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**A USER'S MANUAL FOR THE PROGRAM
TRES4:
RANDOM VIBRATION ANALYSIS OF
VERTICAL-AXIS WIND TURBINES IN TURBULENT WINDS***

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ABSTRACT

TRES4 is a software package that works with the MSC/NASTRAN finite element analysis code to conduct random vibration analysis of vertical-axis wind turbines. The loads on the turbine are calculated in the time domain to retain the nonlinearities of stalled aerodynamic loadings. The loads are transformed into modal coordinates to reduce the number of degrees of freedom. Power spectra and cross spectra of the loads are calculated in the modal coordinate system. These loads are written in NASTRAN Bulk Data format to be read and applied in a random vibration analysis by NASTRAN. The resulting response is then transformed back to physical coordinates to facilitate user interpretation.

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TABLE OF CONTENTS

	PAGE
1. INTRODUCTION	4
1.1 Background	4
1.2 Objectives	4
2. MATHEMATICAL MODEL	5
2.1 Basic Algorithm	5
2.2 Aerodynamic Model	5
3. ORGANIZATION OF SOLUTION	7
3.1 NASTRAN Input File	7
3.2 Extraction of Real Eigenvectors	8
3.3 Preparation of Aerodynamic Loads (TRES4)	8
3.4 NASTRAN Frequency Response Analysis	8
3.5 Post-Processing of Results	9
4. BASIC INPUT DATA	10
4.1 Units	10
4.2 Format	10
4.3 Explanation of Input Variables	10
4.4 Control of Output	12
4.5 ZSET Option	12
4.6 Suppression of Modes	13
4.7 Turbulence Models	13
5. COMPILATION & RUNNING	14
5.1 Machine Dependency	14
5.2 Limitations	14
5.3 Linking	15
6. AIRFOIL DATA	15
7. OUTPUT VIA TRES.DFOR	16

8. AEROELASTIC EFFECTS	16
8.1 Program AEROB5.FOR	17
8.2 Basic Input File	17
9. REFERENCES	18

LIST OF FIGURES

1. SNL/USDA 34m Test Bed Finite Element Model	19
2. Schematic of Total Solution Procedure	20

APPENDICES

- A. NASTRAN Bulk Data Input File
- B. Sample Solution 3 Input
- C. Sample Solution 64 & 71 Input
- D. Sample TRES1.OUT File
- E. Sample Airfoil Data File
- F. Sample Basic Input File (for 34m Test Bed)
- G. Sample Basic Input File for AEROB5.FOR

1. INTRODUCTION

1.1 Background

Vertical axis wind turbines (VAWTs) are machines designed to extract energy from the wind. They differ from horizontal axis wind turbines (HAWTs) in that the structure revolves about an axis that is vertical. One consequence of this arrangement is that under a steady wind the forces experienced by the structure are periodic with frequencies that are multiples of the rotor speed. These cyclic forces give rise to fatigue stresses.

Under non-steady, or turbulent winds, cyclic forces are experienced at frequencies other than the harmonic frequencies. In some circumstances the effect of turbulence on the overall fatigue loading is small, but in other circumstances it has been observed to be considerable. It is, therefore, of importance to be able to predict the structural response under turbulent conditions.

To achieve this goal it is necessary to add considerable complexity to the solution procedure. Not only has the passage of turbulent air to be modeled, but the structural response to (partially) random excitation must be obtained. The first step has been tackled using the method set out by Veers (1984); the second step has been achieved by the use of appropriate MSC/NASTRAN solutions with certain modifications. This manual is concerned with the FORTRAN program TRES4, which prepares the aerodynamic loading for the NASTRAN analysis.

1.2 Objectives

The purpose of this document is, first, to give the reader (who is assumed to have some acquaintance with wind turbine design) some understanding of the basic mathematics. Second, it is intended to give detailed instructions for the use of the program TRES4 and to advise on possible problems.

2. MATHEMATICAL MODEL

2.1 Basic Algorithm

Dynamic structural analysis may be carried out in either the time domain or in the frequency domain. The former involves a step-by-step integration procedure which, for the required number of rotor revolutions (preferably greater than 200), can be very demanding on computer resources and can lead to excessive input and output data. Analysis in the frequency domain is less demanding on data and computation, but both input and output require some interpretation. The second approach has been selected for this procedure.

In order to use the program TRES4 intelligently, some understanding of the basic method is of value. A full review can be found in Malcolm (1988).

If stochastic loads at degrees of freedom a and b are related by cross spectral densities (csd's) $S_{ab}(f)$, then the power spectral density (psd) of the response at degree of freedom i is $S_i(f)$ and is given by

$$S_i(f) = H_{ia}(f)H_{ib}^*(f)S_{ab}(f)$$

where $H_{ia}(f)$ is the frequency response function between degrees of freedom i and a and * indicates the complex conjugate.

In a typical Darrieus rotor finite element model there are about 200 degrees of freedom having aerodynamic loads over a frequency width, which may be discretized into about 100 divisions. The number of terms in the full input would, therefore, be of the order of 2×10^6 . One method of reducing this large file, and the corresponding calculations, is to express the behavior in terms of the modes of natural vibration, thereby reducing the degrees of freedom from 200 to about 20.

The input psd's and csd's can still be very long. Some options exist in TRES4 to help reduce this length by neglecting small values.

MSC/NASTRAN does not normally accept loads as modal components; and it is, therefore, necessary to include modifications (DMAP Alters) to accomplish this.

2.2 Aerodynamic Model

The aerodynamic model used is the double multiple streamtube (DMST) model (Paraschivoiu, 1984) that has been found to give good predictions of performance without undue computation time. The model carries out an iterative momentum balance

calculation at each streamtube into which the swept area is divided at each azimuth position.

In steady winds this calculation need be done for one revolution only. In a turbulent wind it must be done for a number of revolutions so that the full variability of the wind can be represented.

3. ORGANIZATION OF SOLUTION

The total solution procedure consists of five steps.

1. Preparation of MSC/NASTRAN finite element model of rotor and supports.
2. Extraction of real eigenvectors and eigenvalues of the stationary rotor.
3. Use of TRES4 to prepare stochastic aerodynamic loading.
4. Modal frequency response using a suitable NASTRAN solution.
5. Post-processing of output.

3.1 NASTRAN Input File

An example of an MSC/NASTRAN bulk data file is included as Appendix A. It may be prepared in one of a number of ways, although each requires careful evaluation of the structural and inertial properties of the main members.

There is sometimes a choice of ways to model a certain member or feature. TRES4, which reads the NASTRAN bulk file, requires that certain restrictions apply. These are:

- All elements that are to have aerodynamic loads must consist of CBEAM members.
- There is no need to offset the center of mass or center of twist from the grid points.
- The beam members must not be tapered.
- The grid points of the first blade must begin with number 100 (at the top or at the bottom of the rotor) and be numbered consecutively.
- The grid points of the second blade must likewise begin with the number 200.
- Column grid points must have numbers lying between 1 and 99.
- All other grid point numbers (not on the column or blades) must lie above 299.
- To incorporate aerodynamic loading on the central column, the column diameter must be placed in field 10 of the appropriate GRID cards. This field will be read by TRES4 but ignored by NASTRAN.

3.2 Extraction of Real Eigenvectors

The eigenvectors of the stationary rotor are used as generalized coordinates for the aerodynamic loads calculated by TRES4. It is, therefore, necessary to extract these by a suitable NASTRAN solution and to output this information using the PUNCH output option.

MSC/NASTRAN version 66 solutions 3 or 63 or 103 may be used. Appendix B contains sample executive and case control sections for a solution 3 run. The operating system of the computer must be used to ensure that the output is saved under a suitable name.

Appendix A also includes a sample REIG card controlling the extraction of eigenvalues and vectors. It is important that this card and the ASETI cards (for reduction of the dynamic problem) must be the same in this NASTRAN solution as in the subsequent frequency response analyses (see Section 3.4).

3.3 Preparation of Aerodynamic Loads (TRES4)

As Figure 2 indicates, TRES4, which generates the stochastic aerodynamic loads, requires a number of input sources. These are:

- NASTRAN bulk data file (see Section 3.1)
- TRES4 input variables (see Section 4)
- Airfoil data (see Section 6)
- Eigenvectors of the stationary rotor (see Section 3.2)

Figure 2 also shows that TRES4 produces two output files as well as two temporary storage files. One of these (TRES.OUT) contains an echo of the input variables as well as output concerning the variance of the modal loads and output power spectral densities in a format suitable for reading by a post-processing program. The second file (TRESI.OUT) contains data in a format for NASTRAN.

