USER'S MANUAL FOR COMPUTER PROGRAM ROTOR

Masahiro Yasue

August 1974

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Prepared under Contract No. NAS2-7252 by

Aeroelastic and Structures Research Laboratory
Department of Aeronautics and Astronautics
Massachusetts Institute of Technology
Cambridge, Massachusetts 02139

for

AMES RESEARCH CENTER
NATIONAL AERONAUTICS AND SPACE ADMINISTRATION
Moffett Field, California 94035
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**Abstract**

This report presents a detailed description of a computer program to calculate tilt-rotor aircraft dynamic characteristics. This program (named ROTOR) consists of two separate parts. In the first part, the natural frequencies and corresponding mode shapes of the rotor blade and wing are developed from structural data (mass distribution and stiffness distribution). The second part of the program deals with the frequency response (to gust and blade pitch control inputs) and eigenvalues of the tilt-rotor dynamic system, based on the natural frequencies and mode shapes derived beforehand. Sample problems are included to assist the user.

**Key Words** (Suggested by Author(s))

- Notary Wing Dynamics
- Gust Response
- Proprotor
- Tilt-Rotor

**Distribution Statement**

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The computations were performed at the Information Processing Center of the Massachusetts Institute of Technology.
ABSTRACT

This report presents a detailed description of a computer program to calculate tilt-rotor aircraft dynamic characteristics. This program (named ROTOR) consists of two separate parts. In the first part, the natural frequencies and corresponding mode shapes of the rotor blade and wing are developed from structural data (mass distribution and stiffness distribution). The second part of the program deals with the frequency response (to gust and blade pitch control inputs) and eigenvalues of the tilt-rotor dynamic system, based on the natural frequencies and mode shapes derived beforehand. Sample problems are included to assist the user.
# CONTENTS

<table>
<thead>
<tr>
<th>Section</th>
<th>Page</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>INTRODUCTION</td>
</tr>
<tr>
<td>1.1 Purpose and Scope</td>
<td>1</td>
</tr>
<tr>
<td>1.2 Program Outline and Limitations</td>
<td>1</td>
</tr>
<tr>
<td>2</td>
<td>DESCRIPTION OF THE PROGRAMS</td>
</tr>
<tr>
<td>2.1 Description of the FREEVI Program</td>
<td>4</td>
</tr>
<tr>
<td>2.2 Description of the TILDYN Program</td>
<td>6</td>
</tr>
<tr>
<td>3</td>
<td>USER'S GUIDE FOR FREEVI PROGRAM</td>
</tr>
<tr>
<td>3.1 Input Data Requirements</td>
<td>9</td>
</tr>
<tr>
<td>3.2 Output Features</td>
<td>15</td>
</tr>
<tr>
<td>3.3 Example Problems</td>
<td>19</td>
</tr>
<tr>
<td>3.3.1 Application to the Wing</td>
<td>19</td>
</tr>
<tr>
<td>3.3.2 Application to the Blade</td>
<td>19</td>
</tr>
<tr>
<td>4</td>
<td>USER'S GUIDE FOR THE TILDYN PROGRAM</td>
</tr>
<tr>
<td>4.1 Input Data Requirements</td>
<td>20</td>
</tr>
<tr>
<td>4.2 Output Features</td>
<td>31</td>
</tr>
<tr>
<td>4.3 Example Problems</td>
<td>33</td>
</tr>
<tr>
<td>REFERENCES</td>
<td>34</td>
</tr>
<tr>
<td>TABLES</td>
<td>35</td>
</tr>
<tr>
<td>FIGURES</td>
<td>41</td>
</tr>
<tr>
<td>APPENDICES</td>
<td>58</td>
</tr>
<tr>
<td>A</td>
<td>Program List</td>
</tr>
<tr>
<td>A.1 The FREEVI Program List</td>
<td>58</td>
</tr>
<tr>
<td>A.2 The TILDYN Program List</td>
<td>59</td>
</tr>
<tr>
<td>B</td>
<td>INPUT DATA AND OUTPUT LISTING OF THE SAMPLE PROBLEMS</td>
</tr>
<tr>
<td>B.1 Application of the FREEVI Program to the Wing</td>
<td>185</td>
</tr>
<tr>
<td>B.2 Application of the FREEVI Program to the Blade</td>
<td>186</td>
</tr>
<tr>
<td>B.3 Application of the TILDYN Program</td>
<td>192</td>
</tr>
<tr>
<td>APPENDICES</td>
<td>93</td>
</tr>
</tbody>
</table>
LIST OF ILLUSTRATIONS

Figure

1. Flow Chart of the FREEVI Program for Blade and Wing of Natural Frequencies and Mode Shapes 41

2. Flow Chart of the TILDYN Program for Analysis of Tilt Rotor Aircraft Dynamics 43

3. Finite Element Representation with Beam Elements 46

4. Coordinate System for the FREEVI Program 46

5. Data Deck Setup for the FREEVI Program 47

6. Structural Characteristics of the Wing 48

7. Structural Characteristics of Two Proprotor Blades 50

8. Data Deck Setup for the TILDYN Program 54

LIST OF TABLES

Table

1. Boundary Conditions and Output Deflections of the Rotor and Wing in the FREEVI Program 35

2. Description of the Variables 36

3. Description of the Bell and the Boeing Proprotor Designs Considered in this Report 38
SECTiON 1

INTRODUCTION

1.1 Purpose and Scope

Program ROTOR is an in-core program written in FORTRAN IV language for analysis of the dynamic characteristics of the tilt-rotor aircraft.

The analytical model considered here consists of a cantilevered semispan wing with the engine-rotor system at the wing tip (see Fig. 1 of Ref. 1). The dynamic and aeroelastic characteristics of this aircraft are in many ways unique and complicated. The large flexible blades with a large amount of twist have significant coupling between flapping and lagging motion. The engines and gearboxes at the wing tip lead to low wing natural frequencies and possible resonances in the low frequency range.

The purpose of this program is the numerical analysis of the complicated dynamic and aeroelastic behavior of the tilt-rotor aircraft. The first step is the derivation of the equations of motion of the blade and the wing, including inertia forces, blade aerodynamic forces and wing aerodynamic forces. This formulation is described in detail in Ref. 1. Based on the equations of motion, the frequency response of the blade and wing motions to the gust input or blade pitch angle control input are derived. An eigenvalue analysis provides the system stability characteristics.

1.2 Program Outline and Limitations

Program ROTOR consists of two separate parts. One is called FREEVI (free vibration of the tilt-rotor aircraft), which produces the natural frequencies and mode shapes of the free vibration from the blade or from the wing structural characteristic data. The second part is named TILDYN (tilt-rotor dynamics)
which calculates the dynamic characteristics of the aircraft, including eigenvalues and frequency response to the gust and to the pitch-control inputs.

The reason for the separation of the program into two parts is that this system gives the user the opportunity to check the results for the natural frequencies and mode shapes without performing the entire calculation. In addition, the dynamic characteristics can be evaluated easily by changing the input natural frequencies or using different assumed modes without changing the structural characteristics, mass distribution, or stiffness distribution. The disadvantage is that the input data for TILDYN are the output data of FREEVI.

The free vibration problem of the wing and blade is solved as an eigenvalue problem in FREEVI by the finite element method. The wing has three degrees of freedom, vertical bending, chordwise bending and torsion. A large wing tip mass represents the rotor, engine, and gearbox.

Only flapping and lagging motions are considered for the blade. Torsion is neglected as a higher-order effect for the blade case. The rotor types treated here are the hingeless rotor and the gimballed rotor. The maximum number of elements is limited to twenty.

With respect to the TILDYN program, it should be mentioned that the flight configuration is restricted to cruising flight only, with the rotor disk plane perpendicular to the free stream. Both powered and autorotation cases can be treated. Total degrees of freedom considered are nine or eighteen for powered flight. The nine degrees of freedom consist of blade flapping and lagging fundamental modes (each has a collective and two cyclic degrees of freedom) and wing vertical bending, chordwise bending, and torsion modes. The eighteen degrees of freedom include two additional blade modes and three additional wing modes. It should be noted
that description of the blade motion requires three independent degrees of freedom to reduce one equation with periodic coefficients in the rotating system to three equations with constant coefficients in the non-rotating system.

In the autorotation case, one more degree of freedom is added, the rigid body rotation of the rotor, and the total degrees of freedom become ten or nineteen. After the construction of the equations of motion for each case, the frequency response problem is solved. The excitation inputs consist of the following: vertical gust, lateral gust, longitudinal gust, collective-blade pitch control and two cyclic blade pitch controls. By appropriately specifying the excitation input components, the flight in a cross-wind gust can be considered.

The eigenvalue problem to be solved is the usual eigenvalue problem of a linear system of equations. The EISPACK subroutine developed by the Argonne Code Center is used to treat this problem (Refs. 2 and 3).
SECTION 2
DESCRIPTION OF THE PROGRAMS

2.1 Description of the FREEVI Program

This program consists of one main program and twelve subroutines for the computation of the lowest few eigenvalues and eigenvectors of the proprotor dynamic system modelled by the finite-element method, as described in Ref. 1. The outline flow chart is shown in Fig. 1.

Input data include element-structural characteristics (mass distribution, stiffness distribution and angle of twist), rotational speed, and some instruction data for the computation. The boundary conditions are automatically chosen when the calculation case is selected appropriately. Boundary conditions and degrees of freedom are tabulated in Table 1 for the rotor and wing. Next, the element stiffness and mass matrices are assembled globally. From the input information, the boundary conditions are imposed on the global system. The subspace iteration method is applied to find the eigenvalues and eigenvectors of the system (Refs. 4 and 5). Consider the eigenvalue problem of the n-degree-of-freedom equations:

\[ [K][u] = \lambda [M][u] \]  \hspace{1cm} (2.1)

where \([K]\) and \([M]\) are square stiffness and mass matrices with order \(n\), \([u]\) is a matrix of the mode shape and \(\lambda\) is an eigenvalue. When \(m\) eigenvalues and eigenvectors are required, the main steps of the subspace iteration method are as follows:

(a) Assume mode shape matrix \([u_o]\); \(nxm\) matrix containing \(m\) vectors

(b) \([M_R] = [u_o]^T[M][u_o]\); \([K_R] = [u_o]^T[K][u_o]\) where \([M_R]\) and \([K_R]\) are reduced square matrices with order \(m\).
(c) Find eigenvectors \([A]\) (mxm matrix) such that \([K_R][A] = [D][M_R][A]\), with \([D]\) denoting a diagonal matrix.

(d) \([\overline{u}_o] = [u_o][A]\)

(e) \([u_1] = [K]^{-1}[M][\overline{u}_o]\)

(f) \([u_o] = [u_1]\) and go to step (b)

The eigenvalue analysis of the smaller system (order \(m\)) in step (c) is achieved by using the Jacobi method. The criterion of terminating the iteration is defined as

\[
\left| \frac{\lambda_{i+1} - \lambda_i}{\lambda_i} \right| \leq \varepsilon
\]  

(2.2)

Each eigenvalue must satisfy this criterion; the error threshold \(\varepsilon\) can be defined by the user.

Output includes the input data, the eigenvalues, the eigenvectors, and, if required, punched-out cards of the eigenvectors. A built-in message as to whether convergence was achieved is also furnished.

A short description of each of the subroutines is given below:

**MAIN**  
Defines dimensions

**TEIGEN**  
Calculates the normal modes and frequencies

**INPUT**  
Supplies input information

**ELEMK**  
Controls the generation of element stiffness and mass matrices

**MESH**  
Calculates mesh information for the finite element assembly

**ASBV**  
Applies boundary conditions

**FAC**  
Triple matrix factorization

**MTRTR**  
Matrix multiplication

**MULTZ**  
Matrix multiplication

**SOLZ**  
Forward and backward substitution

**DNROOT**  
Eigen-analysis routine

**EIGEN**  
Eigen-analysis routine needed in **DNROOT**

**OUTPUT**  
Output routine

The listing is shown in Appendix A.
2.2 Description of the TILDYN Program

This program to solve the equations of motion of the tilt-rotor aircraft derived in Ref. 1, consists of one main program and twenty-four subroutine programs. The outline flow chart is shown in Fig. 2.

Input data are natural frequencies and corresponding mode shapes of the rotor and wing, aerodynamic coefficients, and flight conditions.

Based on such input data, the coefficients of the equations of motion are derived, using the numerical integration method. Finally, the equations of motion are formulated as a matrix:

\[
\begin{bmatrix} \dddot{x} \\ \ddot{x} \\ \dot{x} \\ x \end{bmatrix} + \begin{bmatrix} A \\ B \\ C \end{bmatrix} \begin{bmatrix} \ddot{x} \\ \dot{x} \\ x \end{bmatrix} + \begin{bmatrix} D \end{bmatrix} \begin{bmatrix} e \end{bmatrix} = 0
\]

(2.3)

\([A], [B], [C], \text{and } [D] \text{ are the coefficient matrices, including inertia terms and aerodynamic terms. The matrix } \{x\} \text{ is a set of variables and } \{e\} \text{ is an exciting force matrix including gust components and blade pitch-control components (see Ref. 1). These equations have nine or eighteen degrees of freedom in the powered flight case. In the autorotation flight case, ten or nineteen degrees of freedom are required, due to the addition of rigid-body rotation (see Table 2).}

The dynamic characteristics of these equations are analyzed by two methods. One is the frequency-response analysis and the other is the eigenvalue analysis. In the frequency-response analysis, the accelerations and velocities of the equations are expressed in terms of a given frequency, and the differential equations are transformed into a set of linear algebraic equations. These linear equations are solved by the Gauss-Jordan reduction to obtain the response to the gust or blade pitch-control input.

The eigenvalue problem is formulated in the usual way. Equation 2.3 is rewritten
to obtain first-order differential equations. The real general matrix eigenvalue problem is solved by the EISPACK package, developed by Argonne National Laboratory to solve a standard matrix eigenvalue-eigenvector problem (Refs. 2 and 3).

A short description for each of the subroutines of the TILDYN program is given below:

- **MAIN**: Defines the sequence of the program
- **BLOCK DATA**: Initializes the coefficients of Gaussian quadrature
- **INITIL**: Initialization of the matrices
- **COEFF**: Defines the points and coefficients of the Gaussian quadrature
- **INPUT**: Supplies input information
- **INTPL**: Interpolation for the numerical integration by Gaussian quadrature
- **AERO**: Defines the aerodynamic coefficients at the points of Gaussian quadrature
- **ORDINT**: Defines the order of the numerical integration
- **INTEG**: Numerical integration
- **F**: Defines the integrand function
- **AINER**: Defines the inertia coefficients of the equations in matrix form
- **AEROMT**: Defines the aerodynamic coefficients of the equations in matrix form
- **EQMTX**: Defines the coefficient matrices [A], [B], [C], and [D] in Eq. 2.3.
- **AUTO**: In the autorotation case, another degree of freedom is added.

\[
\begin{bmatrix}
\dot{x} \\
\dot{x}
\end{bmatrix} = \begin{bmatrix}
-A^{-1}B & -A^{-1}C \\
I & 0
\end{bmatrix}
\begin{bmatrix}
\dot{x} \\
\dot{x}
\end{bmatrix}
\] (2.4)
<table>
<thead>
<tr>
<th>Command</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>GUSTCO</td>
<td>Defines gust and blade pitch control components</td>
</tr>
<tr>
<td>FRQRES</td>
<td>Calculates the frequency response</td>
</tr>
<tr>
<td>GAELI</td>
<td>The Gauss-Jordan reduction routine</td>
</tr>
<tr>
<td>EIGEN</td>
<td>Routine to form the eigenvalue problem and to call EIPACK subroutine</td>
</tr>
<tr>
<td>EIPACK</td>
<td>An eigensystem problem solver for the real general matrix consisting of EISPACK subroutine BALANC, ELMHES, ELTRAN, HQR2 and BALBAK</td>
</tr>
<tr>
<td>BALANC</td>
<td>Balances a real general matrix and isolates eigenvalues whenever possible</td>
</tr>
<tr>
<td>ELMHES</td>
<td>Obtains an upper Hessenberg matrix from a real general matrix</td>
</tr>
<tr>
<td>ELTRAN</td>
<td>Accumulates the elementary similarity transformations for the reduction to upper Hessenberg form</td>
</tr>
<tr>
<td>HQR2</td>
<td>Finds the eigenvalues and eigenvectors</td>
</tr>
<tr>
<td>BALBAK</td>
<td>Forms the eigenvectors by back-transforming those of the corresponding balanced matrix determined by BALANC</td>
</tr>
<tr>
<td>MINV</td>
<td>Inverses a matrix</td>
</tr>
</tbody>
</table>

The listing is shown in Appendix A.
SECTION 3
USER'S GUIDE FOR FREEVI PROGRAM

3.1 Input Data Requirements

The input and output of the computer code is a part of the built-in program with fixed format. This approach requires a minimum knowledge of the programs and programming.

The finite-element model for the input data is shown in Fig. 3. The structure is divided into several elements for application of the finite-element method. The mass distribution, bending and torsional stiffness, and angle of twist are the average values in the element. The unit system used should be consistent throughout the entire program.

This program calculates the natural frequencies and normal modes for five cases, including wing vibration and blade vibration with various boundary conditions (see Table 1). The parameter ICASE specifies the particular case in the program. The parameter IPUNCH specifies whether a punched card deck of the mode shapes is required for input to the program TILDYN.

Uncoupled mode shapes, instead of coupled mode shapes, can be generated, if necessary. The parameter Iguest controls the initial assumed values for the purpose of generating the uncoupled mode shapes.

The value of M expresses the number of eigenvalues and mode shapes required by the user.

Parameters and variables are described in detail below:

DES A vector to express the test identifying information. The user can punch the run identification in the first column through the eightieth column of the first card. The format is 20A4.
ICASE  A parameter to specify the calculation case:
    ICASE=1; wing case with clamped boundary conditions at the root.
    ICASE=2; blade case with boundary conditions clamped for the flapping motion and clamped for the lagging motion at the root.
    ICASE=3; blade case, clamped for flapping and hinged for lagging.
    ICASE=4; blade case, hinged for flapping and clamped for lagging.
    ICASE=5; blade case, both hinged boundary conditions.
It is punched in the integer format as I1 in the first column of the second card.

IPUNCH  A parameter to control whether the mode shapes are punched out in cards for input to the TILDYN program.
    IPUNCH=0; no punched output
    IPUNCH=1; punched output
The parameter is punched in the integer format as I1 in the first column of the third card.

IGUEST  A parameter to control the mode-shape type coupled or uncoupled, both for the blade and the wing.
    IGUEST=0; coupled
    IGUEST=1; uncoupled vertical bending (w)
    IGUEST=2; uncoupled chordwise bending (v)
    IGUEST=3; uncoupled torsion ($\phi$)
It should be noted that the terms PB, RAMDA, COL and THETAE related to coupled motion should be set to zero when uncoupled mode shapes are required. The parameter is punched in the integer format as I1 in the first column of the fourth card.
NET  Total number of elements, maximum number is 20. It is punched out in the integer format as I5 in the first through fifth columns in the fifth card.

NITR  The maximum number of iterations to be performed. If the number of iterations reaches NITR, yet the iteration is not converged, the program execution is terminated and a built-in message appears. Recommended value for NITR is 20. It is punched in the integer format as I5 in the 6th through the 10th columns of the fifth card.

M  Number of vibration modes required by the user. Recommended value for M is less than 10. If \( M = 10 \) to 20, NITR is recommended to be 50.

ERR  The error limit used to compare with \( |(\lambda_{i+1} - \lambda_i)/\lambda_i| \), where \( \lambda_i \) is the eigenvalue calculated at the \( i \)th iteration cycle. The iteration terminates if the calculated value is smaller than ERR. Recommended values for ERR are 0.001 to 0.01. It is punched in the real value format (F10.6) at the first through 10th columns of the sixth card.

OMEG  Rotational speed \( \Omega \) in rad/sec, the direction of rotation is positive for the upward rotational vector when the aircraft configuration is in the helicopter mode. For the wing or non-rotating blade it is set to zero. It is punched in real value format (F10.6) in the first through 10th columns of the seventh card.

RAMDA  Inflow ratio \( \lambda \) is defined as \((V + v)/\Omega R\). It determines the collective pitch of the blade.

For the wing and non-rotating blade, it is set to zero. It is punched in real value format (F10.6) in the first through the 10th columns of the 8th card.
COL  Collective pitch angle in radians ($\theta_D$ in Ref. 1). For the wing case it is set to zero. It is punched in real value format (F10.6) in the first through the 10th columns of the 9th card.

SPKB  The flapwise spring constant at the root of the hinged rotor. If there is no spring, it is set to zero. It is punched in real value format (F10.6) in the 1st through the 10th columns of the 10th card.

SPKC  The lagwise spring constant at the root of the hinged rotor. If there is no spring, it is set to zero. It is punched in real value format (F10.6) in the 11th through 20th columns of the 10th card.

ALPHAH  The number is used to avoid a singularity of the stiffness matrix in the case of the hinged blade. The recommend value for ALPHAH is the squared value ($\lambda^2$) of the first non-zero eigenvalue. The value 5000.0 is appropriate for the first trial. It is punched in real value format (F10.6) in the first through the 10th columns of the 11th card.

EIBE  A vector to express the vertical bending stiffness ($EI_B$) of the element. The length of the vector equals NET. It is punched in the exponent format (E15.7) and five data items can be included per card. These data occupy the 12th card through card $[10+(NET/5)]$ if NET is a multiple of 5. Otherwise, up to card $[11+(NET/5)]$ is occupied.

EICE  A vector to express the chordwise bending stiffness ($EI_C$) of the element. The length of the vector is NET. It is punched in the exponent format (E15.7) and five data items can be included in a card. These data occupy $(NET/5)$ cards if NET is a multiple of 5, otherwise $[1+(NET/5)]$ cards.
THETAE A vector to express the angle of twist $\theta_{AT}$ in radians of the structure element, positive nose up. It should be the average angle of twist over the element. The length of the vector is NET. Eight data items can be punched in real value format (F10.6) in each card. These data occupy (NET/8) cards if NET is a multiple of 8, otherwise $[1+(\text{NET}/8)]$ cards.

AMASE A vector to describe the mass distribution (mass/unit length); its length is NET. It is punched in real value format (F10.6), 8 data items on one card. These data occupy (NET/8) cards if NET is a multiple of 8, otherwise $[1+(\text{NET}/8)]$ cards.

ESE A vector to define the size of the beam element of the blade or wing and its length is NET. It is punched in real value format (F10.6), 8 data items on a card. These data occupy (NET/8) cards if NET is a multiple of 8, otherwise $[1+(\text{NET}/8)]$ cards.

AMN The number to express the tip mass. In the case of the wing, it includes the nacelle and all blade mass as

$$\text{AMN} = M_N + N M_B$$

in the symbols of Ref. 1. If a tip mass exists in the blade, it is also appropriate to use AMN. It is punched in real value format (F10.6) in the first through the 10th columns of the card. The next four numbers PIR, PIY, PIP and PBW are punched on the same card with AMN.

PIR A number to express the rolling moment of inertia of the nacelle and blades at the wing tip:

$$\text{PIR} = I_{PR} + NI_B$$
The format is (F10.6) and it is punched from the 11th to 20th columns.

**PIY**
A number to express the yawing moment of inertia of the nacelle and blades at the wing tip:

\[ \text{PIY} = I_p + \frac{N}{2} I_B + NM_B h^2 \]

The format is (F10.6) and it is punched from the 21st to the 30th columns.

**PIP**
A number to express the pitching moment of inertia of the nacelle and blades at the wing tip:

\[ \text{PIP} = I_p + \frac{N}{2} I_B + NM_B h^2 \]

The format is (F10.6) and it is punched from the 31st to the 40th columns.

**PBW**
A number to express the mass coupling effect at the tip between the wing vertical bending and the torsion due to blade mass:

\[ \text{PBW} = NM_B h \]

The format is (F10.6) and it is punched from the 41st to the 50th columns.

If the calculation case is the wing (ICASE=1), the next three data cards should be added:

**GJ**
A vector to express the torsional rigidity: its length is NET. The format is (E15.7) and five data items can be included in a card. These data occupy (NET/5) cards if NET is a multiple of 5, otherwise \([1+(\text{NET}/5)]\).

**PI**
A vector to express wing mass moment of inertia about the elastic axis per unit length: its length is NET. The format is (E15.7) and five data items can be included in a card. These data occupy (NET/5) cards if NET is a multiple of 5, otherwise \([1+(\text{NET}/5)]\).
PI12 A vector to express wing static mass moment of the segment to define the coupling motion between wing vertical bending and torsion. The vector length is NET and the format is (E15.7). Five data items can be included in a card and data occupy NET/5 cards if NET is a multiple of 5, otherwise \(1+\frac{NET}{5}\).

The data deck setup is shown in Fig. 5 and the example problem data listing is in Appendix B.

A few remarks will now be stated to avoid misuse of the program:

1) A consistent unit system must be adopted.
2) The maximum element number (NET) is 20.
3) Appropriate rotor rotational direction must be chosen. If OMEG is negative, RAMDA (inflow ratio) should be negative. However, COL (the collective pitch) and THETAE (angle of twist) should be positive nose up.
4) If uncoupled mode shapes are required, the coupling terms such as RAMDA, COL, THETA, PBW and PI12 should be set to zero.
5) If there are several cases to be dealt with, the data may consist of several data sets. After the execution of the first case, the computer automatically returns to the beginning of the program and reads the second input data set. Therefore, at the end of the entire calculation, the computer notes the absence of data sets and generates an error message.

3.2 Output Features

All input data are printed out for checking. The built-in messages and outputs in the FREEVI program are as follows:

(a) TENSION DUE TO CENTRIP. FORCE

This prints out the tension force at each nodal
(b) MASS = 0.XXXXXX
This indicates the total mass of the blade or wing.

(c) MOMENT OF INERTIA AT ROOT = 0.XXXXXX
This gives the mass moment of inertia of the blade or wing about the virtual hinge at the root.

(d) MAX. SIZE OF STF IS XXX SPECIFIED SIZE IS XXX
This prints out the specified value of the estimated length of the stiffness matrix and the actual required value for the stiffness matrix. If the specified value is smaller, the program stops. Check the input. If the required value is smaller, no remedy is needed.

(e) THE XXXXTH DIAG. AFTER FACT=0.0, INCOMPLETE FACT
This message appears when the factorization of the mass matrix is not complete. The program also stops. Check the input.

(f) NO. OF NEGATIVE DIAG. = XXXX, FACT COMPLETED
This prints out the number of negative diagonals of the factorized mass matrix. If the printed value is other than zero, the mass matrix is not positive definite. Check the input data.

(g) EIGENVALUES =
At each iteration, calculated eigenvalues are printed out. If eigenvalues satisfy the accuracy requirements, these results are printed out in eigenvalue format (the square value of the natural frequency), radian/second and Hertz.

(h) NO. OF ITERATION = XXXX CONVERGED WITHIN 0.XXXXXX
This indicates that the subspace iteration is completed. The first value printed is the number of the
iteration and the second value is the error limit input by the user.

(i) NO. OF ITERATION = XXXX NOT CONVERGED

This appears instead of (h) message if the user specified maximum number of iterations (NITR) has been reached, yet the eigenvalues have not converged to within the error limit set by the user. The user should check the input for possible errors or change the error limit (ERR) because the previous error limit may be too small to be achieved, or increase the maximum number of iteration (NITR).

(j) REDUCED MASS MATRIX

The lower triangular part of the reduced mass matrix is printed out.

(k) REDUCED STIF MATRIX

The lower triangular part of the reduced stiffness matrix is printed out.

(l) ****BLADE MODE SHAPES**** or ****WING MODE SHAPES****

Mode shapes are printed out. Index I indicates the eigenvalue to which the mode shape corresponds and index J indicates the station number of the node. Symbols W(I,J), V(I,J), PW(I,J), and DV(I,J) are vertical bending (flapping motion), chordwise bending (lagging motion), slope of the vertical bending, and slope of the chordwise bending, for the case of blade vibration. In addition to those symbols, PHI(I,J) and DPHI(I,J) are used for the torsion and slope of the torsion for the wing vibration. The coordinate system is shown in Fig. 4.
Punched Card Output

If IPUNCH is set equal to one, the punched card output is also performed. The format is E13.5 with six data items on a card. The order is \( W(1,1) \) of the first mode to last \( W(1,\text{NET}+1) \), punched on \( [(\text{NET}+1)/6] \) cards if \( \text{NET}+1 \) is a multiple of 6, otherwise \( [(\text{NET}+1)/6+1] \) cards. Next \( V(1,J) \), \( DW(1,J) \) and \( DV(1,J) \) groups are punched. After the first mode shape the group of the second mode shape is punched and it continues to the Mth mode shape. In the case of the wing, the output data of \( \text{PHI}(I,J), \text{DPHI}(I,J) \) are added in the same fashion after the set of \( \text{DV}(I,J) \).
3.3 Example Problems

Example problems cited here for the FREEVI program are taken from Ref. 1.

3.3.1 Application to the Wing

The free vibration of the Bell wing is considered in this report. Structural characteristics (mass distribution, bending stiffness and so on) are shown in Fig. 6. Mass moments of inertia of the nacelle and blades are tabulated in the "Bell" column of Table 3. The listing of both input and output are shown in Appendix B.

3.3.2 Application to the Blade

The hingeless rotor of the Boeing Vertol is studied here. It should be noted that the rotation direction is negative in this case. Structural characteristics are shown in Fig. 7. The listing of both input and output are shown in Appendix B.
4.1 Input Data Requirements

This program has several parameters to designate the case being considered by the user. The first one is ITYPE, which specifies whether collective mode shapes of the blade different from the cyclic mode shapes are needed. If it is the gimballed rotor, the parameter instructs the computer to read more data for the collective mode shapes of the gimballed rotor. The parameter IFLT defines whether the case considered is powered flight or autorotational flight. The next parameter IDOF specifies the number of degrees of freedom. If it is nine, two blade modes (giving six degrees of freedom in the non-rotating system) and three wing modes are necessary. If IDOF is eighteen, two more modes for the blade and three more modes for the wing should be added to the nine degrees-of-freedom system. The parameter IRES specifies execution of the frequency response analysis. The user should decide whether the response based in terms of normal mode shapes or in terms of mode shapes normalized to unity at the blade tip. This is determined by the parameter IFRMAG. The last parameter IEIGEN specifies execution of the eigenvalue analysis.

Parameters and variables are described in input order below:

**DES**
A vector to express the test identifying information. The user can punch the run identification in the first column through the eightieth column of the first card. The format is 80A1.

**ITYPE**
A parameter to control the reading of input data depending upon the type of rotor.

- ITYPE=0; the hingeless rotor in powered flight
- ITYPE=1; the hingeless rotor in autorotational flight.
- the gimballed rotor both in powered and autorotational flight.
The format is (Il) and it is punched in the first column of the second card.

**I FLT**
A parameter to determine the flight condition.

- IFLT=0; powered flight
- IFLT=1; autorotation flight

The format is (Il) and it is punched in the first column of the third card.

**IDO F**
A parameter to define the number of basic elastic deformation degrees of freedom and how many mode shapes are needed. It should be noted that the same number IDOF is used for both powered flight and autorotation flight.

