Calculation of the Forward and Backward Modes of an Overhung Rotor Using *MSC/NASTRAN* for *Windows*

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1. Introduction and Background

The purpose of this paper is to review the methods of computing the forward and backward critical speeds and unbalance response of an overhung rotor using ***MSC/NASTRAN*** for ***Windows***. The study is motivated by the requirement that it is necessary to accurately calculate the critical speeds of gas turbines, including gyroscopic effects. For example, with certain gas turbine designs, the disk gyroscopic effects can almost double the critical speed, as compared to the planar modes of vibration. In general, all finite element programs are basically designed for structural analysis only. ***NASTRAN***, however, allows the incorporation of skew-symmetric mass, damping, and stiffness matrices into the bulk data set through the use of the DMIG command.

NASTRAN has a number of eigenvalue solvers for computing both real and complex eigenvalues. There are several issues that must be faced when attempting to calculate complex eigenvalues using ***MSC/NASTRAN*** for ***Windows***. The ***Windows*** interface is ***FEMAP***, which does not support complex eigenvalue analysis or the direct input of DMIG commands for gyroscopic effects. These additional files may be incorporated through the use of INCLUDE statements. The second, and more important, question is which method to use and also how accurate are the various eigenvalue methods. This report is based on an earlier presentation of ***Rotor-Disk System Gyroscopic Effects in MSC/NASTRAN Dynamic Solutions*** by H. Bedrossian and N. Veikos of Avco Lycoming Division. In this paper, the classical overhung Dimentberg rotor is analyzed. The same Dimentberg model was also analyzed earlier by Gunter and Fang to compare the predicted forward and backward modes using the finite element rotor dynamics program, ***DyRoBeS***, and the undamped critical speed program, ***CRITSPD-PC***.

In the basic Dimentberg rotor, as shown in Figure 1.1, the rotor is simply supported at the bearings and no damping is assumed. Therefore, the eigenvalues for the system should have negligible real components. Figure 1.2 represents the gyroscopic moments acting on the disk, as shown by Dimentberg. The disk gyroscopic moments are shown for small rotation angles Φ_x and Φ_y. The rate of change of the angular momentum vector $I_p \omega$ generates the gyroscopic moments acting on the disk, as shown in Figure 1.2. When the equations of motion are expressed in matrix form, the gyroscopic moments are written as skew symmetric damping terms, as a product of the disk polar moment of inertia, and spin angular velocity.

Figure 1.3 represents the forward and backward critical speeds for the overhung rotor as a function of rotational speed. Note that the intersection of the $\lambda = \omega$ curve is referred to as the synchronous critical speed. With symmetric bearings, this is normally the only critical speed which will be excited by unbalance. The second critical speed increases with speed such that the $\lambda = \omega$ curve may not necessarily intersect. This characteristic is very similar to certain designs of gas turbines. The gyroscopic moment of the turbine or fan may be of sufficient magnitude to elevate the second critical speed beyond the running speed range. The intersection of the $\lambda = \omega$ curve represents the first and second backward critical speeds.

Analytic solutions may be written for the planar and synchronous forward and backward modes. The general solution for an arbitrary rotational speed is given by a fourth order polynomial, as shown in Gunter and Fang. In the paper presented by Bedrossian and Veikos, the overhung rotor forward and backward critical speeds were computed for an angular velocity of 100 rad/sec. The real value of the eigenvalue represents the rate of decay of the wave form. A real positive root is indicative of an instability. In the solutions presented by Bedrossian and Veikos, the real roots of the eigenvalues for a number of modes are relatively large (and positive). This indicates an unstable system, which in reality is an indication of the inaccuracy of the calculation of the real part of the eigenvalue. The purpose of this study was to determine procedures in which not only the forward and backward modes could be computed, but the real part of the eigenvalue also computed with reliable accuracy.

Conclusions

It is concluded that the complex Lanczos method (CLAN) is superior to the Hess. Dynamic reduction must be employed when using Hess to obtain converged answers. Superior results are also obtained with complex Lanczos when dynamic reduction is used. Dynamic reduction is obtained with the **ASET** command. For example, if only the forward and backward modes are desired, then the **ASET** command would select the degrees-of-freedom of 1,2, 4, 5 for node 10, which represents the overhung disk. The number 1 and 2 represent the x and y motions of the disk, and 4 and 5 represent the rotations θ_x and θ_y of the disk.

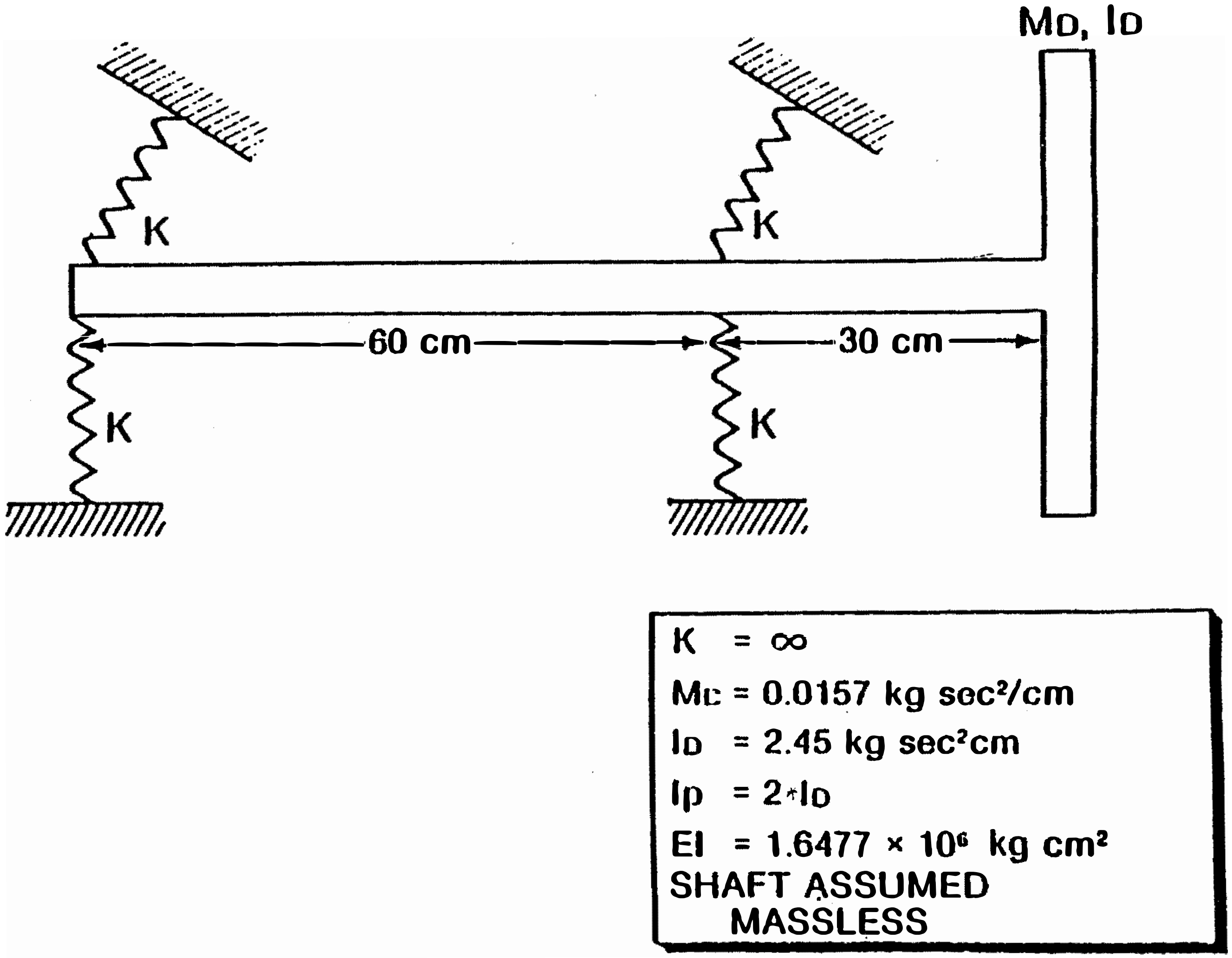


Figure 1.1 Simply Supported Dimentberg Rotor-Disk System (Bedrossian and Veikos)

DISK GYROSCOPIC EFFECT

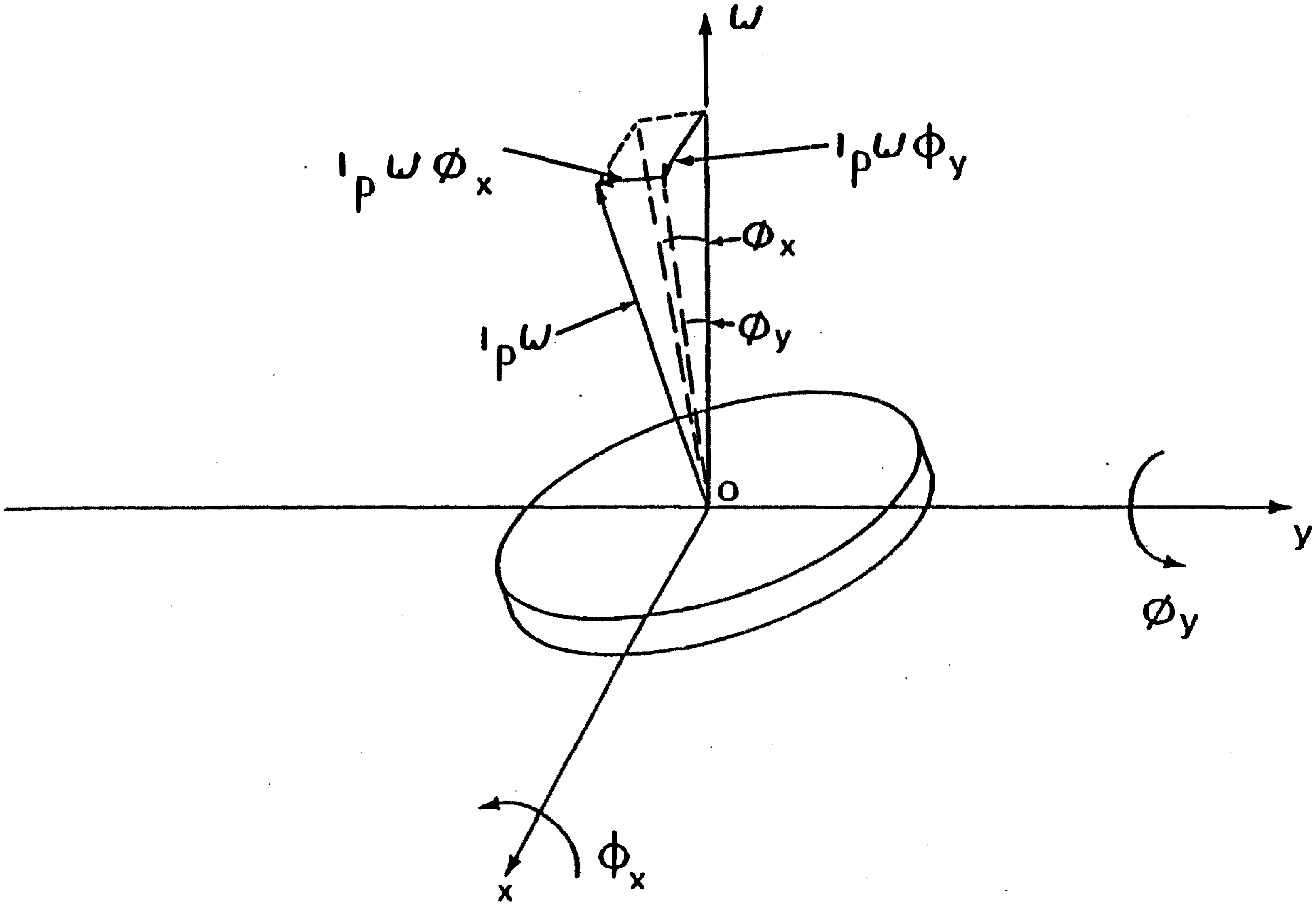


Figure 1.2 Disk Gyroscopic Effect for Small Angular Displacements

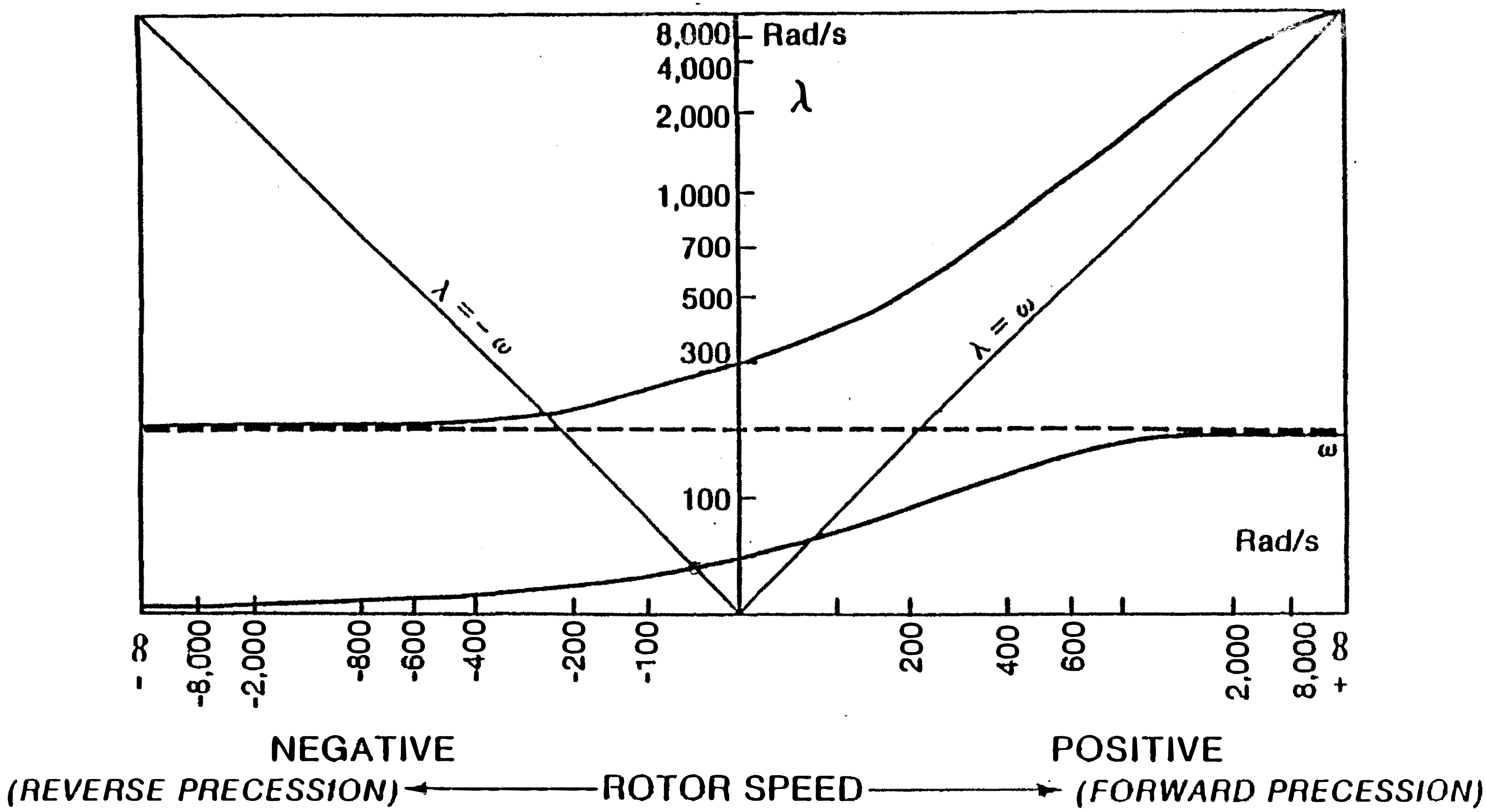


Figure 1.3 Forward and Backward Critical Speeds of Dimentberg Rotor (Bedrossian and Veikos)

2. Planar Modes of Dimentberg Rotor

An ***MSC/NASTRAN for Windows*** model was generated for the overhung Dimentberg rotor. The rotor model is 90 cm long and has 10 nodes. The Dimentberg rotor, as shown in Figure 1.1 (from the paper by Bedrossian and Veikos), uses metric units, but not the standard SI units. The kilogram is treated as a weight unit. The value of E = 1.0E6 Kg/cm^2 was used in Table 4 for the material property (E = 14.22E6 lb/in^2). The cross-sectional I is 1.647 cm^4. This represents a shaft with a 2.407 cm (0.9476 in) diameter. The shaft mass density is ρ = 1.0E-9 Kg/cm^2. This causes a very small mass distribution along the shaft. This will later create problems for computation of accurate complex eigenvalues with the Hess eigensolvers due to the low shaft mass in relationship to the disk. The disk mass is 0.0157 $Kg\text{-}sec^2/cm$ (15.41 Kg or 33.96 lb) and the disk transverse moment of inertia I_d = 2.45 $Kg\text{-}sec^2\text{-}cm$ (821.46 $lb\text{-}in^2$) and the polar $I_p = 2\ I_d$.

