USER'S MANUAL FOR COMPUTER PROGRAM ROTOR

Masahiro Yasue

August 1974

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Prepared under Contract No. NAS2-7262 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.
FOREWORD

This report has been prepared by the Aeroelastic and Structures Research Laboratory (ASRL), Department of Aeronautics and Astronautics, Massachusetts Institute of Technology, Cambridge, Massachusetts, under NASA Contract No. NAS2-7262 from the Ames Research Center, National Aeronautics and Space Administration, Moffett Field, California 94035. Mr. John Rabbott and Dr. Wayne Johnson of the Ames Research Center served as technical monitors. The valuable assistance and advice received from these individuals is gratefully acknowledged.

The research described in this report was supervised by Professor Norman D. Ham and Associate Professor Pin Tong. The author would like to express his deep appreciation and gratitude for their invaluable advice and guidance throughout this study. The author is also deeply indebted to Professor John Dugundji and to Dr. Wayne Johnson, who contributed various useful suggestions. Professor E.A. Witmer's advice and assistance in various phases of the work is acknowledged gratefully.

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.
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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 coeffi­
cients 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: ver­
tical gust, lateral gust, longitudinal gust, collective-blade
pitch control and two cyclic blade pitch controls. By appropri­
ately 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 prob­
lem (Refs. 2 and 3).
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:

\[
[K][u] = \lambda [M][u]
\]  

(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 \([u_0]\); \(n \times m\) matrix containing \(m\) vectors

(b) \([M_R] = [u_0]^T[M][u_0]\); \([K_R] = [u_0]^T[K][u_0]\) 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) \([\overline{u}_0] = [u_0][A]\)

(e) \([u_1] = \{K\}^{-1}[M][\overline{u}_0]\)

(f) \([u_0] = [u_1]\) 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

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

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 assemblage
- **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:

\[
[A] \ddot{x} + [B] \dot{x} + [C] x = [D] e
\]  

(2.3)

\([A], [B], [C], \) and\([D] \) are the coefficient matrices, including inertia terms and aerodynamic terms. The matrix \(x\) is a set of variables and \(e\) 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
\[
\begin{bmatrix}
\dot{x} \\
\ddot{x}
\end{bmatrix}
= 
\begin{bmatrix}
-A^{-1}B & -A^{-1}C \\
I & 0
\end{bmatrix}
\begin{bmatrix}
x \\
\dot{x}
\end{bmatrix}
\] 
(2.4)

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
- **EQNTX** Defines the coefficient matrices \([A], [B], [C],\) and \([D]\) in Eq. 2.3.
- **AUTO** In the autorotation case, another degree of freedom is added
GUSTCO  Defines gust and blade pitch control components
FRQRES  Calculates the frequency response
GAELI   The Gauss-Jordan reduction routine
EIGEN   Routine to form the eigenvalue problem and to call EIPACK subroutine
EIPACK  An eigensystem problem solver for the real general matrix consisting of EISPACK subroutine BALANC, ELMHES, ELTRAN, HQR2 and BALBAK
BALANC  Balances a real general matrix and isolates eigenvalues whenever possible
ELMHES  Obtains an upper Hessenberg matrix from a real general matrix
ELTRAN  Accumulates the elementary similarity transformations for the reduction to upper Hessenberg form
HQR2    Finds the eigenvalues and eigenvectors
BALBAK  Forms the eigenvectors by back-transforming those of the corresponding balanced matrix determined by BALANC
MINV    Inverses a matrix

The listing is shown in Appendix A.
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.
<table>
<thead>
<tr>
<th>Parameter</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>ICASE</strong></td>
<td>A parameter to specify the calculation case:</td>
</tr>
<tr>
<td>ICASE=1:</td>
<td>wing case with clamped boundary conditions at the root.</td>
</tr>
<tr>
<td>ICASE=2:</td>
<td>blade case with boundary conditions clamped for the flapping motion and clamped for the lagging motion at the root.</td>
</tr>
<tr>
<td>ICASE=3:</td>
<td>blade case, clamped for flapping and hinged for lagging.</td>
</tr>
<tr>
<td>ICASE=4:</td>
<td>blade case, hinged for flapping and clamped for lagging.</td>
</tr>
<tr>
<td>ICASE=5:</td>
<td>blade case, both hinged boundary conditions.</td>
</tr>
</tbody>
</table>

It is punched in the integer format as 11 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 11 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 (φ) |

It should be noted that the terms PB, RAMDA, COL and THETAES related to coupled motion should be set to zero when uncoupled mode shapes are required. The parameter is punched in the integer format as 11 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 $|\frac{\lambda_{i+1} - \lambda_i}{\lambda_i}|$, where $\lambda_i$ is the eigenvalue calculated at the ith 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 the 10th columns of the seventh card.

RAMDA Inflow ratio $\lambda$ is defined as $\frac{(V + v)}{\Omega R}$. 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.
THETA \text{E}

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:

$$\text{PIR} = I_P + N I_B$$
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:

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

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:

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

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:

\[
PBW = NM_B h
\]

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 (El5.7) and five data items can be included in a card. These data occupy (NET/5) cards if NET is a multiple of 5, otherwise \(1+(NET/5)\).

PI  A vector to express wing mass moment of inertia about the elastic axis per unit length: its length is NET. The format is (El5.7) and five data items can be included in a card. These data occupy (NET/5) cards if NET is a multiple of 5, otherwise \(1+(NET/5)\).
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 \(1+(\text{NET}/5)\).

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.
(m) 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 $W(1,NET+1)$, punched on $[(NET+1)/6]$ cards if $(NET+1)$ is a multiple of 6, otherwise $[(NET+1)/6+1]$ 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 $M$th mode shape. In the case of the wing, the output data of $PHI(I, J)$, $DPHI(I, J)$ are added in the same fashion after the set of $DV(I, J)$. 
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 autorotation 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 80Al.

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 (II) and it is punched in the first column of the second card.

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

- **I FLT**=0; powered flight
- **I FLT**=1; autorotation flight

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

**I DOF**
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 **I DOF** is used for both powered flight and autorotation flight.

- **I DOF**=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 (**I FLT**=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.
- **I DOF**=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 (II) 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.

- **I RES**=0; it is not carried out.
- **I RES**=1; it is carried out.

The format is (II) 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 (El0.0); 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 (δ3). 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 (CD0 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 (Cm0). The format is either E or F type. It is punched in the 41st through the 50th column of the eleventh card.

WCMA  The wing pitching moment curve slope (Cmα). 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 \{e\}.

- CGUST(1): vertical gust $u_G/V$
- CGUST(2): lateral gust $v_G/V$
- CGUST(3): longitudinal gust $w_G/V$
- CGUST(4): collective pitch control $\theta_o$
- CGUST(5): cyclic cosine pitch control $\theta_{lc}$
- CGUST(6): cyclic sine pitch control $\theta_{ls}$

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 (rad$^2$/sec$^2$). If IDOF is set equal to 9, the latter two eigenvalue columns may have blanks. If the calculation case is the gimballed 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 (rad$^2$/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.
EMSW  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.

G  A matrix to describe the wing vertical bending mode shape ($\gamma$ in Ref. 1) at the nodes. The size of the matrix is $MW \times (NW+1)$, 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.

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

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

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

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

DWPHI  A matrix to describe the wing torsion slope ($d\phi/dy$ 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 \( G(1,1), G(1,2) \) \( \ldots \ldots \ldots \ldots G(1,6) \)

Next card contains \( G(1,7) \) \( \ldots \ldots \ldots \ldots G(1,NW+1) \)

New card contains \( Z(1,1) \) \( \ldots \ldots \ldots \ldots Z(1,6) \)
\( Z(1,7) \) \( \ldots \ldots \ldots \ldots Z(1,NW+1) \)

New card contains \( DG(1,1) \) \( \ldots \ldots \ldots \ldots \)
\( DG(1,7) \) \( \ldots \ldots \ldots \ldots \)

New card contains \( DZ(1,1) \) \( \ldots \ldots \ldots \ldots \)
\( DZ(1,7) \) \( \ldots \ldots \ldots \ldots \)

New card contains \( WPHI(1,1) \) \( \ldots \ldots \ldots \ldots \)
\( WPHI(1,7) \) \( \ldots \ldots \ldots \ldots \)

New card contains \( DWPHI(1,1) \) \( \ldots \ldots \ldots \ldots \)
\( DWPHI(1,7) \) \( \ldots \ldots \ldots \ldots \)

New card contains \( G(2,1) \) \( \ldots \ldots \ldots \ldots G(2,6) \)
\( G(2,7) \)
\( Z(2,1) \)
\( Z(2,7) \)
\( \ldots \)

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

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

The wing mode shapes occupy \( N_W \) cards where

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

A number to specify the blade element quantity. The format is (I2) 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 \(MB(N+1)\) where MB is 2 if IDOF=9 and 4 if IDOF=18. The format is E or F type \((E13.5)\) and \(W(l,1)\) expresses the out-of-plane deflection at the root node of the first mode. \(W(l,N+1)\) 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 inplane bending mode shape \( (V_j \text{ in Ref. 1}) \) 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 \( (dW_j/dr \text{ in Ref. 1}) \) at the node. Other comments are the same as those for \( W \).

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

If the calculation case is the gimballed rotor (\( \text{ITYPE}=1 \)), or autorotational flight (\( \text{ITYPE}=1 \) and \( \text{IFLT}=1 \)), 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 \( W(1,1), W(1,2), \ldots, W(1,6) \)

Next card contains \( W(1,7), \ldots, W(1,N+1) \)

New card contains \( V(1,1) \ldots \)

\[
\begin{align*}
V(1,7) & \ldots \\
DW(1,1) & \\
DW(1,7) & \\
DV(1,1) & \ldots \\
DV(1,6) & \\
DV(1,7) & \ldots \\
DV(1,N+1) & \\
W(2,1) & \\
W(2,7) & \\
V(2,1) & \\
V(2,7) & \\
& \ldots \\
& \ldots \\
& \ldots \\
&DV(MB,1) \ldots 
\end{align*}
\]
Last card contains DV(MB,7) ........   DV(MB,N+1)

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

\[
\begin{aligned}
n_B &= \left\{ \begin{array}{ll}
4MW[(N+1)/6] & \text{if } (N+1) \text{ is a multiple of 6} \\
4MW[(N+1)/6+1] & \text{if } (N+1) \text{ is not a multiple of 6}
\end{array} \right.
\end{aligned}
\]

If the computer calculation case is the gimballed 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 (rad\(^2\)/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 (\( W_j^O \) 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 (\( V_j^O \) 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 (\( dW_j^O/dr \) in Ref. 1). Other comments are the same as those for W.

**DVCOL**  A matrix to describe the blade collective inplane mode shape slope (\( dV_j^O/dr \) 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 $D(NUR)/DT$ (to express $\dot{v}_R$).

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 $v_R$ (rigid-body rotation in autorotation flight). $v_R$ 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":

32
IERROR=XXXXX

The error code is shown as follows:

<table>
<thead>
<tr>
<th>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 autorotation 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>Clamped for all Deflections</td>
<td>Free or Tip Mass if Necessary</td>
<td>Out-of-Plane Bending Inplane Bending</td>
</tr>
<tr>
<td>Gimballed Rotor</td>
<td>Clamped for all Deflections</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Collective Mode</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Cyclic Mode</td>
<td>Hinged for Flapping, Clamped for Lagging</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Autorotation</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Hingeless Rotor</td>
<td>Clamped for Flapping, Hinged for Lagging</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Collective Mode</td>
<td>Clamped for Flapping, Hinged for Lagging</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Cyclic Mode</td>
<td>Clamped for all Deflections</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Gimballed Rotor</td>
<td>Clamped for Flapping, Hinged for Lagging</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Collective Mode</td>
<td>Clamped for Flapping, Hinged for Lagging</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Cyclic Mode</td>
<td>Hinged for Flapping, Clamped for Lagging</td>
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<td></td>
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<tr>
<td>Description</td>
<td>Powered Flight</td>
<td>Autorotation Flight</td>
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<td>---------------------</td>
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<td>Total Degrees of Freedom</td>
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<td>$Q_{10}$</td>
<td>$Q_{10}$</td>
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<tr>
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<td>$Q_{1c}$</td>
<td>$Q_{1c}$</td>
<td>Blade Cyclic Cosine Motion of 1st Natural Frequency</td>
</tr>
<tr>
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<td>$Q_{1s}$</td>
<td>$Q_{1s}$</td>
<td>Blade Cyclic Sine Motion of 1st Natural Frequency</td>
</tr>
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<td>$Q_{20}$</td>
<td>$Q_{20}$</td>
<td>Blade Collective Motion of 2nd Natural Frequency</td>
</tr>
<tr>
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<td>$Q_{2c}$</td>
<td>$Q_{2c}$</td>
<td>Blade Cyclic Cosine Motion of 2nd Natural Frequency</td>
</tr>
<tr>
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<td>$Q_{2s}$</td>
<td>$Q_{2s}$</td>
<td>Blade Cyclic Sine Motion of 2nd Natural Frequency</td>
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<td>$Q_{30}$</td>
<td></td>
<td>Blade Collective Motion of 3rd Natural Frequency</td>
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<td>$Q_{3c}$</td>
<td></td>
<td>Blade Cyclic Cosine Motion of 3rd Natural Frequency</td>
</tr>
<tr>
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<td></td>
<td>Blade Cyclic Sine Motion of 3rd Natural Frequency</td>
</tr>
<tr>
<td>$Q_{40}$</td>
<td>$Q_{40}$</td>
<td></td>
<td>Blade Collective Motion of 4th Natural Frequency</td>
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</tr>
<tr>
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<td></td>
<td>Blade Cyclic Sine Motion of 4th Natural Frequency</td>
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<td>Wing Motion of 4th Natural Frequency</td>
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<td>Wing Motion of 5th Natural Frequency</td>
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<tr>
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<td>$a_6$</td>
<td></td>
<td>Wing Motion of 6th Natural Frequency</td>
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<tr>
<td>$\bar{v}_R$</td>
<td>$\bar{v}_R$</td>
<td></td>
<td>Rotor Rigid-Body Rotation</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_0 )</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>
<tr>
<td>ROTOR</td>
<td>BELLS</td>
</tr>
<tr>
<td>-------</td>
<td>-------</td>
</tr>
<tr>
<td><strong>Type</strong></td>
<td>gimbaled, stiff inplane</td>
</tr>
<tr>
<td><strong>Number of blades, N</strong></td>
<td>3</td>
</tr>
<tr>
<td><strong>Radius, R</strong></td>
<td>156 in.</td>
</tr>
<tr>
<td><strong>Chord, C_B</strong></td>
<td>18.9 in.</td>
</tr>
<tr>
<td><strong>Lock number, γ</strong></td>
<td>3.83</td>
</tr>
<tr>
<td><strong>Solidity, σ</strong></td>
<td>0.089</td>
</tr>
<tr>
<td><strong>Pitch/flap coupling, δ_3</strong></td>
<td>-15 deg.</td>
</tr>
<tr>
<td><strong>Collective pitch, θ_D</strong></td>
<td>1.25 deg.</td>
</tr>
<tr>
<td><strong>Lift-curve slope, a</strong></td>
<td>5.7</td>
</tr>
<tr>
<td><strong>Drag Coefficient, C_Do</strong></td>
<td>0.0065</td>
</tr>
<tr>
<td><strong>Rotor rotation direction, Ω</strong></td>
<td>+1</td>
</tr>
<tr>
<td>**Inflow ratio,</td>
<td>0.7</td>
</tr>
<tr>
<td>**Rotational speed,</td>
<td>458 RPM</td>
</tr>
<tr>
<td><strong>Blade Natural Frequencies</strong></td>
<td>48.9 rad/sec</td>
</tr>
<tr>
<td>first, λ_1/</td>
<td>Ω</td>
</tr>
<tr>
<td>second, λ_2/</td>
<td>Ω</td>
</tr>
<tr>
<td>third, λ_3/</td>
<td>Ω</td>
</tr>
</tbody>
</table>
TABLE 3. CONTINUED

<table>
<thead>
<tr>
<th>Rotor (cont'd)</th>
<th>Bell</th>
</tr>
</thead>
<tbody>
<tr>
<td>Collective Natural Frequency</td>
<td></td>
</tr>
<tr>
<td>first, $\lambda_1^{(0)}/</td>
<td>\Omega</td>
</tr>
<tr>
<td>second, $\lambda_2^{(0)}/</td>
<td>\Omega</td>
</tr>
<tr>
<td>third, $\lambda_3^{(0)}/</td>
<td>\Omega</td>
</tr>
<tr>
<td>fourth $\lambda_4^{(0)}/</td>
<td>\Omega</td>
</tr>
</tbody>
</table>

| Blade flapping inertial, $I_B$ |
| 105 slug-ft$^2$ |

| One blade weight, $M_B$ |
| 133 lb |

<table>
<thead>
<tr>
<th>Wing</th>
</tr>
</thead>
<tbody>
<tr>
<td>Semispan, $L$</td>
</tr>
<tr>
<td>Chord, $c_w$</td>
</tr>
<tr>
<td>Mast height, $h$</td>
</tr>
<tr>
<td>Sweep</td>
</tr>
<tr>
<td>Dihedral</td>
</tr>
<tr>
<td>Lift-curve slope, $a_w$</td>
</tr>
<tr>
<td>Drag coefficient, $C_{D_{\infty}}$</td>
</tr>
</tbody>
</table>

| Moment coefficient $C_{m_{\infty}}$ |
| -0.005 |

| Aerodynamic center, $\bar{c} = x_{\lambda_w}/C_w$ |
| 0.01 |

| Angle of attack, $\alpha_{\infty}$ |
| 2.0 deg |
TABLE 3. CONCLUDED

WING (cont'd)

Natural Frequencies

<table>
<thead>
<tr>
<th>Frequency</th>
<th>BELL</th>
<th>BOEING</th>
</tr>
</thead>
<tbody>
<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>
<tr>
<td>fourth, $\Lambda_4/</td>
<td>\Omega</td>
<td>$</td>
</tr>
<tr>
<td>fifth, $\Lambda_5/</td>
<td>\Omega</td>
<td>$</td>
</tr>
<tr>
<td>sixth, $\Lambda_6/</td>
<td>\Omega</td>
<td>$</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 lb</td>
<td>2000 lb</td>
</tr>
<tr>
<td>Yaw inertia, $I_{py}$</td>
<td>164.8 slug-ft$^2$</td>
<td>250.0 slug-ft$^2$</td>
</tr>
<tr>
<td>Pitch inertia, $I_{pp}$</td>
<td>190.0 slug-ft$^2$</td>
<td>250.0 slug-ft$^2$</td>
</tr>
<tr>
<td>Roll inertia, $I_{pr}$</td>
<td>42.4 slug-ft$^2$</td>
<td>30.0 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 kt</td>
<td>218 kt</td>
</tr>
<tr>
<td>Cruising altitude</td>
<td>sea level</td>
<td>sea level</td>
</tr>
</tbody>
</table>

40
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
1. Eigenvalues by Jacobi Method
   → Calculate the New Mode Shapes Based on the Eigenvalues

2. Make the New Mode Shape Values as the Guest Values
   → Accuracy
      - No
      - 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 PROPORTOR BLADES

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

FIG. 7 CONTINUED
(c) Section Chordwise Bending Stiffness Distribution

FIG. 7 CONTINUED
(d) Angle of Twist

FIG. 7 CONCLUDED
FIG. 8 DATA DECK SETUP FOR THE TILDYN PROGRAM
FIG. 8 CONTINUED
THE FIRST MODE SHAPE

\[ DV(MB, L) - DV(MB, N+1) \]

\[ W(MB, L) - W(MB, N+1) \]

THE MB-TH MODE SHAPE

\[ DV(1, L) - DV(1, N+1) \]

\[ DW(1, L) - DW(1, N+1) \]

\[ V(1, L) - V(1, N+1) \]

\[ W(1, L) - W(1, N+1) \]

BLADE MODE SHAPES

\[ V(l, l) - V(l, N+1) \]

\[ W(l, l) - W(l, N+1) \]

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)

FIG. 8 CONCLUDED
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 AEREOELASTIC AND STRUCTURES RESEARCH LABORATORY
    AUGUST 1974
    ADDRESS ; ELC 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)

CALL TEIGEN(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 /BW/ ICASE, IGUE
COMMON /HELP/ALPHA
DIMENSION NDPE(1), NRCU(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)