3.4 NASTRAN Frequency Response Analysis

Modal frequency response can be carried out using either solutions 30 (a rigid format solution sequence) or 71 (a superelement solution sequence) or 111 (a "structured" solution sequence). This analysis is complicated by the requirements of including the rotating frame effects, which require an initial solution 64 (geometric nonlinear analysis using at least four subcases) in order to incorporate the stiffening effects of the centrifugal forces. One approach is to pass the data base from solution 64 to the subsequent analysis; since the data bases from structured and unstructured solutions are

not compatible, and some changes need to be made to input a data base into a rigid format, the most acceptable choice is the use of solution 71.

Sample executive and case control sections for the combined solution 64 and 71 run are included as Appendix C. Of importance in the solution 64 bulk data is the RFORCE card, which defines the centrifugal loading. The GRAV (gravity) and FORCE (guy cable thrust) should, strictly, also be included, but are probably less significant.

Solution 71 requires the inclusion of a number of modifications. The first is the inclusion of Coriolis and whirling effects. This is done through matrix manipulation (Alter 1087), which relies on basic symmetric and skew symmetric matrices that are defined by DMI cards included at the end of the bulk data file. In addition, the PARAM, OMEGA card must be included to indicate the rotor speed (in radians/s).

Aeroelastic effects on the effective stiffness and damping matrices may also be incorporated as K2PP and B2PP matrices through DMIG cards. If these effects are not included, then it is important to include an estimate of the critical damping of the various modes through a TABDMP1 card, as the example in Appendix D illustrates. This requires a knowledge of the mode shapes of the real eigenvectors and an understanding of what damping to expect in each mode. It has been noted that the blade flatwise symmetric and asymmetric modes experience the most aeroelastic damping.

The consequence of including too little or no damping will be very high response at the natural frequencies of the operating rotor, which will result in overdesign of the rotor components.

3.5 Post-Processing of Results

The output from the NASTRAN random analysis module is in the form of discrete power spectral densities for each selected response. The manner in which these output are requested is illustrated in Appendix C.

Rapid and easy evaluation of results is always important. The designer is interested in knowing the total variance of a particular response and what frequencies dominate this response. The spectra must be extracted from the NASTRAN output by a program designed to read the file or by manual editing. The data may then be plotted by any of a number of commercially available programs. Likewise, the spectra of modal loads included in the file TRES.OUT may be extracted and plotted.

The exact manner in which this post-processing is done will depend on the user's preferences and available hardware and software. It is not, therefore, included with the program TRES4.

4. BASIC INPUT DATA

4.1 Units

TRES4E uses English (imperial) units in contrast to TRES4EM, which uses SI units. The units for the input file variables are given adjacent to the variables as they are described below.

4.2 Format

All comment lines must begin with a '\$' in column one (as in NASTRAN). Free format is used except where noted. An example of a basic input file for the 34m Test Bed is included as Appendix F.

4.3 Explanation of Input Variables

Line 1 (free format)

HT	inches	height of rotor between blade intersection points
DIA	inches	maximum diameter of rotor
HMR	inches	mid-rotor height above ground
RPM	rpm	rotor speed
VBAR	mph	mean ambient wind speed at mid-rotor
WSE		exponent defining vertical wind shear
DELT	seconds	time interval in the definition of wind velocity series
ARHO	lb/ft ³	air density

Line 2 (free format)

C1X		coefficients C1 and C2 for use in Frost & Turner's turbulence
C2X		spectrum for X (longitudinal) and Y (lateral) directions
C1Y		
C2Y		
Z0	m	roughness height used in certain expressions for turbulence
DECAY		decay coefficient used to define coherence of cds's of wind velocities. See Veers 1984.
VAR		turbulence intensity of longitudinal wind (standard deviation/mean value). Used in the Kaimal (stable) and the von Karman (neutral) turbulence expressions.
NSOFT		the number of time intervals over which the velocity time series are smoothed. It is recommended that NSOFT=1.
FMIN		an entire csd will be omitted if its variance is below a value equal to FMIN* (minimum of all NEIG psd's)
CMIN		a minimum value of a certain frequency component of a modal load csd below which it will be omitted from the output

Line 3 (free format)

ISPECT type of formula to be used for atmospheric turbulence (see Section 4.7)

Line 4 (free format)

NHT number of vertical divisions into which the swept area is divided
for definition of wind speed time series

NDIA number of lateral divisions into which the swept area is divided for
definition of wind speed time series. See Section 5.2 for limitations.

NEIG number of real eigenvectors used as generalized coordinates in modal
solution. See Section 5.2 for limitations.

NT number of intervals per rotor revolution in DMST routine (must be
a power of 2). See Section 5.2 for limitations.

NREV number of rotor revolutions in each analysis. NREV must be a power
of 2.

NSECT number of different sections on each blade corresponding to the number
of PBEAM cards required to define the CBEAM blade elements.

NLOOP number of repeated analyses used to generate an ensemble of load
spectra (and correct csd values)

NPMAX the maximum frequency (in multiples of rotor speed) for analysis and
for output

NDIV number of divisions between per-rev frequencies used in output (NREV
must be evenly divisible by NDIV)

NOUT number of loops after which modal loads will be output to TRES.OUT.

NSUP number of eigenvectors to be suppressed in NASTRAN analysis. See
Sections 4.4 and 4.6.

Lines 5, 6, and 7 (A3 format)

These contain YES/NO requests for upwind and downwind dynamic stall and for use of
the ZSET option (see Section 4.4)

Line 8 (free format)

IPRINT option number for output of csd's. Only option #1 is now valid.

Next NSECT lines (format I4,A8,F10.2)

I section number corresponding to PBEAM id number (100+I)

TYPE(I) 8-character alphanumeric description of airfoil profile (which must
correspond to the description in the airfoil data file - see Section 6)

CH(I) inches blade chord

Next 1 up to NEIG lines (free format)

I eigenvalue number

DAMP(I) critical damping for mode I. Note that only non-zero values need be
given, but that at least one line must be entered.

Next NSUP lines (free format)

I mode number to be suppressed from the analysis (see Sections 4.4 and 4.6)

4.4 Control of Output

The objective of the analysis is to obtain meaningful results without dealing with excessive input and output. The definition of what is excessive will depend on the particular computing environment. For example, creating the TRES1.OUT file on a PC and sending the NASTRAN input file to another computer via a modem is more restrictive than working directly with a mainframe computer. The maximum size of TRES4 output is also controlled by the present dimension limitations in the program, which is discussed in Section 5.2.

One method of limiting TRES4 output size is to limit the number of eigenvectors (NEIG) used. It has been found that up to about 22 modes is required to allow the modal formulation of a Darrieus rotor to be an acceptable approximation.

Additionally some modes may be suppressed (NSUP > 0). An indication of what modes are associated with less load can be found by inspection of the TRES.OUT file. It must be pointed out, however, that due to Coriolis coupling of modes, the lack of a certain modal load does not necessarily imply lack of response in that mode.

The resolution of the power and cross spectral densities submitted to NASTRAN can be controlled. The maximum number of intervals between each per-rev frequency is NREV (which must also be a power of 2). If a larger interval is wanted, then NDIV should be put equal to an integer less than NREV and which is evenly divisible into NREV. For average size rotors, a value of NDIV=16 may be adequate; but for slower rotor speeds, up to NDIV=32 may be desirable.

Many of the csd elements are close to zero owing to the lack of correlation between some modal loads, especially at frequencies that are not rotor speed harmonics. These can be removed from the tabular listing by defining a floor value (CMIN) below which they are omitted. Likewise FMIN controls the floor of the total csd variance below which the entire csd table (or part of it) will be omitted. The FMIN value is the multiple applied to the lowest of the modal load psd variances.

4.5 ZSET Option

The number and location of finite element nodes on the blades is usually governed by structural considerations. For example, nodes may be more closely spaced near the root connections. However, the DMST aerodynamic model may not require the same detail, and much computer time may be wasted in this way.

The ZSET is a subset of the blade finite element nodes that is used in the aerodynamic modeling. It is included in the bulk data file, but is preceded by a '\$' so it is ignored by NASTRAN. Following '\$ZSET', up to 20 nodes may be listed in format (A5,20I4) as illustrated in Appendix A.

It is recommended that the ZSET not contain fewer than about 16 nodes and that nodes at the intersection of different airfoils and/or chords be included.

4.6 Suppression of Modes

It is sometimes found that a certain high frequency mode is important in the response while some lower frequency modes are relatively unimportant. Exclusion of the latter can shorten the input file and decrease computing time.

Modes can be suppressed by including their total number as NSUP and listing them as described in Section 4.3 and as illustrated in Appendix F.

4.7 Turbulence Models

The variable ISPECT is a number corresponding to the type of formula used for the atmospheric turbulence. This is a subject on which much has been and, no doubt, will be written (see Malcolm 1990).