Figure 1.3 shows the forward and backward modes for the overhung Dimentberg rotor as a function of rotor speed. As a first test of ***MSC/ Windows***, the planar modes (0 RPM modes) were also re-computed using the RODYN program ***CRITSPD-PC***, in which the rotor was translated into equivalent English units.

Figure 2.1 represents the first planar mode at 8.88 Hz (553 RPM) computed by the transfer matrix program ***CRITSPD-PC***. Figure 2.2 represents the second planar mode at 48.10 Hz. A finite element ***MSC*** model was generated using ***FEMAP*** and the planar undamped modes were computed using the ***MSC/NASTRAN*** standard undamped Lanczos eigensolver. The finite element model has 10 nodes and 9 shaft elements. Figure 2.3 represents the first planar mode computed by ***MSC*** at 8.885 Hz. Figure 2.4 represents the second planar mode computed by ***MSC*** at 48.11 Hz. Thus, the planar modes computed by ***CRITSPD-PC*** and ***MSC*** are identical. Table 2.1 represents the ***MSC/NASTRAN*** data file for the overhung rotor.

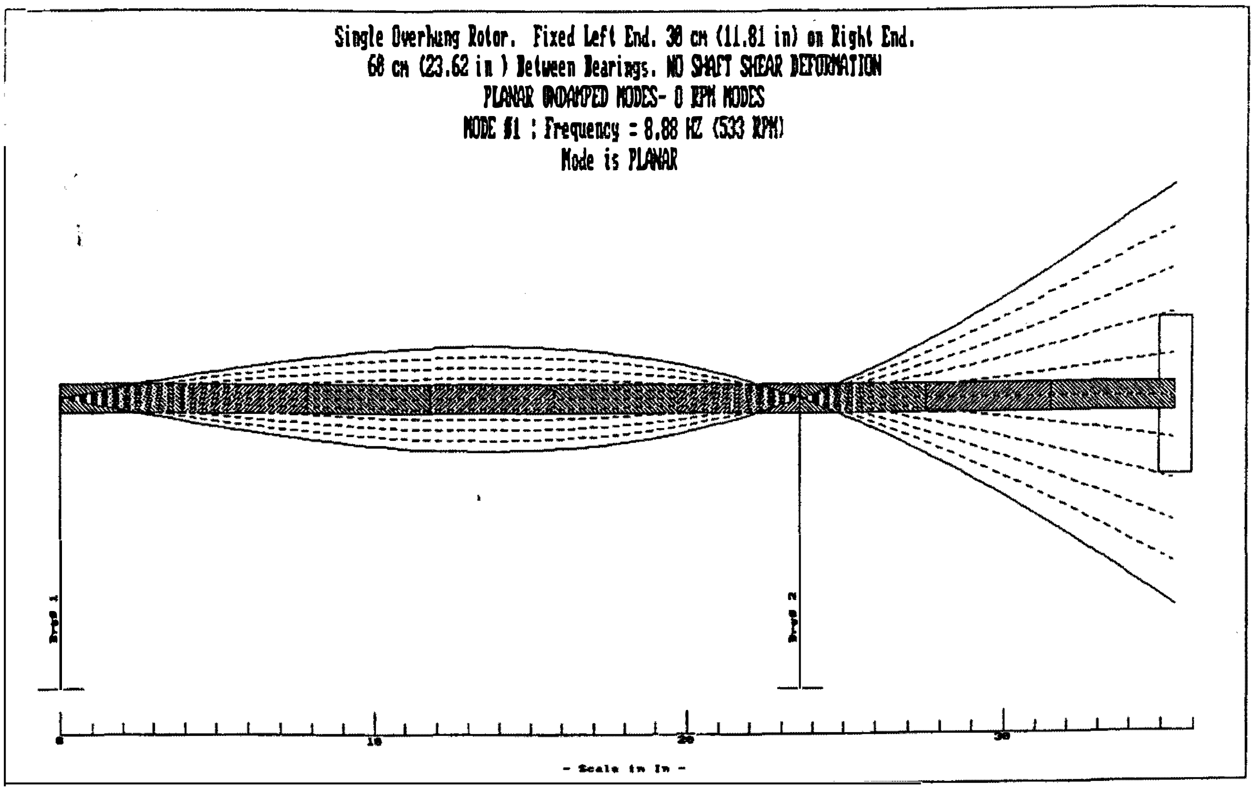


Figure 2.1 First Planar Mode at 8.8 Hz (533 RPM)
Using *CRITSPD-PC*

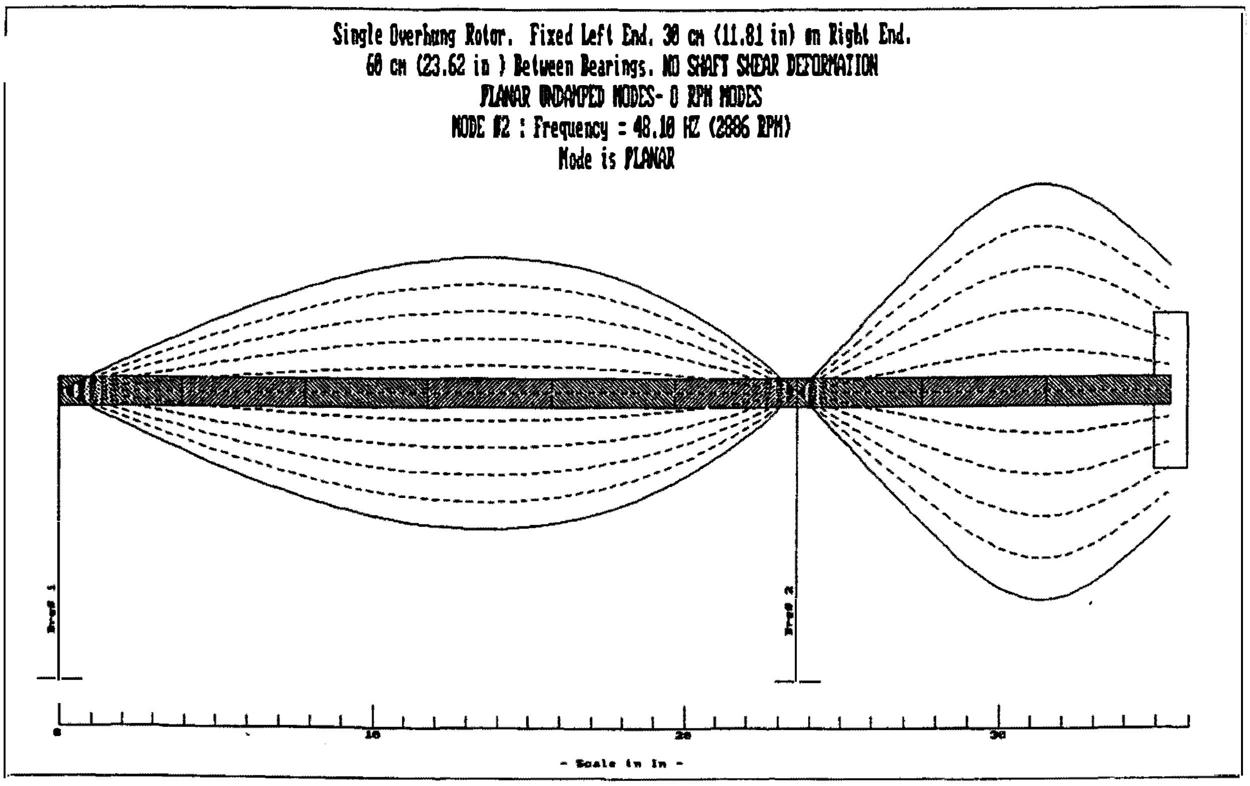


Figure 2.2 Second Planar Mode at 48.10 Hz

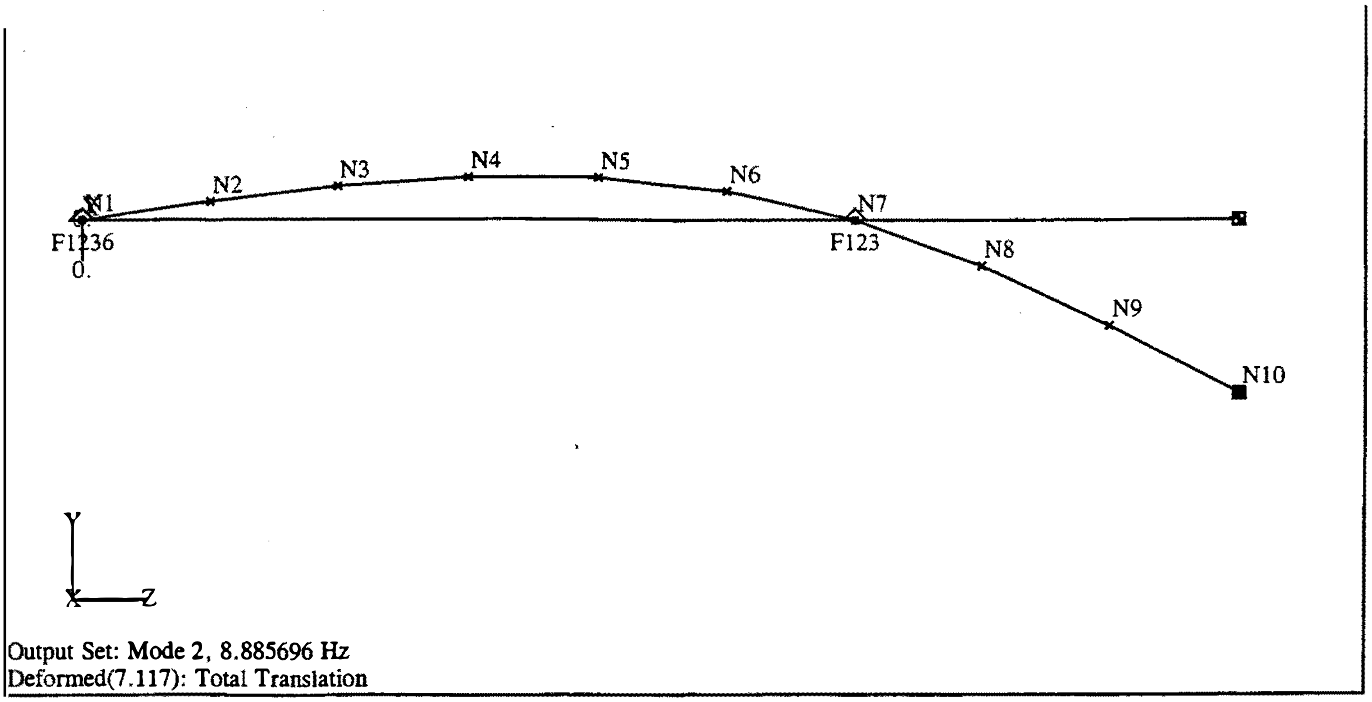


Figure 2.3 First Planar Mode of Dimentberg Rotor at 8.885 Hz (55.8 rad/sec) Using *MSC/Windows*

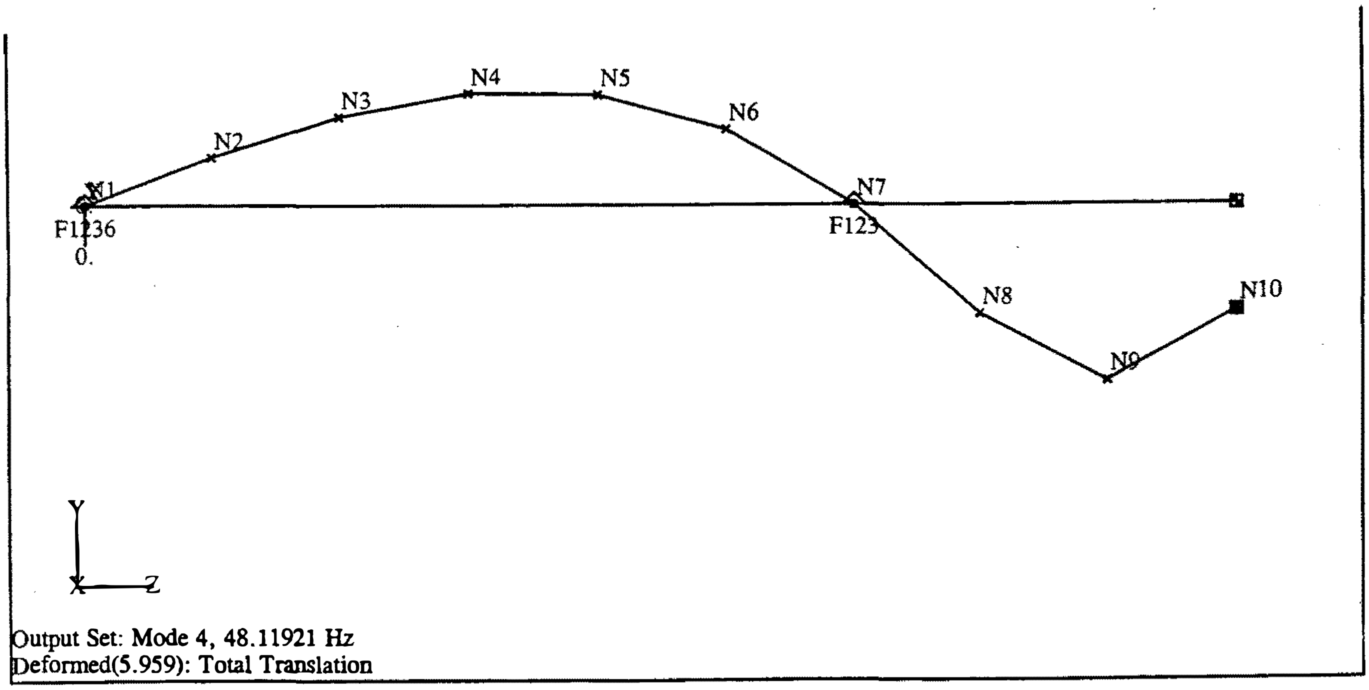


Figure 2.4 Second Planar Mode of Dimentberg Rotor at 48.11 Hz (302 rad/sec) Using *MSC/ Windows*

```
INIT MASTER(S)
ID C:\Mscn4,MSC.N
SOL SEMODES
TIME 10
CEND
METHOD = 1
  ECHO = NONE
  DISPLACEMENT(PLOT) = ALL
  OLOAD(PLOT) = ALL
  SPCFORCE(PLOT) = ALL
  FORCE(PLOT,CORNER) = ALL
  STRESS(PLOT,CORNER) = ALL
  SPC  = 1
BEGIN BULK
$ ****************************************************************
************
$   Written by : MSC.Nastran for Windows
$   Version    : 4.5
$   Modeller   : 7.01
$   Translator : MSC.Nastran
$   From Model : C:\Mscn4w45\examples\finish\TABLE4DIMENTBERG.MOD
$   Date       : Thu Jun 22 11:22:49 2000
$   Output To  : C:\Mscn4w45\examples\OVERHUNG_ROTOR\DIMTPLANAR2
$ ****************************************************************
************
$
PARAM,POST,-1
PARAM,OGEOM,NO
PARAM,AUTOSPC,YES
PARAM,MAXRATIO,1.E+8
PARAM,GRDPNT,0
EIGRL          1      0.1    2000.       10        0
MASS
CORD2C         1        0       0.       0.       0.       0.       0.
1.+MSC.NC1
+MSC.NC1      1.       0.       1.
CORD2S         2        0       0.       0.       0.       0.       0.
1.+MSC.NC2
+MSC.NC2      1.       0.       1.
```

