**2                                                  07001260
      QL2    = QL(I)**2                                                 07001280
      QLDNDD   =QL(I)* DN(I)*(DD2   -D2    )                            07001300
      SUM=SUM+.25*PI*QLDNDD*(.5*QL(I)+Z(I))+AM(I+1)*G*Z(I+1)            07001320
      Q6LDND(I) =                W*QLDNDD                               07001340
      DDPLD(I) = DD2   +D2                                              07001360
      DDL(I) = DDPLD(I)+         U*QL2                                  07001380
50    Q1LDND(I) =            E*QLDNDD                                   07001400
      QM(1)=Q1LDND(1) + AM(1)                                           07001420
      QM(NS)=Q1LDND(NS-1) +AM(NS)                                       07001440
      QID(1) = Q6LDND(1)*DDL(1) + AID(1)                                07001460
      QID(NS)= Q6LDND(NS-1)*DDL(NS-1)    +AID(NS)                       07001480
      QIRO(1)=2.*Q6LDND(1)*DDPLD(1)+AIRO(1)                             07001500
      QIRO(NS)=2.*Q6LDND(NS-1)*DDPLD(NS-1) +AIRO(NS)                    07001520
      DO 55 I=2,NSM1                                                    07001540
      QM(I) =Q1LDND(I-1)+Q1LDND(I) +     AM(I)                          07001560
      QID(I)=Q6LDND(I-1)*DDL(I-1)+Q6LDND(I)*DDL(I)+AID(I)               07001580
55    QIRO(I) = 2.*(Q6LDND(I-1)*DDPLD(I-1)+Q6LDND(I)*DDPLD(I)) +AIRO(I) 07001600
      DO 14 I=1,NS                                                      07001620
      QW(I)=QM(I)*G                                                     07001640
      QIDW(I)=QID(I)*G                                                  07001660
   14 QIROW(I)=QIRO(I)*G                                                07001680
      QMASS=0.0                                                         07001700
      POLARA=0.0                                                        07001720
      DO 42 I=1,NS                                                      07001740
      QMASS=QMASS+QM(I)                                                 07001760
   42 POLARA=POLARA+QIRO(I)                                             07001780
      WEIT =QMASS*G                                                     07001800
```

```
      POLARA=POLARA*G
      CG=SUM/WEIT
      WRITE(6,20)
   20 FORMAT(1H1///)
      WRITE(6,21)
   21 FORMAT(' INPUT ROTOR MASS DATA (I=1,NS)'//)
      IF(MET.EQ.1) GO TO 10
      WRITE(6,12)
   12 FORMAT(' ROTOR MASS ARRAY (QM(I)), LB')
      WRITE(6,404) (QW(I),I=1,NS)
      WRITE(6,13)
   13 FORMAT(' ROTOR TRANSVERSE MASS MOMENT OF INERTIA ARRAY (QID(I)), L
     1B*IN**2')
      WRITE(6,404) (QIDW(I),I=1,NS)
      WRITE(6,15)
   15 FORMAT(' ROTOR POLAR MASS MOMENT OF INERTIA ARRAY (QIRO(I)), LB*IN
     1**2')
      WRITE(6,404) (QIROW(I),I=1,NS)
      WRITE(6,77) WEIT, POLARA,CG
   77 FORMAT(/' TOTAL ROTOR MASS ='1PE13.5,' LB'//' TOTAL ROTOR POLOR MA
     &SS MOMENT OF INERTIA ='1PE13.5,' LB*IN**2'//' THE ROTOR MASS CENTE
     &R OF GRAVITY MEASURED FROM ROTOR STATION  1 ='1PE13.5,' IN')
      GO TO 277
   10 AMASS=.45359237
      AMIN2=2.926396534292
      CG=CG*2.54
      WEIT=WEIT*AMASS
      POLARA=POLARA*AMIN2
      DO 16 I=1,NS
      QW(I)=QW(I)*AMASS
      QIDW(I)=QIDW(I)*AMIN2
   16 QIROW(I)=QIROW(I)*AMIN2
      WRITE(6,18)
   18 FORMAT(' ROTOR MASS ARRAY (QW(I)), KG')
      WRITE(6,404) (QW(I),I=1,NS)
      WRITE(6,19)
   19 FORMAT(' ROTOR TRANSVERSE MASS MOMENT OF INERTIA ARRAY (QIDW(I)),
     1KG*CM**2')
      WRITE(6,404) (QIDW(I),I=1,NS)
      WRITE(6,22)
   22 FORMAT(' ROTOR POLAR MASS MOMENT OF INERTIA ARRAY (QIROW(I)),  KG*
     1CM**2')
```

```
      WRITE(6,404)(QIROW(I),I=1,NS)                                     07002660
      WRITE(6,23) WEIT,POLARA,CG                                        07002680
   23 FORMAT(/' TOTAL ROTOR MASS ='1PE13.5,' KG'//' TOTAL ROTOR POLOR MA07002700
     &SS MOMENT OF INERTIA ='1PE13.5,' KG*CM**2'//' THE ROTOR MASS CENTE07002720
     &R OF GRAVITY MEASURED FROM ROTOR STATION  1 ='1PE13.5,' CM')      07002740
  277 CONTINUE                                                          07002760
      DO 103 I=1,NS                                                     07002780
  103 QME(I)=QM(1)*ECC(I)                                               07002800
      DO 99 I=1,NS                                                      07002840
      FAA=F(1)+ALFA(I)                                                  07002860
      FG=F(1)+GAMMA(I)                                                  07002880
      COSFA=COS(FAA)                                                    07002900
      SINFA=SIN(FAA)                                                    07002920
      COSFG=COS(FG)                                                     07002940
      SINFG=SIN(FG)                                                     07002960
      FDOTSQ=FDOT(1)**2                                                 07002980
      CF=FDOTSQ*QM(I)                                                   07003000
      FC=CF*ECC(I)                                                      07003020
      CM=FDOTSQ*(QID(I)-QIRO(I))                                        07003040
      MC=CM*BETA(I)                                                     07003060
      FXX(I)=CF-QK(I)-FDOT(1)*(QCP(I)+QCHD(I)*FDOT(1)*(1.-QCF(I)))      07003080
      FXY(I)=-QKP(I)+FDOT(1)*(QC(I)-QKHD(I)*FDOT(1)*(1.-QKF(I)))        07003100
      FXC(I)=-FC*COSFA                                                  07003120
      FYC(I)=-FC*SINFA                                                  07003140
      MXX(I)=CM-QKF(I)-FDOT(1)*(QCPF(I)+QCHDF(I)*FDOT(1)*(1.-XCFF(I)))  07003160
      MXY(I)=-QKPF(I)+FDOT(1)*(QCF(I)-QKHDF(I)*FDOT(1)*(1.-XKFF(I)))    07003180
      MXC(I)=-MC*COSFG                                                  07003200
      MYC(I)=-MC*SINFG                                                  07003220
   99 CONTINUE                                                          07003240
      DO 191 J=1,NS44NB                                                 07003260
      CC(J)=0                                                           07003280
      DO 191 I=1,NS44NB                                                 07003300
  191 AA(J,I)=0                                                         07003320
      DO 91  J=1,NS                                                     07003340
      JNS=J+NS                                                          07003360
      J2NS=JNS+NS                                                       07003380
      J3NS=J2NS+NS                                                      07003400
      DO 91 I=1,NS                                                      07003420
      INS=I+NS                                                          07003440
      I2NS=INS+NS                                                       07003460
      I3NS=I2NS+NS                                                      07003480
```

```
      AA(J,I)=C(I,J)*FXX(I)                                             07003500
      AA(J,INS)=C(I,J)*FXY(I)                                           07003520
      AA(J,I2NS)=B(I,J)*MXX(I)                                          07003540
      AA(J,I3NS)=B(I,J)*MXY(I)                                          07003560
      AA(JNS,I)=-AA(J,INS)                                              07003580
      AA(JNS,INS)=AA(J,I)                                               07003600
      AA(JNS,I2NS)=-AA(J,I3NS)                                          07003620
      AA(JNS,I3NS)=AA(J,I2NS)                                           07003640
      AA(J2NS,I)=TF(I,J)*FXX(I)                                         07003660
      AA(J2NS,INS)=TF(I,J)*FXY(I)                                       07003680
      AA(J2NS,I2NS)=TM(I,J)*MXX(I)                                      07003700
      AA(J2NS,I3NS)=TM(I,J)*MXY(I)                                      07003720
      AA(J3NS,I)=-AA(J2NS,INS)                                          07003740
      AA(J3NS,INS)=AA(J2NS,I)                                           07003760
      AA(J3NS,I2NS)=-AA(J2NS,I3NS)                                      07003780
   91 AA(J3NS,I3NS)=AA(J2NS,I2NS)                                       07003800
      DO 92 J=1,NS                                                      07003820
      JNS=J+NS                                                          07003840
      J2NS=JNS+NS                                                       07003860
      J3NS=J2NS+NS                                                      07003880
      DO 92 I=1,NS                                                      07003900
      CC(J)=CC(J)+C(I,J)*FXC(I)+B(I,J)*MXC(I)                           07003920
      CC(JNS)=CC(JNS)+C(I,J)*FYC(I)+B(I,J)*MYC(I)                       07003940
      CC(J2NS)=CC(J2NS)+TF(I,J)*FXC(I)+TM(I,J)*MXC(I)                   07003960
   92 CC(J3NS)=CC(J3NS)+TF(I,J)*FYC(I)+TM(I,J)*MYC(I)                   07003980
      IB1NS=IB1+NS                                                      07004000
      IBNBNS=IBNB+NS                                                    07004020
      DO 93 J=1,NS                                                      07004040
      JNS=J+NS                                                          07004060
      J2NS=JNS+NS                                                       07004080
      J3NS=J2NS+NS                                                      07004100
      AA(J,IB1)=AA(J,IB1)+1.-ZSOL(J)                                    07004120
      AA(J,IBNB)=AA(J,IBNB)+ZSOL(J)                                     07004140
      AA(JNS,IB1NS)=AA(JNS,IB1NS)+1.-ZSOL(J)                            07004160
      AA(JNS,IBNBNS)=AA(JNS,IBNBNS)+ZSOL(J)                             07004180
      AA(J2NS,IB1)=AA(J2NS,IB1)-1./QLL                                  07004200
      AA(J2NS,IBNB)=AA(J2NS,IBNB)+1./QLL                                07004220
      AA(J3NS,IB1NS)=AA(J3NS,IB1NS)-1./QLL                              07004240
      AA(J3NS,IBNBNS)=AA(J3NS,IBNBNS)+1./QLL                            07004260
      AA(J,J)=AA(J,J)-1.                                                07004280
      AA(JNS,JNS)=AA(JNS,JNS)-1.                                        07004300
      AA(J2NS,J2NS)=AA(J2NS,J2NS)-1.                                    07004320
```

```
93    AA(J3NS,J3NS)=AA(J3NS,J3NS)-1.
      DO 94 I=1,NS
      INS=I+NS
      I2NS=INS+NS
      I3NS=I2NS+NS
      AA(IB1,I)=QZ(I)*FXX(I)
      AA(IB1,INS)=QZ(I)*FXY(I)
      AA(IB1,I2NS)=-MXX(I)
      AA(IB1,I3NS)=-MXY(I)
      AA(IBNB,I)=FXX(I)
      AA(IBNB,INS)=FXY(I)
      AA(IBNB,I2NS)=0
      AA(IBNB,I3NS)=0
      AA(IB1NS,I)=-AA(IB1,INS)
      AA(IB1NS,INS)=AA(IB1,I)
      AA(IB1NS,I2NS)=MXY(I)
      AA(IB1NS,I3NS)=-MXX(I)
      AA(IBNBNS,I)=-FXY(I)
      AA(IBNBNS,INS)=FXX(I)
      AA(IBNBNS,I2NS)=0
94    AA(IBNBNS,I3NS)=0
      DO 95 I=1,NS
      CC(IB1)=CC(IB1)+QZ(I)*FXC(I)-MXC(I)
      CC(IBNB)=CC(IBNB)+FXC(I)
      CC(IB1NS)=CC(IB1NS)+QZ(I)*FYC(I)-MYC(I)
95    CC(IBNBNS)=CC(IBNBNS)+FYC(I)
      NSP1=NS+1
      NS4P1=NS4+1
      F1=FDOT(1)
      DO 900 K=1,NB
      XXK(K)=.5*(QKXX(K)+QKYY(K))+QKB(K)
      XYK(K)=.5*(QKXY(K)+QKYX(K))
      XXC(K)=.5*(QCXX(K)+QCYY(K))
      XYC(K)=.5*(QCXY(K)+QCYX(K))
      XXKM(K)=.5*(XXMK(K)+YYMK(K))
      XYKM(K)=.5*(XYMK(K)+YXMK(K))
      XXCM(K)=.5*(XXMC(K)+YYMC(K))
      XYCM(K)=.5*(XYMC(K)+YXMC(K))
      BKM(K)=.5*(BKMX(K)+BKMY(K))
      BCM(K)=.5*(BCMX(K)+BCMY(K))
      BKMM(K)=.5*(XKMM(K)+YKMM(K))
900   BCMM(K)=.5*(XCMM(K)+YCMM(K))
```

```
      NS41=NS4+1
      DO 901 J=1,NS
      DO 901 I=NS41,NS4NB
      J2S=J+NS2
      K=I-NS4
      IK=IB(K)
      INB=I+NB
      I2NB=INB+NB
      I3NB=I2NB+NB
      AA(J,I)=-C(IK,J)*(XXK(K)+F1*XYC(K))
      AA(J,INB)=C(IK,J)*(-XYK(K)+F1*XXC(K))
      AA(J,I2NB)=-B(IK,J)*(XXKM(K)+F1*XYCM(K))
      AA(J,I3NB)=B(IK,J)*(-XYKM(K)+F1*XXCM(K))
      AA(J2S,I)=-TF(IK,J)*(XXK(K)+F1*XYC(K))
      AA(J2S,INB)=TF(IK,J)*(-XYK(K)+F1*XXC(K))
      AA(J2S,I2NB)=-TM(IK,J)*(XXKM(K)+F1*XYCM(K))
901   AA(J2S,I3NB)=TM(IK,J)*(-XYKM(K)+F1*XXCM(K))
      DO 902 I=NS41,NS4NB
      K=I-NS4
      IK=IB(K)
      INB=I+NB
      I2NB=INB+NB
      I3NB=I2NB+NB
      AA(IB1,I)=-QZ(IK)*(XXK(K)+F1*XYC(K))
      AA(IB1,INB)=QZ(IK)*(-XYK(K)+F1*XXC(K))
      AA(IB1,I2NB)=XXKM(K)+F1*XYCM(K)
      AA(IB1,I3NB)=XYKM(K)-F1*XXCM(K)
      AA(IBNB,I)=-(XXK(K)+F1*XYC(K))
      AA(IBNB,INB)=-XYK(K)+F1*XXC(K)
      AA(IBNB,I2NB)=0
902   AA(IBNB,I3NB)=0
      DO 903 J=1,NS
      DO 903 I=NS41,NS4NB
      JS=J+NS
      J2S=J+NS2
      J3S=J+NS3
      INB=I+NB
      I2NB=INB+NB
      I3NB=I2NB+NB
      AA(JS,I)=-AA(J,INB)
      AA(JS,INB)=AA(J,I)
      AA(JS,I2NB)=-AA(J,I3NB)
```

```
      AA(JS,I3NB)=AA(J,I2NB)                                            07006020
      AA(J3S,I)=-AA(J2S,INB)                                            07006040
      AA(J3S,INB)=AA(J2S,I)                                             07006060
      AA(J3S,I2NB)=-AA(J2S,I3NB)                                        07006080
  903 AA(J3S,I3NB)=AA(J2S,I2NB)                                         07006100
      DO 904 J=NS41,NS4NB                                               07006120
      K=J-NS4                                                           07006140
      JK=IB(K)                                                          07006160
      JKS=JK+NS                                                         07006180
      JK2S=JK+NS2                                                       07006200
      JK3S=JK+NS3                                                       07006220
      JNB=J+NB                                                          07006240
      J2NB=JNB+NB                                                       07006260
      J3NB=J2NB+NB                                                      07006280
      AA(J,JK)=-BKM(K)+BM(K)*FDOTSQ                                     07006300
      AA(J,JKS)=F1*BCM(K)                                               07006320
      AA(J,J)=XXK(K)+F1*XYC(K)+BKM(K)-BM(K)*FDOTSQ                      07006340
      AA(J,JNB)=XYK(K)-F1*(XXC(K)+BCM(K))                               07006360
      AA(J2NB,JK2S)=-BKMM(K)+BI(K)*FDOTSQ                               07006380
      AA(J2NB,JK3S)=F1*BCMM(K)                                          07006400
      AA(J2NB,J2NB)=XXKM(K)+F1*XYCM(K)+BKMM(K)-BI(K)*FDOTSQ             07006420
  904 AA(J2NB,J3NB)=XYKM(K)-F1*(XXCM(K)+BCMM(K))                        07006440
      DO 905 J=NS41,NS4NB                                               07006460
      K=J-NS4                                                           07006480
      JK=IB(K)                                                          07006500
      JNB=J+NB                                                          07006520
      J2NB=JNB+NB                                                       07006540
      J3NB=J2NB+NB                                                      07006560
      JKS=JK+NS                                                         07006580
      JK2S=JK+NS2                                                       07006600
      JK3S=JK+NS3                                                       07006620
      AA(JNB,JK)=-AA(J,JKS)                                             07006640
      AA(JNB,JKS)=AA(J,JK)                                              07006660
      AA(JNB,J)=-AA(J,JNB)                                              07006680
      AA(JNB,JNB)=AA(J,J)                                               07006700
      AA(J3NB,JK2S)=-AA(J2NB,JK3S)                                      07006720
      AA(J3NB,JK3S)=AA(J2NB,JK2S)                                       07006740
      AA(J3NB,J2NB)=-AA(J2NB,J3NB)                                      07006760
  905 AA(J3NB,J3NB)=AA(J2NB,J2NB)                                       07006780
      FF=0                                                              07006800
      KL=ISIMEQ(84,NS44NB,1,AA,CC,FF,IA)                                07006820
      IF(KL.EQ.1) GO TO 718                                             07006840
```

```
      WRITE(6,715)
715   FORMAT(' THE SIMULTANEOUS EQUATION SOLUTION USED IN HYSSTA WAS '/
     &' NOT SUCCESSFUL DUE TO MATRIX SINGULARITY.'/
     &' PLEASE VERIFY THE INPUT DATA AND RERUN THE PROGRAM.')
      STOP
718   DO 97 I=1,NS44NB
97    YN(I)=AA(I,1)
      DO 98 I=1,NS
      INS=I+NS
      I2NS=I+NS2
      I3NS=I+NS3
      XX(I)=AA(I,1)
      YY(I)=AA(INS,1)
      IF(XX(I).EQ.0) XX(I)=1.E-20
      IF(YY(I).EQ.0) YY(I)=1.E-20
      RO(I)=SQRT(XX(I)**2+YY(I)**2)
      PHAROO(I)=ATAN2(YY(I),XX(I))*V
      IF(PHAROO(I).LT.0) PHAROO(I)=360.+PHAROO(I)
      XS(I)=AA(I2NS,1)
      YS(I)=AA(I3NS,1)
      IF(YS(I).EQ.0) YS(I)=1.E-20
      IF(XS(I).EQ.0) XS(I)=1.E-20
      ROSL(I)=SQRT(YS(I)**2+XS(I)**2)
      PHAROS(I)=ATAN2(YS(I),XS(I))*V
      IF(PHAROS(I).LT.0) PHAROS(I)=360.+PHAROS(I)
98    CONTINUE
      DO 123 I=1,NB
      M=IB(I)
      MNS=M+NS
      M2NS=M+NS2
      M3NS=M+NS3
      I4NS=I+NS4
      I4NSB=I4NS+NB
      I4NS2B=I4NSB+NB
      I4NS3B=I4NS2B+NB
      XB(I)=YN(I4NS)
      YB(I)=YN(I4NSB)
      XBM(I)= AA(I4NS2B,1)
      YBM(I)= AA(I4NS3B,1)
      XM(I)=YN(M)-XB(I)
      YM(I)=YN(MNS)-YB(I)
      XMM(I)= AA(M2NS,1)-XBM(I)
```

```
      YMM(I)= AA(M3NS,1)-YBM(I)                                         07007700
      XBDO(I)=-F1*YB(I)                                                 07007720
      YBDO(I)=F1*XB(I)                                                  07007740
      XBMDO(I)=-F1*YBM(I)                                               07007760
      YBMDO(I)=F1*XBM(I)                                                07007780
      XMDO(I)=-F1*YM(I)                                                 07007800
      YMDO(I)=F1*XM(I)                                                  07007820
      XMMDO(I)=-F1*YMM(I)                                               07007840
      YMMDO(I)=F1*XMM(I)                                                07007860
      XBMFO(I)=BM(I)*XM(I)*FDOTSQ                                       07007880
      YBMFO(I)=BM(I)*YM(I)*FDOTSQ                                       07007900
      XBIMO(I)=BI(I)*XMM(I)*FDOTSQ                                      07007920
      YBIMO(I)=BI(I)*YMM(I)*FDOTSQ                                      07007940
      IF(XB(I).EQ.0) XB(I)=1.E-20                                       07007960
      IF(YB(I).EQ.0) YB(I)=1.E-20                                       07007980
      BRGRO(I)=SQRT(XB(I)**2+YB(I)**2)                                  07008000
      BRPHAS(I)=ATAN2(YB(I),XB(I))*V                                    07008020
      IF(BRPHAS(I).LT.0) BRPHAS(I)=BRPHAS(I)+360.                       07008040
      MOUNRO(I)=SQRT(XM(I)**2+YM(I)**2)                                 07008060
      IF(XM(I).EQ.0) XM(I)=1.E-20                                       07008080
      IF(YM(I).EQ.0) YM(I)=1.E-20                                       07008100
      MOPHAS(I)=ATAN2(YM(I),XM(I))*V                                    07008120
      IF(MOPHAS(I).LT.0) MOPHAS(I)=360.+MOPHAS(I)                       07008140
      IF(XBM(I).EQ.0) XBM(I)=1.E-20                                     07008160
      IF(YBM(I).EQ.0) YBM(I)=1.E-20                                     07008180
      BSLRO(I)=SQRT(XBM(I)**2+YBM(I)**2)                                07008200
      BSPHAS(I)=ATAN2(YBM(I),XBM(I))*V                                  07008220
      IF(BSPHAS(I).LT.0) BSPHAS(I)=360.+BSPHAS(I)                       07008240
      IF(XMM(I).EQ.0) XMM(I)=1.E-20                                     07008260
      IF(YMM(I).EQ.0) YMM(I)=1.E-20                                     07008280
      ROMM(I)=SQRT(XMM(I)**2+YMM(I)**2)                                 07008300
      PHASMM(I)=ATAN2(YMM(I),XMM(I))*V                                  07008320
      IF(PHASMM(I).LT.0) PHASMM(I)=360.+PHASMM(I)                       07008340
      XBFOR(I)=XXK(I)*XB(I)+XYK(I)*YB(I)+XXC(I)*XBDO(I)+XYC(I)*YBDO(I)  07008360
      YBFOR(I)=XXK(I)*YB(I)-XYK(I)*XB(I)+XXC(I)*YBDO(I)-XYC(I)*XBDO(I)  07008380
      XBMOM(I)=XXKM(I)*XBM(I)+XYKM(I)*YBM(I)+XXCM(I)*XBMDO(I)           07008400
     &+XYCM(I)*YBMDO(I)                                                 07008420
      YBMOM(I)=XXKM(I)*YBM(I)-XYKM(I)*XBM(I)+XXCM(I)*YBMDO(I)           07008440
     &-XYCM(I)*XBMDO(I)                                                 07008460
      XMFOR(I)=BKM(I)*XM(I)+BCM(I)*XMDO(I)                              07008480
      YMFOR(I)=BKM(I)*YM(I)+BCM(I)*YMDO(I)                              07008500
      XMMOM(I)=BKMM(I)*XMM(I)+BCMM(I)*XMMDO(I)                          07008520
```

```
      YMMOM(I)=BKMM(I)*YMM(I)+BCMM(I)*YMMDO(I)
  123 CONTINUE
      IF(MET.EQ.1) GO TO 290
      WRITE(6,301)
  301 FORMAT(1H1,//)
      WRITE(6,302)
  302 FORMAT(' THE COMPUTED STARTING ROTOR DYNAMIC LOADS AND DEFLECTIONS
     & IN ENGLISH UNITS:'/)
      WRITE(6,303)
  303 FORMAT('      ROTOR DISPALCEMENT ARRAY, IN')
      WRITE(6,404) (RO(I),I=1,NS)
      WRITE(6,304)
  304 FORMAT('      ROTOR DISPLACEMENT PHASE ANGLE ARRAY, DEGREES')
      WRITE(6,404) (PHAROO(I),I=1,NS)
      WRITE(6,305)
  305 FORMAT('      BEARING DISPLACEMENT ARRAY, IN')
      WRITE(6,404) (BRGRO(I),I=1,NB)
      WRITE(6,306)
  306 FORMAT('      BEARING DISPLACEMENT PHASE ANGLE ARRAY, DEGREES')
      WRITE(6,404) (BRPHAS(I),I=1,NB)
      WRITE(6,307)
  307 FORMAT('      MOUNT DISPALCEMENT ARRAY, IN')
      WRITE(6,404) (MOUNRO(I),I=1,NB)
      WRITE(6,308)
  308 FORMAT('      MOUNT DISPLACEMENT PHASE ANGLE ARRAY, DEGREES')
      WRITE(6,404) (MCPHAS(I),I=1,NB)
      WRITE(6,309)
  309 FORMAT('      ROTOR SLOPE ARRAY, RADIANS')
      WRITE(6,404) (ROSL(I),I=1,NS)
      WRITE(6,310)
  310 FORMAT('      ROTOR SLOPE PHASE ANGLE ARRAY, DEGREES')
      WRITE(6,404) (PHAROS(I),I=1,NS)
      WRITE(6,311)
  311 FORMAT('      BEARING SLOPE ARRAY, RADIANS')
      WRITE(6,404) (BSLRO(I),I=1,NB)
      WRITE(6,312)
  312 FORMAT('      BEARING SLUPE PHASE ANGLE ARRAY, DEGREES')
      WRITE(6,404) (BSPHAS(I),I=1,NB)
      WRITE(6,313)
  313 FORMAT('      MOUNT SLOPE ARRAY, RADIANS')
      WRITE(6,404) (ROMM(I),I=1,NB)
      WRITE(6,314)
```