IF(INDEX .EQ. 0) GO TO 99
CALL ASBV(STK, STM, IEQ, EK, EM, NDPE, NDT, NCDT, NNODE, MN, NET, INUM)
MA=M
NP=NCDT*M
MM=M*M
CALL FAC(STK, NNNG, ICOL, INUM, U)
IF(NNNG .LT. 0) GO TO 99
CO 3 I=1, M
3 EIG(1) = 0
CG 74 K=1, M
II=(K-1)*N
IY=K*2-1
DO 74 I=1, N
IX=IY
IY=IX*65539
75 IF(IY) 75, 76, 76
76 VFL=IY

TEIG0001
TEIG0002
TEIG0003
TEIG0004
TEIG0005
TEIG0006
TEIG0007
TEIG0008
TEIG0009
TEIG0010
TEIG0011
TEIG0012
TEIG0013
TEIG0014
TEIG0015
TEIG0016
TEIG0017
TEIG0018
TEIG0019
TEIG0020
TEIG0021
TEIG0022
TEIG0023
TEIG0024
TEIG0025
TEIG0026
TEIG0027
TEIG0028
TEIG0029
TEIG0030
TEIG0031
TEIG0032
TEIG0033
TEIG0034
TEIG0035
TEIG0036
74 XLR(II+1)=YFL*0.4656613D-9-0.5C+00
    IF(I1GUEST.EQ.0) GO TO 200
    GO TO (210,220,230,240,220),ICASE
210 GO TO (31C,320,330),IGUEST
C-----W ONLY
31C IX=N/6
    CC 301 K=1,M
    II=NCDT*K-NCDT
    XLR(II+1)=0.0C+00
    DC 301 KK=1,IX
    JJ=KK*6-5
    XLR(II+JJ+2)=0.0C+00
    XLR(II+JJ+4)=0.0D+00
    XLR(II+JJ+5)=0.0D+00
301 XLP(II+JJ+6)=0.00+00
    GO TO 200
C-----V ONLY
32C IX=N/6
    CC 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)=0.00+00
    XLR(II+JJ+3)=0.0D+00
    XLR(II+JJ+5)=0.0D+00
302 XLP(II+JJ+6)=0.00+00
    GO TO 200
C-----PHI ONLY
33C IX=N/6
    CC 303 K=1,M
    II=NCDT*K-NCDT
    CC 303 KK=1,IX
    JJ=KK*6-5
    DO 303 KKK=1,4
303 XLP(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)=0.0DO
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-1)=0.0DO
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)=0.0DO
DO 233 KK=1,IX
233 XLR(II+2*KK+1)=0.0DO
GO TO 200

C------V ONLY

232 IX=N/2
DO 234 K=1,M
II=N*K-N
CC 234 KK=1,IX
234 XLR(II+2*KK)=0.0DO
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)=O. ODO
GO TO 200
C------V ONLY
242 IX=N/2
DO 244 K=1,M
II=N*K-N
XLR(II+1)=O. ODO
DO 244 KK=1,IX
244 XLR(II+2*KK)=O. ODO
200 CONTINUE
IST=1
DO 21 KKK=1,N ITR
IT=(IST-1)*N+1
DO 1 I=1,N
1 Y(I)=XLR(I)
CALL SGLZ(STK,Y,N,M-IST+1,ICOL,INUM,IST)
LL=K=1
II=(K-1)*N
XM=O. O
LCH(K)=O
DO 7 T=1,N
L=DABS(Y(II+I))
IF(D-XM)7,7,5
7 X*O=O
LCH(K)=I
7 CONTINUE
IF(LCH(K) .EQ. O) GO TO 99
E=Y(II+LCH(K))
E=1. O/E
CC IL T=1,N
III=I+II
Y(III)=Y(III)*E
11 XLF(III)=XLR(III)*E
CALL MTRTRM(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 MTRTRM(N,RM,Y,X,IST)
   DO 39 I=1,MM
     SRM(I)=RM(I)
   39 SRK(I)=RK(I)
   CALL DNROOTT(M,RM,RK,U,RV)
   DO 40 I=1,M
40 U(I)=1./U(I)-ALPHA
   WRITE(6,41) (U(I),I=1,M)
41 FORMAT(12X,'EIGENVALUES=',/,(2X,16D13.5))
   DO 22 I=IST,MA
      IST=I
      IF(DABS(EIG:)/U(I)-1.0) .GT. ERR) GO TO 23
22 CONTINUE
   DC 504 I=1,M
   SQUR(I)=CSQRT(DABS(U(I)))
   CYC(I)=SCU(I)*0.5DO/3.14159200
504 CONTINUE
   WRITE(6,505)(SQUR(I),I=1,M)
505 FORMAT(17X,'RADIUS/SEC',/,(2X,16D13.5))
506 FORMAT(17X,'HERTZ',/,(2X,16D13.5))
   WRITE(6,506)(CYC(I),I=1,M)
   DO 10 I=1,NCDT
      DO 10 J=1,M
         JJ=J-1.*NCDT
         XLR(I+JJ)=0.*G
      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
         II=(I-1)*M
         DO 15 J=1,M
            JJ=(J-1)*M
            IJ=JJ+I
         DO 15 K=1,M
            XLR(I+JJ)=XLR(I+JJ)+Y(I+(K-1)*N)*RV((J-1)*M+K)
PM(II)=0.0
RK(I,J)=0.0
DO 15 K=1,M
KK=(K-1)*M
FM(I,J)=RM(I,J)+SRM(KK+I)*RV(JJ+K)
15 RK(I,J)=RK(I,J)+SRK(KK+I)*RV(JJ+K)
CALL MTRTR(M,M,SRM,RV,RM,1)
CALL MTRTR(M,M,SRK,RV,RK,1)
CG 42 I=1,M
KK=M/(M+1)
Y(I)=1./DSQRT(SRM(KK))
II=I*NCOT-NCCT
CG 42 J=1,NCOT
42 XLR(II+J)=XLR(II+J)*Y(I)
CC 17 I=1,M
KK=I/(I-M)
CG 17 J=1,I
II=II+Y(I)
IJ=KK+J
SRM(I,J)=E*SRM(IJ)
17 SRK(I,J)=E*SRK(IJ)
CALL OUTPUT(KKK,M,NCOT,NDT,NOD,NNODE,ERR,XLR,U,SRM,SRK)
GO TO 99
23 CC 25 I=1,M
25 EIG(I)=U(I)
IF(IST.EQ.1) GO TO 45
IQ=IST-1
CG 44 I=1,IQ
II=(I-1)*M
DO 44 J=1,IQ
IJ=II+J
KM(I,J)=SRM(IJI)
44 RK(I,J)=SPK(IJI)
45 CONTINUE
DO 34 I=1,N
CG 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)
CONTINUE
WRITE(6,26) KKK
26 FORMAT(/2X,'NO. OF ITERATION=',I4,2X,'NOT CONVERGED')
RETURN
END
SUPROUTINE INPUT(IEQ,NDPE,NET,NDT,MNC,NODE,NUB,NRCU,ERP,NITR,4)

TO SUPPLY INPUT INFORMATION

DES
COMMENTS AND DESCRIPTIONS
ICASE=1 WING
ICASE=2 BLADE B.C. CANTILEVER+CANTILEVER
ICASE=3 BLADE B.C. CANTILEVER+HINGE
ICASE=4 BLADE B.C. HINGE+CANTILEVER
ICASE=5 BLADE B.C. HINGE+HINGE

IPOUCH=0 NO PUNCH OUTPUT
IPOUCH=1 PUNCH OUTPUT

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

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

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

ERR ERROR TOLERANCE FOR ITERATION
OMEG ROTATION FREO IN RAD / SEC
RAMDA=INFLOW RATIO
COL=COLLECTIVE PITCH ANGLE DETERMINED BY PERFORMANCE ANALYSIS
SPKR,SPKC =SPRING CONSTANT OF THE HINGED BLADE (BEAMWISE
 & CHORDWISE)
ALPHAH=HELPER TO AVOID THE SINGULARITY OF THE STIFFNESS MATRIX

EIBE= EI FOR SPANWISE BENDING
EICE ET FOR CORDWISE BENDING

THETA=AMSLF OF TWIST

AMASF=MASS/UNIT LENGTH

ESE=ELEMENT SIZE

AMN = MASS OF NACELLE AND ALL BLADES OR TIP MASS IN CASE OF BLADES

PI=PEERING MOMENT OF INERTIA OF NACELLE,

PI12=MOMENT OF INERTIA OF NACELLE,

PI12= MASS COUPLING BETWEEN TORSION AND SPANWISE BENDING

IF ICASE=1, NEXT THREE DATA GJ, PI, AND Pi12 SHOULD BE ADDED.

GJ = TORSIONAL RIGIDITY

PI= MOMENT OF INERTIA FOR TORISON

PI12= MASS COUPLING BETWEEN TORISON AND SPANWISE BENDING

POSITIVE IF C.G. IS AHEAD OF ELASTIC AXIS

NDPE= NO OF DEGREES OF FREEDOM PER NODE

NDPN = 4 FOR BLADE MODE

NDPN = 6 FOR WING MODE

COMMON /PUNCH/ IPUNCH

COMMON /PW/ ICASE, IGUEST

COMMON /SPRING/SPRK,SPKC

COMMON/HELP/ALPHAH

DOUBLE PRECISION ALPHAH

DIMENSION NDPE(1),NODE(1), NRCU(1)

DOUBLE PRECISION ERR

DIMENSION JI(20), FICET(20), THETA(20), AMASE(20), ESE(20), TN(21)

DIMENSION GJ (20), PI(20), Pi12 (20)

COMMON /ELEMI/ OMEG, FIE, FICE, THFETAE, AMASF, ESE, TN, GJ, PI, Pi12, AMN,
1 PIP,PIY,PIP,PRW,RI,R,NETT
DIMENSION DES(20)
10 FORMAT (16I5)
1 FORMAT (8E10.6)
4 FORMAT (5E15.7)
149 FORMAT (2A4)
150 FORMAT (11)
TEQ=0
READ(5,149)(DES(I),I=1,20)
READ(5,150)ICASEF
READ(5,150)IPUNCH
READ(5,150)IGUEST
READ (5,10) NFT,NITR,M
IF (ICASEF,50,1) GT 192
50 CONTINUE
GO TO 193
192 NDNP=6
193 CONTINUE
NETT=NET
READ(5,11)ERP
READ(5,1)OMEG
READ(5,1)RAMDA
READ (5,1)COL
READ (5,1)SPKR,SPKC
READ(5,1)ALPHAH
READ (5,4)EIRF(I),I=1,NET
READ (5,4)EICE(I),I=1,NET
READ (5,1)THESEF(I),I=1,NET
READ (5,1)AMASEF(I),I=1,NET
READ (5,1)ESF(I),I=1,NET
READ (5,1)AMHI,PIP,PIY,PIP,PRW
10 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
WRITE(6,105) (EIBE(I),I=1,NET)
WRITE(6,184)
184 FORMAT(1X,'--CHORDWISE BENDING STIFFNESS--')
WRITE(6,105) (EICE(I),I=1,NET)
WRITE(6,185)
185 FORMAT(1X,'--ANGLE OF TWIST--')
WRITE(6,104) (THETAE(I),I=1,NET)
THE=ATAN((RMDA=4.0/3.0)+COL.*SIGN(1.0,OMEG))
DO 302 I=1,NET
302 THETAF(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,'PINCH INERTIA',T64,'MASS COUPLING')
WRITE(6,104) AMN,PIR,PIY,PIP,PRW
NN=NET+1
104 FORMAT (8F15.5)
105 FORMAT(5X,7E15.7)
IF (DONP '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) (OI(I),I=1,NET)
WRITE(6,191)
191 FORMAT(1X,'--MASS COUPLING ALONG SPAN--')
WRITE(6,105) (PI12(I),I=1,NET)
9 FORMAT (/8H *, /12H INPUT DATA/////) 16 FORMAT (25H NO OF DEGRE PER NODE=,13/
& '17H NO OF ELEMENTS=',13/24H NO OF MAX ITER ALLOWED=',13
2 /14H NO OF NODES=, 13/ 6H ERR=, F15.5)

14 NODE=NDPN+NDPN
    NDT=NFT*NDPN+NDPN
    MNC=NDT*NODE-(NODE*NODE-NODE)/2
DC 5 I=1,NDT
    NODE(I)=NODE
    NII=NODE*I-NODE
    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

5 CONTINUE
    GO TO (511,512,513,514,515),ICASE

501 NBU=NDPN-1
    GO TO 506
502 NBU=4
506 DC 6 I=1,NBU
6 NBCU(I)=1
    GO TO 507
503 NBCU=3
    NBCU(I)=1
    NBCU(2)=2
    NBCU(3)=3
    GO TO 507
504 NBCU=3
    NBCU(I)=1
NRCU(2)=2
NRCU(3)=4
GO TO 507
505 NPU=2
NRCU(1)=1
NRCU(2)=2
507 CONTINUE
   R=0
   DO 2 I=1,NET
      R=R+FSE(I)
      TN(NET+1)=AMN*R*OMEG*OMEG
   DO 3 I=1,NET
      II=NET-I+1
      P=R-FSE(I)
      3 TN(II)= TN(II+1) + AMASE(I)*(R+.5*ESE(II))*ESE(II)*OMEG*OMEG
      WRITE (6,15)
      WRITE(6,104) ( TN(I),I=1,NN)
15 FORMAT(/// TENSION DUE TO CENTRIF FORCE)
   R=0.
   BI=0.
   BM=0
   DO 11 I=1,NET
      BM=BM+AMASE(I)*ESE(I)
      PR=R+ESE(I)
      BI= BI+ AMASE(I)*(PR**2-R**2)*.33333333
   11 R=PR
      BM=BM+AMN
      BI=BI+AMN*R*P
      WRITE (6,12) BM,BI,R
12 FORMAT(/// MASS =',E13.5/ MOMENT OF INERTIA AT ROOT=',F13.5/
           TOTAL LENGTH OF THE BEAM=',F13.5))
RETURN
END
SUBROUTINE ELEMK (EKT, EMT, NDE, NE)

? TO CONTROL THE GENERATION OF ELEMENT STIFFNESS AND MASS MATRICES

NCF=8 FOR PLATE MODE
NCE=12 FOR WING MODE
COMMON/SRPRIN/SPKB,SPKC
COMMON/HELP/ALPHAh
DOUBLE PRECISION ALPHAh
DOUBLE PRECISION EKT, EMT
DIMENSICCA EKC(4,4), ETC(4,4), EMC(4,4), EKT(1), EMT(1)
DIMENSION EIBE(20), EICE(20), THETAE(20), AMASE(20), ESE(20), TN(21)
DIMENSION GJ(20), PI(20), PI12(20)
COMMON /ELEM/ EME, EIBE, EICE, THEETA, AMASE, ESE, TN, GJ, PI, PI12, AMN,
1. PIR, PIY, PIP, PBW, BM, BI, R, NETT

EET=NETT
EIB=EIBE(NDE)
EIC=EICE(NDE)
THETA=THETAE(NDE)
AMAS=AMASE(NDE)
ES=ESE(NDE)
T=(TN(NDE)+TN(NDE+1)) *.5
ESS=ES*ES
IF (NDE.EQ.8) GO TO 9
GJE=GJ(NDE)/ES
PIE=PI(NDE)*ES
PI12E=PI12(NDE)*ES

9
EKC(1,1)=12.
EKC(2,1)=6.*ES
EKC(3,1)=-12.
EKC(4,1)=4.*ES
EKC(2,2)=4.*ESS
EKC(3,2)=-6.*ES
EKC(4,2)=2.*ESS
EKC(3,3)=12.
$\text{EKC}(4, 3) = -6.0 \times E S$
$\text{EKC}(4, 4) = 4.0 \times E S S$
$\text{ETC}(1, 1) = 1.2$
$\text{ETC}(2, 1) = 1.0 \times E S$
$\text{ETC}(3, 1) = -1.2$
$\text{ETC}(4, 1) = 1.0 \times E S$
$\text{ETC}(2, 2) = 1.3333333 \times E S S$
$\text{ETC}(3, 2) = -1.0 \times E S$
$\text{ETC}(4, 2) = 0.03333333 \times E S S$
$\text{ETC}(3, 3) = 1.2$
$\text{ETC}(4, 3) = 1.0 \times E S$
$\text{ETC}(4, 4) = 1.3333333 \times E S S$
$\text{EMC}(1, 1) = 156.0 / 420.0$
$\text{EMC}(2, 1) = 22.0 / 420.0 \times E S$
$\text{EMC}(3, 1) = 54.0 / 420.0$
$\text{EMC}(4, 1) = -13.0 / 420.0 \times E S$
$\text{EMC}(2, 2) = 4.0 / 420.0 \times E S S$
$\text{EMC}(3, 2) = -\text{EMC}(4, 1)$
$\text{EMC}(4, 2) = -3.0 / 420.0 \times E S S$
$\text{EMC}(3, 3) = \text{EMC}(1, 1)$
$\text{EMC}(4, 3) = -\text{EMC}(2, 1)$
$\text{EMC}(4, 4) = \text{EMC}(2, 2)$
$CC\ 10\ I=1,4$
$CC\ 10\ J=1,4$
$\text{EMC}(J, I) = \text{EMC}(I, J)$
$\text{EKC}(J, I) = \text{EKC}(I, J)$
$ESSS = E SS \times E S$
$SI = \text{SIN}(\text{THETA})$
$CC = \text{CCS}(\text{THETA})$
$B = (EIC \times CO \times EIC \times SI \times SI) / ESSS$
$C = (EIC \times CC \times CO + EIB \times SI \times SI) / ESSS$
$BC = (EIC - EIB) \times SI \times CO / ESSS$
$1E = T / ES$
$AM = OMEG \times OMEG \times AMAS \times ES$
$AMAE = AMAS \times ES$
$CG\ 5\ I=1,4$
II=(1*I-1)/2
I4=(1+4)*(1+3)/2
DC 1 J=1,1
EKT(I+J)= B*FKC(I,J)+TE*ETC(I,J)
EMT(I+J)= AMAE*EMC(I,J)
EKT(I4+J+4)= C*EKC(I,J)+TE*ETC(I,J)-AM*EMC(I,J)
1
EMT(I4+J+4)= AMAE*EMC(I,J)
CC 2 J=1,4
EMT(I4+J)=0.
2
EKT(I4+J)=BC*EKC(I,J)
IF (NDE .EQ. 81) GO TO 5
1E=(I+2)*(I+7)/2
CC 3 J=1,1
EKT(I8+J+8)=GJE*ETC(I,J)
3
EMT(I8+J+8)= PIE*EMC(I,J)
EG 4 J=1,4
EKT(I8+J+4)=G.
EKT(I8+J+4)=G.
EMT(I8+J+4)=G.
4
EMT(I8+J)=PI12E*EMC(I,J)
5
CONTINUE
IF(N.E.LT.AET) 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(N.E.GT.1) GO TO 101
EKT(3)=EKT(3)+SPKB
EKT(21)=EKT(21)+SPKC
101
CC 162 I=1,36
102
EKT(II)=EKT(II)+EMT(II)*ALPHA
RETURN
END
SUBROUTINE MESH(NDPE,NET,ADT,NCOT,MNC,MN, NOD,NNODE,ICOL,INUM, ANBU, INDEX)

TO CALCULATE MESH INFORMATION OF THE FINITE ELEMENT

DIMENSION NOD(1), ANODE(1), ICOL(1), INUM(1), NDPE(1)