Table 2.1 *NASTRAN* Data File for Planar Modes
of Overhung Dimentberg Rotor

```
$ MSC.Nastran for Windows Constraint Set 1 : PINNED_BRGS
SPC            1       1    1236      0.
SPC            1       7     123      0.
$ MSC.Nastran for Windows Property 1 : DIMBAR
PBAR           1       1     10.   1.647   1.647    3.39      0.
+PR     1
+PR     1     0.      0.      0.      0.      0.      0.      0.
0.+PA     1
+PA     1                     0.
$ MSC.Nastran for Windows Material 1 : TABLE41E6
MAT1           11000000.             0.3   1.E-9      0.      0.
GRID           1       0      0.      0.      0.       0
GRID           2       0      0.      0.     10.       0
GRID           3       0      0.      0.     20.       0
GRID           4       0      0.      0.     30.       0
GRID           5       0      0.      0.     40.       0
GRID           6       0      0.      0.     50.       0
GRID           7       0      0.      0.     60.       0
GRID           8       0      0.      0.     70.       0
GRID           9       0      0.      0.     80.       0
GRID          10       0      0.      0.     90.       0
CBAR           1       1       1       20.099504      0. 0.99504
CBAR           2       1       2       30.099504      0. 0.99504
CBAR           3       1       3       40.099504      0. 0.99504
CBAR           4       1       4       50.099504      0. 0.99504
CBAR           5       1       5       60.099504      0. 0.99504
CBAR           6       1       6       70.099504      0. 0.99504
CBAR           7       1       7       80.099504      0. 0.99504
CBAR           8       1       8       90.099504      0. 0.99504
CBAR           9       1       9      100.099504      0. 0.99504
CONM2         10      10       0  0.0157      0.      0.      0.
+EL     A
+EL     A   2.45      0.    2.45      0.      0.     4.9
ENDDATA 34cc497a
```

Table 2.1 *NASTRAN* Data File for Planar Modes
of Overhung Dimentberg Rotor
(Continued)

3. Complex Eigenvalue Analysis

3.1 Complex Analysis Using Hess

NASTRAN supports three eigenvalue procedures. These procedures are inverse power, Hessenberg, and complex Lanczos. In the paper by Bedrossian and Veikos, the complex Hess procedure was employed. The Hess method stands for the Hessenberg method, which uses a Householder reduction to upper Hessenberg form. This is followed by the Francis QR reduction and direct eigenvalue generation scheme. Wilkinson, in 1965, showed that a general A matrix can be factorized into the product of the unitary Q matrix and an upper triangular R matrix. A QR iteration is performed using the generated Householder matrices. The eigenvectors are extracted from the Hessenberg H matrix. The extraction process for the eigenvectors with Hess may be unstable. The method is better suited for small systems with well defined mass and stiffness matrices. The Hess method has now been superceded by the more efficient complex Lanczos procedure.

The ***MSC Windows*** program's modeler uses the ***FEMAP*** interface. The ***FEMAP*** modeler does not explicitly support the analysis of complex or damped eigenvalues. Therefore, additional statements for executive control, case control, and the Bulk Data statements required in the *NASTRAN* file must be included in order to run a complex eigenvalue analysis. After the analysis is run, the complex mode shapes cannot be displayed since this is not supported in ***FEMAP***.

The following figures illustrate the application of Hess in order to compute the complex eigenvalues of the overhung rotor using ***MSC Windows***. The identical procedure can be used to analyze a generalized gas turbine rotor with actual bearings which include stiffness and damping. Figure 3.1, for example, represents the finite element model generated by the ***FEMAP*** modeler. The figure shows the 10 nodes of the model. The numbers 1, 2, 3, and 6 at the No. 1 bearing represent the degrees of constraint at that location. The left bearing is constrained for x, y translation (1,2), axial motion z (3), and torsional motion (6). The second bearing, at node 7, is constrained for x,y translation and axial motion. This, then, represents a simply supported rotor. In a real rotor, bearings would be attached at this point. The first step in the analysis would be to pick **FILE EXPORT** and export the model to an analysis model, as shown in Figure 3.2.

Figure 3.3 shows that the model will be exported to option 2, Normal Modes/Eigenvalue. The ***FEMAP*** interface can export the model to a variety of finite element solvers, as shown in Figure 3.3. The one selected is for *NASTRAN*. The next step is to write the model as a .dat file, as shown in Figure 3.4. This is the file that *NASTRAN* will use to actually perform the calculations. The .mod file is a modeling file used by ***FEMAP***, which must convert all modeling files into the ASCII text file that the specific finite element program uses. In the case of *NASTRAN*, it is a .dat file. The file name written is **DIMGYR01.dat** and saved in the file folder **OVERHUNG_ROTOR**. In Figure 3.4 are some other .dat files shown. For example, the file **CASECTRL.DAT** is the case control file for statements needed to activate **COMPLEX**. The file **EIGCL.DAT** is the statements used for complex Lanczos. As will be shown later, these statements can either be typed in or they can be added as **INCLUDE** files.

After one clicks on the ***Write*** box in Figure 3.4, the analysis control box appears. Two things are important in this. The first is that the ***Run Analysis*** box must be selected, as shown in Figure 3.5, else the model will not run. The second is that the constraints picked must correspond to the physical bearing constraints of the system. If one were to perform only an undamped eigenvalue analysis, one would just simply click ***OK*** and continue. However, for advanced analysis one would then select ***Advanced***. It is important to note that at this point it is not necessary to indicate either the number of modes or the frequency range since this will be selected by the specific commands of the complex eigensolver.

After the ***Advanced*** option is selected, we obtain the Dynamic Analysis Menu, as shown in Figure 3.6. All the response boxes in this figure refer to undamped eigenvalue analysis only. Nothing has to be selected in this menu. Simply click ***OK*** to continue. Figure 3.7 shows the *NASTRAN* Executive and Control Solution menu. In this box, we must change the solution number from ***SEMODES*** to ***107***. The number ***107*** represents the solution method for complex eigenanalysis. The maximum time also should be reduced from 10,000 minutes to 10 minutes. The output is shown directed to the file **DIMGYRO1**. The Executive Control shows that the problem ID comes from **DIMGYR07.MOD**. After the Executive Control statements are incorporated, one then clicks ***OK*** to continue.

Figure 3. 8 represents the *NASTRAN* Case Control statements that occur before the Bulk Data. At this point, one may click off all components other than Displacement. Note that in

this figure ***Echo*** is listed as ***both***. If ***Echo*** is ***sort*** or ***both***, then a listing of the rotor model is generated. Titles and subtitles may be included to identify the problem. The ***Constraint Set*** must be selected as the "Bearing Pinned Supports." At this point, the Case Control statements may be either hand typed by checking the ***Type Input*** box or by using an INCLUDE file. There are two important Case Control statements that must be included at this point in order to run a complex eigenanalysis. The first is the statement **CMETHOD=99**. The value 99 is arbitrary and simply identifies the eigenvalue solver in the Bulk Data set. The second statement is **B2PP=DIMGYRO**. **B2PP** is a general damping matrix with the quantities defined in the **DMIG** statement for **DIMGYRO**. The gyroscopic components will be specified by this matrix. After these statements have been incorporated, as shown in Figure 3.9, ***OK*** is clicked to return to Case Control, and then click ***OK*** again to proceed to the Bulk Data Set.

Figure 3.10 represents the *NASTRAN* Bulk Data input for Hess with no *ASET* selected. There are two INCLUDE files that must be added to the Bulk Data Set. The first INCLUDE file, or input statement, is the complex eigenvalue procedure. In this case, the eigenvalue procedure shown is Hess and requests 6 modes. The second INCLUDE file is the ***DMIG*** file to incorporate the disk gyroscopics. In the **DMIG** statements shown in Figure 3.10, the first line is a header line. The second two lines represent the gyroscopic moment. The gyroscopic moment is applied at node 10 for directions 4 and 5, which are rotations along the x and y axes. The values of 490 represent the polar moment of inertia $\times 100$ rad/sec. Hence, the file format shown here for **DMIG** may be used to incorporate gyroscopics for any general rotor in which the axis of the rotor is the z axis. These components are placed in the **B2PP** matrix. After the proper Bulk Data statements have either been manually added or incorporated by INCLUDE files, one may click ***OK*** to continue. Figure 3.11, for example, shows the ***INCLUDE.DAT*** file for **DIMGYRO**.

After the file has been run, one must exit *NASTRAN* and examine the ***.F06*** file for data output. Figure 3.12A represents the first page of the ***DIMGYRO.F06*** file. On the first page is an echo of the Executive Control Deck and the Case Control. In the Executive Control, the statement ***SOL 107*** is seen. This calls for the complex eigensolver. Note that under METHOD=1 the statement **CMETHOD=99** has been added. The statement **B2PP=DIMGYRO** under Case Control identifies the **DMIG** statements to incorporate into the generalized damping matrix **B2PP**. Figure 3.12B shows the mass and inertia characteristics of the system. Figure

3.12C issues a warning message and states that the input matrix is rank deficient. It is seen that the Hessenberg method failed to converge. Three frequency values are shown of 28.8 Hz, 6,403 Hz, and 1.1E7 Hz. These numbers are meaningless.

Table 3.1 represents the *NASTRAN.DAT* file generated for the overhung Dimentberg rotor using the Hess complex eigensolver. Note that after the Begin Bulk statement are the statements for **EIGC** and the **DMIG** statements. The last statement in the file is **CONM2** statement for the mass at node 10 with a mass of .0157 and transverse inertia properties of 2.45. One may edit the .dat file and add additions for commands that would be recognized by ***FEMAP***. One cannot modify the **EIGC** command, since it must be incorporated through ***FEMAP*** through the use of **INCLUDE** files. However, other statements, such as nodes and masses, may be added in the **.DAT** file, along with bearings. However, if additions are made to this file, then at the **END DATA** statement, the number **83E67DC8** must be deleted. This is a local code inserted by ***FEMAP*** for card count. Any modification of the **.DAT** file will not operate unless this code is removed.

Complex Hess With ASET

Thus it is seen that in ***MSC/ Windows***, the Hess eigensolver will not properly compute, even though this model is identical to that shown by Bedrossian. The Bedrossian model, using Hess, gave reasonable answers for the first four modes. If one looks carefully at the **MAT1** command, it is seen that the mass density of the shaft is not exactly zero, but is 1.0E-9. This produces an ill-conditioned mass matrix which is, however, capable of producing numbers on a mainframe computer with 64 bits of data, whereas it will not calculate accurately on a PC computer with only 32 bits of accuracy. Therefore, the unmodified Hess procedure is not recommended without the incorporation of dynamic reduction. Dynamic reduction is accomplished through the **ASET** command.

Figure 3.13 represents the constraint set 2 in which all degrees-of-freedom are selected for node point 10. This set will not be used as a constraint, as such, but will be specified in ASET, which represents active degrees-of-freedom. By specifying an ASET, *NASTRAN* uses dynamic reduction and reduces the order of the system to six active degrees-of-freedom. The Hess eigensolver performs essentially what is equivalent to an inversion of the mass matrix. With an ill-conditioned mass matrix, such as generated by the extremely light specification of shaft mass. The Hess eigensolver will not compute properly in ***MSC/ Windows***. However, by defining a set of active degrees-of-freedom on the disk, the system is well defined and the Hess eigensolver operates very well. Figure 3.14 represents the Bulk Data Set in which the **ASET** is selected to represent the Constraint Set 2. Here it is seen that the modes are well computed and are extremely accurate, as shown in Figure 3.15. Note that the real parts of the eigenvalues are extremely small and are of the order of 10^{-9} and smaller. A comparison of the various eigenvalues computed by the different methods is shown in Table 3.2.

In complex eigensolution, the computation of the accurate complex roots is much more difficult than the calculation of the undamped planar modes. Whereas in planar mode computations, it is not critical to reduce the size of the dynamical matrices, it is essential when computing complex modes. Thus, for Hess to properly operate, active degrees-of-freedom must be selected. These active degrees-of-freedom should include the disk translational motion and rotational degrees-of-freedom. Bearing locations in an actual rotor should also be selected. In the cases where it is not desired to have torsional or axial motion, these degrees-of-freedom do not need to be selected.