```
  314   FORMAT('     MOUNT SLOPE PHASE ANGLE ARRAY, DEGREES')           07009380
        WRITE(6,404) (PHASMM(I),I=1,NB)                                 07009400
        WRITE(6,315)                                                    07009420
  315   FORMAT('     BEARING X-FORCE ARRAY, LB')                        07009440
        WRITE(6,404) (XBFOR(I),I=1,NB)                                  07009460
        WRITE(6,316)                                                    07009480
  316   FORMAT('     BEARING Y-FORCE ARRAY, LB')                        07009500
        WRITE(6,404) (YBFOR(I),I=1,NB)                                  07009520
        WRITE(6,317)                                                    07009540
  317   FORMAT('     BEARING XZ-PLANE MOMENT ARRAY, LB-IN')             07009560
        WRITE(6,404) (XBMOM(I),I=1,NB)                                  07009580
        WRITE(6,318)                                                    07009600
  318   FORMAT('     BEARING YZ-PLANE MOMENT ARRAY, LB-IN')             07009620
        WRITE(6,404) (YBMOM(I),I=1,NB)                                  07009640
        WRITE(6,319)                                                    07009660
  319   FORMAT('     MOUNT X-FORCE ARRAY, LB')                          07009680
        WRITE(6,404) (XMFOR(I),I=1,NB)                                  07009700
        WRITE(6,320)                                                    07009720
  320   FORMAT('     MOUNT Y-FORCE ARRAY, LB')                          07009740
        WRITE(6,404) (YMFOR(I),I=1,NB)                                  07009760
        WRITE(6,321)                                                    07009780
  321   FORMAT('     MOUNT XZ-PLANE MOMENT ARRAY, LB-IN')               07009800
        WRITE(6,404) (XMMOM(I),I=1,NB)                                  07009820
        WRITE(6,322)                                                    07009840
  322   FORMAT('     MOUNT YZ-PLANE MOMENT ARRAY, LB-IN')               07009860
        WRITE(6,404) (YMMOM(I),I=1,NB)                                  07009880
        WRITE(6,323)                                                    07009900
  323   FORMAT('     BEARING MASS X-FORCE ARRAY, LB')                   07009920
        WRITE(6,404) (XBMFO(I),I=1,NB)                                  07009940
        WRITE(6,324)                                                    07009960
  324   FORMAT('     BEARING MASS Y-FORCE ARRAY, LB')                   07009980
        WRITE(6,404) (YBMFO(I),I=1,NB)                                  07010000
        WRITE(6,325)                                                    07010020
  325   FORMAT('     BEARING INERTIA XZ-PLANE MOMENT ARRAY, LB-IN')     07010040
        WRITE(6,404) (XBIMO(I),I=1,NB)                                  07010060
        WRITE(6,326)                                                    07010080
  326   FORMAT('     BEARING INERTIA YZ-PLANE MOMENT ARRAY, LB-IN')     07010100
        WRITE(6,404) (YBIMO(I),1=1,NB)                                  07010120
        GO TO 289                                                       07010140
  290   CONTINUE                                                        07010160
        AIN=2.54                                                        07010180
        AF=4.4482216152605                                              07010200
```

```
      AFIN=11.298482902761
      DO 401 I=1,NS
401   RO(I)=RO(I)*AIN
      DO 602 I=1,NB
      BRGRO(I)=BRGRO(I)*AIN
      MOUNRO(I)=MOUNRO(I)*AIN
      XBFOR(I)=XBFOR(I)*AF
      YBFOR(I)=YBFOR(I)*AF
      XMFOR(I)=XMFOR(I)*AF
      YMFOR(I)=YMFOR(I)*AF
      XBMFO(I)=XBMFO(I)*AF
      YBMFO(I)=YBMFO(I)*AF
      XBMOM(I)=XBMOM(I)*AFIN
      YBMOM(I)=YBMOM(I)*AFIN
      XMMOM(I)=XMMOM(I)*AFIN
      YMMOM(I)=YMMOM(I)*AFIN
      XBIMO(I)=XBIMO(I)*AFIN
602   YBIMO(I)=YBIMO(I)*AFIN
      WRITE(6,501)
501   FORMAT(1H1,//)
      WRITE(6,502)
  502 FORMAT(' THE COMPUTED STARTING ROTOR DYNAMIC LOADS AND DEFLECTIONS
     & IN INTERNATIONAL UNITS:'/)
      WRITE(6,503)
503   FORMAT('      ROTOR DISPALCEMENT ARRAY, CM')
      WRITE(6,404) (RO(I),I=1,NS)
      WRITE(6,504)
504   FORMAT('      ROTOR DISPLACEMENT PHASE ANGLE ARRAY, DEGREES')
      WRITE(6,404) (PHAROO(I),I=1,NS)
      WRITE(6,505)
505   FORMAT('      BEARING DISPLACEMENT ARRAY, CM')
      WRITE(6,404) (BRGRO(I),I=1,NB)
      WRITE(6,506)
506   FORMAT('      BEARING DISPLACEMENT PHASE ANGLE ARRAY, DEGREES')
      WRITE(6,404) (BRPHAS(I),I=1,NB)
      WRITE(6,507)
507   FORMAT('      MOUNT DISPALCEMENT ARRAY, CM')
      WRITE(6,404) (MOUNRO(I),I=1,NB)
      WRITE(6,508)
508   FORMAT('      MOUNT DISPLACEMENT PHASE ANGLE ARRAY, DEGREES')
      WRITE(6,404) (MOPHAS(I),I=1,NB)
      WRITE(6,509)
```

```
509   FORMAT('      ROTOR SLOPE ARRAY, RADIANS')                           07011060
      WRITE(6,404) (ROSL(I),I=1,NS)                                        07011080
      WRITE(6,510)                                                         07011100
510   FORMAT('      ROTOR SLOPE PHASE ANGLE ARRAY, DEGREES')               07011120
      WRITE(6,404) (PHAROS(I),I=1,NS)                                      07011140
      WRITE(6,511)                                                         07011160
511   FORMAT('      BEARING SLOPE ARRAY, RADIANS')                         07011180
      WRITE(6,404) (BSLRO(I),I=1,NB)                                       07011200
      WRITE(6,512)                                                         07011220
512   FORMAT('      BEARING SLOPE PHASE ANGLE ARRAY, DEGREES')             07011240
      WRITE(6,404) (BSPHAS(I),I=1,NB)                                      07011260
      WRITE(6,513)                                                         07011280
513   FORMAT('      MOUNT SLOPE ARRAY, RADIANS')                           07011300
      WRITE(6,404) (ROMM(I),I=1,NB)                                        07011320
      WRITE(6,514)                                                         07011340
514   FORMAT('      MOUNT SLOPE PHASE ANGLE ARRAY, DEGREES')               07011360
      WRITE(6,404) (PHASMM(I),I=1,NB)                                      07011380
      WRITE(6,515)                                                         07011400
515   FORMAT('      BEARING X-FORCE ARRAY, NEWTONS')                       07011420
      WRITE(6,404) (XBFOR(I),I=1,NB)                                       07011440
      WRITE(6,516)                                                         07011460
516   FORMAT('      BEARING Y-FORCE ARRAY, NEWTONS')                       07011480
      WRITE(6,404) (YBFOR(I),I=1,NB)                                       07011500
      WRITE(6,517)                                                         07011520
517   FORMAT('      BEARING XZ-PLANE MOMENT ARRAY, NEWTON-CM')             07011540
      WRITE(6,404) (XBMOM(I),I=1,NB)                                       07011560
      WRITE(6,518)                                                         07011580
518   FORMAT('      BEARING YZ-PLANE MOMENT ARRAY, NEWTON-CM')             07011600
      WRITE(6,404) (YBMOM(I),I=1,NB)                                       07011620
      WRITE(6,519)                                                         07011640
519   FORMAT('      MOUNT X-FORCE ARRAY, NEWTONS')                         07011660
      WRITE(6,404) (XMFOR(I),I=1,NB)                                       07011680
      WRITE(6,520)                                                         07011700
520   FORMAT('      MOUNT Y-FORCE ARRAY, NEWTONS')                         07011720
      WRITE(6,404) (YMFOR(I),I=1,NB)                                       07011740
      WRITE(6,521)                                                         07011760
521   FORMAT('      MOUNT XZ-PLANE MOMENT ARRAY, NEWTON-CM')               07011780
      WRITE(6,404) (XMMOM(I),I=1,NB)                                       07011800
      WRITE(6,522)                                                         07011820
522   FORMAT('      MOUNT YZ-PLANE MOMENT ARRAY, NEWTON-CM')               07011840
      WRITE(6,404) (YMMOM(I),I=1,NB)                                       07011860
      WRITE(6,523)                                                         07011880
```

```
523   FORMAT('     BEARING MASS X-FORCE ARRAY, NEWTONS')                07011900
      WRITE(6,404) (XBMFO(I),I=1,NB)                                    07011920
      WRITE(6,524)                                                      07011940
524   FORMAT('     BEARING MASS Y-FORCE ARRAY, NEWTONS')                07011960
      WRITE(6,404) (YBMFO(I),I=1,NB)                                    07011980
      WRITE(6,525)                                                      07012000
525   FORMAT('     BEARING INERTIA XZ-PLANE MOMENT ARRAY, NEWTON-CM')   07012020
      WRITE(6,404) (XBIMO(I),I=1,NB)                                    07012040
      WRITE(6,526)                                                      07012060
526   FORMAT('     BEARING INERTIA YZ-PLANE MOMENT ARRAY, NEWTON-CM')   07012080
      WRITE(6,404) (YBIMO(I),I=1,NB)                                    07012100
289   CONTINUE                                                          07012120
      RETURN                                                            07012140
      END                                                               07012160
C     SUBPROGRAM TO SOLVE SIMULTANEOUS LINEAR EQUATIONS                 08000020
C       ARGUMENTS-                                                      08000040
C                                                                       08000060
C        DATE- 1/13/67   MODIFIED  FOR COMPILATION IN RELEASE 14        08000080
C                                                                       08000100
C                DSM        DIMENSIONED SIZE OF COEFFICIENT MATRIX      08000120
C                NE         ACTUAL NUMBER OF EQUATIONS FOR THIS CALL    08000140
C                NC         NUMBER OF COLUMNS IN CONSTANT MATRIX        08000160
C                A          COEFFICIENT MATRIX                          08000180
C                B          CONSTANT MATRIX                             08000200
C                DET        INPUT - SCALE FACTOR, OUTPUT - FACTOR TIMES 08000220
C                           DETERMINANT VALUE OF COEFFICIENT MATRIX     08000240
C                C          TEMPORARY STORAGE FOR SUBROUTINE            08000260
C                ISIMEQ     RETURNS 1 IF OK, 2 IF OVFLO, 3 IF SINGULAR  08000280
C                IF NC IS NEGATIVE, THE INVERSE OF THE COEFFICIENT      08000300
C                MATRIX IS REQUIRED, MATRIX B IS SET UP AS IDENTITY.    08000320
      FUNCTION ISIMEQ( DSM , NE , NC , A , B , DET , C )                08000340
      LOGICAL DVO                                                       08000360
      INTEGER DSM, C, T, SUB1, SUB2,    R, D                            08000380
      DIMENSION  B(1), C(1)                                             08000400
C     INITIALIZE                                                        08000420
      N          =  NE                                                  08000440
      D = DSM                                                           08000460
      M = IABS(NC)                                                      08000480
      ISIMEQ = 1                                                        08000500
      DVO        =  .FALSE.                                             08000520
      DO 1 I = 1,N                                                      08000540
    1 C(I) = I                                                          08000560
```

```
      IF(NC) 5, 15, 15                                                  08000580
C     INVERSE REQUIRED                                                  08000600
    5 SUB2 = 0                                                          08000620
      DO 10 J = 1,N                                                     08000640
        SUB1 = SUB2                                                     08000660
        DO 6 I = 1,N                                                    08000680
        SUB1 = SUB1 + 1                                                 08000700
    6   B(SUB1) = 0.0                                                   08000720
       SUB1  = SUB2 + J                                                 08000740
       B(SUB1) = 1.0                                                    08000760
   10 SUB2 = SUB2 + D                                                   08000780
      GO TO 15                                                          08000800
      ENTRY IDETRM(DSM, NE, A, DET)                                     08000820
      DIMENSION  A(1)                                                   08000840
      N           =  NE                                                 08000860
      D           =  DSM                                                08000880
      IDETRM      =  1                                                  08000900
      DVO         =  .TRUE.                                             08000920
C     START MAIN LCCP                                                   08000940
   15 DO 1000 L = 1,N                                                   08000960
         LP1 = L+ 1                                                     08000980
        DO 40 I = L,N                                                   08001000
         PIVOT = 0.0                                                    08001020
          SUB1 = (L-1) * D + 1                                          08001040
          SUB2 = SUB1                                                   08001060
            DO 20 J = L,N                                               08001080
             IF(ABS(PIVOT) .GE. ABS(A(SUB1))) GO TO 20                  08001100
             PIVOT = A(SUB1)                                            08001120
             JB = J                                                     08001140
   20       SUB1 = SUB1 + D                                             08001160
C     COMPUTE DETERMINANT                                               08001180
      CALL OVERFL(T)                                                    08001200
        DET = DET * PIVOT                                               08001220
      IF(.NOT. DVO )  GO TO 24                                          08001240
        CALL OVERFL(T)                                                  08001260
      IF(T.EQ.1) IDETRM = 2                                             08001280
C     TEST FOR SINGULAR MATRIX                                          08001300
   24 IF(PIVOT .EQ. 0.0) GO TO 2000                                     08001320
            DO 25 J = L,N                                               08001340
            A(SUB2) = A(SUB2) / PIVOT                                   08001360
   25       SUB2 = SUB2 + D                                             08001380
         IF (DVO) GO TO 35                                              08001400
```

```
         SUB1 = I
          DO 30 J = 1,M
          B(SUB1) = B(SUB1) / PIVOT
   30     SUB1 = SUB1 + D
   35    IF (I .EQ. L) JP = JB
   40   CONTINUE
C     INTERCHANGE COLUMNS
  100   IF (JP .EQ. L) GO TO 260
      IF (DVO) GO TO 110
        T = C(L)
        C(L) = C(JP)
        C(JP) = T
  110     R = D * L - D
          T = D * JP - D
          DO 120 I = 1,N
          SUB1 = R + I
          SUB2 =  T + I
          S = A(SUB1)
          A(SUB1) = A(SUB2)
  120     A(SUB2) = S
        DET = -DET
C     REDUCE PIVOT COLUMN
  260   R = D* L - D
        DO 400 I = 1,N
         IP = R + I
         PIVOT = A(IP)
        IF (I .EQ. L .OR. PIVOT .EQ. 0.0) GO TO 400
         SUB1 = L
         SUB2 = I
          DO 360 J = 1,N
           IF (J .LT. LP1) GO TO 300
            S = PIVOT * A(SUB1)
            A(SUB2) = A(SUB2) - S
           IF (ABS(A(SUB2)) .LT. ABS(2.0E-6 * S)) A(SUB2) = 0.0
  300     IF (DVO .OR. J .GT. M) GO TO 350
            B(SUB2) = B(SUB2) - PIVOT * B(SUB1)
  350      SUB1 = SUB1 + D
  360     SUB2 = SUB2 + D
  400   CONTINUE
 1000 CONTINUE
      IF (DVO) GO TO 1500
C     REARRANGE VARIABLES
```

```
 1100 DO  1201    L=1,N                                                  08002260
       SUB1 = C(L)                                                       08002280
       SUB2 = L                                                          08002300
        DO 1200 J = 1,M                                                  08002320
         A(SUB1) = B(SUB2)                                               08002340
         SUB1 = SUB1 + D                                                 08002360
 1200    SUB2 = SUB2 + D                                                 08002380
 1201 CONTINUE                                                           08002400
 1500 RETURN                                                             08002420
C     SINGULAR COEFFICIENT MATRIX                                        08002440
 2000 IF(CVO)     GO TO 3000                                             08002460
      ISIMEQ      =  3                                                   08002480
      GO TO 1500                                                         08002500
 3000 IDETRM      = ` 3                                                  08002520
      GO TO 1500                                                         08002540
      END                                                                08002560
C     SOLUTION TO A SYSTEM OF 1ST ORDER ORDINARY DIFFERENTIAL EQUATIONS 09100020
C     OF THE INITIAL VALUE TYPE.  THE FOLLOWING METHODS ARE AVAILABLE---09100040
C     1. ADAMS-MOULTON PREDICTOR-CORRECTOR FIXED INCREMENT               09100060
C     2. ADAMS-MOULTON PREDICTOR-CORRECTOR VARIABLE INCREMENT            09100080
C     3. RUNGE-KUTTA (ALSO USED TO GENERATE STARTING VALUES FOR A-M METH09100100
      SUBROUTINE HYSRKA(N,T,Y,H,IND,ITIM,TOL,NERR)                       09100120
      DIMENSION Y(198),F(198,7),YB(198,5),A(198,4)                       09100140
C     N  ORDER OF SYSTEM (IF REDIMENSIONING REQUIRED, CHANGE NN IN DATA 09100160
C     STATEMENT AND ALSO THE 1ST SUBSCRIPT OF F AND YB IN DIMENSION      09100180
C     T  INDEPENDENT VARIABLE -- UPON ENTRY TO RKADAM FROM CALLING       09100200
C     PROGRAM X IS AT BEGINNING OF STEP.  UPON RETURN TO CALLING         09100220
C     PROGRAM X IS AT END OF STEP.                                       09100240
C     Y  SOLUTION VECTOR OF DEPENDENT VARIABLES AS A FUNCTION OF X       09100260
C     H  INCREMENT(ALGEBRAIC) -- UPON ENTRY TO RKADAM FROM CALLING       09100280
C     PROGRAM H IS THE TRIAL INCREMENT FOR THIS STEP.  UPON RETURN TO    09100300
C     CALLING PROGRAM H IS THE TRIAL INCREMENT FOR THE NEXT STEP.        09100320
C     IND  FLAG TO SELECT METHOD                      FROM CALLING PROGRAM09100340
C     =0 ADAMS-MOULTON PREDICTOR-CORRECTOR VARIABLE INCREMENT H          09100360
C     =1 RUNGE-KUTTA FIXED INCREMENT H                                   09100380
C     =2 ADAMS-MOULTON FIXED INCREMENT H                                 09100400
C     ITIM  RESTART FLAG (APPLIES ONLY FOR IND=0,2) FROM CALLING PROGRAM09100420
C     =+1 RESTART WITH FORWARDS(IN THE DIRECTION OF SIGN(H))             09100440
C     INTEGRATION BY RUNGE-KUTTA TO GET STARTING VALUES                  09100460
C     =-1 SAME AS +1 EXCEPT USES BACKWARDS (-SIGN(H)) INTEGRATION        09100480
C     =0  CONTINUE INTEGRATING                                           09100500
C     TOL APPLIES ONLY TO IND=0. ALLOWABLE RELATIVE ERROR BETWEEN THE    09100520
```

```
C       PREDICTED AND CORRECTED SOLUTIONS.        FROM CALLING PROGRAM
C       NERR  ERROR FLAG RETURNED TO CALLING PROGRAM
C       =0 SOLUTION IS VALID
C       =1 SOLUTION INVALID -- N IS INVALID OR ELSE H HAS GONE TO 0
        DATA NN/198/
        NERR=0
        IF(IND.EQ.1)GOTO10
        IF(ITIM.EQ.0)GOTO170
10      NS=0
        CALL OVERFL(K)
C       TEST VALIDITY OF N
        IF(N.GE.1.AND.N.LE.NN)GOTO40
20      NERR=1
30      RETURN
40      IF(IND.NE.1)GOTO50
C       RUNGE-KUTTA
        CALL RUNKUT(N,H,T,Y,Y,A)
        T=T+H
        GO TO 30
C       ADAMS-MOULTON
50      IF(ITIM.LT.0) GO TO 180
C       RESTART FORWARDS INTEGRATION (IN DIRECTION OF X+H
        ISTFLG=1
        IF(IND.EQ.2)ISTFLG=0
        XB=T
        DO60I=1,N
60      YB(I,1)=Y(I)
        L=0
70      DO80I=1,3
        T=XB+H*(I-1)
        J=5-I
        CALL RUNKUT(N,H,T,Y,YB(1,I+1),A)
        DO 75 K=1,N
        IF(ABS(YB(K,I+1)).LE.1.E12)GOTO73
        H=H/10.
        GOTO 83
73      IF(L.NE.0.AND.I.EQ.1)GOTO75
        F(K,J)=A(K,1)
75      Y(K)=YB(K,I+1)
80      CONTINUE
        T=T+H
        CALL FUND(N,T,Y,F)
```

```
      DO 2 I=1,N
      IF(Y(I).GE.1.E14)GOTO3
2     CONTINUE
      GO TO 4
3     RETURN
4     CALL ADAMLT(N,T,Y,H,IND,ITIM,TOL,NERR,ISTFLG,F,A)
      IF(ISTFLG.EQ.0)GOTO110
      H=H/2
83    T=XB
      CALL OVERFL(K)
      IF(K.EQ.1)GOTO100
      DO90I=1,N
90    Y(I)=YB(I,1)
      L=1
      GOTO70
100   H=0.
      GOTO20
C     FOR ITIM = +1, FEED STARTING VALUES BACK TO CALLING PROGRAM ONE AT
C     A TIME (RUNGE-KUTTA SOLNS 1ST 4 PTS AND THEN A-M SOLN FOR 5TH PT)
110   DO120I=1,N
120   YB(I,5)=Y(I)
      NS=2
130   T=XB+H*(NS-1)
      DO140I=1,N
140   Y(I)=YB(I,NS)
      NS=NS+1
      IF(NS.GT.5)NS=0
      GOTO30
C     CONTINUE INTEGRATION PROCEDURE (A-M)
170   IF(NS)190,190,130
180   ISTFLG=0
190   CALL ADAMLT(N,T,Y,H,IND,ITIM,TOL,NERR,ISTFLG,F,A)
      GOTO30
      END
C     4TH ORDER RUNGE-KUTTA INTEGRATION FOR A SYSTEM OF 1ST ORDER,
C     ORDINARY DIFFERENTIAL EQNS.
      SUBROUTINE RUNKUT(N,H,X,Y,YY,A)
C     SEE DIMENSION STATEMENT FOR LIMITATION ON ORDER OF SYSTEM
C     CHANGE DIMENSION AS IS REQUIRED, I.E.,A(MAXORDER,4), V(MAXORDER)
      DIMENSION A(198,4),V(198),Y(198),YY(198)
C     N = ORDER OF SYSTEM
C     H = INTEGRATION STEP
```

```
C     X = INDEPENDENT VARIABLE AT BEGINNING OF STEP
C     Y = VECTOR OF DEPENDENT VARIABLES AT BEGINNING OF STEP
C     YY = SOLUTION VECTOR OF DEPENDENT VARIABLES AT END OF STEP
      X1=H/2.
      X2=X+X1
      X3=X+H
      CALL FUND(N,X,Y,A(1,1))
      DO 2 I=1,N
      IF(Y(I).GE.1.E14)GOTO3
2     CONTINUE
      GO TO 4
3     RETURN
4     DO 10 I=1,N
10    V(I)=Y(I)+X1*A(I,1)
      CALL FUND(N,X2,V,A(1,2))
      DO 12 I=1,N
      IF(Y(I).GE.1.E14)GOTO13
12    CONTINUE
      GO TO 14
13    RETURN
14    DO 20 I=1,N
20    V(I)=Y(I)+X1*A(I,2)
      CALL FUND(N,X2,V,A(1,3))
      DO 22 I=1,N
      IF(Y(I).GE.1.E14)GOTO23
22    CONTINUE
      GO TO 24
23    RETURN
24    DO 30 I=1,N
30    V(I)=Y(I)+H*A(I,3)
      CALL FUND(N,X3,V,A(1,4))
      DO 32 I=1,N
      IF(Y(I).GE.1.E14)GOTO33
32    CONTINUE
      GO TO 34
33    RETURN
34    DO 40 I=1,N
40    YY(I)=Y(I)+H*(A(I,1)+2.*(A(I,2)+A(I,3))+A(I,4))/6.0
      RETURN
      END
C     ADAMS-MOULTON INTEGRATER FOR A SYSTEM OF 1ST ORDER ORDINARY
C     DIFFERENTIAL EQUATIONS OF THE INITIAL VALUE TYPE.
```

```
C     CHOICE OF FIXED OR VARIABLE INCREMENTING.                            09300060
C     IF VARIABLE INCREMENTING THE FOLLOWING RULES WILL APPLY ---          09300080
C     DEFINE YP=PREDICTOR SOLUTION VECTOR                                  09300100
C     DEFINE YC=CORRECTOR SOLUTION VECTOR                                  09300120
C     DEFINE RE=DIFF.RATIO OF YP & YC IF ABS(YC).GT.1 ELSE JUST DIFF.      09300140
C     1. IF TOL*0.02.LE.RE.LE.TOL IS TRUE THEN H IS UNCHANGED AND YC IS    09300160
C     2. IF RE(I).GT.TOL FOR ANY I OF RE THEN H IS HALVED AND YP AND YC    09300180
C     RECOMPUTED.  HALVING THE INCREMENT IS NOT RESTRICTED.                09300200
C     THIS STEP.  H IS REPLACED BY 2*H AND RETURNED (WITH YC) AS NEW       09300220
C     INCREMENT FOR THE NEXT STEP.  H MAY BE DOUBLED ONLY AFTER 4          09300240
C     SUCCESSIVE STEPS USING THE SAME INCREMENT (AN ATTEMPT TO MAINTAIN    09300260
C     STABILITY IN THE SOLUTION).                                          09300280
C     4. IF H IS HALVED AN ENTIRE SET OF DERIVATIVES ARE COMPUTED USING    09300300
C     BACKWARDS (IN THE DIRECTION OF -SIGN(H)) INTEGRATION BY RUNGE-KUTA09300320
C     5. IF H IS DOUBLED PREVIOUS SAVED DERIVATIVES ARE USED.              09300340
C                                                                          09300360
      SUBROUTINE ADAMLT(N,X,Y,H,IND,ITIM,TOL,NERR,ISTFLG,F,A)              09300380
      DIMENSION Y(198),F(198,7),YP(198),YC(198),A(198,4)                   09300400
C     SEE COMMENTS IN SUBROUTINE RKADAM FOR DESCRIPTION OF ARGUMENTS.      09300420
C     IF REDIMENSIONING IS DONE IN RKADAM THEN NN MUST BE CHANGED          09300440
C     ACCORDINGLY IN F(NN,7), YP(NN), AND YC(NN) IN ADAMLT DIMENSION STM09300460
      IF(ITIM.NE.0)GOTO60                                                  09300480
      IF(IND.EQ.2)GOTO10                                                   09300500
      IF(IC.EQ.-1)GOTO30                                                   09300520
10    DO20I=1,N                                                            09300540
      F(I,6)=F(I,5)                                                        09300560
      F(I,5)=F(I,4)                                                        09300580
      F(I,4)=F(I,3)                                                        09300600
      F(I,3)=F(I,2)                                                        09300620
20    F(I,2)=F(I,1)                                                        09300640
      GOTO50                                                               09300660
C     DOUBLE INCREMENT BEING ATTEMPTED THIS STEP (THIS ENTRY)              09300680
30    IC=0                                                                 09300700
      DO40I=1,N                                                            09300720
      F(I,3)=F(I,4)                                                        09300740
40    F(I,4)=F(I,6)                                                        09300760
50    CALL FUND(N,X,Y,F(1,1))                                              09300780
      GOTO90                                                               09300800
C     RESTART                                                              09300820
60    IC=0                                                                 09300840
      IF(ITIM.GT.0)GOTO90                                                  09300860
      DO 70 I=1,N                                                          09300880
```