IF(NBU .GT. 0) GC TO 100
DO 99 I=1,NDT
99 NOD(I)=1
NCOT=NDT
GC TO 98
10 CONTINUE
DO 22 I=1,NBU
    IF ( I .GE. NBU) GO TO 101
    II=I+1
    DO 21 J=II,NBU
        IF ( INUM(II).NE.INUM(J)) GC TO 21
        IF ( J .GE. NBU) GO TO 20
        JI=JI+1
    21 CONTINUE
    DO 19 K=JI,NBU
19 INUM(K-II)= INUM(K)
20 NBU=NBU-1
    J=J-1
21 CONTINUE
22 CONTINUE
101 DO 1 I=1,NCOT
1 NOD(I)=1
    DO 2 I=1,NBU
        IL=INUM(I)
2 NOD(IL)=0
    DO 3 I=2,NCOT
        NOD(I)=NCOT(I-1)+NOD(I-1)
        NCOT=NCOT-NCOT
    3 CONTINUE
4 NCOT=NCOT+1
99 CONTINUE
II=0
DO 5 I=LN+1,NN
II=NDP(I)
DO 54 J=1,NN
ICCL(J)=NCDE(J+II)
DO 55 J=1,NN
II=ICCL(J)
55 NN)DE(J+II)=NJC(J1)
II=II+JJ
DO 6 I=1,NCDE
6 ICCL(I)=I
II=J
DO 88 I=1,NN+1
JJ=NDP(I)
IMIN=NDT
DO 7 J=1,NN
IM=NCDE(J+II)
7 IF(IN .LT. IMIN) IMIN=IN
DO 8 J=1,NN
ID=NCDE(J+II)
8 IF(ICCL(ID) .GT. IMIN) ICCL(ID)=IMIN
II=II+JJ
INUM(I)=0
DO 9 I=2,NCDE
9 INUM(I)=INUM(I-1)+I-ICCL(I)
MN=INUM(NCDE)+NCDE
WRITE(6,16) MN,MNC
16 FORMAT(72X,'MAX. SIZE OF GF IS ',16,5X,'SPECIFIED SIZE IS ',16)
INDEX=1
IF(MNC .LT. MN) INDEX=0
RETURN
END
SUBROUTINE ASBV(STK, STN, IEQ, EK, EM, NOPE, NDT, NCDT, NNODE, MN, NET, INUM)

TO ASSEMBLE AND CONSTRAIN BOUNDARY CONDITIONS

IMPLICIT REAL*8(A-H, O-Z)
DIMENSION STK(1), STN(1), EK(1), EM(1), NOPE(1), NNODE(1), INUM(1)

ID = NCDT + 1
DO 1 I = 1, MN
STK(I) = 0.0

1 STN(I) = 0.0
II = 0
DO 15 N = 1, NET
JJ = NOPE(N)
IF (IEQ EJ) GO TO 3
IF (N .GT. 1) GO TO 8

3 CALL FLEMK(EK, EM, JJ, N)

8 DO 14 1 = 1, JJ

KI = (I - I/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(KNA + KNA
IF (KNA .GT. KMA) KA = INUM(KNA) + KMA
STK(KA) = STK(KA) + FK(KI + J)
STN(KA) = STN(KA) + EM(KI + J)

13 CONTINUE
14 CONTINUE
15 II = JJ * II
RETURN
END
SUBROUTINE FAC(STF, NDT, NNDG, ICOL, INUM, U)
C
C FACTORING A SYMMETRIC MATRIX INT. LDL*
C
IMPLICIT REAL*8(A-H, O-Z)
DIMENSION STF(1), ICOL(1), INUM(1), U(1)
NNDG = 0
IF (STF(11), ICOL(1), INUM(1), U(1))
1 IZR = 1
99 WRITE(6, 100) IZR
1 FORMAT(/2X, 'THE', 'TH DIAG. AFTER FACT. = 0.0, INCOMPLETE FACT.')
NNDG = -1
RETURN
2 NNDG = 0
3 IF (NDT .LT. 2) GC TC 11
DO 10 IR = 2, NDT
II = ICOL(IR)
IF (II .EQ. IR) GC TC 11
JR = INUM(IR)
IF (JR .EQ. IR) GC TC 11
IE = IR - 1.
DO 5 IC = 11, IE
IMAX = IT
IF (II .LT. IC) ICCL(IC) IMAX = ICCL(IC)
JE = IC - 1
SUM = STF(JR + IC)
IF (JE .LT. IMAX) GO TO 55
JC = INUM(IC)
DO 4 J = IMAX, JE
5 SUM = SUM - L(J)*STF(JC + J)
55 U(IC) = SUM
STF(JR + IC) = SUM/STF(INUM(IC) + IC)
J = JR + IC
DO 6 J = 11, IE
6 STF(JJ) = STF(JJ) - L(J)*STF(JP + J)
IF (STF(JJ) .LT. 10)
1 JR = IR
RETURN
GO TO 99
8 NNDG=NNDG+1
10 CONTINUE
11 WRITE(6,101) NNDG
101 FORMAT(/2X,'NO. OF NEGATIVE DIAGS.=',I4,5X,'FACT. COMPLETED')
RETURN
END
SUBROUTINE MTRTR(M,N,RX,XLR,X,IST)
C
C         MATRIX MULTIPLICATION
C
IMPLICIT REAL*A-H,0-Z
DIMENSION RX(1),XLR(1),X(1)
DO 2 I=IST,M
II=(I-1)*N
IJ=(I-1)*M
DO 2 J=1,1
JJ=(J-1)*N
RX(IJ+J)=C.0
DO 2 K=1,N
2 RX(IJ+J)=RX(IJ+J)+XLR(II+K)*X(JJ+K)
DO 3 I=IST,M
JJ=(J-1)*M
DO 3 J=1,1
3 RX((J-1)*M+I)=RX(JJ+J)
RETURN
END

MTRT0001
MTRT0002
MTRT0003
MTRT0004
MTRT0005
MTRT0006
MTRT0007
MTRT0008
MTRT0009
MTRT0010
MTRT0011
MTRT0012
MTRT0013
MTRT0014
MTRT0015
MTRT0016
MTRT0017
MTRT0018
MTRT0019
MTRT0020
SUBROUTINE MULTZ(STF,X,Y,NDT,M,ICOL,INUM,MM)

C MATRIX MULTIPLICATION
C
IMPLICIT REAL*8(A-H,O-Z)
DIMENSION STF(1),X(1),Y(1),ICCL(1),INUM(1)
DO 1 J=1,NCT
1 Y(J)=0.0
MM=M+MM-1
DO 4 I=MM,MMM
II=(I-1)*NDT
DO 3 IR=1,NDT
IS=INUM(IR)
IC=ICCL(IR)
IF=IR-1
IF(IC.GT.IE) GO TO 3
DO 2 J=IC,IE
S=STF(IS+J)
Y(IR)=Y(IR)+S*X(II+J)
2 Y(J)=Y(J)+S*X(II+IP)
3 Y(IP)=Y(IP)+STF(IS+IP)*X(IIP)
DO 4 J=1,NDT
X(IIP)=Y(J)
4 Y(J)=0.0
RETURN
END
SUBROUTINE SOLZ(STF,U,NDT,M,ICOL,INUM,MM)
C
C      SOLVE (LDL*) (U)=U FOR GIVEN L OF M VECTORS OF LENGTH NDT
C
C      IMPLICIT REAL (*)
D    DIMENSION STF(1),U(1),ICOL(1),INUM(1)
C
C      MMM=M+MM-1
C      IF(NDT .LT. 2) GO TO 3
C      DO 2 IR=2,NDT
C      JI=ICOL(IR)
C      JF=IR-1
C      IF(JJ .GT. JE) GO TO 2
C      DO 1 I=MM,MMM
C      II=(I-1)*NCT
C      IS=II+IR
C      DO 1 J=JI,JE
C      U(IS)=U(IS)-STF(INUM(IR)+J)*U(II+J)
C 1 CONTINUE
C      DO 4 IR=1,NDT
C      I=(I-1)*NCT
C 2 CONTINUE
C      DO 4 IR=1,NDT
C      II=II+IR
C      IF(NDT .LT. 2) GO TO 7
C      DO 6 IK=2,NDT
C      IR=NDT-IK+2
C      JI=ICOL(IR)
C      JE=IR-1
C      IF(JJ .GT. JE) GO TO 6
C      DO 5 I=MM,MMM
C      II=(I-1)*NCT
C      IS=II+IR
C 4 CONTINUE
C      U(II+IR)=U(II+IR)/STF(INUM(IR)+IR)
C 5 CONTINUE
C      DO 6 IK=2,NDT
C 3 CONTINUE
C      IR=NDT-IK+2
C      JI=ICOL(IR)
C      JE=IR-1
C      IF(JJ .GT. JE) GO TO 6
C      DO 5 J=JI,JE
C      Y(II+J)=U(II+J)-STF(INUM(IP)+J)*U(IS)
C 6 CONTINUE
C      RETURN
C      END
SOLZ0001
SOLZ0002
SOLZ0003
SOLZ0004
SOLZ0005
SOLZ0006
SOLZ0007
SOLZ0008
SOLZ0009
SOLZ0010
SOLZ0011
SOLZ0012
SOLZ0013
SOLZ0014
SOLZ0015
SOLZ0016
SOLZ0017
SOLZ0018
SOLZ0019
SOLZ0020
SOLZ0021
SOLZ0022
SOLZ0023
SOLZ0024
SOLZ0025
SOLZ0026
SOLZ0027
SOLZ0028
SOLZ0029
SOLZ0030
SOLZ0031
SOLZ0032
SOLZ0033
SOLZ0034
SOLZ0035
SOLZ0036
SUBROUTINE DNRCC7(M,A,B,XL,X)
C
C   EIGENVALUE ANALYSIS ROUTINE
C
DIMENSION A(1),B(1),XL(1),X(1)
DOUBLE PRECISION A,B,XL,X,SUM
K=1
DO 120 J=2,M
L=M*(J-1)
DO 110 I=1,J
L=L+1
K=K+1
110 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)+1
L=M*(J-1)+I
X(L)=X(J)
DO 120 K=1,M
N1=N1+1
N2=N2+1
120 X(L)=X(L)+A(N1)*X(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)=L*L
DO 130 K=1,M
N1=N1+M
N2=N2+1
130 A(L)=A(L)+X(N1)*X(N2)
CALL EIGEN (A,X,M,MV)
L=0
DO 140 I=1,M
L=L+1
140 XL(I)=A(L)
DO 150 I=1,M
N2=0
DO 150 J=1,M
N1=I-M
L=M*(J-1)+I
A(L)=0.0
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=0.0
DO 170 I=1,M
L=L+1
170 SUMV=SUMV+A(L)*A(L)
175 SUMV=DSQRT(SUMV)
DO 180 I=1,M
K=K+1
180 X(K)=A(K)/SUMV
RETURN
END
SUBROUTINE EIGEN(A,R,N,MV)

EIGENVALUE ANALYSIS ROUTINE NEEDED IN DNRDOT

DIMENSION A(I),R(I)
DOUBLE PRECISION A,R,ANORM,ANRMX,THRX,Y,SINX,SINX2,COX2,SIACS,RANGE

10 RANGE=1.C0-12
10 IF(MV-1) 10,25,10
20 IO=-N
30 DO 20 J=1,N
40 IQ=IQ+N
50 DO 20 I=1,N
60 IJ=IQ+I
70 IF(IJ)=C.0
80 IF(I-J) 20,15,20
90 R(I)=1.0
100 CONTINUE
110 CONTINUE
120 ANORM=0.0
130 DO 35 I=1,N
140 DC 35 J=I,N
150 IF(I-J) 30,35,35
160 IA=I+(J-J-J)/2
170 ANORM=ANORM+M(A(AI)*A(AI)
180 CONTINUE
190 IF(ANORM) 165,165,40
200 ANORM=1.414*DSQT(ANORM)
210 ANRMX=ANRMX*RANGE/FLOAT(N)
220 IN0=0
230 THRX=ANRMX
240 THR=THRX/FLOAT(N)
250 L=1
260 M=L+1
270 MQ=(M*M-M)/2
280 LQ=(L=L-L)/2
290 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(LL)/DSQRT(A(LL)*A(LL)+X*X)
IF(X) 70,75,75

70 Y=-Y
SINX=Y/DSQRT(2.0*(1.0+(DSQRT(1.0-Y*Y))))
SINX2=SIX*SNX
COSX=DSQRT(1.0-SN2)
CCS2=CSS*COSX
SNCS=SNX*COSX
ILQ=N*(L-1)
IMQ=N*(M-1)
DC 125 I=1,N
IO=(I+1-1)/2
IF(I-L) 80,115,80
80 IF(I-M) 80,115,80
90 IM=I+MQ
GO TO 95
92 IM=M+IQ
95 IF(I-L) 100,115,105
100 IL=I+LQ
GO TO 110
105 IL=L+IQ
110 X=A(IL)*COSX-A(IM)*SNX
A(IM)=A(IL)*SNX+A(IM)*COSX
A(IL)=X
115 IF(MV=1) 120,125,120
120 ILR=ILQ+I
IMR=IMQ+I
X=MR(ILR)*CSSX-F(IMR)*SNX
R(IMR)=R(ILR)*SNX+F(IMR)*CSS
R(ILR)=X
125 CONTINUE
\begin{align*}
X &= 2.0 \cdot A(\text{LM}) \cdot \sin \theta \\
Y &= A(\text{LL}) \cdot \cos \theta + A(\text{MM}) \cdot \sin \theta - X \\
X &= A(\text{LL}) \cdot \sin \theta \cdot \cos \theta + A(\text{MM}) \cdot \cos \theta + X \\
A(\text{LM}) &= (A(\text{LL}) - A(\text{MM})) \cdot \sin \theta \cdot A(\text{LM}) \cdot (\cos \theta - \sin \theta) \\
A(\text{LL}) &= Y \\
A(\text{MM}) &= X
\end{align*}
SUBROUTINE OUTPUT(KKK,M,NCOT,NDT,NOD,NNODE,EPR,XLR,U,SRM,SRK)

COMMON /PUNCH/  IPUNCH
COMMON /BW/    ICASE, IGuess
DOUBLE PRECISION XLR,SRM,SRK,U,ERR
DIMENSION XLR((1),U((1),SRM(1),SRK(1)
DIMENSION NOD(1),NNODE(1)
DIMENSION XXLR(15,120)
IDERUG=0
WRITE(6,24) KKK,ERR
24 FORMAT(/2X,'NO. OF ITERATION=' ,14,2X,'CONVERGED WITHIN',C13.5)
IF(IDERUG.EQ.0) GO TO 15
WRITE(6,12)
12 FORMAT(/2X,'EIGENVECTORS=' ,/)
DO 14 I=1,M
II=(I-1)*NCOT
14 WRITE(6,13) (XLR(II+J),J=1,NCOT)
13 FORMAT(/,(2X,10D12.5))
CONTINUE
WRITE(6,20)
DO 18 I=1,M
KK=I*M-M
18 WRITE (6,16) (SRM(J+KK), J=1,1)
WRITE(6,21)
DO 19 I=1,M
KK=I*M-M
19 WRITE(6,16) (SRK(J+KK), J=1,1)
16 FORMAT(/,(2X,10D12.5)
20 FORMAT(/23H REDUCED MASS MATRIX /)
21 FORMAT(/23H REDUCED STIF MATRIX /)
NBH=NCOT-NCOT
GO TO (1C1,101,101,102,101),ICASE
101 DC 106 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 204 J=1,NRU
206 XXLR(I,J)=0.0
XXLR(I,3)=XLR((I-1)*NCDT+1)
DO 204 J=2,NCDT
204 XXLR(I,J+NRU)=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('**** BLADE MODE SHAPES ****')
DO 351 I=1,M
WRITE(6,4500)
351 FORMAT('I= ',12/I)
WRITE(6,4900)
4500 FORMAT('I= ',12//I)
WRITE(6,4900)
4900 FORMAT(T5,'K',T12,'w(I,J)',T33,'v(I,J)',T53,'cw(I,J)',T73,
& 'DV(I,J)')
DO351 K=1,NODE
WRITE(6,352) K,(XXLR(:,NOM*(K-1)+J),J=1,NOM)
352 FORMAT((1X,14,E(5X,15.7)))
351 CONTINUE
GO TO 360
333 CONTINUE
NOM=6
NODE=NDT/NOM
WRITE(6,353)
353 FORMAT('**** WING MODE SHAPES ****')
DO 354 I=1,M

OUTPO037
OUTPO038
OUTPO039
OUTPO040
OUTPO041
OUTPO042
OUTPO043
OUTPO044
OUTPO045
OUTPO046
OUTPO047
OUTPO048
OUTPO049
OUTPO050
OUTPO051
OUTPO052
OUTPO053
OUTPO054
OUTPO055
OUTPO056
OUTPO057
OUTPO058
OUTPO059
OUTPO060
OUTPO061
OUTPO062
OUTPO063
OUTPO064
OUTPO065
OUTPO066
OUTPO067
OUTPO068
OUTPO069
OUTPO070
OUTPO071
OUTPO072
WRITE(6,4501)
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(IPUNCH.EC.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 RUTOR

PART 2 ; PROGRAM TILTYN

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PURPOSE

TO ANALYZE THE TILT-ROTOR DYNAMIC SYSTEM BY MEANS
OF FREQUENCY RESPONSE AND EIGENVALUES IN POWERED
AND AUTORCATION FLIGHT

DEVELOPED BY MASAHIRU YASUE
OF AERODELASTIC AND STRUCTURES RESEARCH LABORATORY
AUGUST 1974
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MAIN PROGRAM

TO DEFINE THE SEQUENCE OF THE PROGRAM

COMMON/DOF19/AVY(19,19),BKY(19,19),CCY(19,19),CDY(19,6)
DIMENSION CGUST(6),DCZ(19)
COMMON /PARMT/ ITYPE,IFLT
CONTINUE
5001 FORMAT(1H1)
CALL INITIL
CALL CUFFE
CALL INPUT(CGUST,IDOFS,IRES,IEIGEN)
CALL INTPL
WRITE(6,5001)

-----------------------------------------------------------------------------------
CALL AERODT
CALL ORDINT
WRITE(6,5001)
CALL AINER
CALL AEROMT
CALL EQMTX(IDOF)
IF(IQLT.EQ.C) GO TO 400
CALL AUTO(IDOF)
400 CONTINUE
IDIM=IDOF*IQLT
IF (IRES.EQ.0) GO TO 200
WRITE(6,5001)
CALL GUSTCO(CGUST,DDY,IDIM,DDZ)
CALL FRQRF5(ICIM,AAY,EBY,CY,CDZ,IQLT,IDOF)
200 CONTINUE
IF (IEIGEN.EQ.0) GO TO 1000
WRITE(6,5001)
CALL EIGEN(IDIM,AAY,BAY,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,
2 0.125580,0.186290,0.233193,0.262804,0.272925 /
END
SUBROUTINE INITIL

INITIALIZATION OF THE MATRICES

COMMON/DOF13,DAY(19,19),BBY(19,19),CCY(19,19),DDY(19,6)
COMMON/INERT1/TTMT(4,6,3),TTCTJ(4,6,3),AMJT(4,3,6),CJT(4,3,6)
COMMON/APR/WGUST(4,6),DAMX(6,6),AMX(6,6),DQ(4,6,3),Q(4,6,3)
COMMON/NGAR/TSCS(20,6,6),TSAX(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
MGUST(I,J)=0.0
DAMX(I,J)=0.0
AMX(I,J)=0.0

DO 11 K=1,20
TSDS(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
TSAC(I,J,K)=0.0
12 CONTINUE

DO 13 I=1,19
DO 14 J=1,15
AY(I,J)=0.0
BY(I,J)=0.0
CY(I,J)=0.0
14 CONTINUE
DO 15 K=1,6
DY(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-II+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,
    /0.857642 , 0.730145 , 0.519096 , 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
DO 50 KK=1,NPT
YY(KK)=Y(KK)
50 CONTINUE
DO 60 I=1,NPT
YY(I)=YY(NPT-I+1)
60 CONTINUE
DO 50 JJ=1,NPT
XXX(JJJ)=(Y(JJJ)+1.0)/2.0
50 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
GIMBALLED ROTOR IN BOTH FLIGHTS
IFLT = 0: POWERED FLIGHT IFLT = 1: AUTOROTATION FLIGHT
IDOF = 9: BASIC DEGREES OF FREEDOM IS 9 I DOF IS 18
IRES = 0: FREQUENCY RESPONSE OFF IRES = 1: RESPONSE ON
IFPMAG = 0: MODE NORMALIZED ROTOR RADIUS AND WING SEMISPAN
IFPMAG = 1: NORMAL MODES
IEIGEN = 0: EIGENANALYSIS OFF IEIGEN = 1: EIGENANALYSIS ON

NORDL = 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
HMST = MAST HEIGHT
DL3 = PITCH-FLAP COUPLING COEFFICIENT (RADIAN)
WL = WING SEMISPAN
WCOD = WING CHORD
WCL = WING LIFT CURVE SLOPE
WCD = WING DRAG COEFFICIENT
WCMD = WING PITCHING MOMENT COEFFICIENT
WCMC = WING PITCHING MOMENT CURVE SLOPE
FOL3 = DISTANCE BETWEEN AERODYNAMIC CENTER AND ELASTIC AXIS
C ( NONDIMENSIONALIZED BY WING CHORD, POSITIVE AERODYNAMIC
CENTER AHEAD )