- IDOF=9; In the powered flight case, nine equations are constructed and two mode shapes for the blade and three mode shapes for the wing are necessary. In the autorotation flight (IFLT=1), ten equations are constructed, due to the addition of the rigid-body rotation of the blades. The same number of mode shapes as for the powered flight is necessary.
- IDOF=18; In powered flight, eighteen equations are formulated. In autorotation flight they become nineteen. In total, four mode shapes are necessary for the blade and six for the wing.

The format is (Il) and it is punched in the first two columns of the fourth card.

**I RES**
A parameter to control whether the frequency response analysis is carried out.

- IRES=0; it is not carried out.
- IRES=1; it is carried out.

The format is (Il) and it is punched in the first column of the fifth card.
IFRMAG A parameter to control the type of mode shapes used for the output results.

IFRMAG=0; the frequency response and eigenvector results are based on mode shapes as follows: the predominant components of the blade-coupled-mode shape are normalized to \( R \) (rotor radius) at the maximum deflection point. The wing-bending-mode shapes are normalized to \( L \) (wing semispan) at the maximum deflection point, and the wing-torsion-mode shape is normalized to unity at the maximum deflection point. This type of normalization is for the purpose of obtaining results comparable with those described in Ref. 6.

IFRMAG=1; the frequency response and eigenvector results are based on the normal modes used as input data.

The format is (IL), and it is punched out in the first column of the sixth card.

IEIGEN A parameter to control whether the eigenvalue analysis is executed.

IEIGEN=0; it is not executed.

IEIGEN=1; it is executed.

The format is (IL) and it is punched in the first column of the seventh card.

NOBLD The blade number. The format is (IL) and it is punched in the first column of the eighth card.

ROH The air density. The format is (E10.0); the user can put a datum in either F format or E format in the first ten columns of the ninth card.
OMEGA  The rotor rotational speed (radian/sec). The format is E10.0; the user can choose either E or F type. The datum is put in the eleventh column through the twentieth column of the ninth card. OMEGA can take positive or negative values corresponding to the rotational direction. The sign definition is the same as that of the FREEVI program.

RAMDA  The inflow ratio. The sign should be consistent with the rotational direction of the rotor. The format is either in E or F type. The datum is put in the 21st through 30th column of the ninth card.

VEL  The cruising speed of the aircraft. The format is either E or F type. The datum is put in the 31st through the 40th column of the ninth card.

R  The blade radius. The format is either E or F type. It is punched in the first through the tenth column of the tenth card.

AIB  The blade flapping moment of inertia. The format is either E or F type. It is punched in the eleventh through the 20th column of the tenth card.

CHOD  The mean chord length of the blade. The format is either E or F type. It is punched in the 21st through the 30th column of the tenth card.

CL  The lift-curve slope of the blade. The format is either E or F type. It is punched in the 31st through the 40th column of the tenth card.

CD  The drag coefficient of the blade (C_{D_0}). The format is either E or F type. It is punched in the 41st through the 50th column of the tenth card.
HMAST  The mast height. The format is either E or F type. It is punched in the 51st through the 60th column of the tenth card.

DEL3  The rotor blade pitch-flap coupling ($\delta_3$). The unit is radians. The format is either E or F type. It is punched in the 61st through the 70th column of the tenth card.

WL  The wing semispan length. The format is either E or F type. It is punched in the first through the tenth column of the eleventh card.

WCOD  The mean wing chord length. The format is either E or F type. It is punched in the eleventh through the 20th column of the eleventh card.

WCL  The wing lift curve slope. The format is either E or F type. It is punched in the 21st through the 30th column of the eleventh card.

WCD  The wing drag coefficient ($C_{D_0}$ of the wing). The format is either E or F type. It is punched in the 31st through the 40th column of the eleventh card.

WCMO  The wing pitching moment coefficient ($C_{MO}$). The format is either E or F type. It is punched out in the 41st through the 50th column of the eleventh card.

WCMA  The wing pitching moment curve slope ($C_{m_0}$). The format is either E or F type. It is punched in the 51st through the 60th column of the eleventh card.

EDIS  The distance (nondimensionalized by the wing chord) between the elastic axis and the aerodynamic center of the wing (positive if the aerodynamic center is ahead of the elastic axis). The format is either E or F type. It is punched in the 61st through the 70th column of the 11th card.
WTHET The wing trim angle of attack in radians. The format is either E or F type. It is punched in the 71st through the 80th column of the eleventh card.

CGUST A vector to express the magnitudes of the exciting force components shown in Eq. 2.3 as \( \mathbf{e} \).

\[
\begin{align*}
\text{CGUST}(1): & \text{ vertical gust } u_G/V \\
\text{CGUST}(2): & \text{ lateral gust } v_G/V \\
\text{CGUST}(3): & \text{ longitudinal gust } w_G/V \\
\text{CGUST}(4): & \text{ collective pitch control } \theta_o \\
\text{CGUST}(5): & \text{ cyclic cosine pitch control } \theta_{1c} \\
\text{CGUST}(6): & \text{ cyclic sine pitch control } \theta_{1s}
\end{align*}
\]

If the user specifies 1.0 for one of these quantities, that gust or pitch control quantity becomes the exciting force. Each vector component has either E or F format and occupies ten columns each of the twelfth card.

BRAM A vector to express the blade eigenvalues and its length is 4. The values are the squared values of the natural frequencies (\( \text{rad}^2/\text{sec}^2 \)). If IDOF is set equal to 9, the latter two eigenvalue columns may have blanks. If the calculation case is the gimbaled rotor (ITYPE=1), BRAM should include the cyclic mode eigenvalues of the blade. The format is either E or F type and each component occupies ten columns in order of the 13th card.

WRAM A vector to express the wing eigenvalues and its length is 6. The values are the squared values of the natural frequencies (\( \text{rad}^2/\text{sec}^2 \)). If IDOF is set equal to 9, the latter three eigenvalue columns may have blanks. The format is either E or F type and each component occupies ten columns in order of the 14th card.

NW A number to specify the wing element quantity. The format is (I2) and it is punched in the first two columns of the 15th card.
A vector to describe the wing element size. The vector length is NW and the element size, nondimensionalized by the wing semispan, should be input. The format is either E or F type (E10.0). Each vector component occupies ten columns from the 16th card. The number of the card for EMSW is NW/8 if NW is a multiple of 8. Otherwise [(NW/8) + 1] cards.

A matrix to describe the wing vertical bending mode shape (γ in Ref. 1) at the nodes. The size of the matrix is MWx(NW+1), where MW is 3 if IDOF=9 and 6 if IDOF=18. The format is E or F type (E13.5) and G(1,1) expresses the vertical deflection at the root node of the first mode. G(1,NW+1) is the one at the tip node of the first mode (Fig. 4). The data should be punched in order from the root node to the tip node value. One card can include 6 data.

A matrix to describe the wing chordwise bending mode shape (ζ in Ref. 1) at the node. Other comments are the same as for G.

A matrix to describe the wing vertical bending slope (dy/dy in Ref. 1). Other comments are the same as for G.

A matrix to describe the wing chordwise bending slope (dζ/dy in Ref. 1). Other comments are the same as for G.

A matrix to describe the wing torsion deflection (φ in Ref. 1). Other comments are the same as for G.

A matrix to describe the wing torsion slope (dφ/dy in Ref. 1). Other comments are the same as for G.

The output of the FREEVI program automatically satisfies the deck setup for the TILDYN program, but for convenience the card setup for the wing mode shapes are repeated as follows:
1st card contains $G(1,1), G(1,2) \ldots \ldots \ldots G(1,6)$
Next card contains $G(1,7) \ldots \ldots \ldots G(1,NW+1)$
New card contains $Z(1,1) \ldots \ldots \ldots Z(1,6)$

\[ Z(1,7) \ldots \ldots \ldots Z(1,NW+1) \]

New card contains $DG(1,1) \ldots \ldots \ldots$

\[ DG(1,7) \ldots \ldots \ldots \]

New card contains $DZ(1,1) \ldots \ldots \ldots$

\[ DZ(1,7) \ldots \ldots \ldots \]

New card contains $WPHI(1,1) \ldots \ldots \ldots$

\[ WPHI(1,7) \ldots \ldots \ldots \]

New card contains $DWPHI(1,1) \ldots \ldots \ldots$

\[ DWPHI(1,7) \ldots \ldots \ldots \]

New card contains $G(2,1) \ldots \ldots \ldots G(2,6)$

\[ G(2,7) \]

\[ Z(2,1) \]

\[ Z(2,7) \]

\[ \ldots \]

New card contains $DWPHI(MW,1) \ldots \ldots \ldots$

Last card for the wing mode shape contains $DWPHI(MW,7) \ldots \ldots \ldots$ $DWPHI(MW,NW+1)$

The wing mode shapes occupy $NW$ cards where

\[ NW = \begin{cases} 
6MW[(NW+1)/6] & \text{if } (NW+1) \text{ is a multiple of } 6 \\
6MW[(NW+1)/6+1] & \text{if } (NW+1) \text{ is not a multiple of } 6 
\end{cases} \]

A number to specify the blade element quantity. The format is (12) and it is punched in the first two columns of the next card to the wing mode shapes.
EMS  A vector to describe the blade element size. The vector length is N and the element size, nondimensionalized by the rotor radius, should be input. The format is either E or F type (E10.0). Each vector component occupies ten columns, and the card number is N/8 if the N is a multiple of 8. Otherwise \([N/8+1]\) cards.

AMASS  A vector to describe the mass distribution of the blade. The vector length is \((N+1)\). The value should be the mass distribution (mass per unit length) expressed at the node. The format is either E or F type (E10.0). Each vector component occupies ten columns, and the card number is \((N+1)/8\) if \((N+1)\) is a multiple of 8. Otherwise \([(N+1)/8+1]\) cards.

THETN  A vector to describe the angle of twist of the blade. The vector length is \((N+1)\). The value should be the angle of twist at the node and positive nose up. The format is either E or F type (E10.0). Each vector component occupies ten columns, and the card number is \((N+1)/8\) if \((N+1)\) is a multiple of 8. Otherwise, \([(N+1)/8+1]\) cards.

COL  A number to express the collective pitch angle \(\theta_D\) in Ref. 1) defined from the performance (trim) calculation. The format is either E or F type (E10.0), and it occupies the first ten columns of the next card to THETN.

W  A matrix to describe the blade out-of-plane bending mode shape \((W_j\) in Ref. 1) at the node. The size of the matrix is \(MB \times (N+1)\) where \(MB\) is 2 if \(IDOF=9\) and 4 if \(IDOF=18\). The format is E or F type (E13.5) and \(W(1,1)\) expresses the out-of-plane deflection at the root node of the first mode. \(W(1,N+1)\) is the one at the tip node of the first mode. The data should be punched in order from the root node to the tip node value. One card can include 6 data.
A matrix to describe the blade in-plane bending mode shape
\( V_j \) in Ref. 1) at the node. Other comments are the same
as those for \( W \).

A matrix to describe the blade out-of-plane bending mode
shape slope \( \frac{dW_j}{dr} \) in Ref. 1) at the node. Other com-
ments are the same as those for \( W \).

A matrix to describe the blade in-plane bending mode shape
slope \( \frac{dV_j}{dr} \) in Ref. 1) at the node. Other comments are
the same as those for \( W \).

If the calculation case is the gimballed rotor (ITYPE=1), or auto-
rotational flight (ITYPE=1 and IFLT=1), the above blade-mode shapes
 correspond to the cyclic mode shapes.

The output of the FREEVI program automatically satisfies
the deck setup for the TILDYN program; however, for convenience,
the card setup for blade mode shapes is repeated below:

1st card contains \( W(1,1), W(1,2), \ldots \ldots W(1,6) \)
Next card contains \( W(1,7) \ldots \ldots W(1,N+1) \)
New card contains \( V(1,1) \ldots \ldots \)

\[ V(1,7) \]

\[ DW(1,1) \]

\[ DW(1,7) \]

\[ DV(1,1) \quad DV(1,6) \]

\[ DV(1,7) \quad DV(1,N+1) \]

\[ W(2,1) \]

\[ W(2,7) \]

\[ V(2,1) \]

\[ V(2,7) \]

\[ \vdots \]

\[ \vdots \]

\[ \vdots \]

\[ DV(MB,1) \]

29
Last card contains \( DV(MB,7) \) ........ \( DV(MB,N+1) \)

The blade mode shapes occupy \( n_B \) cards where

\[
 n_B = \begin{cases} 
 4MB[(N+1)/6] & \text{if } (N+1) \text{ is a multiple of 6} \\
 4MB[(N+1)/6+1] & \text{if } (N+1) \text{ is not a multiple of 6}
\end{cases}
\]

If the computer calculation case is the gimbaled rotor (ITYPE=1) or autorotational flight (ITYPE=1 and IFLT=1), the next five data cards as for the collective mode shapes of the blade should be added.

**BRAMO**  
A vector to express the blade collective mode eigenvalues and its length is 4. The values are the squared values of the natural frequencies \((\text{rad}^2/\text{sec}^2)\). If IDOF is set equal to 9, the latter two eigenvalue columns may have blanks. The format is either E or F type and each vector component occupies ten columns in order of the next card to the blade mode shapes.

**WCOL**  
A matrix to describe the blade collective out-of-plane bending mode shape \((W^O_j)\) in Ref. 1) at the node. The size and other comments are the same as those for \(W\).

**VCOL**  
A matrix to describe the blade collective inplane bending mode shape \((V^O_j)\) in Ref. 1) at the node. Other comments are the same as those for \(W\).

**DWCOL**  
A matrix to describe the blade collective out-of-plane mode shape slope \((dW^O_j/dr)\) in Ref. 1). Other comments are the same as those for \(W\).

**DVCOL**  
A matrix to describe the blade collective inplane mode shape slope \((dV^O_j/dr)\) in Ref. 1). Other comments are the same as those for \(W\).

The data deck setup is shown in Fig. 8, and an example problem data listing is given in Appendix B.
A few notes to supplement the input data definitions:

a) The maximum element number (N or NW) is 20

b) If rotor rotational direction is negative, RAMDA should be negative. However, THETN and COL are positive nose up as in the FREEVI program.

c) The mode shapes used in the TILDYN program should be defined as normal modes. Those definitions appear in Eq. 4.7 for the blade and in Eq. 4.12 for the wing in Ref. 1. If modes are not normalized in this way, the calculation will give wrong answers.

d) Output mode shapes from the FREEVI program sometimes include unnecessary mode shapes; for example, the rigid body mode for the collective mode shapes of the gimballed rotor if the user uses the clamped boundary condition for the flapping motion and the hinged boundary condition for the lagging motion to derive the collective mode for autorotational flight.

e) If there are several cases, the data may consist of several data sets. The computer execution continues until it finds the absence of data.

4.2 Output Features

In the output, the identifying title is printed first, as punched in by the user. All input data are printed out below.

After the mode shape listing, the matrices A, B, C, and D of the equations of motion in Eq. 2.3 are listed. When the degrees of freedom of the equations are 18 or 19, the first 9 columns of the coefficient matrix are printed out, followed by the latter 9 or 10 columns of the matrix.

If the user has chosen the frequency response analysis (IRES=1), the results of that calculation appear next. Each
response magnitude is showed corresponding to a nondimensional frequency. If IFRMAG is set equal to zero, the response magnitudes are based on the mode shapes normalized to rotor radius and wing semispan (refer to the explanation of IFRMAG in Section 4.1). In autorotation flight, the rigid-body rotation response is added to the basic form. It should be noted that the rigid-body rotation response is the rotational speed perturbation response, not the deflection response. Therefore, it is termed \( \dot{\nu}_R \).

The eigenvalue analysis consists of the eigenvalue and eigenvector listing. All eigenvalues of the system are printed in the form of complex values with damping ratios, including pairs of complex conjugate values. The eigenvectors corresponding to the eigenvalue are printed. The maximum absolute values of the eigenvector components are normalized to unity. Real parts and imaginary parts express the phase angle between each eigenvector component. If IFRMAG is set to zero, the eigenvectors are expressed based on the mode shapes normalized by rotor radius and wing semispan (refer to the explanation of IFRMAG in Subsection 4.1) as in the frequency response. On the other hand, if IFRMAG is set to unity, all are in length, except \( \nu_R \) (rigid-body rotation in autorotation flight). \( \nu_R \) is an angle, in radians. Therefore, some attention should be paid to comparing the role of each eigenvector.

Only one built-in message is furnished for this program. If an error occurs in the eigenvalue analysis, the message below is automatically printed out after the title "EIGENVALUES":
IERROR=XXXXX

The error code is shown as follows:

<table>
<thead>
<tr>
<th>Value of IERROR</th>
<th>Error Significance</th>
</tr>
</thead>
<tbody>
<tr>
<td>I</td>
<td>The calculation of the Ith eigenvalue failed to converge. Eigenvalues I+1 ... N should be correct.</td>
</tr>
<tr>
<td>-I</td>
<td>The calculation of one or more eigenvectors, including the Ith, failed to converge. All eigenvalues and non-zero eigenvectors are correct.</td>
</tr>
</tbody>
</table>

4.3 Example Problems

Sample problems are carried out here for the Bell and Boeing tilt rotor wings. The flight condition is normal level flight cruising (around 200 kt) at sea level. The detail data is shown in Table 3. The input data listing in Appendix B includes the auto-rotation flight case for the Bell model and the powered flight case for the Boeing model. However, the output listing of only the Bell autorotation flight case is shown as an example in Appendix B.
REFERENCES


<table>
<thead>
<tr>
<th>Boundary Conditions</th>
<th>Root</th>
<th>Tip</th>
<th>Output Deflections</th>
</tr>
</thead>
<tbody>
<tr>
<td>Wing</td>
<td>Clamped for all Deflections</td>
<td>Lumped Mass with Mass and Mass Moment of Inertia</td>
<td>Vertical Bending Chordwise Bending Torsion</td>
</tr>
<tr>
<td>Blade</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Powered</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Hingeless Rotor</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Clamped for all Deflections</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Free or Tip Mass if Necessary</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Gimballed Rotor</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Collective Mode</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
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<td></td>
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</tr>
<tr>
<td>Cyclic Mode</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Hinged for Flapping, Clamped for Lagging</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Autorotation</td>
<td></td>
<td></td>
<td></td>
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<tr>
<td>Hingeless Rotor</td>
<td></td>
<td></td>
<td></td>
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<tr>
<td>Collective Mode</td>
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<td></td>
<td></td>
</tr>
<tr>
<td>Clamped for Flapping, Hinged for Lagging</td>
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<td>Cyclic Mode</td>
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<tr>
<td>Clamped for All Deflections</td>
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<td>Gimballed Rotor</td>
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<td>Collective Mode</td>
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<td>Cyclic Mode</td>
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<td></td>
</tr>
<tr>
<td>Hinged for Flapping, Clamped for Lagging</td>
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<tr>
<td>Total Degrees of Freedom</td>
<td>Description</td>
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<tr>
<td><strong>Powered Flight</strong></td>
<td><strong>Autorotation Flight</strong></td>
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<tr>
<td>9 DOF</td>
<td>18 DOF</td>
<td>10 DOF</td>
<td>19 DOF</td>
</tr>
<tr>
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<td>( Q_{10} )</td>
<td>( Q_{10} )</td>
<td>( Q_{10} )</td>
</tr>
<tr>
<td>( Q_{1c} )</td>
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<td>( Q_{1c} )</td>
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<tr>
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<td>( Q_{ls} )</td>
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<td>( Q_{2c} )</td>
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<tr>
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<td>( Q_{2s} )</td>
<td>( Q_{2s} )</td>
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<td>( Q_{3c} )</td>
<td>( Q_{3c} )</td>
</tr>
<tr>
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<td>( Q_{3s} )</td>
<td>( Q_{3s} )</td>
<td>( Q_{3s} )</td>
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<td>( Q_{40} )</td>
<td>( Q_{40} )</td>
<td>( Q_{40} )</td>
</tr>
<tr>
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<td>( Q_{4c} )</td>
<td>( Q_{4c} )</td>
<td>( Q_{4c} )</td>
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<tr>
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<td>( Q_{4s} )</td>
<td>( Q_{4s} )</td>
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<tr>
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<td>( a_1 )</td>
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<td>( a_3 )</td>
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<tr>
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<td>( a_4 )</td>
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<tr>
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<tr>
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<td>( a_6 )</td>
<td>( a_6 )</td>
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<tr>
<td>( v_R )</td>
<td>( v_R )</td>
<td>( v_R )</td>
<td>( v_R )</td>
</tr>
</tbody>
</table>
TABLE 2 CONCLUDED

(b) Description of \(\{e\}\) in Eq. 2.3

<table>
<thead>
<tr>
<th>Symbol</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>(u_G/V)</td>
<td>Nondimensional Vertical Gust</td>
</tr>
<tr>
<td>(v_G/V)</td>
<td>Nondimensional Lateral Gust</td>
</tr>
<tr>
<td>(w_G/V)</td>
<td>Nondimensional Longitudinal Gust</td>
</tr>
<tr>
<td>(\theta_o)</td>
<td>Collective Pitch Control</td>
</tr>
<tr>
<td>(\theta_{lc})</td>
<td>Lateral Cyclic Pitch Control</td>
</tr>
<tr>
<td>(\theta_{ls})</td>
<td>Longitudinal Cyclic Pitch Control</td>
</tr>
</tbody>
</table>
TABLE 3

DESCRIPTION OF THE BELL AND THE BOEING PROPROROTOR DESIGNS IN POWERED FLIGHT CONSIDERED IN THIS REPORT

<table>
<thead>
<tr>
<th>ROTOR</th>
<th>BELL</th>
<th>BOEING</th>
</tr>
</thead>
<tbody>
<tr>
<td>Type</td>
<td>gimbaled, stiff inplane</td>
<td>cantilever, soft inplane</td>
</tr>
<tr>
<td>Number of blades, N</td>
<td>3</td>
<td>3</td>
</tr>
<tr>
<td>Radius, R</td>
<td>156 in.</td>
<td>150 in.</td>
</tr>
<tr>
<td>Chord, C_B</td>
<td>18.9 in.</td>
<td>14 in.</td>
</tr>
<tr>
<td>Lock number, γ</td>
<td>3.83</td>
<td>4.04</td>
</tr>
<tr>
<td>Solidity, σ</td>
<td>0.089</td>
<td>0.115</td>
</tr>
<tr>
<td>Pitch/flap coupling, δ_3</td>
<td>-15 deg.</td>
<td>0</td>
</tr>
<tr>
<td>Collective pitch, θ_D</td>
<td>1.25 deg.</td>
<td>1.0 deg.</td>
</tr>
<tr>
<td>Lift-curve slope, a</td>
<td>5.7</td>
<td>5.7</td>
</tr>
<tr>
<td>Drag Coefficient, C_Do</td>
<td>0.0065</td>
<td>0.0065</td>
</tr>
<tr>
<td>Rotor rotation direction, $\bar{\Omega}$</td>
<td>+1</td>
<td>-1</td>
</tr>
<tr>
<td>Inflow ratio,</td>
<td>0.7</td>
<td>-0.7</td>
</tr>
<tr>
<td>Rotational speed, $</td>
<td>\Omega</td>
<td>$</td>
</tr>
<tr>
<td>Blade Natural Frequencies</td>
<td></td>
<td></td>
</tr>
<tr>
<td>first, $\lambda_1/</td>
<td>\Omega</td>
<td>$</td>
</tr>
<tr>
<td>second, $\lambda_2/</td>
<td>\Omega</td>
<td>$</td>
</tr>
<tr>
<td>third, $\lambda_3/</td>
<td>\Omega</td>
<td>$</td>
</tr>
</tbody>
</table>
### TABLE 3. CONTINUED

<table>
<thead>
<tr>
<th>Rotor (cont'd)</th>
<th>Bell</th>
<th>Boeing</th>
</tr>
</thead>
<tbody>
<tr>
<td>fourth, $\lambda_4/</td>
<td>\Omega</td>
<td>$</td>
</tr>
<tr>
<td>Collective Natural Frequency</td>
<td></td>
<td></td>
</tr>
<tr>
<td>first, $\lambda_1^{(o)}/</td>
<td>\Omega</td>
<td>$</td>
</tr>
<tr>
<td>second, $\lambda_2^{(o)}/</td>
<td>\Omega</td>
<td>$</td>
</tr>
<tr>
<td>third, $\lambda_3^{(o)}/</td>
<td>\Omega</td>
<td>$</td>
</tr>
<tr>
<td>fourth $\lambda_4^{(o)}/</td>
<td>\Omega</td>
<td>$</td>
</tr>
<tr>
<td>Blade flapping inertia, $I_B$</td>
<td>105 slug-ft(^2)</td>
<td>150 slug-ft(^2)</td>
</tr>
<tr>
<td>One blade weight, $M_B$</td>
<td>133 lb</td>
<td>124 lb</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Wing</th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>Semispan, $L$</td>
<td>200 in.</td>
<td>200 in.</td>
</tr>
<tr>
<td>Chord, $C_w$</td>
<td>62.2 in.</td>
<td>62.2 in.</td>
</tr>
<tr>
<td>Mast height, $h$</td>
<td>51.3 in.</td>
<td>51.3 in.</td>
</tr>
<tr>
<td>Sweep</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>Dihedral</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>Lift-curve slope, $a_w$</td>
<td>5.7</td>
<td>5.7</td>
</tr>
<tr>
<td>Drag coefficient, $C_{D_w}$</td>
<td>0.004</td>
<td>0.004</td>
</tr>
<tr>
<td>Moment coefficient $C_{M_o}$</td>
<td>-0.005</td>
<td>-0.005</td>
</tr>
<tr>
<td>Aerodynamic center, $x/C_w$</td>
<td>0.01</td>
<td>0.01</td>
</tr>
<tr>
<td>Angle of attack, $\alpha_{w0}$</td>
<td>2.0 deg</td>
<td>2.0 deg</td>
</tr>
</tbody>
</table>

39
TABLE 3. CONCLUDED

WING (cont'd)

Natural Frequencies

<table>
<thead>
<tr>
<th>Order</th>
<th>Symbol</th>
<th>Bell</th>
<th>Boeing</th>
</tr>
</thead>
<tbody>
<tr>
<td>first</td>
<td>$\lambda_1$</td>
<td>$0.347/\text{rev}(2.65\text{Hz})$</td>
<td>$0.365/\text{rev}(2.35\text{Hz})$</td>
</tr>
<tr>
<td>second</td>
<td>$\lambda_2$</td>
<td>$0.622/\text{rev}(4.75\text{Hz})$</td>
<td>$0.653/\text{rev}(4.20\text{Hz})$</td>
</tr>
<tr>
<td>third</td>
<td>$\lambda_3$</td>
<td>$1.09/\text{rev}(8.32\text{Hz})$</td>
<td>$1.11/\text{rev}(7.14\text{Hz})$</td>
</tr>
<tr>
<td>fourth</td>
<td>$\lambda_4$</td>
<td>$2.37/\text{rev}(18.1\text{Hz})$</td>
<td>$2.47/\text{rev}(15.9\text{Hz})$</td>
</tr>
<tr>
<td>fifth</td>
<td>$\lambda_5$</td>
<td>$3.76/\text{rev}(28.7\text{Hz})$</td>
<td>$3.95/\text{rev}(25.4\text{Hz})$</td>
</tr>
<tr>
<td>sixth</td>
<td>$\lambda_6$</td>
<td>$10.6/\text{rev}(80.9\text{Hz})$</td>
<td>$12.5/\text{rev}(80.4\text{Hz})$</td>
</tr>
</tbody>
</table>

PYLON

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Bell</th>
<th>Boeing</th>
</tr>
</thead>
<tbody>
<tr>
<td>Weight, $M_p$</td>
<td>$1420 \text{ lb}$</td>
<td>$2000 \text{ lb}$</td>
</tr>
<tr>
<td>Yaw inertia, $I_{py}$</td>
<td>$164.8 \text{ slug-ft}^2$</td>
<td>$250.0 \text{ slug-ft}^2$</td>
</tr>
<tr>
<td>Pitch inertia, $I_{pp}$</td>
<td>$190.0 \text{ slug-ft}^2$</td>
<td>$250.0 \text{ slug-ft}^2$</td>
</tr>
<tr>
<td>Roll inertia, $I_{pr}$</td>
<td>$42.4 \text{ slug-ft}^2$</td>
<td>$30.0 \text{ slug-ft}^2$</td>
</tr>
</tbody>
</table>

FLIGHT CONDITION FOR CALCULATIONS, $\lambda = 0.7$

<table>
<thead>
<tr>
<th>Condition</th>
<th>Bell</th>
<th>Boeing</th>
</tr>
</thead>
<tbody>
<tr>
<td>Cruising speed, $V$</td>
<td>$250 \text{ kt}$</td>
<td>$218 \text{ kt}$</td>
</tr>
<tr>
<td>Cruising altitude</td>
<td>sea level</td>
<td>sea level</td>
</tr>
</tbody>
</table>
Entry

Input

Generate the Element Stiffness and Mass Matrices

Assemble the Global Stiffness and Mass Matrices

Constrain the Boundary Conditions

Assume the Mode Shape Values As an Initial Guest Values

Reduce the System Matrices to the Order of the Number of the Eigenvalues Required

FIG. 1 FLOW CHART OF FREEVI PROGRAM FOR BLADE AND WING OF NATURAL FREQUENCIES AND MODE SHAPES
Eigenvalues by Jacobi Method

Calculate the New Mode Shapes Based on the Eigenvalues

Accuracy

No

Make the New Mode Shape Values as the Guest Values

Yes

Print Out

End

FIG. 1 CONCLUDED
FIG. 2 FLOW CHART OF TILDYN PROGRAM FOR ANALYSIS OF TILT ROTOR AIRCRAFT DYNAMICS
Setup of the Equations of Motion

Autorotation Case

Add the Rigid Body Rotation Degrees of Freedom and Other Modification

Basic Degrees of Freedom 9 DOF

Shrink the Equations to 9 DOF (10 DOF for Autorotation)

FIG. 2 CONTINUED
FIG. 2 CONCLUDED
FIG. 3 COORDINATE SYSTEM FOR FREEVI PROGRAM

FIG. 4 FINITE ELEMENT REPRESENTATION WITH BEAM ELEMENTS
FIG. 5 DATA DECK SETUP FOR THE FREEVI PROGRAM
(a) Mass and Cross-Sectional Moment of Inertia Distribution

FIG. 6 STRUCTURAL CHARACTERISTICS OF THE WING
(b) Stiffness Distribution: Vertical Bending Stiffness $(EI_w)_B$, Chordwise Bending Stiffness $(EI_w)_C$, and Torsional Rigidity $GJ$

FIG. 6  CONCLUDED
FIG. 7 STRUCTURAL CHARACTERISTICS OF TWO PROPROROTOR BLADES

(a) Section Mass Distribution
(b) Section Flapwise Bending Stiffness Distribution

FIG. 7 CONTINUED
FIG. 7 CONTINUED

(c) Section Chordwise Bending Stiffness Distribution

10^6 lb-in^2

0  0.5  1.0

r/R

(BELL)

(BOEING)
(d) Angle of Twist

FIG. 7 CONCLUDED
FIG. 8 DATA DECK SETUP FOR THE TILDYN PROGRAM
FIG. 8 CONTINUED
FIG. 8 CONTINUED
BLADE COLLECTIVE MODE SHAPE DATA IS FURNISHED IF THE CASE IS AUTO-ROTATION FLIGHT (IFLT=1, ITYPE=1) OR GIMBALED ROTOR IN POWERED FLIGHT (IFLT=0, ITYPE=1).
APPENDIX A
PROGRAM LISTING