```
70    YP(I)=Y(I)
C     GET NEW SET OF DERIVATIVES BY BACKWARDS INTEGRATIONS (RUNGE-KUTTA)
      XB=X
      DO80I=1,3
      CALL RUNKUT(N,-H,XB,YP,YP,A)
      XB=X-H*I
      DO 78 K=1,N
78    F(K,I)=A(K,1)
80    CONTINUE
      CALL FUND(N,XB,YP,F(1,4))
90    HH=H/24.
C     PREDICTOR SOLUTION
      DO100I=1,N
100   YP(I)=Y(I)+HH*(55.*F(I,1)-59.*F(I,2)+37.*F(I,3)-9.
     &*F(I,4))
130   CALL FUND(N,X+H,YP,F(1,7))
C     CORRECTOR SOLUTION
      DO140I=1,N
140   YC(I)=Y(I)+HH*(19.*F(I,1)-5.*F(I,2)+F(I,3)+
     &9.*F(I,7))
C     TEST FOR FIXED INCREMENT OPTION
      IF(IND.EQ.0)GOTO145
      X=X+H
      GOTO170
C     TEST RELATIVE ERROR
145   S=1
      DO150I=1,N
      T=ABS(YC(I)-YP(I))
      U=AMAX1(ABS(YC(I)),1.)
      V=U*TOL
      W=V/50.
      IF(T.GT.V)GOTO200
      IF(W.LE.T)S=0.
150   CONTINUE
      ISTFLG=0
      X=X+H
C     TEST IF 4 STEPS HAVE ELAPSED USING SAME INCREMENT FOR DOUBLNG TEST
      IF(IC.LT.3)GOTO160
      IF(S.EQ.0)GOTO170
C     SET H TO 2*H FOR NEXT STEP
      IC=-1
      H=2.*H
```