There are five possible turbulence expressions available within the routine TSPECT of TRES4. They are:

1. Kaimal/Strickland formula (stable atmospheres)
This is dependent on the overall variance and the C1 and C2 values.
2. Frost & Turner
This requires C1, C2 and Z0 values.
3. Kaimal formula (neutral atmospheres)
This requires C1, C2 and Z0 values.
4. von Karman/Fordham (neutral atmospheres)
This requires overall variance, C1 and C2 values, and also a measure of turbulence length--at present set at 120 m.
5. von Karman/Fordham (neutral atmospheres and dependent on height and roughness)
As well as a Z0 value, this expression requires C1, C2 and a characteristic length, also preset at 120 m.

5. COMPILATION AND RUNNING

5.1 Machine Dependency

The program TRES4E, as listed in Appendix G, has been tailored to run on an IBM-compatible PC using a DOS operation system and a Microsoft FORTRAN compiler (version 4.01 was used). It requires that the machine have at least 640k bytes of random access memory.

The program should run without any changes when later versions of the Microsoft compiler are used. The debug option should not be used since this will result in an executable file which is too large. It is recommended that the program not be run on any PC less powerful than an 80286 with an 80287 coprocessor, or excessive run times will result.

If the program is run on any other machine and/or compiler, some modifications will be required. These changes will principally apply to the input and output, the definition of files, especially the two temporary files (on a machine with more memory these files may be held in RAM if appropriate changes are made to the source code).

5.2 Limitations

Design of the program to run on an IBM PC under DOS led to several limitations in the size of arrays and the corresponding physical phenomena. One array, TRH(128,630), is used to store several variables (time series of velocity perturbations, and the transfer matrix, H, of the matrix, S, of spectral densities). This means that the length of the velocity time series must be less than or equal to 128 values. This, in turn, dictates the time interval if the total time elapsed is to be equal to, say, 16 rotor revolutions. For example, the 34m Test Bed turning at 34 rpm requires a total time of 28.2 seconds for 16 revolutions, which, allowing for some additional time, leads to a maximum time interval of about 0.24 seconds. This, in turn, implies an upper limit of about 2.1 Hz in the turbulence frequency spectrum. While most of the turbulence energy will be within this frequency, it could be undesirably restrictive and, where memory allows, the upper limit could be removed.

The other major limitation arises due to the size of the array of spatial cross spectral densities of wind speed perturbations. The dimension of this array is the total number of spatial points at which the velocity series is defined and the number of spectra is the number of elements in one triangle of this array. Limiting this number to 630 implies representing the flow over the swept area at no more than 35 points (or a 7 x 5 array).

5.3 Linking

The size of the program TRES4 requires that it be divided into two parts in order to compile with a Microsoft compiler on a PC. This can be done by compiling the parts separately and then linking them together.

In addition, the fast Fourier transform routine, FFT842, must be separately compiled and linked with the final executable file. This routine is one of many that will perform the necessary operation, but it is the routine that is called in TRES4.

6. AIRFOIL DATA

All the necessary airfoil data are read in by subroutine READAIR, and a sample of an input file is included as Appendix E. This input file must adhere to the following format restrictions.

1. The file may contain lift and drag coefficients for any number of airfoil shapes, but no more than five can be read by one job.
2. Each airfoil may have coefficients listed at up to five Reynolds numbers.
3. Up to 50 angles of attack may be listed for each set of data.
4. If data at more than one Reynolds number are given for a certain airfoil, then the sets must be placed in order of ascending Reynolds number.
5. The last angle of attack in each set must be 180.0 (exactly).
6. The angles of attack used for different airfoils or for different Reynolds numbers of the same airfoil do not have to be the same (in value or in total number).
7. The file must end with "ENDFILE."
8. Each set or group of data must begin with a line having the eight-character alphanumeric airfoil identifier in the first field (corresponding to the alphanumeric used in the basic input data and described in Section 4.3)
9. The second line of each set contains the following, in (F10.0,2F10.4) format:

RE(i,j)	Reynolds number #j for airfoil #i
AS(i,j)	corresponding static stall angle
CDMIN(i,j)	corresponding drag coefficient at zero angle of attack to be added to all listed values
TC(i)	thickness-to-chord ratio for airfoil #i

10. Subsequent lines contain in 3F10.4 format the following:

A	angle of attack (degrees)
CL	lift coefficient
CD	drag coefficient

7. OUTPUT VIA TRES4E.FOR

The program TRES4E can take several hours to run on an 80286 PC when the maximum spatial array is used together with 30 or more ensembles of 16 revolutions each. To avoid having to rerun merely because the variables controlling the TRES1.OUT output are incorrect, the program TRES4E.FOR can be used. This program reads the same basic input file as TRES4E.FOR together with the temporary file (TRES2.TMP) that contains the data for the psd and csd's of the output load.

A new set of data in NASTRAN format can be quickly obtained in this way. For example, if the initial settings resulted in the elimination of too many cross spectral densities, then the value of FMIN in the basic input file can be reduced, and TRES4E.FOR can be run for a more acceptable set of modal load spectra.

8. AEROELASTIC EFFECTS

The displacements of the wind turbine blades (measured in the rotating frame) cause changes in the angle of attack of the relative wind. This in turn affects the aerodynamic forces experienced by the blades. This interaction between structural dynamics and aerodynamics can be described by classical theories of aeroelasticity and has been investigated by Lobitz and Ashwill (1986), Malcolm (1990), and others.

While there are only small changes on the effective stiffness and mass, the main effect is on the damping matrix. The different modes of response experience different degrees of damping. This damping can be extremely important in attenuating structural response due to stochastic loading at rotor natural frequencies.

Aeroelastic damping can be incorporated in one of two ways. It can be incorporated by estimating (largely by experience) the critical damping factors for each of the real modes and including this information in the basic input file (see Section 4.3), in conjunction with an SDAMP statement in the NASTRAN case control section.

Alternatively these effects can be included in the NASTRAN run by inserting the changes to the matrices as a series of DMIG (Direct Matrix Input - G-set) statements. These lines are generated by running a program called AEROB5.FOR, which is described below.

8.1 Program AEROB5.FOR

This program is fully described and documented in Malcolm (1990). It is based on the work by Lobitz and Ashwill (1986) and predicts the same results (at normal operating speeds). The program requires two input files--one is the same NASTRAN bulk data file as was used in the TRES4 program, and the other is described below.

8.2 Basic Input File

A sample input file is included as Appendix G. The same rules as in the TRES4 input file apply concerning comment lines (they require a "\$" in column 1).

Line 1 (free format)

RPM	rpm	rotational speed of rotor
ARHO	lb/ft ³	air density
FLUT	Hz	typical frequency of rotor blades. This is usually set at about 3 times the rotor speed.
AB		fraction of the half-chord by which the center of twist is rear of the half-chord position
CMIN		a minimum value for output values below which they are omitted
NSECT		number of blade sections listed below

Lines 2,3 &4 (A3 format)

"YES"/"NO"	flag for inclusion of rotating frame effects in the calculations
"YES"/"NO"	flag for inclusion of apparent mass terms in output
"YES"/"NO"	flag for use of the ZSET reduced blade node option in place of the full set (see Section 4.5)

Next NSECT lines (format I4,A8,F10.2)

I		section number corresponding to PBEAM id number (100+I)
TYPE(I)		8-character alphanumeric description of airfoil profile (which must correspond to the description in the airfoil data file--see Section 6)
CH(I)	inches	blade chord