A.1 The FREEVI Program Listing
PROGRAM ROTOR
PART 1 ; PROGRAM FREEVI

PURPOSE
TO OBTAIN THE NATURAL FREQUENCIES AND MODE SHAPES
OF THE ROTOR BLADE AND WING OF THE TILT-ROTOR AIRCRAFT

DEVELOPED BY MASAHIRO YASUE
OF AEROELASTIC AND STRUCTURES RESEARCH LABORATORY
AUGUST 1974
ADDRESS ; 6LG 41-211
MASSACHUSETTS INSTITUTE OF TECHNOLOGY
CAMBRIDGE, MASS. 02139

IMPLICIT REAL*8(A-H,O-Z)
DIMENSION NDPE(20), NNODE(252), NOD(126), ICOL(126), INUM(126)
DIMENSION STK(1550), STM(1550), EK(78), EM(78), XLR(1200), X(1200)
DIMENSION Y(1200), U(126), EIG(9), LCH(9), RM(81), RK(81), RV(81)
DIMENSION SRM(81), SRK(81)
1
CALL TEICEN(NDPE,
           NOD, NNODE, ICOL, INUM, STK, STM, EK, EM,
           XLR, U, EIG, LCH, RM, RK, RV, SRM, SRK, X, Y)
GO TO 1
END
SUBROUTINE TEIGEN(NDPE, NOD, NNODE, ICOL, INUM, STK, STM, EK, EM, XLR, U, EIG, LCH, RM, RK, RV, SRM, SRK, X, Y)

TO CALCULATE THE NORMAL MODES AND FREQUENCIES

IMPLICIT REAL*8(A-H, I-Z)
COMMON /BNW/ ICASE , IGUEST
COMMON /HELP/ALPHAH
DIMENSION NDPE(1), NOD(1), NNODE(1), ICOL(1)
DIMENSION INUM(1), STK(1), STM(1), EK(1), EM(1), XLR(1)
DIMENSION U(1), EIG(1), LCH(1)
DIMENSION RM(1), RK(1), RV(1), SRK(1), SRM(1), X(1)
DIMENSION Y(1)
DIMENSION SQU(20), CYC(20)
CALL INPUT(IEQ, NDPE, NET, NDT, MNC, NNODE, NBU, INUM, ERR, NITR, M)
CALL MESH(NDPE, NET, NCT, NCDT, MNC, MN, NOD, NNODE, ICOL, INUM, NBU, INDEX)
IF(INDEX .EQ. 0) GO TO 99
CALL ASBV(STK, STM, IEQ, EK, EM, NDPE, NDT, NCDT, NNODE, MN, NET, INUM)
MA=M
N=NCDT
NP=NCDT*M
MM=M*M
CALL FAC(STK, N, NNDG, ICOL, INUM, U)
IF(NNDG .LT. 0) GO TO 99
DO 3 I=1,M
3 EIG(I)= .0
DO 74 K=1,M
II=(K-1)*N
IY=K*2-1
DO 74 I=1,N
IX=IY
IY=IY+2147483647+1
75 IY=IY+2147483647+1
76 YFL=IY
74 XLR(II+1)=YFL*0.46566136-9-0.5C+00
IF(IGUEST.EQ.0) GO TO 200
GO TO (210,220,230,240,220),ICASE
210 GO TO (310,320,330),IGUEST
C----W ONLY
31C IX=N/6
CO 301 K=1,M
II=NCDT*K-NCDT
XLR(II+1)=0.0D+00
CC 301 KK=1,IX
JJ=KK*6-5
XLR(II+JJ+2)=0.0D+00
XLR(II+JJ+4)=0.0D+00
XLR(II+JJ+5)=0.0D+00
301 XLR(II+JJ+6)=0.0D+00
GO TO 200
C----V ONLY
32C IX=N/6
CO 302 K=1,M
II=NCDT*K-NCDT
XLR(II+1)=0.0D+00
CC 302 KK=1,IX
JJ=KK*6-5
XLR(II+JJ+1)=0.0D+00
XLR(II+JJ+3)=0.0D+00
XLR(II+JJ+5)=0.0D+00
302 XLR(II+JJ+6)=0.0D+00
GO TO 200
C----PHI ONLY
33C IX=N/6
CO 303 K=1,M
II=NCDT*K-NCDT
CO 303 KK=1,IX
JJ=KK*6-5
DO 303 KKK=1,4
303 XLR(II+JJ+KKK)=0.3C+00
GO TO 200
220 GO TO (221, 222), IGuest
C-----W ONLY
221 IX=N/2
DO 201 K=1, M
II=N*K-N
DO 201 I=1, IX
201 XLR(II+2*IX)=0.000
GO TO 200
C-----V ONLY
222 IX=N/2
DO 202 K=1, M
II=K*N-N
DO 202 I=1, IX
202 XLR(II+2*IX)=0.000
GO TO 200
230 GO TO (231, 232), IGuest
C-----W ONLY
231 IX=N/2
DO 233 K=1, M
II=N*K-N
XLR(II+1)=0.000
DO 233 KK=1, IX
233 XLR(II+2*KK+1)=0.000
GO TO 200
C-----V ONLY
232 IX=N/2
DO 234 K=1, M
II=K*N-N
DO 234 KK=1, IX
234 XLR(II+2*KK)=0.000
GO TO 200
240 GO TO (241, 242), IGuest
C-----W ONLY
241 IX=N/2
DO 243 K=1, M
II=N*K-N
DO 243 KK=1,IX
243  XLR(II+2*KK+1)=0.0DO
GO TO 200
C------V ONLY
242  IX=N/2
DO 244 K=1,M
II=N*K-N
XLR(II+1)=0.0DO
DO 244 KK=1,IX
244  XLR(II+2*KK)=0.0DU
200  CONTINUE
IST=1
DO 21 KKK=1,NTR
IT=(IST-1)*N+1
DO 1 I=IT,NM
1  Y(I)=XLR(I)
CALL SOLZ(STK,Y,N,M-IST+1,ICOL,INUM,IST)
CC II K=IST,M
K1=K-1
II=(K-1)*N
XM=0.0
LCH;K)=0
DO 7 I=1,N
C=DAABS(Y(I)+I))
IF(D-XM)7,7,5
5  X*=D
LCH(K)=I
7  CONTINUE
IF(LCH(K) .EQ. 0) GO TO 99
E=Y(II+LCH(K))
E=1.0/E
CC II I=1,N
III=I+II
Y(III)=Y(III)*E
11  XLP(III)=XLR(III)*E
CALL MTRTR(M,N,RK,Y,XLR,IST)
DO 31 I=1,T,NM
31 X(I)=Y(I)
CALL MLLTZ(STM,X,U,N,M-IST+1,ICCL,INUM,IST)
CALL MTRTR(M,N,RM,Y,X,IST)
DO 39 I=1,MM
SRM(I)=RM(I)
39 SRK(I)=RK(I)
CALL DNROOT(M,RM,RK,U,RV)
DO 40 I=1,M
40 U(I)=U(I)-ALPHAH
WRITE(6,41) (U(I),I=1,M)
41 FORMAT(/2X,'EIGENVALUES=',/,2X,1GD13.5))
DO 22 I=IST,MA
IST=I
IF(DABS(EIG(I))/U(I)-1.0) GT. ERR) GO TO 23
22 CONTINUE
DC 504 I=1,M
SQU(I)=CSQR(DABS(U(I)))
CYC(I)=SCU(I)*0.5DO/3.141592DD
504 CONTINUE
WRITE(6,505)(SQU(I),I=1,M)
505 FORMAT(/5X,'RADIANS/SEC',/,2X,1GD13.5))
506 FORMAT(/5X,'HERTZ',/,2X,1GD13.5))
WRITE(6,506)(CYC(I),I=1,M)
DO 10 I=1,NCOT
DO 10 J=1,M
JJ=(J-1)XNCOT
XLR(I+JJ)=O.G
10 DO 10 K=1,M
XLR(I+JJ)=XLR(I+JJ)+Y(I+(K-1)*N)*RV((J-1)*M+K)
DO 15 I=1,M
I I=(I-1)X M
CO 15 J=1,M
JJ=(J-1)X M
IJ=JJ+I
PM(IJ) = 0.0
RK(IJ) = 0.0
DO 15 K = 1, M
KK = (K-1) * M
FM(IJ) = RK(IJ) + SRM(KK+1) * RV(JJ+K)
15 RK(IJ) = RK(IJ) + SRK(KK+1) * RV(JJ+K)
CALL MTRTR(M, M, SRM, RV, RM, 1)
CALL MTRTR(M, M, SKK, RV, RK, 1)
CD 42 I = 1, M
KK = M * [1 - M + I]
Y(I) = I / DSQR(R(SRM(KK)))
II = I * NCST - NCST
CD 42 J = 1, NCST
42 XLR(I + J) = XLR(I + J) * Y(I)
CC 17 I = 1, M
KK = 1 * M - M
CD 17 J = 1, I
E = Y(I) * Y(J)
IJ = KK + J
SRM(IJ) = E * SRM(IJ)
17 SRK(IJ) = E * SRK(IJ)
CALL OUTPUT(KKK, M, NCST, ND, NOD, NNODE, ERR, XLR, U, SRM, SRK)
GO TO 99
23 CD 25 I = 1, M
25 EIG(I) = U(I)
IF(IST.EQ.1) GO TO 45
IQ = IST - 1
CD 44 I = 1, IQ
II = (I - 1) * M
DO 44 J = 1, IQ
IJ = II + J
KK(IJ) = SRM(IJ)
44 RK(IJ) = SPK(IJ)
45 CONTINUE
DO 34 I = 1, N
CD 34 J = IST, M
JJ = (J-1)*N
XLR(I+JJ) = 0.0
DO 34 K = 1, M
34 XLR(I+JJ) = XLR(I+JJ) + X(I+(K-1)*N) * RV((J-1)*M*K)
21 CONTINUE
WRITE(6, 26) KKK
26 FORMAT(/2X, 'NO. OF ITERATION=', I4, 2X, 'NOT CONVERGED')
99 RETURN
END
SURROUNINE INPUT (IEQ,NDPE,NET,NDT,MNC,NODE,NBU,NRCU,ERP,NITR,N)

TO SUPPLY INPUT INFORMATION

DES COMMENTS AND DESCRIPTIONS

ICASE=1 WING CANTILEVER+CANTILEVER
ICASE=2 BLADE B.C. CANTILEVER+HINGE
ICASE=3 BLADE B.C. HINGE+CANTILEVER
ICASE=4 BLADE B.C. HINGE+HINGE
ICASE=5 BLADE B.C. HINGE+HINGE

IPUNCH=0 NO PUNCH OUTPUT
IPUNCH=1 PUNCH OUTPUT

IGUEST=0 COUPLED MODE SHAPES GENERATED
IGUEST=1 W DEFORMATION ONLY
IGUEST=2 V DEFORMATION ONLY
IGUEST=3 PHI DEFORMATION ONLY

-- CAUTION -- TO DERIVE UNGOUPLED MODES, COUPLING TERMS SHOULD BE
-- CAUTION -- SET AT ZERO.
-- CAUTION -- PR IN THE WING, RAMDA, COL, THETA IN THE BLADE

NET NO OF ELEMENTS
NITR = NO OF ITERATION ALLOWED
M = NO OF MODES WANTED

ERR ERROR TOLERANCE FOR ITERATION
OMEG ROTATION FREQ IN RAD / SEC
RAMDA = INFLOW RATIO
COL = COLLECTIVE PITCH ANGLE DETERMINED BY PERFORMANCE ANALYSIS
SPKR, SPKC = SPRING CONSTANT OF THE HINGED BLADE (BEAMWISE
A CHORDWISE)

ALPHA = HELPER TO AVOID THE SINGULARITY OF THE STIFFNESS MATRIX

EIBE = EI FOR SPANWISE BENDING
EICE GT FOR CORONWISE BENDING
THETAE=AMGLF OF TWIST
AMASE=MASS/UNIT LENGTH
ESE=ELEMENT SIZE

AMN = MASS OF NACELLE AND ALL BLADES OR TIP MASS IN CASE OF BLADES
PIP = POILING MOMENT OF INERTIA OF NACELLE
PIY = WAVING MOMENT OF INERTIA OF NACELLE,

HALF OF THAT OF ALL BLADES AND (H**2)*MASS OF ALL BLADES
PIP = PITCHING MOMENT OF INERTIA OF NACELLE,

HALF OF THAT OF ALL BLADES AND (H**2)*MASS OF ALL BLADES
PRW = MASS COUPLING OF WING DUE TO BLADES H*MASS OF BLADES

IF ICASE=1, NEXT THREE DATA GJ, PI, AND PI12 SHOULD BE ADDED.

GJ = TORSIONAL RIGIDITY
PI = MOMENT OF INERTIA FOR TORSION
PI12 = MASS COUPLING BETWEEN TORSION AND SPANWISE BENDING
POSITIVE IF C.G. IS AHEAD OF ELASTIC AXIS

NDPN= NO OF DEGREES OF FREEDOM PER NODE
NDPN= 4 FOR BLADE MODE
NDPN= 6 FOR WING MODE

COMMON /PUNCH/ IPUNCH
COMMON /BW/ ICASE, IGOUEST
COMMON/SIMPING/SPKR,SPKC
COMMON/HELP/ALPHAH
DOUBLE PRECISION ALPHAH
DIMENSION NDPF(1), NODE(1), NBUU(1)
DOUBLE PRECISION FRR
DIMENSION FIRE(20), EICE(20), THETAE(20), AMASE(20), ESE(20), TN(121)
DIMENSION GJ(20), PI(20), PI12 (20)
COMMON /ELEMI/ OMEG, FIRE, EICE, THETAE, AMASE, ESE, TN, GJ, PI, PI12, AMN,
1 PIP,PIY,PIP,PRW,RI,R,NETT
DIMENSION DES(20)
10 FORMAT (16F15)
1 FORMAT (8F10.6)
4 FORMAT (5E15.7)
149 FORMAT (20A4)
150 FORMAT (11)
1EQ=0
READ(5,149)(DES(I),I=1,20)
READ(5,150)ICASEF
READ(5,150)IPUN
READ(5,150)IGUE
READ (5,10)NFT,NITR,M
IF(ICASEF,50,1) GO TO 192
NIDPN=4
GO TO 193
102 NNPN=6
193 CONTINUE
NETT=NET
READ (5,11)ERP
READ (5,1)OMEG
READ (5,1)RAMDA
READ (5,1)COL
READ (5,1)SPK,SPKC
READ (5,1)ALPHAH
READ (5,4) (EIFE(I),I=1,NET)
READ (5,4) (ECIF(I),I=1,NET)
READ (5,1) (THETAE(I),I=1,NET)
READ (5,1) (AMASE(I),I=1,NET)
READ (5,1) (ESF(I),I=1,NET)
READ (5,1) AMMN,PIP,PIY,PIP,PRW
IF (NDPN,EQ.4) GO TO 100
READ (5,4) (GJ(I),I=1,NET)
READ (5,4) (PI(I),I=1,NET)
READ (5,4) (PI2(I),I=1,NET)
100 CONTINUE
191 WRITE(6,181)
192 FORMAT(//5X,45(1H*//)
193 GO TO (151,152,153,154,155),ICASE
194 WRITE(6,171)
195 FORMAT(9X,'BLADE',3X,'BEAM*CANTI',3X,'CHORD*CANTI')
196 GO TO 180
197 WRITE(6,172)
198 FORMAT(9X,'BLADE',3X,'BEAM*CANTI',3X,'CHORD*HINIF')
199 GO TO 180
200 CONTINUE
201 WRITE(6,182)(DES(I),I=1,20)
202 FORMAT(5X,45(1H*///5X,20A4///)
203 WRITE(6,9)
204 WRITE(6,647)IPUNCH,IGUEST
205 FORMAT(1X,'IPUNCH='',I1
206 WRITE(6,16)NDPN,NFT,NITP,M,EPR
207 WRITE(6,114)OMEG
208 FORMAT(6H OMFG=',F15.5)
209 WRITE(6,300)RAMDA
210 FORMAT(8H LAMADA=',F15.5)
211 WRITE(6,301)C01
212 FORMAT(8H COLLECTIVE PITCH=',F15.5)
213 WRITE(6,299)SPKR,SPKC
214 FORMAT(1X,'SPRING=',F15.5,F15.5)
215 WRITE(6,399)ALPHAH
216 FORMAT(1X,'ALPHAH=',D15.5)
217 WRITE(6,183)
218 FORMAT(1X,'--FLAPPING BENDING STIFFNESS--')
WRITE (6, 105) (EIBE(I), I=1, NET)
WRITE (6, 184)
184 FORMAT (1X, '---CHORDWISE BENDING STIFFNESS---')
WRITE (6, 105) (FICE(I), I=1, NET)
WRITE (6, 185)
185 FORMAT (1X, '---ANGLE OF TWIST---')
WRITE (6, 104) (THETAE(I), I=1, NET)
THE = ATAN (PAMDA**4.0/3.0) + COL.*SIGN (1.0, OMEG)
DO 302 I = 1, NET
302 THETA(I) = THETAE(I) * SIGN (1.0, OMEG) + THE
WRITE (6, 186)
186 FORMAT (1X, '---MASS DISTRIBUTION---')
WRITE (6, 104) (AMASE(I), I=1, NET)
WRITE (6, 188)
188 FORMAT (1X, '---ELEMENT SIZE---')
WRITE (6, 104) (ESE(I), I=1, NET)
WRITE (6, 187)
187 FORMAT (8X, 'TIP MASS', T19, 'ROLL INERTIA', T34, 'YAW INERTIA',
& ' T49, 'TILT INERTIA', T64, 'MASS COUPLING')
WRITE (6, 104) AMN, PIR, PIY, PIP, PIR
NN = NET + 1
104 FORMAT (8F15.5)
105 FORMAT (5X, 7F15.7)
IF (NPN .EQ. 4) GO TO 14
WRITE (6, 189)
189 FORMAT (1X, '---TORSIONAL RIGIDITY---')
WRITE (6, 105) (GJ(I), I=1, NET)
WRITE (6, 190)
190 FORMAT (1X, '---MOMENT OF INERTIA---')
WRITE (6, 105) (DI(I), I=1, NET)
WRITE (6, 191)
191 FORMAT (1X, '---MASS COUPLING ALONG SPAN---')
WRITE (6, 105) (DI2(I), I=1, NET)
9 FORMAT (/8H  *  *  /12H  INPUT  DATA  ///)  16
1 FORMAT (25H NO OF DEGRE PER NODE=, I3/
17H NO OF ELEMENTS=, I3/24H NO OF MAX ITER ALLOWED=, I3
2 /14H NO OF NODES=, 13/ 6H ERR=, F15.5)

14 NODE=NDPN+NDPN
NDT=NFT*NDPN+NDPN
MNC=NDT*NODE-(NODE*NODE-NDE)/2
DC 5 I=1,NFT
NODE(1)=NDE
NII=NODE*1-NDE
NDD=NDPN*I-NDPN
NODE(NII)+1=NDD+1
NODE(NII)+5=NDD+2
NODE(NII)+2=NDD+3
NODE(NII)+6=NDD+4
NODE(NII)+3=NDD+NDPN+1
NODE(NII)+7=NDD+NDPN+2
NODE(NII)+4=NDD+NDPN+3
NODE(NII)+8=NDD+NDPN+4
IF (NDPN EQ 4) GO TO 5
NODE(NII)+9=NDD+5
NODE(NII)+10=NDD+6
NODE(NII)+11=NDD+NDPN+5
NODE(NII)+12=NDD+NDPN+6
CONTINUE
GO TO (521,542,553,564,575),CASE

501 NB U=NDPN-1
GO TO 506
502 NBU=4
506 DC 6 I=1,NBU
6 NBCU(I)=1
GO TO 507
503 NBU=3
NBCU(I)=1
NBCU(2)=2
NBCU(3)=3
GO TO 507
504 NBU=3
NBCU(I)=1
505  NPU=2
      NBCU(1)=1
      NBCU(2)=2
507  CONTINUE
R=0
   DO 2  I=1,NET
2    R=R+FSE(I)
    TN(NET+I)=AMN*R*OMEG*OMEG
   DO 3  I=1,NET
3    II=NET-I+1
    P=R-FSE(II)
   TN(II)=TN(II+1)+AMASE(II)*(R+.5*FSE(II))*FSE(II)*OMEG*OMEG
   WRITE (6,15)
   WRITE(6,104) (TN(I), I=1,NN)
15  FORMAT('/// TENSION DUE TO CENTRIF FORC')
R=0.
   BI=0.
   RM=0
   DO 11  I=1,NET
11    BM=BM+AMASE(I)*FSE(I)
    PR=R+FSE(I)
    BI=BI+AMASE(I)*(PR**3-R**3)*.33333333
   R=RR
    BM=BM+AMN
    BI=BI+AMN*R*P
   WRITE (6,12) BM,BI,R
12  FORMAT('/// MASS =',E13.5/ ' MOMENT OF INERTIA AT ROOT=',E13.5/ 
1 ' TOTAL LENGTH OF THE BEAM=',E13.5)
RETURN
END
SUBROUTINE ELEMK (EKT, EMT, NDE, NE)

C TO CONTROL THE GENERATION OF ELEMENT STIFFNESS AND MASS
C MATRICES
C
C ACF=8 FOR PLATE MODE
C ACF=12 FOR WING MODE
C COMMON/SPRING/SPKR,SPKC
C COMMON/HELP/ALPHAP
C DOUBLE PRECISION EKT,EMT
C DIMENSION EKC(4,4), ETC(4,4), EMC(4,4), EKT(1), EMT(1)
C DIMENSION EIE(20), EICE(20), THETAE(20), AMASE(20), ESE(20), TN(21)
C DIMENSION GJ(20), PI2(20), PI12(20)
C COMMON /ELEMT/ OMEX,EIE,EICE,THETAE,AMASE,ESE,TN,GJ,PI,PI12,AMN,
1 PIY,P,PI,PBW,SM,BI,R,NETT
C ET=NETT
C EJE=EJE(N)
C EIC=EICE(N)
C THETA=THETAE(N)
C AMAS=AMASE(N)
C ES=ESE(N)
C T=(TN(N)+TN(N+1))*5
C ESS=ES*ES
C IF (NDE .EQ. 8) GO TO 9
C GJE=GJ(N)/ES
C P1E=PI(N) *ES
C P112E=PI12(N) *ES
C EKC(1,1)=12.
C EKC(2,1)=6.*ES
C EKC(3,1)=-12.
C EKC(4,1)=0.*ES
C EKC(2,2)=4.*ESS
C EKC(3,2)=-6.*ES
C EKC(4,2)=2.*ESS
C EKC(3,3)=12.
EKC(4,3) = -6.0*ESS
EKC(4,4) = 4.0*ESS
ETC(1,1) = 1.2
ETC(2,1) = 1.1*ES
ETC(3,1) = -1.2
ETC(4,1) = -1.1*ES
ETC(2,2) = 13333333*ESS
ETC(3,2) = -1.1*ES
ETC(4,2) = -0.0333333*ESS
ETC(3,3) = 1.2
ETC(4,3) = -1.1*ES
ETC(4,4) = 13333333*ESS
EMC(1,1) = 156.420
EMC(2,1) = 22.420*ES
EMC(3,1) = 54.420
EMC(4,1) = -13.420*ES
EMC(2,2) = 4.420*ESS
EMC(3,2) = -EMC(4,1)
EMC(4,2) = -3.420*ESS
EMC(3,3) = EMC(1,1)
EMC(4,3) = -EMC(2,1)
EMC(4,4) = EMC(2,2)
CG 10 I=1,4
CG 10 J=1,4
EMC(J,J) = EMC(I,J)
EKC(J,J) = EKC(I,J)
ESSS = ESS*ES
S1 = SIN(THETA)
CC = CCS(THETA)
B = (C1R*C0*CO + E1C*S1*S2)/ESSS
C = (E1C*CC*C0 + E1B*S1*S2)/ESSS
BC = (E1C-E1B)*S1*CO/ESSS
1E = T/ES
AM = OMEG*OMEG*AMAS*ES
AMA = AMAS*ES
CG 5 I=1,4
I1=(I1*I1-1)/2
I4=(I4+1)*(I4+3)/2
DC 1 J=1, I
EKT(I1+J)= B*FKC(I1,J)+TE*ETC(I1,J)
EMT(I1+J)= AMAE*EMC(I1,J)
EKT(I14+J4)= C*EKC(I1,J) + TE*ETC(I1,J) - AM*EMC(I1,J)
1
EMT(I14+J4)= AMAE*EMC(I1,J)
CC 2 J=1, 4
EMT(I14+J4)=0.
2
EKT(I14+J)=BC*EKC(I1,J)
IF (NDE .EQ. 8) GO TO 5
I6=(I6+2)*(I6+7)/2
CC 3 J=1, I
EKT(I8+J8)=GJC*ETC(I1,J)
3
EMT(I8+J8)= PIE *EMC(I1,J)
EC 4 J=1, 4
EKT(I8+J )=C.
EKT(I8+J4)=C.
EMT(I8+J4)=C.
4
EMT(I8+J)=PI12E*EMC(I1,J)
5
CONTINUE
IF(NE .LE. NET) GO TO 100
EMT(6)= EMT(6)+AMN
EMT(28)= EMT(28)+AMN
IF(NCE.EQ.8) GO TO 100
EMT(10)= EMT(10)+ PIR
EMT(36)= EMT(36)+ PIY
EMT(66)= EMT(66)+PIP
EMT(58)= EMT(58)+PBK
100
IF(NE.GT.1) GO TO 101
EKT(3)=EKT(3)+SPKB
EKT(21)= EKT(21)+SPKC
101
CC 102 I=1,36
102
EKT(1)=EKT(1)+EMT(I)*ALPHA
RETURN
END
SUBROUTINE MESH(NDPE,NET,ADT,NCCT,MNC,MN, NOD,NNODE,ICOL,INUM, ANOD, INDEX)
C
C TO CALCULATE MESH INFORMATION OF THE FINITE ELEMENT
C
DIMENSION NOD(1),ANODE(1),ICOL(1),INUM(1), NDPE(1)

DO 99 I=1,ADT
99 NOD(I)=1
NCCT=NDT
GO TO 98
10 DO 22 I=1,NBU
22 CONTINUE
21 CONTINUE
101 DO 1 I=1,NCCT
1 NOD(I)=1
 DO 2 I=1,NBU
2 NOD(I)=0
11=INUM(I)
2 NOD(I1)=0
 DO 3 I=2,NCCT
3 NOD(I1)=NCCT(I1)+NOD(I1-1)
NCCT=NCCT-NUD
11=INUM(I)
2 NOD(I1)=0
11=INUM(I)
4 NOD(I1)=NCCT+1
98 CONTINUE

END
II=0
DO 5 I=1,NET
JJ=NDPE(I)
DO 54 J=1,JJ
54 ICCL(J)=NNODE(J+II)
DO 55 J=1,JJ
JJ=ICCL(J)
55 NNODE(J+II)=NJCE(JJ)
5 II=II+JJ
DO 6 I=1,NCDT
6 ICCL(I)=I
II=J
DO 88 I=1,NET
JJ=NDPF(I)
IMIN=NDT
DO 7 J=1,JJ
IN=NNODE(J+II)
7 IF(IN .LT. IMIN) IMIN=IN
DO 8 J=1,JJ
ID=NNODE(J+II)
8 IF(ICCL(ID) .GT. IMIN) ICCL(ID)=IMIN
II=II+JJ
9 INUM(I)=0
DO 9 I=2,NCDT
9 INUM(I)=INUM(I-1)+I-ICCL(I)
MN=INUM(NCDT)+NCDT
WRITE(6,16) MN,MNC
16 FORMAT(72X,'MAX. SIZE OF STF IS',I6,5X,'SPECIFIED SIZE IS ',I6)
INDEX=1
IF(MNC .LT. MN) INDEX=-1
RETURN
END
SUBROUTINE ASBV(STK, STM, IEQ, EK, EM, NDE, NDT, NCDT, NNODE, MN, NET, INUM)

C TO ASSEMBLE AND CONSTRAIN BOUNDARY CONDITIONS
C
IMPLICIT REAL*8(A-H, O-Z)
DIMENSION STK(1), STM(1), EK(1), EM(1), NDE(1), NNODE(1), INUM(1)

ID = NCDT + 1
DO 1 I = 1, MN
  STK(I) = 0.0
  I1 = 0
  DO 15 N = 1, NET
    JJ = NDE(N)
    IF (IEQ .EQ. J) GO TO 3
    IF (N .GT. 1) GO TO 8
  3 CALL FLEMK(EK, EM, JJ, N)
  8 DO 14 I = 1, JJ
    KI = (I*1-I)/2
    KNA = NNODE(I + I)
    IF (KNA .GE. ID) GO TO 14
    DO 13 J = 1, I
      KNA = NNODE(I + J)
      IF (KNA .GE. ID) GO TO 13
      KA = INUM(KMA) + KNA
      IF (KNA .GT. KMA) KA = INUM(KNA) + KMA
    STK(KA) = STK(KA) + FK(KI + J)
    STM(KA) = STM(KA) + EM(KI + J)
  13 CONTINUE
  14 CONTINUE
  15 I1 = JJ + 1
  RETURN
END
SUBROUTINE FAC(STF,NDT,NNDG,ICOL,NUM,U)
C FACTORING A SYMMETRIC MATRIX INTO LDL*
C
IMPLICIT REAL*8(A-H,O-Z)
DIMENSION STF(1),ICOL(1),NUM(1),U(1)
NNDG=1
IF(STF(I)) 2,1,3
1 IZR=1
99 WRITE(6,10C) IZR
1 N NOD(1/2X,'THE',14,'TH DIAG. AFTER FACT.=0.0,INCOMPLETE FACT. '))
NNDG=-1
RETURN
2 NNDG=1
3 IF(NDT.LT.2) GC TC 11
DO 10 IR=2,NDT
II=ICOL(IR)
IF(II.EQ.IR) GC TC 11
JR=NUM(IR)
IE=IR-1
DO 5 IC=II,IE
IMAX=II
IF(II.LT.ICCL(IC)) IMAX=ICCL(IC)
JE=IC-1
SUM=STF(JR+IC)
IF(JE.LT.IMAX) GO TO 55
JC=NUM(IC)
DO 4 J=IMAX,JE
4 SUM=SUM-L(J)*STF(JC+J)
55 U(IC)=SUM
5 STF(JR+IC)=SUM/STF(NUM(IC)+IC)
JJ=JR+1R
DO 6 J=II,IE
6 STF(JJ)=STF(JJ)-L(J)*STF(JP+J)
IF(STF(JJ)) 1,7,10
7 1ZR=IR