```
      GOTO170
160   IC=1+IC
170   DO180I=1,N
180   Y(I)=YC(I)
      GOTO120
200   IF(ISTFLG.NE.0)GOTO120
C     HALVE THE INCREMENT AND RECOMPUTE
      H=H/2.
      CALL OVERFL(K)
      IF(K.NE.1)GOTO60
      H=0
      NERR=1
120   RETURN
      END
      SUBROUTINE FUND(NN,T,YN,BD)
      INTEGER      CONTIN,RIG,CT,CRT
      REAL INPRPM,MX,MY,MXL,MYL,MXR,MYR,      MLS,MRS,MWL,MWR,MWIL,MWIR,
     &KT,MT1,MT2,MTXZ,MTYZ,MXLD,MYLD,MXRD,MYRD,MHX,MHY
      REAL MXLD1,MXLD2,MYLD1,MYLD2,MXRD1,MXRD2,MYRD1,MYRD2
      DIMENSION TORHFM(15),SXL(15),SYL(15),SXR(15),SYR(15),
     &BXL(15),BYL(15),BXR(15),BYR(15)
      DIMENSION XBM(6),YBM(6),XBMDO(6),YBMDO(6),XBMOM(6),YBMOM(6)
      DIMENSION FX(15),FY(15),MX(15),MY(15),FXL(15),FYL(15),FXR(15),
     &FYR(15),
     &MXL(15),MYL(15),MXR(15),MYR(15),FXLD(15),FYLD(15),FXRD(15),
     &FYRD(15),
     &MXLD(15),MYLD(15),MXRD(15),MYRD(15),   XB(6),YB(6),XBDOT(6),
     &YBDOT(6),XBFOR(6),YBFOR(6),FHX(15),FHY(15),MHX(15),MHY(15),
     &XPL(14),YPL(14),MTXZ(14),MTYZ(14),TMTX(14),TMTY(14)
      DIMENSION EI1L(14),EI2L(14),GALEI3(14),EICOM(14),KT(14),
     &             TORQ(15),TORS(15),ISTAR(15),ISTOP(15),
     &YN(198),BD(198),FDD(15),FDOD(15),AR(15),PP(15)
      COMMON NS,NS2,NS3,NS4,NS5,NS6,NS7,NS8,NS9,NS10,NSM1,NSP1,NS2P1,
     &NS4P1,IQ,IPRINT,
     &MM,NB,IB1,IBNB,NNT,ITIM,IUSE,CRT,CONTIN,NOORPM,IASIGN,NPOINT,
     &MOSHA,MET,IND,IPP,ITORQ,IMT,G
      COMMON PI, TSPA,DT,TMAX,DP,      TOLI,GX,GY,Q,S,QLL,QMLOV,HA,FA,GA
      COMMON IB(6),KK(6),RIG(14),JBI(15),CT(15),MT(15)
      COMMON TITLE(18),F(15),FDOT(15),FDOFIX(6),DD(14),D(14),QL(14),
     &P(14),
     &DN(14),EE(14),GG(14),EI(14),GAK(14),SHK(14),AM(15),AID(15),
     &AIRO(15),QM(15),
```

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     &QID(15),QIRO(15),ECC(15),ALFA(15),BETA(15),GAMMA(15),QME(15),
     &FOSTIF(6),
     &Z(15),QZ(15),QK(15),QC(15),QKP(15),QCP(15),QKHD(15),QCHD(15),
     &QKF(15),QCF(15),
     &QKPF(15),QCPF(15),QKHDF(15),QCHDF(15),XKF(15),XCF(15),XKFF(15),
     &XCFF(15),
     &QKXX(6),QKXY(6),QKYY(6),QKYX(6),QCXX(6),QCXY(6),QCYY(6),QCYX(6),
     &XXMK(6),XYMK(6),YYMK(6),YXMK(6),XXMC(6),XYMC(6),YYMC(6),YXMC(6),
     &BI(6),XKMM(6),YKMM(6),XCMM(6),YCMM(6),
     &BKMX(6),BKMY(6),BCMX(6),BCMY(6),BM(6),USV(14),USC(14),
     &UBV(14),UBC(14),UTV(14),UTC(14),CT1(15),CT2(15),CTV(14),CTC(14),
     &MT1(15),MT2(15),AT(15),BT(15),DU(15),HT(15),ET(15),FT(15),GT(15),
     &AA(15),
     &BA(15),DA(15),EA(15),  YNSPA(84),  INPRPM(50)
      COMMON C(15,15),B(15,15),TF(15,15),TM(15,15),BBB(6,3),BDB(6,3),
     &BEB(6,3),
     &BCB(6,3),BHB(6,3),BKB(6,3),BNB(6,3),BROB(6,4)
      DO 25 I=1,NS
      I8NS=I+NS8
      I9NS=I+NS9
      F(I)=YN(I8NS)
25    FDOT(I)=YN(I9NS)
      IF(IUSE.EQ.0) GO TO 28
      IF(NNT.NE.2) GO TO 28
      DO 29 I=1,NS
29    FDD(I)=FDOD(I)
28    IF(NNT.EQ.2) GO TO 408
      TOL=.001
      FXL(1)=0
      FYL(1)=0
      MXL(1)=0
      MYL(1)=0
      FXR(NS)=0
      FYR(NS)=0
      MXR(NS)=0
      MYR(NS)=0
      DO 78 I=1,NS
      FHX(I)=0
      FHY(I)=0
      MHX(I)=0
      MHY(I)=0
      TORHFM(I)=0
```

```
78    CONTINUE
      MBVC=1
      MSVC=1
      MTVC=1
      DO 1 I=1,NSM1
      IF(UBV(I).NE.0) GO TO 11
      IF(UBC(I).NE.0) GO TO 11
1     CONTINUE
      MBVC=0
11    DO 2 I=1,NSM1
      IF(USV(I).NE.0) GO TO 12
      IF(USC(I).NE.0) GO TO 12
2     CONTINUE
      MSVC=0
12    DO 3 I=1,NSM1
      IF(UTV(I).NE.0) GO TO 13
      IF(UTC(I).NE.0) GO TO 13
3     CONTINUE
      MTVC=0
13    DO 4 I=1,NS
4     AR(I)=QIRO(I)+QME(I)*ECC(I)+QID(I)*BETA(I)**2
      DO 72 I=1,NSM1
      KT(I)=GG(I)*PI*(DD(I)**4-D(I)**2)/(32.*QL(I))
      CTV(I)=PI/32.*(DD(I)**4-D(I)**4)/QL(I)*UTV(I)
72    CTC(I)=PI/12.*(DD(I)**3-D(I)**3)*UTC(I)
      DO 73 I=1,NS
      IF(FDOT(I).LT.0) FDOCT=-ABS(FDOT(I))**CT(I)
      IF(FDOT(I).GE.0) FDOCT=FDOT(I)**CT(I)
      TORS(I)=-CT1(I)*FDOCT-CT2(I)*FDOT(I)
      IF(ITORQ.EQ.0) GO TO 73
      IF(FDOT(I).LT.0) FDOMT=-ABS(FDOT(I))**MT(I)
      IF(FDOT(I).GE.0) FDOMT=FDOT(I)**MT(I)
      TORS(I)=TORS(I)+MT1(I)*FDOMT+MT2(I)*FDOT(I)+AT(I)+BT(I)*T+DU(I)*
     &T**HT(I)+ET(I)*SIN(FT(I)*T+GT(I))
73    CONTINUE
      DO 59 I=1,NS
      ISTAR(I)=0
59    ISTOP(I)=0
      NSTOT=0
      I=0
66    I=I+1
      IF(I.GT.NSM1) GO TO 69
```

```
      IF(RIG(I).EQ.0) GO TO 66
      NSTOT=NSTOT+1
      ISTAR(NSTOT)=I
      I=I+1
      IF(I.EQ.NS) GO TO 68
67    IF(RIG(I).EQ.0) GO TO 68
      I=I+1
      IF(I.GT.NSM1) GO TO 68
      GO TO 67
68    ISTOP(NSTOT)=I
      GO TO 66
69    CONTINUE
      IF(NSTOT.NE.0) GO TO 154
      DO 153 I=1,NS
      I9NS=I+NS9
153   FDD(I)=TORS(I)/AR(I)
      GO TO 155
154   DO 156 I=1,NS
      I9NS=I+NS9
      IF(I.GE.1.AND.I.LT.ISTAR(1)) GO TO 157
      IF(I.LE.NS.AND.I.GT.ISTOP(NSTOT)) GO TO 157
      NST1=NSTOT-1
      DO 158 J=1,NST1
      IF(I.GT.ISTOP(J).AND.I.LT.ISTAR(J+1)) GO TO 157
158   CONTINUE
157   FDD(I)=TORS(I)/AR(I)
156   CONTINUE
      DO 151 I=1,NSTOT
      IR=ISTAR(I)
      IP=ISTOP(I)
      TOR=0
      ARO=0
      DO 144 J=IR,IP
      TOR=TOR+TORS(J)
144   ARO=ARO+AR(J)
      JJ=ISTAR(I)
      FDD(JJ)=TOR/ARO
      IR1=IR+1
      DO 152 IJ=IR1,IP
152   FDD(IJ)=FDD(JJ)
151   CONTINUE
155   CONTINUE
```

```
      DO 24 I=1,NS
24    FDOD(I)=FDD(I)
      DO 74 I=1,NSM1
      GAL=QL(I)/(GG(I)*PI/4.*(DD(I)**2-D(I)**2)/SHK(I)+GAK(I))
      EI1L(I)=QL(I)/(EI(I)+EE(I)*PI/64.*(DD(I)**4-D(I)**4))
      EI2L(I)=QL(I)/2.*EI1L(I)
      EI3L=QL(I)/1.5*EI2L(I)
      GALEI3(I)=GAL+EI3L
74    EICOM(I)=EI1L(I)*GALEI3(I)-EI2L(I)**2
      NNT=2
408   DO 204 I=1,NSM1
      INS=I+NS
      I2NS=I+NS2
      I3NS=I+NS3
      EX=YN(I2NS+1)-YN(I2NS)
      EY=YN(I3NS+1)-YN(I3NS)
      XMX=YN(I+1)-YN(I)
      YMY=YN(INS+1)-YN(INS)
      FXX=XMX-QL(I)*YN(I2NS)
      FYY=YMY-QL(I)*YN(I3NS)
      HX=QL(I)*YN(I2NS+1)-XMX
      HY=QL(I)*YN(I3NS+1)-YMY
      FXL(I+1)=(EI2L(I)*EX-EI1L(I)*FXX)/EICOM(I)
      FYL(I+1)=(EI2L(I)*EY-EI1L(I)*FYY)/EICOM(I)
      MXL(I+1)=(EI2L(I)*FXX-GALEI3(I)*EX)/EICOM(I)
      MYL(I+1)=(EI2L(I)*FYY-GALEI3(I)*EY)/EICOM(I)
      FXR(I)=(EI2L(I)*EX-EI1L(I)*HX)/EICOM(I)
      FYR(I)=(EI2L(I)*EY-EI1L(I)*HY)/EICOM(I)
      MXR(I)=(GALEI3(I)*EX-EI2L(I)*HX)/EICOM(I)
204   MYR(I)=(GALEI3(I)*EY-EI2L(I)*HY)/EICOM(I)
      IF(IUSE.EQ.0) GO TO 271
      IF(MSVC.EQ.0.AND.MBVC.EQ.0) GO TO 271
      DO 294 I=1,NSM1
      I4NS=I+NS4
      I5NS=I+NS5
      I6NS=I+NS6
      I7NS=I+NS7
      EX=YN(I6NS+1)-YN(I6NS)
      EY=YN(I7NS+1)-YN(I7NS)
      XMX=YN(I4NS+1)-YN(I4NS)
      YMY=YN(I5NS+1)-YN(I5NS)
      FXX=XMX-QL(I)*YN(I6NS)
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```
      FYY=YMY-QL(I)*YN(I7NS)
      HX=QL(I)*YN(I6NS+1)-XMX
      HY=QL(I)*YN(I7NS+1)-YMY
      FXLD(I+1)=(EI2L(I)*EX-EI1L(I)*FXX)/EICOM(I)
      FYLD(I+1)=(EI2L(I)*EY-EI1L(I)*FYY)/EICOM(I)
      MXLD(I+1)=(EI2L(I)*FXX-GALEI3(I)*EX)/EICOM(I)
      MYLD(I+1)=(EI2L(I)*FYY-GALEI3(I)*EY)/EICOM(I)
      FXRD(I)=(EI2L(I)*EX-EI1L(I)*HX)/EICOM(I)
      FYRD(I)=(EI2L(I)*EY-EI1L(I)*HY)/EICOM(I)
      MXRD(I)=(GALEI3(I)*EX-EI2L(I)*HX)/EICOM(I)
294   MYRD(I)=(GALEI3(I)*EY-EI2L(I)*HY)/EICOM(I)
      DO 99 I=1,NS
      SXL(I)=0
      SYL(I)=0
      SXR(I)=0
      SYR(I)=0
      BXL(I)=0
      BYL(I)=0
      BXR(I)=0
99    BYR(I)=0
      DO 101 I=1,NS
      SVXL=0
      SVYL=0
      SCXL=0
      SCYL=0
      SVXR=0
      SVYR=0
      SCXR=0
      SCYR=0
      IF(I.EQ.1) GO TO 103
      FLS=FXL(I)**2+FYL(I)**2
      IF(FLS.EQ.0) FLS=1.E-20
      FWIL=FDOT(I)-(FYLD(I)*FXL(I)-FXLD(I)*FYL(I))/FLS
      FDL=ABS(FWIL/FDOT(I))
      IF(FDL.LT.TOL) FWL=0
      IF(FDL.GE.TOL) FWL=FWIL/ABS(FWIL)
      FXLD(I)=FXLD(I)+FDOT(I)*FYL(I)
      FYLD(I)=FYLD(I)-FDOT(I)*FXL(I)
      FXLD1=ABS(FXLD(I)/(FDOT(I)*FYL(I)))
      FYLD1=ABS(FYLD(I)/(FDOT(I)*FXL(I)))
      IF(FXLD1.LT.TOL) FXLD2=0
      IF(FXLD1.GE.TOL) FXLD2=FXLD(I)/ABS(FXLD(I))
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      IF(FYLD1.LT.TOL) FYLD2=0                                          10004780
      IF(FYLD1.GE.TOL) FYLD2=FYLD(I)/ABS(FYLD(I))                       10004800
      IF(MSVC.EQ.0) GO TO 103                                           10004820
      IF(USV(I-1).EQ.0) GO TO 104                                       10004840
      UG=USV(I-1)/GG(I-1)                                               10004860
      SVXL=UG*(FXLD(I)+FWIL*FYL(I))                                     10004880
      SVYL=UG*(FYLD(I)-FWIL*FXL(I))                                     10004900
104   IF(USC(I-1).EQ.0) GO TO 103                                       10004920
      UG=USC(I-1)/GG(I-1)                                               10004940
      SCXL=UG*(ABS(FXL(I))*FXLD2+FWL*FYL(I))                            10004960
      SCYL=UG*(ABS(FYL(I))*FYLD2-FWL*FXL(I))                            10004980
103   IF(I.EQ.NS) GO TO 102                                             10005000
      FRS=FXR(I)**2+FYR(I)**2                                           10005020
      IF(FRS.EQ.0) FRS=1.E-20                                           10005040
      FWIR=FDOT(I)-(FYRD(I)*FXR(I)-FXRD(I)*FYR(I))/FRS                  10005060
      FDR=ABS(FWIR/FDOT(I))                                             10005080
      IF(FDR.LT.TOL) FWR=0                                              10005100
      IF(FDR.GE.TOL) FWR=FWIR/ABS(FWIR)                                 10005120
      FXRD(I)=FXRD(I)+FDOT(I)*FYR(I)                                    10005140
      FYRD(I)=FYRD(I)-FDOT(I)*FXR(I)                                    10005160
      FXRD1=ABS(FXRD(I)/(FDOT(I)*FYR(I)))                               10005180
      FYRD1=ABS(FYRD(I)/(FDOT(I)*FXR(I)))                               10005200
      IF(FXRD1.LT.TOL) FXRD2=0                                          10005220
      IF(FXRD1.GE.TOL) FXRD2=FXRD(I)/ABS(FXRD(I))                       10005240
      IF(FYRD1.LT.TOL) FYRD2=0                                          10005260
      IF(FYRD1.GE.TOL) FYRD2=FYRD(I)/ABS(FYRD(I))                       10005280
      IF(MSVC.EQ.0) GO TO 102                                           10005300
      IF(USV(I).EQ.0) GO TO 105                                         10005320
      UG=USV(I)/GG(I)                                                   10005340
      SVXR=UG*(FXRD(I)+FWIR*FYR(I))                                     10005360
      SVYR=UG*(FYRD(I)-FWIR*FXR(I))                                     10005380
105   IF(USC(I).EQ.0) GO TO 102                                         10005400
      UG=USC(I)/GG(I)                                                   10005420
      SCXR=UG*(ABS(FXR(I))*FXRD2+FWR*FYR(I))                            10005440
      SCYR=UG*(ABS(FYR(I))*FYRD2-FWR*FXR(I))                            10005460
102   BVXL=0                                                            10005480
      BVYL=0                                                            10005500
      BCXL=0                                                            10005520
      BCYL=0                                                            10005540
      BVXR=0                                                            10005560
      BVYR=0                                                            10005580
      BCXR=0                                                            10005600
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      BCYR=0
      IF(MBVC.EQ.0) GO TO 120
      IF(I.EQ.1) GO TO 113
      MLS=MXL(I)**2+MYL(I)**2
      IF(MLS.EQ.0) MLS=1.E-20
      MWIL=FDOT(I)-(MYLD(I)*MXL(I)-MXLD(I)*MYL(I))/MLS
      MDL=ABS(MWIL/FDOT(I))
      IF(MDL.LT.TOL) MWL=0
      IF(MDL.GE.TOL) MWL=MWIL/ABS(MWIL)
      MXLD(I)=MXLD(I)+FDOT(I)*MYL(I)
      MYLD(I)=MYLD(I)-FDOT(I)*MXL(I)
      MXLD1=ABS(MXLD(I)/(FDOT(I)*MYL(I)))
      MYLD1=ABS(MYLD(I)/(FDOT(I)*MXL(I)))
      IF(MXLD1.LT.TOL) MXLD2=0
      IF(MXLD1.GE.TOL) MXLD2=MXLD(I)/ABS(MXLD(I))
      IF(MYLD1.LT.TOL) MYLD2=0
      IF(MYLD1.GE.TOL) MYLD2=MYLD(I)/ABS(MYLD(I))
      IF(UBV(I-1).EQ.0) GO TO 114
      UE=UBV(I-1)/EE(I-1)
      SVXL=SVXL+UE*(FXLD(I)+FWIL*FYL(I))
      SVYL=SVYL+UE*(FYLD(I)-FWIL*FXL(I))
      BVXL=UE*(MXLD(I)+MWIL*MYL(I))
      BVYL=UE*(MYLD(I)-MWIL*MXL(I))
114   IF(UBC(I-1).EQ.0) GO TO 113
      UE=UBC(I-1)/EE(I-1)
      SCXL=SCXL+UE*(ABS(FXL(I))*FXLD2+FWL*FYL(I))
      SCYL=SCYL+UE*(ABS(FYL(I))*FYLD2-FWL*FXL(I))
      BCXL=UE*(ABS(MXL(I))*MXLD2+MWL*MYL(I))
      BCYL=UE*(ABS(MYL(I))*MYLD2-MWL*MXL(I))
113   IF(I.EQ.NS) GO TO 120
      MRS=MXR(I)**2+MYR(I)**2
      IF(MRS.EQ.0) MRS=1.E-20
      MWIR=FDOT(I)-(MYRD(I)*MXR(I)-MXRD(I)*MYR(I))/MRS
      MDR=ABS(MWIR/FDOT(I))
      IF(MDR.LT.TOL) MWR=0
      IF(MDR.GE.TOL) MWR=MWIR/ABS(MWIR)
      MXRD(I)=MXRD(I)+FDOT(I)*MYR(I)
      MYRD(I)=MYRD(I)-FDOT(I)*MXR(I)
      MXRD1=ABS(MXRD(I)/(FDOT(I)*MYR(I)))
      MYRD1=ABS(MYRD(I)/(FDOT(I)*MXR(I)))
      IF(MXRD1.LT.TOL)  MXRD2=0
      IF(MXRD1.GE.TOL) MXRD2=MXRD(I)/ABS(MXRD(I))
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      IF(MYRD1.LT.TOL) MYRD2=0
      IF(MYRD1.GE.TOL) MYRD2=MYRD(I)/ABS(MYRD(I))
      IF(UBV(I).EQ.0) GO TO 115
      UE=UBV(I)/EE(I)
      SVXR=SVXR+UE*(FXRD(I)+FWIR*FYR(I))
      SVYR=SVYR+UE*(FYRD(I)-FWIR*FXR(I))
      BVXR=UE*(MXRD(I)+MWIR*MYR(I))
      BVYR=UE*(MYRD(I)-MWIR*MXR(I))
115   IF(UBC(I).EQ.0) GO TO 120
      UE=UBC(I)/EE(I)
      SCXR=SCXR+UE*(ABS(FXR(I))*FXRD2+FWR*FYR(I))
      SCYR=SCYR+UE*(ABS(FYR(I))*FYRD2-FWR*FXR(I))
      BCXR=UE*(ABS(MXR(I))*MXRD2+MWR*MYR(I))
      BCYR=UE*(ABS(MYR(I))*MYRD2-MWR*MXR(I))
120   FHX(I)=SVXL+SCXL+SVXR+SCXR
      FHY(I)=SVYL+SCYL+SVYR+SCYR
      SXL(I)=SVXL+SCXL
      SYL(I)=SVYL+SCYL
      SXR(I)=SVXR+SCXR
      SYR(I)=SVYR+SCYR
      MHX(I)=BVXL+BCXL+BVXR+BCXR
      MHY(I)=BVYL+BCYL+BVYR+BCYR
      BXL(I)=BVXL+BCXL
      BYL(I)=BVYL+BCYL
      BXR(I)=BVXR+BCXR
      BYR(I)=BVYR+BCYR
101   CONTINUE
      TORHFM(I)=0
      DO 131 I=1,NS
      INS=I+NS
      I2NS=I+NS2
      I3NS=I+NS3
      IF(I.EQ.1) GO TO 122
      TORHFM(I)=SXR(I-1)*(YN(INS)-YN(INS-1))-SYR(I-1)*(YN(I)-YN(I-1))
     &+BXR(I-1)*(YN(I3NS)-YN(I3NS-1))-BYR(I-1)*(YN(I2NS)-YN(I2NS-1))
122   IF(I.EQ.NS) GO TO 131
      TORHFM(I)=TORHFM(I)-SXL(I+1)*(YN(INS+1)-YN(INS))+SYL(I+1)*
     &(YN(I+1)-YN(I))-BXL(I+1)*(YN(I3NS+1)-YN(I3NS))
     &+BYL(I+1)*(YN(I2NS+1)-YN(I2NS))
131   CONTINUE
271   DO 118 I=1,NB
      IBI=IB(I)
```

```
      IBNS=IBI+NS
      IB2NS=IBI+NS2
      IB3NS=IBI+NS3
      IB4NS=IBI+NS4
      IB5NS=IBI+NS5
      IB6NS=IBI+NS6
      IB7NS=IBI+NS7
      I10S=I+NS10
      I10SB=I10S+NB
      I10S2B=I10SB+NB
      I10S3B=I10S2B+NB
      I10S4B=I10S3B+NB
      I10S5B=I10S4B+NB
      I10S6B=I10S5B+NB
      I10S7B=I10S6B+NB
      XB(I)=YN(IBI)-YN(I10S)
      YB(I)=YN(IBNS)-YN(I10SB)
      XBM(I)=YN(IB2NS)-YN(I10S2B)
      YBM(I)=YN(IB3NS)-YN(I10S3B)
      XBDOT(I)=YN(IB4NS)-YN(I10S4B)
      YBDOT(I)=YN(IB5NS)-YN(I10S5B)
      XBMDO(I)=YN(IB6NS)-YN(I10S6B)
118   YBMDO(I)=YN(IB7NS)-YN(I10S7B)
      DO 810 I=1,NB
      ACA=SQRT(XB(I)**2+YB(I)**2)
      K4=KK(I)
      DO 811 K=1,K4
      K1=K+1
      IF(ACA.LE.BROB(I,K1)) GO TO 116
      IF(K.EQ.KK(I)) GO TO 116
811   CONTINUE
116   BRONET=ACA-BROB(I,K)
      FOSTIF(I)=((FDOT(I)-FDOF1X(I))*(BNB(I,K)+BBB(I,K)*BRONET)+BKB(I,K)
     &)*(BCB(I,K)*BRONET**BHB(I,K)+BDB(I,K)*BRONET+BEB(I,K))
      XBFOR(I)=FOSTIF(I)*XB(I)+QKXX(I)*XB(I)+QKXY(I)*YB(I)+QCXX(I)*
     &XBDOT(I)+QCXY(I)*YBDOT(I)
      YBFOR(I)=FOSTIF(I)*YB(I)+QKYY(I)*YB(I)-QKYX(I)*XB(I)+QCYY(I)*
     &YBDOT(I)-QCYX(I)*XBDOT(I)
      XBMOM(I)=XXMK(I)*XBM(I)+XYMK(I)*YBM(I)+XXMC(I)*XBMDO(I)+XYMC(I)*
     &YBMDO(I)
      YBMOM(I)=YYMK(I)*YBM(I)-YXMK(I)*XBM(I)+YYMC(I)*YBMDO(I)-YXMC(I)*
     &XBMDO(I)
```

```
810   CONTINUE
      DO 119 I=1,NB
      I10S=I+NS10
      I10SB=I10S+NB
      I10S2B=I10SB+NB
      I10S3B=I10S2B+NB
      I10S4B=I10S3B+NB
      I10S5B=I10S4B+NB
      I10S6B=I10S5B+NB
      I10S7B=I10S6B+NB
      IF(BM(I).EQ.0) GO TO 215
      BD(I10S4B)=(XBFOR(I)-BKMX(I)*YN(I10S)-BCMX(I)*YN(I10S4B))/BM(I)
      BD(I10S5B)=(YBFOR(I)-BKMY(I)*YN(I10SB)-BCMY(I)*YN(I10S5B))/BM(I)
215   IF(BI(I).EQ.0) GO TO 119
      BD(I10S6B)=(XBMOM(I)-XKMM(I)*YN(I10S2B)-XCMM(I)*YN(I10S6B))/BI(I)
      BD(I10S7B)=(YBMOM(I)-YKMM(I)*YN(I10S3B)-YCMM(I)*YN(I10S7B))/BI(I)
119   CONTINUE
      IF(IPP.EQ.0) GO TO 205
      IF(IUSE.EQ.0) GO TO 301
      DO 291 I=1,NS
      IF(T.EQ.0) THH=0
      IF(T.NE.0) THH=T**HA
291   PP(I)=AA(I)+BA(I)*T+DA(I)*THH+EA(I)*SIN(FA*T+GA)
      DO 292 I=2,NSM1
292   PP(I)=PP(I)+PP(I-1)
      DO 222 I=1,NSM1
      INS=I+NS
      PPL=PP(I)/QL(I)
      XMX=YN(I+1)-YN(I)
      YMY=YN(INS+1)-YN(INS)
      XPL(I)=XMX*PPL
222   YPL(I)=YMY*PPL
301   DO 302 I=1,NSM1
      FXL(I+1)=FXL(I+1)+XPL(I)
      FYL(I+1)=FYL(I+1)+YPL(I)
      FXR(I)=FXR(I)-XPL(I)
302   FYR(I)=FYR(I)-YPL(I)
205   IF(IMT.EQ.0) GO TO 299
      IF(IUSE.EQ.0) GO TO 303
      DO 300 I=1,NSM1
      I2NS=I+NS2
      I3NS=I+NS3
```

```
      TORQ(I)=.5*KT(I)*(F(I+1)-F(I))
      IF(MTVC.EQ.0) GO TO 80
      FDOTP=FDOT(I+1)-FDOT(I)
      FDORA=2.*FDOTP/(FDOT(I+1)+FDOT(I))
      IF(FDORA.LT.TOL) FDOAB=0
      IF(FDORA.GE.TOL) FDOAB=FDOTP/ABS(FDOTP)
      TORQ(I)=TORQ(I)+.5*(CTV(I)*FDOTP+CTC(I)*FDOAB)
80    MTYZ(I)=-(YN(I2NS+1)-YN(I2NS))*TORQ(I)
      MTXZ(I)=(YN(I3NS+1)-YN(I3NS))*TORQ(I)
      TMTX(I)=MTXZ(I)*2./QL(I)
300   TMTY(I)=MTYZ(I)*2./QL(I)
303   DO 304 I=1,NSM1
      FXL(I+1)=FXL(I+1)-TMTX(I)
      FYL(I+1)=FYL(I+1)-TMTY(I)
      FXR(I)=FXR(I)+TMTX(I)
      FYR(I)=FYR(I)+TMTY(I)
      MXL(I+1)=MXL(I+1)+MTXZ(I)
      MYL(I+1)=MYL(I+1)+MTYZ(I)
      MXR(I)=MXR(I)+MTXZ(I)
304   MYR(I)=MYR(I)+MTYZ(I)
299   DO 209 I=1,NS
      FX(I)=FXL(I)+FXR(I)+FHX(I)
      FY(I)=FYL(I)+FYR(I)+FHY(I)
      MX(I)=MXL(I)+MXR(I)+MHX(I)
209   MY(I)=MYL(I)+MYR(I)+MHY(I)
      DO 207 I=1,NS
      XFOR=0
      YFOR=0
      XMOM=0
      YMOM=0
      K=JBI(I)
      IF(K.EQ.0) GO TO 766
      XFOR=XBFOR(K)
      YFOR=YBFOR(K)
      XMOM=XBMOM(K)
      YMOM=YBMOM(K)
766   FAA=F(I)+ALFA(I)
      COSFA=COS(FAA)
      SINFA=SIN(FAA)
      FG=F(I)+GAMMA(I)
      COSFG=COS(FG)
      SINFG=SIN(FG)
```

```
      INS=I+NS
      I2NS=I+NS2
      I3NS=I+NS3
      I4NS=I+NS4
      I5NS=I+NS5
      I6NS=I+NS6
      I7NS=I+NS7
      I9NS=I+NS9
      FDOTSQ=FDOT(I)**2
      WHIR=(YN(I5NS)*YN(I)-YN(I4NS)*YN(INS))/(YN(I)**2+YN(INS)**2)
      WHIRM=(YN(I7NS)*YN(I2NS)-YN(I6NS)*YN(I3NS))/
     &(YN(I2NS)**2+YN(I3NS)**2)
      BD(I4NS)=1./QM(I)*(FX(I)-(QK(I)*YN(I)+QC(I)*YN(I4NS)
     &+XFOR
     &+QKHD(I)*YN(INS)*(FDCT(I)-XKF(I)*WHIR)+QCHD(I)*YN(I5NS)*
     &(FDOT(I)-XCF(I)*WHIR)
     &+QKP(I)*YN(INS)+QCP(I)*YN(I5NS))) +ECC(I)*(FDD(I)*SINFA+
     &FDOTSQ*COSFA)-GX
      BD(I5NS)=1./QM(I)*(FY(I)-(QK(I)*YN(INS)+QC(I)*YN(I5NS)
     &+YFOR
     &-QKHD(I)*YN(I)*(FDOT(I)-XKF(I)*WHIR)-QCHD(I)*YN(I4NS)*
     &(FDOT(I)-XCF(I)*WHIR)
     &-QKP(I)*YN(I)-QCP(I)*YN(I4NS)))-ECC(I)*(FDD(I)*COSFA-
     &FDOTSQ*SINFA)-GY
      BD(I6NS)=1./QID(I)*(MX(I)-QKF(I)*YN(I2NS)-QCF(I)*YN(I6NS)
     &-QKHDF(I)*YN(I3NS)*(FDOT(I)-XKFF(I)*WHIRM)-QCHDF(I)*YN(I7NS)*
     &(FDOT(I)-XCFF(I)*WHIRM)-XMOM
     &-QKPF(I)*YN(I3NS)-QCPF(I)*YN(I7NS)-QIRO(I)*FDOT(I)*YN(I7NS)
     &-BETA(I)*(QIRO(I)-QID(I))*(FDD(I)*SINFG+FDOTSQ*COSFG))
207   BD(I7NS)=1./QID(I)*(MY(I)-QKF(I)*YN(I3NS)-QCF(I)*YN(I7NS)
     &+QKHDF(I)*YN(I2NS)*(FDOT(I)-XKFF(I)*WHIRM)+QCHDF(I)*YN(I6NS)*
     &(FDOT(I)-XCFF(I)*WHIRM)-YMOM
     &+QKPF(I)*YN(I2NS)+QCPF(I)*YN(I6NS)+QIRO(I)*FDOT(I)*YN(I6NS)
     &-BETA(I)*(QIRO(I)-QID(I))*(-FDD(I)*COSFG+FDOTSQ*SINFG))
      IF(IUSE.EQ.0) GO TO 788
      DO 411 I=1,NS
      FAA=F(I)+ALFA(I)
      FG=F(I)+GAMMA(I)
      COSFA=COS(FAA)
      SINFA=SIN(FAA)
      COSFG=COS(FG)
      SINFG=SIN(FG)
```

```
      I4NS=I+NS4
      I5NS=I+NS5
      I6NS=I+NS6
      I7NS=I+NS7
      I9NS=I+NS9
      COMB=QME(I)*((BD(I5NS)+GY)*COSFA-(BD(I4NS)+GX)*SINFA)
     &+QID(I)*BETA(I)*(BD(I7NS)*COSFG-BD(I6NS)*SINFG)
     &-QIRO(I)*FDOT(I)*BETA(I)*(YN(I7NS)*SINFG+YN(I6NS)*COSFG)
      IF(FDOT(I).LT.0) FDOCT=-ABS(FDOT(I))**CT(I)
      IF(FDOT(I).GE.0) FDOCT=FDOT(I)**CT(I)
      COMB=COMB+CT1(I)*FDOCT+CT2(I)*FDOT(I)
      IF(ITORQ.EQ.0) GO TO 233
      IF(FDOT(I).LT.0) FDOMT=-ABS(FDOT(I))**MT(I)
      IF(FDOT(I).GE.0) FDOMT=FDOT(I)**MT(I)
      COMB=COMB-(MT1(I)*FDOMT+MT2(I)*FDOT(I)+AT(I)+BT(I)*T+DU(I)*T
     &**HT(I)+ET(I)*SIN(FT(I)*T+GT(I)))
233   IF(I.EQ.1) GO TO 413
      COMB=COMB+KT(I-1)*(F(I)-F(I-1))
      IF(MTVC.EQ.0) GO TO 413
      FDOTM=FDOT(I)-FDOT(I-1)
      FDOMRA=2.*ABS(FDOTM/(FDOT(I)+FDOT(I-1)))
      IF(FDOMRA.LT,TOL) FDOMAB=0
      IF(FDOMRA.GE.TOL) FDOMAB=FDOTM/ABS(FDOTM)
      COMB=COMB+CTV(I-1)*FDOTM+CTC(I-1)*FDOMAB
413   IF(I.EQ.NS) GO TO 414
      COMB=COMB-KT(I)*(F(I+1)-F(I))
      IF(MTVC.EQ.0) GO TO 414
      FDOTN=FDOT(I+1)-FDOT(I)
      FDONRA=2.*ABS(FDOTN/(FDOT(I+1)+FDOT(I)))
      IF(FDONRA.LT.TOL) FDONAB=0
      IF(FDONRA.GE.TOL) FDONAB=FDOTN/ABS(FDOTN)
      COMB=COMB-CTV(I)*FDOTN-CTC(I)*FDONAB
414   TORS(I)=-COMB-TORHFM(I)
411   CONTINUE
      IF(NSTOT.NE.0) GO TO 54
      DO 53 I=1,NS
      I9NS=I+NS9
53    FDD(I)=TORS(I)/AR(I)
      GO TO 55
54    DO 56 I=1,NS
      I9NS=I+NS9
      IF(I.GE.1.AND.I.LT.ISTAR(1)) GO TO 57
```

```
      IF(I.LE.NS.AND.I.GT.ISTOP(NSTOT)) GO TO 57
      NST1=NSTOT-1
      DO 58 J=1,NST1
      IF(I.GT.ISTOP(J).AND.I.LT.ISTAR(J+1)) GO TO 57
58    CONTINUE
57    FDOD(I)=TORS(I)/AR(I)
56    CONTINUE
      DO 50 1=1,NSTOT
      IR=ISTAR(I)
      IP=ISTOP(I)
      TOR=0
      ARO=0
      DO 51 J=IR,IP
      TOR=TOR+TORS(J)
51    ARO=ARO+AR(J)
      JJ=ISTAR(I)
      FDOD(JJ)=TOR/ARO
      IR1=IR+1
      DO 52 IJ=IR1,IP
52    FDOD(IJ)=FDOD(JJ)
50    CONTINUE
55    CONTINUE
      IUSE=0
788   CONTINUE
      DO 812 I=1,NS4
      I4NS=I+NS4
812   BD(I)=YN(I4NS)
      DO 813 I=1,NS
      I8NS=I+NS8
      I9NS=I+NS9
      BD(I9NS)=FDD(I)
813   BD(I8NS)=YN(I9NS)
      NB4=NB*4
      DO 503 I=1,NB4
      I10S=I+NS10
      I10S4B=I10S+NB4
503   BD(I10S)=YN(I10S4B)
      DO 216 I=1,NB
      K=IB(I)
      KNS=K+NS
      K4NS=K+NS4
      K5NS=K+NS5
```

```
      I10S=I+NS10                                                       10012340
      I10SB=I10S+NB                                                     10012360
      I10S4B=I10S+NB4                                                   10012380
      I10S5B=I10SB+NB4                                                  10012400
      IF(BM(I).NE.0) GO TO 217                                          10012420
      BD(I10S4B)=BD(K4NS)*YN(I10S)/YN(K)                                10012440
      BD(I10S5B)=BD(K5NS)*YN(I10SB)/YN(KNS)                             10012460
217   IF(BI(I).NE.0) GO TO 216                                          10012480
      K2NS=K+NS2                                                        10012500
      K3NS=K+NS3                                                        10012520
      K6NS=K+NS6                                                        10012540
      K7NS=K+NS7                                                        10012560
      I10S2B=I10SB+NB                                                   10012580
      I10S3B=I10S2B+NB                                                  10012600
      I10S6B=I10S5B+NB                                                  10012620
      I10S7B=I10S6B+NB                                                  10012640
      BD(I10S6B)=BD(K6NS)*YN(I10S2B)/YN(K2NS)                           10012660
      BD(I10S7B)=BD(K7NS)*YN(I10S3B)/YN(K3NS)                           10012680
216   CONTINUE                                                          10012700
      RETURN                                                            10012720
      END                                                               10012740
      SUBROUTINE HYSMET(YNN,IC,II)                                      05000000
      INTEGER       CONTIN,RIG,CT,CRT                                   05000020
      REAL INPRPM,   MT1,MT2,MOSQ,MOWHIR,MORO,MOPHAS,MOFOR,MOFOPH        05000040
      DIMENSION WHIRR(15),WHSLOP(15),SLOP(15)                           05000060
      DIMENSION                PHAROS(15),BSLRO(6),BSPHAS(6),           05000080
     &ROMM(6),                                                          05000100
     &PHASMM(6),BGPHAS(6)                                               05000120
      DIMENSION XBM(6),YBM(6),XBMOM(6),YBMOM(6),XMF(6),YMF(6),          05000140
     &XMOM(6),YMOM(6)                                                   05000160
      DIMENSION TT(50),RPMM(50),WHRATI(50),FORC(50,6),BRGR(50,6),ROMAX(505000180
     &0),ROSTA(50),ISTATN(50),XXT(50),YYT(50)                           05000200
      DIMENSION XX(15),YY(15),RO(15),          PHARO(15),WHRVLO(15),    05000220
     &WHRATO(15),                                                       05000240
     &           XB(6),YB(6),XBDOT(6),YBDOT(6),BRGRO(6),XBFOR(6),       05000260
     &YBFOR(6),                                                         05000280
     &BRGFOR(6),BRFOPH(6),MORO(6),MOPHAS(6),MOFOR(6),MOFOPH(6),         05000300
     &MOWHIR(6),                                                        05000320
     &XMFOR(6),YMFOR(6),REV(15),RPM(15),YNN(198)                        05000340
      COMMON NS,NS2,NS3,NS4,NS5,NS6,NS7,NS8,NS9,NS10,NSM1,NSP1,NS2P1,   05000360
     &NS4P1,IP,IPRINT,                                                  05000380
     &NN,NB,IB1,IBNB,NNT,ITIM,IUSE,CRT,CONTIN,NOORPM,IASIGN,NPOINT,     05000400
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     &MOSHA,MET,IND,IPP,ITORQ,IMT,G
      COMMON PI, T,DT,TMAX,DP,      TOLI,GX,GY,Q,S,QLL,QMLOV,HA,FA,GA
      COMMON IB(6),KK(6),RIG(14),JBI(15),CT(15),MT(15)
      COMMON TITLE(18),F(15),FDOT(15),FDOFIX(6),DD(14),D(14),QL(14),
     &P(14),
     &DN(14),EE(14),GG(14),EI(14),GAK(14),SHK(14),AM(15),AID(15),
     &AIRO(15),
     &QM(15),
     &QID(15),QIRO(15),ECC(15),ALFA(15),BETA(15),GAMMA(15),QME(15),
     &FOSTIF(6),
     &Z(15),QZ(15),QK(15),QC(15),QKP(15),QCP(15),QKHD(15),QCHD(15),
     &QKF(15),QCF(15),
     &QKPF(15),QCPF(15),QKHDF(15),QCHDF(15),XKF(15),XCF(15),XKFF(15),
     &XCFF(15),
     &QKXX(6),QKXY(6),QKYY(6),QKYX(6),QCXX(6),QCXY(6),QCYY(6),QCYX(6),
     &XXMK(6),XYMK(6),YYMK(6),YXMK(6),XXMC(6),XYMC(6),YYMC(6),YXMC(6),
     &BI(6),XKMM(6),YKMM(6),XCMM(6),YCMM(6),
     &BKMX(6),BKMY(6),BCMX(6),BCMY(6),BM(6),USV(14),USC(14),
     &UBV(14),UBC(14),UTV(14),UTC(14),CT1(15),CT2(15),CTV(14),CTC(14),
     &MT1(15),MT2(15),AT(15),BT(15),DU(15),HT(15),ET(15),FT(15),GT(15),
     &AA(15),
     &BA(15),DA(15),EA(15),   YN(84),   INPRPM(50)
      COMMON C(15,15),B(15,15),TF(15,15),TM(15,15),BBB(6,3),BDB(6,3),
     &BEB(6,3),
     &BCB(6,3),BHB(6,3),BKB(6,3),BNB(6,3),BROB(6,4)
404   FORMAT(1PE21.4,1P4E13.4)
      A=180./PI
      H=A/6.
      V=.5/PI
      DO 32 I=1,NS
      INS=I+NS
      I2NS=I+NS2
      I3NS=I+NS3
      I4NS=I+NS4
      I5NS=I+NS5
      I6NS=I+NS6
      I7NS=I+NS7
      ROSQ=YNN(I)**2+YNN(INS)**2
      RO(I)=SQRT(ROSQ)
      XX(I)=YNN(I)
      YY(I)=YNN(INS)
      IF(YY(I).EQ.0) YY(I)=1.E-20
```

```
      IF(XX(I).EQ.0) XX(I)=1.E-20                                      05001260
      PHARO(I)=ATAN2(YY(I),XX(I))*A                                    05001280
      IF(PHARO(I).LT.0) PHARO(I)=360.+PHARO(I)                         05001300
      WHRVLO(I)=(YNN(I5NS)*YNN(I)-YNN(I4NS)*YNN(INS))/ROSQ             05001320
      SLOPSQ=YNN(I2NS)**2+YNN(I3NS)**2                                 05001340
      WHSLOP(I)=(YNN(I7NS)*YNN(I2NS)-YNN(I6NS)*YNN(I3NS))/SLOPSQ*H     05001360
      SLOP(I)=SQRT(SLOPSQ)                                             05001380
      IF(YNN(I2NS).EQ.0) YNN(I2NS)=1.E-20                              05001400
      IF(YNN(I3NS).EQ.0) YNN(I3NS)=1.E-20                              05001420
      PHAROS(I)=ATAN2(YNN(I3NS),YNN(I2NS))*A                           05001440
32    IF(PHAROS(I).LT.0) PHAROS(I)=360.+PHAROS(I)                      05001460
      DO 224 I=1,NB                                                    05001480
      I10S=I+NS10                                                      05001500
      I10SB=I10S+NB                                                    05001520
      I10S2B=I10SB+NB                                                  05001540
      I10S3B=I10S2B+NB                                                 05001560
      I10S4B=I10S3B+NB                                                 05001580
      I10S5B=I10S4B+NB                                                 05001600
      I10S6B=I10S5B+NB                                                 05001620
      I10S7B=I10S6B+NB                                                 05001640
      J=IB(I)                                                          05001660
      JNS=J+NS                                                         05001680
      J2NS=J+NS2                                                       05001700
      J3NS=J+NS3                                                       05001720
      J4NS=J+NS4                                                       05001740
      J5NS=J+NS5                                                       05001760
      J6NS=J+NS6                                                       05001780
      J7NS=J+NS7                                                       05001800
      J9NS=J+NS9                                                       05001820
      XB(I)=(YNN(J)-YNN(I10S))                                         05001840
      YB(I)=(YNN(JNS)-YNN(I10SB))                                      05001860
      XBDOT(I)=(YNN(J4NS)-YNN(I10S2B))                                 05001880
      YBDOT(I)=(YNN(J5NS)-YNN(I10S3B))                                 05001900
      IF(XB(I).EQ.0) XB(I)=1.E-20                                      05001920
      IF(YB(I).EQ.0) YB(I)=1.E-20                                      05001940
      BRGRO(I)=SQRT(XB(I)**2+YB(I)**2)                                 05001960
      BGPHAS(I)=ATAN2(YB(I),XB(I))*A                                   05001980
      IF(BGPHAS(I).LT.0) BGPHAS(I)=360.+BGPHAS(I)                      05002000
      XBFOR(I)=FOSTIF(I)*XB(I)                                         05002020
     &+QKXX(I)*XB(I)+QKXY(I)*YB(I)+QCXX(I)*XBDOT(I)+QCXY(I)*YBDOT(I)   05002040
      YBFOR(I)=FOSTIF(I)*YB(I)                                         05002060
     &+QKYY(I)*YB(I)-QKYX(I)*XB(I)+QCYY(I)*YBDOT(I)-QCYX(I)*XBDOT(I)   05002080
```

```
      IF(XBFOR(I).EQ.0) XBFOR(I)=1.E-20
      IF(YBFOR(I).EQ.0) YBFOR(I)=1.E-20
      BRGFOR(I)=SQRT(XBFOR(I)**2+YBFOR(I)**2)
      BRFOPH(I)=ATAN2(YBFOR(I),XBFOR(I))*A
      IF(BRFOPH(I).LT.0) BRFOPH(I)=BRFOPH(I)+360.
      MOSQ=YNN(I10S)**2+YNN(I10SB)**2
      MOWHIR(I)=(YNN(I10S5B)*YNN(I10S)-YNN(I10S4B)*YNN(I10SB))/MOSQ
      MOWHIR(I)=MOWHIR(I)/YNN(J9NS)
      MORO(I)=SQRT(MOSQ)
      IF(YNN(I10S).EQ.0) YNN(I10S)=1.E-20
      IF(YNN(I10SB).EQ.0) YNN(110SB)=1.E-20
      MOPHAS(I)=ATAN2(YNN(I10SB),YNN(I10S))*A
      IF(MOPHAS(I).LT.0) MOPHAS(I)=MOPHAS(I)+360.
      XBM(I)=YNN(J2NS)-YNN(I10S2B)
      YBM(I)=YNN(J3NS)-YNN(I10S3B)
      IF(1.NE.2) GO TO 2
C     THE LOAD COMPUTATIONS SKIPPED BY "GO TO 2" ARE NOT NEEDED IN WRITE
C     -OUT, HOWEVER THEY ARE RETAINED FOR POSSIBLE FUTURE USE.
      XMFOR(I)=BKMX(I)*YNN(I10S)+BCMX(I)*YNN(I10S4B)
      YMFOR(I)=BKMY(I)*YNN(I10SB)+BCMY(I)*YNN(I10S5B)
      IF(XMFOR(I).EQ.0) XMFOR(I)=1.E-20
      IF(YMFOR(I).EQ.0) YMFOR(I)=1.E-20
      MOFOR(I)=SQRT(XMFOR(I)**2+YMFOR(I)**2)
      MOFOPH(I)=ATAN2(YMFOR(I),XMFOR(I))*A
      IF(MOFOPH(I).LT.0) MOFOPH(I)=MOFOPH(I)+360.
      XBMDOT=YNN(J6NS)-YNN(I10S6B)
      YBMDOT=YNN(J7NS)-YNN(I10S7B)
      XBMOM(I)=XXMK(I)*XBM(I)+XYMK(I)*YBM(I)+XXMC(I)*XBMDOT+XYMC(I)
     &*YBMDOT
      YBMOM(I)=YYMK(I)*YBM(I)-YXMK(I)*XBM(I)+XXMC(I)*YBMDOT-YXMC(I)
     &*XBMDOT
      XMOM(I)=XKMM(I)*YNN(I10S2B)+XCMM(I)*YNN(I10S6B)
      YMOM(I)=YKMM(I)*YNN(I10S3B)+YCMM(I)*YNN(I10S7B)
    2 IF(XBM(I).EQ.0) XBM(I)=1.E-20
      IF(YBM(I).EQ.0) YBM(I)=1.E-20
      BSLRO(I)=SQRT(XBM(I)**2+YBM(I)**2)
      BSPHAS(I)=ATAN2(YBM(I),XBM(I))*A
      IF(BSPHAS(I).LT.0) BSPHAS(I)=360.+BSPHAS(I)
      IF(YNN(I10S2B).EQ.0) YNN(I10S2B)=1.E-20
      IF(YNN(I10S3B).EQ.0) YNN(I10S3B)=1.E-20
      ROMM(I)=SQRT(YNN(I10S2B)**2+YNN(I10S3B)**2)
      PHASMM(I)=ATAN2(YNN(I10S3B),YNN(I10S2B))*A
```

```
224   IF(PHASMM(I).LT.0) PHASMM(I)=360.+PHASMM(I)
      DO 225 I=1,NS
      I8NS=I+NS8
      I9NS=I+NS9
      REV(I)=YNN(I8NS)*V
      WHIRR(I)=WHRVLO(I)*H
      RPM(I)=YNN(I9NS)*H
225   WHRATO(I)=WHRVLO(I)/YNN(I9NS)
      AIN=2.54
      AF=4.4482216152605
      DO 38 I=1,NB
      BRGRO(I)=BRGRO(I)*AIN
38    MORO(I)=MORO(I)*AIN
      DO 39 I=1,NS
39    RO(I)=RO(I)*AIN
      IF(IP.LT.IPRINT) GO TO 164
      IP=0
      WRITE(6,304)
304   FORMAT('     ROTOR SPIN REVOLUTION ARRAY')
      WRITE(6,404) (REV(I),I=1,NS)
      WRITE(6,305)
305   FORMAT('     ROTOR DISPLACEMENT ARRAY, CM')
      WRITE(6,404) (RO(I),I=1,NS)
      WRITE(6,386)
386   FORMAT('     ROTOR DISPLACEMENT PHASE ANGLE ARRAY, DEGREES')
      WRITE(6,404) (PHARO(I),I=1,NS)
      WRITE(6,306)
306   FORMAT('     ROTOR SLOPE ARRAY, RADIANS')
      WRITE(6,404) (SLOP(I),I=1,NS)
      WRITE(6,307)
307   FORMAT('     ROTOR SLOPE PHASE ANGLE ARRAY, DEGREES')
      WRITE(6,404) (PHAROS(I),I=1,NS)
      WRITE(6,308)
308   FORMAT('     ROTOR SPIN SPEED ARRAY, RPM')
      WRITE(6,404) (RPM(I),I=1,NS)
      WRITE(6,309)
309   FORMAT('     ROTOR DISPLACEMENT WHIRL FREQUENCY ARRAY, RPM')
      WRITE(6,404) (WHIRR(I),I=1,NS)
      WRITE(6,310)
310   FORMAT('     ROTOR SLOPE WHIRL FREQUENCY ARRAY, RPM')
      WRITE(6,404) (WHSLOP(I),I=1,NS)
      WRITE(6,311)
```

```
311   FORMAT('     BEARING DISPLACEMENT ARRAY, CM')
      WRITE(6,404) (BRGRO(I),I=1,NB)
      WRITE(6,312)
312   FORMAT('     BEARING DISPLACEMENT PHASE ANGLE ARRAY, DEGREES')
      WRITE(6,404) (BGPHAS(I),I=1,NB)
      WRITE(6,313)
313   FORMAT('     MOUNT DISPLACEMENT ARRAY, CM')
      WRITE(6,404) (MORO(I),I=1,NB)
      WRITE(6,314)
314   FORMAT('     MOUNT DISPLACEMENT PHASE ANGLE ARRAY, DEGREES')
      WRITE(6,404) (MOPHAS(I),I=1,NB)
      WRITE(6,315)
315   FORMAT('     BEARING MASS WHIRL/ROTOR SPIN FREQUENCY RATIO ARRAY')
      WRITE(6,404) (MOWHIR(I),I=1,NB)
      WRITE(6,316)
316   FORMAT('     BEARING SLOPE ARRAY, RADIANS')
      WRITE(6,404) (BSLRO(I),I=1,NB)
      WRITE(6,317)
317   FORMAT('     BEARING SLOPE PHASE ANGLE ARRAY, DEGREES')
      WRITE(6,404) (BSPHAS(I),I=1,NB)
      WRITE(6,388)
388   FORMAT('     MOUNT SLOPE ARRAY, RADIANS')
      WRITE(6,404) (ROMM(I),I=1,NB)
      WRITE(6,319)
319   FORMAT('     MOUNT SLOPE PHASE ANGLE ARRAY, DEGREES')
      WRITE(6,404) (PHASMM(I),I=1,NB)
  164 IF(CRT.EQ.0) RETURN
      IC=1+IC
      TT(IC)=T
      RPMM(IC)=RPM(IASIGN)
      WHRATI(IC)=WHIRR(IASIGN)/RPM(IASIGN)
      XXT(IC)=XX(IASIGN)*AIN
      YYT(IC)=YY(IASIGN)*AIN
      DO 500 I=1,NB
      FORC(IC,I)=BRGFOR(I)*AF
  500 BRGR(IC,I)=BRGRO(I)
      J=1
      DO 510 I=1,NS
      IF(RO(J).LT.RO(I))J=I
  510 CONTINUE
      ROMAX(IC)=RO(J)
      ISTATN(IC)=J
```

```
      ROSTA(IC)=RO(IASIGN)                                              05004620
      IF(MOSHA.EQ.0)GOTO163                                             05004640
      IF(ACCEL.EQ.0)GOTO163                                             05004660
      IF(II.GT.NOORPM)GOTO163                                           05004680
      IF(RPM(IASIGN).LT.INPRPM(II))GOTO163                              05004700
      II=1+II                                                           05004720
C     PLOT 1                                                            05004740
      REAL CHAR11(21),CHAR21(8),CHAR31(9),CHARSS(4),SYMBOL/'*'/         05004760
      DATA CHAR11/'ROTOR 3-DIMENSIONAL MODE SHAPE WITH PHASE ANGLES (DEG05004780
     1REES) LABELED AS SHOWN, AT RPM='/,CHAR21/'ROTOR AXIAL LENGTH,  CEN05004800
     2TIMETERS'/,CHAR31/'ROTOR DEFLECTION VECTOR, CENTIMETERS'/         05004820
      CALL LRLEGN(TITLE,72,0,1.15,9.99,0.)                              05004840
      CALL LRLEGN(CHAR11,84,0,1.463,9.67,0.)                            05004860
      CALL LRCNVT(RPMM(IC),3,CHARSS,4,13,5)                             05004880
      CALL LRLEGN(CHARSS,13,0,8.6,9.67,0.)                              05004900
      CALL LRLEGN(CHAR21,27,0,4.31,0.,0.)                               05004920
      CALL LRCURV(Z,RO,NS,2,SYMBOL,0.)                                  05004940
      DO 1005 I=1,NS                                                    05004960
      CALL LRCNVT(PHARO(I),3,CHARSS,3,4,0)                              05004980
      CALL LRLABL(CHARSS,4,0,Z(I),RO(I),0.)                             05005000
 1005 CONTINUE                                                          05005020
      CALL LRLEGN(CHAR31,31,1,0.,4.6,1.)                                05005040
  163 IF(T.GE.TMAX) GO TO 1040                                          05005050
      IF(IC.LT.NPOINT)RETURN                                            05005060
 1040 NPOINT =IC                                                        05005080
      IC=0                                                              05005100
C     PLOT 2                                                            05005120
      CALL LRLEGN(TITLE,72,0,1.15,9.99,0.)                              05005140
      REAL CHAR12(7)/'ROTOR SPIN SPEED VERSUS TIME'/,CHAR22(4)/'TIME, SE05005160
     1CONDS    '/,CHAR32(6)/'ROTOR SPIN SPEED, RPM    '/                05005180
      CALL LRCURV(TT,RPM,NPOINT,2,SYMBOL,0.)                            05005200
      CALL LRCURV(TT,RPM,NPOINT,3,SYMBOL,0.)                            05005220
      CALL LRLEGN(CHAR12,28,0,3.50,9.67,0.)                             05005240
      CALL LRLEGN(CHAR22,13,0,4.86,0.,0.)                               05005260
      CALL LRLEGN(CHAR32,21,1,0.,4.95,1.)                               05005280
C     PLOT 3                                                            05005300
      CALL LRLEGN(TITLE,72,0,1.15,9.99,0.)                              05005320
      REAL CHAR13(19)/'ROTOR WHIRL-TO-SPIN FREQUENCY RATIO VERSUS ROTOR 05005340
     1SPIN SPEED AT ROTOR STATION'/                                     05005360
      CALL LRCURV(RPM,WHRATI,NPOINT,2,SYMBOL,0.)                        05005380
      CALL LRCURV(RPM,WHRATI,NPOINT,3,SYMBOL,0.)                        05005400
      CALL LRCNVT(IASIGN,1,CHARSS,1,3,0)                                05005420
```

```
      CALL LRLEGN(CHARSS,3,0,7.85,9.67,0.)                               05005440
      CALL LRLEGN(CHAR13,76,0,1.795,9.67,0.)                             05005460
      CALL LRLEGN(CHAR13,35,1,C.,3.47,0.)                                05005480
      CALL LRLEGN(CHAR32,21,0,4.55,0.,1.)                                05005500
C     PLOT 4                                                             05005520
C     PLOT RPM VS FORC FUNCTIONS                                         05005540
      CALL PLOTBR(FORC)                                                  05005560
      CALL LRLEGN(TITLE,72,0,1.15,9.99,0.)                               05005580
      REAL CHAR14(24)/'BEARING REACTIONS VERSUS ROTOR SPIN SPEED WITH BE05005600
     1ARING LOCATION STATION NUMBERS LABELED AS SHOWN'/,CHAR24(7)/'BEARI05005620
     2NG REACTIONS, NEWTONS  '/                                          05005640
      CALL LRLEGN(CHAR14,96,0,1.385,9.67,0.)                             05005660
      CALL LRLEGN(CHAR32,21,0,4.55,0.,0.)                                05005680
      CALL LRLEGN(CHAR24,25,1,0.,4.37,1.)                                05005700
C     PLOT 5                                                             05005720
C     PLOT RPM VS BRGR FUNCTIONS                                         05005740
      CALL PLOTBR(BRGR)                                                  05005760
      CALL LRLEGN(TITLE,72,0,1.15,9.99,0.)                               05005780
      REAL CHAR15(25)/'JOURNAL DISPLACEMENT VERSUS ROTOR SPIN SPEED WITH05005800
     1 BEARING LOCATION STATION NUMBERS LABELED AS SHOWN '/,CHAR25(9)/  05005820
     2'JOURNAL DISPLACEMENTS, CENTIMETERS  '/                            05005840
      CALL LRLEGN(CHAR15,99,0,1.21,9.67,0.)                              05005860
      CALL LRLEGN(CHAR32,21,0,4.55,0.,0.)                                05005880
      CALL LRLEGN(CHAR25,29,1,C.,4.52,1.)                                05005900
C     PLOT 6                                                             05005920
      CALL LRANGE(0.,0.,0.,0.)                                           05005940
      REAL CHAR16(13)/'MAXIMUM ROTOR DEFLECTIONS VERSUS ROTOR SPIN SPEED05005960
     1   '/,CHAR26(22)/'(THE STATION NUMBERS WHERE THE MAXIMUM DEFLECTIO05005980
     2NS OCCUR ARE SHOWN) '/,CHAR36(10)/'MAXIMUM ROTOR DEFLECTIONS, CENT05006000
     3IMETERS  '/                                                        05006020
      CALL LRCURV(RPM,ROMAX,NPOINT,2,SYMBOL,0.)                          05006040
      DO 1006 I=1,NPOINT                                                 05006060
      CALL LRCNVT(ISTATN(I),1,CHARSS,1,3,0)                              05006080
 1006 CALL LRLABL(CHARSS,3,0,RPM(I),ROMAX(I),0.)                         05006100
      CALL LRLEGN(TITLE,72,0,1.15,9.99,0.)                               05006120
      CALL LRLEGN(CHAR16,49,0,3.45,9.756,0.)                             05006140
      CALL LRLEGN(CHAR26,67,0,2.75,9.639,0.)                             05006160
      CALL LRLEGN(CHAR32,21,0,4.55,0.,0.)                                05006180
      CALL LRLEGN(CHAR36,33,1,0.,4.52,1.)                                05006200
C     PLOT 7                                                             05006220
      REAL CHAR17(17)/'(THE STATION NUMBER WHERE THE ROTOR DEFLECTIONS O05006240
     1CCUR IS SHOWN)'/                                                   05006260
```

```
      CALL LRCURV(RPM,ROSTA,NPOINT,2,SYMBOL,0.)                          05006280
      DO 1007 I=1,NPOINT                                                  05006300
      CALL LRCNVT(IASIGN,1,CHARSS,1,3,0)                                  05006320
 1007 CALL LRLABL(CHARSS,3,0,RPM(I),ROSTA(I),0.)                          05006340
      CALL LRLEGN(TITLE,72,0,1.15,9.99,0.)                                05006360
      CALL LRLEGN(CHAR16(3),41,0,3.45,9.756,0.)                           05006380
      CALL LRLEGN(CHAR17,63,0,2.75,9.639,0.)                              05006400
      CALL LRLEGN(CHAR32,21,0,4.55,0.,0.)                                 05006420
      CALL LRLEGN(CHAR36(3),25,1,0.,4.25,1.)                              05006440
C     PLOT 8                                                              05006460
      REAL CHAR18( 8)/'ROTOR ORBIT X-Y PLOT AT STATION '/,                05006480
     1CHAR28(5)/'X-AXIS, CENTIMETERS '/,                                  05006500
     2CHAR38(5)/'Y-AXIS, CENTIMETERS '/                                   05006520
 2000 CALL LRLEGN(TITLE,72,0,1.15,9.99,0.)                                05006540
      CALL LRLEGN(CHAR18,32,0,3.45,9.67,0.)                               05006560
      CALL LRCNVT(IASIGN,1,CHARSS,1,2,0)                                  05006580
      CALL LRLEGN(CHARSS,2,0,9.25,9.67 ,0.)                               05006600
      CALL LRLEGN(CHAR28,16,0,4.31,0.,0.)                                 05006620
      CALL LRLEGN(CHAR38,16,1,0.,5.,0.)                                   05006640
      XMIN=1E70                                                           05006660
      YMIN=1E70                                                           05006680
      XMAX=-1E70                                                          05006700
      YMAX=-1E70                                                          05006720
      DO 2010 I=1,NPOINT                                                  05006740
      XMIN=AMIN1(XMIN,XXT(I))                                             05006760
      YMIN=AMIN1(YMIN,YYT(I))                                             05006780
      XMAX=AMAX1(XMAX,XXT(I))                                             05006800
 2010 YMAX=AMAX1(YMAX,YYT(I))                                             05006820
      CALL LRANGE(XMIN,XMAX,YMIN,YMAX)                                    05006840
      CALL LRCURVE(XX,YY,NPOINT,2,SYMBOL,1.)                              05006860
      RETURN                                                              05006880
      END                                                                 05006900
```

```
      SUBROUTINE PLOTBR(F,RPM,NPOINT,NB,IB)                               11000020
      DIMENSION F(50,6),RPM(50),IB(6),Y(2)                                11000040
C     GET LIMITS OF F & RPM                                               11000060
      Y(1)=1.E70                                                          11000080
      Y(2)=-1.E70                                                         11000100
      DO 10 I=1,NB                                                        11000120
      DO 10 J=1,NPOINT                                                    11000140
      Y(1)=AMIN1(Y(1),F(J,I))                                             11000160
   10 Y(2)=AMAX1(Y(2),F(J,I))                                             11000180
      CALL LRANGE(RPM(1),RPM(NPOINT),Y(1),Y(2))                           11000200
```

```
C     PLOT EACH OF THE NB FUNCTIONS
      DO 20 I=1,NB
      CALL LRCURV(RPM,F(I,1),NPOINT,2,Y,0.)
      CALL LRCNVT(IB(I),1,Y,1,3,0)
      DO 20 J=1,NPOINT
   20 CALL LRLABL(Y,3,0,RPM(J),F(J,I),0.)
      RETURN
      END
```

```
TEST DATA: DATAES (STEADY-STATE INPUT USING ENGLISH UNITS)    APR.4,197300000001
 &MUST DT=.00005,TMAX=.010,DP=.002,NS=3,NB=2,              IB=1,3,DD=1,1,
 QL=5,5,MET=0, FDOT1=60000,                                          &END
 &OPTION       DN=0,0,GG=1.2E7,1.2E7,AM=3*50,ALFA=3*45,AID=3*50,AIRO=3*25,
 IPRINT=2,
 BETA=.0057,0,-.0057,GAMMA=3*45,XKMM=2*2.E6,YKMM=2*2.E6,BM=2*30,BI=2*30,
 XXMK=2*1.E6,YYMK=2*1.E6,KK=2,2,FDOFIX=2*3000,
 BBB=18*10,  BCB=18*1,   BDB=18*10,  BEB=18*10,  BHB=18*2,
   BKB(1,1)=1.E5,BKB(2,1)=1.E5,BKB(1,2)=1.,BKB(2,2)=1.,BNB(1,1)=10.,
 BNB(2,1)=10.,BNB(1,2)=1.,BNB(2,2)=1.,BROB(1,2)=1.,BROB(2,2)=1.,
 BROB(1,3)=1.,BROB(2,3)=1.,YKMM=2*2.E6, QKXX=2*0,QKYY=2*0,          &END
TEST DATA: DATAET (TRANSIENT SPIN SPEED INPUT DATA,ENGLISH UNITS) APR.73
 &MUST DT=.00005,TMAX=.010,DP=.002,NS=3,NB=2,              IB=1,3,DD=1,1,
 QL=5,5,MET=0, FDOT1=1000,                                           &END
 &OPTION       DN=0,0,GG=1.2E7,1.2E7,AM=3*50,ALFA=3*45,AID=3*50,AIRO=3*25,
 ITORQ=1,            GAMMA=3*45,AT(3)=1.E6, BM=2*30,BI=2*30,
            KK=2,2,FDOFIX=2*3000.,   CRT=1,XXMK=2*0,YYMK=2*0,
 BBB=18*10,  BCB=18*1,   BDB=18*10,  BEB=18*10,  BHB=18*2,
   BKB(1,1)=1.E5,BKB(2,1)=1.E5,BKB(1,2)=1.,BKB(2,2)=1.,BNB(1,1)=10.,
 BNB(2,1)=10.,BNB(1,2)=1.,BNB(2,2)=1.,BROB(1,2)=1.,BROB(2,2)=1.,
 BROB(1,3)=1.,BROB(2,3)=1.,                QKXX=2*0,QKYY=2*0,          &END
 TEST DATA: DATAMS (STEADY-STATE INPT DATA USING INTERN'L UNITS)  APR.73
 &MUST DT=.00005,TMAX=.010,DP=.002,NS=3,NB=2,              IB=1,3,DD=2*2.54,
       MET=1, FDOT1=60000,  QL=2*12.7,                               &END
 &OPTION DN=0,0,GG=2*8273708.751,AM=3*22.6796185,ALFA=3*45,AID=3*146.319827,
 AIRO=3*73.159913,  BETA=.0057,0,-.0057,GAMMA=3*45,XKMM=2*22596965.8,
 IPRINT=2,
 YKMM=2*22596965.8,XXMK=2*11298482.9,YYMK=2*11298482.9,BM=2*13.6077711,
 BI=2*87.79189602,KK=2,2,FDOFIX=2*3000,
```

```
BBB=18*6.8947572,BCB=18*.15500031,BDB=18*3.937007874,BEB=18*10,BHB=18*2,
BKB(1,1)=175126.84,BKB(2,1)=175126.84,BKB(1,2)=1.7512684,BKB(2,2)=1.7512684,
BNB(1,1)=17.512684,BNB(2,1)=17.512684,BNB(1,2)=1.7512684,BNB(2,2)=1.7512684,
 BROB(1,2)=2.54,BROB(2,2)=2.54,BROB(1,3)=2.54,BROB(2,3)=2.54,QKXX=2*0,QKYY=2*0,
                                        &END
TEST DATA: DATAMT (TRANSIENT SPIN SPEED INPUT DATA,INTERN'L UNITS) AP.73
 &MUST DT=.00005,TMAX=.010,DP=.002,NS=3,NB=2,           IB=1,3,DD=2*2.54,
       MET=1, FDOT1=1000,  QL=2*12.7,                            &END
 &OPTION DN=0,0,GG=2*8273708.751,AM=3*22.6796185,ALFA=3*45,AID=3*146.319827,
            KK=2,2,FDOFIX=2*3000.,ITORQ=1,AT(3)=11298482.903,
 AIRO=3*73.159913,     CRT=1,        GAMMA=3*45,
        XXMK=2*0,YYMK=2*0,                            BM=2*13.6077711,
 BI=2*87.79189602,KK=2,2,FDOFIX=2*3000,
 BBB=18*6.8947572,BCB=18*.15500031,BDB=18*3.937007874,BEB=18*10,BHB=18*2,
 BKB(1,1)=175126.84,BKB(2,1)=175126.84,BKB(1,2)=1.7512684,BKB(2,2)=1.7512684,
 BNB(1,1)=17.512684,BNB(2,1)=17.512684,BNB(1,2)=1.7512684,BNB(2,2)=1.7512684,
  BROB(1,2)=2.54,BROB(2,2)=2.54,BROB(1,3)=2.54,BROB(2,3)=2.54,QKXX=2*0,QKYY=2*0,
                                        &END
 15-STATION ROTOR AND 6-BEARING ROTOR SYSTEM                          10000000
 &MUST DT=.00005,TMAX=.003,DP=.001,NS=15,NB=6,IB=2,4,7,9,12,14,DD=14*1,
 QL=14*2,MET=0,FDOT1=60000,                                      &END
 &OPTION     AM=15*50,    AID=15*50,   AIRO=15*25,               &END
```