WTHET = WING TRIM ANGLE OF ATTACK (RADIANS )

CGUST = EXCITING FORCE COMPONENTS

BRED = (BLADE NATURAL FREQUENCY )**2  (RADIANS/SEC)**2
WRED = (WING NATURAL FREQUENCY )**2  (RADIANS/SEC)**2

NW = WING ELEMENT NUMBER
EMSW = WING ELEMENT SIZE NORMALIZED BY THE SEMITSPAN
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
EMSB = BLADE ELEMENT SIZE NORMALIZED BY THE ROTOR RADIUS
AMAS = MASS DISTRIBUTION AT THE NODE OF THE BLADE
THETN = ANGLE OF TWIST AT THE NODE OF THE BLADE
COL = COLLECTIVE PITCH ANGLE DETERMINED BY THE PERFORMANCE (RADIANS)
W = OUT-OF-PLANE MODE COMPONENT AT THE NODE OF THE BLADE
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

PRAB = (COLLECTIVE MODE NATURAL FREQUENCY OF THE BLADE)**2
(PRAB = (COLLECTIVE MODE NATURAL FREQUENCY OF THE WING)**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
DWOI = OUT-OF-PLANE SLOPE COMPONENT OF THE BLADE COLLECTIVE MODE
DVCOI = INPLANE SLOPE COMPONENT OF THE BLADE COLLECTIVE MODE AT THE NODE
DIMENSION RMAX(4), RMAX(4), WMAX(6), RIG(6),
DIMENSION CGUST(6), SMB(4), SMB(4), SWG(S), DES(80),
COMMON /PARK/ ITYPE, IFLT
COMMON /AMAG/ T(5), C(6), T(5, 6)
COMMON /AROT/ DEN(D), VR0(D), D(RE), RAMA, SNOEG
COMMON /APRO/ WOLO, ROH, CHD, ATP, CK, HMAST, ALOCK, AND, HRT
COMMON /ARAF/ BLAM(4), W(6), RAM(6), W(6), BLAM(4), RAMO(4),
COMMON /GMR/ V(4, 21), W(4, 21), NW(4, 21), DW(4, 21), THETA(21),
COMMON /FMS/ M(20), AMASS(20), N, NDP
COMMON /GINO/ VCOL(4, 21), WCOL(4, 21), DVCOL(4, 21), DCOL(4, 21),
COMMON /WING/ NW, NDPW, FMSW(20), G(6, 21), D(6, 21), Z(6, 21), DZ(6, 21),
* WPHI(6, 21), DPHI(6, 21)
COMMON /HIC/ WL, WCQ, WCL, WCQ, WCQ, WCQ, WCM, WTHET, VV
COMMON /COPI/ AKPC(4), AKPO(4)
COMMON /FRM/ FB(4), FR(4), FRW(6), IFRM
COMMON /THF/ THE(21), MP, MW
IFPRIG = 0
MR = 2
MW = 3
READ(5, 5030) (DES(1), T = 1, 90)
READ(5, 5001) ITYPE
READ(5, 5001) IFLT
READ(5, 2034) TDOF
IE(! TDOF, EQ. 9) GO TO 62
MP = 4
MW = 6
CONTINUE
READ(5, 5001) TRES
READ(5, 5001) IFRM
READ(5, 5001) EIGEN
READ(5, 5001) NROLD
READ(5, 5000) ROH, OMEGA, RAMA, VEL
READ(5, 5000) R, AIR, CHD, CL, CO, HMAST, DEL3
READ(5, 5000) W, WCOM, WCL, WCQ, WCQ, WCM, EDIS, WTHET
READ(5, 5000) CGUST
READ(5,5000) RRAM
READ(5,5000) WRAM
READ(5,2034) NW
NDPW=NW+1
READ(5,5000)(EMSW(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)(  
DWPHT(I,J),J=1,NDPW)
CONTINUE
READ(5,2034) N
NDP=N+1
READ(5,5000)(EMSK,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 J=1,NDP
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)
AKPC(I)=DW(I,1)*TAN(DEL2)*(-1.0)
CONTINUE
IF(ITYPE.EQ.1)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)(  
OWCOL(I,J),J=1,NDP)
READ(5,1001)(  
OVCOL(I,J),J=1,NDP)
AKPD(I)=OWCOL(I,1)*TAN(DEL3)*(-1.0)
CONTINUE
DO 200 I=1,4
BLAMO(I) = BRAMO(I) / OMEGA**2
SBM(I) = SORT(BLAMO(I))
200 CONTINUE

100 CONTINUE
IF(INOF.EQ.18) GO TO 101
DO 305 I = 4, 6
DO 305 J = 1, NDWP
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
DWPHI(I, J) = 0.0
305 CONTINUE
DO 307 I = 3, 4
DO 306 J = 1, NDP
WI(I, J) = 0.0
DW(I, J) = 0.0
VI(I, J) = 0.0
306 DV(I, J) = 0.0
307 AKPC(I) = 0.0
IF(I TYPE.EQ.0) GO TO 101
DO 308 I = 3, 4
DO 309 J = 1, NDP
WCOL(I, J) = 0.0
DWCOL(I, J) = 0.0
VCOL(I, J) = 0.0
309 DVCOL(I, J) = 0.0
308 AKPO(I) = 0.0
101 CONTINUE
DO 22 I = 1, NDP
THETA(I) = THETN(I) + COL
22 CONTINUE
DO 6 I = 1, 4
BLAM(I) = BRAM(I) / OMEGA**2
6 SBM(I) = SORT(BLAM(I))
DO 5 I=1,6
WLAM(I)=WRAM(I)/OMEGA**2

5  SWG(I)=SQR(T(WLAM(I))
DO 30 I=1,6
TT(I,1)=6(I,NDPW)
TT(I,2)=Z(I,NDPW)
TT(I,3)=DZ(I,NDPW)
TT(I,4)=WPHI(I,NDPW)
TT(I,5)=DG(I,NDPW)
30  CONTINUE
IF(IFT.EQ.0) GO TO 23
DO 24 I=1,6
24  TT(I,5)=0.0
23  CONTINUE
DO 40 I=1,6
DO 40 J=1,6
40  C(I,J)=DZ(I,NDPW)*WPHI(J,NDPW)-DZ(J,NDPW)*WPHI(I,NDPW)
ALOCK=ROH*CL*CHOD*R**4/AIB
ANO=FLOAT(NORL)
HR=HMAST/R
SNOMEG=SIGN(1.0,OMEGA)

2034 FORMAT(12)
5003 FORMAT(80A1)
5001 FORMAT(11)
5000 FORMAT(8E10.0)
1001 FORMAT(6F13.5)

C. ****************** PRINT OUT OF INPUT DATA ******************
WRITE(6,5002) (DES(I),I=1,80)
5002 FORMAT(/10X,100(1H*),/20X,80A1,/10X,100(1H*)/)
WRITE(6,5004) (TYPE,IFLT,IDOIF,IFRS,IEIGEN,IFRMAG)
5004 FORMAT(/10X,'ITYPE=',I2,3X,'IFLT=',I2,
5  'IDOIF=',I2,3X,'IFRS=',I2,3X,'IEIGEN=',I2,3X,'IFRMAG=',I2)
WRITE(6,1)NORL,ROH,CHOC,AIR,HMAST,ALOCK
1  FORMAT(/H,'NO OF BLADES',T75,'ROH',T41,'CHORD',T59,'!*B'
9,$,'HMAST',T94,'LOCK NO',
C/ T7,12,T18.5(1PE15.7,2X))
WRITE(6,20)OMEGA,P,VFL,CL,CD,THETA
2  FORMAT('/// T6,'OMEGA',T25,'P',T41,'VFL',T59,'CL',T74,'CD',
#,T44,`THETA'      //1X,6(1PE15.7,2X))
WRITE(6,61)COL,DFL3
61  FORMAT('/// T6,'COllective PITCH',T25,'DFL3'      //1X,2(1PE15.7,2X))
WRITE(6,31)WL,WCD,WCL,WCD,WCMO,WCMa
3  FORMAT('/// T6,'WING L',T25,'WING CHOP',T41,'WING CL',T59,'WING CD',
#,T74,'WING CMa',T94,'WING CMA'      //1X,6(1PE15.7,2X))
WRITE(6,4)EDTS,WTHET
4  FORMAT('/// T6,'DISTANCE AC EA',T25,'WING ALPHAH',
#,T1X,2(1PE15.7,2X))
WRITE(6,25)
250  FORMAT('/// 1X,35(1H-)/1X,'EIGENVALUES (NATURAL FREQUENCIES )'
8   /1X,35(1H-)/2X,1(--(RAD/SEC)**2--)')
   IF(TYPE.EQ.0) GO TO 254
   WRITE(6,251)(RPAIO(I),I=1,MR)
251  FORMAT('/// 1X,'**PLAIDE COLLECTIVE**'//4X,4(F12.3,3X))
   WRITE(6,252)
252  FORMAT('/// 1X,'**PLAIDE Cyclic**')
   GO TO 255
254  WRITE(6,253)
253  FORMAT('/// 1X,'**PLAIDE**')
255  WRITE(6,256)(RPAO(I),I=1,MR)
256  FORMAT(4X,4(F12.3,3X))
   WRITE(6,257)(WPAM(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)(S3M(I),I=1,MR)
351  FORMAT('/// 1X,'**PLAIDE COLLECTIVE/OMEGA**'//4X,4(F12.3,3X))
   WRITE(6,352)
352  FORMAT('/// 1X,'**PLAIDE 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))
WRITE(6,357)(SWG(I),I=1,MW)
357 FORMAT('/1X, ' **WING/OMEGA**')
WRITE(6,409)
358 FORMAT(//1X,'EXCITING FORCE COMPONENTS')
WRITE(6,358)CGUST
359 FORMAT(//T6,'U GUST',T25,'V GUST', T41,'W GUST', T59,
* 'THETA 0',T74,'THETA 10', T94,'THETA 15',//1X,
* 6(1PE15.7,2X))
DO 430 I=1,MB
DO 431 J=1,NDP
RIG(I)=0.0
PA=ARS(W(I,J))
IF(PA -RIG(I)) 460,460,461
461 PTG(I)=PA
460 PA=ARS(V(I,J))
IF(PA -RIG(I)) 431,431,462
462 RIG(I)=PA
431 CONTINUE
430 BMAX(I)=RIG(I)
DO 435 I=1,MW
DO 435 J=1,NDPW
RIG(I)=0.0
PA=ARS(G(I,J))
IF(PA -RIG(I)) 465,465,466
465 RIG(I)=PA
466 PA=Z(I,J))
IF(PA -RIG(I)) 436,436,467
467 RIG(I)=PA
436 CONTINUE
435 WMAX(I)=RIG(I)
IF(IYPE, EQ.0) GO TO 480
DO 440 I=1,MR
DO 441 J=1,NDP
PIG(I) = 0.0
PA = ABS(WCOL(I,J))
IF(PA - RIG(I)) 470, 470, 471
471  BIG(I) = PA
470  PA = ABS(VCOL(I,J))
IF(PA - RIG(I)) 441, 441, 472
472  BIG(I) = PA
441  CONTINUE
440  BOMAX(I) = PIG(I)
GO TO 487
487  CONTINUE
DO 481 I = 1, MB
481  ROMAX(I) = RMAX(I)
487  CONTINUE
DO 475 I = 1, MB
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, MB), (WMAX(I), I = 1, MW)
5005  FORMAT(///(10X, E15.7))
477  CONTINUE
RETURN
END
SUBROUTINE INTPL

C INTERPOLATION FOR THE NUMERICAL INTEGRATION
C
C INTERPOLATION FUNCTION-------HERMIT INTERPOLATION(2 POINTS)
C INTERPOLATION FUNCTION-------LAGRANGIAN INTERPOLATION FOR THE ANGLE OF TWIST
COMMON/THE/THTETN(21) ,ME,MW
COMMON /PARMT/ IYPE ,IFLT
COMMON /AREA1/OMEGA,R,VEL,CL,CD,RAMDA,SNOMFG
COMMON/WICH/WM,WCNO,WCL,WCMO,WCMA,EDIS,WTHET,VV
DIMENSION WX(21)
COMMON/WING/ NW,NOPW,EMS(21),G(6,21),DG(6,21),Z(6,21),DZ(6,21),
*WPHI(6,21),DPHI(6,21)
DIMENSION GI(6,21),ZI(6,21),WPHII(6,20)
COMMON/WIMCD/STR(20,3,6),TSTP(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,NOP
COMMON /GINO/ VCOL(4,21),WCOL(4,21),DVCOL(4,21),DWCOL(4,21)
COMMON /AREA2/VJ(4,21),VI(4,20),THETA(20) ,AMASS(20)
*VCOL(4,20),WCOL(4,20)
COMMON /AREA2/NPT,XX(20),A(20)
DEBUG=0
WRITE(6,50)
50 FORMAT(/1x,'**** BLADE MODE SHAPES *****
XX(1)=0,0
DU 8: I=1,N
XX(I+1)=XX(I)+EMS(I)
80 CONTINUE
IF(IYPE.EQ. ) GOTO 10
WRITE(6,51)
51 FORMAT(/1x,--- COLLECTIVE MODES ---
C0 36 I=1,MB
WRITE(6,4500)I
WRITE(6,4999)
WRITE(6,3)(J,XX(J),VCOL(I,J),DVCOL(I,J),WCOL(I,J),DWCOL(I,J),
* J=1,NOP*