FACT0001
FACT0002
FACT0003
FACT0004
FACT0005
FACT0006
FACT0007
FACT0008
FACT0009
FACT0010
FACT0011
FACT0012
FACT0013
FACT0014
FACT0015
FACT0016
FACT0017
FACT0018
FACT0019
FACT0020
FACT0021
FACT0022
FACT0023
FACT0024
FACT0025
FACT0026
FACT0027
FACT0028
FACT0029
FACT0030
FACT0031
FACT0032
FACT0033
FACT0034
FACT0035
FACT0036
GO TO 99
8 NNDG=NNDG+1
10 CONTINUE
11 WRITE(6,101) NNDG
101 FORMAT(12X,'NO. OF NEGATIVE DIAGS.=I4,5X,'FACT. COMPLETED')
RETURN
END
SUBROUTINE MTRTR(M,N,R*,XLR,X,IST)
C
MATRIX MULTIPLICATION
C
IMPLICIT REAL*8(A-H,O-Z)
DIMENSION RM(1),XLR(1),X(1)
DO 2 I=IST,M
II=(I-1)*M
IJ=(I-1)*M
DO 2 J=1,1
JJ=(J-1)*N
RM(IJ+J)=C*O
DO 2 K=1,N
2 RM(IJ+J)=RM(IJ+J)+XLR(I1+K)*X(JJ+K)
DO 3 I=IST,M
JJ=(J-1)*M
DO 3 J=1,1
3 RM((J-1)*M+I)=RM(JJ+J)
RETURN
END
SUBROUTINE MULTZ(STF,X,Y,NDT,M,ICCL,NUM,MM)

MATRIX MULTIPLICATION

IMPLICIT REAL*8(A-H,O-Z)
DIMENSION STF(1),X(1),Y(1),ICCL(1),NUM(1)
DO 1 J=1,NDT
1 Y(I)=0
MM=M+MM-1
DO 4 I=MM,MM
II=(I-1)*NDT
DO 3 IR=1,NDT
IS=NUM(IR)
IC=ICCL(IR)
IF=IR-1
IF(IC.GT.IE) GC TC 3
DO 2 J=IC,IE
S=STF(IS+J)
Y(IR)=Y(IR)+S*X(I+J)
2 Y(J)=Y(J)+S*X(I+IP)
3 Y(IP)=Y(IP)+STF(IS+IP)*X(I+IR)
DO 4 J=1,NDT
X(I+J)=Y(J)
4 Y(J)=0
RETURN
END
SUBROUTINE SOLZ(STF,U,NDT,M,ICOL,INUM,MM)
C
C Solve (DLT)(U)=U for given U of M vectors of length NDT
C
IMPLICIT REAL*8(A-H,O-Z)
DIMENSION STF(1),U(1),ICOL(1),INUM(1)
MM=M+MM-1
IF(NDT.LT.2) GO TO 3
DO 2 IR=2,NDT
JI=ICOL(IR)
JF=IR-1
IF(JJ.GT.JE) GO TO 2
DO 1 I=MM,MMM
II=(I-1)*NCT
IS=II+IR
DO 1 J=JI,JE
1 U(IS)=U(IS)-STF(INUM(IR)+J)*U(II+J)
2 CONTINUE
3 DC 4 I=MM,MMM
II=(I-1)*NCT
DO 4 IR=1,NDT
4 U(II+IR)=U(II+IR)/STF(INUM(IR)+IR)
IF(NDT.LT.2) GO TO 7
DO 6 IK=2,NDT
IR=NDT-IK+2
JI=ICOL(IR)
JE=IR-1
IF(JJ.GT.JE) GO TO 6
DO 5 I=MM,MMM
II=(I-1)*NCT
IS=II+IR
DO 5 J=JI,JE
5 U(II+J)=U(II+J)-STF(INUM(IP)+J)*U(IS)
6 CONTINUE
7 KRETURN
END
SUBROUTINE DNRC1T(M,A,N,XL,X)

C EIGENVALUE ANALYSIS ROUTINE

DIMENSION A(1),B(1),XL(1),X(1)
DOUBLE PRECISION A,B,XL,X,SUM
K=1
DO 100 J=2,M
N=M*(J-1)
DO 100 I=1,J
L=L+1
K=K+1
100 B(K)=B(L)
MV=0
CALL EIGEN (B,X,M,MV)
L=0
DO 110 J=1,M
L=L+J
110 XL(J)=1.0/DSQRT(CABS(B(L)))
K=J
DO 115 J=1,M
DO 115 I=1,M
K=K+1
115 B(K)=X(K)*XL(J)
DO 120 I=1,M
N2=0
DO 120 J=1,M
N1=M*(J-1)
L=M*(J-1)+1
X(L)=J.*C
DO 120 K=1,M
N1=N1+1
N2=N2+1
120 XL(L)=X(L)+A(N1)*A(N2)
L=0
DO 130 J=1,M
DO 130 I = 1, J
N1 = I - M
N2 = M * (J - 1)
L = L + 1
A(L) = C * C
DO 130 K = 1, M
N1 = N1 + M
N2 = N2 + 1
130 A(L) = A(L) + X(N1) * B(N2)
CALL EIGEN (A, X, M, MV)
L = 0
DO 140 I = 1, M
N2 = C
DC 150 J = L, M
N1 = I - M
L = M - (J - 1) + 1
A(L) = C * C
DO 150 K = 1, M
N1 = N1 + M
N2 = N2 + 1
150 A(L) = A(L) + B(N1) * X(N2)
L = 0
K = 0
DO 180 J = 1, M
SUMV = 0
DO 170 I = 1, M
L = L + 1
170 SUMV = SUMV + A(L) * A(L)
175 SUMV = SQRT(SUMV)
DO 180 I = 1, M
K = K + 1
180 X(K) = A(K) / SUMV
RETURN
END
SUBROUTINE EIGEN(A,R,N,MV)
C EIGENVALUE ANALYSIS ROUTINE NEEDED IN DNROOT
C
DIMENSION A(1),R(1)
DOUBLE PRECISION A,R,ANORM,ANRMX,THR,X,Y,SINX,SINX2,COSX,
1 COSX2,SINCS,RANGE
5 RANGE=1.0*10-12
10 IQ=-N
20 DO J=1,N
30 IQ=IQ+N
40 DO I=1,N
50 IJ=IQ+I
60 P(IJ)=C.0
70 IF(IJ) 20,25,10
80 R(IJ)=1.0
90 CONTINUE
100 CONTINUE
110 ANORM=0.0
200 DO 35 J=1,N
300 DO 35 I=1,N
400 IF(I-J) 30,35,30
500 IA=I+(J-J-J)/2
600 ANORM=ANORM+A(I)*A(I)
700 CONTINUE
800 IF(ANORM) 165,165,40
900 ANORM=1.414*DSQRT(ANORM)
1000 ANRMX=ANORM*RANGE/FLOAT(N)
1100 INO=0
1200 THR=ANORM
1300 THR=THR/FLOAT(N)
1400 L=1
1500 M=L+1
1600 MQ=(M*M-M)/2
1700 LQ=(L*L-L)/2
1800 LM=L+MQ
IF (CARS(A(LM))=THR) 130,65,65
IND=1
LL=L+LQ
MM=M+MQ
X=0.5/(A(LL)-A(MM))
Y=-A(LM)/DSQRT(A(LM)*A(LM)+X*X)
IF (X) 70,75,75
70 Y=-Y
SINX=Y/DSQRT(2.0*(1.0+DSQRT(1.0-Y*Y)))
SINX2=SINX*SINX
COSX=DSQRT((1.0-SINX2))
CCSX2=COSX*COSX
SINCS=SIANX*COSX
ILQ=N*(L-1)
IMQ=N*(M-1)
DC 125 I=1,N
IQ=(I+I-1)/2
IF (I-L) 80,115,80
90 IF (I-M) 85,115,90
85 IM=I+MQ
GO TO 95
95 IM=I+IQ
45 IF (I-L) 100,135,105
100 LI=L+LQ
GO TO 110
105 LI=L+IQ
110 X=A(IL)*COSX-A(IM)*SINX
A(IM)=A(IL)*SINX+A(IM)*COSX
A(IL)=X
115 IF (MV-1) 120,125,120
120 ILK=ILQ+I
IMR=IMQ+I
X=I(ILR)*CCSX-F(IMR)*SINX
R(IMR)=R(ILR)*SINX+F(IMR)*COSX
R(ILR)=X
125 CONTINUE
\[ X = 2 \cdot 0 \cdot A(\text{LM}) \cdot \sin CS \]
\[ Y = A(\text{LL}) \cdot C\cos X2 + A(MM) \cdot \sin X2 - X \]
\[ X = A(\text{LL}) \cdot \sin X2 + A(MM) \cdot C\cos X2 + X \]
\[ A(\text{LM}) = (A(\text{LL}) - A(MM)) \cdot \sin CS + A(\text{LM}) \cdot (\cos X2 - \sin X2) \]
\[ A(\text{LL}) = Y \]
\[ A(\text{MM}) = X \]

130 IF (M-N) 135, 14C, 135
135 M=M+1
G0. TO 60.
140 IF (L-(N-L)) 145, 15C, 145
145 L=L+1
G0. TO 45
150 IF (IND-L) 160, 155, 160
155 IND=0
G0. 10. 50.
160 IF (THP-AMX) 165, 165, 45
165 IC=N
G3. 135 1=I,N
10=IQ+N
L=1+(I-1)/2
JW=I*(I-2)
J=185 1=I,N
JO=JQ+N
MM=J+(J-J)/2
1F (A(\text{LL}) - A(MM)) 17C, 185, 185
170 X=A(\text{LL})
A(\text{LL})=A(MM)
A(MM)=X
1F (MV-1) 175, 185, 175
175 D0. 185 K=1,N
ILR=IC+K
IMR=JO+K
X=R(ILR)
P(\text{ILR})=P(IMR)
130 R(IMR)=X
185 CONTINUE
P'T, TURN
FNS
SUBROUTINE OUTPUT(KKK, M, NCDT, NDT, NOD, NNODE, EPR, XLR, U, SRM, SRK)

COMMON /PUNCH/ IPUNCH
COMMON /ICASE, IGUEST /
DOUBLE PRECISION XLR, SRM, SRK, U, ERR
DIMENSION XLR(1), U(1), SRM(1), SRK(1)
DIMENSION NOD(1), NNODE(1)
DIMENSION XXLF(15, 120)

IDEBUG = 0
WRITE(6, 24) KKK, ERR
24 FORMAT(/2X, 'NO. OF ITERATION=', I4, 2X, 'CONVERGED WITHIN', C13.5)
IF(IDEBUG.EQ.0) GO TO 15
WRITE(6, 12)
12 FORMAT(/2X, 'EIGENVECTORS=', /)
DO 14 I = 1, M
II = (I-1)*NCDT
14 WRITE(6, 13) (XLR(I+J), J = 1, NCDT)
13 FORMAT(/, (2X, 10D13.5))
CONTINUE
WRITE(6, 20)
DO 18 I = 1, M
KK = I*M-M
18 WRITE(6, 16) (SRM(J+KK), J = 1, I)
WRITE(6, 21)
DO 19 I = 1, M
KK = I*M-M
19 WRITE(6, 16) (SRM(J+KK), J = 1, I)
16 FORMAT(/, (2X, 10D13.5))
20 FORMAT(/, 'REDUCED MASS MATRIX')
21 FORMAT(/, 'REDUCED STIF MATRIX')
DO 200 I = 1, M
DO 201 J = 1, NBU

XXLR(I,J)=0.0
201 CONTINUE
DO 202 J=1,NCDT
202 XXLR(I,NBU+J)=XLR((I-1)*NCDT+J)
100 CONTINUE
GO TO 205
102 DO 203 I=1,M
DO 206 J=1,NBU
206 XXLR(I,J)=0.0
XXLR(I,3)=XLR((I-1)*NCDT+1)
DO204 J=2,NCDT
204 XXLR(I,J+NBU)=XLR((I-1)*NCDT+J)
203 CONTINUE
205 CONTINUE
IF(ICASE.EQ.1) GO TO 333
NOM=4
NODE=NDT/NOM
WRITE(6,350)
350 FORMAT(///1X,'***** BLADE MODE SHAPES *****')
DO 351 I=1,M
WRITE(6,450C)I
450 FORMAT(///1X,'I=',I,12//)
WRITE(6,49GC)I
490 FORMAT(T5,'K',T13,'W(I,J)',T33,'V(I,J)',T53,'DH(I,J)',T73, &
   'OV(I,J)')
DO351 K=1,NODE
WRITE(6,352) K,(XXLR(:,NOM*(K-1)+J),J=1,NOM)
352 FORMAT((1X,14,E(5X,E15.7)))
351 CONTINUE
GO TO 360
333 CONTINUE
NOM=6
NODE=NDT/NOM
WRITE(6,353)
353 FORMAT(///1X,'***** WING MODE SHAPES *****')
DO 354 I=1,M
WRITE(6,45(L,1))
WRITE(6,4901)
4901 FORMAT(T5,'K',T12,'W(I,J)',T33,'V(I,J)',T53,'DW(I,J)',T73,
& 'DV(I,J)',T53,'PHI(I,J)',T113,'DPHI(I,J)')
DO 355 K=1,NODE
WRITE(6,352) K,(XXLR(I,NOM*(K-1)+J),J=1,NOM)
355 CONTINUE
354 CONTINUE
360 CONTINUE
IF(IFUNCH.EQ.C) GO TO 370
DO 359 I=1,M
DO 358 K=1,NOM
WRITE(7,357) (XXLR(I,NOM*(J-1)+K),J=1,NODE)
357 FORMAT(6E13.5)
358 CONTINUE
359 CONTINUE
370 CONTINUE
WRITE(6,371)
371 FORMAT(1H1)
RETURN
END
A.2 The TILDYN Program Listing
PROGRAM RKCHJ
PART 2; PROGRAM TILCYN

***********

PURPOSE
To analyze the Tilt-Rotor Dynamic System by means of frequency response and eigenvalues in powered and autorotation flight.

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MAIN PROGRAM

TJ DEFINE THE SEQUENCE OF THE PROGRAM

COMMON/DOF18,BAY(19,19),CCY(19,19),CBY(19,19)
DIMENSION CCYST(6),DCZ(19)
COMMON /PARAM/ ITYPE,IFLT
CONTINUE
5001 FORMAT(1H1)
CALL INPUT(CGST,IDOBI,IRES,IEIEN)
CALL INTPL
WRITE(6,5001)
CALL AERODT
CALL ORDINT
WRITE(6,5001)
CALL AINER
CALL AEROMT
CALL EQMTX(IDOF)
IF(IFLT.EQ.C) GO TO 400
CALL AUTO(IDOF)

400 CONTINUE
IDIM=IDOF+IFLT
IF (IFLT.EQ.0) GO TO 200
WRITE(6,5001)
CALL GUSTCO(GGUST,DDY,IDIM,DDZ)
CALL FQORFS(INIM,AAY,BBY,CCY,CDZ,IFLT,IDOF)

200 CONTINUE
IF (IEIGEN.EQ.0) GO TO 1000
WRITE(6,5001)
CALL EIGEN(IDIM,AAY,BBY,CCY,CCY,IDOF)

1000 CONTINUE
WRITE(6,5001)
GO TO 1
END
BLOCK DATA

C

TO INITIALIZE THE COEFFICIENTS OF GAUSSIAN QUADRATURE
C

COMMON /AREA2/NPT,XXX(20),A(20)
DATA NPT/11/
DATA A(1),A(2),A(3),A(4),A(5),A(6)/0.055668,
A 0.125580, 0.186290, 0.233193, 0.262804, 0.272925 /
END
SUBROUTINE INITIL

C INITIALIZATION OF THE MATRICES

COMMON/DOF13/DAV(19,19),BBY(19,19),CCY(19,19),DDY(19,6)
COMMON/INERTI/TIIT(4,6,3),TTCTJ(4,6,3),AMJT(4,3,6),CJT(4,3,6)
COMMON/APR/WGUST(6,6),DAMX(6,6),AMX(6,6),DQ(4,6,3),Q(4,6,3)
COMMON/WINGAR/TSCS(20,6,6),TSAS(20,6,6),TSAG(20,6,3)

DO 10 I=1,4
DO 10 J=1,6
DO 10 K=1,3
TTMT(I,J,K)=0.0
TTCTJ(I,J,K)=0.0
AMJT(I,K,J)=0.0
CJT(I,K,J)=0.0
DG(I,J,K)=0.0
G(I,J,K)=0.0
DHMAX(I,K,J)=0.0
HMAX(I,K,J)=0.0
1 CONTINUE
DO 11 I=1,6
DO 11 J=1,6
WGUST(I,J)=0.0
DAMX(I,J)=0.0
AMX(I,J)=0.0
DO 11 K=1,20
TSCS(K,I,J)=0.0
TSAS(K,I,J)=0.0
11 CONTINUE
DO 12 I=1,20
DO 12 J=1,6
DO 12 K=1,3
TSAG(I,J,K)=0.0
12 CONTINUE
DO 13 I=1,19

INIT0001 INIT0002 INIT0003 INIT0004 INIT0005 INIT0006 INIT0007 INIT0008 INIT0009 INIT0010 INIT0011 INIT0012 INIT0013 INIT0014 INIT0015 INIT0016 INIT0017 INIT0018 INIT0019 INIT0020 INIT0021 INIT0022 INIT0023 INIT0024 INIT0025 INIT0026 INIT0027 INIT0028 INIT0029 INIT0030 INIT0031 INIT0032 INIT0033 INIT0034 INIT0035 INIT0036
DO 14 J=1,15
  AAY(I,J)=0.0
  BBY(I,J)=0.0
  CCY(I,J)=0.0
  CONTINUE
14  DO 15 K=1,6
  DDY(I,K)=0.0
15  CONTINUE
13  CONTINUE
RETURN
END
SUBROUTINE COEFF

C TO DEFINE THE POINTS AND COEFFICIENTS OF GAUSSIAN QUADRATURE
C

DIMENSION Y(20),YY(20)
COMMON /AREA2/NPT,XXX(20),A(20)
NPTH=NPT/2
IF((FLOAT(NPTH)-NPT/2.0)*NE.0.0)GO TO 100
READ(5,5000)(Y(I),I=1,NPTH),(A(J),J=1,NPTH)

5000 FORMAT(9F10.5)
DO 10 II=1,NPTH
Y(NPTH+II)=-Y(NPTH-II+1)
A(NPTH+II)=A(NPTH-1II+1)
10 CONTINUE
GO TO 200

100 NPTH1=NPTH+1
DATA Y(1),Y(2),Y(3),Y(4),Y(5),Y(6)/0.978228,
  0.857632 ,0.730152, 0.619096 , 0.269543 , 0.0 /
DO 20 MM=1,NPTH
A(NPTH+MM+1)=A(NPTH-MM+1)
Y(NPTH+MM+1)=-Y(NPTH-MM+1)
20 CONTINUE

260 DO 50 KK=1,NPT
YY(KK)=Y(KK)
50 CONTINUE

50 DO 60 I=1,NPT
Y(I)=YY(NPT-I+1)
60 CONTINUE
50 CONTINUE

50 DO 30 JJJ=1,NPT
XXX(JJJ)=(Y(JJJ)+1.0)/2.0
30 CONTINUE
RETURN
END
SUBROUTINE INPUT(CGUST, IDOF, IRES, IEIGEN)

TO SUPPLY INPUT INFORMATION

DES = IDENTIFYING INFORMATION

ITYPE = 0: HINGELESS ROTOR IN POWERED FLIGHT

ITYPE = 1: HINGELESS ROTOR IN AUTOROTATIONAL FLIGHT

GIMBALED ROTOR IN BOTH FLIGHTS

IFT = 0: POWERED FLIGHT

IFT = 1: AUTOROTATION FLIGHT

IDO = 9: BASIC DEGREES OF FREEDOM IS 9

IDO = 18: DOF IS 18

IRES = 0: FREQUENCY RESPONSE OFF

IRES = 1: RESPONSE ON

IPMAG = 0: MODE NORMALIZED ROTOR RADIUS AND WING SEMISPAN

IPMAG = 1: NORMAL MODES

IEIGEN = 0: EIGENANALYSIS OFF

IEIGEN = 1: EIGENANALYSIS ON

NBL = NUMBER OF BLADES

POH = AIR DENSITY

OMEGA = ROTATIONAL SPEED (RAD/SEC)

RAMDA = INFLOW RATIO

VEL = CRUISING FLIGHT SPEED

R = ROTOR RADIUS

ATB = BLADE FLAPPING MOMENT OF INERTIA

CHOD = BLADE CHORD

CL = BLADE LIFT CURVE SLOPE

CD = BLADE DRAG COEFFICIENT

HMAST = MAST HEIGHT

DLP3 = PITCH-FLAP COUPLING COEFFICIENT (RADIAN)

WL = WING SEMISPAN

WCH = WING CHORD

WCL = WING LIFT CURVE SLOPE

WCD = WING DRAG COEFFICIENT

WCMO = WING PITCHING MOMENT COEFFICIENT

WCMO = WING PITCHING MOMENT CURVE SLOPE

FDIS = DISTANCE BETWEEN AERODYNAMIC CENTER AND ELASTIC AXIS

INPU0001

INPU0002

INPU0003

INPU0004

INPU0005

INPU0006

INPU0007

INPU0008

INPU0009

INPU0010

INPU0011

INPU0012

INPU0013

INPU0014

INPU0015

INPU0016

INPU0017

INPU0018

INPU0019

INPU0020

INPU0021

INPU0022

INPU0023

INPU0024

INPU0025

INPU0026

INPU0027

INPU0028

INPU0029

INPU0030

INPU0031

INPU0032

INPU0033

INPU0034

INPU0035

INPU0036
C (NONDIMENSIONALIZED BY WING CHORD, POSITIVE AERODYNAMIC
CENTER AHEAD )
WTHET= WING TRIM ANGLE OF ATTACK (RADIANS)
CGUST= EXCITING FORCE COMPONENTS
BRAM= (BLADE NATURAL FREQUENCY )**2 (RADIANS/SEC)**2
WRAM= (WING NATURAL FREQUENCY )**2 (RADIANS/SEC)**2
NW= WING ELEMENT NUMBER
EMS= WING ELEMENT SIZE NORMALIZED BY THE SEMISPAN
G= VERTICAL BENDING MODE COMPONENT AT THE NODE OF THE WING
Z= CHORDWISE BENDING MODE COMPONENT AT THE NODE OF THE WING
DG= VERTICAL BENDING MODE SLOPE AT THE NODE OF THE WING
DZ= CHORDWISE BENDING MODE SLOPE AT THE NODE OF THE WING
WPHI= TORSION MODE COMPONENT AT THE NODE OF THE WING
DWPHI= TORSION MODE SLOPE AT THE NODE OF THE WING
N= BLADE ELEMENT NUMBER
EMS= BLADE ELEMENT SIZE NORMALIZED BY THE ROTOR RADIUS
AMASS= MASS DISTRIBUTION AT THE NODE OF THE BLADE
THEN= ANGLE OF TWIST AT THE NODE OF THE BLADE
CCLI= COLLECTIVE PITCH ANGLE DETERMINED BY THE PERFORMANCE (RADIANS)
W= OUT-OF-PLANE MODE COMPONENT AT THE NODE OF THE WING
V= INPLANE MODE COMPONENT AT THE NODE OF THE BLADE
DW= OUT-OF-PLANE MODE SLOPE COMPONENT AT THE NODE OF THE BLADE
DV= INPLANE MODE SLOPE COMPONENT AT THE NODE OF THE BLADE
BRMCO= (COLLECTIVE MODE NATURAL FREQUENCY OF THE BLADE)**2
(RADIANS/SEC)**2
WCOI= OUT-OF-PLANE COMPONENT OF THE BLADE COLLECTIVE MODE AT THE NODE
VCOI= INPLANE COMPONENT OF THE BLADE COLLECTIVE MODE AT THE NODE
DWCOI= OUT-OF-PLANE SLOPE COMPONENT OF THE BLADE COLLECTIVE MODE AT THE NODE
DVCOI= INPLANE SLOPE COMPONENT OF THE BLADE COLLECTIVE MODE AT THE NODE
DIMENSION RMAX(4), RMAX(4), WMAX(4), RIG(6)
DIMENSION CCUST(6), SBM(4), SBM(4), SWG(6), DES(80)
COMMON /PAWM/ ITYPE, IFLT
COMMON/AMAT/TT(6,5), C(6,6), T(5,6)
COMMON /AREAL/OMEGA,R, VEL, CL, CD, RAMDA, SNOME
COMMON /APEA/NURLD, ROH, CHOD, ATR, CK, HMAST, ALOCK, AND, HR
COMMON /ARFR/BLAM(4), W1AM(6), BRAM(4), WRAM(6), BLAGO(4), BRAMO(4)
COMMON/GIM/ V(4,21), W(4,21), DV(4,21), DW(4,21), THETA(21),
*EMS(25), AMASS(20), IN, ND
COMMON /GINO/ VCOL(4,21), WCOL(4,21), DVRCL(4,21), DWCL(4,21)
COMMON/WING/ NW, NDPM, EMSW(20), G(6,21), DG(6,21), Z(6,21), DZ(6,21),
*WPHI(6,21), DWPHI(6,21)
COMMON/WICH/WL, WCOL, WCL, WCD, WCMD, WCMA, EDIS, WTHET, VV
COMMON /COUPL/ AKPC(4), AKPO(4)
COMMON/FRMAG/ FRB(4), FRRD(4), FRW(6), IFRMAG
COMMON/THF/THTN(21), MA, MW
IDFRIG=0
MR=2
MW=3
READ(5,5003)(DES(1), i=1,90)
READ(5,5001) ITYPE
READ(5,5001) IFLT
READ(5,2034) I1DF
IE(!1DF, EQ.9) GO TO 62
MP=4
MW=6
CONTINUE
READ(5,5001) IRES
READ(5,5001) IFRMAG
READ(5,5001) IEIGEN
READ(5,5001) NOOLD
READ(5,5000) ROH, OMEGA, RAMDA, VEL
READ(5,5000) R, ATR, CHOD, CL, CD, HMAST, DEL3
READ(5,5000) WI, WCOD, WCL, WCD, WCMD, WCMA, EDIS, WTHET
READ(5,5000) CCUST

102
READ(5,5000) PRAM
READ(5,5000) WRAM
READ(5,1034) NW
NDPW=NDW+1
READ(5,5000)(EMS(K),K=1,NW)
DO 60 I=1,NW
READ(5,1001)( G(I,J),J=1,NDPW)
READ(5,1001)( Z(I,J),J=1,NDPW)
READ(5,1001)( DG(I,J),J=1,NDPW)
READ(5,1001)( DZ(I,J),J=1,NDPW)
READ(5,1001)( WPHI(I,J),J=1,NDPW)
READ(5,1001)( DWHPI(I,J),J=1,NDPW)
CONTINUE
READ(5,1034) NW
NDPW=NDW+1
READ(5,5000)(EMS(K),K=1,N)
READ(5,5000)(AMASS(J),J=1,NDP)
READ(5,5000)(THETN(J),J=1,NDP)
READ(5,5000)(ICOL)
DO 60 I=1,MW
READ(5,1001)( W(I,J),J=1,NDP)
READ(5,1001)( V(I,J),J=1,NDP)
READ(5,1001)( DW(I,J),J=1,NDP)
READ(5,1001)( DV(I,J),J=1,NDP)
AKPD(I)=DW(I,1)*TAN(DEL2)*(-1.0)
CONTINUE
IF(TYPEF.EQ.5) GO TO 100
READ(5,5000) PRAMO
DO 52 I=1,MR
READ(5,1001)( WCOL(I,J),J=1,NDP)
READ(5,1001)( VCOL(I,J),J=1,NDP)
READ(5,1001)( DOWC(I,J),J=1,NDP)
READ(5,1001)( DVCOL(I,J),J=1,NDP)
AKPD(I)=DOWC(I,1)*TAN(DEL3)*(-1.0)
CONTINUE
DO 200 I=1,4
BLAMO(I) = BAMS(O(I)) / OMEGA**2
SBM0(I) = SORT(BLM0(I))