FINITE ELEMENT ROTOR MODEL

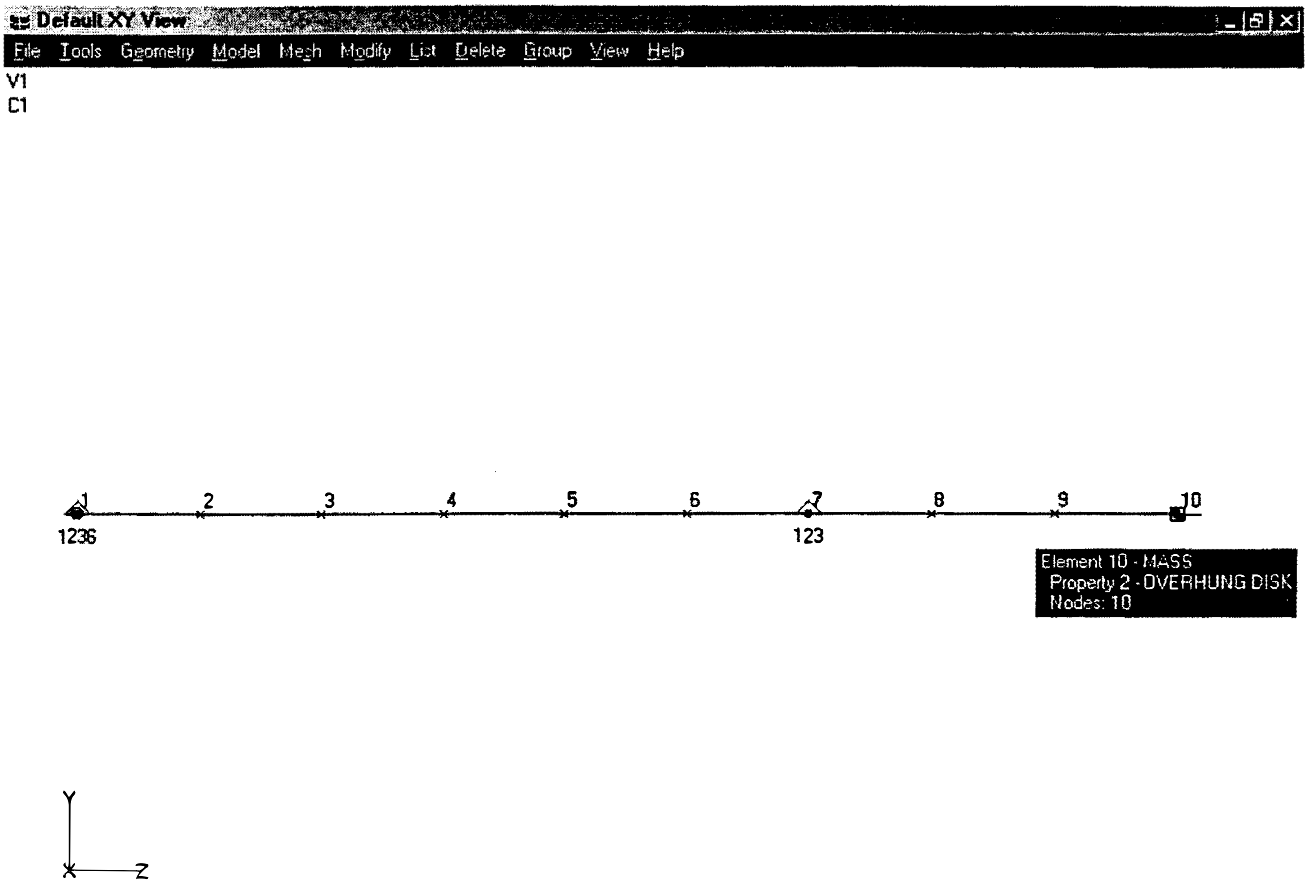


Figure 3.1 Overhung Dimentberg Rotor With Simple Support Bearing Constraints

EXPORT ANALYSIS

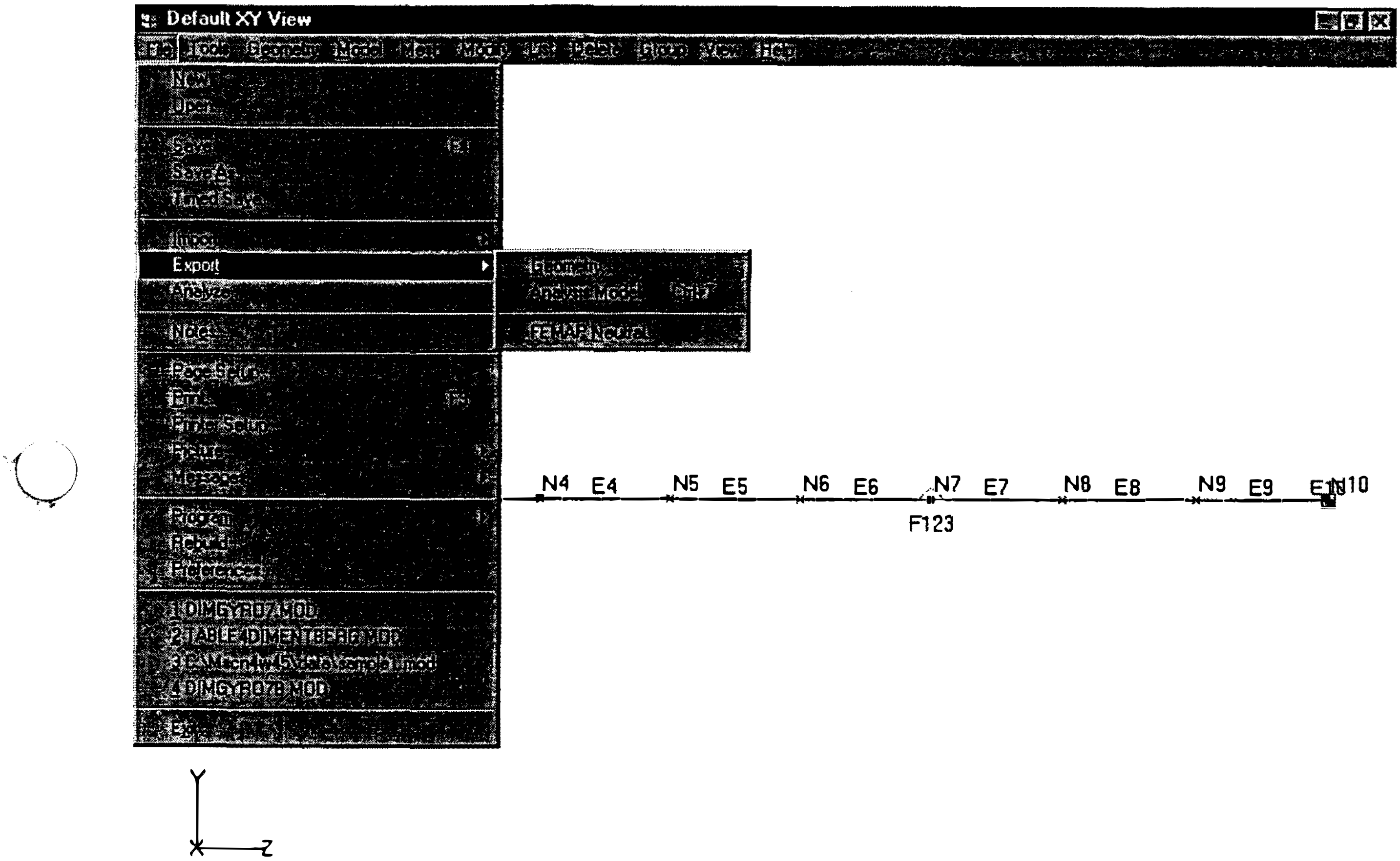


Figure 3.2 Export MOD Analysis Model For Complex Eigenvalue Computations

EXPORT ANALYSIS TO NORMAL MODES

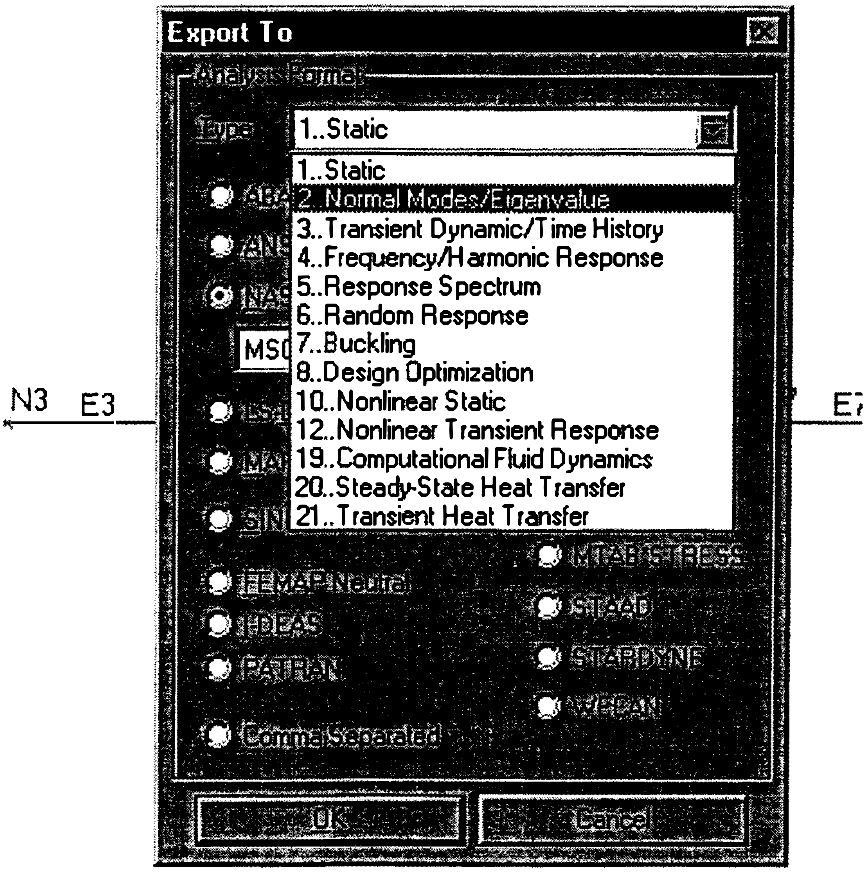


Figure 3.3 Export Analysis To Normal Modes/Eigenvalue

WRITE MODEL TO NASTRAN AS .DAT FILE

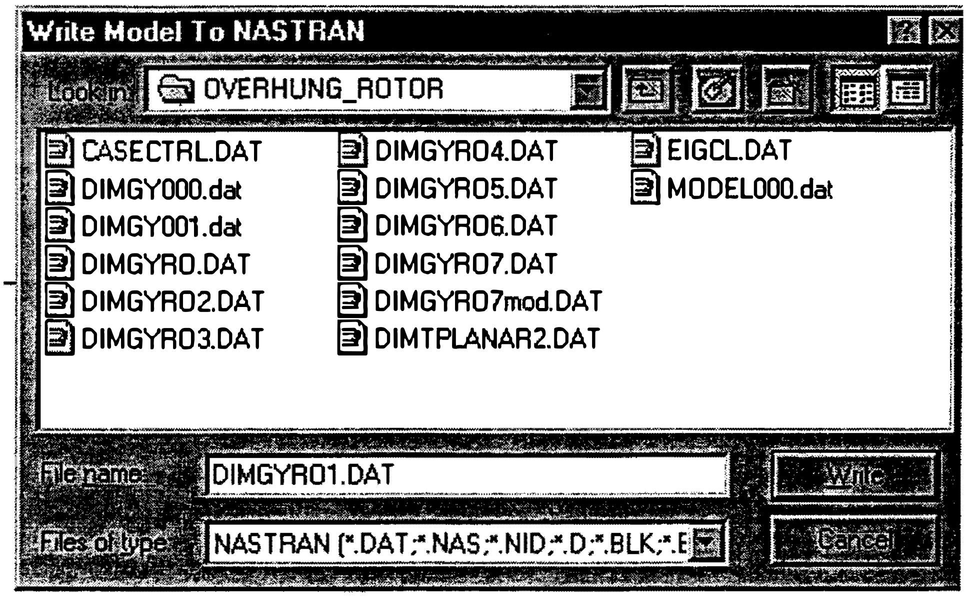
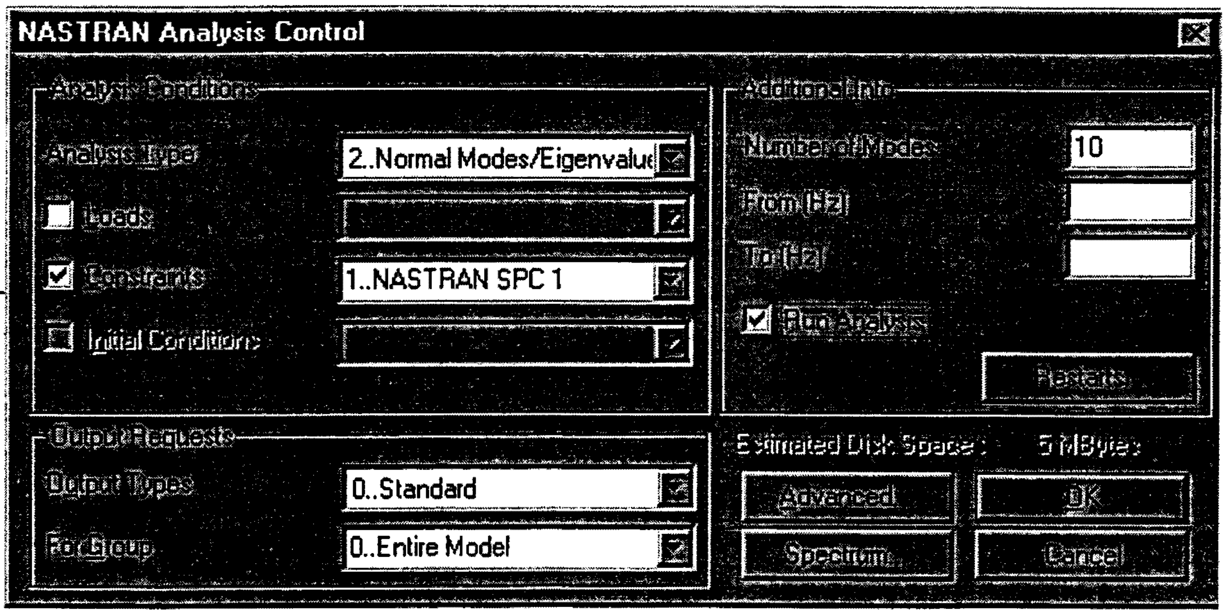


Figure 3.4 Convert Graphics FEMAP MOD File To A NASTRAN .DAT File

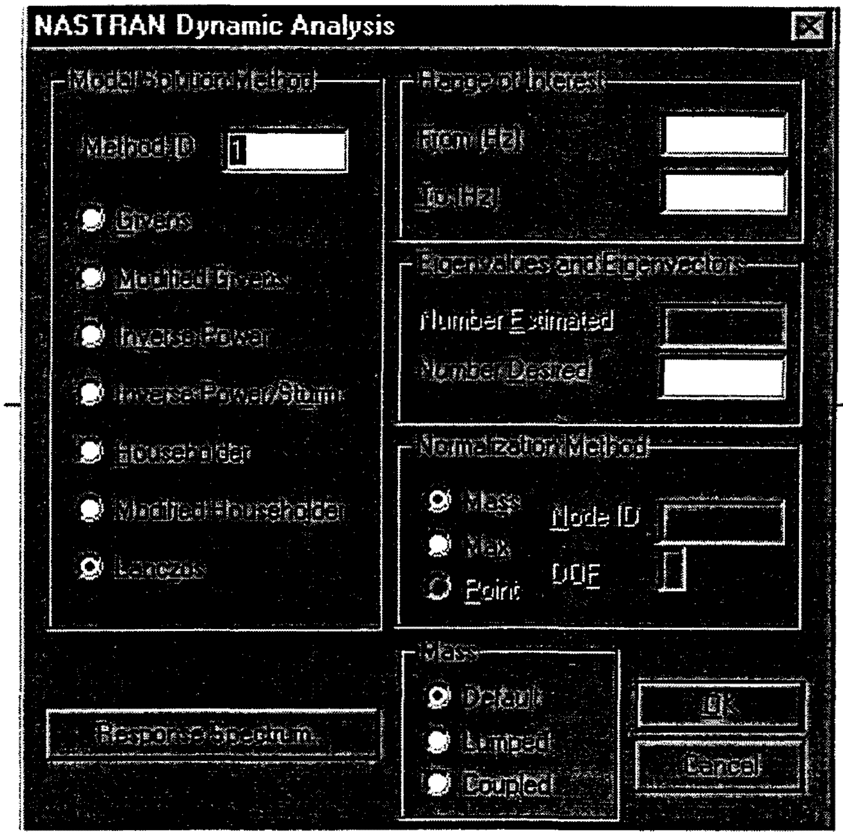
ANALYSIS CONTROL



(CHECK RUN ANALYSIS TO COMPUTE MODEL)
SELECT ADVANCED To Continue Analysis

Figure 3.5 Analysis Control To Initial Eigenvalue Computations

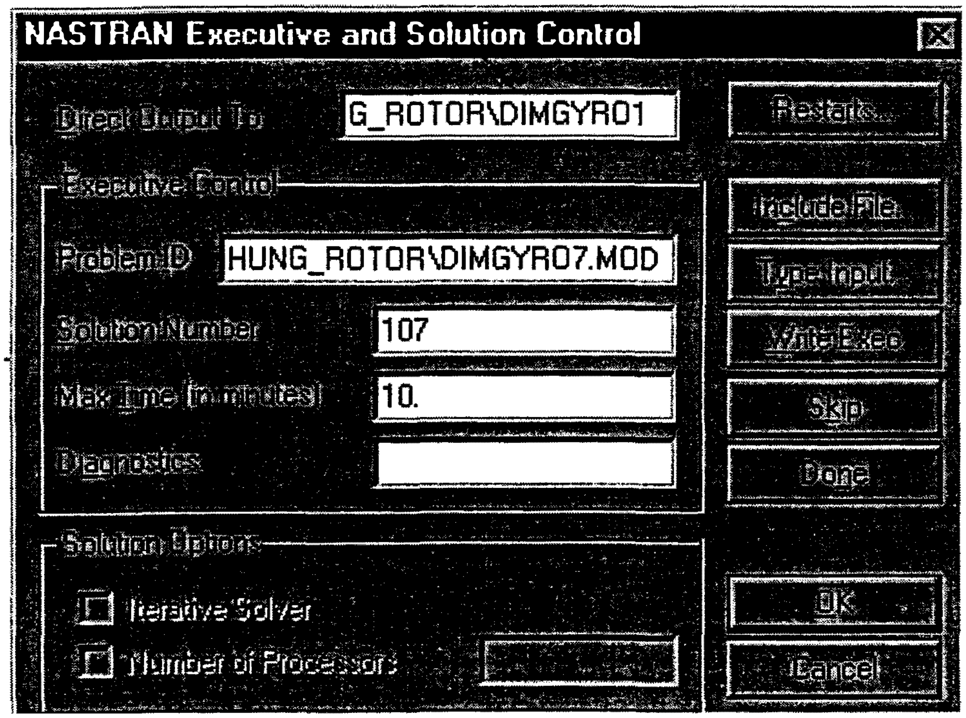
DYNAMIC ANALYSIS



NO SELECTION CHOISES REQUIRED HERE FOR COMPLEX EIGENVALUES
MODAL SOLUTIONS & FREQUENCY OPTIONS ARE FOR UNDAMPED MODAL ANALYSIS ONLY
(Click OK To Continue)

