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User's Guide for the NREL Force and Loads Analysis Program (FLAP)

Version 2.2

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Summary

The following report gives the reader an overview of and instructions on the proper use of the National Renewable Energy Laboratory Force and Loads Analysis Program (FLAP, version 2.2). It is intended as a tool for prediction of rotor and blade loads and response for two- or three-bladed rigid hub wind turbines. The effects of turbulence are accounted for.

The objectives of the report are to give an overview of the code and also show the methods of data input and correct code execution steps in order to model an example two-bladed rigid hub turbine. A large portion of the discussion (Sections 6.0, 7.0, and 8.0) is devoted to the subject of inputting and running the code for wind turbulence effects. The ability to include turbulent wind effects is perhaps the biggest change in the code since the release of FLAP version 2.01 in 1988.

This report is intended to be a user's guide. It does not contain a theoretical discussion on equations of motion, assumptions, underlying theory, etc. It is intended to be used in conjunction with Wright, Buhl, and Thresher (1988).

Hopefully, this report will assist new users in the understanding of code input preparation and correct code execution.

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Nomenclature

C_D	Drag coefficient
C_L	Lift coefficient
deg	Degrees
ft	Feet
m	Meters
rad	Radians
Ω	Rotor rotation rate (RPM)

1.0 Introduction

The following report is intended to be a guide for the correct use of the National Renewable Energy Laboratory (NREL) Force and Loads Analysis Program (FLAP, Version 2.2). The original equations of motion that formed the basis for FLAP (version 2.01) have been retained. The main change is the ability to calculate blade response and loads caused by turbulence.

Degrees of freedom include four-blade elastic flap modes. A prescribed time-dependent sinusoidal yaw function can be input to the code.

The report gives a general overview of the code. A description of new input variables (compared to FLAP version 2.01 of 1988) is given. Then, an example of a two-bladed, rigid hub wind turbine is described. Preparation of the basic data input file for this two-bladed turbine is described. Then, the methods of turbulent wind input preparation and input of turbulence to FLAP are explained. Finally, an interactive run session for both modules is illustrated. Code listings and output results are contained in the appendices.

2.0 Code Overview

FLAP (Force and Loads Analysis Program) analyzes two- or three-bladed rigid hub rotors. It predicts blade loads that result from such effects as gravity, windshear, tower shadow, and turbulent wind fluctuations. It also predicts shaft loads caused by gravity, windshear, and tower shadow.

Degrees of freedom included in this model are four elastic flap modes for the blade. Blade torsion and edgewise degrees of freedom are not included. The tower top is assumed to be fixed in space. The model assumes constant rotor speed. Although machine yaw is not considered to be a degree of freedom, a prescribed time-dependent yaw motion can be input to the code.

FLAP is basically a derivative of the Force and Loads Analysis Program (FLAP, Version 2.01) (Wright, Buhl, and Thresher, 1988).

This version of FLAP is similar to FLAP 2.01 in that a quasi-steady linear aerodynamic model is used to compute blade aerodynamic forces. The lift is modeled as a linear function of angle of attack up to stall. Past stall, lift is set equal to a constant. The drag is modeled as a quadratic function involving lift coefficient. For more details, see Section 5.0 of Wright, Buhl, and Thresher (1988).

FLAP is composed of two modules (FLAP1 and FLAP2). The first module is a preprocessor that reads blade and machine property data. It computes such items as blade flapwise frequencies and modeshapes as well as stiffness, mass, coriolis, and other matrices. These quantities are variables that do not generally change from one run to the next and, thus, are computed once.

Distributed blade properties such as the blade's stiffness, weight, twist, and chord may be read into Module 1 at unevenly spaced points. The input data is then interpolated to form sets of evenly spaced data. Another capability of this module is calculation of the blade's flapwise frequencies and modeshapes. This information is written to a file for examination by the user. From this information, the user can check the effects of mass and stiffness on blade frequencies and modeshapes.