200 CONTINUE
100 CONTINUE
IF(INOF. EQ. 18) GO TO 101
DO 305 I = 4, 6
DO 305 J = 1, NDPW
G(I, J) = 0.0
DG(I, J) = 0.0
Z(I, J) = 0.0
DZ(I, J) = 0.0
WPHI(I, J) = 0.0
DWP1H(I, J) = 0.0
305 CONTINUE
DO 307 I = 3, 4
DO 306 J = 1, NDP
W(I, J) = 0.0
DW(I, J) = 0.0
V(I, J) = 0.0
306 DV(I, J) = 0.0
307 KP0C(I) = 0.0
IF(ITYPE. EQ. 0) GO TO 101
DO 308 I = 3, 4
DO 309 J = 1, NDP
WC0L(I, J) = 0.0
DC0L(I, J) = 0.0
VCOl(I, J) = 0.0
309 DC0L(I, J) = 0.0
308 AKPOC(I) = 0.0
101 CONTINUE
DO 22 I = 1, NDP
THETA(I) = THERIN(I) + COL
22 CONTINUE
DO 6 I = 1, 4
BLAM(I) = BAMS(I) / OMEGA**2
SBM(I) = SORT(BLM0(I))
6
DO 5 I=1,6
WLAM(I)=WRAM(I)/OMEGA**2
5
SWG(I)=SQRT(WLAM(I))
DO 30 I=1,6
TT(I,1)=G(I,NDPW)
TT(I,2)=Z(I,NDPW)
TT(I,3)=DZ(I,NDPW)
TT(I,4)=WPHT(I,NDPW)
TT(I,5)=-DG(I,NDPW)
30 CONTINUE
IF(IFTL.EQ.0) GO TO 23
DO 24 I=1,6
24 TT(I,5)=0.0
23 CONTINUE
DC 40 I=1,6
DO 40 J=1,6
40 CI(I,J)=DZ(I,NDPW)*WPHT(J,NDPW)-DZ(J,NDPW)*WPHT(I,NDPW)
ALOCK=ROH*CT*CHOD*R**4/AIB
AND=FLOAT(NORD)
HR=HMAST/R
SNMEG=SIGN(1.0,OMEGA)
2034 FORMAT(12)
5003 FORMAT(80A1)
5001 FORMAT(I1)
5000 FORMAT(8E10.0)
1001 FORMAT(6F13.5)
C ************** PRINT OUT OF INPUT DATA **************
WRITE(6,5002) (DEF(I),I=1,80)
5002 FORMAT(///10X,100(1H*),//20X,80A1,///10X,100(1H*)///)
WRITE(6,5004) (TYPE,ITFL,IFDOF,IFRES,IEIGEN,IFRMA)
5004 FORMAT(///10X,'ITYPE=',I2,3X,'ITFL=',I2,
& 12,3X,'IFDOF=',I1,3X,'IFRES=',I1,3X,'IEIGEN=',I1,3X,'IFRMA=',I2)
WRITE(6,1)NORD,ROH,CHOD,AIR,HMAST,ALOCK
1 FORMAT(/// T4,'NO OF BLADES',T25,'ROH',T41,'CHORD',T59,'!B'
& $,T74,'HMAST',T94,'LOCK NO',
</// T7,12,T18,5(1PE15.7,2X))
WRITE(6,2) OMEGA,P,VFL,CL,CD,GRAMDA
2 FORMAT(/' T6,'OMEGA',T25,'P',T41,'VFL',T59,'CL',T74,'CD'
#,T44,'GRAMDA'   //IX, 6(1PE15.7,2X))
WRITE(6,61) COL,DFL3
61 FORMAT(/' T6,'COLLECTIVE PITCH',T25,'DFL3'    //IX,2(1PE15.7,2X))
WRITE(6,3) WL,WCDW,WCL,WCD,WCMO,WCMA
3 FORMAT(/' T6,'WING L',T25,'WING CHOD',T41,'WING CL',T59,'WING CD'
#,T74,'WING CM',T94,'WING CMAC
#/1X,6(1PE15.7,2X))
WRITE(6,4) EDTS,WHTET
4 FORMAT(/' T6,'DISTANCE AC EA',T25,'WING ALPHAFH'
#/1X,2(1PE15.7,2X))
WRITE(6,256)
256 FORMAT(/' 1X,35(1H-)/1X,'EIGENVALUES ( NATURAL FREQUENCIES )'
#   /'1X,35(1H-)/2X, '--( RAD/SEC )**2--')
IF(TYPE.EQ.0) GO TO 254
WRITE(6,251)(RPMO(I),I=1,MR)
251 FORMAT(/'1X, ' **PLADEF COLLECTIVE**/4X,4(F12.3,3X))
WRITE(6,252)
252 FORMAT(/'1X, ' **PLADEF CYCLIC**)
GO TO 255
253 WRITE(6,253)
254 FORMAT(/'1X, ' **PLADEF**)
255 WRITE(6,256)(RPM(I),I=1,MR)
256 FORMAT(4X,4(F12.3,3X))
WRITE(6,257)(WRAM(I),I=1,MW)
257 FORMAT(/'1X, ' **WING**/4X,6(F12.3,3X))
WRITE(6,408)
408 FORMAT(/'2X, '-- RAD/SEC/OMEGA --')
IF(TYPE.EQ.0) GO TO 354
WRITE(6,351)(S3MD(I),I=1,MR)
351 FORMAT(/'1X, ' **PLADEF COLLECTIVE/OMEGA**/4X,4(F12.3,3X))
WRITE(6,352)
352 FORMAT(/'1X, ' **PLADEF CYCLIC/OMEGA**')
GO TO 355
354 WRITE(6,353)
353  FORMAT(/1X,  **BLADE/OMEGA***)
355  WRITE(6,356)(SBM(I),I=1,MB)
356  FORMAT(4X,4(F12.3,3X))
357  WRITE(6,357)(SWG(I),I=1,MW)
358  FORMAT(/1X,  **WING/OMEGA***/4X,6(F12.3,3X))
409  WRITE(6,409)
409  FORMAT(/1X, 'EXCITING FORCE COMPONENTS')
422  WRITE(6,358)GUST
358  FORMAT(/'T6','U GUST',T25,'V GUST', T41,'W GUST', T59,
*          'THETA 01',T74,'THETA 10', T94,'THETA IS','/1X,
*          6(1PE15.7,2X))
423  DO 420 I=1,MB
424  DO 431 J=1,NDP
425     RIG(I)=0.0
426     PA=ARS(W(I,J))
427     IF(PA   -RIG(I)) 460,460,461
428  429     PIG(I)=PA
430     PA=ARS(V(I,J))
431     IF(PA   -RIG(I)) 431,431,462
432  433     RIG(I)=PA
434  435     CONTINUE
436  BMAX(I)=RIG(I)
437  DO 438 I=1,MW
438  DO 439 J=1,NDPW
439     RIG(I)=0.0
440     PA=ARS(G(I,J))
441     IF(PA   -RIG(I)) 465,465,466
442  443     RIG(I)=PA
444     PA=Z(I,J))
445     IF(PA   -RIG(I)) 436,436,467
446  447     RIG(I)=PA
448  449     CONTINUE
450  WMAX(I)=RIG(I)
451  IF(I1YPE.EQ.0) GO TO 480
452  DO 440 I=1,MR
453  DO 441 J=1,NDP
PIG(I)=0.0
PA=ARS(WCOL(I,J))
IF(PA  
   -RIG(I)) 470,470,471
471  BIGN(I)=PA
470  PA=ARS(VCOL(I,J))
IF(PA  
   -RIG(I)) 441,441,472
472  BIGN(I)=PA
441  CONTINUE
440  BOMAX(I)=RIG(I)
GO TO 487
480 DO 481 I=1,MB
481  BOMAX(I)=RMAX(I)
487 CONTINUE
DO 475 I=1,MW
FPB(I)=BMAX(I) /R
FRBO(I)=BOMAX(I) /R
475 CONTINUE
DO 476 I=1,MW
FRW(I)=WMAX(I) /WL
476 CONTINUE
FPW(3)=ABS(WPHI(3,NDPW))
IDERUG=0
IF( IDERUG.EQ.0 ) GO TO 477
WRITE(6,5005)(RMAX(I),I=1,MB),(BOMAX(I),I=1,MW),
( WMAX(I),I=1,MW )
5005 FORMAT((/10X,E15.7))
477 CONTINUE
RETURN
END
SUBROUTINE INTPL

C INTERPOLATION FOR THE NUMERICAL INTEGRATION

C INTERPOLATION FUNCTION-------HERMIT INTERPOLATION (2 POINTS)

C INTERPOLATION FUNCTION-------LAGRANGIAN INTERPOLATION FOR THE ANGLE OF TWIST

COMMON /THE/ THETN(21), MB, MW
COMMON /PARMT/ ITYPE, IFLT
COMMON /AREA1/ OMEGA, R, VEL, CL, CD, RAMDA, SNOMFG
COMMON /WICH/WL, WCD, WCL, WCMO, WCMA, EDIS, WTHET, VV
DIMENSION WX(21)
COMMON/WING/ NW, NDPW, EMSW(21), GI(6,21), DG(6,21), Z(6,21), DZ(6,21), WPHII(6,21)
DIMENSION GI(6,21), ZI(6,21), WPHII(6,20)
COMMON/WICD/STR(20), TSTEP(20,6,3)
DIMENSION XX(21)
COMMON/GIN/ V(4,21), W(4,21), DV(4,21), DW(4,21), THETA(21), EMS(20), AMASS(20), N, NDP
COMMON/GINO/ VCOL(4,21), WCOL(4,21), DVCOL(4,21), DWCOL(4,21)
COMMON /AREA2/ VI(4,21), WI(4,21), THETA(I), AMASS(I)

*COMMON /AREA3/ V(4,21), WCOL(4,21), DVCOL(4,21), DWCOL(4,21)

COMMON /NPT, XXX(20), A(20)
IDEBUG=0
WRITE(6,50)
50 FORMAT(///1X,'***** BLADE MODE SHAPES *****')
XX(I)=0.0
DU 8: I=1,N
XX(I+1)=XX(I)+EMS(I)
80 CONTINUE
IF(IATYPE.EQ. ) GOTO 10
WRITE(6,51)
51 FORMAT(///1X,'--- COLLECTIVE MODES ---')
CONTINUE
WRITE(6,50)
WRITE(6,51)
* J=1,NDP)
36  CONTINUE
   WRITE(6,52)
52 FORMAT(//I8,'--- CYCLIC MODES ---')
100 CONTINUE
   DO 35 I=1,MR
500 FORMAT(// 1x,'I=',I1)
35 WRITE(6,4500)
   WRITE(6,4500)
4500 FORMAT( T5,'J',T13,'X(J)',T33,'V(I,J)',T53,'DV(I,J)',T73,'W(I'
$\%$,J')',T93,'DW(I,J)')
   WRITE(6,4990)
4990 FORMAT( I4,5(5X,E15.7))
35 CONTINUE
   WRITE(6,5999)
5999 FORMAT(// T5,'J',T13,'XX(J)',T33,'THETN(J)',T53,'AMASS(J)')
   WRITE(6,4100)
   WRITE(6,4100)
4100 FORMAT( I4,3(5X,E15.7))
   DO 70 II=1,NPT
   DO 60 I=1,NDP
50 IF(XX(I),GE.XXX(II)) GO TO 110
   CONTINUE
110 EA=XX(I)-XX(I-1)
   EB=XX(I)+XX(I-1)
   XKSI=2.0/EA*XX(II)-EB/EA
   FL=(XKSI+2.0)*(XKSI-1.0)**2/4.0
   F2=(XKSI-XKSI)*(XKSI+1.0)**2/4.0
   G1=(XKSI+1.0)*(XKSI-1.0)**2/4.0
   G2=(XKSI-1.0)*(XKSI+1.0)**2/4.0
   FL1=(1.0-XKSI)/2.0
   F2L=(1.0*XKSI)/2.0
   DC 90 JJ=1,4
   VI(JJ,II)=V(JJ,1-1)*F1+V(JJ,II)*F2+(DV(JJ,I-1)*G1+DV(JJ,II)*G2)
   WI(JJ,II)=W(JJ,1-1)*F1+W(JJ,II)*F2+(DV(JJ,I-1)*G1+DV(JJ,II)*G2)
   2*EA/2.0*RS
   2*EA/2.0*RS
IF(ITYPE.EQ.0)GO TO 90
VICOL(JJ,II)=VICOL(JJ,II-1)*F1+VICOL(JJ,II)*F2+(DVCOL(JJ,II-1)*G1
* +DVCOL(JJ,II)*G2)*EA/2.0*R
WICOL(JJ,II)=WICOL(JJ,II-1)*F1+WICOL(JJ,II)*F2+(DWCOL(JJ,II-1)*G1
* +DWCOL(JJ,II)*G2)*EA/2.0*R
90 CONTINUE
AMASS(I) =AMASS(I-1)*F1+AMASS(I)*F2+AMASS(I)*G1
THETA(I) = THETA(I-1)*F1+THETA(I)*F2+THETA(I)*G1

70 CONTINUE
IF(IDEBUG.EQ.0) GO TO 400
WRITE(6,5048)
5048 FORMAT(/// T5,'J',T13,'XXX(J)',T33,'VI(1,J)',T53,'WI(1,J)',T73,
* VI(2,J)',T93,'WI(2,J)'),
WRITE(6,3)(JJ,XXX(JJ),VI(1,JJ),WI(1,JJ),VI(2,JJ),WI(2,JJ),JJ=1,
* NPT)
WRITE(6,5047)
5047 FORMAT(/// T5,'J',T13,'XXX(J)',T33,'VI(3,J)',T53,'WI(3,J)',T73,
* VI(4,J)',T93,'WI(4,J)'),
WRITE(6,3)(JJ,XXX(JJ),VI(3,JJ),WI(3,JJ),VI(4,JJ),WI(4,JJ),JJ=1,
* NPT)
WRITE(6,5046)
5046 FORMAT(/// T5,'J',T13,'XXX(J)',T33,'AMASS(J)',T53,'THETA(J)'),
WRITE(6,4)(JJ,XXX(JJ),AMASS(JJ),THETA(JJ),JJ=1,NPT)
400 CONTINUE
WRITE(6,53)
53 FORMAT(///1X,***** WING MODE SHAPES *****)
WX(I)=0.0
DO 81 I=1,NW
WX(I+I)=WX(I)+EMSW(I)
81 CONTINUE
DO 38 II=1,MW
WRITE(6,7000)II
7000 FORMAT(///1X,*II=*,II)
WRITE(6,7001)
7001 FORMAT(T5,'J',T9,'WX(J)',T25,'G(II,J)',T41,'DG(II,J)',T57,
* 'Z(II,J)',T73,'DZ(II,J)',T89,'WPHI(II,J)',T105,'DWPHEL(II,J)')
WRITE(6,5)(J,WX(I),G(I,I,J),DG(I,I,J),Z(I,I,J),DZ(I,I,J),WPHI(I,I,J),
%DWPHI(I,I,J),J=1,NPT)
5 FORMAT(1X,T4,7(1X,E15.7))
38 CONTINUE
DO 10 I=1,NPT
DO 20 I=1,NPT
IF(WX(I).GE.XXX(I)) GO TO 220
20 CONTINUE
220 WEA=WX(I)-WX(I-1)
WEB=WX(I)+WX(I-1)
XKSI=2.0/WEA*XSSS(I)-WEB/WEA
F1=(XKSI+2.0)*XKSI-1.0)**2/4.0
F2=(2.0-XKSI)*XKSI-1.0)**2/4.0
G1=(XKSI+1.0)*XKSI-1.0)**2/4.0
G2=(XKSI-1.0)*XKSI-1.0)**2/4.0
DO 31 IJ=1,6
GI(IJ,II)=G(IJ,II-1)*F1+G(IJ,II)*F2+(DG(IJ,II-1)*G1+DG(IJ,II)*G2)*
*WEA/2.0*WL
ZI(IJ,II)=Z(IJ,II-1)*F1+Z(IJ,II)*F2+(DZ(IJ,II-1)*G1+DZ(IJ,II)*G2)*
*WEA/2.0*WL
WPHI(IJ,II)=WPHI(IJ,II-1)*F1+WPHI(IJ,II)*F2+(DWPHI(IJ,II-1)*G1+
@DWPHI(IJ,II)*G2)*WEA/2.0*WL
STR(I,1,IJ)=GI(IJ,II)
STR(I,2,IJ)=ZI(IJ,II)
STR(I,3,IJ)=WPHI(IJ,II)
TSTR(I,1,IJ,1)=GI(IJ,II)
TSTR(I,1,IJ,2)=ZI(IJ,II)
TSTR(I,1,IJ,3)=WPHI(IJ,II)
37 CONTINUE
10 CONTINUE
IF(IDBUG.EQ.0) GO TO 401
WRITE(6,7)3
7003 FORMAT(//T5,*J*,T9,'XXX(J)',T25,'GI(1,J)',T41,'HI(1,J)',T57,
*'WPHI(1,J)',T73,'G12(J)',T89,'H(2,J)',T105,'WPHI(2,J)')
WRITE(6,5)(J,XXX(J),GI(1,J),ZI(1,J),WPHI(1,J),GI(2,J),ZI(2,J),
@WPHI(2,J),J=1,NPT)
WRITE(6,7004)
7004 FORMAT(/// T5,'J',T9,'XXX(J)',T25,'GI(3,J)',T41,'HI(3,J)',T57,
@'WPHII(3,J)',T73,'GI(4,J)',T89,'HI(4,J)',T105,'WPHII(4,J)')
WRITE(6,5)(J,XXX(J),GI(3,J),ZI(3,J),WPHII(3,J),GI(4,J),ZI(4,J),
@WPHII(4,J),J=1,NPT)
WRITE(6,7005)
7005 FORMAT(/// T5,'J',T9,'XXX(J)',T25,'GI(5,J)',T41,'HI(5,J)',T57,
@'WPHII(5,J)',T73,'GI(6,J)',T89,'HI(6,J)',T105,'WPHII(6,J)')
WRITE(6,5)(J,XXX(J),GI(5,J),ZI(5,J),WPHII(5,J),GI(6,J),ZI(6,J),
@WPHII(6,J),J=1,NPT)
401 CONTINUE
RETURN
END
SUBROUTINE AERODT
C
C     TO DEFINE THE AERODYNAMIC COEFFICIENTS AT THE POINTS OF GAUSSIAN
C     QUADRATURE
C
COMMON /PARMT/   ITYPE , IFLT
COMMON /AREA1/Omega, R, VEL, CL, CD, RAMDA, SNOMEG
COMMON /AREA2/NOBLD, RCH, CHOD, AIR, CK, FLST, ALock, AND, HR
COMMON /AREA3/NPT, XXX(2C), A(2C)
COMMON /AREA4/VI(J=4,20), W(J=4,20), THETA(J=20), AMASSI(J=20)
C     , VICOL(4,20), WICL(4,20)
COMMON/AREA5/H(4,20), HI(4,20), HV(4,20), HRZ(4,20), HNR(4,20),
C     COMWO(4,20), VOW(4,20), W(4,20), V(4,20)
COMMON/AREA6/0H(J=4,20), OWO(J=4,20), OVI(J=4,20), OHI(J=4,20),
C     CHIV(J=4,20), DHIV(J=4,20)
COMMON/AKKH/FTOP(J=20), FTLPO(2C), FTLPO(20), FT2P1(20), FZ2P0(20),
C     FZDP0(20), FZ1P1(20), FZ2P2(20)
C     , FT3P0(2C), FT3P1(2C), FZ3P1(20), FZ3P2(20)
COMMON/AKFH/HIII(J=4,20), HIIV(J=4,20), HIV(J=4,20), HVII(J=4,20)
COMMON/WHIC/WR(20), STR(20,6,3), TSTR(20,6,3)
COMMON/WICH/WL, WC0C, WCL, WCD, WCMG, WCM, EDIS, WTHET, VV
COMMON/WHIC/WSGC(20), WSC(20,6,3), TSC(20,6,3)
DIMENSION DAWA(3,3), AWA(3,3), AN(3,3)
DIMENSION TSC(20), TSA(20,6,3)
DO 1 I=1,3
DO 1 J=1,3
DAWA(I,J)=0.0
1 AWA(I,J)=C.G
DO 2 I=1,20
DO 2 J=1,6
DO 2 K=1,3
TD(1,J,K)=U.C
2 TSA(I,J,K)=C.G
CK=-0.5*ROH*CL*CHOD*R**4
CA=CD/CL
CA1=1.0+CA
CA2=1.0-CA
AR=ABS(RAMCA)
RAMCA=AR
DC 11 JJ=1,A2
XSQ=SQRT(RAMCA**2+XXX(JJ)**2)
TAU0=1.0/XSQ
TAU1=XXX(JJ)/XSQ
TAU2=XXX(JJ)**2/XSQ
TAU3=XXX(JJ)**3/XSQ
ALPHA=THETA(JJ)-ATAN(RAMCA/XXX(JJ))+ATAN(RAMDA-4.3/3.0)
FTH0=RAMDA**3+ALPHA*TAU0+RAMCA**2*CA*TAU1+RAMDA*ALPHA*TAU2
/+/CA*TAU3
FTH1=RAMDA**2+CA*TAU0+RAMCA**2*TAU1+2.0*CA*TAU2
FTH2=2.0*RAMCA**2*ALPHA*TAU0+RAMDA*CA2*TAU1+ALPHA*TAU2
FTH3=RAMDA**2+TAU0+RAMCA*TAU2
FTHC=-FTH0*SNOMEG
FTH1=-FTH1
FTH2=-FTH2*SNOMEG
FTH3=-FTH3*SNOMEG
FZ0=-RAMDA**3+CA*TAU0+RAMDA**2*ALPHA*TAU1+RAMDA*CA*TAU2
/+/ALPHA*TAU3
FZ1=RAMDA**2+ALPHA*TAU0+RAMCA**2*TAU1+2.0*ALPHA*TAU2
FZ2=-2.0*RAMDA**2+CA*TAU0+RAMCA*ALPHA*TAU1-CALTAU2
FZ3=RAMDA**2+TAU1+TAU3
FZ1=FZ1*SNOMEG
DO 200 J=1,4
DO 100 I=1,4
IF(IYPE.EQ.0) GO TO 100
CH(J,I,JJ)=FTH1*VICOL(J,J,JJ)*VICOL(I,J,JJ)+FZ1*VICOL(J,J,JJ)*
2*VICOL(I,J,JJ)*FTH2*VICOL(J,J,JJ)*VICOL(I,J,JJ)+FZ2*VICOL
100 CONTINUE
HI(J,J,JJ)=FTHI*V1(J,J,JJ)*FZ1*W1(J,J,JJ)
HI(J,JJ) = (FTH2*VI(J,JJ) + FZ2*WI(J,JJ))*XXX(JJ)
HRZ(J,JJ) = FTH2*VI(J,JJ) + FZ2*WI(J,JJ)
HHT(J,JJ) = (FTH1*VI(J,JJ) + FZ1*WI(J,JJ))*XXX(JJ)
WO(J,JJ) = AMASSI(JJJ)*WI(J,JJ)
VO(J,JJ) = AMASSI(JJJ)*VI(J,JJ)
WI(J,JJ) = AMASSI(JJJ)*WI(J,JJ)*XXX(JJJ)
VI(J,JJ) = AMASSI(JJJ)*VI(J,JJ)*XXX(JJJ)
HI1(J,JJ) = FTH1*VI(J,JJ) + FTH2*WI(J,JJ)
HV(J,JJ) = HI1(J,JJ)*XXX(JJJ)
HV1(J,JJ) = FZ1*VI(J,JJ) + FTH0*WI(J,JJ)
CH1(J,JJ) = FZ3*WI(J,JJ) + FTH2*VI(J,JJ)
IF (ITYPE,EG,0) GO TO 200
0W(J,JJ) = AMASSI(JJJ)*VICOL(J,JJ)
UV(J,JJ) = AMASSI(JJJ)*VICOL(J,JJ)*XXX(JJJ)
HRZ(J,JJ) = FTH2*VICOL(J,JJ) + FZ2*VICOL(J,JJ)
HHT(J,JJ) = (FTH1*VICOL(J,JJ) + FZ1*VICOL(J,JJ))*XXX(JJJ)
WHI(J,JJ) = FZ3*VICOL(J,JJ) + FTH3*VICOL(J,JJ)
WHV(J,JJ) = FZ1*VICOL(J,JJ) + FZ2*VICOL(J,JJ)
CH1(J,JJ) = (FTH1*VICOL(J,JJ) + FTH2*VICOL(J,JJ))*XXX(JJJ)
CONTINUE
C AERC FOR WING DUE TO BLADES
FT1P1(JJJ) = FTH0*XXX(JJJ)
FT1P2(JJJ) = FTH1
FT1P2(JJJ) = FTH1*XXX(JJJ)*#2
FT2P1(JJJ) = FTH2*XXX(JJJ)
FZ2F(JJJJ) = FZ2
FZ1P1(JJJ) = FZ1*XXX(JJJ)
FZ2P2(JJJ) = FZ2*XXX(JJJ)*#2
FT3P0(JJJ) = FTH3
FT3P1(JJJ) = FTH3*XXX(JJJ)
FZ3P0(JJJ) = FZ3
FZ3P1(JJJ) = FZ3*XXX(JJJ)
CONTINUE
AERO FOR WING DUE TO ITSELF

RAMDA= ARAMDA
RC=ROH*WCD
DAWA(1, 1)=-0.5*RC*VEL*WCL+WCD)
DAWA(1, 2)=RC*WCL*WTHET*VEL
DAWA(2, 1)=-0.5*RC*WCL*WTHET*VEL
DAWA(2, 2)=-RC*WCD*VEL
DAWA(3, 1)=-0.5*RC*WCD*VEL*(WCL*EDIS+WCM)
DAWA(3, 2)=RC*WCD*(WCMO+WCMWA*WTHET+WCL*WTHET*EDIS)*VEL
AWA(1, 3)=0.5*RC*WCL*VEL*
AWA(3, 3)=C.5*RC*WCL*VEL*2*(WCMO+WCMW*EOIS)
AWA(1, 1)=DAWA(1, 1)*VEL
AWA(1, 2)=DAWA(1, 2)*VEL
AWA(2, 1)=DAWA(2, 1)*VEL
AWA(2, 2)=DAWA(2, 2)*VEL
AWA(3, 1)=DAWA(3, 1)*VEL
AWA(3, 2)=DAWA(3, 2)*VEL

501 I=1,NFT
502 J=1,6
503 K=1,3

TSDA(I1, I, J)=TSTR(I1, I, K)*DAWA(K, J)+TSCA(I1, I, J)
TSA(I1, I, J)=AWA(K, J)+TSA(I1, I, J)
TSAC(I1, I, J)=TSTR(I1, I, K)*AWA(K, J)+TSAC(I1, I, J)

CONTINUE
502
CONTINUE
501
RETURN

END
SUBROUTINE CRDINT

TO DEFINE THE ORDER OF NUMERICAL INTEGRATION

COMMON /PARMT/   IYPE, IFLT
COMMON /AREA1/OMEGA, R, VEL, CL, CD, RAMDA, SNOMEG
COMMON /AREA6/NOBLD, ROH, CHO, AIAB, CK, HMAST, ALOCK, ANO, HR
COMMON/AREA5/AHB(4,4), AHI(4), AHII(4), AHRZ(4), AHNR(4), AWO(4)
COMMON/AEC/OAH(4,4), OAHI(4), OAHII(4), OAHIII(4), OAHIV(4)
COMMON/AER/DFTOP1, AFT1P0, AFT1P2, AFT2P1, AFZOPO, AFZ1P1, AFZ2PO,
COMMON/AER/HII(4), AHIV(4), AHV(4), AHVI(4), AHVII(4)
COMMON/WCH/WL, WCMO, WCMA, EDIS, WTHET, VV
COMMON/ARWNG/DARWA(6,6), ARWA(6,6), ARWG(6,3)
IDEBUG=0
NN=1
DO 100 JQ=1,4
DO 100 IQ=1,4
CALL INTEG(FSUM, NN, JQ, IQ)
100 CONTINUE
NK=NN
1000 NN=NN+1
DO 200 JQ=1,4
CALL INTEG(FSUM, NN, JQ, IQ)
FSUM=FSUM*CK/R
NM=NN-NK
GO TO (2,3,4,5), NM
2 AHB(JQ)=FSUM
GO TO 200
3 AHII(JQ)=FSUM
GO TO 200
4 AHRZ(JQ)=FSUM
GO TO 200
5 AHNR(JQ)=FSUM
200 CONTINUE
   IF(NN.LT.5) GO TO 1000
   NK=NN
2000 NN=NN+1
   DO 300 JQ=1,4
      CALL INTEG(FSUM,NN,JQ,IQ)
      FSUM=FSUM*R**2
      NM=NN-NK
      GO TO (6,7,8,9),NM
6   AWO(JQ)=FSUM
      GO TO 300
7   AVI(JQ)=FSUM
      GO TO 300
8   AVI(JQ)=FSUM
      GO TO 300
9   AVI(JQ)=FSUM
300 CONTINUE
   IF(NN.LT.9) GO TO 2000
   NK=NN
3000 NN=NN+1
   CALL INTEG(FSUM,NN,JQ,IQ)
   FSUM=FSUM*CK*ANO
   NM=NN-NK
   GO TO (10,11,12,13,14,15,16,17),NM
10  AFO1P1=FSUM
      GO TO 400
11  AFO1P2=FSUM
      GO TO 400
12  AFO1P3=FSUM
      GO TO 400
13  AFO2P1=FSUM
      GO TO 400
14  AFO2P0=FSUM
      GO TO 400
15  AFO2P1=FSUM
      GO TO 400
16  AFZ2PO=FSUM
    GO TO 400
17  AFZ2P2=FSUM
400  IF(NN.LT.17) GO TO 3000
    NK=NN
4000  NN=NN+1
    DO 500  JQ=1,4
    CALL INTEG(FSUM,NN,JQ,IQ)
    FSUM=FSUM/R*CK*ANO
    NM=NN-NK
    GO TO ( 18,19,20,21,22),NM
18  AHIII(JQ)=FSUM
    GO TO 500
19  AHIII(JQ)=FSUM
    GO TO 500
20  AHIII(JQ)=FSUM
    GO TO 500
21  AHIIV(JQ)=FSUM
    GO TO 500
22  AHIIV(JQ)=FSUM
500  CONTINUE
    IF(NN.LT.22) GO TO 4000
    NK=NN
5000  NN=NN+1
    DO 600  JQ=1,6
    DO 600  IQ=1,6
    CALL INTEG(FSUM,NN,JQ,IQ)
    NM=NN-NK
    GO TO ( 23,24),NM
23  FSUM=FSUM*WL/ABS(OMEGA)
    CARWA(JQ,IQ)=FSUM
    GO TO 600
24  FSUM=FSUM*WL/OMEGA**2
    ARWA(JQ,IQ)=FSUM
600  CONTINUE
    IF(NN.LT.24) GO TO 5000
NN=25
DO 700 JQ=1,6
DO 700 IQ=1,3
CALL INTEGR(FSUM,NN,JQ,IC)
FSUM=FSUM*WL/OMEGA**2
ARWG(JQ,IQ)=FSUM
700 CONTINUE
NN=25
DO 801 JQ=1,4
CALL INTEGR(FSUM,NN,JQ,IC)
FSUM=FSUM*CK/R
CAHII(JQ)=FSUM
801 CONTINUE
NK=NN
2003 NN=NN+1
CALL INTEGR(FSUM,NN,JQ,IC)
FSUM=FSUM*CK*AND
NK=NN-NK
GOTO (27,28,29,30),NM
27 AFT3P0=FSUM
GO TO 2003
28 AFT3P1=FSUM
GO TO 2003
29 AFZ3P0=FSUM
GC TO 2003
30 AFZ3P1=FSUM
IF(IDEBUG.EQ.0) GO TO 450
WRITE(6,50)((AH(I,J),J=1,4),I=1,4)
50 FORMAT(6,51)AH1,AHII,AHRZ,AHNR,AHIII,AHIV,AHV,AHVI,AHVI,CAHII
51 FORMAT(2X,AH1',T10,4(E15.7,2X))
% /2X,'AHII', T10,4(E15.7,2X)
% /2X,'AHRZ', T10,4(E15.7,2X)
% /2X,'AHNR', T10,4(E15.7,2X)
% /2X,'AHIII', T10,4(E15.7,2X)
% /2X,'AHIV', T10,4(E15.7,2X)
DO 780 JO=1,4
CALL INTEG(FSUM,NN,JO,IQ)
FSUM=FSUM*CK/R*ANO
OAHV(JQ)=FSUM
CONTINUE
NN=NN+1
DO 781 JO=1,4
CALL INTEG(FSUM,NN,JO,IQ)
FSUM=FSUM*CK/R*ANO
OAHV(JQ)=FSUM
CONTINUE
IF (ICFBUG.EQ.0) GO TO 851
WRITE(6,80) ((OAH(I,J),J=1,4),I=1,4)
FORMAT(2X,'OAH',4(T10,4(E15.7,2X)/1X))
WRITE(6,81) OAWD,OAV1,OAHII,OAHV,OAHIV
FORMAT(2X,'OAWD',T10,4(E15.7,2X))
FORMAT(2X,'OAV1',T10,4(E15.7,2X))
FORMAT(2X,'OAHII',T10,4(E15.7,2X))
FORMAT(2X,'OAHV',T10,4(E15.7,2X))
FORMAT(2X,'OAHIV',T10,4(E15.7,2X))
RETURN
END
SUBROUTINE INTEGR(FSUM,NN,JQ,IQ)
C
C NUMERICAL INTEGRATION----GALSSIAN QUADRATURE
C
COMMON /AREA2/NPT,XXX(20),A(20)
SUM=0.0
DO 40 JJJ=1,NPT
X=XXX(JJJ)
SUM=SUM+A(JJJ)*F(X,NN,JJJ,JQ,IQ)
40 CONTINUE
FSUM=0.5*SUM
RETURN
END
FUNCTION F(X,NN,JJJ,JQ,IC)