9. REFERENCES

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Fig. 1. Finite Element Grid

Fig. 2. Schematic of total solution

APPENDIX A

NASTRAN Bulk Data Input File

```
$TITLE=37.5/45 137.5/110 BULK DATA M6T235A W/ AER+AIR //OMG=2.0
BEGIN BULK
$ D MALCOLM VERSION OF ATEST.DAT. MODIFIED TO "11-87 MODEL" MARCH'88
$ PBEAM STRESS RECOVERY MODIFIED 18 MARCH 88. LOCAL COORDS MODIFIED
$ COLUMN CONNECTIONS. SLBULK3-LOCAL COORDS CORRECTED 18 JULY 89.
CBEAM      1      10      1      2      1.00
CBEAM      2      10      2      3      1.00
CBEAM      3      10      3      4      1.00
CBEAM      4      20      4      5      1.00
CBEAM      5      30      5      6      1.00
CBEAM      6      30      6      7      1.00
CBEAM      7      30      7      8      1.00
CBEAM      8      30      8      9      1.00
CBEAM      9      30      9     10      1.00
CBEAM     10      30     10     11      1.00
CBEAM     11      30     11     12      1.00
CBEAM     12      30     12     13      1.00
CBEAM     13      30     13     14      1.00
CBEAM     14      30     14     15      1.00
CBEAM     15      30     15     16      1.00
CBEAM     16      30     16     17      1.00
CBEAM     17      30     17     18      1.00
CBEAM     18      30     18     19      1.00
CBEAM     19      30     19     20      1.00
CBEAM     20      30     20     21      1.00
CBEAM     21      30     21     22      1.00
CBEAM     22      30     22     23      1.00
CBEAM     23      40     23     24      1.00
CBEAM     24      50     24     25      1.00
CBEAM     25      50     25     26      1.00
$ BLADE 1 CONNECTIONS
CBEAM     100      60      24     100      1.00      0.00      1.00
CBEAM     101      101     100     101      1.00      0.00      0.00
CBEAM     102      101     101     102      1.00      0.00      0.00
CBEAM     103      102     102     103      1.00      0.00      0.00
CBEAM     104      103     103     104      1.00      0.00      0.00
CBEAM     105      103     104     105      1.00      0.00      0.00
CBEAM     106      103     105     106      1.00      0.00      0.00
CBEAM     107      103     106     107      1.00      0.00      0.00
CBEAM     108      104     107     108      1.00      0.00      0.00
CBEAM     109      105     108     109      1.00      0.00      0.00
CBEAM     110      106     109     110      1.00      0.00      0.00
CBEAM     111      106     110     111      1.00      0.00      0.00
CBEAM     112      106     111     112      1.00      0.00      0.00
CBEAM     113      106     112     113      1.00      0.00      0.00
CBEAM     114      106     113     114      1.00      0.00      0.00
CBEAM     115      107     114     115      1.00      0.00      0.00
CBEAM     116      108     115     116      1.00      0.00      0.00
CBEAM     117      109     116     117      1.00      0.00      0.00
CBEAM     118      109     117     118      1.00      0.00      0.00
CBEAM     119      109     118     119      1.00      0.00      0.00
CBEAM     120      109     119     120      1.00      0.00      0.00
CBEAM     121      109     120     121      1.00      0.00      0.00
CBEAM     122      109     121     122      1.00      0.00      0.00
CBEAM     123      109     122     123      1.00      0.00      0.00
CBEAM     124      109     123     124      1.00      0.00      0.00
CBEAM     125      109     124     125      1.00      0.00      0.00
CBEAM     126      109     125     126      1.00      0.00      0.00
```

CBEAM	127	108	126	127	1.00	0.00	0.00
CBEAM	128	107	127	128	1.00	0.00	0.00
CBEAM	129	106	128	129	1.00	0.00	0.00
CBEAM	130	106	129	130	1.00	0.00	0.00
CBEAM	131	106	130	131	1.00	0.00	0.00
CBEAM	132	106	131	132	1.00	0.00	0.00
CBEAM	133	106	132	133	1.00	0.00	0.00
CBEAM	134	105	133	134	1.00	0.00	0.00
CBEAM	135	104	134	135	1.00	0.00	0.00
CBEAM	136	103	135	136	1.00	0.00	0.00
CBEAM	137	103	136	137	1.00	0.00	0.00
CBEAM	138	103	137	138	1.00	0.00	0.00
CBEAM	139	103	138	139	1.00	0.00	0.00
CBEAM	140	102	139	140	1.00	0.00	0.00
CBEAM	141	101	140	141	1.00	0.00	0.00
CBEAM	142	101	141	142	1.00	0.00	0.00
CBEAM	143	60	142	4	1.00	0.00	-1.00
\$ BLADE 1 STRUTS							
CBEAM	1000	250	23	1000	1.00	0.00	1.00
CBEAM	1001	260	1000	102	1.00	0.00	1.00
CBEAM	1002	250	5	1001	1.00	0.00	-1.00
CBEAM	1003	260	1001	140	1.00	0.00	-1.00
\$ BLADE 2 CONNECTIONS							
CBEAM	200	60	24	200	-1.00	-.00	1.00
CBEAM	201	101	200	201	-1.00	-.00	0.00
CBEAM	202	101	201	202	-1.00	-.00	0.00
CBEAM	203	102	202	203	-1.00	-.00	0.00
CBEAM	204	103	203	204	-1.00	-.00	0.00
CBEAM	205	103	204	205	-1.00	-.00	0.00
CBEAM	206	103	205	206	-1.00	-.00	0.00
CBEAM	207	103	206	207	-1.00	-.00	0.00
CBEAM	208	104	207	208	-1.00	-.00	0.00
CBEAM	209	105	208	209	-1.00	-.00	0.00
CBEAM	210	106	209	210	-1.00	-.00	0.00
CBEAM	211	106	210	211	-1.00	-.00	0.00
CBEAM	212	106	211	212	-1.00	-.00	0.00
CBEAM	213	106	212	213	-1.00	-.00	0.00
CBEAM	214	106	213	214	-1.00	-.00	0.00
CBEAM	215	107	214	215	-1.00	-.00	0.00
CBEAM	216	108	215	216	-1.00	-.00	0.00
CBEAM	217	109	216	217	-1.00	-.00	0.00
CBEAM	218	109	217	218	-1.00	-.00	0.00
CBEAM	219	109	218	219	-1.00	-.00	0.00
CBEAM	220	109	219	220	-1.00	-.00	0.00
CBEAM	221	109	220	221	-1.00	-.00	0.00
CBEAM	222	109	221	222	-1.00	-.00	0.00
CBEAM	223	109	222	223	-1.00	-.00	0.00
CBEAM	224	109	223	224	-1.00	-.00	0.00
CBEAM	225	109	224	225	-1.00	-.00	0.00
CBEAM	226	109	225	226	-1.00	-.00	0.00
CBEAM	227	108	226	227	-1.00	-.00	0.00
CBEAM	228	107	227	228	-1.00	-.00	0.00
CBEAM	229	106	228	229	-1.00	-.00	0.00
CBEAM	230	106	229	230	-1.00	-.00	0.00
CBEAM	231	106	230	231	-1.00	-.00	0.00
CBEAM	232	106	231	232	-1.00	-.00	0.00
CBEAM	233	106	232	233	-1.00	-.00	0.00
CBEAM	234	105	233	234	-1.00	-.00	0.00
CBEAM	235	104	234	235	-1.00	-.00	0.00
CBEAM	236	103	235	236	-1.00	-.00	0.00
CBEAM	237	103	236	237	-1.00	-.00	0.00
CBEAM	238	103	237	238	-1.00	-.00	0.00
CBEAM	239	103	238	239	-1.00	-.00	0.00
CBEAM	240	102	239	240	-1.00	-.00	0.00
CBEAM	241	101	240	241	-1.00	-.00	0.00
CBEAM	242	101	241	242	-1.00	-.00	0.00
CBEAM	243	60	242	4	-1.00	-.00	1.00
\$ BLADE 2 STRUTS							
CBEAM	2000	250	23	2000	-1.00	-.00	1.00
CBEAM	2001	260	2000	202	-1.00	-.00	1.00
CBEAM	2002	250	5	2001	-1.00	-.00	-1.00