Figure 3.6 NASTRAN Dynamic Analysis

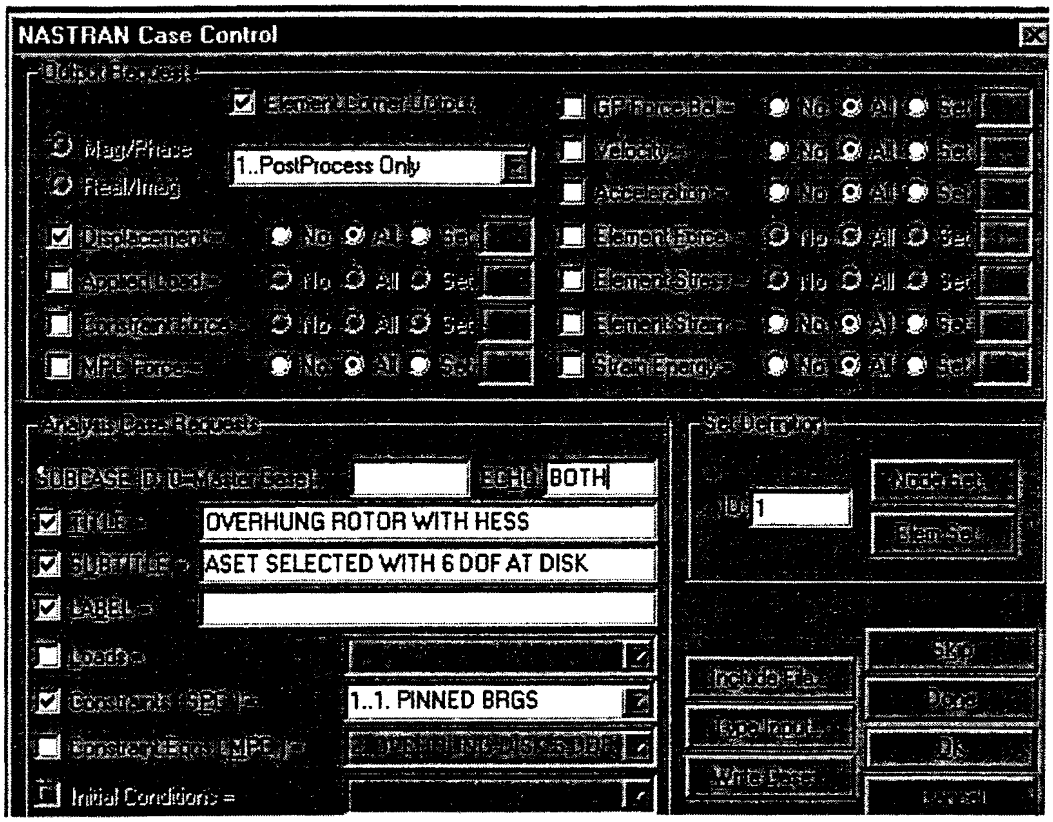
NASTRAN Executive and Solution Control



OUTPUT To C:\Mscn4w45\examples\OV.....\DIMGYRO1
PROBLEM ID C:\Msc .\ex..\OVER..\DIMGYRO7.MOD
Change From Sol SEMODES To 107 For COMPLEX Modes
Reduce Time From 10000 To 10 min
(Click OK To Continue)

Figure 3.7 NASTRAN Exeative and Solution Control

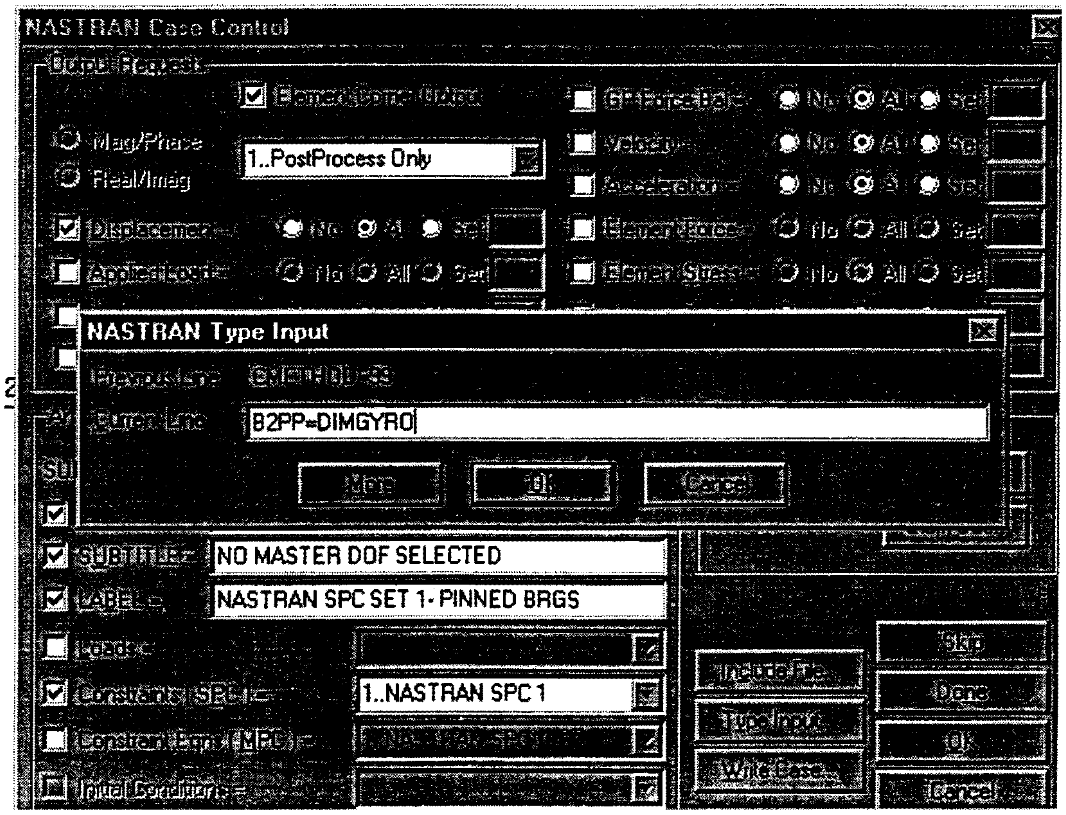
NASTRAN Case Control With HESS



Click On Type Input..
CMETHOD=99 (Complex Solution Activation)
B2PP=DIMGYRO (Specify Gyroscopic Matrix)
SDISP=ALL
(Above Statements may be pretyped for Include File)
(Click OK After Returning to Case Control)

Figure 3.8 NASTRAN Case Control

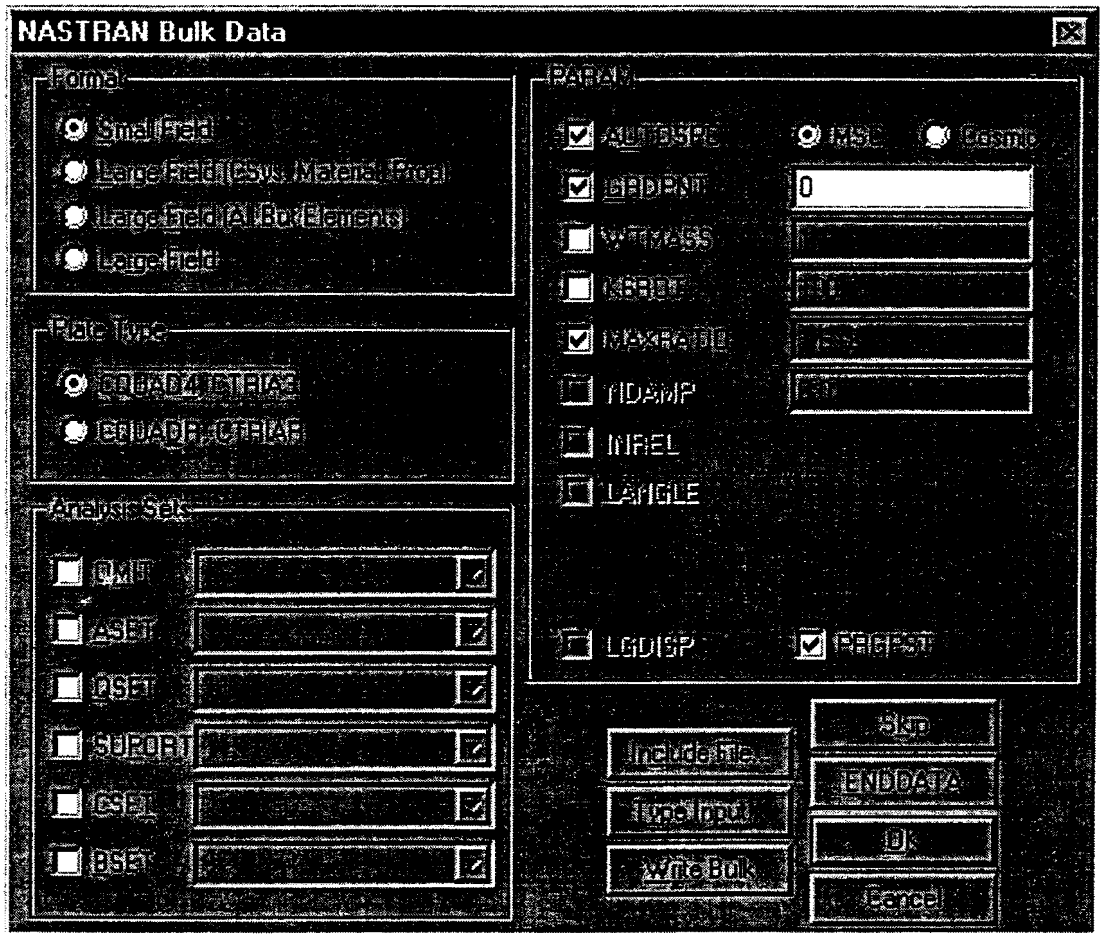
NASTRAN Type Input For Case Control



(Click MORE For Next Line)
(Click OK at Last Include Statement To Return)

Figure 3.9 NASTRAN Case Control

BULK DATA SET INPUT FOR COMPLEX HESS
With DIMGYRO & No ASET Selected



(Click on Type Input or Include File to insert the following statements)
EIGC, 99 , HESS , , , , , 6 (Request 6 Modes)

DMIG, DIMGYRO, 0 , 1 , 1
DMIG, DIMGYRO, 10 , 4 , , 10 , 5 , -490.0
DMIG, DIMGYRO, 10 , 5 , , 10 , 4 , 490.0
(Click on OK to Continue)