C TO DEFINE THE INTEGRAND FUNCTIONS

C COMMON/AREA/4/H(4,4,20),HI(4,20),HII(4,20),HRZ(4,20),HNR(4,20),
%WO(4,20),VQ(4,20),V1(4,20),V1(4,20)
A ,OH(4,4,20),OHG(4,20),OV1(4,20),OHIII(4,20),CHIII(4,20)
A ,OHV(4,20),OHIV(4,20)
COMMON/AKKH/FTOP1(20),FT1P0(20),FT1P2(20),FT2P1(20),FZ2P0(20),
/FZOP0(20),FZ1P1(20),FZ2P2(20)
A ,FT3P0(20),FT3P1(20),FZ3P0(20),FZ3P1(20)
COMMON/ADF/HII(4,20),HIV(4,20),HV(4,20),HVII(4,20),HVIII(4,20)
COMMON/WINGAR/TSAS(20,6,6),TSAS(20,6,6),TSAG(20,6,3)
G T0(1,2,3,4,5,6,7,8,9,10,11,12,13,14,15,16,17,18,19,20)
G21,22,23,24,25,26,27,28,29,30,31,32,33,34,35,36),NN
1 F=H(JC,IC,JJJ)
RETURN
2 F=HI(JQ,JJJ)
RETURN
3 F=HII(JQ,JJJ)
RETURN
4 F=HR/(JC,JJJ)
RETURN
5 F=HNR(JC,JJJ)
RETURN
6 F=WO(JQ,JJJ)
RETURN
7 F=VD(JC,JJJ)
RETURN
8 F=V1(JC,JJJ)
RETURN
9 F=V1(JQ,JJJ)
RETURN
10 F=FTOP1(JJJ)
RETURN
11 F=FT1P6(JJJ)
RETURN
RETURN
12 F=FT1P2(JJJ)
RETURN
13 F=FT2P1(JJJ)
RETURN
14 F=FZ0P0(JJJ)
RETURN
15 F=FZ1P1(JJJ)
RETURN
16 F=FZ2P0(JJJ)
RETURN
17 F=FZ2P2(JJJ)
RETURN
18 F=HIII(JQ, JJJ)
RETURN
19 F=HV(JQ, JJJ)
RETURN
20 F=HV(JQ, JJJ)
RETURN
21 F=HVI(IQ, JJJ)
RETURN
22 F=HVI(JQ, JJJ)
RETURN
23 F=TS(3)(JJJ, IQ, IQ)
RETURN
24 F=TSAS(JJJ, JQ, IQ)
RETURN
25 F=TSAG(JJJ, JQ, IQ)
RETURN
26 F=CHIII(JQ, JJJ)
RETURN
27 F=FT3P0(JJJ)
RETURN
28 F=FT3P1(JJJ)
RETURN
29 F=F3P0(JJJ)
RETURN
30  F=FZ3P1(JJJ)
RETURN
31  F=OH(JQ,JQ,JQ)
RETURN
32  F=QWO(JQ,JQ,JQ)
RETURN
33  F=QV1(JQ,JQ,JQ)
RETURN
34  F=OHIII(JQ,JQ,JQ)
RETURN
35  F=OHV(JQ,JQ,JQ)
RETURN
36  F=OHIV(JQ,JQ,JQ)
RETURN
END
SUBROUTINE A1NER
C TO DEFINE THE EQUATION'S COEFFICIENTS IN MATRIX FORM RELATING TO
C INERTIA TERMS
C
COMMON /PAMT/ ITYPE, IFLT
COMMON /AREA1/OMEGA, R, VEL, CL, CD, LAMDA, SNOMEG
COMMON /AREA6/ NOBLD, ROH, CHOD, AIB, CK, HMAST, ALOCK, ANO, HR
COMMON /AREA5/ AHI(4, 1), AHI(4, 2), AHI(4, 3), AHRZ(4), AMNR(4), AQO(4), AVO(4)
A, AVI(4), AVII(4), OAH(4, 4), OAVO(4), OAVI(4), OAVII(4), OAHIII(4), CAHIII(4)
A
OAHIV(4), OAHV(4)
COMMON /INERTI/ TTMI(4, 6, 3), TTCTJ(4, 6, 3), AMJT(4, 3, 6), CJT(4, 3, 6)
COMMON/AMATIC/TT(6, 5), C(6, 6), T(5, 6)
DIMENSION AMT(4, 5, 3), CJ(4, 3, 5), AM(4, 3, 5), TCJ(4, 5, 3)
DO 50 I=1, 4
DC 50 J=1, 5
DC 50 K=1, 3
AMT(I, J, K)=0.0
CJ(I, K, J)=0.0
DC 210 NM=1, 4
AMT(NM, 1, 3)=-AVO(NM)/R
AMT(NM, 2, 1)=AQO(NM)/R
AMT(NM, 3, 2)=-AVC(NM)*HR
AMT(NM, 3, 3)=AWI(NM)
AMT(NM, 4, 2)=-AWI(NM)
AMT(NM, 4, 3)=-AVO(NM)*HR
AMT(NM, 5, 1)=AV1(NM)
IF(I, ITYPE, EQ, 0) GO TO 30C
AMT(NM, 2, 1)=AQW0(NM)/R
AMT(NM, 5, 1)=OAV1(NM)
300 CONTINUE
DC 2 I=1, 6
DC 2 J=1, 3
DC 2 K=1, 5
DC 2 TTMI(NM, I, J)=TT(I, K)*AMT(NM, K, J)+TTMI(NM, I, J)
DO 3 1=1, 6
DC 3 J=2,3
TTMT(NM,1,J)=0.5*TTMT(NM,1,J)
CJ(NM,2,3)=2.0*AW1(NM)
CJ(NM,3,4)=2.5*AW1(NM)
DC 5 I=1,5
DC 5 J=1,3
5 TCJ(NM,1,J)=CJ(NM,1,J)
CC 6 I=1,6
DO 6 J=1,3
DC 6 K=1,5
6 TCTCJ(NM,1,J)=TT(I,K)*TCJ(NM,K,J)*TCTCJ(NM,1,J)
DO 100 I=1,6
DC 100 J=2,3
100 TCTCJ(NM,1,J)=0.5*TCTCJ(NM,1,J)
CC 7 I=1,5
CC 7 J=1,6
7 T(I,J)=TT(J,I)
CC 8 I=1,3
DC 8 J=1,5
8 AM(NM,1,J)=AMT(NM,1,J)
DO 9 I=1,3
DC 9 J=1,6
DC 9 K=1,5
9 AMT(NM,1,J)=AM(NM,1,K)*T(K,J)+AMT(NM,1,J)
DO 10 I=1,3
CO 10 J=1,6
DC 10 K=1,5
10 CJT(NM,1,J)=CJ(NM,1,K)*T(K,J)+CJT(NM,1,J)
21U CONTINUE
RETURN
END
SUBROUTINE AEROMT

TO DEFINE THE EQUATION'S COEFFICIENTS IN MATRIX FORM RELATING TO AERODYNAMIC TERMS

COMMON /PARMT/ ITYPE , IFLT
COMMON /AREA6/NBLOD ,RCH,CHOD, AIB,CKHMAST, ALOCK,AND,HR
COMMON /AREA5/ AHI(4,4), AHI(4), AHI(4), AHRZ(4), AHR(4), AW(4), AVO(4)
COMMON /AREA4/ AHI(4), AHI(4), CAH(4), OAV(4), OAVH(4), OAVH(4), CAHII(4)
COMMON /AREA3/ CAH(4), OAVH(4)
COMMON /AREA2/ AHI(4), AHI(4), CAH(4), OAV(4), OAVH(4), OAVH(4), CAHII(4)
COMMON /AREA1/ AHI(4), AHI(4), CAH(4), OAV(4), OAVH(4), OAVH(4), CAHII(4)
COMMON /AREA0/ AHI(4), AHI(4), CAH(4), OAV(4), OAVH(4), OAVH(4), CAHII(4)
COMMON /AERO/ AFTOP1, AFT1F0, AFT1P2, AFT2P1, AF2P0P0, AFZ1P1, AFZ2P0,
COMMON /AMATIC/ TT(6,5), C(6,6), T(5,6)
COMMON /ARR/WGUST(6,6), CAMX(6,6), AMX(6,6), DQ(4,6,3), Q(4,6,3)
COMMON /COUPL/ AKPC(4), AKPO(4)
DIMENSION CDHMX(4,3,5), CHMX(4,3,5)
DIMENSION GUST(5,6), CCAMX(5,5), CCDAMX(6,5), CAMX(5,5), CCAMX(6,5)
*CDQ(4,5,3), CQ(4,5,3)
CC 100 I=1,4
CC 100 J=1,3
CC 100 K=1,5
CDHMX(I,J,K)=0.0
CHMX(I,J,K)=0.0
CQ(I,K,J)=0.0
100
CC(I,K,J)=0.0
DC 101 I=1,5
DC 102 J=1,5
CMX(I,J)=0.0
1J2 CCAMX(I,J)=.0
CC 103 K=1,6
GUST(K,K)=0.0
CCDAMX(K,1)=0.0
103 CCAMX(K,1)=0.0
101 CONTINUE
DO 1 I=1,2
DO 1 J=1,6
1 T(I,J)=T(I,J)/R
DO 2 I=1,6
DO 2 J=1,2
2 TT(I,J)=TT(I,J)/R
GUST(1,1)=0.5*AFT1PO
GUST(2,3)=AFZ2PO
GUST(3,1)=-0.5*AFZ1P1
GUST(3,2)=-HR*AFT1PO *C.5
GUST(4,1)=0.5*HR*AFT1PO
GUST(4,2)=-AFZ1P1 *0.5
GUST(5,3)=AFT2P1
GUST(1,6)=J.5*AFT3P0
GUST(2,4)=AFZ3PO
GUST(3,5)=-0.5*HR*AFT3PC
GUST(3,6)=0.5*AFZ3P1
GUST(4,5)=-0.5*AFZ3P1
GUST(4,6)=-0.5*HR*AFT3PO
GUST(5,4)=AFT3P1
DO 5 I=1,6
DO 5 J=1,6
DO 5 K=1,5
5 WGUST(I,J)=TT(I,K)*GUST(K,J)+WGUST(I,J)
DO 6 I=1,6
DO 6 J=1,3
6 WGUST(I,J)=WGUST(I,J)*ABS(RAMDA)
CDAMX(1,1)=0.5*AFT1PO
CDAMX(1,3)=-0.5*AFT2P1
CDAMX(1,4)=0.5*HR*AFT1PO
CDAMX(2,2)=AFZ2PO
CDAMX(2,5)=AFZ1P1
CDAMX(3,1)=-C.5*AFZ1P1
CDAMX(3,3)=0.5*(HR**2*AFT1PO+AFZ2P2)
CDAMX(3,4)=0.5*HR*(AFT2P1-AFZ1P1)
CCAMX(4,1) = 0.5*HR*AFT1PO
CCAMX(4,3) = HR*(-AFT2P1+AFZ1P1) * 0.5
CCAMX(4,4) = 0.5 *(HR**2*AFT1P0+AFZ2P2)
CCAMX(5,2) = AFT2P1
CCAMX(5,5) = AFT1P2

DC 9 I=1,6
DC 9 K=1,6
DC 9 J=1,5
DO 9 K=1,5
CCDAMX(I,J) = TT(I,K)*CDAMX(K,J) + CCDAMX(I,J)

DC 11 I=1,6
DC 11 J=1,6
DC 11 K=1,5

DAMX(I,J) = CDAMX(I,X)*T(K,J) + DAMX(I,J)
AMDA = ABS(AMDA)
CAMX(1,4) = -0.5*AMDA*AFT1P0+AFZOPQ
CAMX(3,3) = HR*(AFZOPQ-0.5*AMDA*AFT1P0)
CAMX(3,4) = 0.5*AMDA*AFZ1P1-AFTOP1
CAMX(4,3) = -0.5*AMDA*AFZ1P1
CAMX(4,4) = HR*(-0.5*AMDA*AFT1PC+AFZOPU)
DC 12 I=1,6
DC 12 J=1,5
DC 12 K=1,5

CCAMX(I,J) = TT(I,K)*CA MX(K,J) + CCAMX(I,J)

DC 13 I=1,6
DC 13 J=1,6
DC 13 K=1,5

AMX(I,J) = CCAMX(I,K)*T(K,J) + AMX(I,J)

DO 40 NM=1,4
CEQ(NM,1,3) = -0.5*AHIII(NM)
CEQ(NM,2,1) = AHV(NM)
CEQ(NM,3,2) = -0.5*HR*AHIII(NM)
CEQ(NM,3,3) = 0.5*AHVI(NM)
CEQ(NM,4,2) = -0.5*AHVI(NM)
CEQ(NM,4,3) = -0.5*HR*AHIII(NM)
CEQ(NM,5,1) = AHIV(NM)
CQ(NM,1,2) = 0.5*AHIII(NM) * SIKCMEG
CQ(NM,3,2)=0.5*(AHVI(NM)*AHVI(NM)*SNOMEG)
CQ(NM,3,3)=-0.5*HR*AHIII(NM)*SNOMEG
CQ(NM,4,2)=0.5*HR*AHIII(NM)*SNOMEG
CQ(NM,4,3)=0.5*(AHVI(NM)+AHVI(NM)*SNOMEG)
IF(ITYPE.EQ.0) GO TO 110
CDQ(NM,2,1)=0AHV(NM)
CDQ(NM,5,1)=0AHV(NM)
CQ(NM,1,3)=0.5*AKPC(NM)*AFT3P0
CQ(NM,2,1)=AKPC(NM)*AFT3P0
CQ(NM,3,2)=CQ(NM,3,2)-0.5*HR*AKPC(NM)*AFT3P0
CQ(NM,3,3)=CQ(NM,3,3)+0.5*AKPC(NM)*AFZ3P1
CQ(NM,4,2)=CQ(NM,4,2)-0.5*AKPC(NM)*AFZ3P1
CQ(NM,4,3)=CQ(NM,4,3)-0.5*HR*AKPC(NM)*AFT3P0
CQ(NM,5,1)=AKPC(NM)*AFT3P1

110 CONTINUE
DO 16 I=1,6
DO 16 J=1,3
DO 16 K=1,5
Q(NM,I,J)=TT(I,K)*CQ(NM,K,J)+Q(NM,I,J)
16 DQ(NM,I,J)=TT(I,K)*CDQ(NM,K,J)+DQ(NM,I,J)
C AERO FOR BLADES DUE TO WING MOTION
CDHMX(NM,1,2)=AHRZ(NM)
CDHMX(NM,1,5)=AHNR(NM)
CDHMX(NM,2,3)=-HR*AHII(NM)
CDHMX(NM,2,4)=-AHII(NM)
CDHMX(NM,3,1)=-AHII(NM)
CDHMX(NM,3,3)=AHII(NM)
CDHMX(NM,3,4)=-HR*AHII(NM)
CHM(NM,2,3)=AMDA*AHII(NM)
CHM(NM,3,4)=AMDA*AHII(NM)
DC 20 I=1,3
DO 20 J=1,6
DC 20 K=1,5
DHMAX(NM,I,J)=CDHMX(NM,I,K)*T(K,J)+DHMAX(NM,I,J)
20 DHMAX(NM,I,J)=CHM(NM,I,K)*T(K,J)+DHMAX(NM,I,J)
40 CONTINUE
SUBROUTINE EQMTX(IDOF)

TO DEFINE THE COEFFICIENT MATRICES A, B, C AND D IN EQ. 2.3

COMMON /PARMT/ ITYPE, IFLT
COMMON/AREA,B/BLAM(4),WLAM(6),BRAM(4),WRAM(6),BLAMO(4),BRAMO(4)
COMMON /AREA1/OMEGA, R, VEL, CL, CD, RAMDA, SNOMEG
COMMON /AREA5/NOBLD, FCH, CHOD, A1B, CK, FMST, ALOCK, ANO, HR
COMMON/AMATC/TT(6,5),C(6,6), T(5,6)
COMMON/AREA5/AH(4,4),AH1(4,4),AHII(4,4),AHRZ(4,4),AHNR(4,4),AOD(4,4),AVO(4,4)
COMMON/INERTI/TTMT(4,6,3),TTCTJ(4,6,3),AMJT(4,3,6),CJT(4,3,6)
COMMON /ARR/WGUST(6,6),CAMX(6,6),AMX(6,6),DQ(4,6,3),Q(4,6,3)
COMMON /ARR/DAW(6,6),DARWA(6,6),ARWG(6,6)
COMMON /DOF18/AA(19,19),B(19,19),CCY(19,19),DDY(19,6)
COMMON /COUPL/ AKPC(4),AKPD(4)
WRITE(6,50)

450 FCRMAT(///1X,75(1H-1)///15X,44HEQUATIONS OF MOTION ; A\times X + B\times X^2 + C
Ex=X=D\times E ,///1X,75(1H-1)///)
DO 801 I=1,18
801 AAY(I,I)=1.0
DO 802 NM=1,4
DO 802 I=1,3
DO 802 J=1,6
AAY(3*(NM-1)+I,J+12)=AMJT(NM,I,J)
802 AAY(J+12,3*(NM-1)+I)=ANC*TTMT(NM,J,I)
DO 804 I=1,4
B(3*I-1,3*I-1)=2.*SNOMEG
9.34 B(3*I-1,3*I-1)=-2.*SNOMEG
DO 805 J=1,4
DC 806 I=1,4
DO 805 K=1,3
805 B(3*(J-1)+K,3*(I-1)+K)=AH(J,I)
DC 8.16 NM=1,4
BBY (3*(NM-1)+I, J+12) = DHMAX(NM, I, J) + CJT(NM, I, J) * S Nome
BBY (J+12, 3*(NM-1)+I) = DC(NM, J, I) - ANO*TTCTJ(NM, J, I) * SNome
BBY(J+12, J+12) = DAMX(I, J) + C(I, J) * S Nome - DARWA(I, J)

CC 8U9 I=1, 4
CC 8UJ J=1, 4
CC 8U9 I=1, 4
CC 8UJ J=1, 4
CCY (3*I-1)+1, 3*(I-1)+1 = BLAM(I)
CCY (3*I-1)+2, 3*(I-1)+2 = BLAM(I)-1.0
CCY (3*I, 3*I) = BLAM(I)-1.0

CCY (3*J-1, 3*I) = AH(J, I) * S Nome

CCY (3*J, 3*I-1) = -AH(J, I) * S Nome

CC 811 NM=1, 4
DO 811 I=1, 3
DO 811 J=1, 6
CCY (3*(NM-1)+I, J+12) = HMAX(NM, I, J)
CCY (J+12, 3*(NM-1)+I) = G(NM, J, I)

DC 812 I=1, 6
DO 812 J=1, 6
CCY(I+12, J+12) = AMX(I, J) - ARWA(I, J)

CC 813 I=1, 6
CC 814 NM=1, 4
CDY (3*(NM-1)+1, 4) = -CAHIII(NM)
CDY (3*(NM-1)+2, 5) = -CAHIII(NM)
ECY (3*(NM-1)+3, 6) = -CAHIII(NM)
DDY(3*NM-1, 2) = AHI(NM) * ABS(RAMCA) * (-1.0)
DDY(3*NM-2, 3) = AHRZ(NM) * ABS(RAMDA) * (-1.0)

CCY (3*NM, 1) = -AHI(NM) * ABS(RAMDA) * (-1.0)

CC 815 I=1, 6
CC 816 J=1, 3
CCY(I+12, J) = -WGUST(I, J) + ARWG(I, J)
CC 817 J=4, 6
817  CEY(I+12,J)=-WGUST(I,J)
815  CONTINUE
     IF(IYREDLEQ0)GO TO 300
     DD 550 J=1,4
     CC 550 I=1,4
550  BBY(3*(J-1)+1,3*(I-1)+1)=OAHI(I,J)
     CC 550 I=1,4
     CCY(3*(I-1)+1,3*(I-1)+1)=BLAMO(I)
     CCY(3*(I-1)+2,3*(I-1)+2)=BLAM(I)-1.0
     CCY(3*I,3*I)=BLAM(I)-1.0
     DC 502 J=1,4
     ED 502 I=1,4
     CCY(3*J-2,3*I-2)=CCY(3*J-2,3*I-2)+AKPD(I)*OAHIII(J)
     CCY(3*J-1,3*I-1)=CCY(3*J-1,3*I-1)+AKPC(I)*CAHIII(J)
552  CCY(3*J,3*I+1)=CCY(3*J,3*I)+AKPC(I)*CAHIII(J)
     DC 501 NM=1,4
     CDY(3*(NM-1)+1,4)=-OAHIII(NM)
300  CONTINUE
     IF(IYREDLEQ.9)GO TO 100
     IF(IYREDLEQ.9)GO TO 205
     WRITE(6,451)
     WRITE(6,6)('( AAY(I,J),J=1,9),I=1,18')
     WRITE(6,6)('( BRY(I,J),J=1,9),I=1,18')
     WRITE(6,5)
     WRITE(6,452)
     WRITE(6,6)('( BBY(I,J),J=1,9),I=1,18')
     WRITE(6,6)('( BBY(I,J),J=10,18),I=1,18')
     WRITE(6,5)
     WRITE(6,453)
     WRITE(6,6)('( CCY(I,J),J=1,9),I=1,18')
     WRITE(6,6)('( CCY(I,J),J=10,18),I=1,18')
     WRITE(6,5)
     WRITE(6,454)
     WRITE(6,7)('( CDY(I,J),J=1,6),I=1,18')
     WRITE(6,1H1)
     FORMAT(1H1)
     FORMAT('////1X,18(/1X,9(E12.5,1X))')
7   FORMAT(//1X,18(/1X,6(E12.5,1X)))
451  FORMAT(2CX,'A MATRIX=')
452  FORMAT(//20X,'B MATRIX=')
453  FORMAT(//20X,'C MATRIX=')
454  FORMAT(//20X,'D MATRIX=')
RETURN
CONTINUE
DO 201 I=1,6
DC 201 J=7,9
AAY(I,J)=AAY(I,J+6)
BRY(I,J)=BRY(I,J+6)
CCY(I,J)=CCY(I,J+6)
AAY(J,I)=AAY(J+6,I)
BRY(J,I)=BRY(J+6,I)
201  CCY(J,I)=CCY(J+6,I)
DO 202 I=7,9
DC 202 J=7,9
AAY(I,J)=AAY(I+6,J+6)
BRY(I,J)=BRY(I+6,J+6)
CCY(I,J)=CCY(I+6,J+6)
DO 203 I=7,9
DC 203 J=7,9
204  CCY(I,J)=CDY(I+6,J)
IF(FLX.EQ.0) GO TO 205
WRITE(6,451)
WRITE(6,850)((AAY(I,J),J=1,9),I=1,9)
WRITE(6,452)
WRITE(6,850)((BRY(I,J),J=1,9),I=1,5)
WRITE(6,453)
WRITE(6,850)((CCY(I,J),J=1,9),I=1,9)
WRITE(6,454)
WRITE(6,550)((DDY(I,J),J=1,6),I=1,9)
850  FORMAT(//1X,9(/1X,9(E12.5,1X)))
950  FORMAT(//1X,9(/1X,6(E12.5,1X)))
205  CONTINUE
RETURN
SUBROUTINE AUTO(IDOF)

IN AUTOROTATION FLIGHT ANOTHER DEGREE OF FREEDOM IS ADDED

COMMON /PARMT/   ITYPE ,IFLT
COMMON /AMATIC/TT(6,5),C(6,6)  ,T(5,6)
COMMON /AREA6/NOBLD,ROH,CHOD,AIR,CK,HMAST ,ALCCK ,ANG,HR

COMMON /JEF18/AAV(19,19),BBY(19,19),CCY(19,19),DDY(19,6)
COMMON /COUPL/  AKPC(4),AKP0(4)
COMMON /AERO/AF1P1,AF1P2,AF2P1,AF2P2,AF2PO,AFZ1P1,AFZ2P0,
@AFZ2P2,AH1(4),AH11(4),AH111(4),AHV(4),AHV1(4),AHV11(4)

-NE=4
-NH=6
-NR=19

DO 11 I=1,NB
 AAY(3*I-2,NR)=AV1(I)
 AAY(NR,3*I-2)=AV1(I)*ANG
 BBY(3*I-2,NR)=AHNR(I)
 BBY(NR,3*I-2)=AHIV(I)
 CONTINUE

11 DO 12 I=1,NB
 BBY(NR,3*NB+I)=AF2P1*T(2,I)
 BBY(3*NR+I,NR)=AFZ1P1*T(2,I)
 CONTINUE

AAY(NR,NR)=AIR*AND
BBY(NR,NR)=AF1P2
CCY(NR,3)=-AF2P1
DDY(NR,4)=-AF3P1
IF(ITYPE.EQ.0) GO TO 13

DO 14 I=1,NB
 AAY(3*I-2,NR)=AV1(I)
 AAY(NR,3*I-2)=AV1(I)*ANG

AUTO0001
AUTO0002
AUTO0003
AUTO0004
AUTO0005
AUTO0006
AUTO0007
AUTO0008
AUTO0009
AUTO0010
AUTO0011
AUTO0012
AUTO0013
AUTO0014
AUTO0015
AUTO0016
AUTO0017
AUTO0018
AUTO0019
AUTO0020
AUTO0021
AUTO0022
AUTO0023
AUTO0024
AUTO0025
AUTO0026
AUTO0027
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AUTO0029
AUTO0030
AUTO0031
AUTO0032
AUTO0033
AUTO0034
AUTO0035
AUTO0036
BBY(NR, 3*I-2)=UATHV(I)
CCY(NR, 3*I-2)=AKPG(I)*AFT3P1
14 CONTINUE
13 CONTINUE
IF(IDCF, EG. 9) GO TO 100
WRITE(6, 451)
WRITE(6, 6) (AAY(I, J), J=1,9), I=1,19
WRITE(6, 8) (AAY(I, J), J=10,19), I=1,19
WRITE(6, 5)
WRITE(6, 452)
WRITE(6, 6) (BBY(I, J), J=1,9), I=1,19
WRITE(6, 8) (BBY(I, J), J=10,19), I=1,19
WRITE(6, 5)
WRITE(6, 453)
WRITE(6, 6) (CCY(I, J), J=1,9), I=1,19
WRITE(6, 8) (CCY(I, J), J=10,19), I=1,19
WRITE(6, 5)
WRITE(6, 454)
WRITE(6, 7) (DDY(I, J), J=1,6), I=1,19
5 FORMAT(1H1)
6 FORMAT(/1X, 19(/1X, 9(E12.5, 1X)))
7 FORMAT(/1X, 19(/1X, 6(E12.5, 1X)))
8 FORMAT(/1X, 19(/1X, 10(E12.5, 1X)))
RETURN
14 CONTINUE
DC 15 I=1,6
AAY(I, 1I)=AAY(I, 19)
BBY(I, 1I)=BBY(I, 19)
CCY(I, 1I)=CCY(I, 19)
DDY(I, 1I)=DDY(I, 19)
16 CONTINUE
DO 16 I=1,3
AAY(I*6, 1I)=AAY(I+12, 1I)
BBY(I+6,I)=BBY(I+12,19)
CCY(I+6,I)=CCY(I+12,19)
AAY(I,i+6)=AAY(I+19,1+12)
BBY(I+19,1+12)=BBY(I+19,1+12)
CCY(I+6,I)=CCY(I+19,1+12)

CONTINUE
AAY(10,10)=AAY(19,19)
BBY(19,19)=BBY(19,19)
CCY(10,10)=CCY(19,19)
WRITE(6,451)
WRITE(6,850)((AAY(I,J),J=1,10),I=1,10)
WRITE(6,452)
WRITE(6,850)((BBY(I,J),J=1,10),I=1,10)
WRITE(6,453)
WRITE(6,850)((CCY(I,J),J=1,10),I=1,10)
WRITE(6,454)
WRITE(6,850)((DDY(I,J),J=1,6),I=1,10)

451 FORMAT(20X,'A MATRIX=')
452 FORMAT(//20X,'B MATRIX=')
453 FORMAT(//20X,'C MATRIX=')
454 FORMAT(//20X,'D MATRIX=')
850 FORMAT(//1X,10('E12.5,1X'))
950 FORMAT(//1X,10('E12.5,1X'))
RETURN
END
SUBROUTINE GUSTCC(CELST,DBY,L,NZ)
  C
  TO DEFINE GUST AND BLADE PITCH CONTROL COMPONENTS
  C
  DIMENSION CELST(6),ECY(19,6),NZ(19)
  DO 1 I=1,L
  DO 2 I=1,L
  DO 2 J=1,6
  2 DBZ(I)=ECY(I,J)*CELST(J)*CLZ(I)
RETURN
END
GUST0001
GUST0002
GUST0003
GUST0004
GUST0005
GUST0006
GUST0007
GUST0008
GUST0009
GUST0010
GUST0011
GUST0012
SUBROUTINE FRQRES(L,AAA,HEF,CCC,DOD,IFLT,ICDF)
C
C) TO CALCULATE THE FREQUENCY RESPONSE
C
DIMENSION AAA(19,19),HEF(19,19),CCC(19,19),DOD(19)
DOUBLE PRECISION FREQ,DPF(19,19),DPG(19,19),DPF(19)
COMPLEX=1.0,CCC(19,19),CCC(19),DOD(19)
WRITE(6,10C2)
100 FORMAT(/10X,'1Q1C',T22,'Q1C',T34,'Q1S',T46,'Q2C',T54,'Q2C',T70,)
+ 'Q2S',T82,'WING 1', T94,'WING 2',T106,'WING 3')
G: T) 1003
1004 FORMAT(/10X,'1Q1C',T22,'Q1C',T34,'Q1S',T46,'Q2C',T54,'Q2C',T70,)
+ 'Q2S',T82,'Q3C',T94,'Q3C',T106,'Q3S' /10X,'Q4S',T22,)
+ 'Q4C',T34,'Q4S',T46,'WING 1', T54,'WING 2', T70,'WING 3',)
+ 'T82','WING 4', T94,'WING 5',T106,'WING 6')
1005 CONTINUE
IF(1FLT.EQ.0) GC TO 1007
WRITE(6,10C5)
1006 FORMAT(/10X,'C(A/R)/DT')
1007 CONTINUE
DO 100 I=1,L
DO 100 J=1,L
DPF(I,J)=AAA(I,J)
DPG(I,J)=CCC(I,J)
100 CONTINUE
DO 100 I=1,L
BPO(I) =CCC(I)
1001 CONTINUE
IK=1
FREQ=L*0.04
211  F=F+G+C+[C.GG C
IK=IK+1
GO TO 511
311  F=F+G+C+[C.GG C
IK=IK+1
GO TO 511
611  F=F+G+C+[C.GG C
IK=IK+1
GO TO 511
711  F=F+G+C+[C.GG C
IK=IK+1
GO TO 511
811  F=F+G+C+[C.GG C
IK=IK+1
GO TO 511
511  DO 100 I=1,L
DO 100 J=1,L
100  CCMA(I,J)=CMPLX(CPC(I,J))/FREQ**2< DPA(I,J), FREQ=OPH(I,J))
DO 301 I=1,L
301  CCME(I)=D CMPLX( CPC(I),C.GG C)
CALL GAEC(I(CCMA,CCMC,L,FREQ,IDO,F,FLT)
IF(1K.LT.10) GC TO 211
IF(1K.LT.25) GC TO 311
IF(1K.LT.37) GC TO 411
IF(1K.LT.57) GC TO 611
IF(1K.LT.71) GC TO 711
RETURN
END
SUBROUTINE GAEL1(A,Y,N,FRG,ILFE,ILRT)
C
C THE GAUSS-JORDAN REDUCTION
C
COMPLEX X (16), (15,15), Y (15), X (15)
DOUBLE PRECISION FRG, FCAPS
DIMENSION Ax (15)
COMMON / FFMAG/ , FRB (4), FRC (4), FRW (L), IFRMAG
K = N - 1
DO 10 I = 1, M
L = I + 1
DO 10 J = L, N
IF (CCABS (A (I, J)) .GE. E0000000D0) GO TO 10
DO 8 K = L, N
A (J, K) = A (J, K) - A (I, K) * A (J, I) / A (I, I)
8 CONTINUE
Y (J) = Y (J) - Y (I) * A (J, I) / A (I, I)
10 CONTINUE
X (N) = Y (N) / A (N, N)
DO 20 I = 1, M
K = N - I
L = K + 1
DO 20 J = L, N
Y (K) = Y (K) - X (J) * A (K, J)
20 X (K) = Y (K) / A (K, K)
DO 40 I = 1, N
40 A (I) = CCABS (X (I))
IF (IFRMAG .GE. 1) GO TO 50
IF (ITDF .GE. 9) GO TO 51
LT = 4
LTT = 6
GO TO 54
51 LT = 2
LTT = 3
54 GC 52 1 = 1, LT
DO 52 J = 1, 3
52  ABX(3*(I-1)+J) = ABX(3*(I-1)+J)*FRB(I)
55  DO 55 I = 1, LT
55  ABX(3*(I-1)+1) = ABX(3*(I-1)+1)*FRBD(I)/FRB(I)
53  DO 53 I = 1, LT
53  ABX(I+3*LT) = ABX(I+3*LT)*FRW(I)
50  CONTINUE
50  IF (IFLT.EQ.0) GO TO 56
56  ABX(N) = FREQ*ABX(N)
50  CONTINUE
100  WRITE(6,100) FREQ
100  FORMAT(1X,'---',F6.2, '---')
200  WRITE(6,200)(ABX(I), I = 1, N)
200  FORMAT(1X,9(E10.3,2X))
RETURN
END
SUBROUTINE EIGEN(N,AAA,RRB,CCC,DDD,IO2E)