CBEAM	2003	260	2001	240	-1.00	-.00	-1.00	
\$ LOWER RESTRAINTS								
GRID	15000		1.000	0.000	0.000		123456	
CELAS2	10000.300E+07		1	1	15000	1		
CELAS2	10001.300E+07		1	2	15000	2		
CELAS2	10002.200E+08		1	6	15000	6		
CDAMP2	9000 1.0E07		1	6	15000	6		
\$ UPPER RESTRAINTS								
GRID	15003				1768.98		123456	
CELAS2	10003.480E+05		26	1	15003	1		
CELAS2	10004.480E+05		26	2	15003	2		
\$ CONCENTRATED MASSES								
CONM2	5000	2			6100.00			
CONM2	5001	4			10084.00			
CONM2	5002	11			2910.00			
CONM2	5003	17			2910.00			
CONM2	5004	23			9200.00			
CONM2	5005	26			25300.00			
CONM2	5006	101			459.00			
CONM2	5007	141			856.00			
CONM2	5008	201			459.00			
CONM2	5009	241			856.00			
\$								
EIGR	21	MGIV				22		+BC
+BC MAX								
EIGC,11,HESS,MAX,,,,,+EIGC1								
+EIGC1,0.,10.7,0.,13.2,3.,1,12								
\$								
FORCE,103,	26,0.,.320E+06,0.,0.,-1.							
GRAV	101	386.40		0.0	0.0	-1.0		
LOAD,100,1.,1.,101,1.,102,1.,103								
RFORCE	102			0.625	0.0	0.0	1.0	2
SPC1	200	3	1					
\$ COLUMN POINTS								
GRID	1		0.000	0.000	0.000		3	1.00
GRID	2		0.000	0.000	33.667			1.00
GRID	3		0.000	0.000	67.333			120.00
GRID	4		0.000	0.000	101.000			
GRID	5		0.000	0.000	151.000			
GRID	6		0.000	0.000	234.332			
GRID	7		0.000	0.000	317.665			
GRID	8		0.000	0.000	400.997			
GRID	9		0.000	0.000	484.329			
GRID	10		0.000	0.000	567.662			
GRID	11		0.000	0.000	650.994			
GRID	12		0.000	0.000	734.327			
GRID	13		0.000	0.000	817.659			
GRID	14		0.000	0.000	900.991			
GRID	15		0.000	0.000	984.324			
GRID	16		0.000	0.000	1067.660			
GRID	17		0.000	0.000	1150.990			
GRID	18		0.000	0.000	1234.320			
GRID	19		0.000	0.000	1317.650			
GRID	20		0.000	0.000	1400.990			
GRID	21		0.000	0.000	1484.320			
GRID	22		0.000	0.000	1567.650			
GRID	23		0.000	0.000	1650.980			
GRID	24		0.000	0.000	1700.980			
GRID	25		0.000	0.000	1734.980			120.00
GRID	26		0.000	0.000	1768.980			
\$ BLADE 1 POINTS								
GRID	100		36.000	0.000	1700.980			
GRID	101		69.762	0.000	1676.000			
GRID	102		103.524	0.000	1651.010			
GRID	103		135.678	0.000	1627.220			
GRID	104		189.519	0.000	1587.380			
GRID	105		243.360	0.000	1547.540			
GRID	106		297.201	0.000	1507.700			
GRID	107		351.042	0.000	1467.860			
GRID	108		375.158	0.000	1450.020			
GRID	109		396.961	0.000	1429.410			

GRID	110	431.132	0.0001395.770
GRID	111	463.908	0.0001360.780
GRID	112	495.236	0.0001324.480
GRID	113	525.063	0.0001286.940
GRID	114	553.340	0.0001248.210
GRID	115	570.536	0.0001223.630
GRID	116	584.366	0.0001197.010
GRID	117	611.392	0.0001138.270
GRID	118	632.674	0.0001077.210
GRID	119	648.016	0.0001014.400
GRID	120	657.278	0.000 950.410
GRID	121	660.375	0.000 885.826
GRID	122	656.320	0.000 811.952
GRID	123	644.205	0.000 738.966
GRID	124	624.175	0.000 667.744
GRID	125	596.470	0.000 599.142
GRID	126	561.424	0.000 533.985
GRID	127	545.786	0.000 508.382
GRID	128	526.981	0.000 485.008
GRID	129	496.172	0.000 448.271
GRID	130	463.897	0.000 412.815
GRID	131	430.208	0.000 378.699
GRID	132	395.161	0.000 345.980
GRID	133	358.814	0.000 314.712
GRID	134	335.678	0.000 295.613
GRID	135	310.518	0.000 279.274
GRID	136	267.887	0.000 251.590
GRID	137	225.257	0.000 223.905
GRID	138	182.626	0.000 196.220
GRID	139	139.995	0.000 168.535
GRID	140	106.448	0.000 146.750
GRID	141	71.224	0.000 123.875
GRID	142	36.000	0.000 101.000
\$ BLADE 1 STRUTS			
GRID	1000	60.000	0.0001650.980
GRID	1001	60.000	0.000 151.000
\$ BLADE 2 GRID POINTS			
GRID	200	-36.000	-.0001700.980
GRID	201	-69.762	-.0001676.000
GRID	202	-103.524	-.0001651.010
GRID	203	-135.678	-.0001627.220
GRID	204	-189.519	-.0001587.380
GRID	205	-243.360	-.0001547.540
GRID	206	-297.201	-.0001507.700
GRID	207	-351.042	-.0001467.860
GRID	208	-375.158	-.0001450.020
GRID	209	-396.961	-.0001429.410
GRID	210	-431.132	-.0001395.770
GRID	211	-463.908	-.0001360.780
GRID	212	-495.236	-.0001324.480
GRID	213	-525.063	-.0001286.940
GRID	214	-553.340	-.0001248.210
GRID	215	-570.536	-.0001223.630
GRID	216	-584.366	-.0001197.010
GRID	217	-611.392	-.0001138.270
GRID	218	-632.674	-.0001077.210
GRID	219	-648.016	-.0001014.400
GRID	220	-657.278	-.000 950.410
GRID	221	-660.375	-.000 885.826
GRID	222	-656.320	-.000 811.952
GRID	223	-644.205	-.000 738.966
GRID	224	-624.175	-.000 667.744
GRID	225	-596.470	-.000 599.142
GRID	226	-561.424	-.000 533.985
GRID	227	-545.786	-.000 508.382
GRID	228	-526.981	-.000 485.008
GRID	229	-496.172	-.000 448.271
GRID	230	-463.897	-.000 412.815
GRID	231	-430.208	-.000 378.699
GRID	232	-395.161	-.000 345.980
GRID	233	-358.814	-.000 314.712

GRID	234	-335.678	-.000	295.613				
GRID	235	-310.518	-.000	279.274				
GRID	236	-267.887	-.000	251.590				
GRID	237	-225.257	-.000	223.905				
GRID	238	-182.626	-.000	196.220				
GRID	239	-139.995	-.000	168.535				
GRID	240	-106.448	-.000	146.750				
GRID	241	-71.224	-.000	123.875				
GRID	242	-36.000	-.000	101.000				
\$ BLADE 2 STRUTS								
GRID	2000	-60.000	-.000	1650.980				
GRID	2001	-60.000	-.000	151.000				
\$ MATERIAL PROPERTIES								
MAT1	10.290E+08.110E+08			.284E+00				
MAT1	20.100E+08.400E+07			.978E-01				
\$								
PBEAM	10	10.352E+03.352E+05.352E+05		.704E+05				+ESP0001
+ESP0001	16.000	0.000 -16.000 0.000 0.000 -16.000 0.000						16.000+PBE1001
+PBE1001	YESA	1.0						
PBEAM	20	10.491E+03.240E+06.240E+06		.480E+06				+ESP0002
+ESP0002	32.500	0.000 -32.500 0.000 0.000 -32.500 0.000						32.500+PBE1002
+PBE1002	YESA	1.0						
PBEAM	30	20.188E+03.335E+06.335E+06		.670E+06				+ESP0003
+ESP0003	60.000	0.000 -60.000 0.000 0.000 -60.000 0.000						60.000+PBE1003
+PBE1003	YESA	1.0						
PBEAM	40	10.491E+03.240E+06.240E+06		.480E+06				+ESP0004
+ESP0004	32.500	0.000 -32.500 0.000 0.000 -32.500 0.000						32.500+PBE1004
+PBE1004	YESA	1.0						
PBEAM	50	10.352E+03.352E+05.352E+05		.704E+05				+ESP0005
+ESP0005	16.000	0.000 -16.000 0.000 0.000 -16.000 0.000						16.000+PBE1005
+PBE1005	YESA	1.0						
PBEAM	60	10.100E+02.400E+05.800E+05		.400E+05				
PBEAM	101	20.200E+03.400E+05.400E+05		.100E+05				+ESP0007
+ESP0007	5.145	0.000 -5.145 0.000 0.000 -22.900 0.000						26.100+PBE1007
+PBE1007	YESA	1.0						
PBEAM	102	20.100E+03.100E+04.200E+05		.200E+04				11.30+ESP0008
+ESP0008	5.040	0.000 -5.040 0.000 0.000 -22.500 0.000						25.500+PBE1008
+PBE1008	YESA	1.0						
PBEAM	103	20.574E+02.583E+03.945E+04		.143E+04				0.92+ESP0009
+ESP0009	5.040	0.000 -5.040 0.000 0.000 -26.230 0.000						26.230+PBE1009
+PBE1009	YESA	0.25						+PBE1091
+PBE1091	YESA	0.50						+PBE1092
+PBE1092	YESA	0.75						+PBE1093
+PBE1093	YESA	1.00						
PBEAM	104	20.847E+02.884E+03.150E+05		.220E+04				3.81+ESP0010
+ESP0010	5.145	0.000 -5.145 0.000 0.000 -22.400 0.000						26.600+PBE1010
+PBE1010	YESA	1.0						
PBEAM	105	20.564E+02.321E+03.732E+04		.830E+03				3.50+ESP0011
+ESP0011	3.870	0.000 -3.870 0.000 0.000 -20.200 0.000						22.800+PBE1011
+PBE1011	YESA	1.0						
PBEAM	106	20.327E+02.184E+03.398E+04		.478E+03				0.82+ESP0012
+ESP0012	3.780	0.000 -3.780 0.000 0.000 -22.250 -0.188						22.250+PBE1012
+PBE1012	YESA	0.25						+PBE1121
+PBE1121	YESA	0.40						+PBE1122
+PBE1122	YESA	0.75						+PBE1123
+PBE1123	YESA	1.00						
PBEAM	107	20.564E+02.321E+03.732E+04		.830E+03				2.65+ESP0013
+ESP0013	3.870	0.000 -3.870 0.000 0.000 -20.200 0.000						22.800+PBE1013
+PBE1013	YESA	1.0						
PBEAM	108	20.462E+02.195E+03.446E+04		.509E+03				2.17+ESP0014
+ESP0014	3.330	0.000 -3.330 0.000 0.000 17.400 0.000						19.600+PBE1014
+PBE1014	YESA	1.0						
PBEAM	109	20.260E+02.112E+03.236E+04		.296E+03				0.44+ESP0015
+ESP0015	3.240	0.00 -3.240 0.00 0.000 -19.020 0.0000						19.020+PBE1015
+PBE1015	YESA	0.5						+PBE1151
+PBE1151	YESA	1.0						
PBEAM	250	10.100E+02.252E+06.504E+06		.252E+06				
PBEAM	260	10.450E+02.200E+04.200E+05		.200E+04				+ESP0026
+ESP0026	1.050	0.000 -1.050 0.000 0.000 -21.000 0.000						21.000+PBE1026
+PBE1026	YESA	1.0						
\$ MASTER DEGREES OF FREEDOM FOR EIGENVALUE EXTRACTION								

```

$ASET1,12,5,9,14,19,23,26
$ASET1,123,108,115,121,127,134
$ASET1,123,208,215,221,227,234
$
$ZSET 102 104 106 108 111 113 115 118 120 122 124 127 129 131 134 136 138 140
$$ZSET 102 105 108 111 115 118 121 124 127 131 134 137 140
$$ZSET 120 121 122
$PARAM GRDPNT 0
$AER 1.15E 7 2.00
PARAM WTMASS .002588
PARAM MAXRATIO 9.E12
$PARAM,LMODES,22
$PARAM,DDRMM,-1
$PARAM,G,0.04
$PARAM,MODACC,+1
$ ROTATING FRAME EFFECTS
$
PARAM OMEGA 3.5600
DMI SKEW 0 1 1 0 6 6
DMI SKEW 2 1 -1.00
DMI SKEW 1 2 1.00
DMI SYM 0 6 1 0 6 6
DMI SYM 1 1 1.00
DMI SYM 2 2 1.00
DMIG SOFTNING 0 1 3 0
DMIG SOFTNING 4 1 4 1 .1E-09
DMIG CORIOL 0 1 3 0
DMIG CORIOL 4 1 4 2 .1E-09
DMIG CORIOL 4 2 4 1 .1E-09
ENDDATA