36 CONTINUE
WRITE(6,52)
52 FORMAT(//I6,'--- CYCLIC MODES ---')
100 CONTINUE
DO 35 I=1,MR
WRITE(6,4504)I
4504 FORMAT(/I6,I1,I1)
WRITE(6,4999)
4999 FORMAT(5X,'I',I13,'XJ',I33,'VT',I53,'DV',I53,'W',I73,'TH',I93,'AMAS',I11)
WRITE(6,315)(J,XX(J),V(I,J),DV(I,J),W(I,J),DW(I,J),J=1,NOP)
3 FORMAT((1X,14,5(5X,E15.7)))
35 CONTINUE
WRITE(6,5999)
5999 FORMAT(1X,14,5(5X,E15.7))
DO 70 II=1,NPT
DO 60 I=1,NOP
IF(XX(I),GE,XX(I)) GO TO 110
60 CONTINUE
110 EA=XX(I)-XX(I-1)
EB=XX(I)+XX(I-1)
XXI=2.0/EA*XX(I)-EB/EA
FL=(XXI+2.0)*(XXI-1.0)**2/4.0
F2=(2.0-XXI)*(XXI+1.0)**2/4.0
G1=(XXI+1.0)*(XXI-1.0)**2/4.0
G2=(XXI-1.0)*(XXI+1.0)**2/4.0
FL=(1.0-XXI)/2.0
F2L=(1.0+XXI)/2.0
DC 90 JJ=1,4
VI(JJ,II)=V(JJ,II-1)*F1+V(JJ,II)*F2+(DV(JJ,II-1)*G1+DV(JJ,II)*G2)
*EA/2.0*R
WI(JJ,II)=W(JJ,II-1)*F1+W(JJ,II)*F2+(DW(JJ,II-1)*G1+DW(JJ,II)*G2)
*EA/2.0*R
IF (ITYPE.EQ.0) GO TO 90
VICOL(JJ,II)=VCOL(JJ,II-1)*F1+VCOL(JJ,II)*F2+(DVCOL(JJ,II-1)*G1
* +DVCOL(JJ,II)*G2)*EA/2.0*R
WICOL(JJ,II)=WCOL(JJ,II-1)*F1+WCOL(JJ,II)*F2+(DWCOL(JJ,II-1)*G1
* +DWCOL(JJ,II)*G2)*EA/2.0*R
90 CONTINUE
AMASS(II)=AMASS(II-1)*F1+AMASS(II)*F2L
THETA(II)=THETA(II-1)*F1L+THETA(II)*F2L.
70 CONTINUE
IF (IDBUG.EQ.0) GO TO 400
WRITE(6,5048)
5048 FORMAT(/,T5,'J',T13,'XXX(J)',T33,'VI(1,JI)',T53,'WI(1,JI)',T73,
* 'VI(2,JI)',T93,'WI(2,JI)' )
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,JI)',T53,'WI(3,JI)',T73,
* 'VI(4,JI)',T93,'WI(4,JI)' )
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(JI)',T53,'THETA(JI)' )
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+1)=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(55,'J',T9,'WX(J)',T25,'G(II,JI)',T41,'DG(II,JI)',T57,
* 'Z(II,JI)',T73,'DZ(II,JI)',T89,'WPHI(II,JI)',T105,'DWPHI(II,JI)')
```
WRITE(6,5)(J,WX(J),G(I,J),DG(I,J),Z(I,J),DZ(I,J),WPHI(I,J),
%DPHI(I,J),J=1,NDPW)
5 FORMAT((1X, T4,7(1X,E15.7)))
38 CONTINUE
DO 10 I=1,NPT
DO 20 I=1,NOPW
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*XXX(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 I=1,6
GI(I,J)=G(I,J,1-1)*F1+G(I,J)*F2+(DG(I,J,1-1)*G1+DG(I,J)*G2)*
*WEA/2.0 *WL
ZI(I,J)=Z(I,J,1-1)*F1+Z(I,J)*F2+(DZ(I,J,1-1)*G1+DZ(I,J)*G2)*
*WEA/2.0 *WL
WPHI(I,J)=WPHI(I,J,1-1)*F1+WPHI(I,J)*F2+(DPHI(I,J,1-1)*G1+
+DPHI(I,J)*G2)*
DWPHI(I,J)=G2*WEA/2.0*WL
STR(I,1,J)=GI(I,J,1)
STR(I,2,J)=ZI(I,J,1)
STR(I,3,J)=WPHI(I,J,1)
TSTR(I,1,J,1)=GI(I,J,1)
TSTR(I,1,J,2)=ZI(I,J,1)
TSTR(I,1,J,3)=WPHI(I,J,1)
37 CONTINUE
10 CONTINUE
IF(DEBUG.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,'GI(2,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),
+DPHI(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,'H(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,'H(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 AERODY

TO DEFINE THE AERODYNAMIC COEFFICIENTS AT THE POINTS OF GAUSSIAN QUADRATURE

COMMON /PARMT/ ITYPE, IFLT
COMMON /AREA1/OMEGA, R,VEL, CL, CD, RAMDA, SNOMEG
COMMON /AREA2/NOBD, RCH, CHOD, AIB, CK, MAST, ALOCK, ANO, HR
COMMON /AREA3/VI(4,2), WI(4,20), THETAI(20), AMASSI(20)

COMMON /AREA4/F(4,4,20), HI(4,20), HI(4,20), HRZ(4,20), HNR(4,20),

COMMON/VICOL(4,20), WICL(4,20)

COMMON/AMASSI(20), VIO(4,20), WI(4,20), VI(4,20)

COMMON/CHV(4,20), OCHV(4,20)

COMMON/TT0P1(20), FT1P0(20), FT1P2(20), FT2P1(20), FT2P0(20),

/FT2P0(20), FT2P1(20), FT2P2(20)

COMMON/THI1I(4,2C), TIV(4,20), HV(4,20), HV(4,20), HV(4,20)

COMMON/CHV(20), STR(20, 3, 6), TSTR(20, 6, 3)

COMMON/CHV(20), WCOC, WCL, WCD, WCMG, WCMA, EDIS, NHET, VV

COMMON/WINGA/TSCE(20, 3, 6), TCE(20, 3, 6), TCS(20, 3, 6)

DIMENSION DAWA(3, 3), AWA(3, 3), AWG(3, 3)

DIMENSION TSCE(20, 6, 3), TCA(20, 6, 3)

DO 1 I=1, 3
DO 1 J=1, 3
DAWA(I,J)=0.0
AWA(I,J)=C.C

1

DO 2 I=1, 20
DO 2 J=1, 6
DO 2 K=1, 3
TSCE(I,J,K)=U.C

2

TSCE(I,J,K)=C.C

CK=-0.5*RCH*CL*CHOD*R**4

CA=CD/CL
CA1 = 1.0 + CA
CA2 = 1.0 - CA
AR0 = CA + RAMDA
RAMCA = A0S * (RAMCA)
DO 11 JJ = 1, NPT
XSQ = SQRT(RAMCA**2 + XXX(JJ)**2)
TAU0 = 1.0 / XSQ
TAU1 = XXX(JJ) / XSQ
TAU2 = XXX(JJ)**2 / XSQ
ALPHA = T0ETA(A(JJ) - ATAN(RAMCA / XXX(JJ)) + ATAN(RAMDA + 4.0 / 3.0))
FTH0 = RAMDA**2 * ALPA * TAU0 + RAMCA**2 * CA * TAU1 + RAMDA * ALPHA * TAU2
/ CA * TAU3
FTH1 = RAMDA**2 * CA * TAU0 + RAMCA * ALPA * TAU1 + 2.0 * CA * TAU2
FTH2 = 2.0 * RAMCA**2 * TAUU - RAMDA * CA2 * TAU1 + ALPA * 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 * ALPA * TAU1
*/ ALPA * TAU2
FZ1 = RAMDA**2 * ALPA * TAU0 + RAMCA * CA2 * TAU1 + 2.0 * ALPA * TAU2
FZ2 = - 2.0 * RAMDA**2 * CA * TAU0 + RAMCA * ALPA * TAU1 - CA1 * TAU2
FZ3 = RAMDA**2 * TAU1 + TAU3
FZ1 = FZ1 * SNOMEG
DO 200 J = 1, 4
DO 100 I = 1, 4
IF (ITYPE = EQ.0) GO TO 100
CH(I,J,JJ) = FTH1 * VICOL(J,J,JJ) * VICOL(I,J,J) + FZ1 * VICOL(I,J,J) + FZ2 * VICOL(J,J,JJ)
CONTINUE
100 CONTINUE
HI(J,J,J) = FTH1 * V1(J,J,J) + FZ1 * W1(J,J,J)
HI(J, JJ) = (FT2*VI(J, JJ) + FZ2*WI(J, JJ)) * XXX(JJ)
HR(J, JJ) = FTH*VI(J, JJ) + FZ2*WI(J, JJ)
HN(J, JJ) = (FT2*VI(J, JJ) + FZ2*WI(J, JJ)) * XXX(JJ)
WO(J, JJ) = AMASSI(JJ)*WI(J, JJ)
VO(J, JJ) = AMASSI(JJ)*VI(J, JJ)
WI(J, JJ) = AMASSI(JJ)*WI(J, JJ) * XXX(JJ)
VI(J, JJ) = AMASSI(JJ)*VI(J, JJ) * XXX(JJ)
HI(J, JJ) = FT2*VI(J, JJ) + FTH*WI(J, JJ)
HV(J, JJ) = HI(J, JJ) * XXX(JJ)
HV(J, JJ) = FZ2*VI(J, JJ) + FTH*WI(J, JJ)
CHI(J, JJ) = FZ3*WI(J, JJ) + FTH*VI(J, JJ)
IF (ITYPE, EQ, 0) GO TO 200
DO(C, JJ) = AMASSI(JJ)*VICOL(J, JJ)
DV(J, JJ) = AMASSI(JJ)*VICOL(J, JJ) * XXX(JJ)
HR(J, JJ) = FTH2*VICOL(J, JJ) + FZ2*VICOL(J, JJ)
HN(J, JJ) = (FT2*VICOL(J, JJ) + FZ2*VICOL(J, JJ)) * XXX(JJ)
OH(J, JJ) = FZ2*VICOL(J, JJ) + FTH3*VICOL(J, JJ)
CHV(J, JJ) = FZ3*VICOL(J, JJ) + FTH3*VICOL(J, JJ)

200 CONTINUE
C AERO FOR WING DUE TO ITSELF

RAMDA = ARAMDA
RC = RHO * WCOD
DAWA(1,1) = -0.5 * RC * VEL * WCL * WCOD
DAWA(1,2) = RC * WCL * WTHET * VEL
DAWA(2,1) = -0.5 * RC * WCL * WTHET * VEL
DAWA(2,2) = -RC * WCOD * VEL
DAWA(3,1) = -0.5 * RC * WCOD * VEL * (WCL * EDIS * WCMA)
DAWA(3,2) = RC * WCOD * (WCMA + WCMA * WTHET + WCL + WTHET * EDIS) * VEL
DAWA(1,3) = 0.5 * RC * WCOD * VEL * 2
DAWA(3,3) = 0.5 * RC * WCOD * VEL * 2 * (WCMA + WCMA * EDIS)

AWG(1,1) = DAWA(1,1) * VEL
AWG(1,2) = DAWA(1,2) * VEL
AWG(2,1) = DAWA(2,1) * VEL
AWG(2,2) = DAWA(2,2) * VEL
AWG(3,1) = DAWA(3,1) * VEL
AWG(3,2) = DAWA(3,2) * VEL

DO 501 I = 1, NFT
DO 502 J = 1, 6
DO 502 K = 1, 3
TSDA(I, I, K) = TSTR(I, I, K) * DAWA(K, J) + TSA(I, I, J)
TSA(I, I, J) = DAWA(I, J)
TSAG(I, I, J) = TSTR(I, I, K) * AWG(K, J) + TSAG(I, I, J)

502 CONTINUE

END
SUBROUTINE CRDINT

TO DEFINE THE ORDER OF NUMERICAL INTEGRATION

COMMON /PARMT/ ITYPE, IFLT
COMMON /AREA1/ OMEGA, R, VEL, CL, CD, RAMDA, SNAMEG
COMMON /AREA6/ NOBLC, ROH, CHOD, AIB, CK, HMAST, ALOCK, ABO, HR
COMMON /AREA5/ AH(4,4), AHI(4), AHI(4), AHRZ(4), AHN(4), AWC(4), AVD(4)
COMMON /AREA2/ AF3, AF1, AF1P, AF1P, AF1P, AF1P, AF1P, AF1P,
COMMON /AREA1/ AM1(4), AM1(4), AM1(4), AM1(4), AM1(4), AM1(4)
COMMON /AREA0/ AM1(4), AM1(4), AM1(4), AM1(4), AM1(4)

IODEBUG=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 (12, 3, 4, 5), NM
2 AHI(JQ)=FSUM
GO TO 200
3 AHI(JQ)=FSUM
GO TO 200
4 AHRZ(JQ)=FSUM
GO TO 200
5 AHN(JQ)=FSUM

OR01 0001
OR01 0002
OR01 0003
OR01 0004
OR01 0005
OR01 0006
OR01 0007
OR01 0008
OR01 0009
OR01 0010
OR01 0011
OR01 0012
OR01 0013
OR01 0014
OR01 0015
OR01 0016
OR01 0017
OR01 0018
OR01 0019
OR01 0020
OR01 0021
OR01 0022
OR01 0023
OR01 0024
OR01 0025
OR01 0026
OR01 0027
OR01 0028
OR01 0029
OR01 0030
OR01 0031
OR01 0032
OR01 0033
OR01 0034
OR01 0035
OR01 0036
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   AW0(JQ)=FSUM
   GO TO 300
7   AV0(JQ)=FSUM
   GO TO 300
8   AW(JQ)=FSUM
   GO TO 300
9   AV(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  AFT0P1=FSUM
   GO TO 400
11  AFT1P1=FSUM
   GO TO 400
12  AFT1P2=FSUM
   GO TO 400
13  AFT2P1=FSUM
   GO TO 400
14  AFXOP0=FSUM
   GO TO 400
15  AFX1P1=FSUM
   GO TO 400
16    AFZ2PO=FSUM
      GO TO 4000
17    AFZ2P2=FSUM
4000  IF(NN.LT.17) GO TO 3000
      NK=NN
      DO 500  JQ=1,4
      CALL INTEG(FSUM,NN,JQ,IQ)
      FSUM=FSUM/R*CK*ANO
      NM=NN-NK
      IF(NN.LT.22) GO TO (18,19,20,21,22),NM
18    AHI1(JQ)=FSUM
      GO TO 500
19    AHIV(JQ)=FSUM
      GO TO 500
20    AHV(JQ)=FSUM
      GO TO 500
21    AHVI(JQ)=FSUM
      GO TO 500
22    AHVII(JQ)=FSUM
      CONTINUE
500   IF(NN.LT.22) GO TO 4000
      NK=NN
      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(DMEGA)
      CARWAV(JQ,IQ)=FSUM
      GO TO 600
24    FSUM=FSUM*WL/DMEGA**2
      ARWAV(JQ,IQ)=FSUM
      CONTINUE
       IF(NN.LT.24) GO TO 5000
NN=25
DO 700 JQ=1,6
DO 700 IQ=1,3
CALL INTEG(FSUM,NN,JQ,IC)
FSUM=FSUM*WL/OMEGA**2
ARWG(JQ,IQ)=FSUM
700 CONTINUE
NN=25
DO 801 JQ=1,4
CALL INTEG(FSUM,NN,JQ,IC)
FSUM=FSUM*CK/R
CAHHI(IQ)=FSUM
801 CONTINUE
NN=NN+1
CALL INTEG(FSUM,NN,JQ,IC)
FSUM=FSUM*CK*AND
NN=NN-NK
GOTO (27,28,29,30),NM
27 AFT3PO=FSUM
GO TO 2003
28 AFT3PI=FSUM
GO TO 2003
29 AFZ3PO=FSUM
GO TO 2003
30 AFZ3PI=FSUM
IF (IDEBUG.EQ.0) GO TO 450
WRITE(6,50) ((AH(I,J),J=1,4),I=1,4)
50 FORMAT(1X,2X,'AH',4(T10,4(E15.7,2X)/1X))
WRITE(6,51)AHII,AHII,AHRZ,AHNR,AHIII,AHIV,AHV,AHVII,CAHIII
51 FORMAT(2X,'AHI',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)
$\quad /2X, 'AHV', T10, 4(E15.7, 2X)$
$\quad /2X, 'AHVI', T10, 4(E15.7, 2X)$
$\quad /2X, 'AHVII', T10, 4(E15.7, 2X)$
$\quad /2X, 'CAHIII', T10, 4(E15.7, 2X)$

WRITE(6, 82) AFT3P0, AFT3P1, AFZ3P0, AFZ3P1

82 FORMAT(2X, 'AFT3P0', T10, E15.7)
* /2X, 'AFT3P1', T10, E15.7
* /2X, 'AFZ3P0', T10, E15.7
* /2X, 'AFZ3P1', T10, E15.7

450 CONTINUE
IF (TYPE.EQ.0) GO TO 851
NN=NN+1
DO 101 JQ=1, 4
DO 101 IQ=1, 4
CALL INTEGRAL(FSUM, NN, JQ, IQ)
DAH(JQ, IQ)=CK*FSUM/R**2
101 CONTINUE
NK=NN
NN=NN+1
DO 301 JQ=1, 4
CALL INTEGRAL(FSUM, NN, JQ, IQ)
FSUM=FSUM*CK/R
NM=NN-NK
GO TO (32, 33), NM
32 DAW0(JQ)=FSUM
GO TO 301
33 DAVI(JQ)=FSUM
301 CONTINUE
IF (NN.LT.33) GO TO 2001
NN=NN+1
DO 302 JQ=1, 4
CALL INTEGRAL(FSUM, NN, JQ, IQ)
FSUM=FSUM*CK/R
DAHIII(JQ)=FSUM
302 CONTINUE
NN=NN+1
DO 780 JQ=1, 4
CALL INTEGR(FSUM, NN, JQ, IQ)
FSUM=FSUM*CK/R*ANO
OAHV(JQ)=FSUM
780 CONTINUE
NN=NN+1
DO 781 JQ=1, 4
CALL INTEGR(FSUM, NN, JQ, IQ)
FSUM=FSUM*CK/P*ANO
OAHV(JQ)=FSUM
781 CONTINUE
IF (ICFBUG.EQ.0) GO TO 851
WRITE(6,80) (OAHI(I, J), J=1, 4), I=1, 4)
80 FORMAT(2X, 'OAHI', 4(T10,4(E15.7,2X)/1X))
WRITE(6,81) OAHO, OAV1, OAHII, OAHV, OAHIV
81 FORMAT(2X, 'OAHO' ,T10,4(E15.7,2X)
      /2X, 'OAV1' ,T10,4(E15.7,2X)
      /2X, 'OAHII' ,T10,4(E15.7,2X)
      /2X, 'OAHV' ,T10,4(E15.7,2X)
      /2X, 'OAHIV' ,T10,4(E15.7,2X)
51 RETURN
END
SUBROUTINE INTEG(FSU,NN,JQ,IQ)
C NUMERICAL INTEGRATION-----GAUSSIAN 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, JJ, JJ, IC)

TO DEFINE THE INTEGRAND FUNCTIONS

COMMON/AREA4/H(4, 4, 20), HI(4, 20), HIII(4, 20), HRZ(4, 20), HNR(4, 20),
  VW(4, 4, 20), VO(4, 20), W1(4, 20), W1(4, 20),
  a, CH(4, 4, 20), OWE(4, 20), ODV(4, 20), OHI(4, 20), OHI(4, 20), OHI(4, 20)
  a, OHV(4, 20), OHV(4, 20),
  COMMON/AHKH/FTOP1(20), FT1P0(20), FT1P1(20), FT2P1(20), FZ2P0(20),
  /FZOP0(20), FZ1P1(20), FZ2P2(20),
  a, FT3P0(20), FT3P1(20), FZ3P0(20), FZ3P1(20)
  COMMON/ADFL/HIII(4, 20), H1V(4, 20), HV(4, 20), HVI(4, 20), HVII(4, 20),
  COMMON/WINGAR/TSAS(20, 6, 6), TSAS(20, 6, 6), TSAS(20, 6, 3),
  GC TO(1, 2, 3, 4, 5, 6, 7, 8, 9, 10, 11, 12, 13, 14, 15, 16, 17, 18, 19, 20,
  21, 22, 23, 24, 25, 26, 27, 28, 29, 30, 31, 32, 33, 34, 35, 36)

1  F=H(JJ, IC, JJ, JJ)
   RETURN
2  F=HI(JJ, JJ, JJ)
   RETURN
3  F=HII(JJ, JJ, JJ)
   RETURN
4  F=HR(JJ, JJ, JJ)
   RETURN
5  F=HNR(JJ, JJ, JJ)
   RETURN
6  F=VO(JJ, JJ, JJ)
   RETURN
7  F=V1(JJ, JJ, JJ)
   RETURN
8  F=V1(JJ, JJ, JJ)
   RETURN
9  F=V1(JJ, JJ, JJ)
   RETURN
10 F=FTOP1(JJ, JJ, JJ)
    RETURN
11 F=FT1P(JJ, JJ, JJ)
    RETURN
RETURN
F=FT1P2(JJJ)
RETURN
F=FT2P1(JJJ)
RETURN
F=FZ2P0(JJJ)
RETURN
F=FZ1P1(JJJ)
RETURN
F=FZ2P2(JJJ)
RETURN
F=HII(JQ,JJJ)
RETURN
F=HIV(JQ,JJJ)
RETURN
F=HV(JQ,JJJ)
RETURN
F=HVI(JQ,JJJ)
RETURN
F=HVII(JQ,JJJ)
RETURN
F=TS3S(JJJ,JQ,IQ)
RETURN
F=TSAS(JJJ,JQ,IQ)
RETURN
F=TSAG(JJJ,JQ,IQ)
RETURN
F=CHIII(JQ,JJJ)
RETURN
F=FT3P0(JJJ)
RETURN
F=FT3P1(JJJ)
RETURN
F=FZ3P0(JJJ)
RETURN
30 F=FZ3P1(JJJ)
RETURN
31 F=OH(JQ,IC,JJJ)
RETURN
32 F=OWO(JQ,JJJ)
RETURN
33 F=OV1(JQ,JJJ)
RETURN
34 F=OHIII(JQ,JJJ)
RETURN
35 F=OHV(JQ,JJJ)
RETURN
36 F=OHIV(JQ,JJJ)
RETURN
END
SUBROUTINE AINER
C
C TO DEFINE THE EQUATION'S COEFFICIENTS IN MATRIX FORM RELATING TO
C INERTIA TERMS
C
COMMON /PARMT/ ITYPE, IFLT
COMMON /AREA1/OMEGA, R, VEL, CL, CD, RAMDA, SNOMEG
COMMON /AREA6/NOBLD, POH, CHOD, AIB, CK, HMAST, ALOCK, AON, HR
COMMON /AREA/ AHI(4, 1), AHI(4, 2), AHI(4, 3), AHRZ(4), AMO(4), AVO(4)
   , OAVH3(4), OAVH4(4)
COMMON /INERTIA/ TMT(4, 6, 3), TTCTJ(4, 6, 3), AMJT(4, 3, 6), CJT(4, 3, 6)
COMMON /AMATIC/ T(6, 5), C(6, 5), 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
DO 50 J = 1, 5
DO 50 K = 1, 3
AMT(I, J, K) = 0.0
50
CJ(I, K, J) = 0.0
DC 210 NM = 1, 4
AMT(NM, 1, 3) = -AVO(NM) / R
AMT(NM, 2, 1) = AWO(NM) / R
AMT(NM, 3, 2) = -AVC(NM) * HR
AMT(NM, 3, 3) = AHI(NM)
AMT(NM, 4, 2) = -AHI(NM)
AMT(NM, 4, 3) = -AVO(NM) * HR
AMT(NM, 5, 1) = AHI(NM)
IF (ITYPE, EQ, 0) GO TO 300
AMT(NM, 2, 1) = AWO(NM) / R
AMT(NM, 5, 1) = OAV1(NM)
300 CONTINUE
DC 2 I = 1, 6
DC 2 J = 1, 3
DO 2 K = 1, 5
2
TMT(NM, I, J) = TT(I, K) * AMT(NM, K, J) + TMT(NM, I, J)
DO 3 I = 1, 6
3
DC 3 J=2,3
3 TTMT(NM,I,J)=0.5*TTMT(NM,I,J)
   CJ(NM,2,3)=2.0*AW1(NM)
   CJ(NM,3,4)=2.8*AW1(NM)
DC 5 I=1,5
DC 5 J=1,3
5 TCJ(NM,I,J)=CJ(NM,J,I)
CC 6 I=1,6
DO 6 J=1,3
DC 6 K=1,5
6 TTCTJ(NM,I,J)=TT(I,J)*TCJ(NM,K,J)+TTCTJ(NM,I,J)
DO 100 I=1,6
DC 100 J=2,3
100 TTCTJ(NM,I,J)=0.5*TTCTJ(NM,I,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,I,J)=AMT(NM,J,I)
DO 9 I=1,3
DC 9 J=1,6
DC 9 K=1,5
9 AMJT(NM,I,J)=AM(NM,I,K)*T(K,J)+AMJT(NM,I,J)
DO 10 I=1,3
CC 10 J=1,6
DC 10 K=1,5
10 CJT(NM,I,J)=CJ(NM,I,K)*T(K,J)+CJT(NM,I,J)
210 CONTINUE
RETURN
END
SUBROUTINE AEROMT
C
C TO DEFINE THE EQUATION'S COEFFICIENTS IN MATRIX FORM RELATING TO
C AERODYNAMIC TERMS
C
CCMION /PARMT/ ITYPE, IFLT
COMMON /AREA6/NOBLD, RCH, CHOD, AIB, CK, HMAST, ALOCK, AND, HR
COMMON /AREA5/AHI(4,4), AHI(4,4), AHRZ(4), AHNR(4), AWO(4), AVO(4)
C
C
COMMON /AREA1/OMEGA, R, VEL, CL, CD, RAMDA, SNOEDEC