ROUTINE TO FORM AN EIGENVALUE PROBLEM AND TO CALL EIPACK SUBROUTINE

DIMENSION AAA(19,19),RRB(19,19),CCC(19,19),DDD(19,6)
DIMENSION A(361),L(19),N(19),AINV(19,19)
DIMENSION AAA(19,19),RRB(19,19),CCC(19,19),DDD(19,6)
REAL*8 AFRG(38,38),WPI(38),WI(38),ZP(38,38)
REAL*8 SCALE(38)
INTEGER INT(38)
DIMENSION BIG(25),ARMOD(25,25),DAMP(38)
COMPLEX AMOD(25,25),RTGCOM(25);
COMMON/FRMAG/ FRR(4),FRBO(4),FRW(6),FRMAG
ICEBUG=0
WRITE(6,153)
DO 3003 I=1,N
CO 3004 J=1,N
AAA(I,J)=C.0
RRB(I,J)=0.0
CCN(I,J)=0.0
DO 3005 K=1,6
BBN(I,K)=0.0
3005 CONTINUE
LI=0
DO 1000 J=1,N
DO 1700 I=1,N
LI=LI+1
1000 A(LL)=AAA(I,J)
CALL MINV(A,N,D,L,M)
LI=0
DO 2006 J=1,N
DO 2000 I=1,N
LL=LL+1
2000 AINV(I,J)=A(LL)
DO 3000 I=1,N
DO 3001 J=1,N
DO 3001 K=1,N
AAN(I,J)=AINV(I,K)*AAA(K,J)+AAN(I,J)
RRN(I,J)=ATNV(I,K)*BRR(K,J)+RRN(I,J)
3001
CCN(I,J)=ATNV(I,K)*CCC(K,J)+CCN(I,J)
DO 3002 J=1,6
DO 3002 K=1,N
3002
DDN(I,J)=ATNV(I,K)*DDD(K,J)+DDN(I,J)
3000 CONTINUE
6000 N2=2*N
DO 300 I=1,N
DO 300 J=1,N
AEIG(I,J)=-RRN(I,J)
300
AEIG(I,J+N)=-CCN(I,J)
DO 301 I=1,N
DO 301 J=1,N2
301 AEIG(I+N,J)=0.0000
DO 312 I=1,N
302 AEIG(I+N,I)=1.0000
CALL EPACK(3B,N2,AEIG,WR, WI, ZP, IERROR, SCALE, INT)
IF (IERROR.EQ.0) GO TO 152
WRITE(6,150) IERROR
150 FORMAT(15X,'IERROR=',I5)
152 CONTINUE
IF (IERROR.EQ.0) GO TO 61
WRITE(6,67)(WI(I),I=1,N)
67 FORMAT(15X,'W(I)=',W(I),I=1,N)
N3=N/3
DC 400 I=1,N3
IJ=6*(I-1)+1
KL=6*(IJ-1)+6
400 WRITE(6,251) ((ZP(I,J),J=IJ,KL),I=1,N2)
251 FORMAT(15X,'ZP(I,J)=',ZP(I,J),J=IJ,KL,I=1,N2)
IF (3*N3.EQ.0) GO TO 61
K=2*(N-3*N3)
IJ=KL+1
KL=KL+K
WRITE(6,751) (ZP(I,J), J=1J, Kl), I=1, N2!
751 CONTINUE
FORMAT(/1X,(/1X,(2D15.7)))
61 CONTINUE
DO 140 I=1, N2
XX=SGNJ(WR(I))*2+W(1)**2
IF(XX.EQ.0.0) GO TO 141
DAMP(I)=-<SGNL(WR(I))/SQRT(XX)
GO TO 140
141 DAMP(I)=0.0
140 CONTINUE
N1=N1+1
LK=0
LKK=0
NTOT=0
I=1
64 CONTINUE
IF(I.GE.N2+1) GO TO 63
NTOT=NTOT+1
K=NTOT
IF(W(I).EQ.0.0) GO TO 65
INT(I)=K
INT(I+1)=K
LK=LKK+1
LKK=LK+1
IF(IDERBUG.F0.0) GO TO 66
WRITE(6,691), N2, LK, LKK, K
69 FORMAT(1X,4I5)
68 CONTINUE
DO 50 J=N1, N2
IF(IDERBUG.F0.0) GO TO 71
WRITE(6,721)ZP(J,LK), ZP(J,LKK)
72 FORMAT(1X,2D15.7)
71 CONTINUE
AMOD(K,J-N1+1)=CMPLX(SGNL(ZP(J,LK)),SGNL(ZP(J,LKK)))
50 CONTINUE
I=I+2
GO TO 64
CONTINUE
    INT(I)=K
    L,K=L,K+1
    L,K=L
    IF(IFRUG.EQ.0) GO TO 73
    WRITE(6,69)I,L,K,L,K,K
73  CONTINUE
    DC 66 J=N1,N2
    IF(IFRUG.EQ.0) GO TO 74
    WRITE(6,71)ZP(J,LK),ZP(J,LK)
74  CONTINUE
    AMOD(K,I-M1+1)=CMPLX(SNGL(ZP(J,LK)),0.0)
66  CONTINUE
    I=I+1
    GO TO 64
63  CONTINUE
    IF(IFRAG.EQ.1) GO TO 130
    IF(IFDF.EQ.9) GO TO 131
    LT=4
    LTT=6
    GO TO 134
131  LT=2
    LTT=3
134  CONTINUE
    DC 136 JT=1,NTOT
    DC 132 I=1,LT
    DC 132 J=1,3
132  AMOD(IJ,3*(I-1)+J)= AMOD(IJ,3*(I-1)+J)*FRB(I)
    DC 135 I=1,LT
135  AMOD(IJ,3*(I-1)+1)= AMOD(IJ,3*(I-1)+1)*FRRD(I)/FRB(I)
    DC 133 I=1,LT
133  AMOD(IJ,1+3*LT)=AMOD(IJ,1+3*LT)*FRW(I)
136  CONTINUE
136  CONTINUE
    GO 51 I=1,NTOT
DO 51 J=1,N
 51  AMOD(I,J)=ABS(AMOD(I,J))
DO 52 I=1,NTOT
 52  BIG(I)=0.0
DO 53 J=1,N
IF(AMOD(I,J) .LE. BIG(I)) 53,53,54
 54  BIG(I)=AMOD(I,J)
 54  BIGCOM(I)=AMOD(I,J)
CONTINUE
53  CONTINUE
52  CONTINUE
DO 60 I=1,NTOT
DO 60 J=1,N
 60  AMOD(I,J)=AMOD(I,J)/BIG(I)
 60  AMOD(I,J)=AMOD(I,J)/BIGCOM(I)
CONTINUE
153  FORMAT('///15X,20(1H*)///20X,'EIGENVALUES',///15X, 20(1H*)',**
 153  &   ///20X,'** REAL PART **',3X,'** IMAGINARY PART **'
 153  &   ///,10X,'** DAMPING RATIO **'/
WRITE(6,151)(INT(I),WR(I),WI(I),DAMP(I),I=1,N2)
151  FORMAT('///9X,'NO. ',12.5X,DI5.7,5X,DI5.7,15X,15.7)
WRITE(6,59)
59  FORMAT('///5X, 20 (1H*),///10X, 'EIGENVECTORS',///5X, 20(1H*)',**
 59  &   ///10X,'** REAL PART **',3X,'** IMAGINARY PART **'
WRITE(6,154)I,WR(IP),WI(IP)
154  FORMAT('///2X,'-- CORRESPONDING TO NO. ',12.1X,'EIGENVALUE --',**
 154  &   ///5X,('D10.3,'),'IMAG('D10.3,')'),**
 154  &   ///8X,'** ABSOLUTE VALUE **',20X,'** REAL PART **',2X,
 154  &   ///2X,'** IMAGINARY PART **',**
IF((IP+1).GT.N2) GO TO 752
IF(INT(IP).EQ.INT(IP+1)) IP=IP+1
157  CONTINUE
DO 56 J=1,N
WRITE(6,57)AMOD(I,J),AMOD(I,J)
57  FORMAT(10X,F15.7,22X,F15.7,3X,F15.7)
SUBROUTINE EIPACK(NM, N, A, WR, WI, Z, IERR, SCALE, INT)

AN EIGENSYSTEM PROBLEM SOLVER FOR THE GENERAL MATRIX

INTEGER INT(N)
CALL BALANC(NM, N, LOW, IGH, SCALE)
CALL ELMHES(NM, N, LOW, IGH, A, INT)
CALL ELTRAN(NM, N, LOW, IGH, A, INT, Z)
CALL HQR2(NM, N, LOW, ICH, A, WB, WI, Z, IERR)
CALL BAIRAK(NM, N, LOW, IGH, SCALE, N, Z)
RETURN
END
SUBROUTINE BALANC(NM,N,A,LOW,IGH,SCALF)

INTEGER I,J,K,L,M,N,JJ,NM,IGH,LOW,IEXC
REAL*8 A(NM,N),SCALE(N)
REAL*8 DABS
LOGICAL NOCONV

THIS SUBROUTINE IS A TRANSLATION OF THE ALGOL PROCEDURE BALANCE,
NUM. MATH. 13, 293-304(1969) BY PARLETT AND REINSCH.
HANLECK FOR AUTO. COMP., VCL.II-LINEAR ALGEBRA, 315-326(1971).

THIS SUBROUTINE BALANCES A REAL MATRIX AND ISOLATES
EIGENVALUES WHENEVER POSSIBLE.

ON INPUT:
NM MUST BE SET TO THE ROW DIMENSION OF TWO-DIMENSIONAL
ARRAY PARAMETERS AS DECLARED IN THE CALLING PROGRAM
DIMENSION STATEMENT;
A IS THE ORDER OF THE MATRIX;
A CONTAINS THE INPUT MATRIX TO BE BALANCED.

ON OUTPUT:
A CONTAINS THE BALANCED MATRIX;
LCW AND IGH ARE TWO INTEGERS SUCH THAT A(I,J)
IS EQUAL TO ZERO IF
(1) I IS GREATER THAN J AND
(2) J=1,...,LCW-1 OR I=IGH+1,...,N;

ON ERROR:
NOCONV = .TRUE. IF AN EIGENVALUE CANNOT BE ISOLATED;
SCALE CONTAINS INFORMATION DETERMINING THE
PERMUTATIONS AND SCALING FACTORS USED.

SUI~PPOSE THAT THE PRINCIPAL SUBMATRIX IN ROWS LCW THROUGH IGH
HAS BEEN BALANCED, THAT P(I,J) DENOTES THE INDEX INTERCHANGED
WITH J DURING THE PERMUTATION STEP, AND THAT THE ELEMENTS
OF THE DIAGONAL MATRIX LSBF ARE DENOTED BY C(I,J). THEN
SCALE(J) = P(J), \quad \text{FOR } J = 1, \ldots, LCW-1
= C(J,J), \quad J = LCW, \ldots, IGH
= P(J), \quad J = IGH+1, \ldots, N.

THE ORDER IN WHICH THE INTERCHANGES ARE MADE IS N TO IGH+1,
THEN 1 TO LCW-1.

NOTE THAT 1 IS RETURNED FOR IGH IF IGH IS ZERO FORMALLY.

THE ALGOL PROCEDURE EXC CONTAINED IN BALANCE APPEARS IN
BALANC IN LINE. (NOTE THAT THE ALGOL RULES OF IDENTIFIERS
K,L HAVE BEEN REVERSED.)

QUESTIONS AND COMMENTS SHOULD BE DIREC~EC TO B. S. GARBCW,
APPLIED MATHEMATICS DIVISION, ARGONNE NATIONAL LABORATORY

RACIX IS A MACHINE DEPENDENT PARAMETER SPECIFYING
THE BASE OF THE MACHINE FLOATING POINT REPRESENTATION.
RACIX = 16.00 FOR LONG FCFM ARITHMETIC
CN S360: :::::::::::

DATA RACIX/2421CCCCC0CCCOCCCO/

B2 = RACIX * RACIX
K = 1
L = K
GO TO 1CC

IN-LINE PROCEDURE FOR ROW AND
C  COLUMN EXCHANGE
20  SCALE(M) = J
   IF (J .EQ. M) GC TC 5C
C
   DC 3C I = L, L
   F = A(I, J)
   A(I, J) = A(I, M)
   A(I, M) = F
30  CONTINUE
C
   DC 4C I = K, N
   F = A(J, I)
   A(J, I) = A(M, I)
   A(M, I) = F
40  CONTINUE
C
50  GC TC (8C,130), IEXC
C  SEARCH FOR ROWS ISOLATING AN EIGENVALUE
C  AND PUSH THEM DOWN
50  IF (L .EQ. 1) GC TC 28C
   L = L - 1
C
80  IF (L .EQ. 1) GC TC 28C
   L = L - 1
C
80  FOR J=L STEP -1 UNTIL 1 DO --
100  DC 120 JJ = 1, L
    J = L + 1 - JJ
C
110  I = 1, L
    IF (I .EQ. J) GC TC 110
    IF (A(J, I) .NE. C.CDC) GC TC 12C
110  CONTINUE
C
110  M = L
    IEXC = 1
120  CONTINUE
C
120  GC TC 14C

C ::::::::::: SEARCH FOR COLUMNS ISOLATING AN EIGENVALUE
AND PUSH THEM LEFT :::::::::::

130 K = K + 1
C
140 CC 170 J = K, L
C
CC 150 I = K, L
IF (I .EQ. J) GC TO 150
IF (A(I,J) .NE. C.OCC) GC TC 170
150 CONTINUE
C
W = K
IEXC = 2
GC TC 20
170 CONTINUE
C ::::::::::: NOW BALANCE THE SUBMATRIX IN ROWS K TO L ::::::::::
DO 180 I = K, L
180 SCALE(I) = L.OCC
C ::::::::::: ITERATIVE LLCP FOR NCRM REDUCTION ::::::::::
190 NOCCNV = .FALSE.
C
270 I = K, L
C = C*CDC
R = C*CDC
C
200 J = K, L
IF (J .EQ. I) GC TC 200
C = C + CABS(A(J,I))
R = R + CABS(A(I,J))
200 CONTINUE
C
G = R / RACIX
F = L.OCC
S = C + R
210 IF (C .GE. G) GC TC 220
F = F + RACIX
C = C * R
GC TC 21C

220  G = R * RADIX

230  IF (C .LT. G) GC TC 240
F = F / RADIX
C = C / R
GC TC 230

C :::::::::::::::::: NOW BALANCE ::::::::::::::::

240  IF ((C + P) / F .GE. 0.9500 * S) GC TC 270
G = 1.0000 / F
SCALE(I) = SCALE(I) * F
NOCCNV = .TRUE.

C

250  CC 25C J = K, N

A(I,J) = A(I,J) * G
C

260  CC 26C J = I, L

A(J,I) = A(J,I) + F
C

270  CONTINUE
C

IF (NOCCNV) GC TC 190
C

280  LOW = K
LOW = L
RETURN
C ::::::::::::::: LAST CARD OF BALANC :::::::::::::::
END
SUBROUTINE ELMHES(N,N,LCH,IGH,A,INT)

INTEGER I,J,M,N,L,A,NM,IGH,KPI,LCW,MP1,MP2

REAL*8 A(N,N)
REAL*8 X,Y
REAL*8 CARS
INTEGE INT(IGH)

THIS SUBROUTINE IS A TRANSLATION OF THE ALGOL PROCEDURE ELMHES,
NUM. MATH. 12, 349-361 (1968) BY MARTIN AND WILKINSON.


GIVEN A REAL GENERAL MATRIX, THIS SUBROUTINE
RECEIVES A SUBMATRIX SITUATED IN RCWS AND COLUMNS
LCW THROUGH IGH TO UPPER HESENBERG FORM BY
STABILIZED ELEMENTARY SIMILARITY TRANSFORMATIONS.

ON INPLT:

AM MUST BE SET TO THE ROW DIMENSION OF THE DIMENSIONAL
 ARRAY PARAMETERS AS DECLARED IN THE CALLING PROGRAM
 DIMENSION STATEMENT;

A IS THE ORDER OF THE MATRIX;

LOW AND IGH ARE INTEGERS DETERMINED BY THE BALANCING
SUBROUTINE BALANC. IF BALANC HAS NOT BEEN LSED,
SET LCW=1, IGH=N;

A CONTAINS THE INPLT MATRIX.

ON OUTPUT:

73210001-73210002
73210003-73210004
73210005-73210006
73210007-73210008
73210009-73210010
73210011-73210012
73210013-73210014
73210015-73210016
73210017-73210018
73210019-73210020
73210021-73210022
73210023-73210024
73210025-73210026
73210027-73210028
73210029-73210030
73210031-73210032
73210033-73210034
73210035-73210036
A contains the Hessenberg matrix. The multipliers which were used in the reduction are stored in the remaining triangle under the Hessenberg matrix;

int contains information on the rows and columns interchanged in the reduction, only elements low through |I| are used.

Questions and comments should be directed to B. S. Garabedian, Applied Mathematics Division, Argonne National Laboratory.

---

La = igh - 1
Kpi = low + 1
if (la .lt. kpi) go to 200

do 180 m = kpi, la
   mm1 = m - 1
   x = c * c0
   i = m
   cc 100 j = m, igh
      if (dabs(a(j,mm1)) .le. dabs(x)) go to 100
      y = a(j,mm1)
      i = j
   100 continue

int(m) = 1
if (i .eq. m) go to 130

::: INTERCHANGE ROWS AND COLUMNS OF A :::::

cc 110 j = mm1, n
   y = a(i,j)
   a(i,j) = a(m,j)
   a(m,j) = y
110 continue
C 0C 12C J = I, IGF
     Y = A(J,I)
     A(J,I) = A(J,N)
     A(J,N) = Y
120 CONTINUE
C :::::::::: END INTERCHANGE ::::::::::
130 IF (X .EQ. C.GCC) GC TO 180
     MP1 = N + 1
C 0C 16C I = MP1, IGF
     Y = A(I,MP1)
     IF (Y .EQ. C.GCC) GC TC 16C
     Y = Y / X
     A(I,MP1) = Y
C 0C 14C J = M, N
140 A(I,J) = A(I,J) - Y * A(M,J)
C 0C 15C J = 1, IGF
150 A(J,N) = A(J,N) + Y * A(J,I)
C 160 CONTINUE
C 180 CONTINUE
C 200 RETURN
C :::::::::: LAST CARD OF ELFINES ::::::::::
END
SUBROUTINE ELTRAN(NM, A, LCH, IGH, A, INT, Z)

INTEGER I, J, N, KL, PP, NP, NW, IGH, LOW, MPI
REAL*8 A(NM, IGH), Z(NW, N)
INTEGER INT(IGH)

THIS SUBROUTINE IS A TRANSLATION OF THE ALGCL PROCEDURE ELMTRANS,
NUM. MATH. 16, 181-204 (1970) BY PETERS AND WILKINSON.

THIS SUBROUTINE ACCUMULATES THE STABILIZED ELEMENTARY
SIMILARITY TRANSFORMATIONS USED IN THE REDUCTION OF A
REAL GENERAL MATRIX TO UPPER HESSENBURG FORM BY ELMHES.

ON INPUT:

NM MUST BE SET TO THE ROW DIMENSION OF THE D-COMENSIONAL
ARRAY PARAMETERS AS DECLARED IN THE CALLING PROGRAM
DIMENSION STATEMENT;

N IS THE ORDER OF THE MATRIX;

LCH AND IGH ARE INTEGERS DETERMINED BY THE BALANCING
SUBROUTINE BALANC. IF BALANC HAS NOT BEEN USED,
SET LOW=1, IGH=N;

A CONTAINS THE MULTIPLIERS WHICH WERE USED IN THE
REDUCTION BY ELMHES IN ITS LOWER TRIANGLE
BELOW THE SUBDIAGONAL;

INT CONTAINS INFORMATION ON THE ROWS AND COLUMNS
INTERCHANGE IN THE REDUCTION BY ELMHES.
ONLY ELEMENTS LOW THROUGH IGH ARE USED.
ON CLIPUT:

Z CONTAINS THE TRANSFORMATION MATRIX PRODUCED IN THE REDUCTION BY ELMFES.

QUESTIONS AND COMMENTS SHOULD BE DIRECTED TO B. S. GARBOW, APPLIED MATHEMATICS DIVISION, ARGONNE NATIONAL LABORATORY

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::: INITIALIZE Z TO Identity MATRIX ::::

CC 8C I = 1, N

CC 60 J = 1, N

60 Z(I,J) = 0.0

80 CONTINUE

KL = IGt - LOW - 1
IF (KL .LT. 1) CC TC 2C0

::: FOR MP=IGH-1 STEP -1 UNTIL LCH+1 CC ::::

CC 140 MP = 1, KL

MP = IGt - MP

MP1 = MP + 1

CC 1CO I = MP1, IGt

1CO Z(I,MP) = A(I,MP-1)

C

I = INT(MP)

IF (I .LT. IGt) CC TC 140

CC 1?C J = MP, IGt

Z(MP,J) = Z(I,J)

Z(I,J) = C.CCC
130 CONTINUE
C  
Z(I,MP) = L.CCC
140 CONTINUE
C
200 RETURN
C
END
Subroutine HQR2(NM,N,LCW,ICF,H,WR,VI,Z,IERR)

INTEGER I,J,K,L,N,E11,II,LL,MP,NA,NM,AN,
     ICF,ITS,LCW,MP2,ENP2,IERR
REAL*8 H(NM,N),HR(N),WR(N),VI(N),Z(NM,N)
REAL*8 P,Q,R,S,T,H,X,Y,RA,SA,VI,VR,ZZ,NCMP,MACHP
REAL*8 CSCRT,CAES,CSIGN
INTEGER MNC
LOGICAL ACTLAS
COMPLEX*16 Z3
COMPLEX*16 COMFLX
REAL*8 T3(2)
EQUIVALENCE (Z3,T3(1))

This subroutine is a translation of the Algol procedure HQR2, 87210018

This subroutine finds the eigenvalues and eigenvectors 87210022
of a real upper Hessenberg matrix by the QR method. The 87210023
eigenvectors of a real general matrix can also be found 87210024
if ELMHES and ELTRAN or CRTHERS and CRTRAN have 87210025
been used to reduce this general matrix to Hessenberg form 87210026
and to accumulate the similarity transformations.

On input:

NM must be set to the row dimension of two-dimensional 87210027
array parameters as declared in the calling program.

DIMENSION:

N is the order of the matrix.
LCW and IGH are integers determined by the balancing
SLBCUTNE BALANC. IF BALANC HAS NOT BEEN USED, 
SET LCW=1, IGH=N;

1 CONTAINS THE UPPER HESSEBERG MATRIX;
Z CONTAINS THE TRANSFORMATION MATRIX PROCED BY ELTRAN
AFTER THE REDUCTION BY ELMHES, OR BY CRTRAN AFTER THE
REDUCTION BY CRTHES, IF PERFORMED. IF THE EIGENVECTORS
OF THE HESSEBERG MATRIX ARE DESIRED, Z MUST CONTAIN THE
IDENTITY MATRIX.

ON OUTPUT:
1 HAS BEEN DESTROYED;
WR AND WI CONTAIN THE REAL AND IMAGINARY PARTS,
RESPECTIVELY, OF THE EIGENVALUES. THE EIGENVALUES
ARE UNCRRCUETE EXCEPT THAT COMPLEX CONJUGATE PAIRS
OF VALUES APPEAR CONSECUTIVELY WITH THE EIGENVALUE
HAVING THE POSITIVE IMAGINARY PART FIRST. IF AN
ERROR EXIT IS MADE, THE EIGENVALUES SHOULD BE CORRECT
FOR INDICES IERR+1,...,N;

Z CONTAINS THE REAL AND IMAGINARY PARTS OF THE EIGENVECTORS.
IF THE I-TH EIGENVALUE IS REAL, THE I-TH COLUMN OF Z
CONTAINS ITS EIGENVECTOR. IF THE I-TH EIGENVALUE IS COMPLEX
WITH POSITIVE IMAGINARY PART, THE I-TH AND (I+1)-TH
COLUMNS OF Z CONTAIN THE REAL AND IMAGINARY PARTS OF ITS
EIGENVECTOR. THE EIGENVECTORS ARE UNCRRCUALIZED. IF AN
ERROR EXIT IS MADE, NONE OF THE EIGENVECTORS HAS BEEN FOUND;

IERR IS SET TO
ZERO FOR NORMGAL RETURN,
J IF THE J-TH EIGENVALUE HAS NOT BEEN
DETERMINE AFTER 30 ITERATIONS.
ARITHMETIC IS REAL EXCEPT FOR THE REPLACEMENT OF THE ALGOL PROCEDURE CCIV BY COMPLEX DIVISION.

QUESTIONS AND COMMENTS SHOULD BE DIRECTED TO B. S. GAREGW, APPLIED MATHEMATICS DIVISION, ARGONNE NATIONAL LABORATORY

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MACHER IS A MACHINE DEPENDENT PARAMETER SPECIFYING THE RELATIVE PRECISION OF FLOATING POINT ARITHMETIC.
MACHER = 16.00CC**(-13) FOR LONG FORM ARITHMETIC
C
CN 5360 :
CATA MACHER/7341CC0CC0CC0CC0CC0CC0CC0/

IEFR = C

STCRE RCCTS ISOLATED BY BALANC :

DC 5C I = 1, N
IF (I .GE. LCW .AND. I .LE. ICH) GC TC 5C
WR(I) = P(I,I)
WH(I) = C.CCC

50 CONTINUE

EN = ICH
T = C.CCC

SEARCH FOR NEXT EIGENVALUES :

IF (EN .LT. LCW) GC TC 340
ITS = C
NA = EN - 1
ENM2 = NA - 1

LCCK FOR SINGLE SMALL SUPER-DIAGONAL ELEMENT
FCR L=EN STEP -1 UNTIL LCW CC -- :

CC LL = LCW, EN
L = EN + LCW - LL
IF (L .EQ. LCW) GC TC 100
IF (CAPS(H(L,L-1)) .LE. MACHER * (CAPS(H(L-1,L-1)))
x + CABS((L,L))) GC TC 1CC

FO CONTINUE

1CG X = T(EK,EN)
   IF (L.EQ. EN) CC TC 270
   Y = H(N,NA)
   W = T(EK,NA) * T(NA,EN)
   IF (L.EQ. NA) GC TC 280
   IF (ITS .EQ. 3C) GC TC 100C
   IF (ITS .NE. 1C .AND. ITS .NE. 2C) GC TC 130

C :::::::::::::: FORM EXCEPTIONAL SHIFT ::::::::::::::
T = T + X

C
CO 120 I = LOW, EN
120 H(I,1) = T(I,1) - X

C
S = CABS(H(EK,NA)) + CABS(H(NA,ENW2))
X = C*75CC * S
Y = X
W = -C*4375CC * S * S

130 ITS = ITS + 1

C :::::::::::::: CHECK FOR TWO CONSECUTIVE SMALL
C :: SUB-DIAGONAL ELEMENTS.
C :: FOR L = EN-2 STEP -1 UNTIL L CC -- :::::::::::::::

CC 140 MM = L, ENW2
M = ENW2 + L - MM
ZZ = H(M,M)
R = X - ZZ
S = Y - ZZ
P = (R * S - W) / H(M+1,M) + H(M,M+1)
C = H(M+1,M+1) - ZZ - R - S
R = H(M+2,M+1)
S = CABS(P) + CABS(C) + CABS(R)
F = P / S
G = Q / S
R = R / S
IF (H .EQ. L) GC TC 150
    IF (DABS(H(N,N-1)) * (DABS(C) + DABS(R)) .LE. MAXEP * DABS(P)) GC TC 150
        X = DABS(H(N,N-1)) + DABS(ZZ) + DABS(I(H(M+1),N+1))) GC TC 150
    140 CONTINUE

C 150 MP2 = N + 2

C CC 160 I = MP2, EN
    T(I, I-2) = C * CCC
    IF (I .EQ. MP2) GC TO 16C
    T(I, I-3) = C * CCC

160 CONTINUE
C ::::::::: DDBLUE CR STEP INVOLVING REWS L TC EN AND COLUMNS M TC EN :::::::::

C CC 260 K = N, NA
    NCTLAS = K .NE. NA
    IF (K .EQ. N) GC TC 17C
    P = T(K, K-1)
    C = T(K+1, K-1)
    R = C * CDC
    IF (NCTLAS) R = T(K+2, K-1)
    X = DABS(P) + DABS(C) + DABS(R)
    IF (X .EQ. C * CDC) GC TC 26C
    P = P / X
    C = C / X
    R = R / X

170 S = CSIGN(CSCRT(P*P+Q*Q+R*R, P)
    IF (K .EQ. N) GC TC 180
    H(K, K-1) = -S * X

180 IF (L .NE. N) H(K, K-1) = -H(K, K-1)

C 190 P = P + S
    X = P / S
    Y = C / S
    ZZ = R / S
    C = C / P

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R = R / P

C ::::::::::: ROW MODIFICATION :::::::::::

CC 210 J = K, N
P = R(K, J) + C * H(K+1, J)
IF (.NOT. NOTLAS) GO TO 200
F = P + R * T(K+2, J)
T(K+2, J) = T(K+2, J) - P * ZZ
200 T(K+1, J) = H(K+1, J) - P * Y
T(K, J) = T(K, J) - P * X
210 CONTINUE

C J = MINC(FN, K+3)

C ::::::::::: COLUMN MODIFICATION :::::::::::