```

APPENDIX B

Sample Solution 3 Input

```
NASTRAN
ID SNL34, RPM00
TIME 10
SOL 3
COMPILE SOL3,SOUIN=MSCSOU,NOLIST,NOREF
CEND
ECHO=UNSORT
TITLE=SNL34 SOL03 TEST
METHOD=21
DISP(PUNCH)=ALL
BEGIN BULK
.
.
.
put bulk data deck here
.
.
/EOB
```

APPENDIX C

Sample Solution 64 and 71 Input

Solution 64

```
NASTRAN
ID HPVAWT, RPM40
TIME 10
SOL 64
COMPILE SOL64,SOUIN=MSCOU,NOLST,NOREF
CEND
ECHO=UNSORT
TITLE=SNL34 SOL64 TEST
SUBCASE 1
SUBCASE 2
SUBCASE 3
SUBCASE 4
SET 300=4,7,10,12,102,105,110,115,120,125,215
SET 400=2,7,101,105,106,116,125,131
SET 500=2,7,10,101,105,106
DIST=300
FORCE=400
STRESS=500
BEGIN BULK
.
.
put bulk data deck here.
.
.
/EOB
```

NOTE: This solution must be run in conjunction with solution 71 so that the data base is transferred from one to the other.

Solution 71

```
NASTRAN
ASSIGN UNIT=11
ID SNLTB,TEST
TIME 10
SOL71
DIAG 64
COMPILE SOL71,SOUIN=MSCOU,NOLIST,NOREF
ALTER 1087
MATMOD SYM,SIL,,,/SYMG,/5 $PLACE BASIC SYM 6*6 IN G*G MATRIX
MPYAD MGG,SYMG,/KGSYM// -1 $MPLY MGG BY -SYMG
PARAMR ///'MPY'/S,N,OMEGASQ/V,Y,OMEGA/V,Y,OMEGA $OMEGASQ=OMEGA2
PARAMR ///'COMPLEX'//S,N,OMEGASQ/0.0/V,N,COMEGASQ $COMEGASQ=OMEGASQ,0.0
ADD KGSYM,K2PP/KSOFT/COMEGASQ $KSOFT=KGSYM*W} +K2GG
$MODTRL KSOFT///6/ $
EQUIV KSOFT,K2PP/ALWAYS
MATMOD SKEW,SIL,,,/SKEWG,/5 $PLACE BASIC SKEW 6*6 IN G*G MATRIX
MPYAD MGG,SKEWG,/MGSKEW $MPLY MGG BY SKEWG
PARAMR ///'MPY'/S,N,OMEGA2/V,Y,OMEGA2/2.0 $OMEGA2=2*OMEGA
PARAMR ///'COMPLEX'//V,N,OMEGA2/0.0/S,N,COMEGA2 $COMEGA2=(OMEGA2,0.0)
ADD MGSKEW,B2PP/CORIOLIS/COMEGA2 $CORIOLIS=COMEGA2*MGSKEW+K2PP
EQUIV CORIOLIS,B2PP/ALWAYS $
$ ALTER FOR PH-REVISION
ALTER 1134
```

```

$ NOTE THAT KHH ETC. MAY NOT NECESSARILY BE DIAGONAL.
GKAM      USETD,PHIA,MI,LAMA,DIT,,,CASESS/MUHH,BUHH,KUHH,PHIDUH/
          NOUE/LMODES/LFREQ/HFREQ/
          -1/-1/-1/V,N,NUH1/V,N,NUH2 $
ADD       KUHH,MUHH/OMEGSQ///2 $
DIAGONAL  OMEGSQ/OMEG/COLUMN/0.5 $
ADD       OMEG,/PHMOD/0.159155 $
MATPRN    FHMOD// $
PURGE     MUHH,BUHH,KUHH,PHIDUH/ALWAYS $
$ RE-DEFINE MATRIX PH.
PARAML    FOL//'TRAILER'/1/S,N,NFQ $
PRTPARM    ///'NFQ' $
PARAML    PHF//'TRAILER'/1/S,N,NCPHF $
PARAML    PHF//'TRAILER'/2/S,N,NMOD $
PARAM     //DIV/V,N,NCASE/NCPHF/NFQ $
PRTPARM    ///C,N,NCASE $ NCASE NOT USED ANYWHERE.
TYPE      PARM,,I,NFQT $
          NFQT=NFQ*2 $
MATGEN     ,/PUB/4/NMOD/NCPHF/0/NFQT/NCPHF/1/NFQT/NMOD $
ADD        PUB,/PUBDUP/ $
ADD        PUB,PUBDUP/PUC///2 $ REPLACE COL. NO. WITH UNITY.
$ SECOND-LEVEL SEPARATION WITH DMI-HSUP DE-ACTIVATES SPECIFIED
$ MODAL CONTRIBUTIONS. IT COMPLEMENTS LMODES,LFREQ AND HFREQ.
$ AND, IT OBVIATES NEED TO CHANGE SUBCASES AND RANDPS.
PARAML     HSUP// 'PRES'////S,N,HFLAG $
EQUIV      PUC,PUC1/HFLAG $
COND       LHS1,HFLAG $
MATGEN     ,/HONE/4/1/NMOD/1/NMOD/NMOD/1/1/1 $
ADD        HONE,HSUP/HSEL/((-1.,0.) $
$ PRINT FREQUENCIES AFTER SECOND-LEVEL SEPARATION VIA HSUP.
PARTN      FHMOD,,HSEL/FDROPP,FKEEP,,/1 $
MATPRN      FKEEP,FDROPP// $
MATMOD      HSEL,,,,/HSELD,/28 $
MPYAD       PUC,HSELD,/PUC1/ $
LABEL       LHS1 $
TRNSP      PUC1/PHFNEW/ $
MODTRL      PHFNEW////3 $ CHANGE TO COMPLEX.
EQUIV       PHFNEW,PHF/ALWAYS $
$MATPRN     PHF// $
ALTER 1135
COND        LHS2,HFLAG $
MPYAD       HSELD,UHVF,/UHVFNEW/ $
EQUIV       UHVFNEW,UHVF/ALWAYS $
LABEL       LHS2 $
$ ALTER FOR ROUTING FREQ. RESP. TO TAPE49.
ALTER 1143
PARAM       //STSR/V,N,OPU/2 $
PARAM       //STSR/C,Y,TPU=49/-2 $
ALTER 1144
PARAM       //STSR/OPU/-2 $
ALTER 1323
PARAM       //STSR/V,N,OPU/2 $
PARAM       //STSR/C,Y,TPU=49/-2 $
ALTER 1324,1324
PARAM       //STSR/OPU/-2 $
$ ALTER FOR PRINTING MODAL PSD-OUTPUT.
$/READ,S30SDP
CEND
ECH0=UNSORT
TITLE=SNL34 TEST
SET 10=0
SEALL=10 $ INCLUDE WHEN SOL 71 RUN SEPARATELY
$SELG=10
$SELR=10
$SEKR=10
$SEMR=10
METHOD = 21
$SDAMP = 101 $ INCLUDE WHEN MODAL DAMPING IS TO BE ADDED
FREQ=101
DLOAD=99 $ DUMMY LOAD
RANDOM=101