Figure 3.10 NASTRAN Bulk Data Input Using HESS With No ASET

INCLUDE DIMGYRO.DAT FILE FOR DISK GYROSCOPIC MOMENT EFFECT At 100 RAD/Sec

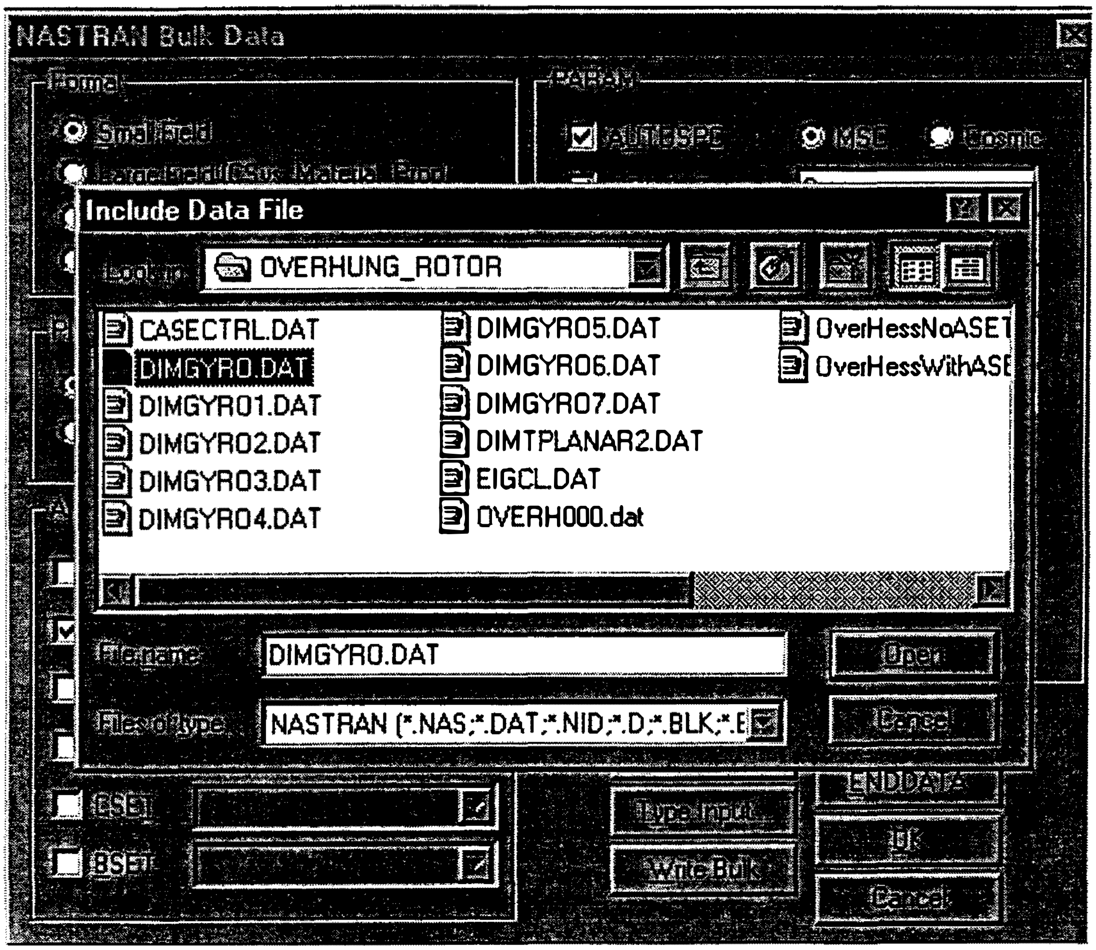


Figure 3.11 Include Dat File For DIMGYRO For Disk Gyroscopics

EX. CONTROL FOR UNCONVERGED HESS

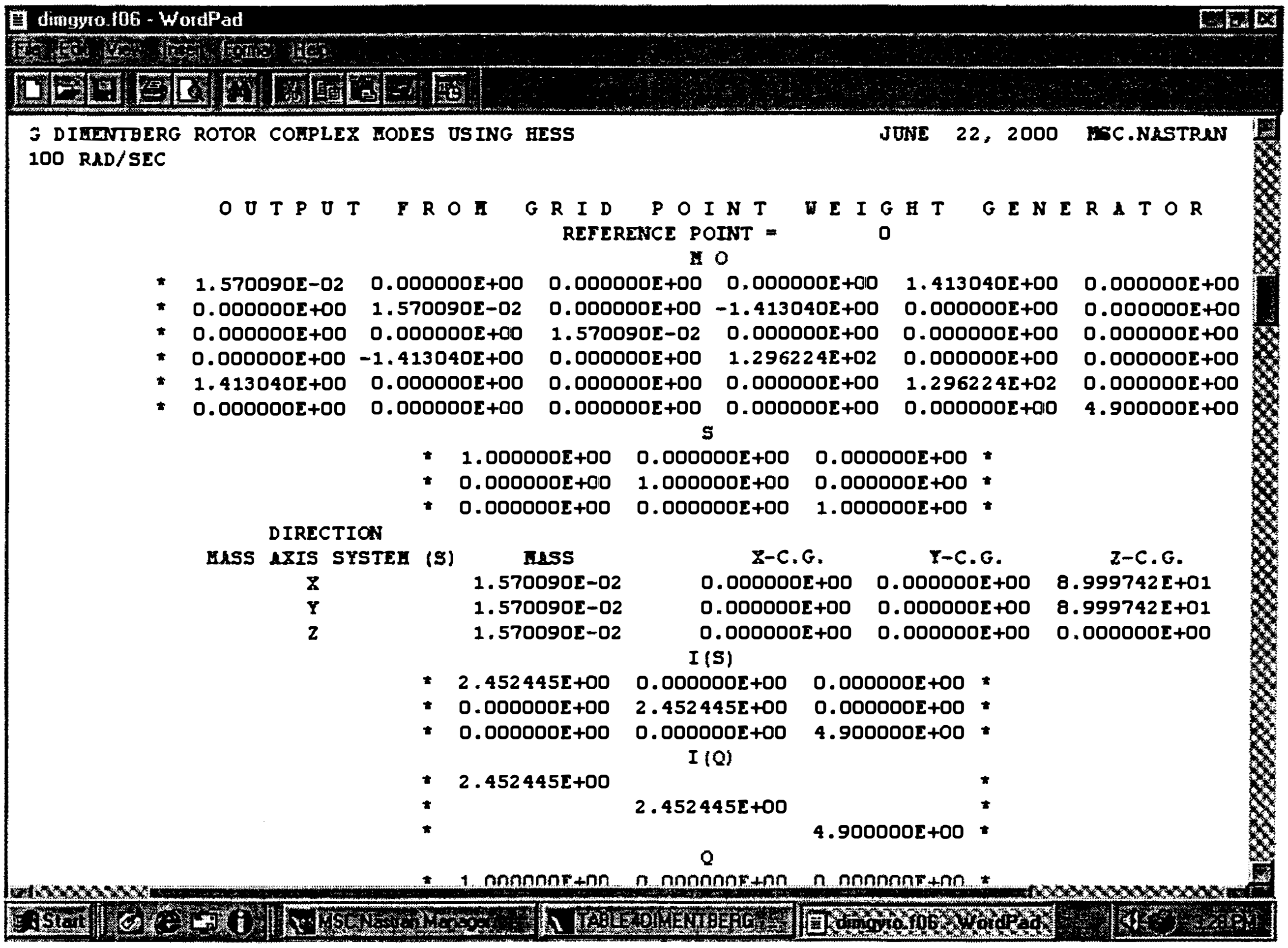
dimgyro.f06 - WordPad

```
   N A S T R A N    E X E C U T I V E    C O N T R O L    D E C K    E C H O


 ID C:\MSCN4,MSC.N
 SOL 107
 TIME 10
 CEND
 OVERHUNG DIMENTBERG ROTOR COMPLEX MODES USING HESS                           JUNE  22, 2000  MSC.N
  OMEGA=100 RAD/SEC

                                     C A S E    C O N T R O L    D E C K    E C H O
             CARD
             COUNT
               1        METHOD = 1
               2        CMETHOD=99
               3        B2PP=DIMGYRO
               4        SDISP=ALL
               5          ECHO = NONE
               6          TITLE = OVERHUNG DIMENTBERG ROTOR COMPLEX MODES USING HESS
               7          SUBTITLE = OMEGA=100 RAD/SEC
               8          DISPLACEMENT(PLOT) = ALL
               9          SPC  = 1
              10        BEGIN BULK
                             INPUT BULK DATA CARD COUNT =       55
                       TOTAL COUNT=        42
 USER INFORMATION MESSAGE 4109 (OUTPX2)  THE LABEL IS XXXXXXXX FOR FORTRAN UNIT 12
                           (MAXIMUM SIZE OF FORTRAN RECORDS WRITTEN =        7 WORDS.)
                                 (NUMBER OF FORTRAN RECORDS WRITTEN =        8 RECORDS.)
```

Figure 3.12a Output .fo6 File Showing Unconverged Modes For HESS Solution

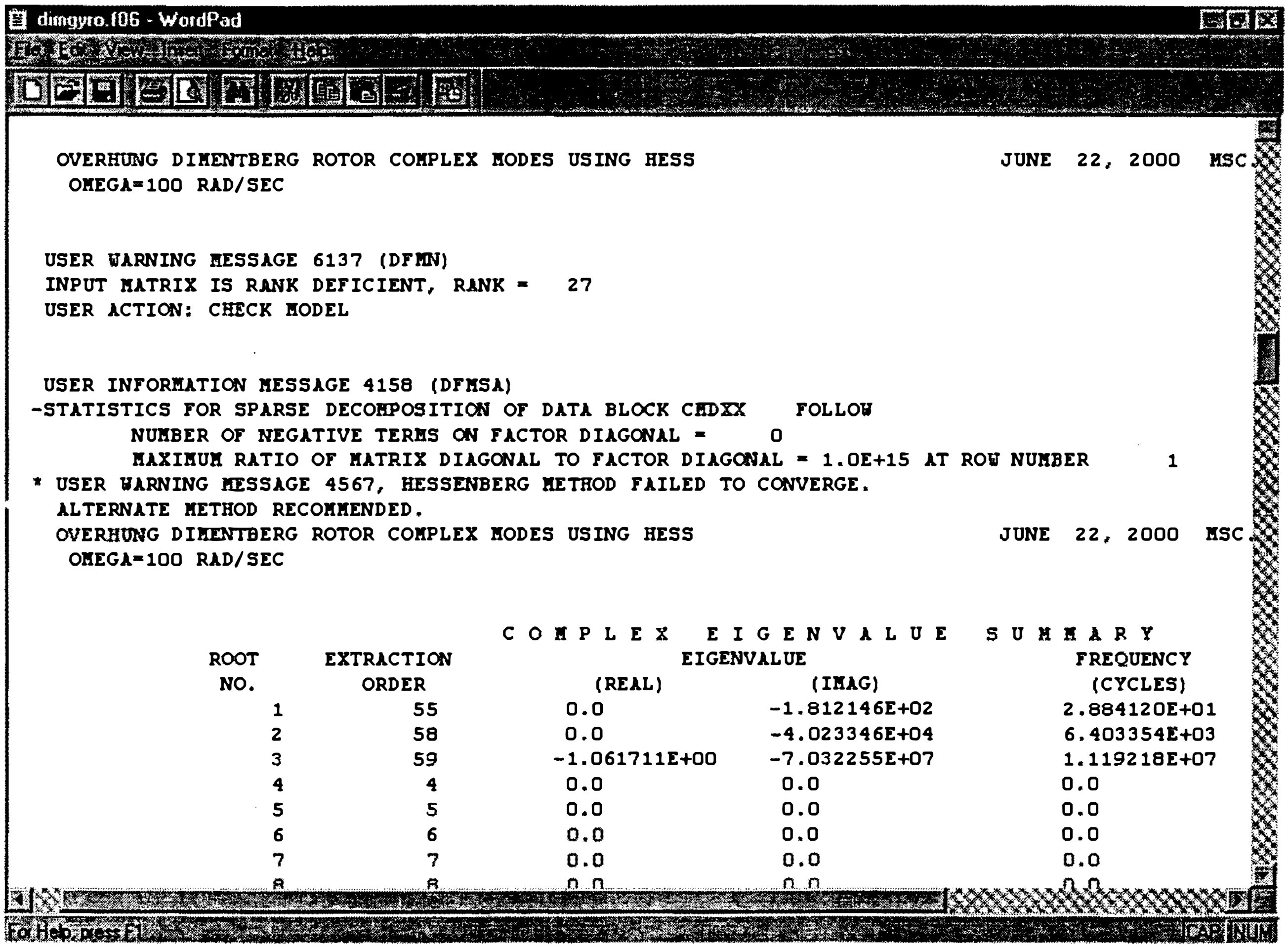


```
dimgyro.f06 - WordPad

3 DIMENTBERG ROTOR COMPLEX MODES USING HESS                          JUNE  22, 2000   MSC.NASTRAN
100 RAD/SEC

               O U T P U T   F R O M   G R I D   P O I N T   W E I G H T   G E N E R A T O R
                                          REFERENCE POINT =          0
                                                   M O
      *  1.570090E-02  0.000000E+00  0.000000E+00  0.000000E+00  1.413040E+00  0.000000E+00
      *  0.000000E+00  1.570090E-02  0.000000E+00 -1.413040E+00  0.000000E+00  0.000000E+00
      *  0.000000E+00  0.000000E+00  1.570090E-02  0.000000E+00  0.000000E+00  0.000000E+00
      *  0.000000E+00 -1.413040E+00  0.000000E+00  1.296224E+02  0.000000E+00  0.000000E+00
      *  1.413040E+00  0.000000E+00  0.000000E+00  0.000000E+00  1.296224E+02  0.000000E+00
      *  0.000000E+00  0.000000E+00  0.000000E+00  0.000000E+00  0.000000E+00  4.900000E+00
                                                    S
                         *  1.000000E+00  0.000000E+00  0.000000E+00  *
                         *  0.000000E+00  1.000000E+00  0.000000E+00  *
                         *  0.000000E+00  0.000000E+00  1.000000E+00  *
             DIRECTION
        MASS AXIS SYSTEM (S)     MASS              X-C.G.        Y-C.G.        Z-C.G.
                X            1.570090E-02       0.000000E+00  0.000000E+00  8.999742E+01
                Y            1.570090E-02       0.000000E+00  0.000000E+00  8.999742E+01
                Z            1.570090E-02       0.000000E+00  0.000000E+00  0.000000E+00
                                                  I(S)
                         *  2.452445E+00  0.000000E+00  0.000000E+00  *
                         *  0.000000E+00  2.452445E+00  0.000000E+00  *
                         *  0.000000E+00  0.000000E+00  4.900000E+00  *
                                                  I(Q)
                         *  2.452445E+00                              *
                         *                2.452445E+00                *
                         *                              4.900000E+00  *
                                                    Q
                         *  1.000000E+00  0.000000E+00  0.000000E+00  *
```


Figure 3.12b Output .fo6 File Showing Unconverged Modes For HESS Solution



dimgyro.f06 - WordPad

```
  OVERHUNG DIMENTBERG ROTOR COMPLEX MODES USING HESS                         JUNE  22, 2000  MSC
   OMEGA=100 RAD/SEC


 USER WARNING MESSAGE 6137 (DFMN)
 INPUT MATRIX IS RANK DEFICIENT, RANK =   27
 USER ACTION: CHECK MODEL


 USER INFORMATION MESSAGE 4158 (DFMSA)
-STATISTICS FOR SPARSE DECOMPOSITION OF DATA BLOCK CMDXX    FOLLOW
       NUMBER OF NEGATIVE TERMS ON FACTOR DIAGONAL =      0
       MAXIMUM RATIO OF MATRIX DIAGONAL TO FACTOR DIAGONAL = 1.0E+15 AT ROW NUMBER      1
 * USER WARNING MESSAGE 4567, HESSENBERG METHOD FAILED TO CONVERGE.
  ALTERNATE METHOD RECOMMENDED.
  OVERHUNG DIMENTBERG ROTOR COMPLEX MODES USING HESS                         JUNE  22, 2000  MSC
   OMEGA=100 RAD/SEC


                                      C O M P L E X   E I G E N V A L U E   S U M M A R Y
            ROOT      EXTRACTION                     EIGENVALUE                         FREQUENCY
             NO.        ORDER              (REAL)               (IMAG)                  (CYCLES)
                1           55          0.0               -1.812146E+02             2.884120E+01
                2           58          0.0               -4.023346E+04             6.403354E+03
                3           59         -1.061711E+00      -7.032255E+07             1.119218E+07
                4            4          0.0                0.0                      0.0
                5            5          0.0                0.0                      0.0
                6            6          0.0                0.0                      0.0
                7            7          0.0                0.0                      0.0
```

For Help, press F1

CAP NUM

Figure 3.12c Output .fo6 File Showing Unconverged Modes For HESS Solution

```
INIT MASTER(S)
$DIMGYRO2.DAT   6/21/00 OVERHUNG DIMENTBERG ROTOR ON PINNED SUPPORTS
$ COMPLEX EIGENVALUES COMPUTED WITH HESS USING ACTIVE DOF AT NODE 10
INT1,T2,T3.R1,R2,&R3
$ NOTE ASET COMMAND FOR NODE 10
ID C:\Mscn4,MSC.N
SOL 107
TIME 10
CEND
METHOD = 1
CMETHOD=99
B2PP=DIMGYRO
SDISP=ALL
  ECHO = NONE
  TITLE = DIMENTBERG ROTOR WITH ASET ON NODE 10 -HESS
  SUBTITLE = OMEGA=100 RAD/SEC - PINNED BRGS
  DISPLACEMENT(PLOT) = ALL
  SPC  = 1
BEGIN BULK
EIGC, 99, HESS ,   ,    ,    ,     , 6
DMIG, DIMGYRO , 0  ,  1  , 1
DMIG, DIMGYRO , 10 , 4 ,   , 10 ,  5 , -490.0
DMIG , DIMGYRO , 10 , 5 ,   ,  10 , 4 , 490.0
$ ***********************************************************************
*******
$   Written by : MSC.Nastran for Windows
$   Version    : 4.5
$   Modeller   : 7.01
$   Translator : MSC.Nastran
$   From Model : C:\Mscn4w45\examples\finish\TABLE4DIMENTBERG.MOD
$   Date       : Thu Jun 22 17:22:59 2000
$   Output To  : C:\Mscn4w45\examples\OVERHUNG_ROTOR\DIMGYRO2
$ ***********************************************************************
*******
$
PARAM,POST,-1
PARAM,OGEOM,NO
PARAM,AUTOSPC,YES
PARAM,MAXRATIO,1.E+8
PARAM,GRDPNT,0
EIGRL           1      0.1    2000.        6        0
MASS
CORD2C          1        0       0.       0.       0.       0.       0.
1.+MSC.NC1
+MSC.NC1       1.       0.       1.
```

Table 3.1 NASTRAN .dat File For Complex Eigensolution Solution Using HESS

```
CORD2S         2      0      0.     0.     0.     0.     0.
1.+MSC.NC2
+MSC.NC2       1.     0.     1.
$ MSC.Nastran for Windows Constraint Set 1 : PINNED_BRGS
SPC            1      1    1236     0.
SPC            1      7     123     0.
$ MSC.Nastran for Windows Constraint Set 2 : ACTIVEDOF
ASET           10  123456
$ MSC.Nastran for Windows Property 1 : DIMBAR
PBAR           1      1     10.  1.647  1.647   3.39     0.
+PR      1
+PR      1     0.     0.     0.     0.     0.     0.     0.
0.+PA    1
+PA      1                   0.
$ MSC.Nastran for Windows Material 1 : TABLE41E6
MAT1            11000000.          0.3  1.E-9     0.     0.
GRID           1      0      0.     0.     0.      0
GRID           2      0      0.     0.    10.      0
GRID           3      0      0.     0.    20.      0
GRID           4      0      0.     0.    30.      0
GRID           5      0      0.     0.    40.      0
GRID           6      0      0.     0.    50.      0
GRID           7      0      0.     0.    60.      0
GRID           8      0      0.     0.    70.      0
GRID           9      0      0.     0.    80.      0
GRID          10      0      0.     0.    90.      0
CBAR           1      1      1      20.099504     0. 0.99504
CBAR           2      1      2      30.099504     0. 0.99504
CBAR           3      1      3      40.099504     0. 0.99504
CBAR           4      1      4      50.099504     0. 0.99504
CBAR           5      1      5      60.099504     0. 0.99504
CBAR           6      1      6      70.099504     0. 0.99504
CBAR           7      1      7      80.099504     0. 0.99504
CBAR           8      1      8      90.099504     0. 0.99504
CBAR           9      1      9     100.099504     0. 0.99504
CONM2         10     10      0  0.0157     0.     0.     0.
+EL      A
+EL      A  2.45     0.   2.45     0.     0.    4.9
ENDDATA 83e67dc8
```

Table 3.1 NASTRAN .dat File For Complex Eigensolution Solution Using HESS (Continued)