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APPENDIX F

IBM 360/370 COMPUTER RESULTS

Table XXIII provides the computation results for a transient spin speed rotor operation in the International Unit System. Table XXIV is the constant speed rotor dynamic performance for a rotor configuration having 15 rotor stations and 6 support bearings, which represents the current maximum computer program capacity.

TABLE XXIII

```
THE FOLLOWING ARE THE VALUES OF INPUT DATA USED IN THIS RUN WITH TITLE DESCRIPTION ON THE NEXT LINE.

          TEST DATA: DATAMT (TRANSIENT SPIN SPEED INPUT DATA,INTERN'L UNITS) AP.73

4TH ORDER RUNGE-KUTTA FIXED STEP INTEGRATION TECHNIQUE IS USED IN THIS RUN.

 I. GENERAL PARAMETERS

   IND =    1,         0=USING ADAMS-MOULTON PREDICTOR-CORRECTOR VARIABLE STEP INTEGRATION TECHNIQUE
                       1=USING 4TH ORDER RUNGE-KUTTA FIXED STEP INTEGRATION TECHNIQUE
                       2=USING ADAMS-MOULTON FIXED STEP INTEGRATION TECHNIQUE
   MET =    1,         1=INTERNATIONAL UNITS,   0=ENGLISH UNITS,
   CONTIN=0,           1=CONTINUATION FROM A PREVIOUS RUN,   0=A NEW RUN
                       WHEN CONTIN=1 ADDITIONAL INPUT OF PUNCHED CARDS MUST BE PROVIDED,
                       AND THE DT VALUE ON THE PUNCHED CARD WILL OVERRIDE THE DT VALUE ON THE SECOND LINE BELOW.
   T =  0.0            SEC. STARTING TIME
   DT=  5.00000E-05 SEC. SUGGESTED INTEGRATION TIME STEP
   TMAX =  1.00000E-02 SEC. MAXIMUM RUN TIME
   DP=  2.00000E-03 SEC,  COMPUTED RESULTS MIMIMUM PRINTING TIME INTERVALS
   IPRINT =    1,      PRINTING FREQUENCY 1 PER   1 MINIMUM PRINTING INTERVALS (DP)
   CRT = 1,            1=CRT PRODUCED,   0=NO CRT
   MOSHA = 1,          1=ROTOR MODE SHAPE CRT WILL BE PRODUCED PROVIDED THAT CRT=1,
                       0=THE CRT WILL NOT BE PRODUCED.
   NPOINT = 25,        THE NUMBER OF POINTS (ONE PER MIMIMUM PRINTOUT STEP) PER CRT GRAPH,
                       THE RANGE OF NPOINT IS 1 THROUGH 50.
   NOORPM =  1,        THE NUMBER OF ROTOR SPIN SPEEDS AT OR NEAR AND ABOVE WHICH
                       THE ROTOR MODE SHAPE CRT WILL BE PRODUCED PROVIDED THAT MOSHA=1 AND CRT=1.
   IASIGN =  1,        THE ROTOR STATION NUMBER AT WHICH THE ROTOR SPIN SPEED VERSUS TIME CRT, DISPLACEMENT
                       WHIRL/SPIN SPEED FREQUENCY RATIO CRT AND ROTOR ORBIT X-Y PLOT CRT WILL BE PRODUCED.
   INPRPM ARRAY        INPUT RPM ARRAY AT OR ABOVE EACH OF WHICH A 3-DIMENSION ROTOR MODEL SHAPE WILL BE PRODUCE
        0.0

   NS =  3,            NUMBER OF ROTOR STATIONS
   NB =  2,            NUMBER OF BEARING STATIONS

   BEARING STATION LOCATION ARRAY (IB(K),K=1,NB):
      1             3

   NUMBER OF NONLINEAR BEARING STIFFNESS SECTIONS FOR EACH OF THE BEARING STATIONS (KK(K),K=1,NB)
      2             2
```

```
F(1) =  1.000000E-20 DEGREES,    STARTING ROTOR SPIN ANGULAR POSITION
FDOT(1) =  1.000000E 03 RPM,     STARTING ROTOR SPIN AND WHIRL SPEED

ROTOR SECTION TORSIONAL ELASTICITY CONTROL VARIABLE (RIG(J),J=1,NS-1)
                 1=TORSIONALLY RIGID ROTOR SECTION IS ASSUMED
                 0=ACTUAL TORSIONALLY ELASTIC ROTOR SECTION IS USED
   0             0
```