We assume in this version of FLAP that both blades have identical mass, stiffness, twist, and chord distributions. In Module 1, mass, stiffness, and other matrices are calculated for only one blade. The effects of mass, pitch, and twist imbalances are not accounted for in this model.

The second module (FLAP2) calculates the blade equations of motion and computes blade and low-speed shaft loads. The code calculates the rotor response to such input as gravity, windshear, tower shadow, yaw misalignment, and yaw rate. The response to these inputs is generally a steady-state one. The code is run with initial values for the blade deflection and velocity. Once the blade reaches a steady-state trim solution, the blade deflection and loads are calculated and written to a file. The shaft loads are also calculated and written to a separate file.

The rotor response and load calculations resulting from time-dependent yaw motion or turbulent wind input is handled differently than the trim case. In those cases, a steady-state trim solution is calculated first, before the code enters the transient portion of the solution process. The results of this trim solution are then used as initial conditions for the transient analysis. After this trim solution is completed, the time clock is started, and the model is run, with the yaw function evaluated at each azimuth position. The yaw-function values for the initial yaw-angle displacement, yaw-angle amplitude, and maximum yaw velocity are set by the user during the model-run setup. Because the yaw function is given independently of the rotor model, the model solution from one rotor revolution to the next will not be steady state.

The number of revolutions to be run in the yaw solution is set by the user during run setup. After each rotor-revolution solution in the yaw routine, loads are computed and printed out.

The procedure for calculating rotor response and loads resulting from turbulent wind fluctuations is similar to the yaw solution procedure described above. The code first calculates rotor response for a trim (steady-state) solution. The computed values for blade deflection and velocity at zero azimuth (blade straight up) are then used as initial conditions for the transient analysis.

In order to run a turbulence analysis with FLAP, a file of turbulent, rotationally sampled wind data is needed. Such a file of data can be generated by such codes as the VEERS Three-Dimensional Wind Simulation (Veers, 1988). Additional details of this file generation and code execution with turbulence will be given in Sections 6.0 and 7.0. Example input to Module 1 are described next, including preparation of blade property data for an example turbine. First, some new code input parameters are described.

3.0 New Code Inputs

New code inputs include NUMSCN, TIMINC, MSTAT, and STA. All these variables are related to the input of turbulent windspeed fluctuations from a separate file. This file of windspeed data must be produced using a separate code, such as the VEERS model (Veers, 1988).

NUMSCN is the number of lines of windspeed data in the turbulent wind input file. For example, a windspeed file may have 8,192 lines of data. TIMINC is the time increment between each line of wind data. An example file might be sampled in the VEERS model at 24 Hz so that TIMINC = 1/24 sec (.041667 sec). MSTAT is the number of blade stations at which turbulent wind data are input. At the present time, only a value of MSTAT = 2 is input. STA represents the actual points on the rotor at which wind data are input, in this case, at 20 and 40 ft. These stations correspond to the 50% and 100% blade radial stations. It is important to note that STA represents the distance from the rotor center of rotation and not the distance from the blade root. More details will be given in Sections 6.0 and 7.0 on turbulence input.

4.0 Example Turbine Description

We will show the data input file preparation for an example two-bladed, rigid-hub turbine. Before showing code input, the turbine will be described. This is a fictitious two-bladed, rigid-hub wind turbine.

The example wind turbine, shown in Figure 4-1, is a two-bladed, fixed-pitch, free-yaw, downwind, stall-controlled rotor turbine. It has a rotor diameter of 24 m (80 ft) and features wood epoxy composite rotor blades. These blades use LS(1)-04XX airfoils with thickness distribution and planform shown in Figure 4-2. This blade has a chord taper ratio of 2.2 beginning at the 30% blade radial station. Figure 4-2 also describes the linear trailing-edge-drop twist distribution of 4.0 deg. Blade stiffness and mass distributions are shown in Figures 4-3 and 4-4. The lift and drag profiles for the LS(1) are shown in Figure 4-5. The blade pitch is set to zero degrees measured at the 75% blade span. The rotor has a solidity of 0.035 and a coning angle of 7.0 deg angled away from the tower. The teetered rotor has a delta-3 angle of zero degrees and rotates at a constant rotational speed of 60 RPM. Aerodynamically shaped tip vanes mounted at the blade tip perpendicular to the spanwise axis provide overspeed protection and assist in high-wind stops. Table 4-1 summarizes the major turbine specifications for the test turbine.