```

```

K2PP=SOFTNING
B2PP=CORIOL
OUTPUT
SET 8=2001
SET 9=7,101,104,106,107,111,115,120,124,125,127,130
$SDISP(SORT2,PHASE) = ALL
$DISP(SORT2,PHASE) = 7
ELFO(SORT2,PHASE) = 8
ELSTRESS(SORT2,PHASE) = 9
$ THE NO OF SUBCASES MUST BE 2 TIMES THE NO OF MODES REQUESTED
$   ON THE LMODES CARD
SUBCASE 1
SUBCASE 2
SUBCASE 3
SUBCASE 4
SUBCASE 5
SUBCASE 6
SUBCASE 7
SUBCASE 8
SUBCASE 9
SUBCASE 10
$SUBCASE 11
$SUBCASE 12
$SUBCASE 13
$SUBCASE 14
$SUBCASE 15
$SUBCASE 16
$SUBCASE 17
$SUBCASE 18
$SUBCASE 19
$SUBCASE 20
$SUBCASE 21
$SUBCASE 22
OUTPUT(XYOUT)
XTITLE = FREQUENCY (HERTZ)
YTIT = PSD OF FORCE IN UPPER RESTRAINT
XYPRINT ELFO PSDF / 2001(2)
YTIT = PSD OF STRESS IN ELEMENT 101 AT END A;C,D,E,F
XYPRINT STRESS PSDF / 101(4),101(5),101(6),101(7)
YTIT = PSD OF STRESS IN ELEMENT 104 AT END B;C,D,E,F
XYPRINT STRESS PSDF / 104(104),104(105),104(106),104(107)
YTIT = PSD OF STRESS IN ELEMENT 106 AT END A; C D E F
XYPRINT STRESS PSDF / 106(4),106(5),106(6),106(7)
YTIT = PSD OF STRESS IN ELEMENT 107 AT END A; C,D,E,F
XYPRINT STRESS PSDF / 107(4),107(5),107(6),107(7)
YTIT = PSD OF STRESS IN ELEMENT 111 AT END A ;C,D,E,F
XYPRINT STRESS PSDF / 111(4),111(5),111(6),111(7)
YTIT = PSD OF STRESS IN ELEMENT 115 AT END B; C,D,E,F
XYPRINT STRESS PSDF / 115(104),115(105),115(106),115(107)
YTIT = PSD OF STRESS IN ELEMENT 120 AT END B; C,D,E,F
XYPRINT STRESS PSDF / 120(104),120(105),120(106),120(107)
YTIT = PSD OF STRESS IN ELEMENT 124 AT END B; C,D,E,F
XYPRINT STRESS PSDF / 124(104),124(105),124(106),124(107)
YTIT = PSD OF STRESS IN ELEMENT 125 AT END B; C,D,E,F
XYPRINT STRESS PSDF / 125(104),125(105),125(106),125(107)
YTIT = PSD OF STRESS IN ELEMENT 127 AT END A; C,D,E,F
XYPRINT STRESS PSDF / 127(4),127(5),127(6),127(7)
YTIT = PSD OF STRESS IN ELEMENT 130 AT END B; C,D,E,F
XYPRINT STRESS PSDF / 130(104),130(105),130(106),130(107)
YTIT = PSD OF STRESS IN ELEMENT 7 AT C,E
XYPRINT STRESS PSDF / 7(4),7(6)
$TITLE=37.5/45 137.5/110 BULK DATA M6T235A W/ AER+AIR //OMG=2.0
BEGIN BULK
.
.
insert bulk data deck using ASET and LMODES cards.
.
.
ENDDATA

```


APPENDIX D

Sample TRES1.OUT File

```

$
$ DE-ACTIVATE UNWANTED MODES
$
DMI      HSUP      0      2      1      0      3      1
DMI      HSUP      1      18     1.0    19     1.0    3      1
$
$ DEFINITION OF DUMMY LOAD
$
RLOAD1    99      99      99      99
DAREA     99      2      1      .00
TABLED1    99
+TABD100   .0      1.0    100.0    1.0    ENDT      +TABD100
$
$ FREQUENCY RESPONSE RANGE
$
FREQ1     101     .00000    .15625    12
$
$ MODAL DAMPING
$
TABDMP1    101     CRIT
+TAB1000   .000     .000     .000     .000     .000     .000     ENDT      +TAB1000
$
$ DEFINITION OF DISCRETE PSDS
$
RANDPS     101      1      1      1.0      1001
TABRND1    1001
+TAB1001    .000    .3395+7    .156    .3305+5    .313    .3811+5    .469    .8285+5+TAB1002
+TAB1002    .625    .1835+7    .781    .6795+5    .938    .2060+5    1.094    .7657+5+TAB1003
+TAB1003    1.250    .1771+7    1.406    .5855+5    1.563    .1282+5    1.719    .7934+4+TAB1004
+TAB1004    1.875    .4773+4    ENDT
RANDPS     101      2      2      1.0      1002
TABRND1    1002
+TAB1005    .000    .4768+5    .156    .1775+6    .313    .1077+7    .469    .9947+6+TAB1006
+TAB1006    .625    .2009+6    .781    .1230+6    .938    .2735+6    1.094    .3671+6+TAB1007
+TAB1007    1.250    .1450+6    1.406    .7834+5    1.563    .1042+6    1.719    .8901+5+TAB1008
+TAB1008    1.875    .6198+6    ENDT
RANDPS     101      1      1      1.0      1001
TABRND1    1003
+TAB1009    .000    .1050+5    .156    .3876+6    .313    .2846+6    .469    .2799+6+TAB1010
+TAB1010    .625    .1285+7    .781    .4825+6    .938    .1727+6    1.094    .4455+6+TAB1011
+TAB1011    1.250    .9533+6    1.406    .4496+6    1.563    .1165+6    1.719    .9378+5+TAB1012
+TAB1012    1.875    .9934+4    ENDT
ECHOON
$
$ DEFINITION OF (UPPER TRIANGLE) CROSS SPECTRAL DENSITIES
$
RANDPS     101      1      2      1.0      1004
TABRND1    1004
+TAB1013    .000    .1006+6    .156    .5502+6    .313    .0000+0    .469    .1980+5+TAB1014
+TAB1014    .625    .0000+0    .781    .6795+5    .938    .6111+5    1.094    .9237+5+TAB1015
+TAB1015    1.250    .8622+4    1.406    .0000+0    1.719    .0000+0    1.875    .1190+4+TAB1016
+TAB1016    ENDT
RANDPS     101      1      2      -1.0      1005
TABRND1    1005
+TAB1017    .000    .0000+0    .156    .0000+0    .313    .9273+5    .469    .3022+5+TAB1018
+TAB1018    .625    .4535+5    .781    .0000+0    .938    .1994+5    1.094    .8733+4+TAB1019
+TAB1019    1.406    .0000+0    1.719    .6782+4    1.875    .0000+0    ENDT
RANDPS     101      1      2      1.0      1006
TABRND1    1006
+TAB1020    .000    .4127+5    .156    .3305+5    .313    .0000+0    .938    .0000+0+TAB1021
+TAB1021    1.094    .3327+5    1.250    .1891+6    1.406    .5855+5    1.563    .1671+5+TAB1022
+TAB1022    1.875    .9031+4    ENDT