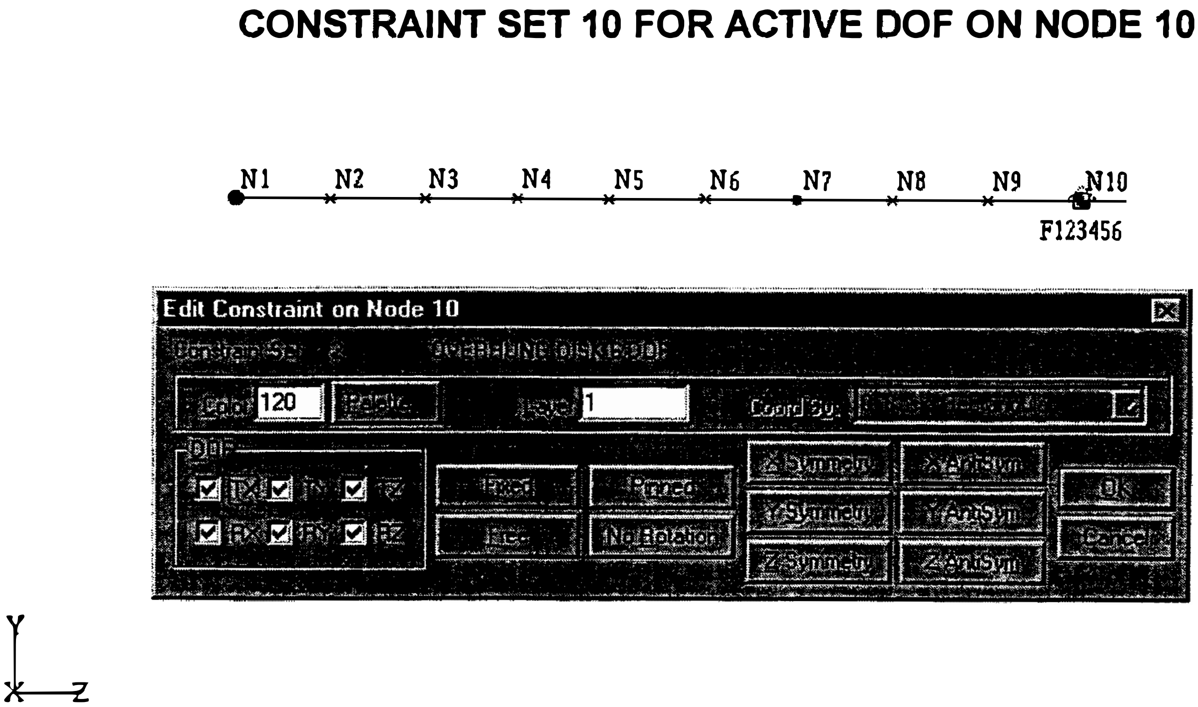
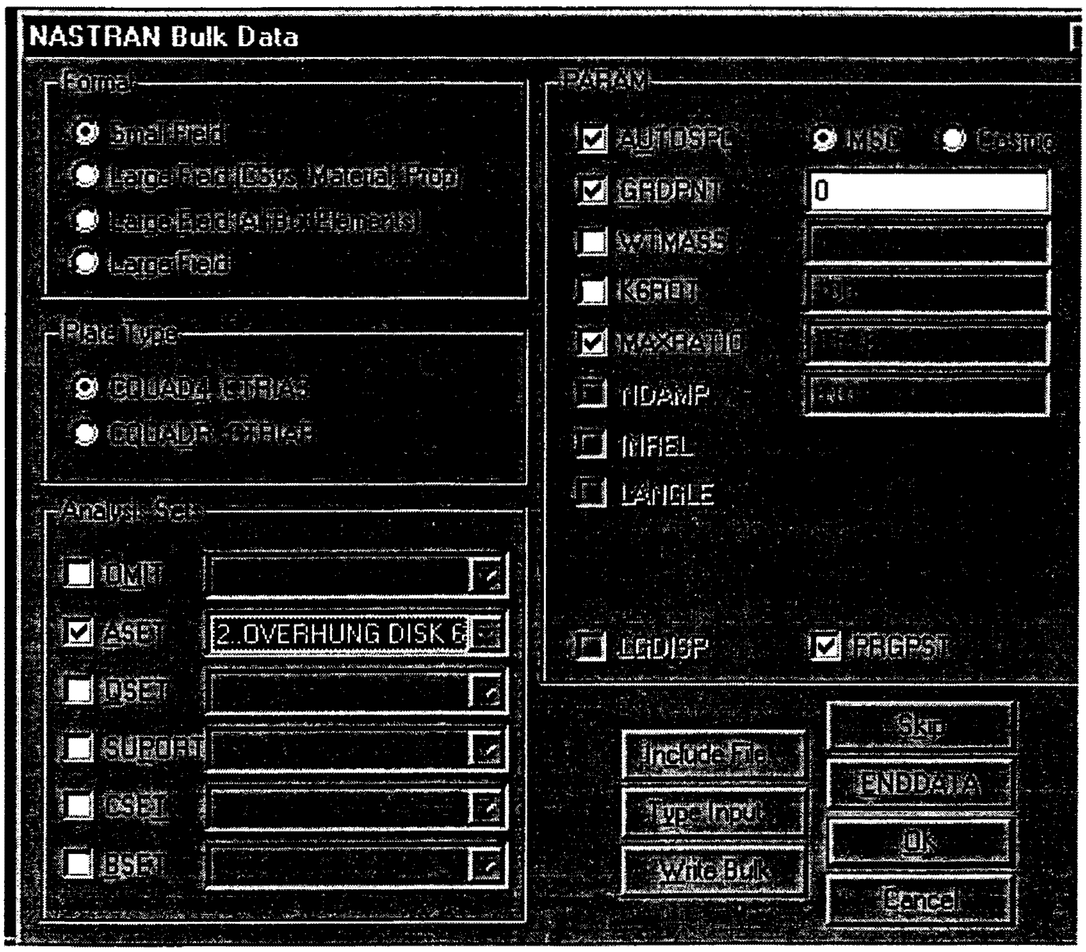


Figure 3.13 Generation of Active Degrees of Freedom For Disk At Node 10

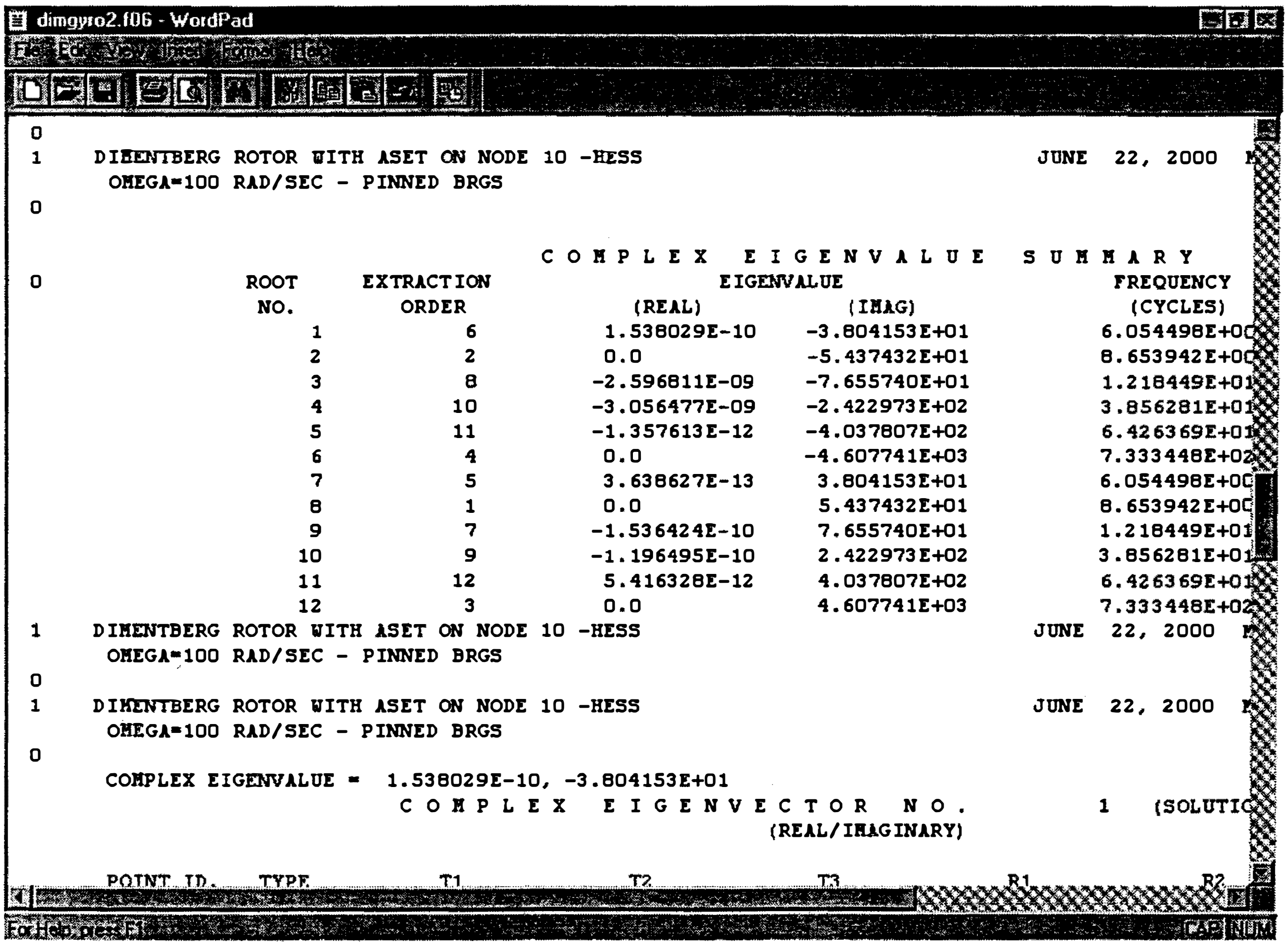
BULK DATA SET FOR COMPLEX HESS
With DIMGYRO And ASET SELECTED



Use Type Input & Include File For HESS
and Gyroscopic Moments at 100 RAD/Sec

Figure 3.14 NASTRAN Bulk Data Input With ASET Selected With 6 Active Degrees of Freedom At The Overhung Disk

DIMENTBERG ROTOR MODES AT 100 RAD/SEC
Using 6 Active DOF At Node 10 - HESS METHOD



```
dimgyro2.f06 - WordPad
0
1    DIMENTBERG ROTOR WITH ASET ON NODE 10 -HESS                                    JUNE  22, 2000
      OMEGA=100 RAD/SEC - PINNED BRGS
0
                                      C O M P L E X   E I G E N V A L U E   S U M M A R Y
0               ROOT      EXTRACTION                  EIGENVALUE                         FREQUENCY
                 NO.         ORDER            (REAL)          (IMAG)                     (CYCLES)
                   1             6        1.538029E-10     -3.804153E+01               6.054498E+0
                   2             2        0.0              -5.437432E+01               8.653942E+0
                   3             8       -2.596811E-09     -7.655740E+01               1.218449E+0
                   4            10       -3.056477E-09     -2.422973E+02               3.856281E+0
                   5            11       -1.357613E-12     -4.037807E+02               6.426369E+0
                   6             4        0.0              -4.607741E+03               7.333448E+0
                   7             5        3.638627E-13      3.804153E+01               6.054498E+0
                   8             1        0.0               5.437432E+01               8.653942E+0
                   9             7       -1.536424E-10      7.655740E+01               1.218449E+0
                  10             9       -1.196495E-10      2.422973E+02               3.856281E+0
                  11            12        5.416328E-12      4.037807E+02               6.426369E+0
                  12             3        0.0               4.607741E+03               7.333448E+0
1    DIMENTBERG ROTOR WITH ASET ON NODE 10 -HESS                                    JUNE  22, 2000
      OMEGA=100 RAD/SEC - PINNED BRGS
0
1    DIMENTBERG ROTOR WITH ASET ON NODE 10 -HESS                                    JUNE  22, 2000
      OMEGA=100 RAD/SEC - PINNED BRGS
0
      COMPLEX EIGENVALUE =  1.538029E-10, -3.804153E+01
                              C O M P L E X   E I G E N V E C T O R   N O .          1   (SOLUTI
                                                          (REAL/IMAGINARY)

      POINT ID.   TYPE          T1            T2            T3            R1            R2
```

Figure 3.15 Dimentberg Rotor Complex Modes At 100 Rad/Sec Using HESS Eigensolver With ASET Command With 6 Active DOF At Overhung Disk

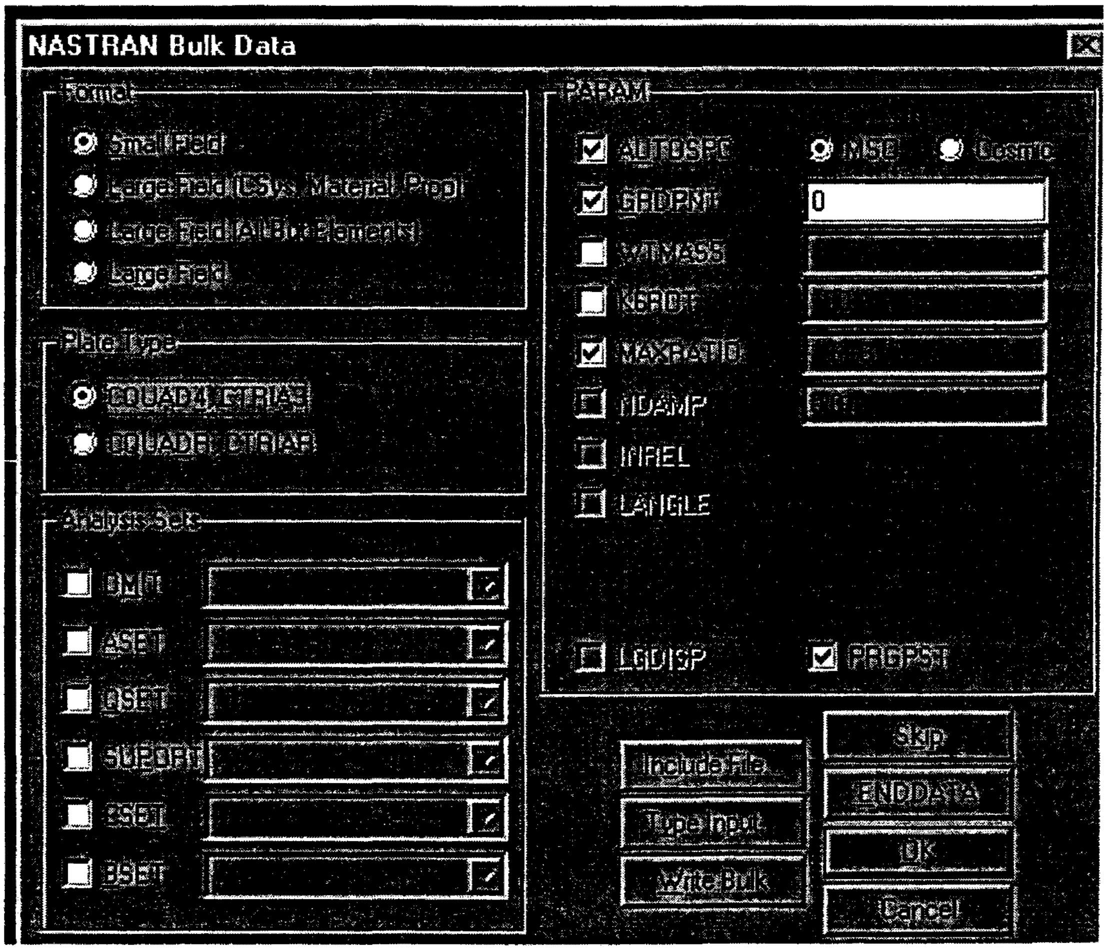
3.2 Eigenvalue Analysis Using Complex Lanczos

Figure 3.16 represents the *NASTRAN* Bulk Data Set in which the INCLUDE files for *DIMGYRO.DAT* and *EIGCL.DAT* are shown. The command for CLAN represents the complex Lanczos eigenvalue solver. The complex Lanczos eigenvalue solver is not as sensitive to the near singular conditions of the mass matrix as is the Hess method.

Figure 3.17 represents the eigenvalues computed with complex Lanczos with no ASET selected. Note that the numbers are extremely accurate when compared to Table 3.2 and the real roots of the system are smaller than the values obtained by the Hess method, including ASET. Figure 3.18 represents the *NASTRAN* Bulk Data Set in which the ASET is selected for the complex eigenvalue analysis. Figure 3.19 represents the INCLUDE file for *EIGCL.DAT*. After the analysis has been run, the *DIMGYRO5.F06* file is opened in order to look at the computed eigenvalues generated by the complex Lanczos procedure, as shown in Figure 3.20.