COMMON /AERO/ AFTOP1, AFT1P0, AFT1P2, AFT2P1, AFT2P0, AFZ1P0, AFZ1P1, AFZ2P0, AFZ2P1, AHI(4,4), AHI(4,4), AHRZ(4), AHNR(4), AWO(4), AVO(4)
C
C
COMMON /AMATIC/TT(6,5), C(6,6), T(5,6)
COMMON /ARR/WGUST(6,6), CAMX(6,6), AMX(6,6), DQ(1), Q(4,6), Q(4,6,3)
C
C
C
COMMON /COUPL/ AKPC(4), AKPO(4)
DIMENSION CDHMX(4,3,5), CHMX(4,3,5)
DIMENSION GUST(5,6), CCAHX(5,5), CCDAMX(6,5), CAMX(5,5), CCAMX(6,5)
C
C
C
CC 190 I=1,4
CC 190 J=1,3
CC 190 K=1,5
CC 190 CDHMX(I,J,K)=0.0
CC 190 CHMX(I,J,K)=0.0
CC 190 CQ(I,K,J)=0.0
190 CG(I,J,K)=0.0
CC 191 I=1,5
CC 192 J=1,5
CC 192 CAMX(I,J)=0.0
192 CAMX(I,J)=0.0
CC 193 I=1,6
CC 193 K=1,6
CC 193 CDAMX(I,J,K)=0.0
193 CDAMX(I,J,K)=0.0
CC 193 CCAMX(I,J,K)=0.0
193 CCAMX(I,J,K)=0.0
CONTINUE
DO 1 I=1,2
DO 1 J=1,6
1 T(I,J)=T(I,J)/R
CO 2 I=1,6
DO '2 J=1,2
2 TT(I,J)=TT(I,J)/R
GUST(1,1)=0.5*AFT1P0
GUST(2,3)=AFZ2P0
GUST(3,1)=-0.5*AFZ1P1
GUST(3,2)=-HR*AFT1P0*C.5
GUST(4,1)=0.5*HR*AFT1P0
GUST(4,2)=-AFZ1P1*C.5
GUST(5,3)=AFT2P1
GUST(1,6)=J.5*AFT3P0
GUST(2,4)=AFZ3P0
GUST(3,5)=-0.5*HR*AFT3P0
GUST(3,6)=0.5*AFZ3P1
GUST(4,5)=-0.5*AFZ3P1
GUST(4,6)=0.5*HR*AFT3P0
GUST(5,4)=AFT3P1
DO 5 I=1,6
DO 5 J=1,6
DO 5 K=1,5
5 WGLST(I,J)=TT(I,K)*GUST(K,J)+WGLST(I,J)
DO 6 I=1,6
DO 6 J=1,3
6 WGLST(I,J)=WGLST(I,J)*ABS(RAMDA)
CCAMX(1,1)=0.5*AFT1P0
CCAMX(1,3)=-0.5*AFT2P1
CCAMX(1,4)=0.5*HR*AFT1P0
CCAMX(2,2)=AFZ2P0
CCAMX(2,5)=AFZ1P1
CCAMX(3,1)=0.5*AFZ1P1
CCAMX(3,3)=0.5*(HR**2*AFT1P0+AFZ2P2)
CCAMX(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 * AFT1PO + AFZ2P2 )
CCAMX(5,5) = AFT2P1
CCAMX(8,5) = AFT1P2

DC 9 I = 1, 6
DC 9 J = 1, 5
DO 9 K = 1, 5
9 CCDAMX(I, J) = TT(I, K) * CCAMX(K, J) + CCDAMX(I, J)
DC 11 I = 1, 6
CO 11 J = 1, 6
DC 11 K = 1, 5
11 DAMX(I, J) = CCDAMX(I, K) * T(K, J) + DAMX(I, J)
AMDA = ABS( RAMDA )
CAMX(1, 4) = - 0.5 * AMDA * AFT1PO + AFZ0P0
CAMX(3, 3) = HR * (AFZ0P0 - 0.5 * AMDA * AFT1PO)
CAMX(3, 4) = 0.5 * AMDA * AFZ1P1 + AFT0P1
CAMX(4, 3) = - 0.5 * AMDA * AFZ1P1
CAMX(4, 4) = HR * ( - 0.5 * AMDA * AFT1PO + AFZ0P0 )
DC 12 I = 1, 6
DC 12 J = 1, 5
DC 12 K = 1, 5
12 CCDAMX(I, J) = TT(I, K) * CAMX(K, J) + CCDAMX(I, J)
DC 13 I = 1, 6
DC 13 J = 1, 6
DC 13 K = 1, 5
13 AMX(I, J) = CCDAMX(I, K) * T(K, J) + AMX(I, J)
DO 40 NW = 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) * SHCMEG
CQ(NM,3,2)=0.5*(AHVII(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*(AHVII(NM)-AHVI(NM)*SNOMEG)
IF(IATYPE.EQ.0) GO TO 110
CDQ(NM,2,1)=0AHV(NM)
CDQ(NM,5,1)=0AHIV(NM)
CQ(NM,1,3)=0.5*AKPC(NM)*AFI3P0
CQ(NM,2,1)=AKPO(NM)*AFI3P0
CQ(NM,3,2)=CQ(NM,3,2)-0.5*HR*AKPC(NM)*AFI3P0
CQ(NM,3,3)=CQ(NM,3,3)+0.5*AKPC(NM)*AFI3P1
CQ(NM,4,2)=CQ(NM,4,2)-0.5*AKPC(NM)*AFI3P1
CQ(NM,4,3)=CQ(NM,4,3)-0.5*HR*AKPC(NM)*AFI3P0
CQ(NM,5,1)=AKPO(NM)*AFI3P1
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,1,3)=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)
CHMX(NM,2,3)=AMDA*AHII(NM)
CHMX(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 HMAX(NM,I,J)=CHMX(NM,I,K)*T(K,J)+HMAX(NM,I,J)
40 CONTINUE
SUBROUTINE EQMTX(IDOF)
C TO DEFINE THE COEFFICIENT MATRICES A, B, C AND D IN EQ. 2.3
C
COMMON /PARMT/ ITYPE, IFIL
COMMON /AREA8/BLAM(4),WLAM(6),BRAM(4),WRAM(6),BLAMG(4),BRAMG(4)
COMMON /AREA1/OMEGA,REV,VEL,CL,CD,RAMDA,SNOMEG
COMMON /AREA6/NOBLD,FCH,AIB,CK,HMAST,ALOCK,ANQ,HR
COMMON /AMATIC/TT(6,5),C(6,6),T(5,6)
A,CAH(4),OAHI(4)
COMMON /ARR/WTMT(4,6,3),TTCTJ(4,6,3),AMJT(4,3,6),CJT(4,3,6)
COMMON /ARR/WTMT(4,6,3),TTCTJ(4,6,3),AMJT(4,3,6),CJT(4,3,6)
COMMON /ARR/WTMT(4,6,3),TTCTJ(4,6,3),AMJT(4,3,6),CJT(4,3,6)
COMMON /ARI/WGTK(4,4),AKPO(4)
WRITE(6,50)
50 FORMAT(/1X,75(1H-)/15X,48HEQUATIONS OF MOTION ; A*X"+B*X'+C
&X*X=D*E ,/1X,75(1H-)/15X)
DO 801 I=1,18
801 AAY(I,I)=1.0
DO 802 NM=1,4
DD 802 NM=1,4
DO 812 I=1,3
DD 812 NM=1,4
DD 812 J=1,6
AAY((3*NM-1)*I+J+12)=BAYT(JM,J,M,NM)
DO 804 I=1,4
804 BAY((3*I-1,3*I)+2)=2.0*SNOMEG
DO 805 J=1,4
805 BAY((3*I-1,3*I-1)+K)+2)*SNOMEG
DO 805 K=1,3
DO 805 NM=1,4
DO 806 I=1,3
DO 806 J=1,6
BBY(3*(NM-1)+I,J+12)=DHMAX(NM,I,J)+CJT(NM,I,J)*SNOMEQ
8C6 BBY(J+12,3*(NM-1)+1)=CC(NM,J,I)-AN0*TTCTJ(NM,J,I)*SNOMEQ
DC 808 I=1,6
DC 808 J=1,6
8C8 BBY(I+12,J+12)=DAMX(I,J)+C(I,J)*SNOMEQ-DARWA(I,J)
CC 809 I=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
809 CCY(3*I,3*I)=BLAM(I)-1.0
DC 810 C J=1,4
CO 810 I=1,4
CCY(3*J-1,3*I)=AH(J,I)*SNOMEQ
810 CCY(3*J,3*I-1)=-AH(J,I)*SNOMEQ
DC 811 NM=1,4
DO 811 I=1,3
DO 811 J=1,6
CCY(3*(NM-1)+I,J+12)=HMXX(NM,I,J)
811 CCY(J+12,3*(NM-1)+I)=G(NM,J,I)
DO 812 I=1,6
CO 812 J=1,6
812 CCY(I+12,J+12)=AMX(I,J) -ARWA(I,J)
CC 813 I=1,6
813 CCY(I+12,I+12)=CCY(I+12,I+12)+WLAM(I)
DC 814 NM=1,4
CDY(3*(NM-1)+1,4)=-CAHIII(NM)
DOY(3*(NM-1)+2,5)=-CAHIII(NM)
ECY(3*(NM-1)+3,6)=-CAHIII(NM)
DBY(3*NM-1,2)=AHI(NM)*ABS(RAMCA)*(-1.0)
DDY(3*NM-2,3)=AHRI(NM)*ABS(RAMDA)*(-1.0)
814 CCY(3*NM,1)=AHI(NM)*ABS(RAMDA)*(-1.0)
CC 815 I=1,6
CC 815 J=1,3
816 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
810   IF(IY,AEQ.0)GO TO 300
800   DD 555 J=1,4
790   CC 55u I=1,4
780   BBY(3*(J-1)+1,3*(I-1)+1)=DAH(J,I)
770   CC 555 I=1,4
760   CCY(3*(I-1)+1,3*(I-1)+1)=BLAMO(I)
750   CCY(3*(I-1)+2,3*(I-1)+2)=BLAM(I)-1.0
740   CCY(3*I,3*I)=BLAM(I)-1.0
730   DC 502 J=1,4
720   CC 502 I=1,4
710   CCY(3*J-2,3*I-2)=CCY(3*J-2,3*I-2)+AKP(I)*DAHII(J)
700   CCY(3*J-1,3*I-1)=CCY(3*J-1,3*I-1)+AKPC(I)*CAHII(J)
690   CCY(3*J,3*I)=CCY(3*J,3*I)+AKP(I)*CAHII(J)
680   DC 501 NM=1,4
670   CDY(3*(NM-1)+1,4)=-DAHII(NM)
660  CONTINUE
650   IF(IDOF.EQ.9)GO TO 100
640   IF(IYTNE.0)GO TO 205
630   WRITE(6,451)
620   WRITE(6,6)('(AAY(I,J),J=1,9),I=1,18)
610   WRITE(6,6)('(AAY(I,J),J=10,18),I=1,18)
600   WRITE(6,5)
590   WRITE(6,452)
580   WRITE(6,6)('(BBY(I,J),J=1,9),I=1,18)
570   WRITE(6,6)('(BBY(I,J),J=10,18),I=1,18)
560   WRITE(6,5)
550   WRITE(6,453)
540   WRITE(6,6)('(CCY(I,J),J=1,9),I=1,18)
530   WRITE(6,6)('(CCY(I,J),J=10,18),I=1,18)
520   WRITE(6,5)
510   WRITE(6,454)
500   WRITE(6,7)('(CDY(I,J),J=1,6),I=1,18)
490   FORMAT(1H1)
480   FORMAT(///1X,18(*1X,9(E12.5,1X)))
7    FORMAT(/X,18(/1X,6(E12.5,1X)))
451  FORMAT(2X,'A MATRIX=')
452  FORMAT(/20X,'B MATRIX=')
453  FORMAT(/20X,'C MATRIX=')
454  FORMAT(/20X,'D MATRIX=')
      RETURN
100  CONTINUE
    DO 201 I=1,6
    DC 201 J=7,9
    AAY(I,J)=AAY(I,J+6)
    EBY(I,J)=EBY(I,J+6)
    CCY(I,J)=CCY(I,J+6)
    AAY(I,J)=AAY(J+6,I)
    BBY(I,J)=BBY(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)
    EBY(I,J)=EBY(I+6,J+6)
202  CCY(I,J)=CCY(I+6,J)
    DO 204 I=7,9
    DC 204 J=1,6
    CCY(I,J)=CDY(I+6,J)
100   IF(.FLT.*E.0) GO TO 205
    WRITE(*,451)
    WRITE(6,850)(AAY(I,J),J=1,9),I=1,9
    WRITE(6,452)
    WRITE(6,850)(EBY(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(6,850)(CDY(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
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, RCH, CHOD, AIB, CK, HMAST, ALCK, ANG, HR
& CAH(4), OAH(4)
COMMON /DF18/ AAY(19,19), BBY(19,19), CCY(19,19), DDY(19,6)
COMMON /COUPL/ AEP(4), APO(4)
COMMON /AERO/ AFTOP1, AFT1P0, AFT1P2, AFT2P1, AFZ0P0, AFZ1P1, AFZ2P0,
& AFZ2P2, AH111(4), AH111(4), AH1V(4), AH1V(4), AH1V(4), AH1V(4)
& AFT3P0, AFT3P1, AFZ3P0, AFZ3P1

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)
11 CONTINUE
DO 12 I=1,Nh
BBY(NR,3*Nh+I)=AFT2P1*T(2,I)
& BBY(3*Nr+I,NR)=AFZ1P1*T(2,I)
12 CONTINUE
AAY(NR,NR)=AIB*AND
BBY(NR,NR)=AFT1P2
CCY(NR,3)=-AFT2P1
DDY(NR,4)=-AFZ3P1
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

CONTINUE

IF(IDCF,EC.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)
FORMAT(1H1)
FORMAT(///1X,19(/1X,9(E12.5,1X)))
FORMAT(///1X,19(/1X,6(E12.5,1X)))
FORMAT(///1X,19(/1X,10(E12.5,1X)))
RETURN
CONTINUE
DC 15 I=1,6
AAY(I,19)=AAY(I,19)
BBY(I,19)=BBY(I,19)
CCY(I,19)=CCY(I,19)
AAY(19,I)=AAY(19,I)
BBY(19,I)=BBY(19,I)
CCY(19,I)=CCY(19,I)
CCY(19,I)=DDY(19,I)
CONTINUE
DO 16 I=1,3
AAY(I+6,19)=AAY(I+12,19)
BY(I+6,10)=BY(I+12,19)
CCY(I+6,10)=CCY(I+12,19)
AAY(I+6,I+6)=AAY(I+19,I+12)
BBY(I+10,I+6)=BBY(I+19,I+12)
CCY(I+10,I+6)=CCY(I+19,I+12)

CONTINUE
AAY(10,10)=AAY(19,19)
BBY(10,10)=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(/1X,15(E12.5,1X)))
950 FORMAT(/1X,10(/1X,6(E12.5,1X)))
RETURN
END
SUBROUTINE GUSTCC(CEUST,DCY,L,NDZ)
C
C       TO DEFINE GLST AND BLADE PITCH CONTROL COMPONENTS
C
DIMENSION CEUST(6),DCY(19,6),NDZ(19)
DO 1 I=1,L
1       DZ(I)=0.0
DO 2 J=1,6
2       DZ(I)=DCY(I,J)*CEUST(J)*CL2(I)
RETURN
END
SUBROUTINE FREQRES(L, AAA, HEF, CCC, DDD, IFLT, IDCF)

C  TO CALCULATE THE FREQUENCY RESPONSE
C
DIMENSION AAA(I9,19), HEF (I9,19), CCC(I9,19), DDD(I9,19)
C DOUBLE PRECISION FREQ, DPA(I9,19), DPC(I9,19), DP(I9,19)
C COMPLEX Q(I9,19), CCC(I9,19), DDD(I9,19)
C COMPLEX

WRITE(*,IC01)
100 FORMAT(/1X,'FREQUENCY RESPONSE',/1X,15X,'/FREQUENCY/CVMECA--')
C IF (IDLF.EQ.18) GC TC 1001
WRITE(*,IC02)
1001 WRITE(*,IC03)
1004 FORMAT(/1X,'Q1C',T22,'Q1C',T34,'Q1C',T46,'Q2C',T94,'Q2C',T70,
       'Q2C',T82,'WING 1', T94,'WING 2', T106,'WING 3')
G: T) 1003
1005 WRITE(*,IC06)
1006 CONTINUE
IF (IFLT.EQ.0) GC TC 1007
WRITE(*,IC09)
1007 CONTINUE
DO 100 I=1,L
DO 100 J=1,L
DPA(I,J)=AAA(I,J)
DPC(I,J)=CCC(I,J)
100 CONTINUE
DO 101 I=1,L
BPO(I)=CCC(I)
101 CONTINUE
IK=L
FREQ=0.0

FRQK0001
FRQK0002
FRQK0003
FRQK0004
FRQK0005
FRQK0006
FRQK0007
FRQK0008
FRQK0009
FRQK0010
FRQK0011
FRQK0012
FRQK0013
FRQK0014
FRQK0015
FRQK0016
FRQK0017
FRQK0018
FRQK0019
FRQK0020
FRQK0021
FRQK0022
FRQK0023
FRQK0024
FRQK0025
FRQK0026
FRQK0027
FRQK0028
FRQK0029
FRQK0030
FRQK0031
FRQK0032
FRQK0033
FRQK0034
FRQK0035
FRQK0036
211  F=FC=FREQ+L,CICL
IK=IK+1
GO TO 511
311  F=FC=FREQ+L,CICL
IK=IK+1
GO TO 511
611  F=FC=FREQ+L,CICL
IK=IK+1
GO TO 511
711  F=FC=FREQ+L,CICL
IK=IK+1
GO TO 511
811  F=FC=FREQ+L,CICL
IK=IK+1
GO TO 511
511  DO 100 I=1,L
DO 100 J=1,L
100  CCMA(I,J)=CCMPLX(CPC(I,J)-FREQ-2* DPA(I,J),FREQ+OPH(I,J))
DC 301 1=1,L
3.1  CCME(I)=DCMPLX( CPC(I),L,CICL)
   (ALL GAEPICMA,CMC,L,FREQ,INDF,IFLT)
   IF(IK.LT.10) GC TO 211
   IF(IK.LT.25) GC TO 311
   IF(IK.LT.37) GC TO 611
   IF(IK.LT.57) GC TO 711
   IF(IK.LT.71) GC TO 211
RETURN
END
SUBROUTINE GAEL1(A,Y,N,FRC,FLE,FELT)
C
C       THE GAUSS-JORDAN REDUCTION
C
C
COMPLEX*16/(15,15),Y(15),X(15)
DOUBLE PRECISION FRC,FLE,FELT
DIMENSION A(N)(N)
COMMON/FRMAG/,FRB(4),FRBC(4),FRW(L),IFRMAG
R=X-1
DO 10 I=1,N
L=I+1
DO 10 J=I,N
DO 10 E 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(K)=Y(K)/A(K,K)
DO 40 I=1,N
K=N-I
L=K+1
DO 40 J=L,N
20 Y(K)=Y(K)-X(J)*A(K,J)
30 X(K)=Y(K)/A(K,K)
DO 40 I=1,N
40 IF (X(1) EQ 0) THEN 50
46 A?X(1)=CCABS(X(1))
IF (IFRMAG .EQ. 1) GO TO 50
IF (IFRMAG .EQ. 9) GO TO 51
LT=4
LTT=6
GO TO 54
51 LT=2
LTT=3
54 GO 52 I=1,LT
DO 52 J=1,3
52  \text{ABX}(3*(I-1)+J) = \text{ABX}(3*(I-1)+J) \times \text{FRB}(I)

55  \text{DO} \hspace{1em} \text{DC} \hspace{1em} \text{I}=1,\text{LT}

55  \text{ABX}(3*(I-1)+1) = \text{ABX}(3*(I-1)+1) \times \text{FRBO}(I)/\text{FRB}(I)

53  \text{DO} \hspace{1em} \text{I}=1,\text{LTT}

53  \text{ABX}(I+3*\text{LT}) = \text{ABX}(I+3*\text{LT}) \times \text{FRW}(I)

50  \text{CONTINUE}

100  \text{WRITE}(6,100) \hspace{1em} \text{FREQ}

100  \text{FORMAT}('/3X,','--',F 6.2,'--')

100  \text{WRITE}(6,200)\{} \text{ABX}(I),I=1,N\}\}

200  \text{FORMAT}('/8X,9(E10.3,2X)/')

\text{RETURN}

\text{END}
SUBROUTINE EIGEN(N,AAA,RRR,CCC,DDD, IDD)
C
C ROUTINE TO FORM AN EIGENVALUE PROBLEM AND TO CALL EIPACK SUBROUTINE
C
DIMENSION AAA(19,19), RRR(19,19), CCC(19,19), DDD(19,6)
DIMENSION A(361), L(19), M(19), AINV(19,19)
DIMENSION AAA(19,19), RRR(19,19), CCC(19,19), DDD(19,6)
REAL*8 AFIG(38,38), WP(38), WI(38), ZP(38,38)
REAL*8 SCALE(38)
INTEGER INT(38)
DIMENSION RIG(25), ARMOD(25,25), DAMP(38)
COMPLEX AMOD(25,25), RTGCMM(25)
COMMON/FRMAG/, FR1(4), FR20(4), FRW(6), IFRMAG
!CEBUG=0
WRITE(6,153)
DO 3003 I=1,N
DO 3004 J=1,N
AAN(I,J)=C.O
BBN(I,J)=O.O
CCN(I,J)=O.O
DO 3005 K=1,6
BDN(I,K)=O.O
3005 CONTINUE
LI=O
DO 1000 J=1,N
DO 1000 I=1,N
LI=LI+1
1000 A(LL)=AAA(I,J)
CALL MINV(A,N,D,L,M)
LI=O
DO 2006 J=1,N
DO 2006 I=1,N
LI=LL+1
2000 AINV(I,J)=A(LL)
DO 3000 I=1,N
DO 3000 J=1,N
DO 3001 K=1,N
AAN(I,J)=AINV(I,K)*AAA(K,J)+AAN(I,J)
BRN(I,J)=BRNV(I,K)*BBR(K,J)+BRN(I,J)
3001 CCN(I,J)=AINV(I,K)*CCC(K,J)+CCN(I,J)
DO 3002 J=1,6
DO 3002 K=1,N
3002 DGN(I,J)=AINV(I,K)*DDD(K,J)+DGN(I,J)
3000 CONTINUE...
6000 N2=2*N
DO 300 I=1,N
DO 300 J=1,N
AEIG(I,J)=-BRN(I,J)
300 AFIG(I,J+N)=-CCN(I,J)
DC 301 I=1,N
DC 301 J=1,N2
301 AFIG(I+N,J)=0.0D0
DO 372 I=1,N
302 AFIG(I+N+I)=1.0D0
CALL EPACK(3B,N2,AEIG,WR, WI, ZP, IERROR, SCALE, INT)
IF(IERROR.00.0) GO TO 152
WRITE(6,150) IERROR
150 FORMAT(15X,'IERROR=',I5)
152 CONTINUE
IF(IERROR.00.0) GO TO 61
WRITE(6,67) (WP(I),WI(I),I=1,N2)
67 FORMAT(/10X,N15.7,2X,N15.7)
N3=N/3
DC 400 IL=1,N3
IJ=6+(IL-1)+1
KL=IL+(IL-1)+6
400 WRITE(6,251) ((ZP(I,J),J=IJ,KL),I=1,N2)
251 FORMAT(/1X,(2D15.7,4X,2D15.7,4X,2D15.7))
IE(3-N3,FO,N) GO TO 61
K=2*(N-3*N3)
IJ=KL+1
KL=KL+K
WRITE(6,751)((ZP(I,J),J=1J,K(I)),I=1,N2)
751  FORMAT(/1X,(/1X, (ZD15.7)))

CONTINUE

DO 140 I=1,N2
XX=SNGL(WR(I)*2+WI(I)*2)
IF(XX.EQ.0.0) GO TO 141
DAMP(I)=-SNGL(WR(I))/SQRRT(XX)
GO TO 140

141  DAMP(I)=0.0

140  CONTINUE

M1=N1+1
LK=0
LKK=0
NTOT=0
I=1

CONTINUE

IF(I.GE.N2+1) GO TO 63
NTOT=NTOT+1
K=NTOT
IF(WI(I).EQ.0.0) GO TO 65
   INT(I)=K
   INT(I+1)=K
LK=LKK+1
LKK=IK+1
IF(IDBUG.EQ.0) GO TO 68
WRITE(6,69))I,LK,LKK,K
69  FORMAT(1X,4I5)

CONTINUE

DO 50 J=1,N2
IF(IDBUG.EQ.0) GO TO 71
WRITE(6,72)ZP(J,LK),ZP(J,LKK)
72  FORMAT(1X,2D15.7)

CONTINUE

AMOQ(K,J-N1+1)=CMPLX(SNGL(ZP(J,LK)),SNGL(ZP(J,LKK)))

50  CONTINUE

I=I+2
65 GO TO 64
66 CONTINUE
   INT(I) = K
67 LK = LK + 1
68 LKK = LK
   IF(1DFRUG.EQ.0) GO TO 73
   WRITE(6,69)1, LK, LKK, K
73 CONTINUE
   DC 66 J = N1, N2
   IF(1DFRUG.EQ.0) GO TO 74
   WRITE(6,72)ZP(J, LK), ZP(J, LKK)
74 CONTINUE
   AMOD(K, I-M1+1) = COMPLX(SNGL(ZP(J, LK)), 0.0)
66 CONTINUE
   I = I + 1
63 GO TO 64
65 CONTINUE
   IF(IFRMAG.EQ.1) GO TO 130
   IF(IFDF.EQ.9) GO TO 131
   LT = 4
67 LTT = 6
   GO TO 134
131 I = 2
   LTT = 3
134 CONTINUE
   DC 136 J = 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)*FRRO(I)/FRB(I)
   DC 133 I = 1, LTT
133 AMOD(IJ, I+3*LT) = AMOD(IJ, I+3*LT)+FRW(I)
136 CONTINUE
136 CONTINUE
   GO 51 I = 1, NTOT
DO 51 J=1,N
   ARMOD(I,J)=CABS(AMOD(I,J))
DO 52 I=1,NTOT
   BIG(I)=0.0
DO 53 J=1,N
   IF(ARMOD(I,J) - BIG(I)) GT 53,53,54
   BIG(I)=ARMOD(I,J)
   BIGCOM(I)=AMOD(I,J)
CONTINUE