TABLE XXIII. Continued

```
II. ROTOR GEOMETRY AND MECHANICAL PROPERTIES (J=1,NS-1),(I=1,NS)

  OUTSIDE DIAMETER ARRAY (DD(J)), CM
       2.54000E 00  2.54000E 00
  INSIDE DIAMETER ARRAY (D(J)), CM
       0.0          0.0
  SECTION LENGTH ARRAY (QL(J)), CM
       1.27000E 01  1.27000E 01
  MASS DENSITY ARRAY (DN(J)), KG/CM**3
       0.0          0.0
  ELASTICITY MODULUS ARRAY (EE(J)), NEWTON/CM**2
       2.06840E 07  2.06840E 07
  SHEAR MODULUS ARRAY (GG(J)), NEWTON/CM**2
       8.27371E 06  8.27371E 06
  POISSON'S RATIO ARRAY (P(J))
       3.00000E-01  3.00000E-01
  PRODUCT OF ELASTICITY AND AREA INERTIA ARRAY (EI(J)), NEWTON*CM**2
       0.0          0.0
  PRODUCT OF SHEAR MODULUS, AREA AND SHEAR FACTOR ARRAY (GAK(J)), NEWTONS
       0.0          0.0
  ADDITIONAL MASS ARRAY (AM(I)), KG
       2.26796E 01  2.26796E 01  2.26796E 01
  ADDITIONAL TRANSVERSE MASS MOMENT OF INERTIA ARRAY (AID(I)), KG*CM**2
       1.46320E 02  1.46320E 02  1.46320E 02
  ADDITIONAL POLAR MASS MOMENT OF INERTIA ARRAY (AIRO(I)), KG*CM**2
       7.31599E 01  7.31599E 01  7.31599E 01
  MASS ECCENTRICITY ARRAY (ECC(I)), CM
       2.54000E-04  2.54000E-04  2.54000E-04
  ECCENTRICITY PHASE ANGLE ARRAY (ALFA(I)), DEGREES
       4.50000E 01  4.50000E 01  4.50000E 01
  MASS INERTIA MISALIGNMENT ANGLE ARRAY (BETA(I)), DEGREES
       0.0          0.0          0.0
  MISALIGNMENT PHASE ANGLE ARRAY (GAMMA(I)), DEGREES
       4.50000E 01  4.50000E 01  4.50000E 01
```

```
III. LINEAR SUPPORT BEARING AND MOUNT PARAMETERS (K=1,NB)

   MOUNT X-FORCE STIFFNESS COEFFICIENT ARRAY (BKMX(K)), NEWTON/CM
        3.50250E 06  3.50250E 06
   MOUNT Y-FORCE STIFFNESS COEFFICIENT ARRAY (BKMY(K)), NEWTON/CM
        3.50250E 06  3.50250E 06
   MOUNT X-FORCE DAMPING COEFFICIENT ARRAY (BCMX(K)), NEWTON*SEC/CM
        0.0          0.0
   MOUNT Y-FORCE DAMPING COEFFICIENT ARRAY (BCMY(K)), NEWTON*SEC/CM
        0.0          0.0
   MOUNT XZ-PLANE STIFFNESS MOMENT COEFFICIENT ARRAY (XKMM(K)), NEWTON*CM/RADIAN
        2.25970E 07  2.25970E 07
   MOUNT YZ-PLANE STIFFNESS MOMENT COEFFICIENT ARRAY (YKMM(K)), NEWTON*CM/RADIAN
        2.25970E 07  2.25970E 07
   MOUNT XZ-PLANE DAMPING MOMENT COEFFICIENT ARRAY (XCMM(K)), NEWTON*CM*SEC/RADIAN
        0.0          0.0
   MOUNT YZ-PLANE DAMPING MOMENT COEFFICIENT ARRAY (YCMM(K)), NEWTON*CM*SEC/RADIAN
        0.0          0.0
   BEARING MASS ARRAY (BM(K)), KG
        1.36078E 01  1.36078E 01
   BEARING TRANSVERSE MASS MOMENT OF INERTIA ARRAY (BI(K)), KG*CM**2
        8.77919E 01  8.77919E 01
   BEARING IN-PHASE STIFFNESS X-FORCE COEFFICIENT ARRAY (QKXX(K)), NEWTON/CM
        0.0          0.0
   BEARING IN-PHASE STIFFNESS Y-FORCE COEFFICIENT ARRAY (QKYY(K)), NEWTON/CM
        0.0          0.0
   BEARING OUT-OF-PHASE STIFFNESS X-FORCE FROM Y-DISPLACEMENT COEFFICIENT ARRAY (QKXY(K)), NEWTON/CM
        0.0          0.0
   BEARING OUT-OF-PHASE STIFFNESS Y-FORCE FROM X-DISPLACEMENT COEFFICIENT ARRAY (QKYX(K)), NEWTON/CM
        0.0          0.0
   BEARING IN-PHASE DAMPING X-FORCE COEFFICIENT ARRAY (QCXX(K)), NEWTON*SEC/CM
        0.0          0.0
   BEARING IN-PHASE DAMPING Y-FORCE COEFFICIENT ARRAY (QCYY(K)), NEWTON*SEC/CM
        0.0          0.0
   BEARING OUT-OF-PHASE DAMPING X-FORCE FROM Y-VELOCITY COEFFICIENT ARRAY (QCXY(K)), NEWTON*SEC/CM
        0.0          0.0
   BEARING OUT-OF-PHASE DAMPING Y-FORCE FROM X-VELOCITY COEFFICIENT ARRAY (QCYX(K)), NEWTON*SEC/CM
        0.0          0.0
   BEARING IN-PHASE STIFFNESS XZ-PLANE MOMENT COEFFICIENT ARRAY (XXMK(K)), NEWTON*CM/RADIAN
        0.0          0.0
   BEARING IN-PHASE STIFFNESS YZ-PLANE MOMENT COEFFICIENT ARRAY (YYMK(K)), NEWTON*CM/RADIAN
        0.0          0.0
   BEARING OUT-OF-PHASE STIFFNESS XZ-PLANE MOMENT FROM YZ-PLANE
   SLOPE ROTATION COEFFICIENT ARRAY (XYMK(K)), NEWTON*CM/RADIAN
```

```
      0.0             0.0
 BEARING OUT-OF-PHASE STIFFNESS YZ-PLANE MOMENT FROM XZ-PLANE
 SLOPE ROTATION COEFFICIENT ARRAY (YXMK(K)), NEWTON*CM/RADIAN
      0.0             0.0
 BEARING IN-PHASE DAMPING XZ-PLANE MOMENT COEFFICIENT ARRAY (XXMC(K)), NEWTON*CM*SEC/RADIAN
      0.0             0.0
 BEARING IN-PHASE DAMPING YZ-PLANE MOMENT COEFFICIENT ARRAY (YYMC(K)), NEWTON*CM*SEC/RADIAN
      0.0             0.0
 BEARING OUT-OF-PHASE DAMPING XZ-PLANE MOMENT FROM YZ-PLANE
 SLOPE VELOCITY COEFFICIENT ARRAY (XYMC(K)), NEWTON*CM*SEC/RADIAN
      0.0             0.0
 BEARING OUT-OF-PHASE DAMPING YZ-PLANE MOMENT FROM XZ-PLANE
 SLOPE VELOCITY COEFFICIENT ARRAY (YXMC(K)), NEWTON*CM*SEC/RADIAN
      0.0             0.0


IV. NONLINEAR BEARING PARAMETERS (K=1.NF), (L=1,KK(K))

 SPIN SPEED PARAMETER ARRAY (FDOFIX(K)), RADIANS/SEC
      3.00000E 03  3.00000E 03

 THE NONLINEAR STIFFNESS COEFFICIENTS FOR STIFFNESS SECTIONS 1,2,3, ETC. FOR THE 1TH BEARING ARE:

 BBB(K,L), NEWTON*SEC/(RADIAN*CM**2)
      6.89476E 00  6.89476E 00
 BCB(K,L), 1./CM**BHB(I,L)
      1.55000E-01  1.55000E-01
 BDB(K,L), 1./CM
      3.93701E 00  3.93701E 00
 BEB(K,L), DIMENSIONLESS
      1.00000E 01  1.00000E 01
 BKB(K,L), NEWTON/CM
      1.75127E 05  1.75127E 00
 BNB(K,L), (NEWTON*SEC)/(CM*RADIAN)
      1.75127E 01  1.75127E 00
 BHB(K,L), DIMENSIONLESS
      2.00000E 00  2.00000E 00
 BROB(K,L+1), CM
      0.0          2.54000E 00  2.54000E 00

 THE NONLINEAR STIFFNESS COEFFICIENTS FOR STIFFNESS SECTIONS 1,2,3, ETC. FOR THE 2TH BEARING ARE:
```

TABLE XXIII. Continued

```
BBE(K,L), NEWTON*SEC/(RADIAN*CM**2
     6.89476E 00  6.89476E 00
BCE(K,L), 1./CM**BHE(I,L)
     1.55000E-01  1.55000E-01
BDE(K,L), 1./CM
     3.93701E 00  3.93701E 00
BEB(K,L), DIMENSIONLESS
     1.00000E 01  1.00000E 01
BKE(K,L), NEWTON/CM
     1.75127E 05  1.75127E 00
BNB(K,L), (NEWTON*SEC)/(CM*RADIAN)
     1.75127E 01  1.75127E 00
BHB(K,L), DIMENSIONLESS
     2.00000E 00  2.00000E 00
BRCB(K,L+1), CM
     0.0          2.54000E 00  2.54000E 00
```

```
V. ROTOR-TO-CASING GENERAL STIFFNESS AND DAMPING FORCE AND MOMENT COEFFICIENTS (I=1,NS)

   IN-PHASE STIFFNESS FORCE COEFFICIENT ARRAY (QK(I)), NEWTON/CM
        0.0           0.0           0.0
   OUT-OF-PHASE STIFFNESS FORCE COEFFICIENT ARRAY (QKP(I)), NEWTON/CM
        0.0           0.0           0.0
   IN-PHASE DAMPING FORCE COEFFICIENT ARRAY (QC(I)), NEWTON*SEC/CM
        0.0           0.0           0.0
   OUT-OF-PHASE DAMPING FORCE COEFFICIENT ARRAY (QCP(I)), NEWTON*SEC/CM
        0.0           0.0           0.0
   IN-PHASE STIFFNESS MOMENT COEFFICIENT ARRAY (QKF(I)), NEWTON*CM/RADIAN
        0.0           0.0           0.0
   OUT-OF-PHASE STIFFNESS MOMENT COEFFICIENT ARRAY (QKPF(I)), NEWTON*CM/RADIAN
        0.0           0.0           0.0
   IN-PHASE DAMPING MOMENT COEFFICIENT ARRAY (QCF(I)), NEWTON*CM*SEC/RADIAN
        0.0           0.0           0.0
   OUT-OF-PHASE DAMPING MOMENT COEFFICIENT ARRAY (QCPF(I)), NEWTON*CM*SEC/RADIAN
        0.0           0.0           0.0
   WHIRL STIFFNESS FORCE FACTOR ARRAY (XKF(I)), DIMENSIONLESS
        0.0           0.0           0.0
   WHIRL DAMPING FORCE FACTOR ARRAY (XCF(I)), DIMENSIONLESS
        0.0           0.0           0.0
```

```
WHIRL STIFFNESS MOMENT FACTOR ARRAY (XKFF(I)), DIMENSIONLESS
     0.0          0.0          0.0
WHIRL DAMPING MOMENT FACTOR ARRAY (XCFF(I)), DIMENSIONLESS
     0.0          0.0          0.0
OUT-OF-PHASE STIFFNESS FORCE WHIRL-SPIN COEFFICIENT ARRAY (QKHD(I)), NEWTON*SEC/CM
     0.0          0.0          0.0
OUT-OF-PHASE DAMPING FORCE WHIRL-SPIN COEFFICIENT ARRAY (QCHD(I)), NEWTON*SEC**2/CM
     0.0          0.0          0.0
OUT-OF-PHASE STIFFNESS MOMENT WHIRL-SPIN COEFFICIENT ARRAY (QKHDF(I)), NEWTON*CM*SEC/RADIAN
     0.0          0.0          0.0
OUT-OF-PHASE DAMPING MOMENT WHIRL-SPIN COEFFICIENT ARRAY (QCHDF(I)), NEWTON*CM*SEC**2/RADIAN
     0.0          0.0          0.0


VI. ROTOR DRIVE AND DAMPING TORQUE PARAMETERS (I=1,NS)

   TORQUE CONTROL VARIABLE  (ITORQ) = 1
                1=INCLUDING DRIVE AND DAMPING TORQUE IN COMPUTATION
                0= EXCLUDING THE TORQUE

   TORQUE TRANSVERSE EFFECT CONTROL VARIABLE  (IMT) = 0
                1=INCLUDING THE EFFECTS
                0=EXCLUDING THE EFFECTS

   CT(I) ARRAY (CT(I) MUST BE POSITIVE INTEGERS), DIMENSIONLESS
     1            1            1
   CT1(I) ARRAY, (NEWTON*CM)/(RADIANS/SEC)**CT(I)
     0.0          0.0          0.0
   CT2(I) ARRAY, (NEWTON*CM)/(RADIANS/SEC)
     0.0          0.0          0.0
   MT(I) ARRAY (MT(I) MUST BE POSITIVE INTEGERS), DIMENSIONLESS
     1            1            1
   MT1(I) ARRAY, (NEWTON*CM)/(RADIANS/SEC)**MT(I)
     0.0          0.0          0.0
   MT2(I) ARRAY, NEWTON*CM/(RADIANS/SEC)
     0.0          0.0          0.0
   AT(I) ARRAY, NEWTON*CM
     0.0          0.0          1.12985E 07
   BT(I) ARRAY, (NEWTON*CM)/SEC
     0.0          0.0          0.0
   DU(I) ARRAY, (NEWTON*CM)/SEC**HT(I)
```

TABLE XXIII. Continued

```
     0.0            0.0            0.0
ET(I) ARRAY, NEWTON*CM
     0.0            0.0            0.0
HT(I) ARRAY (HT(I) MUST BE POSITIVE NUMBER), DIMENSIONLESS
     1.00000E 00  1.00000E 00  1.00000E 00
FT(I) ARRAY, RADIANS/SEC
     0.0            0.0            0.0
GT(I) ARRAY, RADIANS
     0.0            0.0            0.0
```

VII. ROTOR AXIAL LOADING PARAMETERS (I=1,NS)

```
AXIAL LOADING CONTROL VARIABLE  (IPP) = 0
                1=INCLUDING AXIAL LOADING TRANSVERSE EFFECTS
                0=EXCLUDING THE EFFECTS

AA(I) ARRAY, NEWTONS
     0.0            0.0            0.0
BA(I) ARRAY, NEWTONS/SEC
     0.0            0.0            0.0
DA(I) ARRAY, NEWTONS/SEC**HA
     0.0            0.0            0.0
[illegible](I) ARRAY, NEWTONS
     0.0            0.0            0.0
HA DIMENSIONLESS,  FA RADIANS/SEC,  GA RADIANS (HA MUST BE A POSITIVE NUMBER.)
     1.00000E 00  0.0            0.0
```

VIII. ROTOR SYSTEM G-LOADING PARAMETERS

```
TRANSVERSE ACCELERATION OR GRAVITY LOADING IN MINUS X-DIRECTION (GX), CM/SEC**2
     0.0
TRANSVERSE ACCELERATION OR GRAVITY LOADING IN MINUS Y-DIRECTION (GY), CM/SEC**2
     0.0
```

TABLE XXIII. Continued

```
IX. ROTOR MATERIAL MECHANICAL HYSTERESIS PARAMETERS (J=1,NS-1)

  TRANSVERSE SHEAR VISCOUS COEFFICIENT ARRAY (USV(J)), NEWTON*SEC/CM**2
       0.0          0.0
  TRANSVERSE SHEAR COULOMB FRICTION COEFFICIENT ARRAY (USC(J)), NEWTON/CM**2
       0.0          0.0
  TRANSVERSE BENDING VISCOUS COEFFICIENT ARRAY (UBV(J)), NEWTON*SEC/CM**2
       0.0          0.0
  TRANSVERSE BENDING COULOMB FRICTION COEFFICIENT ARRAY (UBC(J)), NEWTON/CM**2
       0.0          0.0
  TORSIONAL SHEAR VISCOUS COEFFICIENT ARRAY (UTV(J)), NEWTON*SEC/CM**2
       0.0          0.0
  TORSIONAL SHEAR COULOMB FRICTION COEFFICIENT ARRAY (UTC(J)), NEWTON/CM**2
       0.0          0.0

*** THIS IS THE END OF INPUT DATA. ***
```

TABLE XXIII. Continued

```
INPUT ROTOR MASS DATA (I=1,NS)

ROTOR MASS ARRAY (CW(I)), KG
        2.2680E 01   2.2680E 01   2.2680E 01
ROTOR TRANSVERSE MASS MOMENT OF INERTIA ARRAY (QIDW(I)), KG*CM**2
        1.4632E 02   1.4632E 02   1.4632E 02
ROTOR POLAR MASS MOMENT OF INERTIA ARRAY (QIROW(I)),  KG*CM**2
        7.3160E 01   7.3160E 01   7.3160E 01

TOTAL ROTOR MASS =  6.80388E 01 KG

TOTAL ROTOR POLOR MASS MOMENT OF INERTIA = 2.19479E 02 KG*CM**2

THE ROTOR MASS CENTER OF GRAVITY MEASURED FROM ROTOR STATION  1 =  1.27000E 01 CM
```

TABLE XXIII. Continued

```
THE COMPUTED STARTING ROTOR DYNAMIC LOADS AND DEFLECTIONS IN INTERNATIONAL UNITS:

ROTOR DISPALCEMENT ARRAY, CM
      1.0437E-06   6.3956E-06   1.0437E-06
ROTOR DISPLACEMENT PHASE ANGLE ARRAY, DEGREES
      4.5000E 01   4.5000E 01   4.5000E 01
BEARING DISPLACEMENT ARRAY, CM
      7.7006E-07   7.7006E-07
BEARING DISPLACEMENT PHASE ANGLE ARRAY, DEGREES
      4.5000E 01   4.5000E 01
MOUNT DISPALCEMENT ARRAY, CM
      2.7367E-07   2.7367E-07
MOUNT DISPLACEMENT PHASE ANGLE ARRAY, DEGREES
      4.5000E 01   4.5000E 01
ROTOR SLOPE ARRAY, RADIANS
      6.1942E-07   4.6994E-13   6.1942E-07
ROTOR SLOPE PHASE ANGLE ARRAY, DEGREES
      4.5000E 01   2.2347E 02   2.2500E 02
BEARING SLOPE ARRAY, RADIANS
      6.1942E-07   6.1942E-07
BEARING SLOPE PHASE ANGLE ARRAY, DEGREES
      4.5000E 01   2.2500E 02
MOUNT SLOPE ARRAY, RADIANS
      1.4142E-20   1.4142E-20
MOUNT SLOPE PHASE ANGLE ARRAY, DEGREES
      4.5000E 01   4.5000E 01
BEARING X-FORCE ARRAY, NEWTONS
      6.7750E-01   6.7750E-01
BEARING Y-FORCE ARRAY, NEWTONS
      6.7750E-01   6.7750E-01
BEARING XZ-PLANE MOMENT ARRAY, NEWTON-CM
      0.0          0.0
BEARING YZ-PLANE MOMENT ARRAY, NEWTON-CM
      0.0          0.0
MOUNT X-FORCE ARRAY, NEWTONS
      6.7779E-01   6.7779E-01
MOUNT Y-FORCE ARRAY, NEWTONS
      6.7779E-01   6.7779E-01
MOUNT XZ-PLANE MOMENT ARRAY, NEWTON-CM
      2.2597E-13   2.2597E-13
MOUNT YZ-PLANE MOMENT ARRAY, NEWTON-CM
```

TABLE XXIII. Continued

```
      2.2597E-13   2.2597E-13
BEARING MASS X-FORCE ARRAY, NEWTONS
      2.8877E-04   2.8878E-04
BEARING MASS Y-FORCE ARRAY, NEWTONS
      2.8877E-04   2.8878E-04
BEARING INERTIA XZ-PLANE MOMENT ARRAY, NEWTON-CM
      0.0          0.0
BEARING INERTIA YZ-PLANE MOMENT ARRAY, NEWTON-CM
      0.0          0.0
```

TABLE XXIII. Continued

```
THE AVERAGE REAL STEP-TIME FOR THIS PRINTOUT =  5.0000E-05 SEC
REAL TIME =  2.0000E-03 SEC
   ROTOR SPIN REVOLUTION ARRAY
         1.0409E 00   1.6896E 00   2.2854E 00
   ROTOR DISPLACEMENT ARRAY, CM
         3.9161E-04   4.9792E-04   4.6049E-04
   ROTOR DISPLACEMENT PHASE ANGLE ARRAY, DEGREES
         2.2126E 02   1.2713E 02   3.2585E 02
   ROTOR SLOPE ARRAY, RADIANS
         1.4624E-05   6.0415E-05   2.6559E-05
   ROTOR SLOPE PHASE ANGLE ARRAY, DEGREES
         2.6255E 02   2.4686E 02   6.8056E 01
   ROTOR SPIN SPEED ARRAY, RPM
         1.2852E 05   9.3465E 04   7.5964E 04
   ROTOR DISPLACEMENT WHIRL FREQUENCY ARRAY, RPM
         9.6132E 04   5.6058E 04   6.9474E 04
   ROTOR SLOPE WHIRL FREQUENCY ARRAY, RPM
         1.8957E 05   5.0833E 04   8.5740E 04
   BEARING DISPLACEMENT ARRAY, CM
         5.1758E-04   8.5426E-04
   BEARING DISPLACEMENT PHASE ANGLE ARRAY, DEGREES
         2.6703E 02   2.5912E 02
   MOUNT DISPLACEMENT ARRAY, CM
         3.7212E-04   5.2382E-04
   MOUNT DISPLACEMENT PHASE ANGLE ARRAY, DEGREES
         1.3597E 02   2.0936E 02
   BEARING MASS WHIRL/ROTOR SPIN FREQUENCY RATIO ARRAY
         4.9669E-01   8.9265E-01
   BEARING SLOPE ARRAY, RADIANS
         1.4624E-05   2.6559E-05
   BEARING SLOPE PHASE ANGLE ARRAY, DEGREES
         2.6255E 02   6.8056E 01
   MOUNT SLOPE ARRAY, RADIANS
         1.4142E-20   1.4142E-20
   MOUNT SLOPE PHASE ANGLE ARRAY, DEGREES
         4.5000E 01   4.5000E 01
```

TABLE XXIII. Continued

```
THE AVERAGE REAL STEP-TIME FOR THIS PRINTOUT =  5.0000E-05 SEC
REAL TIME =  4.0000E-03 SEC
    ROTOR SPIN REVOLUTION ARRAY
          6.3530E 00   6.6488E 00   6.8613E 00
    ROTOR DISPLACEMENT ARRAY, CM
          1.4763E-04   8.8419E-05   4.9277E-04
    ROTOR DISPLACEMENT PHASE ANGLE ARRAY, DEGREES
          5.8004E 01   1.6585E 02   2.1807E 02
    ROTOR SLOPE ARRAY, RADIANS
          9.1329E-05   5.5015E-05   2.7031E-05
    ROTOR SLOPE PHASE ANGLE ARRAY, DEGREES
          2.9203E 02   3.1762E 02   3.2272E 02
    ROTOR SPIN SPEED ARRAY, RPM
          1.5983E 05   1.8299E 05   2.5008E 05
    ROTOR DISPLACEMENT WHIRL FREQUENCY ARRAY, RPM
          1.1345E 05   2.0256E 05   1.3214E 05
    ROTOR SLOPE WHIRL FREQUENCY ARRAY, RPM
          5.8662E 04   8.4068E 04   1.0500E 05
    BEARING DISPLACEMENT ARRAY, CM
          7.5800E-05   8.4462E-04
    BEARING DISPLACEMENT PHASE ANGLE ARRAY, DEGREES
          1.6352E 02   2.2355E 02
    MOUNT DISPLACEMENT ARRAY, CM
          1.8310E-04   3.9242E-04
    MOUNT DISPLACEMENT PHASE ANGLE ARRAY, DEGREES
          3.4495E 01   7.3132E 01
    BEARING MASS WHIRL/ROTOR SPIN FREQUENCY RATIO ARRAY
          4.1517E-01   3.7830E-01
    BEARING SLOPE ARRAY, RADIANS
          9.1329E-05   2.7031E-05
    BEARING SLOPE PHASE ANGLE ARRAY, DEGREES
          2.9203E 02   3.2272E 02
    MOUNT SLOPE ARRAY, RADIANS
          1.0616E-20   1.0616E-20
    MOUNT SLOPE PHASE ANGLE ARRAY, DEGREES
          2.2500E 02   2.2500E 02
```

TABLE XXIII. Continued

```
THE AVERAGE REAL STEP-TIME FOR THIS PRINTOUT =  4.9997E-05 SEC
REAL TIME =  5.9999E-03 SEC
   ROTOR SPIN REVOLUTION ARRAY
         1.4696E 01   1.4870E 01   1.4976E 01
   ROTOR DISPLACEMENT ARRAY, CM
         4.5415E-04   9.7343E-05   6.2877E-04
   ROTOR DISPLACEMENT PHASE ANGLE ARRAY, DEGREES
         1.0942E 02   1.9332E 02   2.1870E 02
   ROTOR SLOPE ARRAY, RADIANS
         7.9714E-06   5.1886E-05   1.3695E-05
   ROTOR SLOPE PHASE ANGLE ARRAY, DEGREES
         2.1683E 00   1.7462E 02   3.3820E 02
   ROTOR SPIN SPEED ARRAY, RPM
         3.5521E 05   2.6937E 05   2.6326E 05
   ROTOR DISPLACEMENT WHIRL FREQUENCY ARRAY, RPM
         2.2838E 05   6.4035E 05   1.4412E 05
   ROTOR SLOPE WHIRL FREQUENCY ARRAY, RPM
         2.2282E 05   9.6007E 04   1.9082E 05
   BEARING DISPLACEMENT ARRAY, CM
         5.4450E-04   9.7500E-04
   BEARING DISPLACEMENT PHASE ANGLE ARRAY, DEGREES
         1.3613E 02   2.2724E 02
   MOUNT DISPLACEMENT ARRAY, CM
         2.4689E-04   3.6534E-04
   MOUNT DISPLACEMENT PHASE ANGLE ARRAY, DEGREES
         1.1916E 01   6.2048E 01
   BEARING MASS WHIRL/RUTOR SPIN FREQUENCY RATIO ARRAY
         2.3335E-01   4.3621E-01
   BEARING SLOPE ARRAY, RADIANS
         7.9714E-06   1.3695E-05
   BEARING SLOPE PHASE ANGLE ARRAY, DEGREES
         2.1683E 00   3.3820E 02
   MOUNT SLOPE ARRAY, RADIANS
         1.7985E-21   1.7985E-21
   MOUNT SLOPE PHASE ANGLE ARRAY, DEGREES
         4.5000E 01   4.5000E 01
```

TABLE XXIII. Continued

```
THE AVERAGE REAL STEP-TIME FOR THIS PRINTOUT =  4.9997E-05 SEC
REAL TIME =  7.9998E-03 SEC
    ROTOR SPIN REVOLUTION ARRAY
          2.5577E 01   2.6344E 01   2.7131E 01
    ROTOR DISPLACEMENT ARRAY, CM
          3.1284E-04   5.5849E-05   3.0756E-04
    ROTOR DISPLACEMENT PHASE ANGLE ARRAY, DEGREES
          6.7787E 01   5.9530E 01   2.6740E 02
    ROTOR SLOPE ARRAY, RADIANS
          2.9170E-05   4.0107E-05   1.4817E-05
    ROTOR SLOPE PHASE ANGLE ARRAY, DEGREES
          2.2756E 02   1.2620E 02   4.3652E 01
    ROTOR SPIN SPEED ARRAY, RPM
          3.9007E 05   3.5295E 05   4.3977E 05
    ROTOR DISPLACEMENT WHIRL FREQUENCY ARRAY, RPM
          3.1057E 05   5.0121E 05   3.9932E 05
    ROTOR SLOPE WHIRL FREQUENCY ARRAY, RPM
          4.5081E 04   1.1539E 05   1.4637E 05
    BEARING DISPLACEMENT ARRAY, CM
          5.0718E-05   7.2507E-04
    BEARING DISPLACEMENT PHASE ANGLE ARRAY, DEGREES
          1.5978E 02   3.1620E 02
    MOUNT DISPLACEMENT ARRAY, CM
          3.1867E-04   5.7142E-04
    MOUNT DISPLACEMENT PHASE ANGLE ARRAY, DEGREES
          5.8635E 01   1.6009E 02
    BEARING MASS WHIRL/ROTOR SPIN FREQUENCY RATIO ARRAY
          1.6760E-01   1.8763E-01
    BEARING SLOPE ARRAY, RADIANS
          2.9170E-05   1.4817E-05
    BEARING SLOPE PHASE ANGLE ARRAY, DEGREES
          2.2756E 02   4.3652E 01
    MOUNT SLOPE ARRAY, RADIANS
          7.9143E-21   7.9143E-21
    MOUNT SLOPE PHASE ANGLE ARRAY, DEGREES
          4.5000E 01   4.5000E 01
```

TABLE XXIII. Continued

```
THE AVERAGE REAL STEP-TIME FOR THIS PRINTOUT =  4.9997E-05 SEC
REAL TIME =  9.9996E-03 SEC
   ROTOR SPIN REVOLUTION ARRAY
         4.1348E 01   4.1059E 01   4.0988E 01
   ROTOR DISPLACEMENT ARRAY, CM
         3.2148E-04   5.2678E-04   5.4880E-04
   ROTOR DISPLACEMENT PHASE ANGLE ARRAY, DEGREES
         1.7682E 01   2.6550E 02   1.9603E 02
   ROTOR SLOPE ARRAY, RADIANS
         1.8714E-05   2.7208E-05   9.0280E-06
   ROTOR SLOPE PHASE ANGLE ARRAY, DEGREES
         2.1710E 02   3.5496E 02   9.3012E 01
   ROTOR SPIN SPEED ARRAY, RPM
         5.0895E 05   4.3490E 05   5.3388E 05
   ROTOR DISPLACEMENT WHIRL FREQUENCY ARRAY, RPM
         3.7416E 05   2.0284E 05   2.7905E 05
   ROTOR SLOPE WHIRL FREQUENCY ARRAY, RPM
         4.5421E 04   7.4383E 04   1.0646E 05
   BEARING DISPLACEMENT ARRAY, CM
         2.1211E-04   8.2830E-04
   BEARING DISPLACEMENT PHASE ANGLE ARRAY, DEGREES
         6.4863E 01   1.9560E 02
   MOUNT DISPLACEMENT ARRAY, CM
         2.3589E-04   2.7954E-04
   MOUNT DISPLACEMENT PHASE ANGLE ARRAY, DEGREES
         3.3642E 02   1.4741E 01
   BEARING MASS WHIRL/ROTOR SPIN FREQUENCY RATIO ARRAY
         1.3551E-01   2.8277E-01
   BEARING SLOPE ARRAY, RADIANS
         1.8714E-05   9.0280E-06
   BEARING SLOPE PHASE ANGLE ARRAY, DEGREES
         2.1710E 02   9.3012E 01
   MOUNT SLOPE ARRAY, RADIANS
         1.3680E-20   1.3680E-20
   MOUNT SLOPE PHASE ANGLE ARRAY, DEGREES
         2.2500E 02   2.2500E 02
```