Figure 3.21 represents the complex eigenvalues computed by the complex Lanczos procedure, including dynamic reduction with six master degrees-of-freedom. Note that the real components of the eigenvalues are smaller than that computed by Hess. Table 3.2 represents a summary of the forward and backward modes of the overhung motor computed by *CRITSPD-PC* and the various *NASTRAN* eigensolvers. It should be noted that the eigenvalues computed using Hess by Bedrossian are not as accurate as the values computed by Hess with ASET or the complex Lanczos procedure. The complex Lanczos procedure with dynamic reduction is extremely accurate and is the recommended procedure. Under no circumstances should the Hess method be used without including dynamic reduction. In general, the complex Lanczos procedure with dynamic reduction is the preferred method of solution.

NASTRAN Bulk Data



Include Bulk Data Files:

DIMGYRO.DAT	**Gyroscopic Moment at Node 10**
EIGCL.DAT	**EIGC , 99, CLAN, MAX , , , , 6**

Figure 3.16 NASTRAN Bulk Data Files Including Statement For Complex Lanczos

EIGENVALUES COMPUTED WITH CLAN (COMPLEX LANZCOS)
(No ASET SELECTED)
OMEGA = 100 Rad/Sec

ASET NOT SELECTED

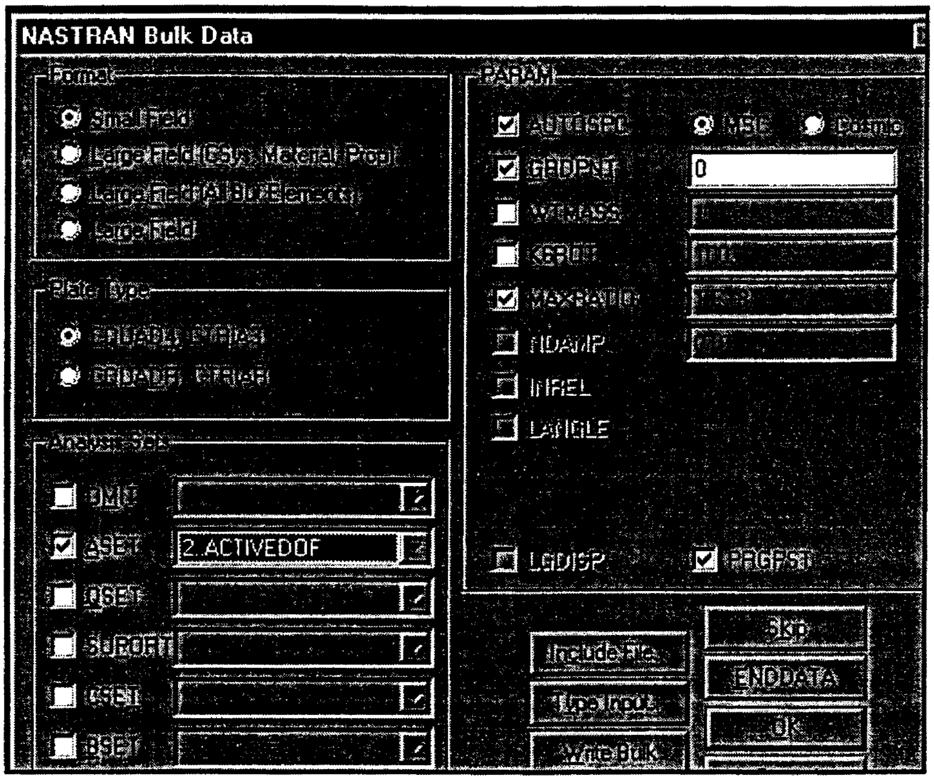
C O M P L E X   E I G E N V A L U E   S U M M A R Y

ROOT NO.	EXTRACTION ORDER	EIGENVALUE (REAL)	EIGENVALUE (IMAG)	FREQUENCY (CYCLES)
1	2	-1.032507E-14	-38.04153	6.054498
2	4	1.078582E-13	-54.37432	8.653942
3	6	-2.630673E-13	-76.55740	12.1845
4	8	1.369192E-11	-242.2973	38.56281
5	10	-4.261119E-12	-403.7807	64.26369
6	12	2.367644E-07	-4607.741	733.3448
7	14	-2.083216E-04	-46,698.26	7,432.259
8	16	-1.442527E-01	-46,704.94	7,433.321
9	18	1.445568E+02	-1.527773E+05	24,315.26
10	20	7.532198E+03	-2.430117E+05	38,676.51
11	21	-3.743962E+05	-5.046615E+05	8.031937E+04
12	1	-3.792799E-14	3.804153E+01	6.054498E+00
13	3	-9.575674E-16	5.437432E+01	8.653942E+00
14	5	-1.631334E-12	7.655740E+01	1.218449E+01
15	7	4.988204E-12	2.422973E+02	3.856281E+01
16	9	-1.739384E-11	4.037807E+02	6.426369E+01
17	11	-2.395634E-07	4.607741E+03	7.333448E+02
18	13	-1.613639E-04	4.669826E+04	7.432259E+03
19	15	1.397492E-01	4.670493E+04	7.433320E+03
20	17	-1.445433E+02	1.527773E+05	2.431526E+04
21	19	-7.532321E+03	2.430120E+05	3.867656E+04
22	22	3.743848E+05	5.046758E+05	8.032166E+04

ACCURATE EIGENVALUES COMPUTED WITH ILL-CONDITIONED MATRIX

Figure 3.17 Eigenvalues Computed With Complex Lanczos And No Dynamic Reduction (No ASET Constraints)

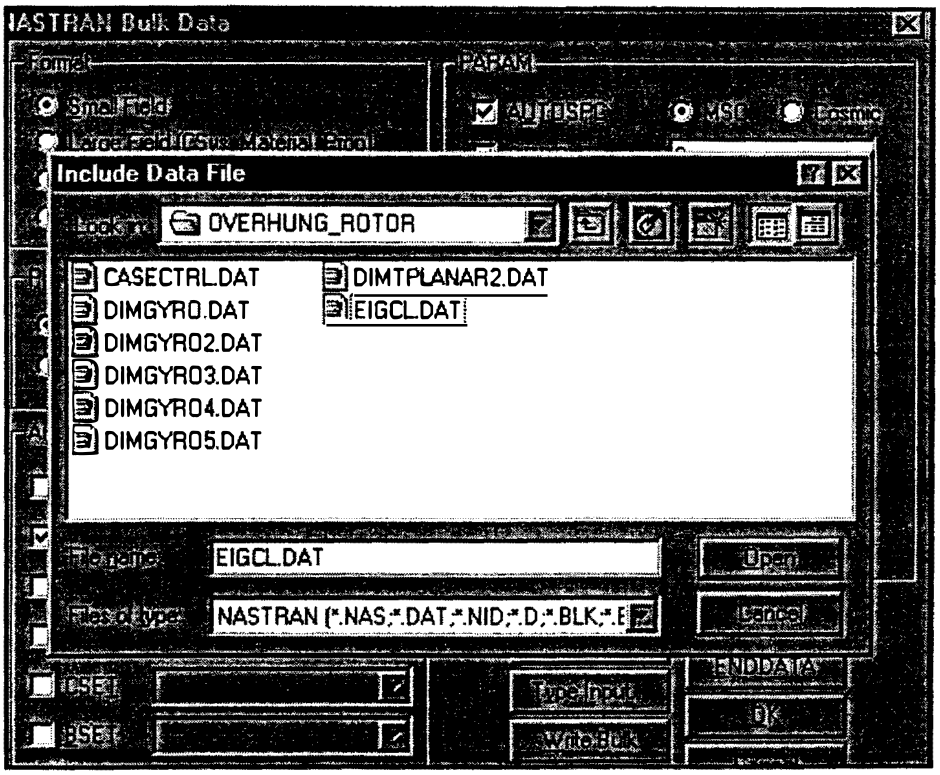
NASTRAN Bulk Data With ASET SELECTED



ACTIVE DEGREES OF FREEDOM AT DISK OVERHANG NODE 10
ACTIVE DOF= 123456- LATERAL, TORSION & AXIAL

Figure 3.18 NASTRAN Bulk Data With ASET Selected

INCLUDE FILES FOR BULK DATA ARE:
EIGCL- COMPLEX LANCZOS
DIMGYRO- DISK GYROSCOPIC MOMENTS




```
$DIMGYRO.DAT  GYROSCOPIC MOMENTS ON OVERHUNG
$ GYRO MOMENT ADDED AT NODE 10 ROT DOF 4 &5
$ USE B2PP=DIMGYRO IN CASE CONTROL
DMIG, DIMGYRO , 0 , 1 , 1
DMIG, DIMGYRO , 10 , 4 ,   , 10 , 5 , -490.0
DMIG, DIMGYRO , 10 , 5 ,   , 10 , 4 ,  490.0

$ EIGCL.DAT   COMPLEX LANCZOS
$ SEARCH FOR 6 MODES, NO SEARCH RANGE SPECIFIED
EIGC, 99, CLAN , MAX , ,   ,  , 6
```

Figure 3.19 Include File EIGCL.dat For Complex Lanczos and DIMGYRO.dat For Disk Gyroscopic Moments

OPEN DIMGYRO5.fo6 FOR EIGENVALUES

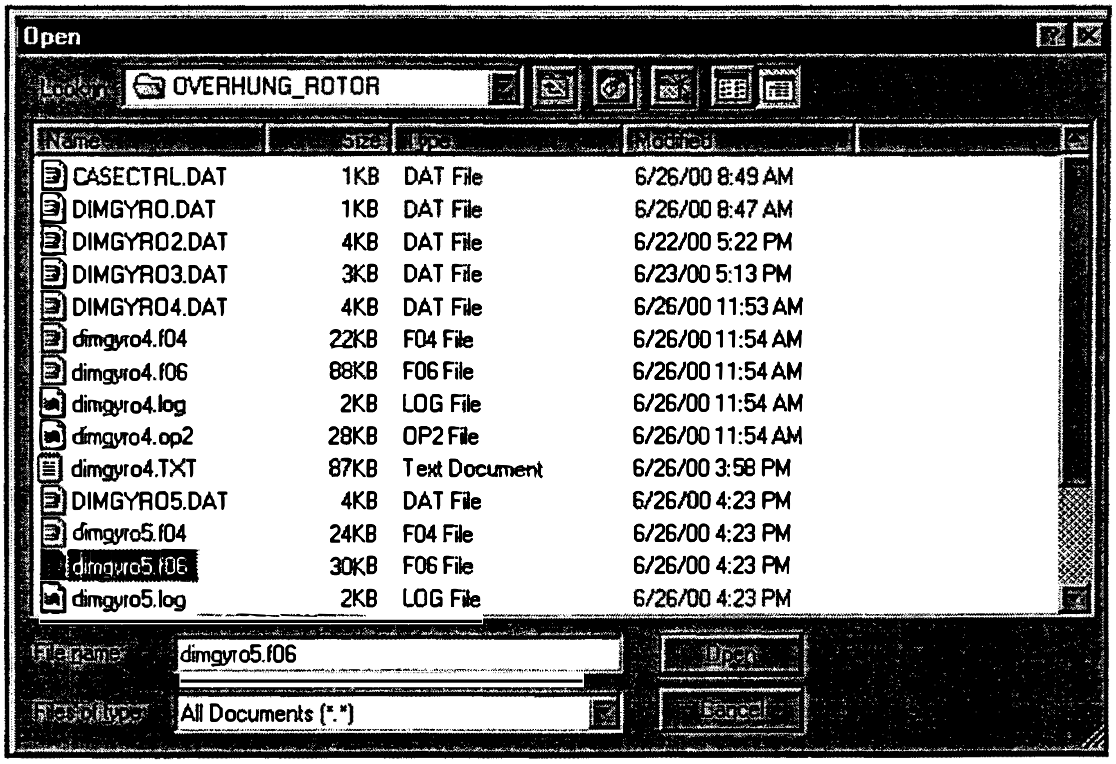


Figure 3.20 Open Output File Dimgyro5.f06 For Complex Lanczos Results With ASET

EIGENVALUES COMPUTED WITH CLAN (COMPLEX LANCZOS) 6 MASTER DOFS SELECTED AT NODE 10-OVERHANG OMEGA = 100 RAD/SEC

E I G E N V A L U E A N A L Y S I S S U M M A R Y (COMPLEX LANCZOS METHOD)

NUMBER OF MODES FOUND................. 12

NUMBER OF SHIFTS USED... 1

NUMBER OF DECOMPOSITIONS.............. 1

NUMBER OF VECTORS IN CORE............. 12

C O M P L E X E I G E N V A L U E S U M M A R Y
DIMENTBERG ROTOR WITH COMPLEX LANCZOS MSC.NASTRAN 8/25/99
OMEGA=100 RAD/SEC
ASET AT NODE 10 WITH DOF123456

ROOT NO.	EXT ORDER	EIGENVALUE (REAL)	EIGENVALUE (IMAG)	FREQUENCY (CYCLES)	DAMPING COEFFICIENT
1	2	8.049117E-16	-3.804153E+01	6.054498E+00	-4.231752E-17
2	4	-6.249168E-14	-5.437432E+01	8.653942E+00	2.298573E-15
3	6	1.773581E-14	-7.655740E+01	1.218449E+01	-4.633337E-16
4	8	-3.691052E-11	-2.422973E+02	3.856281E+01	3.046713E-13
5	10	8.104933E-12	-4.037807E+02	6.426369E+01	-4.014523E-14
6	12	-9.614503E-09	-4.607741E+03	7.333448E+02	4.173196E-12
7	1	4.440059E-13	3.804153E+01	6.054498E+00	-2.334322E-14
8	3	-2.936124E-13	5.437432E+01	8.653942E+00	1.079967E-14
9	5	1.700459E-12	7.655740E+01	1.218449E+01	-4.442312E-14
10	7	-4.717046E-12	2.422973E+02	3.856281E+01	3.893602E-14
11	9	5.296805E-12	4.037807E+02	6.426369E+01	-2.623605E-14
12	11	1.288693E-08	4.607741E+03	7.333448E+02	-5.593599E-12

Figure 3.21 Eigenvalues Computed With Complex Lanczos and Dynamic Reduction

Table 3.2

Forward and Backward Modes of Overhung Dimentberg Rotor at 100 Rad/Sec With Various *NASTRAN* Eigensolvers							
Mode	***CRITSPD-PC*** **Hz**	**Hess Fig. 4 (No ASET)**	**Hess** ***MSC/4.5***	**Hess** ***MSC/4.5*** **(ASET)**	**Lanczos** ***MSC/4.5*** **(No ASET)**	**Lanczos** ***MSC/4.5*** **(ASET)**	**Comments**
N_{b1} (P-$_{\text{real root}}$)	6.05 Hz (38.01 rad/sec)	6.10 Hz (+1.29E-7)	28.84 Hz (Unconverged)	6.054 Hz (1.5E-10)	6.054 Hz (5.42E-16)	6.054 Hz (-4.23E-17)	1st Backward Mode
N_{f1} (P-$_{\text{real root}}$)	12.18 Hz (75.90 rad/sec)	11.21 Hz (-3.67E-9)	640.3 (Unconverged)	12.18 Hz (-2.6E-9)	12.18 Hz (6.87E-15)	12.18 Hz (-4.63E-16)	2nd Forward Mode
N_{b2} (P-$_{\text{real root}}$)	38.54 Hz (242.15 rad/sec)	36.72 Hz (3.38E-2)	1.1192E7 (Unconverged)	38.56 Hz (-3.06E-9)	38.56 Hz (1.369E-11)	38.56 Hz (-1.13E-13)	2nd Backward Mode
N_{f2} (P-$_{\text{real root}}$)	64.25 Hz (403.69 rad/sec)	63.61 Hz (2.60E-1)	0	64.26 Hz (-1.35E-12)	64.26 Hz (-4.26E-12)	64.26 Hz (8.1E-12)	2nd Forward Mode
N_{A1}	(4,605.6 rad/sec)	–	0	733.3 Hz (0.0)	733.3 Hz (2.37E-7)	733 Hz (-9.61E-9)	Axial
N_{T1}	(54.35 rad/sec)	–	0	8.65 Hz (0.0)	8.65 Hz (1.08E-13)	8.65 Hz (-6.25E-14)	Torsional