CC 220 I = 1, J
F = X * T(I, K) + Y * T(I, K+1)
IF (.NOT. NOTLAS) GO TO 220
P = P + ZZ * H(I, K+2)
T(I, K+2) = H(I, K+2) - P * R
220 T(I, K+1) = T(I, K+1) - P * Q
T(I, K) = T(I, K) - P
230 CONTINUE

C ::::::::::: ACCUMULATE TRANSFORMATIONS :::::::::::

CC 250 I = LCIW, ICF
P = X * Z(T(I, K)) + Y * Z(T(I, K+1))
IF (.NOT. NOTLAS) GO TO 250
P = P + ZZ * Z(T(I, K+2))
Z(T(I, K+2)) = Z(T(I, K+2)) - P * R
240 Z(T(I, K+1)) = Z(T(I, K+1)) - P * G
Z(T(I, K)) = Z(T(I, K)) - P
250 CONTINUE

C 260 CONTINUE

C GC TC 70

C ::::::::::: ONE RCCT FCLND :::::::::::

270 F(EN, EN) = X + T
! WR(EN) = H(EN,EN)
! WI(EN) = C.CDC
! EN = NA
! GC TC 60
C :::::::::::::: TWC RCCTS FOUND ::::::::::::::
260 P = (Y - X) / Z.CDC
C = P * P + W
ZZ = DSQRT(DAPS(C));
H(EN,EN) = X + T
X = H(EN,EN)
H(NA,NA) = Y + T
IF (C .LT. C.CDC) GC TC 32C
C :::::::::::::: REAL PAIR ::::::::::::::
ZZ = P * CSIGN(ZZ,P)
WR(NA) = X + ZZ
WR(EN) = WR(NA)
IF (ZZ .NE. 0.CCC) WR(EN) = X - W / ZZ
WI(NA) = C.CDC
WI(EN) = C.CDC
X = H(EN,NA)
R = CSQRT(X*X+ZZ*ZZ)
P = X / R
Q = ZZ / R
C :::::::::::::: ROW MODIFICATION ::::::::::::::
CC 290 J = NA, N
ZZ = H(NA,J)
H(NA,J) = Q * ZZ + P * H(EN,J)
H(EN,J) = Q * H(EN,J) - P * ZZ
290 CONTINUE
C :::::::::::::: COLUMN MODIFICATION ::::::::::::::
CC 300 I = 1, EN
ZZ = H(I,NA)
H(I,NA) = Q * ZZ + P * H(I,EN)
H(I,EN) = Q * H(I,EN) - P * ZZ
300 CONTINUE
C :::::::::::::: ACCUMULATE TRANSFORMATIONS ::::::::::::::
DC 310 I = LCH, IGH
ZZ = Z(I, NA)
Z(I, NA) = C * ZZ + P * Z(I, EN)
Z(I, EN) = C * Z(I, EN) - P * ZZ
310 CONTINUE
C
GC TC 330
C ::::::::::: COMPLEX PAIR :::::::::::
320 WR(NA) = X * P
WR(EN) = X * P
WI(NA) = ZZ
WI(EN) = -ZZ
330 EN = ENM2
GC TC 60
C ::::::::::: ALL RCCTS FOUND. BACKSUBSTITUTTE TO FIND
C VECTORS OF UPPER TRIANGULAR FORM :::::::::::
340 NCRM = 0.0DC
K = 1
C
CC 360 I = 1, N
C
CC 350 J = K, N
350 NCRM = NORM + DABS(H(I, J))
C
K = 1
360 CONTINUE
C
IF (NORM .EQ. C.CCC) GC TO 1CO1
C ::::::::::: FOR EN=N STEP -1 UNTIL 1 CC -- :::::::::::
DC 6CO NN = 1, N
EN = N + 1 - NN
P = WR(EN)
C = WI(EN)
NA = EN - 1
IF (C) 710, 6CC, 8CC
C ::::::::::: REAL VECTOR :::::::::::

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600 \[ M = FN \]
\[ f(E_N, EN) = 1.000 \]
\[ IF (M .EQ. C) GC TC 800 \]

C :::::::::: FOR I=EN-1 STEP -1 UNTIL 1 GC :::::::::::

CC 700 II = 1, NA
I = EN - II
\[ h = H(I,I) - P \]
\[ P = H(I, EN) \]
\[ IF (M .GT. NA) GC TO 620 \]

C

610 \[ DD 61C J = M, NA \]
\[ R = R + f(I,J) * H(J, EN) \]

C

620 \[ IF (W(I) .GE. C.000) GC TC 630 \]
\[ ZZ = W \]
\[ S = R \]
\[ GC TC 700 \]
\[ M = I \]
\[ IF (W(I) .NE. C.000) GC TC 640 \]
\[ T = h \]
\[ IF (W .GE. C.000) T = MACHEP * NORM \]
\[ f(I, EN) = -R / T \]
\[ GC TO 700 \]

C :::::::::: SOLVE REAL EQUATIONS :::::::::::

640 \[ X = f(I,I+1) \]
\[ Y = f(I+1,I) \]
\[ G = (W(R(I)) - P) * (W(P(I)) - P) + W(I) * W(I) \]
\[ T = (X * S - ZZ * R) / Q \]
\[ f(I, EN) = T \]
\[ IF (CAPS(X) .GE. CAPS(ZZ)) GC TO 650 \]
\[ f(I+1, EN) = (-R - W * T) / X \]
\[ GC TO 700 \]

650 \[ f(I+1, EN) = (-S - Y * T) / ZZ \]

700 \[ CCONTINUE \]

C :::::::::: FND REAL VECTOR :::::::::::
\[ GC TC 800 \]
C ::::::::::::: COMPLEX VECTOR :::::::::::

710 M = NA

C ::::::::::: LAST VECTOR COMPONENT CHOSEN IMAGINARY SC THAT
C EIGENVECTOR MATRIX IS TRIANGULAR :::::::::::

IF (DAPS(H(EN,NA)) .LE. DAPS(H(NA,EN))) GC TC 720

H(NA,NA) = C / H(EN,NA)
H(NA,EN) = -(H(EN,EN) - P) / H(EN,NA)

GC TC 73C

720 Z3 = CCPLX(C,CCC,-H(NA,EN)) / CCPLX(H(NA,NA)-P,C)
H(NA,NA) = T3(1)
H(NA,EN) = T3(2)

730 H(EN,NA) = C*CCC
H(EN,EN) = I*CCC
EN2 = NA - 1

IF (EN2 .EQ. C) GC TC 80C

C

CC 79C II = 1, ENM2
I = NA - II
w = H(I,I) - P
RA = C*CCC
SA = H(I,EN)

CC 76C J = P, NA
RA = RA + H(I,J) * H(J,NA)
SA = SA + H(I,J) * H(J,EN)

760 CONTINUE

C

IF (W(I) .GE. C*CCC) GC TC 77C
ZZ = w
R = RA
S = SA

GC TC 79C

770 P = I

IF (W(I) .LE. C*ODC) GC TC 780
Z3 = CCPLX(-RA,-SA) / CCPLX(w,C)
H(I,NA) = T3(1)
C :::::::::: SOLVE COMPLEX EQUATIONS ::::::::::

780  X = H(I,I+1)
Y = H(I+1,I)
VR = (WR(I) - P) * (WR(I) - P) + WI(I) * WI(I) - C * C
VI = (WR(I) - P) * 2.0 * C
IF (VR .GE. C .AND. VI .GE. 0.0) VR = 2.0 * EP * CCM

785  Z3 = CCMPLX(X*R-ZZ*RA+Q*SA,X*S-ZZ*SA-C*RA) / CCMPLX(VR,VI)
H(I,NA) = T3(I)
H(I,EN) = T3(2)
IF (DABS(X) .LE. DABS(ZZ) + CABS(0.0)) GC TO 785
H(I+1,NA) = (-RA - w * H(I,NA) + C * H(I,EN)) / X
H(I+1,EN) = (-SA - w * H(I,EN) - C * H(I,NA)) / X
GC TO 75C

175  CCONTINUE

C :::::::::: END COMPLEX VECTOR ::::::::::

800  CCONTINUE

820  Z(I,J) = H(I,J)

840  CCONTINUE

C :::::::::: MULTIPLY BY TRANSFORMATION MATRIX TO GIVE

860  GC TO 85C

C :::::::::: VECTORS OF ORIGINAL FULL MATRIX.

C :::::::::: FOR J=N STEP -1 UNTIL LCW GC -- ::::::::::

DO 880 JJ = LCW, N
J = N - LCW - JJ

880  CCONTINUE


\( N = \text{MIN}(I, J) \)

\[
\begin{align*}
\text{CC 860} & \quad I = LCH, ICH \\
\text{CC 860} & \quad ZZ = 0.000
\end{align*}
\]

\[
\begin{align*}
\text{CC 860} & \quad K = LCH, N \\
\text{860} & \quad ZZ = ZZ + Z(I, K) \times H(K, J)
\end{align*}
\]

\[
\begin{align*}
\text{860} & \quad Z(I, J) = ZZ \\
\text{860} & \quad \text{CONTINUE}
\end{align*}
\]

\[
\begin{align*}
\text{GC 1E 1C01} & \quad \text{SET ERRCR -- NC CONVERGENCE TO AN}\n\text{C 1C00} & \quad \text{EIGENVALUE AFTER 3C ITERATIONS} \quad \text{1E1F} \\
\text{1C01} & \quad \text{IEFR = FA} \\
\text{1C01} & \quad \text{RETURN}
\end{align*}
\]

\[
\begin{align*}
\text{C 1C01} & \quad \text{LAST CARD OF HQR2} \quad \text{1E1F}
\end{align*}
\]

\text{ENC}
SUBROUTINE BALBAK(N,N,LCH,IGH,SCALE,N,Z)

INTEGER I,J,K,M,N,II,AM,IGH,LOW
REAL*8 SCALE(N),Z(N,N)
REAL*8 S

THIS SUBROUTINE IS A TRANSLATION OF THE ALGCL PROCEDURE BALBAK,
NUM. MATH. 13, 293-304(1969) BY PARLETT AND REINSCH.
HANDBOOK FOR ALTC. COMP., VCL.II-LINEAR ALGEBRA, 315-326(1971).

THIS SUBROUTINE FORMS THE EIGENVECTORS OF A REAL GENERAL
MATRIX BY BACK TRANSFORMING THOSE OF THE CORRESPONDING
BALANCED MATRIX DETERMINED BY BALANC.

ON INPUT:

M MUST BE SET TO THE ROW DIMENSION OF TWO-DIMENSIONAL
ARRAY PARAMETERS AS DECLARED IN THE CALLING PROGRAM
DIMENSION STATEMENT;

N IS THE ORDER OF THE MATRIX;

LCH AND IGH ARE INTEGERS DETERMINED BY BALANC;

SCALE CONTAINS INFORMATION DETERMINING THE PERMUTATIONS
AND SCALING FACTORS USED BY BALANC;

M IS THE NUMBER OF COLUMNS OF Z TO BE BACK TRANSFORMED;

Z CONTAINS THE REAL AND IMAGINARY PARTS OF THE EIGEN-
VECTORS TO BE BACK TRANSFORMED IN ITS FIRST M COLUMNS.

ON OUTPUT:
Z CONTAINS THE REAL AND IMAGINARY PARTS OF THE
TRANSFORMED EIGENVECTORS IN ITS FIRST P COLUMNS.

QUESTIONS AND COMMENTS SHOULD BE DIRECTED TO B. S. GARBOW,
APPLIED MATHEMATICS DIVISION, ARGONNE NATIONAL LABORATORY

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

IF (IGH .EQ. LCH) GO TO 12C

DC 110 I = LCH, IGH
S = SCALE(I)

::: LEFT HANDED EIGENVECTORS ARE BACK TRANSFORMED

::: IF THE PRECEDING STATEMENT IS REPLACED BY
::: S = 1.CCC/SCALE(I).

CO 1CC J = 1, M
1CO Z(I,J) = Z(I,J) * S

110 CONTINUE

::: FOR I=LCH-1 STEP -1 UNTIL 1, 
::: IGH+1 STEP 1 UNTIL N CC -- :::::

120 DC 140 II = 1, N
I = II
IF (I .GE. LCH .AND. I .LE. IGH) GO TO 140
IF (I .LT. LCH) I = LCH - II
K = SCALE(I)
IF (K .EQ. I) GO TO 140

DC 130 J = 1, M
S = Z(I,J)
Z(I,J) = Z(K,J)
Z(K,J) = S

130 CONTINUE

140 CONTINUE
RETURN

LAST CARD OF BALBAK

END
SUPROUTINE MINV

PURPOSE
  INVERT A MATRIX

USAGE
  CALL MINV(A,N,D,L,M)

DESCRIPTION OF PARAMETERS
  A - INPUT MATRIX, DESTROYED IN COMPUTATION AND REPLACED BY
      RESULTANT INVERSE.
  N - CFRDE OF MATRIX A
  D - RESULTANT DETERMINANT
  L - WORK VECTOR OF LENGTH N
  M - WORK VECTOR OF LENGTH N

REMARKS
  MATRIX A MUST BE A GENERAL MATRIX

SUBROUTINES AND FUNCTION SUBPROGRAMS REQUIRED
  NONE

METHOD
  THE STANDARD GAUSS-JORDAN METHOD IS USED. THE DETERMINANT
  IS ALSO CALCULATED. A DETERMINANT OF ZERO INDICATES THAT
  THE MATRIX IS SINGULAR.
IF A DOUBLE PRECISION VERSION OF THIS ROUTINE IS DESIRED, THE C IN COLUMN 1 SHOULD BE REMOVED FROM THE DOUBLE PRECISION STATEMENT WHICH FOLLOWS.

DOUBLE PRECISION A, D, BIGA, IJK

THE C MUST ALSO BE REMOVED FROM DOUBLE PRECISION STATEMENTS APPEARING IN OTHER ROUTINES USED IN CONJUNCTION WITH THIS ROUTINE.

THE DOUBLE PRECISION VERSION OF THIS SUBROUTINE MUST ALSO CONTAIN DOUBLE PRECISION FORTRAN FUNCTIONS. ABS IN STATEMENT 10 MUST BE CHANGED TO DBS.

SEARCH FOR LARGEST ELEMENT

D = 1.0
NK = -N
DO 10 K = 1, N
NK = NK + N
M(K) = K
KK = NK + K
BIGA = A(KK)
DO 20 J = K, N
IZ = N*(J-1)
CO 20 I = K, N
IJ = IZ + I
10 IF (ABS(BIGA) - ABS(A(IJ))) > 0, 20 15
15 BIGA = A(IJ)
L(K) = I
M(K) = J
20 CONTINUE
C INTERCHANGE ROWS
J=L(K)
IF(J-K) 35,35,25
25 KI=K-N
DO 30 I=1,N
KI=KI+N
HELC=-A(KI)
JI=KI-K+J
A(KI)=A(JI)
30 A(JI)=HELD
C INTERCHANGE COLUMNS
35 I=M(K)
IF(I-K) 45,45,38
38 JP=N*(I-1)
DO 40 J=1,N
JK=NK+J
JI=JF+J
HOLD=-A(JK)
A(JK)=A(JI)
40 A(JI)=HOLD
C DIVIDE COLUMN BY MINUS PIVOT (VALUE OF PIVOT ELEMENT IS
CONTAINED IN BIGA)
45 IF(BIGA) 48,46,48
46 D=G*0
RETURN
48 DO 55 I=1,N
IF(I-K) 56,55,50
50 IK=NK+I
A(IK)=A(IK)/(-BIGA)
55 CONTINUE
C REDUCE MATRIX
C
DO 65 I=1,N
IK=IK+I
HICLE=A(IK)
IJ=I-N
DO 65 J=1,N
IJ=IJ+N
IF(I-K) 6C,65,6C
61 IF(J-K) 62,65,6C
62 KJ=IJ-I+K
A(IJ)=HICLE*A(KJ)+A(IJ)
65 CONTINUE
C DIVIDE ROW BY PIVOT
C
KJ=K-N
DC 75 J=1,N
KJ=KJ+N
IF(J-K) 70,75,7C
70 A(KJ)=A(KJ)/BICA
75 CONTINUE
C PRODUCT OF PIVOTS
C
D=C*BICA
C REPLACE PIVOT BY RECIPROCAL
C
A(KK)=1.0/BICA
30 CONTINUE
C FINAL RCW AND COLUMN INTERCHANGE
C
K=N
140  \( K = (K-1) \)
150  IF(\( K \)) 150,150,165
155  \( I = L(K) \)
160  IF(\( I-K \)) 12C,12C,1C8
165  \( JQ = N \times (K-1) \)
170  \( JR = N \times (I-1) \)
175  DO 110  \( J = 1, N \)
180  \( JK = JQ + J \)
185  HOLE = A(\( JK \))
190  \( JI = JR + J \)
195  A(\( JK \)) = -A(\( JI \))
200  A(\( JI \)) = HOLE
205  IF(\( J-K \)) 160,160,125
210  \( KI = K - N \)
215  DO 130  \( I = 1, N \)
220  \( KI = KI + N \)
225  HOLE = A(\( KI \))
230  \( JI = KI - K + J \)
235  A(\( KI \)) = -A(\( JI \))
240  A(\( JI \)) = HOLE
245  GC TO 100
250  RETURN
END
APPENDIX B

INPUT DATA AND OUTPUT LISTING OF THE SAMPLE PROBLEMS

B.1 Application of the FREEVI Program to the Wing

B.1.1 Input Data Listing for the Bell Wing

The FREEVI program input data for the wing are illustrated in this section. The structural data are shown in Fig. 6 and in Table 3.
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B.1.2 The FEEVI program output data for the Bell Wing. The example output of the Bell wing is shown in this subsection.
**INPUT DATA**

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**FLAPPING RENDELING STIFFNESS**

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**CHORDWISE RENDELING STIFFNESS**

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**ANGLE OF TWIST**

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**MASS DISTRIBUTION**

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**ELEMENT SIZE**

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**TORQUAL RIGIDITY**

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**MOMENT OF INERTIA**

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**MASS COUPLING ALONG SPAN**

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TENSION DUE TO CENTRIFUGE FORCE

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MASS = 0.62615E+01
MOMENT OF INERTIA AT ROOT = 0.21483E+06
TOTAL LENGTH OF THE BEAM = 0.20000E+03

MASS SIZE OF STF IS 484
SPECIFIED SIZE IS 654

NO. OF NEGATIVE DIAGS. = 0  FACT. COMPLETED

EIGENVALUES=

0.28091D+03  0.85998D+03  0.16245D+05  0.34651D+05  0.26544D+06  0.53363D+06

EIGENVALUES=

0.27768D+03  0.89084D+03  0.27300D+04  0.12968D+05  0.32495D+05  0.26217D+06

EIGENVALUES=

0.27768D+03  0.89084D+03  0.27300D+04  0.12968D+05  0.32495D+05  0.26217D+06

EIGENVALUES=

0.27768D+03  0.89084D+03  0.27300D+04  0.12968D+05  0.32495D+05  0.26217D+06

EIGENVALUES=

0.27768D+03  0.89084D+03  0.27300D+04  0.12968D+05  0.32495D+05  0.26217D+06

EIGENVALUES=

0.16664D+03  0.29847D+03  0.52250D+03  0.11384D+03  0.18360D+03  0.51074D+03

RADIANS/SPC

0.10090D+01  0.47503D+01  0.83158D+01  0.19124D+02  0.24689D+02  0.81287D+02

NO. OF ITERATION = 5 CONVERGED WITHIN 0.10000D-02

REDUCED MASS MATRIX

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REDUCED STIFF MATRIX

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<th>DH(I,J)</th>
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B.2 Application of the FREEVI Program to the Blade

B.2.1 The FREEVI Program Input Data Listing for the Boeing Rotor (Hingeless Rotor)

The input data deck setup is illustrated in this subsection for the hingeless rotor. Structural data are shown in Fig. 7.
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B.2.2 The FREEVI Program Output Data for the Boeing Blade

The example output of the Boeing blade is shown in this subsection.
BLADE BEAM CANTI CHORD CANTI

**POURING BLADE FOR POWERED FLIGHT --- CLAMPED & CLAMPED B.C.**

8/19/74

**INPUT DATA**

| IPUNCH | IQUEST | NO. OF DEGREES PER NODE | NO. OF ELEMENTS | NO. OF MAX ITER ALLOWED | NO. OF MODES | ERR | OMEGA | LAMBDA | COLLECTIVE PITCH | SPRING | ALPHAT | FLAPPING BENDING STIFFNESS | CHORDWISE BENDING STIFFNESS | ANGLE OF TWIST | MASS DISTRIBUTION | ELEMENT SIZE | TIP MASS | ROLL INERTIA | YAW INERTIA | PITCH INERTIA | MASS COUPLING |
|--------|--------|-------------------------|-----------------|--------------------------|--------------|-----|--------|--------|-------------------|---------|--------|---------------------------|---------------------------|--------------|-----------------|------------|----------|----------------|----------------|----------------|----------------|----------------|
| 1      | 0      | 4                        | 10              | 20                       | 4            | 0.0130 | -40.4221 | -0.7600 | 0.01745           | 0.0     | 0.85250D+04    | (0.106000E+09 0.190000E+09 0.500000E+07 0.750000E+17 0.550000E+17 0.500000E+17 0.450000E+17) | (0.110000E+09 0.400000E+09 0.460000E+08 0.200000E+09 0.500000E+09 0.520000E+09 0.510000E+09) | 0.69810 | 0.47120 | 0.34030 | 0.25310 | 0.18330 | 0.12220 | 0.06110 | 0.0        |
|        |        |                          |                 |                          |              | 0.06110 | -0.1340 | 0.0158 | 0.00104           |         | 0.01658        | (0.156000E+09 0.600000E+09 0.300000E+09 0.500000E+09 0.300000E+09 0.300000E+09 0.300000E+09) | (0.156000E+09 0.600000E+09 0.300000E+09 0.500000E+09 0.300000E+09 0.300000E+09 0.300000E+09) | 0.69810 | 0.47120 | 0.34030 | 0.25310 | 0.18330 | 0.12220 | 0.06110 | 0.0        |
|        |        |                          |                 |                          |              | 0.0123  | 0.00104 | 0.0123 | 0.00104           |         | 0.0158        | (15.6000 15.6000 15.6000 15.6000 15.6000 15.6000 15.6000) | (15.6000 15.6000 15.6000 15.6000 15.6000 15.6000 15.6000) | 0.69810 | 0.47120 | 0.34030 | 0.25310 | 0.18330 | 0.12220 | 0.06110 | 0.0        |

**TENSION DUE TO CENTRIFugal FORCE**

7279.442 2349.4323 2172.573 2250.3160 21241.5357 10287.7658 17123.0469 10444.1730

**MASS = 0.41476E+04**

**MOMENT OF INERTIA AT ROOT = 0.16714E+14**

**TOTAL LENGTH OF THE BEAM = 0.15400E+03**

**MAX. SIZE OF STEP IS 244**

**SPECIFIED SIZE IS 324**

**NO. OF NEGATIVE DIAGS. = 0**

**FACT. COMPLETED**
**EIGENVALUES**

- 0.108800 + 04
- 0.283400 + 03
- 0.275400 + 03
- 0.273400 + 03
- 0.285200 + 04
- 0.189500 + 05
- 0.755500 + 05
- 0.285100 + 04
- 0.188800 + 05
- 0.749300 + 05

**RADIAN/SEC**

- 0.304200 + 02
- 0.534000 + 02
- 0.374300 + 03
- 0.273700 + 03

**HERTZ**

- 0.531970 + 01
- 0.849930 + 01
- 0.218720 + 02
- 0.435670 + 02

**NO. OF ITERATION** = 5 **CONVERGED WITHIN** 0.100000 + 02

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**REDUCED MASS MATRIX**

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B.3 The TILDYN Program Examples

B.3.1 Input Data Listing for the TILDYN Program

In this subsection, the sample problem data deck setup is illustrated. The flight condition is powered flight for the Boeing model and autorotation flight for the Bell model. The data for the computation is shown in Table 3 in detail.
| 1.1468 | 0.7-40.422 | -0.7 | 4414.882 |
| 156.4 | 1800.4 | 0.76456 | 5.7 | 0.0065 | 55.224 |
| 2.0 | 621 | 5.7 | 0.004 | -0.05 | 0.01 |
| 1 | 0.0 | 0.0 |
| 1.1172 | 2561.9 | 0.00616 | 14527.6 |
| 217.68 | 656.57 | 2.0022 | 5588.4 | 25466.0 | 253710.0 |
| 0.225 | 0.105 | 0.105 | 0.105 | 0.105 | 0.092 |
| 0.073 | 0.0 |

| C.66E4E-C2 | C.2646E6E-C1 | 0.56422E-C1 | 0.9757E-C1 | 0.14798E+00 |
| C.26E6E+CC | C.32718E+00 | 0.37453E+00 |
| C.0 | -0.1921E-C9 | -0.3535E-C9 | -0.4754E-U9 | -0.5194E-39 | -0.4479E-09 |
| -0.3691E-C9 | -0.1257E-C5 | -0.6137E-11 | 0.24547E-10 |
| 0.0 | C.4581E-C3 | 0.11282E-02 | 0.1708E-02 | 0.21954E-02 | 0.25905E-02 |
| -0.1706E-C1 | -0.3216E-02 | 0.3261E-02 |
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| 0.8105E-11 | 0.7522E-11 | C.4516E-11 | 0.6689E-12 |
| 0.0 | 0.1246E-C4 | C.4174E-04 | 0.8541E-04 | 0.1235E-03 | 0.1616E-03 |
| C.2893E-C2 | C.3106E-C2 | 0.2116E-02 | 0.3261E-02 |
| C.0 | -0.7516E-11 | -0.3767E-11 | -0.4053E-11 | 0.7830E-12 | 0.5404E-11 |
| 0.8105E-11 | 0.7522E-11 | C.4516E-11 | 0.6689E-12 |
| 0.0 | 0.1246E-C4 | C.4174E-04 | 0.8541E-04 | 0.1235E-03 | 0.1616E-03 |
| C.1582E-C3 | C.2375E-C3 | 0.2713E-03 | 0.2579E-03 |
| C.0 | 0.3113E-C6 | 0.4124E-C6 | 0.1576E-05 | 0.1775E-05 | 0.1815E-05 |
| -0.3113E-C6 | -0.4124E-C6 | 0.1576E-05 | 0.1775E-05 | 0.1815E-05 |
| C.1816E-C5 | 0.1816E-05 | 0.1816E-05 |
| 0.0 | -0.6380E-C9 | -0.1062E-08 | -0.5680E-09 | 0.2714E-09 | 0.4604E-09 |
| 0.61255E-C9 | 0.6565E-09 | 0.5223E-10 |
| 0.0 | 0.1528E-C1 | 0.3634E-01 | 0.6625E-01 | 0.1945E+00 | 0.1583E+00 |
| 0.2134E+00 | 0.2731E+00 | 0.3275E+00 | 0.3172E+00 |
| 0.0 | -0.2441E-10 | -0.6735E-11 | 0.2605E-10 | 0.3640E-10 | 0.2952E-10 |
| 0.5040E-11 | -0.2134E-10 | -0.2615E-10 | 0.9610E-12 |
| 0.7193E-C3 | 0.1273E-02 | 0.1753E-02 | 0.2157E-02 | 0.2487E-02 | 0.2687E-02 |
| 8/20/74 | DATA0001 | ITYPE | DATA0002 | IFLT | DATA0003 | DOF | DATA0004 | FREQRE | DATA0005 | IFRMAG | DATA0006 | IEIGEN | DATA0007 | DATA0008 | DATA0009 | DATA0010 | DATA0011 | DATA0012 | DATA0013 | DATA0014 | DATA0015 | DATA0016 | DATA0017 | DATA0018 | DATA0019 | DATA0020 | DATA0021 | DATA0022 | DATA0023 | DATA0024 | DATA0025 | DATA0026 | DATA0027 | DATA0028 | DATA0029 | DATA0030 | DATA0031 | DATA0032 | DATA0033 | DATA0034 | DATA0035 | DATA0036 |
| 0.27435E-02 | 0.29258E-02 | 0.3C262E-02 | 0.3E188E-02 | 0.18532E-11 | 0.19364E-11 | DATA0037 |
| 0.1676VE-11 | 0.12374E-11 | 0.7E357E-12 | 0.2531E-12 | 0.15182E-11 | DATA0038 |
| 0.7E357E-14 | 0.8E356E-14 | 0.276C7E-13 | 0.21686E-13 | 0.90527E-14 | 0.45720E-14 | DATA0040 |
| -0.16357E-13 | -0.24832E-13 | -0.25312E-13 | -0.3C556E-13 | DATA0041 |
| 0.47765E-01 | 0.61E8E-01 | 0.7E357E-01 | 0.2531E-01 | 0.21795E-01 | 0.33683E-01 | DATA0042 |
| 0.55867E-06 | 0.5E562E-06 | 0.12690E-07 | 0.19E55E-07 | 0.13769E-05 | 0.11962E-05 | DATA0043 |
| 0.80224E-06 | 0.3E436E-06 | 0.12690E-07 | 0.19E55E-07 | DATA0044 |
| 0.71923E-03 | 0.8778E-03 | 0.2531E-03 | 0.21795E-03 | 0.50960E-03 | 0.62045E-03 | DATA0045 |
| 0.20161E-07 | 0.16769E-07 | 0.12014E-07 | 0.19E55E-07 | 0.14514E-07 | DATA0046 |
| -0.21872E-07 | -0.21124E-07 | -0.12014E-07 | 0.19E55E-07 | DATA0047 |
| -0.46056E-03 | -0.17642E-02 | -0.31557E-02 | -0.45620E-02 | -0.59703E-02 | DATA0048 |
| -0.73783E-02 | -0.87354E-02 | -0.16C17E-01 | -0.19994E-01 | DATA0049 |
| -0.12235E-04 | -0.15239E-04 | -0.58235E-04 | -0.61598E-04 | -0.66841E-04 | DATA0050 |
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B.3.2 The Output Printout for the TILDYN Program

The output printout is illustrated for autorotation flight of the Bell model in this subsection.
BELL ROTOR AUTOROTATION FLIGHT 9-DOF U-GUST FREQ ANALYSIS & EIGEN  R/18/74

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COLLECTIVE PITCH DEL3

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WING L WING CHORD WING CL WING CD WING CMD WING CMA

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DISTANCE AC EA WING ALPHAH

| 1.0000000E-02 | 3.0999999E-02 |

EIGENVALUES (NATURAL FREQUENCIES)

---(RAD/SEC)---

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**EXCITING FORCE COMPONENTS**

** **** BLADE MODE SHAPES **** **

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**Note:** The values in the matrices represent coefficients in the equations of motion.
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### CORRESPONDING TO NO. 2 EIGENVALUE

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**CORRESPONDING TO NO. 6 EIGENVALUE**

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** ABSOLUTE VALUE **

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-- CORRESPONDING TO NO. 8 EIGENVALUE --

** ABSOLUTE VALUE **

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** CORRESPONDING TO NO. 9 EIGENVALUE **

(-0.109D+00) + IMAG( 0.245D+00)

** ABSOLUTE VALUE **

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** REAL PART **

** IMAGINARY PART **

** CORRESPONDING TO NO. 10 EIGENVALUE **

(-0.282D+00) + IMAG( 0.412D-01)

** ABSOLUTE VALUE **

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( -0.3180D+01 + IMAG( 0.0 ) )

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