TABLE XXIII. Concluded

```
THE AVERAGE REAL STEP-TIME FOR THIS PRINTOUT =  4.9997E-05 SEC
REAL TIME =  1.2000E-02 SEC
    ROTOR SPIN REVOLUTION ARRAY
          5.8582E 01   5.9002E 01   5.9982E 01
    ROTOR DISPLACEMENT ARRAY, CM
          3.9141E-04   2.3597E-04   4.8473E-04
    ROTOR DISPLACEMENT PHASE ANGLE ARRAY, DEGREES
          5.5261E 01   1.5905E 02   1.6942E 02
    ROTOR SLOPE ARRAY, RADIANS
          1.7360E-05   1.8611E-05   2.1428E-06
    ROTOR SLOPE PHASE ANGLE ARRAY, DEGREES
          1.8825E 02   3.0457E 02   1.7320E 02
    ROTOR SPIN SPEED ARRAY, RPM
          6.7872E 05   5.1762E 05   5.7634E 05
    ROTOR DISPLACEMENT WHIRL FREQUENCY ARRAY, RPM
          5.0098E 05   2.2608E 05   2.5694E 05
    ROTOR SLOPE WHIRL FREQUENCY ARRAY, RPM
         -3.0180E 02  -8.1006E 03   1.0006E 05
    BEARING DISPLACEMENT ARRAY, CM
          4.3195E-04   6.6849E-04
    BEARING DISPLACEMENT PHASE ANGLE ARRAY, DEGREES
          6.4011E 01   1.5759E 02
    MOUNT DISPLACEMENT ARRAY, CM
          7.4693E-05   2.1801E-04
    MOUNT DISPLACEMENT PHASE ANGLE ARRAY, DEGREES
          2.9687E 02   3.1048E 02
    BEARING MASS WHIRL/ROTOR SPIN FREQUENCY RATIO ARRAY
          3.1111E-01   3.1532E-01
    BEARING SLOPE ARRAY, RADIANS
          1.7360E-05   2.1428E-06
    BEARING SLOPE PHASE ANGLE ARRAY, DEGREES
          1.8825E 02   1.7320E 02
    MOUNT SLOPE ARRAY, RADIANS
          1.2626E-20   1.2626E-20
    MOUNT SLOPE PHASE ANGLE ARRAY, DEGREES
          4.5000E 01   4.5000E 01
```

TABLE XXIV.

```
THE FOLLOWING ARE THE VALUES OF INPUT DATA USED IN THIS RUN WITH TITLE DESCRIPTION ON THE NEXT LINE.

            15-STATION ROTOR AND 6-BEARING ROTOR SYSTEM


4TH ORDER RUNGE-KUTTA FIXED STEP INTEGRATION TECHNIQUE IS USED IN THIS RUN.


I. GENERAL PARAMETERS

 IND =    1,          0=USING ADAMS-MOULTON PREDICTOR-CORRECTOR VARIABLE STEP INTEGRATION TECHNIQUE
                      1=USING 4TH ORDER RUNGE-KUTTA FIXED STEP INTEGRATION TECHNIQUE
                      2=USING ADAMS-MOULTON FIXED STEP INTEGRATION TECHNIQUE
 MET =    0,          1=INTERNATIONAL UNITS,    0=ENGLISH UNITS,
 CONTIN=0,            1=CONTINUATION FROM A PREVIOUS RUN,    0=A NEW RUN
                      WHEN CONTIN=1 ADDITIONAL INPUT OF PUNCHED CARDS MUST BE PROVIDED,
                      AND THE DT VALUE ON THE PUNCHED CARD WILL OVERRIDE THE DT VALUE ON THE SECOND LINE BELOW.
 T =   0.0            SEC. STARTING TIME
 DT=  5.00000E-05 SEC. SUGGESTED INTEGRATION TIME STEP
 TMAX =  3.00000E-03 SEC. MAXIMUM RUN TIME
 DP=  1.00000E-03 SEC,  COMPUTED RESULTS MIMIMUM PRINTING TIME INTERVALS
 IPRINT =   1,        PRINTING FRECUENCY 1 PER    1 MINIMUM PRINTING INTERVALS (DP)
 CRT = 0,             1=CRT PRODUCED,    0=NO CRT
 MOSHA = 1,           1=ROTOR MODE SHAPE CRT WILL BE PRODUCED PROVIDED THAT CRT=1,
                      0=THE CRT WILL NOT BE PRODUCED.
 NPOINT = 25,         THE NUMBER OF POINTS (ONE PER MIMIMUM PRINTOUT STEP) PER CRT GRAPH,
                      THE RANGE OF NPOINT IS 1 THROUGH 50.
 NOORPM =  1,         THE NUMBER OF ROTOR SPIN SPEEDS AT OR NEAR AND ABOVE WHICH
                      THE ROTOR MODE SHAPE CRT WILL BE PRODUCED PROVIDED THAT MOSHA=1 AND CRT=1.
 IASIGN =  1,         THE ROTOR STATION NUMBER AT WHICH THE ROTOR SPIN SPEED VERSUS TIME CRT, DISPLACEMENT
                      WHIRL/SPIN SPEED FREQUENCY RATIO CRT AND ROTOR ORBIT X-Y PLOT CRT WILL BE PRODUCED.
 INPRPM ARRAY         INPUT RPM ARRAY AT OR ABOVE EACH OF WHICH A 3-DIMENSION ROTOR MODEL SHAPE WILL BE PRODUCE
       0.0

 NS = 15,             NUMBER OF ROTOR STATIONS
 NB =  6,             NUMBER OF BEARING STATIONS

 BEARING STATION LOCATION ARRAY (IB(K),K=1,NB):
    2            4             7             9             12
   14

 NUMBER OF NONLINEAR BEARING STIFFNESS SECTIONS FOR EACH OF THE BEARING STATIONS (KK(K),K=1,NB)
```

TABLE XXIV. Continued

```
   1            1            1            1            1
   1

F(1) =   1.00000E-20 DEGREES,    STARTING ROTOR SPIN ANGULAR POSITION
FDOT(1) =   6.00000E 04 RPM,     STARTING ROTOR SPIN AND WHIRL SPEED

ROTOR SECTION TORSIONAL ELASTICITY CONTROL VARIABLE (RIG(J),J=1,NS-1)
                1=TORSIONALLY RIGID ROTOR SECTION IS ASSUMED
                0=ACTUAL TORSIONALLY ELASTIC ROTOR SECTION IS USED
   0            0            0            0            0
   0            0            0            0            0
   0            0            0            0
```

TABLE XXIV. Continued

```
II. ROTOR GEOMETRY AND MECHANICAL PROPERTIES (J=1,NS-1),(I=1,NS)

  OUTSIDE DIAMETER ARRAY (DD(J)), IN.
       1.00000E 00  1.00000E 00  1.00000E 00  1.00000E 00  1.00000E 00
       1.00000E 00  1.00000E 00  1.00000E 00  1.00000E 00  1.00000E 00
       1.00000E 00  1.00000E 00  1.00000E 00  1.00000E 00
  INSIDE DIAMETER ARRAY (D(J)), IN.
       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
  SECTION LENGTH ARRAY (GL(J)), IN.
       2.00000E 00  2.00000E 00  2.00000E 00  2.00000E 00  2.00000E 00
       2.00000E 00  2.00000E 00  2.00000E 00  2.00000E 00  2.00000E 00
       2.00000E 00  2.00000E 00  2.00000E 00  2.00000E 00
  MASS DENSITY ARRAY (DN(J)), LB/IN**3
       3.00000E-01  3.00000E-01  3.00000E-01  3.00000E-01  3.00000E-01
       3.00000E-01  3.00000E-01  3.00000E-01  3.00000E-01  3.00000E-01
       3.00000E-01  3.00000E-01  3.00000E-01  3.00000E-01
  ELASTICITY MODULUS ARRAY (EE(J)), LB/IN**2
       3.00000E 07  3.00000E 07  3.00000E 07  3.00000E 07  3.00000E 07
       3.00000E 07  3.00000E 07  3.00000E 07  3.00000E 07  3.00000E 07
       3.00000E 07  3.00000E 07  3.00000E 07  3.00000E 07
  SHEAR MODULUS ARRAY (GG(J)), LB/IN**2
       1.15000E 07  1.15000E 07  1.15000E 07  1.15000E 07  1.15000E 07
       1.15000E 07  1.15000E 07  1.15000E 07  1.15000E 07  1.15000E 07
       1.15000E 07  1.15000E 07  1.15000E 07  1.15000E 07
  POISSON'S RATIO ARRAY (P(J))
       3.00000E-01  3.00000E-01  3.00000E-01  3.00000E-01  3.00000E-01
       3.00000E-01  3.00000E-01  3.00000E-01  3.00000E-01  3.00000E-01
       3.00000E-01  3.00000E-01  3.00000E-01  3.00000E-01
  PRODUCT OF ELASTICITY AND AREA INERTIA ARRAY (EI(J)), LB*IN**2
       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
  PRODUCT OF SHEAR MODULUS, AREA AND SHEAR FACTOR ARRAY (GAK(J)), LB
       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
  ADDITIONAL MASS ARRAY (AM(I)), LB
```

```
      5.00000E 01  5.00000E 01  5.00000E 01  5.00000E 01  5.00000E 01
      5.00000E 01  5.00000E 01  5.00000E 01  5.00000E 01  5.00000E 01
      5.00000E 01  5.00000E 01  5.00000E 01  5.00000E 01  5.00000E 01
  ADDITIONAL TRANSVERSE MASS MOMENT OF INERTIA ARRAY (AID(I)), LB*IN**2
      5.00000E 01  5.00000E 01  5.00000E 01  5.00000E 01  5.00000E 01
      5.00000E 01  5.00000E 01  5.00000E 01  5.00000E 01  5.00000E 01
      5.00000E 01  5.00000E 01  5.00000E 01  5.00000E 01  5.00000E 01
  ADDITIONAL POLAR MASS MOMENT OF INERTIA ARRAY (AIRO(I)), LB*IN**2
      2.50000E 01  2.50000E 01  2.50000E 01  2.50000E 01  2.50000E 01
      2.50000E 01  2.50000E 01  2.50000E 01  2.50000E 01  2.50000E 01
      2.50000E 01  2.50000E 01  2.50000E 01  2.50000E 01  2.50000E 01
  MASS ECCENTRICITY ARRAY (ECC(I)), IN.
      1.00000E-04  1.00000E-04  1.00000E-04  1.00000E-04  1.00000E-04
      1.00000E-04  1.00000E-04  1.00000E-04  1.00000E-04  1.00000E-04
      1.00000E-04  1.00000E-04  1.00000E-04  1.00000E-04  1.00000E-04
  ECCENTRICITY PHASE ANGLE ARRAY (ALFA(I)), DEGREES
      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
  MASS INERTIA MISALIGNMENT ANGLE ARRAY (BETA(I)), DEGREES
      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
  MISALIGNMENT PHASE ANGLE ARRAY (GAMMA(I)), DEGREES
      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


III. LINEAR SUPPORT BEARING AND MOUNT PARAMETERS (K=1,NB)

  MOUNT X-FORCE STIFFNESS COEFFICIENT ARRAY (BKMX(K)), LB/IN
      2.00000E 06  2.00000E 06  2.00000E 06  2.00000E 06  2.00000E 06
      2.00000E 06
  MOUNT Y-FORCE STIFFNESS COEFFICIENT ARRAY (BKMY(K)), LB/IN
      2.00000E 06  2.00000E 06  2.00000E 06  2.00000E 06  2.00000E 06
      2.00000E 06
  MOUNT X-FORCE DAMPING COEFFICIENT ARRAY (BCMX(K)), LB*SEC/IN
      0.0          0.0          0.0          0.0          0.0
      0.0
  MOUNT Y-FORCE DAMPING COEFFICIENT ARRAY (BCMY(K)), LB*SEC/IN
```

TABLE XXIV. Continued

```
     0.0          0.0          0.0          0.0          0.0
     0.0
MOUNT XZ-PLANE STIFFNESS MOMENT COEFFICIENT ARRAY (XKMM(K)), LB*IN/RADIAN
     2.00000E 06  2.00000E 06  2.00000E 06  2.00000E 06  2.00000E 06
     2.00000E 06
MOUNT YZ-PLANE STIFFNESS MOMENT COEFFICIENT ARRAY (YKMM(K)), LB*IN/RADIAN
     2.00000E 06  2.00000E 06  2.00000E 06  2.00000E 06  2.00000E 06
     2.00000E 06
MOUNT XZ-PLANE DAMPING MOMENT COEFFICIENT ARRAY (XCMM(K)), LB*IN*SEC/RADIAN
     0.0          0.0          0.0          0.0          0.0
     0.0
MOUNT YZ-PLANE DAMPING MOMENT COEFFICIENT ARRAY (YCMM(K)), LB*IN*SEC/RADIAN
     0.0          0.0          0.0          0.0          0.0
     0.0
BEARING MASS ARRAY (BM(K)), LB
     0.0          0.0          0.0          0.0          0.0
     0.0
BEARING TRANSVERSE MASS MOMENT OF INERTIA ARRAY (BI(K)), LB*IN**2
     0.0          0.0          0.0          0.0          0.0
     0.0
BEARING IN-PHASE STIFFNESS X-FORCE COEFFICIENT ARRAY (QKXX(K)), LB/IN
     1.00000E 06  1.00000E 06  1.00000E 06  1.00000E 06  1.00000E 06
     1.00000E 06
BEARING IN-PHASE STIFFNESS Y-FORCE COEFFICIENT ARRAY (QKYY(K)), LB/IN
     1.00000E 06  1.00000E 06  1.00000E 06  1.00000E 06  1.00000E 06
     1.00000E 06
BEARING OUT-OF-PHASE STIFFNESS X-FORCE FROM Y-DISPLACEMENT COEFFICIENT ARRAY (QKXY(K)), LB/IN
     0.0          0.0          0.0          0.0          0.0
     0.0
BEARING OUT-OF-PHASE STIFFNESS Y-FORCE FROM X-DISPLACEMENT COEFFICIENT ARRAY (QKYX(K)), LB/IN
     0.0          0.0          0.0          0.0          0.0
     0.0
BEARING IN-PHASE DAMPING X-FORCE COEFFICIENT ARRAY (QCXX(K)), LB*SEC/IN
     0.0          0.0          0.0          0.0          0.0
     0.0
BEARING IN-PHASE DAMPING Y-FORCE COEFFICIENT ARRAY (QCYY(K)), LB*SEC/IN
     0.0          0.0          0.0          0.0          0.0
     0.0
BEARING OUT-OF-PHASE DAMPING X-FORCE FROM Y-VELOCITY COEFFICIENT ARRAY (QCXY(K)), LB*SEC/IN
     0.0          0.0          0.0          0.0          0.0
     0.0
BEARING OUT-OF-PHASE DAMPING Y-FORCE FROM X-VELOCITY COEFFICIENT ARRAY (QCYX(K)), LB*SEC/IN
     0.0          0.0          0.0          0.0          0.0
     0.0
```

TABLE XXIV. Continued

```
BEARING IN-PHASE STIFFNESS XZ-PLANE MOMENT COEFFICIENT ARRAY (XXMK(K)), LB*IN/RADIAN
     1.00000E 06  1.00000E 06  1.00000E 06  1.00000E 06  1.00000E 06
     1.00000E 06
BEARING IN-PHASE STIFFNESS YZ-PLANE MOMENT COEFFICIENT ARRAY (YYMK(K)), LB*IN/RADIAN
     1.00000E 06  1.00000E 06  1.00000E 06  1.00000E 06  1.00000E 06
     1.00000E 06
BEARING OUT-OF-PHASE STIFFNESS XZ-PLANE MOMENT FROM YZ-PLANE
SLOPE ROTATION COEFFICIENT ARRAY (XYMK(K)), LB*IN/RADIAN
     0.0          0.0          0.0          0.0          0.0
     0.0
BEARING OUT-OF-PHASE STIFFNESS YZ-PLANE MOMENT FROM XZ-PLANE
SLOPE ROTATION COEFFICIENT ARRAY (YXMK(K)), LB*IN/RADIAN
     0.0          0.0          0.0          0.0          0.0
     0.0
BEARING IN-PHASE DAMPING XZ-PLANE MOMENT COEFFICIENT ARRAY (XXMC(K)), LB*IN*SEC/RADIAN
     0.0          0.0          0.0          0.0          0.0
     0.0
BEARING IN-PHASE DAMPING YZ-PLANE MOMENT COEFFICIENT ARRAY (YYMC(K)), LB*IN*SEC/RADIAN
     0.0          0.0          0.0          0.0          0.0
     0.0
OUT-OF-PHASE DAMPING XZ-PLANE MOMENT FROM YZ-PLANE
SLOPE VELOCITY COEFFICIENT ARRAY (XYMC(K)), LB*IN*SEC/RADIAN
     0.0          0.0          0.0          0.0          0.0
     0.0
BEARING OUT-OF-PHASE DAMPING YZ-PLANE MOMENT FROM XZ-PLANE
SLOPE VELOCITY COEFFICIENT ARRAY (YXMC(K)), LB*IN*SEC/RADIAN
     0.0          0.0          0.0          0.0          0.0
     0.0



IV. NONLINEAR BEARING PARAMETERS (K=1,NB), (L=1,KK(K))

  SPIN SPEED PARAMETER ARRAY (FDCFIX(K)), RADIANS/SEC
     0.0          0.0          0.0          0.0          0.0
     0.0

  THE NONLINEAR STIFFNESS COEFFICIENTS FOR STIFFNESS SECTIONS 1,2,3, ETC. FOR THE 1TH BEARING ARE:

  BBB(K,L), LB*SEC/(RADIAN*IN**2)
     0.0
  BCB(K,L), 1./IN**BHB(I,L)
```

TABLE XXIV. Continued

```
      0.0
BDB(K,L), 1./IN
      0.0
BEB(K,L), DIMENSIONLESS
      0.0
BKB(K,L), LB/IN
      0.0
BNE(K,L), (LB*SEC)/(IN*RADIAN)
      0.0
BHB(K,L), DIMENSIONLESS
      1.00000E 00
BROB(K,L+1), IN
      0.0          5.00000E-03

THE NONLINEAR STIFFNESS COEFFICIENTS FOR STIFFNESS SECTIONS 1,2,3, ETC. FOR THE 2TH BEARING ARE:

BBB(K,L), LB*SEC/(RADIAN*IN**2)
      0.0
BCB(K,L), 1./IN**BHB(I,L)
      0.0
BDB(K,L), 1./IN
      0.0
BEB(K,L), DIMENSIONLESS
      0.0
BKB(K,L), LB/IN
      0.0
BNB(K,L), (LB*SEC)/(IN*RADIAN)
      0.0
BHB(K,L), DIMENSIONLESS
      1.00000E 00
BROB(K,L+1), IN
      0.0          5.00000E-03

THE NONLINEAR STIFFNESS COEFFICIENTS FOR STIFFNESS SECTIONS 1,2,3, ETC. FOR THE 3TH BEARING ARE:

BBB(K,L), LB*SEC/(RADIAN*IN**2)
      0.0
BCB(K,L), 1./IN**BHB(I,L)
      0.0
BDB(K,L), 1./IN
      0.0
BEB(K,L), DIMENSIONLESS
      0.0
BKB(K,L), LB/IN
```

TABLE XXIV. Continued

```
      0.0
BNB(K,L), (LB*SEC)/(IN*RADIAN)
      0.0
BHB(K,L), DIMENSIONLESS
      1.00000E 00
BROB(K,L+1), IN
      0.0            5.00000E-03

THE NONLINEAR STIFFNESS COEFFICIENTS FOR STIFFNESS SECTIONS 1,2,3, ETC. FOR THE 4TH BEARING ARE:

BBB(K,L), LB*SEC/(RADIAN*IN**2)
      0.0
BCB(K,L), 1./IN**BHB(I,L)
      0.0
BDB(K,L), 1./IN
      0.0
BEB(K,L), DIMENSIONLESS
      0.0
BKB(K,L), LB/IN
      0.0
BNB(K,L), (LB*SEC)/(IN*RADIAN)
      0.0
BHB(K,L), DIMENSIONLESS
      1.00000E 00
BROB(K,L+1), IN
      0.0            5.00000E-03

THE NONLINEAR STIFFNESS COEFFICIENTS FOR STIFFNESS SECTIONS 1,2,3, ETC. FOR THE 5TH BEARING ARE:

BBB(K,L), LB*SEC/(RADIAN*IN**2)
      0.0
BCB(K,L), 1./IN**BHB(I,L)
      0.0
BDB(K,L), 1./IN
      0.0
BEB(K,L), DIMENSIONLESS
      0.0
BKB(K,L), LB/IN
      0.0
BNB(K,L), (LB*SEC)/(IN*RADIAN)
      0.0
BHB(K,L), DIMENSIONLESS
      1.00000E 00
BROB(K,L+1), IN
```

```
      0.0            5.00000E-03

THE NONLINEAR STIFFNESS COEFFICIENTS FOR STIFFNESS SECTIONS 1,2,3, ETC. FOR THE 6TH BEARING ARE:

BBB(K,L), LB*SEC/(RADIAN*IN**2)
      0.0
BCB(K,L), 1./IN**BHB(I,L)
      0.0
BDB(K,L), 1./IN
      0.0
BEB(K,L), DIMENSIONLESS
      0.0
BKB(K,L), LB/IN
      0.0
BNB(K,L), (LB*SEC)/(IN*RADIAN)
      0.0
BHB(K,L), DIMENSIONLESS
      1.00000E 00
BROB(K,L+1), IN
      0.0            5.00000E-03


V. ROTOR-TO-CASING GENERAL STIFFNESS AND DAMPING FORCE AND MOMENT COEFFICIENTS (I=1,NS)

IN-PHASE STIFFNESS FORCE COEFFICIENT ARRAY (QK(I)), LB/IN
      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
OUT-OF-PHASE STIFFNESS FORCE COEFFICIENT ARRAY (QKP(I)), LB/IN
      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
IN-PHASE DAMPING FORCE COEFFICIENT ARRAY (QC(I)), LB*SEC/IN
      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
OUT-OF-PHASE DAMPING FORCE COEFFICIENT ARRAY (QCP(I)), LB*SEC/IN
      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
IN-PHASE STIFFNESS MOMENT COEFFICIENT ARRAY (QKF(I)), LB*IN/RADIAN
```

TABLE XXIV. Continued

```
     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
 OUT-OF-PHASE STIFFNESS MOMENT COEFFICIENT ARRAY (QKPF(I)), LB*IN/RADIAN
     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
 IN-PHASE DAMPING MOMENT COEFFICIENT ARRAY (QCF(I)), LB*IN*SEC/RADIAN
     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
 OUT-OF-PHASE DAMPING MOMENT COEFFICIENT ARRAY (QCPF(I)), LB*IN*SEC/RADIAN
     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
 WHIRL STIFFNESS FORCE FACTOR ARRAY (XKF(I)), DIMENSIONLESS
     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
 WHIRL DAMPING FORCE FACTOR ARRAY (XCF(I)), DIMENSIONLESS
     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
 WHIRL STIFFNESS MOMENT FACTOR ARRAY (XKFF(I)), DIMENSIONLESS
     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
 WHIRL DAMPING MOMENT FACTOR ARRAY (XCFF(I)), DIMENSIONLESS
     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
 OUT-OF-PHASE STIFFNESS FORCE WHIRL-SPIN COEFFICIENT ARRAY (QKHD(I)), LB*SEC/IN
     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
 OUT-OF-PHASE DAMPING FORCE WHIRL-SPIN COEFFICIENT ARRAY (QCHD(I)), LB*SEC**2/IN
     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
 OUT-OF-PHASE STIFFNESS MOMENT WHIRL-SPIN COEFFICIENT ARRAY (QKHDF(I)), LB*IN*SEC/RADIAN
     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
 OUT-OF-PHASE DAMPING MOMENT WHIRL-SPIN COEFFICIENT ARRAY (QCHDF(I)), LB*IN*SEC**2/RADIAN
```

```
     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


VI. ROTOR DRIVE AND DAMPING TORQUE PARAMETERS (I=1,NS)

 TORQUE CONTROL VARIABLE  (ITORQ) = 0
                1=INCLUDING DRIVE AND DAMPING TORQUE IN COMPUTATION
                0=EXCLUDING THE TORQUE

 TORQUE TRANSVERSE EFFECT CONTROL VARIABLE  (IMT) = 0
                1=INCLUDING THE EFFECTS
                0=EXCLUDING THE EFFECTS

 CT(I) ARRAY (CT(I) MUST BE POSITIVE INTEGERS), DIMENSIONLESS
   1            1            1            1            1
   1            1            1            1            1
   1            1            1            1            1
 CT1(I) ARRAY, LB*IN/(RADIANS/SEC)**CT(I)
     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
 CT2(I) ARRAY, LB*IN/(RADIANS/SEC)
     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
 MT(I) ARRAY (MT(I) MUST BE POSITIVE INTEGERS), DIMENSIONLESS
   1            1            1            1            1
   1            1            1            1            1
   1            1            1            1            1
 MT1(I) ARRAY, LB*IN/(RADIANS/SEC)**MT(I)
     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
 MT2(I) ARRAY, LB*IN/(RADIANS/SEC)
     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
 AT(I) ARRAY, LB*IN
     0.0          0.0          0.0          0.0          0.0
```

TABLE XXIV. Continued

```
      0.0          0.0          0.0          0.0          0.0
      0.0          0.0          0.0          0.0          0.0
 BT(I) ARRAY, LB*IN/SEC
      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
 DU(I) ARRAY, LB*IN/SEC**HT(I)
      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
 ET(I) ARRAY, LB*IN
      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
 HT(I) ARRAY (HT(I) MUST BE POSITIVE NUMBER), DIMENSIONLESS
      1.00000E 00  1.00000E 00  1.00000E 00  1.00000E 00  1.00000E 00
      1.00000E 00  1.00000E 00  1.00000E 00  1.00000E 00  1.00000E 00
      1.00000E 00  1.00000E 00  1.00000E 00  1.00000E 00  1.00000E 00
 FT(I) ARRAY, RADIANS/SEC
      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
 GT(I) ARRAY, RADIANS
      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


VII. ROTOR AXIAL LOADING PARAMETERS (I=1,NS)

 AXIAL LOADING CONTROL VARIABLE (IPP) = 0
                 1=INCLUDING AXIAL LOADING TRANSVERSE EFFECTS
                 0=EXCLUDING THE EFFECTS

 AA(I) ARRAY, LB
      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
 BA(I) ARRAY, LB/SEC
      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
   DA(I) ARRAY, LB/SEC**HA
      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
   EA(I) ARRAY, LB
      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
   HA DIMENSIONLESS,  FA RADIANS/SEC,  GA RADIANS (HA MUST BE A POSITIVE NUMBER.)
      1.00000E 00  0.0          0.0


VIII. ROTOR SYSTEM G-LOADING PARAMETERS

   TRANSVERSE ACCELERATION OR GRAVITY LOADING IN MINUS X-DIRECTION (GX), IN/SEC**2
      0.0
   TRANSVERSE ACCELERATION OR GRAVITY LOADING IN MINUS Y-DIRECTION (GY), IN/SEC**2
      0.0


IX. ROTOR MATERIAL MECHANICAL HYSTERESIS PARAMETERS (J=1,NS-1)

   TRANSVERSE SHEAR VISCOUS COEFFICIENT ARRAY (USV(J)), LB*SEC/IN**2
      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
   TRANSVERSE SHEAR COULOMB FRICTION COEFFICIENT ARRAY (USC(J)), LB/IN**2
      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
   TRANSVERSE BENDING VISCOUS COEFFICIENT ARRAY (UBV(J)), LB*SEC/IN**2
      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
   TRANSVERSE BENDING COULOMB FRICTION COEFFICIENT ARRAY (UBC(J)), LB/IN**2
      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
 TORSIONAL SHEAR VISCOUS COEFFICIENT ARRAY (UTV(J)), LB*SEC/IN**2
     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
 TORSIONAL SHEAR COULOMB FRICTION COEFFICIENT ARRAY (UTC(J)), LB/IN**2
     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

*** THIS IS THE END OF INPUT DATA. ***
```