53
DO 60 I=1,NTOT
   DO 60 J=1,N
      ARMOD(I,J)=ARMOD(I,J)/BIG(I)
      AMOD(I,J)=AMOD(I,J)/BIGCOM(I)
CONTINUE
60
FORMAT(//15X,20(1H*))/20X,'EIGENVALUES',//15X, 20(1H*)
   &  ,//20X,'** REAL PART **', 3X,'** IMAGINARY PART ***'
   &  ,10X,'** DAMPING RATIO ***/
WRITE(6,151)(INT(I),WR(I),WI(I),DAMP(I),I=1,N2)
151
FORMAT(//9X,'NO.',I2,5X,D15.7,5X,D15.7,15X,E15.7)
WRITE(6,59)
59
FORMAT(1H1,,'/5X, 20 (1H*),//10X, 'EIGENVECTORS',//5X, 20(1H*)
   IP=0
DO 55 !1=1,NTOT
   IP=IP+1
   WRITE(6,154)IP,WR(IP),WI(IP)
154
FORMAT(//2X,'** CORRESPONDING TO NO.',I2,1X,'EIGENVALUE --',
   &  ,5X,('D10.3,','D10.3,'),'
   &  ,//8X,'** ABSOLUTE VALUE **',20X,'** REAL PART /**',2X,
   &  ,** IMAGINARY PART /**',//)
IF(IP+1.GT.N2) GO TO 752
IF(INT(IP).EQ.INT(IP+1)) IP=IP+1
752
CONTINUE
DO 56 J=1,N
   WRITE(6,57)ARMOD(I,J), AMOD(I,J)
57
FORMAT(10X,F15.7,22X,E15.7,3X,F15.7)
SUBROUTINE EIPACK(NM, N, A, WR, WI, Z, IERR, SCALE, INT)

AN EIGENSYSTEM PROBLEM SOLVER FOR THE GENERAL MATRIX

REAL*8 A(NM,N), Z(NM,N), WR(N), WI(N), SCALE(N)
INTEGER INT(N)
CALL BALANC(NM,N, A, 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, WR, WI, Z, IERR)
CALL BAIRAK(NM,N, LOW, IGH, SCALE, N, Z)
RETURN
END
SUBROUTINE BALANC(NM,N,A,LOW,IGH,SCALE)

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

THIS SUBROUTINE IS A TRANSLATION OF THE ALGOL PROCEDURE BALANCE,
NUM. MATH. 13, 293-304 (1969) BY PARLETT AND REINSCH.

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;

LCH 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,...,LCH-1 OR I=IGH+1,...,N;
SCALE CONTAINS INFORMATION DETERMINING THE
PERMUTATIONS AND SCALING FACTORS USED.

SUPPOSE 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 LSEC ARE DENOTED BY C(I,J). THEN

\[
\text{SCALE}(J) = P(J), \quad \text{for } J = 1, \ldots, \text{LCW}-1
\]

\[
= C(I,J), \quad J = \text{LCW}, \ldots, \text{IGH}
\]

\[
= P(J), \quad J = \text{IGH}+1, \ldots, N.
\]

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

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

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 DIRECTED TO R. S. GARBCW,
APPLIED MATHEMATICS DIVISION, ARCMENE NATIONAL LABORATORY

-----------------------------------------------65210060

::: :::::::: RACIX IS A MACHINE DEPENDENT PARAMETER SPECIFYING
THE BASE OF THE MACHINE FLOATING POINT REPRESENTATION.
RACIX = 16.0 FOR LONG FORM ARITHMETIC

CN S360 :::::::::

DATA RACIX/Z421CCCCCC0C0C0C0C0/

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

::: :::::::: IN-LINE PROCEDURE FOR ROW AND
COLUMN EXCHANGE:

20 SCALE(M) = J
   IF (J .EQ. M) GC TC 5C
C
   DC 3C I = 1, 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
   :::::::::: SEARCH FOR ROWS ISOLATING AN EIGENVALUE
   :::::::::: AND PUSH THEM DOWN :::::::::::
C
   80 IF (L .EQ. 1) GC TC 28C
      L = L - 1
   C
   :::::::::: FOR J=L STEP -1 UNTIL I DO -- ::::::::::
100 DC 120 JJ = 1, L
      J = L + 1 - JJ
C
   DC 110 I = 1, L
      IF (I .EQ. J) GC TC 110
      IF (A(J,I) .NE. C(CDC)) GC TC 12C
110 CONTINUE
C
   M = L
   IEXC = 1
   GC TC 20
120 CONTINUE
C
   GC TC 14C
C ::::::::::: SEARCH FOR COLUMNS ISOLATING AN EIGENVALUE
C 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
M = K
IEXC = 2
GC TC 20
170 CONTINUE
C ::::::::::: NOW BALANCE THE SUBMATRIX IN ROWS K TO L :::::::::::
CO 180 I = K, L
180 SCALE(I) = 1.OCC
C ::::::::::: ITERATIVE LCCP FOR NCRM REDUCTION :::::::::::
190 NOCCNV = .FALSE.
C
200 CC 270 I = K, L
C = C.CDC
R = C.CDC
C
CC 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 = 1.OCC
S = C + R
210 IF (C .GE. G) GC TC 220
F = F * RACIX
C = C * P2
GC TC 21C
220 G = R * RADIX
230 IF (C .LT. G) GC TC 240
F = F / RADIX
C = C / P2
GC TC 230
C :::::::::: : NOW BALANCE :::::::::
240 IF ((C + P) / F .GE. 0.9500 * S) GC TC 270
G = 1.0CC / F
SCALE(I) = SCALE(I) * F
ACCCNV = .TRUE.
C
CC 25C J = K, N
250 A(I,J) = A(I,J) * G
C
CC 26C J = I, L
260 A(J,I) = A(J,I) * F
C
270 CONTINUE
C
IF (ACCCNV) GC TC 190
C
280 LOW = K
ICH = L
RETURN
C :::::::::: : LAST CARD OF BALANC ::::::::::
END
SUBROUTINE ELHES(NM,N,LCH,IGH,A,INT)

INTEGER I,J,M,N,LA,NM,IGH,KPI,LCW,MP1,MP1
REAL*8 A(NM,N)
REAL*8 X,Y
REAL*8 CAES
INTEGER INT(IGH)

THIS SUBROUTINE IS A TRANSLATION OF THE ALGOL PROCEDURE ELHES,
NUM. MATH. 12, 349-368 (1968) BY MARTIN AND WILKINSON.

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

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;

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

ON OUTPUT:

A CONTAINS THE INPLT MATRIX.
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. Galerkin, Applied Mathematics Division, Argonne National Laboratory.

---

LA = IGH - 1
KPI = LOW + 1
IF (LA .LT. KPI) GC TC 200

DC 180 M = KPI, LA
MM1 = M - 1
X = C .OBO
I = M

DC 100 J = M, IGH
IF (DABS(A(J,MM1)) .LE. DABS(X)) GC TC 100
X = A(J,MM1)
I = J
CONTINUE

100

INT(M) = I
IF (I .EQ. M) GC TC 130

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

DC 110 J = MM1, N
Y = A(I,J)
A(I,J) = A(M,J)
A(M,J) = Y
CONTINUE

110
C
DC 12C J = 1, IGF
Y = A(J, I)
A(J, I) = A(J, N)
A(J, N) = Y
120 CONTINUE
C :::::::::: END INTERCHANGE ::::::::::
130 IF (X *EC* C *OCC) GC TO 180
MP1 = N + 1
C
CC 160 I = MP1, IGF
Y = A(I, MP1)
IF (Y *EC* C *CDC) GC TC 16C
Y = Y / X
A(I, MP1) = Y
C
CC 14C J = M, N
A(I, J) = A(I, J) - Y * A(M, J)
C
CC 15C J = 1, IGF
A(J, P) = A(J, P) + Y * A(J, I)
C
160 CONTINUE
C
180 CONTINUE
C
200 RETURN
C :::::::::: LAST CARC OF ELMFES ::::::::::
END
SUBROUTINE ELTRAN(N,W,A,LCH,IGH,A,INT,Z)

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

THIS SUBROUTINE IS A TRANSLATION OF THE ALGOL PROCEDURE ELMTRANS,
NUM. MATH. 16, 181-204(1976) BY PETERS AND WILKINSON.

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

ON INPUT:

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

N IS THE ORDER OF THE MATRIX;

LOW 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
INTERCHANGED IN THE REDUCTION BY ELMHES.
ONLY ELEMENTS LOW THROUGH IGH ARE USED.
ON OUTPUT:

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

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

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:::  ::::: INITIALIZE Z TO IDENTITY MATRIX ::::: ::::  :::::

CC 80 $I = 1, N$

60 $Z(I,J) = 0.0$

80 CONTINUE

K$L = IGF - LOW - 1$

IF (K$L .LT. 1) CC TC 200

:::  ::::: FOR $MP = IGH - 1$ STEP -1 UNTIL $LOW + 1$ CC ::::: :::::

CC 140 $MP = 1, K$L

MP = IGH - MP

MP1 = MP + 1

CC 100 $I = MP1, IGH$

100 $Z(I,MP) = A(I,MP-1)$

C

I = INT(MP)

IF (I .EQ. MP) CC TC 140

CC 130 $J = MP, IGH$

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

Z(I,J) = C,C$C$C
130 CONTINUE
C
2(1,MP) = 1.000
140 CONTINUE
C
200 RETURN
C
)::: LAST CARD OF ELTRAN :::::
END
SUBROUTINE HCR2(NM,N,LCW,IGF,F,WRI,WRI,Z,IERR)

X       ICH,ITS,LCW,PM2,EP2,IERR
REAL*8 H(IN,N),WRI(N),Z(IN,N),WRI(Z),Z(IN,N)
REAL*8 P,Q,R,S,T,L,N,Y,G,SA,VI,VR,ZZ,NCRP,MACHEP
REAL*8 CSCTR,CAE,CSTN
INTEGER MNC
LOGICAL ACTLAS
COMPLEX*16 Z3
COMPLEX*16 CMFLX
REAL*8 T3(2)
EQUIVALENCE (Z3,T3(1))

THIS SUBROUTINE IS A TRANSLATION OF THE ALGCL PROCEDURE HCR2,

NUM. MATH. 16, 181-204 (1970) BY PETERS AND WILKINSON.


THIS SUBROUTINE FINDS THE EIGENVALUES AND EIGENVECTORS

OF A REAL UPPER HESSENiER MATRIX BY THE QR METHOD. THE

EIGENVECTORS OF A REAL GENERAL MATRIX CAN ALSO BE FOUND

IF ELMHES AND ELMTRAN OR CRTHES AND CRTRAN HAVE

BEEN USED TO REDUCE THIS GENERAL MATRIX TO HESSEΝER FORM

AND TO ACCUMULATE THE SIMILARITY TRANSFORMATIONS.

ON INPUT:

NM 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;
LCM AND LGM ARE INTEGERS DETERMINED BY THE BALANCING
SUBROUTINE BALANC. IF BALANC HAS NOT BEEN USED,
SET LCM=1, LGM=N;

Z CONTAINS THE UPPER HESENBERG MATRIX;

Z CONTAINS THE TRANSFORMATION MATRIX PROCLED BY ELTRAN
AFTER THE REDUCTION BY ELMHE, OR BY CRTRAN AFTER THE
REDUCTION BY CRTHES, IF PERFORMED. IF THE EIGENVECTORS
OF THE HESENBERG MATRIX ARE DESIRED, Z MUST CONTAIN THE
IDENTITY MATRIX.

ON OUTPUT:

Z HAS BEEN DESTROYED;

WR AND WI CONTAIN THE REAL AND IMAGINARY PARTS,
RESPECTIVELY, OF THE EIGENVALUES. THE EIGENVALUES
ARE UNORDERED 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 LANCWRMALIZED. IF AN
ERROR EXIT IS MADE, NONE OF THE EIGENVECTORS HAS BEEN FOUND;

IERR IS SET TO
ZERO FOR NRMAL RETURN,
J IF THE J-TH EIGENVALUE HAS NOT BEEN
DETERMINED 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. GARECW, APPLIED MATHEMATICS DIVISION, ARGONNE NATIONAL LABORATORY

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MACHEP IS A MACHINE DEPENDENT PARAMETER SPECIFYING THE RELATIVE PRECISION OF FLOATING POINT ARITHMETIC.

MACHEP = 16.0CC**(-13) FOR LONG FCSV ARITHMETIC.

CATA MACHEP/7341C00000C000000000/ 872100073

IEFR = C

STCRRC PBSIS ISOLES BY BALANC

DC 5C I = 1, N

IF (I .GE. LCW .AND. I .LE. IGK) GC TC 5C

WR(I) = P(I,I)

W(I) = C.CCC

50 CONTINUE

EN = IGK

T = C.CCC

SEARCH FCR NEXT EIGENVALUES

IF (EN .LT. LCW) GC TC 340

ITS = C

NA = EN - 1

ENM2 = NA - 1

LCCK FCR SINGLE SMALL SUB-DIAGONAL ELEMENT

FCR L=EN STEP -1 UNTIL LCW CC --

PC LL = LCW, EN

L = EN + LCW - LL

IF (L .EQ. LCW) GC TC 1CO

IF (CAPS(H(L,L-1)) .LE. MACHEP * (CAPS(H(L-1,L-1))
X = \text{CABS}(H(L, L))) \text{ CC TC 1CC}

\text{CONTINUEC}

1CC X = H(EN, EN)
IF (L \text{ EQ} EN) CC TC 270
Y = H(NA, NA)
W = H(EN, NA) \times H(NA, EN)
IF (L \text{ EQ} NA) CC TC 280
IF (ITS \text{ \& EQ} 3C) CC TC 100C
IF (ITS \text{ \& NE} 1C \text{ \& AND} ITS \text{ \& NE} 2C) CC TC 130

\text{CONTINUEC}

120 H(I, I) = H(I, I) - X

S = \text{CABS}(H(EN, NA)) + \text{CABS}(H(NA, EN2))
X = C.75CC \times S
Y = X
W = -C.4375CC \times S \times S

130 ITS = ITS \text{ + 1}

\text{CONTINUEC}

140 MM = L, EN2
M = FMN2 + L - MM
ZZ = H(M, M)
R = X - ZZ
S = Y - ZZ
P = (R \times 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 = \text{CABS}(P) + \text{CABS}(C) + \text{CABS}(R)
P = P / S
Q = Q / S
R = R / S
IF (N .EQ. L) GC TC 150
  IF (DABS(H(H,N-1)) * (DABS(C) + DABS(R)) .LE. MAC*EP * DABS(P)) GC TC 150
  X = (DABS(H(H-1,N-1)) + DABS(ZZ) + DABS(H(M+1,M+1))) GC TC 150
140 CC  CONTINUE
C 150 MP2 = N + 2
C
CC 160 T = MP2, EN
  T(I, I-2) = C*CCEC
  IF (I .EQ. MP2) GC TO 16C
  T(I, I-3) = C*CCEC
160 CC CONTINUE
C ::::::::::: DOUBLE GPS STEP INVOLVING RWS L TC EN AND
C COLUMNS M TC EN :::::::::::

CC 260 K = M, NA
  NCTLAS = K .NE. AA
  IF (K .EQ. M) GC TC 17C
    P = T(K, K-1)
    G = T(K+1, K-1)
    R = C*CDC
    IF (NCTLAS) R = T(K+2, K-1)
    X = DABS(P) + DABS(G) + DABS(R)
    IF (X .EQ. C*CDC) GC TC 26C
    P = P / X
    G = G / X
    R = R / X
170 S = CSIGN(CSCRT(P*P+Q*Q+R*R), P)
  IF (K .EQ. M) GC TC 180
    H(K, K-1) = -S * X
180 CC TC 19C
    IF (L .NE. M) T(K, K-1) = -H(K, K-1)
190 P = P + S
    X = P / S
    Y = C / S
    ZZ = R / S
    G = C / P

R = R / P

C :::::::::: ROW MODIFICATION :::::::::::
CC 210 J = K, K
P = P(K, J) + C * H(K+1, J)
IF (.NOT. NOTLAS) GO TO 220
F = P + R * H(K+2, J)
H(K+2, J) = H(K+2, J) - P * Z
220 F(K+1, J) = H(K+1, J) - P * Y
F(K, J) = H(K, J) - P * X
210 CONTINUE
C J = MINT(NI, K+3)

C :::::::::: COLUMN MODIFICATION :::::::::::
CC 220 I = I, J
F = X * H(I, J) + Y * H(I, J+1)
IF (.NOT. NCTLAS) GO TO 230
P = P + ZZ * H(I, K+2)
H(I, K+2) = H(I, K+2) - P * R
230 H(I, K+1) = H(I, K+1) - P * Q
F(I, K) = F(I, K) - P
220 CONTINUE
C :::::::::: ACUMULATE TRANSFORMATIONS :::::::::::
CC 250 I = LCIW, ICF
P = X * Z(I, K) + Y * Z(I, K+1)
IF (.NOT. NCTLAS) GO TO 240
P = P + ZZ * Z(I, K+2)
Z(I, K+2) = Z(I, K+2) - P * R
240 Z(I, K+1) = Z(I, K+1) - P * C
Z(I, K) = Z(I, K) - P
250 CONTINUE
C 260 CONTINUE
C GC TC 70
C :::::::::: CNE RCCT FCLND :::::::::::
270 H(EA, EA) = X + T
WRITE(EN) = H(EN,EN)
WRITE(EN) = C.CDC
EN = NA
GE TC 60

C ::::::::::::::: TWO RECTS FOUND :::::::::::::::
280 P = (Y - X) / Z.CDC
G = P * P + W
ZZ = DSQRT(DAPS(G))
H(EN,EN) = X + T
X = H(EN,EN)
H(NA,NA) = Y + T
IF (G LT C.CDC) GE TC 32C

C ::::::::::::::: REAL PAIR :::::::::::::::
ZZ = P + CSIGN(ZZ,P)
WRITE(NA) = X + ZZ
WRITE(EN) = WRITE(NA)
IF (ZZ NE 0.0000) WRITE(EN) = X - W / ZZ
WRITE(NA) = C.CDC
WRITE(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, I
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 ::::::::::::::: COL/MODIFICATION :::::::::::::::
CC 300 I = I, 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 ::::::::::::: CCMPLEX PAIR :::::::::::::
320 WR(NA) = X + P
WR(EN) = X + P
WI(NA) = ZZ
WI(EN) = -ZZ
330 EN = EN+2
GC TC 60
C
C :::::::::: ALL RCCTS FCUND. BACKSUBSTITL TE TO FIND
C VECTORS OF UPPER TRIANGULAR FORM :::::::::::::
340 NCRM = 0.0CO
K = 1
C
C CC 360 I = I, N
C
C CC 350 J = K, N
350 NCRM = NORM + DARS(H(I,J))
C
K = 1
360 CC CONTINUE
C
IF (NORM .EQ. C.CCC) GC TO ICO:
C
::: FOR EN=N STEP -1 UNTIL 1 CC -- :::::::::::::
DC 360 NN = 1, N
EN = N + 1 - NN
P = WR(EN)
C = WI(EN)
NA = EN - 1
IF (C) 710, 6CC, 8CC
C
::: REAL VECTOR :::::
C
M = FN
F(EN, EN) = 1.0C
IF (NA .EQ. C) GC TC 8CC
C :::::::::: FOR I=EA-1 STEP -1 UNTIL 1 GC -- :::::::::::
CC 7CC II = 1, NA
I = EA - II
w = H(I, I) - P
P = H(I, EN)
IF (M .GT. NA) GC TO 62C
C
GO 61C J = M, NA
610 R = R + H(I, J) * H(J, EN)
C
620 IF (WI(I) .GE. C.OD0) GC TC 630
ZZ = W
S = R
GC TC 7CC
630 M = I
IF (WI(I) .NE. C.CCO) GC TC 640
T = w
IF (W .EQ. C.CCC) T = MACHEP * NORM
H(I, EN) = -R / T
GO TO 7CC
C :::::::::: SOLVE REAL EQUATIONS :::::::::::
640 X = H(I, I+1)
Y = H(I+1, I)
G = (KR(I) - P) * (WP(I) - P) + WI(I) * WI(I)
T = (X * S - ZZ * R) / Q
H(I, EN) = T
IF (CAPS(X) .LE. CAPS(ZZ)) GO TO 650
H(I+1, EN) = (-R - W * T) / X
GC TO 7CC
650 H(I+1, EN) = (-S - Y * T) / ZZ
760 CONTINUE
C :::::::::: FIND REAL VECTOR ::::::::::
GC TC 8CC
C  :::::::::::  COMPLEX VECTOR  : :::::::::  

710  

C  :::::::::::  LAST VECTOR COMPONENT CHosen IMAGINARY SC THAT  

C  EIGENVECTOR MATRIX IS TRIANGULAR  : :::::::::  

I F (D APS(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  = CC M PLX(H,CDC,-H(NA,EN)) / CC M PLX(H(NA,NA)-P,C)  

H(NA,NA) = T3(1)  

H(NA,EN) = T3(2)  

730  

H(EN,NA) = C*CDC  

H(EN,EN) = 1*CCC  

ENM2 = NA - 1  

I F (ENM2 .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)  