```

RANDPS	101	1	2	-1.0	1007			
TABRND1	1007							+TAB1023
+TAB1023	.000	.0000+0	.156 .0000+0	.313 .3811+5	.469 .8285+6			+TAB1024
+TAB1024	.625	.1007+6	.781 .6319+5	.938 .2992+5	1.250 .0000+0			+TAB1025
+TAB1025	1.406	.7294+5	1.563 .8934+4	1.719 .9023+4	1.875 .0000+0			+TAB1026
+TAB1026	ENDT							
RANDPS	101	1	3	1.0	1008			
TABRND1	1008							+TAB1027
+TAB1027	.000	.0000+0	.156 .0000+0	.313 .7255+4	.469 .0000+0			+TAB1028
+TAB1028	.625	.0000+0	.781 .6795+5	.938 .3819+5	1.094 .1440+5			+TAB1029
+TAB1029	1.406	.0000+0	1.563 .5931+4	1.719 .9995+4	1.875 .8289+4			+TAB1030
+TAB1030	ENDT							
RANDPS	101	1	3	-1.0	1009			
TABRND1	1009							+TAB1031
+TAB1031	.000	.4059+6	.156 .2004+5	.313 .7022+4	.469 .7466+5			+TAB1032
+TAB1032	.625	.0000+0	.781 .0000+0	.938 .4448+5	1.094 .0000+0			+TAB1033
+TAB1033	1.719	.0000+0	1.875 .6437+4	ENDT				
RANDPS	101	1	3	1.0	1010			
TABRND1	1010							+TAB1034
+TAB1034	.000	.0000+0	.156 .3661+5	.313 .5989+4	.469 .5539+5			+TAB1035
+TAB1035	.625	.3581+4	.781 .6795+5	.938 .1169+5	1.094 .4880+4			+TAB1036
+TAB1036	ENDT							
RANDPS	101	2	3	1.0	1011			
TABRND1	1011							+TAB1037
+TAB1037	.000	.1954+5	.156 .3453+5	.313 .1138+5	.469 .5485+4			+TAB1038
+TAB1038	.625	.1835+6	.781 .4211+4	.938 .7770+5	1.875 .0000+0			+TAB1039
+TAB1039	ENDT							
RANDPS	101	2	3	-1.0	1012			
TABRND1	1012							+TAB1040
+TAB1040	.000	.0000+0	.156 .5043+5	.313 .1238+6	.469 .0000+0			+TAB1041
+TAB1041	.625	.0000+0	.781 .7390+5	.938 .5522+5	1.094 .2948+5			+TAB1042
+TAB1042	1.250	.0000+0	1.406 .0000+0	1.563 .1539+5	1.719 .2513+4			+TAB1043
+TAB1043	1.875	.4948+4	ENDT					
RANDPS	101	2	3	1.0	1013			
TABRND1	1013							+TAB1044
+TAB1044	.000	.9351+4	.156 .0000+0	.313 .0000+0	.469 .8523+6			+TAB1045
+TAB1045	.625	.1004+5	.781 .8388+4	.938 .7829+5	1.094 .7441+5			+TAB1046
+TAB1046	1.250	.0000+0	1.406 .2391+5	1.563 .1928+4	1.719 .0000+0			+TAB1047
+TAB1047	1.875	.3000+4	ENDT					
RANDPS	101	2	3	-1.0	1014			
TABRND1	1014							+TAB1048
+TAB1048	.000	.0000+0	.156 .0000+0	.313 .9841+5	.469 .0000+0			+TAB1049
+TAB1049	.625	.1046+6	.781 .0000+0	.938 .2338+5	1.094 .7657+5			+TAB1050
+TAB1050	1.250	.0000+0	1.406 .5209+5	1.563 .6682+4	1.875 .2333+4			+TAB1051
+TAB1051	ENDT							

APPENDIX E

Sample Airfoil Data File

SNLA1850 MOD LAMINAR SECTION (EPPLER) NOV '83. REC'D NOV 85 AT INDAL
5000000.0 12.0 0.0 .18

0.00	0.0000	0.0051
2.00	0.2200	0.0051
4.00	0.4400	0.0053
6.00	0.6139	0.0101
8.00	0.7759	0.0119
10.00	0.9100	0.0300
12.00	0.9600	0.0760
14.00	0.8400	0.1570
16.00	0.6000	0.2100
18.00	0.5200	0.2360
20.00	0.5600	0.2600
30.12	0.9398	0.6068
40.14	1.0868	0.9670
50.09	1.0608	1.2920
60.13	0.9229	1.5822
70.04	0.6914	1.7982
80.00	0.4062	1.9443
89.97	0.0863	1.9963
100.08	-0.2441	1.9650
110.02	-0.5483	1.8529
119.95	-0.8055	1.6579
129.95	-0.8570	1.2985
139.94	-0.9015	0.9876
149.90	-0.7438	0.6093
159.99	-0.4656	0.2835
169.95	-0.5747	0.0774
180.00	0.0083	0.0151

SNLA1850 MOD LAMINAR SECTION (EPPLER) NOV '83. REC'D NOV 85 AT INDAL
10000000.0 12.0 0.0 .18

0.00	0.0000	0.0047
2.00	0.2200	0.0049
4.00	0.4400	0.0063
6.00	0.6580	0.0090
8.00	0.8122	0.0106
10.00	0.9400	0.0300
12.00	1.0000	0.0760
14.00	0.8800	0.1570
16.00	0.6700	0.2100
18.00	0.5700	0.2360
20.00	0.6000	0.2600
26.00	0.8099	0.4400
30.12	0.9398	0.6068
40.14	1.0868	0.9670
50.09	1.0608	1.2920
60.13	0.9229	1.5822
70.04	0.6914	1.7982
80.00	0.4062	1.9443
89.97	0.0863	1.9963
100.08	-0.2441	1.9650
110.02	-0.5483	1.8529
119.95	-0.8055	1.6579
129.95	-0.8570	1.2985
139.94	-0.9015	0.9876
149.90	-0.7438	0.6093
159.99	-0.4656	0.2835
169.95	-0.5747	0.0774
180.00	0.0083	0.0151

APPENDIX F

Sample Basic Input File (for 34m Test Bed)

```
$ TRESL.DAT supplies basic data for turbulent response of SNL 34
$   for use with TRES4E
$ HT   DIA   HMR   RPM   VBAR   WSE   DELT   ARHO in free format
1780.0 1320.0 1134.0 37.5  45.0  0.16  0.24  0.0766
$
$ C1X  C2X  C1Y  C2Y  Z0   DECAY  VAR  NSOFT  FMIN  CMIN  in free format
11.87 1928  4.00 70.0  .001  7.50  0.30  1    0.10  4.E1
$
$ TURBULENCE SPECTRUM TYPE # free format
1
$
$ NHT,NDIA,NEIG,NT,NREV,NSECT,NLOOP,NPMAX,NDIV,NOUT,NSUP in free format
  1  1  3  8  4  9  2  3  4  1  2
$
$ INCLUDE DYNAMIC STALL? "YES" OR "NO ", A3 FORMAT
YES
$ INCLUDE COLUMN LOADING? "YES" OR "NO ", A3 FORMAT
YES
$ USE A REDUCED ZSET OF BLADE NODES?
YES
$ select option (1,2,or 3) for printing of cross spectra (free format)
1
$ NSECT(I,TYPE(I), CH(I)) in format (I4,A8,F10.2)
  1NACA0021  48.0
  2NACA0021  48.0
  3NACA0021  48.0
  4NACA0021  48.0
  5SNLA1850  42.0
  6SNLA1850  42.0
  7SNLA1850  42.0
  8SNLA1850  36.0
  9SNLA1850  36.0
$ eigenvalue numbers and associated critical damping factors, free format
$ default value=.00 If no input, enter one dummy line, then end with "$"
2,0.00
$
$ list of eigenvectors to be suppressed (one to a line, free format)
18
19
$ end
.
```

APPENDIX G

Sample Basic Input File for AEROB5.FOR

```
$ AEROBSL.DAT data for SNL 34M ROTOR . AEROB program.
$ RPM ARHO FLUT AB CMIN NSECT (free format)
  37.5 0.0766 4.0 -.2 0.1 9
$ rotational terms included? (A3 format)
YES
$ apparent mass terms included? (A3 format)
NO
$ ZSET used? "YES/NO" free format
YES
$ I ,TYPE(I), CH(I) in format (I4,A8,F10.2)
  1NACA0021 48.0
  2NACA0021 48.0
  3NACA0021 48.0
  4NACA0021 48.0
  5SNLA1850 42.0
  6SNLA1850 42.0
  7SNLA1850 42.0
  8SNLA1850 36.0
  9SNLA1850 36.0
..
```

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