TABLE XXIV. Continued

```
INPUT ROTOR MASS DATA (I=1,NS)

ROTOR MASS ARRAY (QM(I)), LB
        5.0236E 01   5.0471E 01   5.0471E 01   5.0471E 01   5.0471E 01
        5.0471E 01   5.0471E 01   5.0471E 01   5.0471E 01   5.0471E 01
        5.0471E 01   5.0471E 01   5.0471E 01   5.0471E 01   5.0236E 01
ROTOR TRANSVERSE MASS MOMENT OF INERTIA ARRAY (QID(I)), LB*IN**2
        5.0093E 01   5.0186E 01   5.0186E 01   5.0186E 01   5.0186E 01
        5.0186E 01   5.0186E 01   5.0186E 01   5.0186E 01   5.0186E 01
        5.0186E 01   5.0186E 01   5.0186E 01   5.0186E 01   5.0093E 01
ROTOR POLAR MASS MOMENT OF INERTIA ARRAY (QIRO(I)), LB*IN**2
        2.5029E 01   2.5059E 01   2.5059E 01   2.5059E 01   2.5059E 01
        2.5059E 01   2.5059E 01   2.5059E 01   2.5059E 01   2.5059E 01
        2.5059E 01   2.5059E 01   2.5059E 01   2.5059E 01   2.5029E 01

TOTAL ROTOR MASS =  7.56595E 02 LB

TOTAL ROTOR POLOR MASS MOMENT OF INERTIA =  3.75824E 02 LB*IN**2

THE ROTOR MASS CENTER OF GRAVITY MEASURED FROM ROTOR STATION  1 =  1.40000E 01 IN
```

TABLE XXIV. Continued

```
THE COMPUTED STARTING ROTOR DYNAMIC LOADS AND DEFLECTIONS IN ENGLISH UNITS:

   ROTOR DISPALCEMENT ARRAY, IN
         9.6375E-05   1.1464E-04   1.0801E-04   9.1755E-05   1.3325E-04
         6.5154E-05   1.6200E-04   5.2792E-05   1.6189E-04   6.5280E-05
         1.3306E-04   9.2014E-05   1.0787E-04   1.1484E-04   9.6258E-05
   ROTOR DISPLACEMENT PHASE ANGLE ARRAY, DEGREES
         1.8000E 02   1.8000E 02   1.8000E 02   1.8000E 02   1.8000E 02
         1.8000E 02   1.8000E 02   1.8000E 02   1.8000E 02   1.8000E 02
         1.8000E 02   1.8000E 02   1.8000E 02   1.8000E 02   1.8000E 02
   BEARING DISPLACEMENT ARRAY, IN
         7.6426E-05   6.1170E-05   1.0800E-04   1.0793E-04   6.1343E-05
         7.6559E-05
   BEARING DISPLACEMENT PHASE ANGLE ARRAY, DEGREES
         1.8000E 02   1.8000E 02   1.8000E 02   1.8000E 02   1.8000E 02
         1.8000E 02
   MOUNT DISPALCEMENT ARRAY, IN
         3.8212E-05   3.0585E-05   5.4000E-05   5.3962E-05   3.0671E-05
         3.8280E-05
   MOUNT DISPLACEMENT PHASE ANGLE ARRAY, DEGREES
         1.8000E 02   1.8000E 02   1.8000E 02   1.8000E 02   1.8000E 02
         1.8000E 02
   ROTOR SLOPE ARRAY, RADIANS
         2.0832E-05   2.6402E-05   4.6424E-05   4.5939E-05   6.1848E-05
         5.6906E-05   2.3319E-05   1.7479E-07   2.3734E-05   5.7217E-05
         6.1708E-05   4.6087E-05   4.6502E-05   2.6333E-05   2.1127E-05
   ROTOR SLOPE PHASE ANGLE ARRAY, DEGREES
         1.0458E-20   1.8000E 02   1.0227E-20   1.8000E 02   1.0115E-20
         1.8000E 02   1.0124E-20   3.6000E 02   1.8000E 02   1.0018E-20
         1.8000E 02   1.0150E-20   1.8000E 02   1.0204E-20   1.8000E 02
   BEARING SLOPE ARRAY, RADIANS
         1.7601E-05   3.0626E-05   1.5546E-05   1.5823E-05   3.0725E-05
         1.7555E-05
   BEARING SLOPE PHASE ANGLE ARRAY, DEGREES
         1.8000E 02   1.8000E 02   1.0124E-20   1.8000E 02   1.0150E-20
         1.0204E-20
   MOUNT SLOPE ARRAY, RADIANS
         8.8006E-06   1.5313E-05   7.7732E-06   7.9114E-06   1.5363E-05
         8.7777E-06
   MOUNT SLOPE PHASE ANGLE ARRAY, DEGREES
         1.8000E 02   1.8000E 02   1.0124E-20   1.8000E 02   1.0150E-20
```

TABLE XXIV. Continued

```
     1.0204E-20
BEARING X-FORCE ARRAY, LB
    -7.6426E 01  -6.1170E 01  -1.0800E 02  -1.0793E 02  -6.1343E 01
    -7.6559E 01
BEARING Y-FORCE ARRAY, LB
    -1.3384E-20  -1.0693E-20  -1.8876E-20  -1.8873E-20  -1.0682E-20
    -1.3387E-20
BEARING XZ-PLANE MOMENT ARRAY, LB-IN
    -1.7601E 01  -3.0626E 01   1.5546E 01  -1.5823E 01   3.0725E 01
     1.7555E 01
BEARING YZ-PLANE MOMENT ARRAY, LB-IN
    -3.1241E-21  -5.4180E-21   2.7469E-21  -2.7261E-21   5.4430E-21
     3.1265E-21
MOUNT X-FORCE ARRAY, LB
    -7.6425E 01  -6.1170E 01  -1.0800E 02  -1.0792E 02  -6.1342E 01
    -7.6559E 01
MOUNT Y-FORCE ARRAY, LB
    -1.3384E-20  -1.0693E-20  -1.8875E-20  -1.8873E-20  -1.0682E-20
    -1.3387E-20
MOUNT XZ-PLANE MOMENT ARRAY, LB-IN
    -1.7602E 01  -3.0626E 01   1.5546E 01  -1.5823E 01   3.0725E 01
     1.7555E 01
MOUNT YZ-PLANE MOMENT ARRAY, LB-IN
    -3.1241E-21  -5.4180E-21   2.7469E-21  -2.7261E-21   5.4431E-21
     3.1265E-21
BEARING MASS X-FORCE ARRAY, LB
     0.0          0.0          0.0          0.0          0.0
     0.0
BEARING MASS Y-FORCE ARRAY, LB
     0.0          0.0          0.0          0.0          0.0
     0.0
BEARING INERTIA XZ-PLANE MOMENT ARRAY, LB-IN
     0.0          0.0          0.0          0.0          0.0
     0.0
BEARING INERTIA YZ-PLANE MOMENT ARRAY, LB-IN
     0.0          0.0          0.0          0.0          0.0
     0.0
```

TABLE XXIV. Continued

```
THE AVERAGE REAL STEP-TIME FOR THIS PRINTOUT =  5.0000E-05 SEC
REAL TIME =  1.0000E-03 SEC
    ROTOR SPIN REVOLUTION ARRAY
          1.0000E 00   1.0000E 00   1.0000E 00   1.0000E 00   1.0000E 00
          1.0000E 00   1.0000E 00   1.0000E 00   1.0000E 00   1.0000E 00
          1.0000E 00   1.0000E 00   1.0000E 00   1.0000E 00   1.0000E 00
    ROTOR DISPLACEMENT ARRAY, IN
          9.6261E-05   1.1466E-04   1.0801E-04   9.1825E-05   1.3324E-04
          6.5192E-05   1.6195E-04   5.2856E-05   1.6186E-04   6.5339E-05
          1.3310E-04   9.2031E-05   1.0783E-04   1.1482E-04   9.6206E-05
    ROTOR DISPLACEMENT PHASE ANGLE ARRAY, DEGREES
          1.8006E 02   1.7992E 02   1.8005E 02   1.7991E 02   1.8002E 02
          1.7996E 02   1.8000E 02   1.7994E 02   1.8004E 02   1.7983E 02
          1.8006E 02   1.7995E 02   1.8001E 02   1.8001E 02   1.8002E 02
    ROTOR SLOPE ARRAY, RADIANS
          2.1023E-05   2.5969E-05   4.6836E-05   4.5617E-05   6.1923E-05
          5.6818E-05   2.3410E-05   1.9549E-07   2.3605E-05   5.7021E-05
          6.2195E-05   4.5655E-05   4.6889E-05   2.6066E-05   2.1141E-05
    ROTOR SLOPE PHASE ANGLE ARRAY, DEGREES
          3.5925E 02   1.8032E 02   3.5963E 02   1.8010E 02   3.5987E 02
          1.8001E 02   3.5987E 02   3.4607E 02   1.7999E 02   8.9808E-02
          1.7973E 02   2.6911E-01   1.7975E 02   2.5997E-01   1.7983E 02
    ROTOR SPIN SPEED ARRAY, RPM
          6.0000E 04   6.0000E 04   6.0000E 04   6.0000E 04   6.0000E 04
          6.0000E 04   6.0000E 04   6.0000E 04   6.0000E 04   6.0000E 04
          6.0000E 04   6.0000E 04   6.0000E 04   6.0000E 04   6.0000E 04
    ROTOR DISPLACEMENT WHIRL FREQUENCY ARRAY, RPM
          5.9981E 04   5.9992E 04   6.0005E 04   6.0026E 04   6.0007E 04
          5.9994E 04   5.9999E 04   5.9988E 04   6.0007E 04   6.0055E 04
          6.0008E 04   5.9987E 04   5.9990E 04   5.9984E 04   5.9996E 04
    ROTOR SLOPE WHIRL FREQUENCY ARRAY, RPM
          6.0044E 04   5.9601E 04   6.0109E 04   5.9852E 04   6.0012E 04
          5.9983E 04   6.0066E 04   6.2785E 04   5.9915E 04   5.9959E 04
          6.0110E 04   5.9804E 04   6.0137E 04   5.9805E 04   6.0053E 04
    BEARING DISPLACEMENT ARRAY, IN
          7.6438E-05   6.1217E-05   1.0797E-04   1.0790E-04   6.1354E-05
          7.6548E-05
    BEARING DISPLACEMENT PHASE ANGLE ARRAY, DEGREES
          1.7992E 02   1.7991E 02   1.8000E 02   1.8004E 02   1.7995E 02
          1.8001E 02
```

TABLE XXIV. Continued

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MOUNT DISPLACEMENT ARRAY, IN
      3.8219E-05   3.0608E-05   5.3983E-05   5.3952E-05   3.0677E-05
      3.8274E-05
MOUNT DISPLACEMENT PHASE ANGLE ARRAY, DEGREES
      1.7992E 02   1.7991E 02   1.8000E 02   1.8004E 02   1.7995E 02
      1.8001E 02
BEARING MASS WHIRL/ROTOR SPIN FREQUENCY RATIO ARRAY
      9.9986E-01   1.0004E 00   9.9998E-01   1.0001E 00   9.9979E-01
      9.9974E-01
BEARING SLOPE ARRAY, RADIANS
      1.7313E-05   3.0411E-05   1.5607E-05   1.5737E-05   3.0437E-05
      1.7377E-05
BEARING SLOPE PHASE ANGLE ARRAY, DEGREES
      1.8032E 02   1.8010E 02   3.5987E 02   1.7999E 02   2.6906E-01
      2.6000E-01
MOUNT SLOPE ARRAY, RADIANS
      8.6565E-06   1.5206E-05   7.8034E-06   7.8686E-06   1.5219E-05
      8.6887E-06
MOUNT SLOPE PHASE ANGLE ARRAY, DEGREES
      1.8032E 02   1.8010E 02   3.5987E 02   1.7999E 02   2.6921E-01
      2.5992E-01
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TABLE XXIV. Continued

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THE AVERAGE REAL STEP-TIME FOR THIS PRINTOUT =  5.0000E-05 SEC
REAL TIME =  2.0000E-03 SEC
    ROTOR SPIN REVOLUTION ARRAY
          2.0000E 00   2.0000E 00   2.0000E 00   2.0000E 00   2.0000E 00
          2.0000E 00   2.0000E 00   2.0000E 00   2.0000E 00   2.0000E 00
          2.0000E 00   2.0000E 00   2.0000E 00   2.0000E 00   2.0000E 00
    ROTOR DISPLACEMENT ARRAY, IN
          9.6261E-05   1.1479E-04   1.0789E-04   9.1923E-05   1.3309E-04
          6.5336E-05   1.6180E-04   5.2946E-05   1.6177E-04   6.5395E-05
          1.3298E-04   9.2047E-05   1.0782E-04   1.1488E-04   9.6209E-05
    ROTOR DISPLACEMENT PHASE ANGLE ARRAY, DEGREES
          1.8004E 02   1.7988E 02   1.8008E 02   1.7993E 02   1.8004E 02
          1.7990E 02   1.8005E 02   1.7984E 02   1.8006E 02   1.7988E 02
          1.8008E 02   1.7989E 02   1.8007E 02   1.7994E 02   1.8001E 02
    ROTOR SLOPE ARRAY, RADIANS
          2.1184E-05   2.6125E-05   4.6736E-05   4.5678E-05   6.1876E-05
          5.6780E-05   2.3439E-05   4.5362E-08   2.3582E-05   5.6985E-05
          6.2249E-05   4.5919E-05   4.6937E-05   2.6175E-05   2.1158E-05
    ROTOR SLOPE PHASE ANGLE ARRAY, DEGREES
          3.5917E 02   1.7912E 02   3.5995E 02   1.7963E 02   3.5990E 02
          1.7993E 02   7.4177E-02   1.9727E 01   1.7980E 02   3.5989E 02
          1.8012E 02   3.5965E 02   1.8014E 02   3.5971E 02   1.8000E 02
    ROTOR SPIN SPEED ARRAY, RPM
          6.0000E 04   6.0000E 04   6.0000E 04   6.0000E 04   6.0000E 04
          6.0000E 04   6.0000E 04   6.0000E 04   6.0000E 04   6.0000E 04
          6.0000E 04   6.0000E 04   6.0000E 04   6.0000E 04   6.0000E 04
    ROTOR DISPLACEMENT WHIRL FREQUENCY ARRAY, RPM
          5.9970E 04   6.0012E 04   6.0008E 04   6.0030E 04   6.0007E 04
          5.9982E 04   6.0006E 04   5.9987E 04   5.9999E 04   6.0065E 04
          6.0002E 04   5.9998E 04   6.0003E 04   5.9981E 04   6.0004E 04
    ROTOR SLOPE WHIRL FREQUENCY ARRAY, RPM
          6.0020E 04   5.9893E 04   6.0040E 04   5.9988E 04   5.9986E 04
          6.0017E 04   5.9992E 04   9.7137E 04   5.9917E 04   5.9993E 04
          6.0050E 04   5.9988E 04   6.0033E 04   5.9987E 04   6.0036E 04
    BEARING DISPLACEMENT ARRAY, IN
          7.6525E-05   6.1282E-05   1.0787E-04   1.0785E-04   6.1365E-05
          7.6588E-05
    BEARING DISPLACEMENT PHASE ANGLE ARRAY, DEGREES
          1.7988E 02   1.7993E 02   1.8005E 02   1.8006E 02   1.7989E 02
          1.7994E 02
```

TABLE XXIV. Continued

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MOUNT DISPLACEMENT ARRAY, IN
     3.8262E-05   3.0641E-05   5.3933E-05   5.3922E-05   3.0682E-05
     3.8294E-05
MOUNT DISPLACEMENT PHASE ANGLE ARRAY, DEGREES
     1.7988E 02   1.7993E 02   1.8005E 02   1.8006E 02   1.7939E 02
     1.7994E 02
BEARING MASS WHIRL/ROTOR SPIN FREQUENCY RATIO ARRAY
     1.0002E 00   1.0005E 00   1.0001E 00   9.9999E-01   9.9997E-01
     9.9968E-01
BEARING SLOPE ARRAY, RADIANS
     1.7416E-05   3.0452E-05   1.5626E-05   1.5721E-05   3.0613E-05
     1.7450E-05
BEARING SLOPE PHASE ANGLE ARRAY, DEGREES
     1.7912E 02   1.7963E 02   7.4299E-02   1.7980E 02   3.5965E 02
     3.5971E 02
MOUNT SLOPE ARRAY, RADIANS
     8.7085E-06   1.5226E-05   7.8129E-06   7.8609E-06   1.5307E-05
     8.7252E-06
MOUNT SLOPE PHASE ANGLE ARRAY, DEGREES
     1.7912E 02   1.7963E 02   7.3934E-02   1.7980E 02   3.5965E 02
     3.5971E 02
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TABLE XXIV. Continued

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THE AVERAGE REAL STEP-TIME FOR THIS PRINTOUT =  5.0000E-05 SEC
REAL TIME =  3.0000E-03 SEC
    ROTOR SPIN REVOLUTION ARRAY
          3.0000E 00   3.0000E 00   3.0000E 00   3.0000E 00   3.0000E 00
          3.0000E 00   3.0000E 00   3.0000E 00   3.0000E 00   3.0000E 00
          3.0000E 00   3.0000E 00   3.0000E 00   3.0000E 00   3.0000E 00
    ROTOR DISPLACEMENT ARRAY, IN
          9.6278E-05   1.1493E-04   1.0777E-04   9.2096E-05   1.3292E-04
          6.5509E-05   1.6166E-04   5.3089E-05   1.6164E-04   6.5441E-05
          1.3295E-04   9.2133E-05   1.0777E-04   1.1492E-04   9.6222E-05
    ROTOR DISPLACEMENT PHASE ANGLE ARRAY, DEGREES
          1.8011E 02   1.7994E 02   1.8003E 02   1.7995E 02   1.8003E 02
          1.7988E 02   1.8006E 02   1.7984E 02   1.8003E 02   1.7989E 02
          1.8002E 02   1.7989E 02   1.8010E 02   1.7994E 02   1.8005E 02
    ROTOR SLOPE ARRAY, RADIANS
          2.1254E-05   2.6413E-05   4.6630E-05   4.5868E-05   6.1945E-05
          5.6909E-05   2.3425E-05   7.7659E-08   2.3652E-05   5.7160E-05
          6.1953E-05   4.6100E-05   4.6837E-05   2.6406E-05   2.1377E-05
    ROTOR SLOPE PHASE ANGLE ARRAY, DEGREES
          3.5888E 02   1.7992E 02   3.5944E 02   1.7994E 02   3.5980E 02
          1.7991E 02   3.5983E 02   3.0921E 02   1.8000E 02   3.5998E 02
          1.7991E 02   3.2905E-01   1.7989E 02   3.1901E-01   1.7988E 02
    ROTOR SPIN SPEED ARRAY, RPM
          6.0000E 04   6.0000E 04   6.0000E 04   6.0000E 04   6.0000E 04
          6.0000E 04   6.0000E 04   6.0000E 04   6.0000E 04   6.0000E 04
          6.0000E 04   6.0000E 04   6.0000E 04   6.0000E 04   6.0000E 04
    ROTOR DISPLACEMENT WHIRL FREQUENCY ARRAY, RPM
          5.9985E 04   6.0014E 04   5.9994E 04   6.0012E 04   6.0002E 04
          5.9990E 04   5.9988E 04   5.9977E 04   5.9991E 04   6.0002E 04
          6.0001E 04   6.0011E 04   6.0005E 04   6.0013E 04   6.0005E 04
    ROTOR SLOPE WHIRL FREQUENCY ARRAY, RPM
          5.9931E 04   6.0186E 04   5.9863E 04   6.0131E 04   5.9926E 04
          6.0059E 04   5.9921E 04   6.3928E 04   5.9906E 04   6.0099E 04
          5.9911E 04   6.0172E 04   5.9916E 04   6.0248E 04   5.9892E 04
    BEARING DISPLACEMENT ARRAY, IN
          7.6623E-05   6.1398E-05   1.0777E-04   1.0776E-04   6.1423E-05
          7.6614E-05
    BEARING DISPLACEMENT PHASE ANGLE ARRAY, DEGREES
          1.7995E 02   1.7995E 02   1.8006E 02   1.8003E 02   1.7989E 02
          1.7994E 02
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TABLE XXIV. Continued

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MOUNT DISPLACEMENT ARRAY, IN
       3.8310E-05   3.0698E-05   5.3887E-05   5.3879E-05   3.0711E-05
       3.8307E-05
MOUNT DISPLACEMENT PHASE ANGLE ARRAY, DEGREES
       1.7994E 02   1.7995E 02   1.8006E 02   1.8003E 02   1.7989E 02
       1.7994E 02
BEARING MASS WHIRL/ROTOR SPIN FREQUENCY RATIO ARRAY
       1.0002E 00   1.0002E 00   9.9980E-01   9.9985E-01   1.0002E 00
       1.0002E 00
BEARING SLOPE ARRAY, RADIANS
       1.7608E-05   3.0579E-05   1.5616E-05   1.5768E-05   3.0733E-05
       1.7604E-05
BEARING SLOPE PHASE ANGLE ARRAY, DEGREES
       1.7992E 02   1.7994E 02   3.5983E 02   1.8000E 02   3.2892E-01
       3.1911E-01
MOUNT SLOPE ARRAY, RADIANS
       8.8045E-06   1.5289E-05   7.8084E-06   7.8841E-06   1.5367E-05
       8.8021E-06
MOUNT SLOPE PHASE ANGLE ARRAY, DEGREES
       1.7992E 02   1.7994E 02   3.5983E 02   1.8000E 02   3.2933E-01
       3.1880E-01
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TABLE XXIV. Continued

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THE AVERAGE REAL STEP-TIME FOR THIS PRINTOUT =  5.0000E-05 SEC
REAL TIME =  4.0000E-03 SEC
    ROTOR SPIN REVOLUTION ARRAY
          3.9999E 00   3.9999E 00   3.9999E 00   3.9999E 00   3.9999E 00
          3.9999E 00   3.9999E 00   3.9999E 00   3.9999E 00   3.9999E 00
          3.9999E 00   3.9999E 00   3.9999E 00   3.9999E 00   3.9999E 00
    ROTOR DISPLACEMENT ARRAY, IN
          9.6120E-05   1.1496E-04   1.0767E-04   9.2281E-05   1.3286E-04
          6.5604E-05   1.6155E-04   5.3185E-05   1.6162E-04   6.5563E-05
          1.3299E-04   9.2125E-05   1.0771E-04   1.1501E-04   9.6059E-05
    ROTOR DISPLACEMENT PHASE ANGLE ARRAY, DEGREES
          1.8007E 02   1.7997E 02   1.7999E 02   1.7997E 02   1.8000E 02
          1.7996E 02   1.8000E 02   1.7994E 02   1.8000E 02   1.7989E 02
          1.8003E 02   1.7994E 02   1.7998E 02   1.7997E 02   1.8002E 02
    ROTOR SLOPE ARRAY, RADIANS
          2.1299E-05   2.5908E-05   4.7116E-05   4.5634E-05   6.2200E-05
          5.6920E-05   2.3540E-05   1.6083E-07   2.3595E-05   5.6965E-05
          6.2278E-05   4.5521E-05   4.7168E-05   2.6130E-05   2.1569E-05
    ROTOR SLOPE PHASE ANGLE ARRAY, DEGREES
          3.5919E 02   1.7982E 02   3.5967E 02   1.7987E 02   3.5984E 02
          1.7991E 02   3.5981E 02   2.3712E 01   1.8018E 02   1.7189E-01
          1.7993E 02   1.3985E-01   1.8007E 02   2.2675E-01   1.8000E 02
    ROTOR SPIN SPEED ARRAY, RPM
          6.0000E 04   6.0000E 04   6.0000E 04   6.0000E 04   6.0000E 04
          6.0000E 04   6.0000E 04   6.0000E 04   6.0000E 04   6.0000E 04
          6.0000E 04   6.0000E 04   6.0000E 04   6.0000E 04   6.0000E 04
    ROTOR DISPLACEMENT WHIRL FREQUENCY ARRAY, RPM
          5.9988E 04   5.9997E 04   6.0011E 04   6.0009E 04   6.0006E 04
          6.0000E 04   5.9981E 04   5.9969E 04   5.9995E 04   5.9994E 04
          6.0011E 04   6.0009E 04   5.9980E 04   6.0014E 04   6.0010E 04
    ROTOR SLOPE WHIRL FREQUENCY ARRAY, RPM
          6.0137E 04   5.9894E 04   6.0073E 04   6.0038E 04   5.9968E 04
          6.0045E 04   5.9966E 04   6.6508E 04   5.9996E 04   6.0060E 04
          6.0016E 04   5.9954E 04   6.0000E 04   6.0022E 04   6.0030E 04
    BEARING DISPLACEMENT ARRAY, IN
          7.6643E-05   6.1521E-05   1.0770E-04   1.0775E-04   6.1417E-05
          7.6674E-05
    BEARING DISPLACEMENT PHASE ANGLE ARRAY, DEGREES
          1.7997E 02   1.7997E 02   1.8000E 02   1.8000E 02   1.7994E 02
          1.7997E 02
```

TABLE XXIV. Concluded

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MOUNT DISPLACEMENT ARRAY, IN
      3.8320E-05   3.0760E-05   5.3848E-05   5.3872E-05   3.0708E-05
      3.8336E-05
MOUNT DISPLACEMENT PHASE ANGLE ARRAY, DEGREES
      1.7997E 02   1.7997E 02   1.8000E 02   1.8000E 02   1.7994E 02
      1.7997E 02
BEARING MASS WHIRL/ROTOR SPIN FREQUENCY RATIO ARRAY
      9.9994E-01   1.0001E 00   9.9969E-01   9.9992E-01   1.0001E 00
      1.0002E 00
BEARING SLOPE ARRAY, RADIANS
      1.7272E-05   3.0422E-05   1.5693E-05   1.5730E-05   3.0347E-05
      1.7420E-05
BEARING SLOPE PHASE ANGLE ARRAY, DEGREES
      1.7982E 02   1.7987E 02   3.5981E 02   1.8018E 02   1.2964E-01
      2.2688E-01
MOUNT SLOPE ARRAY, RADIANS
      8.6360E-06   1.5211E-05   7.8467E-06   7.8652E-06   1.5174E-05
      8.7102E-06
MOUNT SLOPE PHASE ANGLE ARRAY, DEGREES
      1.7982E 02   1.7987E 02   3.5981E 02   1.8017E 02   1.4027E-01
      2.2648E-01
```

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