C  

CC 76C J = P, NA  

RA = RA + H(I,J) * H(J,NA)  

SA = SA + H(I,J) * H(J,EN)  

760  

CONTINUE  

C  

I F (W(I) .GE. C*CDC) GC TC 77C  

Z2  = w  

R = RA  

S = SA  

GC TC 79C  

770  

P = I  

I F (W(I) .NE. C*CDC) GC TC 780  

Z3  = CC M PLX(-RA,-SA) / CC M PLX(w,C)  

H(I,NA) = T3(1)
C ::::::::::: SOLVE COMPLEX EQUATIONS :::::::::::

780

\[ X = H(I, I+1) \]
\[ Y = H(I+1, I) \]
\[ VR = (WR(I) - P) * (WR(I) - P) + W[I(I) * WI(I) - C * C] \]
\[ VI = (WR(I) - P) * 2.0CO * C \]
\[ IF (VR . GE. C . CCC . ANC. VI . EC. O . CCO) VR = \frac{2.0AC*EP * \%CRM}{X} \]
\[ Z3 = CCMPLEX(X*R-ZZ*RA+Q*SA, X*S-ZZ*SA-C*RA) / CCMPLEX(WR, VI) \]
\[ H(I, NA) = T3(I) \]
\[ H(I, EN) = T3(2) \]
\[ IF (DABS(X) . LE. DABS(ZZ) + CABS(Q)) GC TO 785 \]
\[ H(I+1, NA) = (-R * - W * H(I, NA) + C * H(I, EN)) / X \]
\[ H(I+1, EN) = (-SA - W * H(I, EN) - C * H(I, NA)) / X \]

GC TO 75C

785

\[ Z3 = CCMPLEX(-R-Y*H(I, NA), -S-Y*H(I, EN)) / DCMPLEX(ZZ, Q) \]
\[ H(I+1, NA) = T3(I) \]
\[ H(I+1, EN) = T3(2) \]

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$N = \text{MIN}(J, ICH)$

C

DEC I = LCH, ICH
ZZ = 0.000
C

DEC K = LCH, N
860 ZZ = ZZ + Z(I, K) * H(K, J)
C

Z(I, J) = ZZ
860 CONTINUE
C

GO TO 1001
C

::: SET ERRCR -- NC CONVERGENCE TO AN
EIGENVALUE AFTER 3G ITERATIONS :::::::::::::
C

1000 IEFR = FA
1001 RETURN
C

::: LAST CARD OF HQR2 :::::::::::
END
SUBROUTINE BALBAK(N, N, LCH, IGH, SCALE, N, Z)
INTEGER I, J, K, M, N, II, MM, IGF, LOW
REAL*8 SCALE(N), Z(2*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:

N 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 M COLUMNS.

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

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

CC 110 I = LCW, IGH
    S = SCALE(I)


          S = LC/DSCALE(I).

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

1C0 CONTINUE

CC 110 CONTINUE FOR I=LCW-1 STEP -1 UNTIL 1,

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

CC 1CC J = 1, M
    S = Z(I,J)
    Z(I,J) = Z(K,J)
    Z(K,J) = S

130 CONTINUE

140 CONTINUE
C
RETURN
C :::::::::: LAST CARD OF BAKBAC ::::::::
END

7021C073
7021C074
70210075
7021C076
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 - COLUMNS 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.

SUBROUTINE MINV(A,N,D,L,M)
DIMENSION A(1),L(1),M(1)
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,HOLD

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

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 80 K=1,N
NK=NK+N
L(K)=K
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))) 15,20,20
15 BIGA=A(IJ)
L(K)=I
M(K)=J
20 CONTINUE
C INTERCHANGE ROWS

J=1(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=JK+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

C CONTINUE
C REDUCE MATRIX
C
DO 65 I=1,N
IK=IK+1
HCLE=A(IK)
IJ=I-N
DO 65 J=1,N
IJ=IJ+N
IF(I-K) 6C,65,6C
61 IF(J-K) 62,65,62
62 KJ=IJ-I+K
A(IJ)=HCLE*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 ROW AND COLUMN INTERCHANGE
C
K=N
140 \( K = (\gamma - 1) \)
    IF \( K \) 150, 150, 1C5
145 \( I = L(K) \)
    IF \( I - K \) 12C, 12C, 1C8
148 \( JQ = N * (K-1) \)
    JR = N * (I-1)
    DO 110 J = 1, N
    JK = JQ + J
    HOLE = A(JK)
    JI = JR + J
    A(JK) = -A(JI)
110 A(JI) = HOLE
120 J = M(K)
    IF \( J - K \) 1CQ, 1QC, 125
125 \( KI = K - N \)
    DO 130 I = 1, N
    KI = KI + N
    HOLE = A(KI)
    JI = KI - K + J
    A(KI) = -A(JI)
130 A(JI) = HOLE
    GC TO 100
15C RETLRN
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.
**WING**

**BELL WING**

**INPUT DATA**

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--- FLAPPING BENDING STIFFNESS ---

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--- CHORDWISE BENDING STIFFNESS ---

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--- ELEMENT SIZE ---

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--- TOPONINAL RIGIDITY ---

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--- MOMENT OF INERTIA ---

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--- MASS COUPLING ALONG SPAN ---

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**8/17/74**
TENSION DUE TO CENTRIFUGAL FORCE

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0.0 & 0.0 & 0.0 & 0.0 & 0.0 \\
\end{bmatrix}
\]

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

MAX. SIZE OF STIFFNESS MATRIX = 484
SPECIFIED SIZE IS 654

NO. OF NEGATIVE EIGENVALUES = 0
FACT. COMPLETED

EIGENVALUES =

\[
\begin{bmatrix}
0.28091D+03 & 0.89980D+03 & 0.16249D+05 & 0.34651D+05 & 0.29540D+06 \\
0.27768D+03 & 0.90840D+03 & 0.27303D+07 & 0.12970D+05 & 0.37610D+05 \\
0.27768D+03 & 0.89084D+03 & 0.27300D+04 & 0.12568D+05 & 0.32494D+05 \\
0.27768D+03 & 0.89084D+03 & 0.27300D+04 & 0.12968D+05 & 0.32494D+05 \\
0.27764D+03 & 0.89084D+03 & 0.27300D+04 & 0.12968D+05 & 0.26097D+06 \\
\end{bmatrix}
\]

RADIANS/SPC

\[
\begin{bmatrix}
0.16664D+12 & 0.29847D+02 & 0.29847D+02 & 0.29847D+02 & 0.29847D+02 \\
\end{bmatrix}
\]

HERTZ

\[
\begin{bmatrix}
0.29540D+06 & 0.34651D+05 & 0.29540D+06 & 0.34651D+05 & 0.29540D+06 \\
\end{bmatrix}
\]

REDUCED MASS MATRIX

\[
\begin{bmatrix}
0.10000D+01 & 0.11699D-02 & 0.10000D+01 \\
-0.51510D-20 & -0.33625D-21 & 0.10000D+01 \\
-0.11669D-19 & -0.13470D-17 & -0.92236D-19 & 0.10000D+01 \\
0.88490D-24 & -0.13376D-20 & 0.12102D-18 & 0.10999D-19 & 0.13000D+01 \\
-0.51757D-20 & 0.76910D-20 & 0.13915D-17 & 0.86670D-18 & -0.20838D-19 & 0.10000D+01 \\
\end{bmatrix}
\]

REDUCED STIFFNESS MATRIX

\[
\begin{bmatrix}
0.27768D+03 & 0.12656D+03 & 0.89830D+03 \\
-0.59669D-13 & 0.38262D-17 & 0.23300D+04 \\
-0.36503D-17 & -0.11880D-16 & 0.93751D-16 & 0.12968D+05 \\
0.74794D-16 & 0.63537D-13 & -0.58999D-18 & 0.32494D+05 \\
-0.44715D-16 & 0.12674D-12 & 0.11159D-15 & 0.80910D-14 & 0.16965D-15 & 0.20860D+06 \\
\end{bmatrix}
\]
### **WING MODE SHAPE**

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<th>DW(I,J)</th>
<th>D(I,J)</th>
<th>PH(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.
**Input Data**

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- IQUEST = 0
- NO OF DEGREE PER NODE = 4
- NO OF ELEMENTS = 10
- NO OF MAX ITER ALLOWED = 70
- NO OF MODES = 4
- ERR = 0.00130
- OMEGA = -0.42210
- LAMBDA = -0.70000
- COLLECTIVE PITCH = 0.01745
- SPRING = 0.0
- ALPHA = 0.852500 + 0

**Flapping Bending Stiffness**

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**Chordwise Bending Stiffness**

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**Angle of Twist**

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**Mass Distribution**

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**Element Size**

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**Tip Mass Roll Inertia, Yaw Inertia, Pitch Inertia, Mass Coupling**

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**Tension Due to Centrifugal Force**

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**Mass = 0.414766 + 0**

**Moment of Inertia at Root = 0.16714E+14**

**Total Length of the Beam = 0.154000 + 0**

**Max. Size of Step is 244; Specified Size is 334**

**No. of Negative Diags = 0; FACT. Completed**
**EIGENVALUES**

0.20830D+04 0.12950D+05 0.27559D+06

0.11180D+04 0.28840D+04 0.19059D+05 0.92430D+15

0.11172D+04 0.28520D+04 0.18937D+05 0.75559D+15

0.11172D+04 0.28519D+04 0.18886D+05 0.74534D+05

0.11172D+04 0.28519D+04 0.18886D+05 0.74534D+05

**RADIAN/SEC**

0.33424D+02 0.53403D+02 0.13743D+03 0.27374D+03

**HERTZ**

0.53197D+01 0.84993D+01 0.21872D+02 0.43567D+02

**NO. OF ITERATION= 5 CONVERGED WITHIN 8.100C6=0-2**

**REDUCED MASS MATRIX**

0.10000D+01 0.20346D-19 0.10000D+01

0.21682D-16 0.54538D-20 0.10000D+01

0.92709D-20 0.19679D-21 0.12149D-19 0.10000D+01

**REDUCED STIF MATRIX**

0.96422D+04 0.59174D-14 0.11377D+05

-0.77329D-15 0.45209D-15 0.27411D+03

0.99997D-15 0.51587D-15 0.83459D+05

**** BLADE MODE SHAPES ****

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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.
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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 Autotation Flight

**9-DOF U-Gust Freq Analysis & Eigen**

**R/18/74**

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**Collective Pitch Del3**

| 2.1800000E-02 | -2.6179999E-01 |

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**Eigenvalues (Natural Frequencies)**

--- (Rad/Sec) ---

**Blade Collective**

| 7988.699 | 37453.000 |

**Blade Cyclic**

| 2389.100 | 4143.398 |
**WING**


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**--- COLLECTIVE MODES ---**

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**PADI SEC/OMEGA**

**BLADE CYCLIC/OMEGA**

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### Equations of Motion

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## Frequency Response

### Frequency/Omega

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### Eigenvalues

**Eigenvectors**

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--- CORRESPONDING TO NO. 3 EIGENVALUE ---

(-0.148D+00)+IMAG(0.242D+01)

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--- CORRESPONDING TO NO. 4 EIGENVALUE ---

(-0.202D+00)+IMAG(0.195D+01)

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<td>0.4656667E+00</td>
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**CORRESPONDING TO NO. 8 EIGENVALUE**

<table>
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<tr>
<th><strong>ABSOLUTE VALUE</strong></th>
<th><strong>REAL PART</strong></th>
<th><strong>IMAGINARY PART</strong></th>
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<tbody>
<tr>
<td>0.1800445E-02</td>
<td>0.6788953E-03</td>
<td>0.1667545E-02</td>
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<tr>
<td>0.2911242E+00</td>
<td>0.2866872E+00</td>
<td>0.5063349E-01</td>
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<tr>
<td>0.4352518E+00</td>
<td>0.4194663E+00</td>
<td>-0.1161560E+00</td>
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<td>0.4240496E-03</td>
<td>0.4478541E-04</td>
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<td>0.5676120E-04</td>
<td>-0.6437076E+00</td>
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<td>0.6621398E+00</td>
<td>0.1607376E+00</td>
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<td>0.1486531E-02</td>
<td>0.1260288E-01</td>
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<tr>
<td>0.2067684E-01</td>
<td>-0.9552761E-02</td>
<td>0.1834010E-01</td>
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<td>0.1675374E-01</td>
<td>0.1418500E-01</td>
<td>0.8914784E-02</td>
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** CORRESPONDING TO NO. 9 EIGENVALUE **

** ABSOLUTE VALUE **

<table>
<thead>
<tr>
<th>Real Part</th>
<th>Imaginary Part</th>
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<tbody>
<tr>
<td>0.2436947E-03</td>
<td>0.8291703E-04</td>
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<tr>
<td>0.5692835E+00</td>
<td>-0.5446492E+00</td>
</tr>
<tr>
<td>0.5258981E+00</td>
<td>0.9681088E+00</td>
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<tr>
<td>-0.1357527E-04</td>
<td>0.4603972E-05</td>
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<tr>
<td>0.9552389E+00</td>
<td>-0.1093801E-01</td>
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<tr>
<td>0.1000000E+01</td>
<td>0.1000000E+00</td>
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<tr>
<td>0.8736736E-01</td>
<td>-0.8715111E-01</td>
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<tr>
<td>0.2357626E-02</td>
<td>0.1651092E-02</td>
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<tr>
<td>0.8463684E-02</td>
<td>0.7221349E-02</td>
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<tr>
<td>0.4402682E-02</td>
<td>0.4384559E-02</td>
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** CORRESPONDING TO NO. 10 EIGENVALUE **

** ABSOLUTE VALUE **

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<th>Real Part</th>
<th>Imaginary Part</th>
</tr>
</thead>
<tbody>
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<td>0.2436394E-02</td>
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<td>0.1000000E+01</td>
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<td>0.9246252E+00</td>
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<tr>
<td>0.1798500E-04</td>
<td>-0.9399982E-05</td>
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<td>0.6785136E+00</td>
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<tr>
<td>0.4797139E+00</td>
<td>-0.2741120E+00</td>
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<tr>
<td>0.4522312E-01</td>
<td>0.4182056E-01</td>
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<tr>
<td>0.5225778E-02</td>
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<tr>
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<tr>
<td>0.5858627E-01</td>
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** CORRESPONDING TO NO. 11 EIGENVALUE **

** ABSOLUTE VALUE **

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<th>Value</th>
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<th>** IMAGINARY PART **</th>
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<tr>
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<td>0.1062824E+00</td>
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<tr>
<td>0.5789774E-01</td>
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<tr>
<td>0.2153117E-03</td>
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<tr>
<td>0.3157100E-01</td>
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<tr>
<td>0.7271057E-01</td>
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<tr>
<td>0.3048246E-02</td>
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<tr>
<td>0.6654162E-02</td>
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<tr>
<td>0.2990245E-02</td>
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<tr>
<td>0.1000000E+01</td>
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