The distance from the yaw axis to the center of the hub is 6.79 ft.

Figure 4-1. Illustration of example turbine

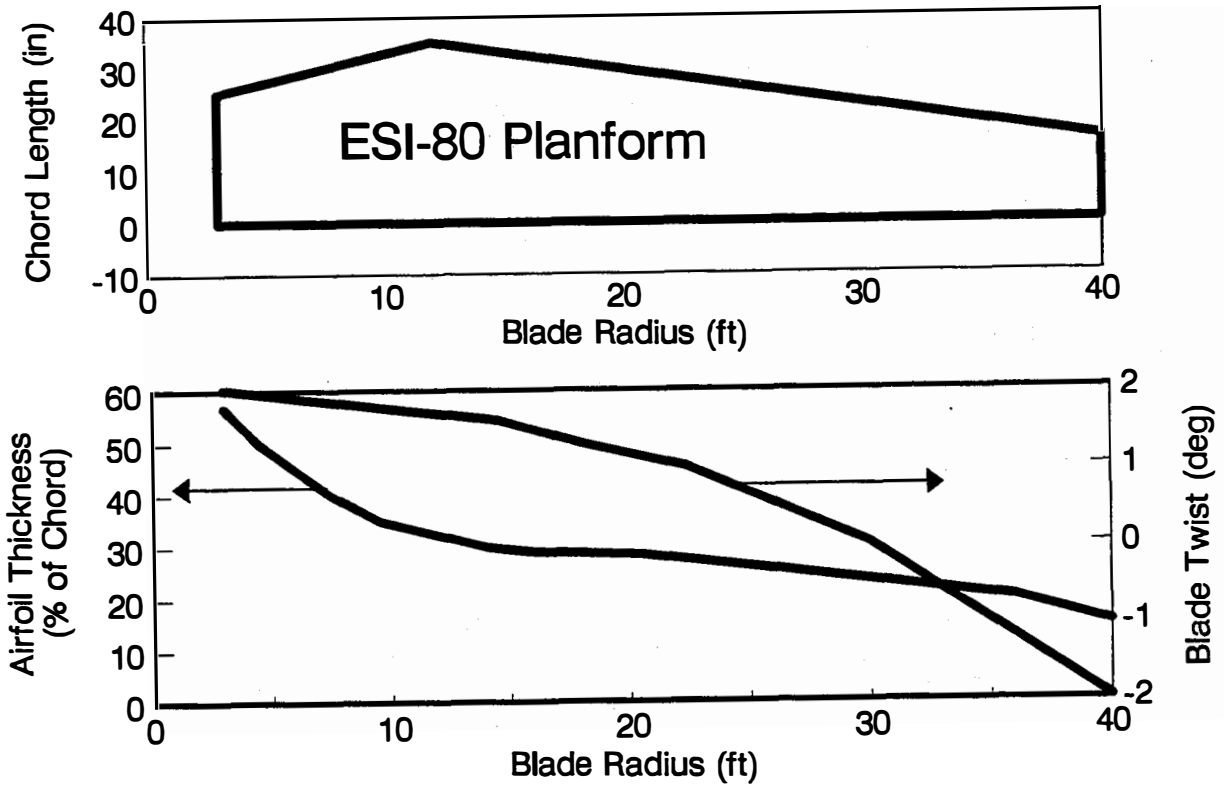

Figure 4-2. Turbine blade planform, thickness, and twist

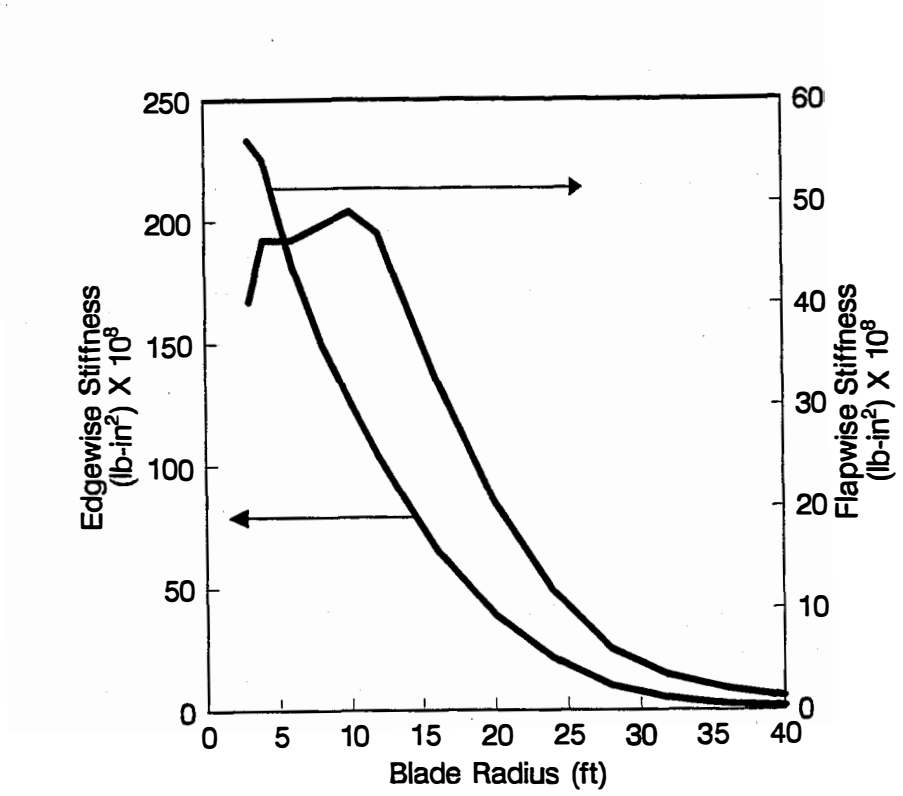

Figure 4-3. Turbine blade stiffness distribution

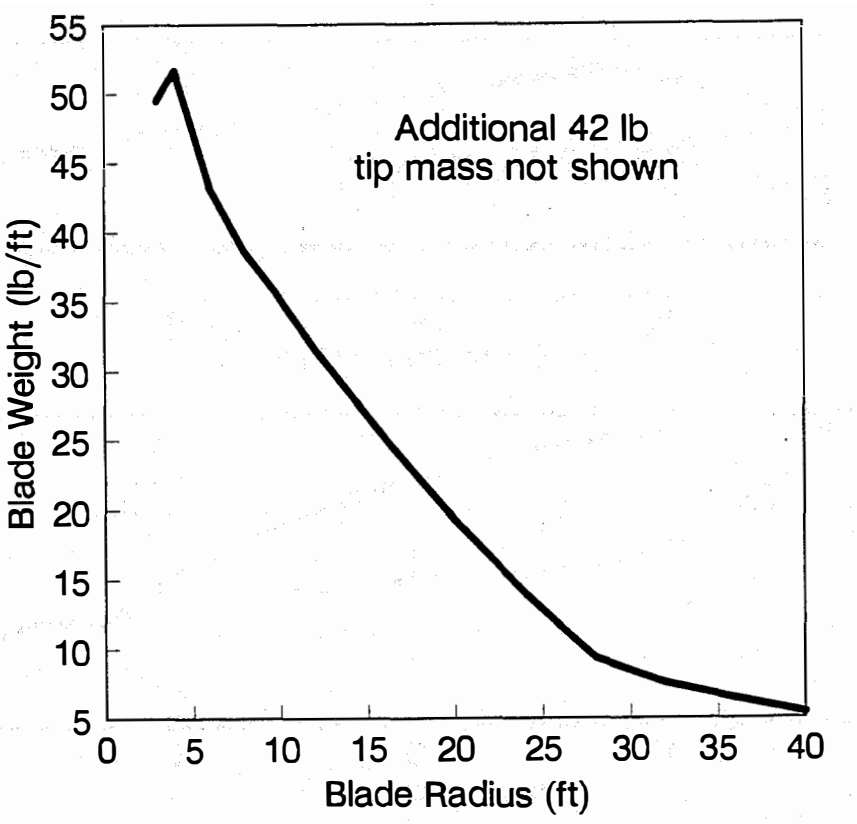

Figure 4-4. Turbine blade weight distribution

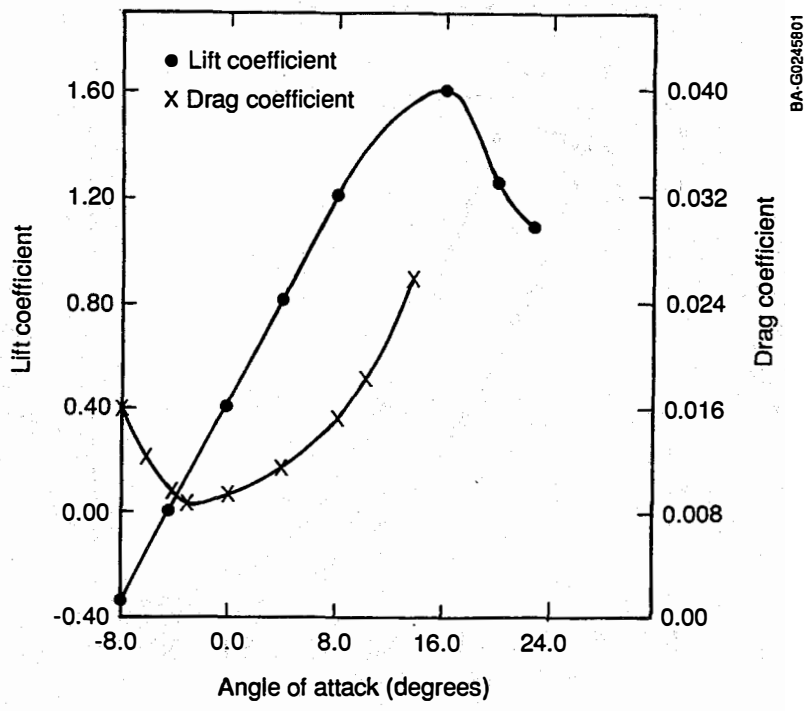

Figure 4-5. Lift profile for the LS(1) airfoil

Table 4-1. Example Turbine Specifications.

Rated Power	250 kW
Rated Windspeed	20.3 m/s (45 mph) Rotor
Diameter	24.5 m (80 ft)
Rotor Type	Two-Bladed Rigid Hub
Rotor Orientation	Downwind
Blade Construction	Wood Epoxy Composite
Rotor Airfoil	NASA LS(1) 0417
Tip Speed	77.9 m/s (173 mph)
Cut-in Windspeed	5.9 m/s (13 mph)
Rotor RPM	60 RPM
Generator RPM	1,800 RPM
Generator Type	300-kW Induction, 3 Phase
Gearbox	Planetary
Hub Height	24.9 m (81.5 ft)
Tower	Open - Truss
Pitch Control	None
Yaw	Passive
Overspeed Control	Tip Vanes
Total System Weight	9,750 Kg (21,500 lbs)
Coning	7 deg

Rotating Natural Frequencies	
First Flapwise	2 Hz
Second Flapwise	7.8 Hz

5.0 Preparation of Input Data

Appendix A, page A-2, shows the basic input file to Module 1 for the turbine. We will now describe the basis for assigning values to these inputs.

ALENTH (ft)

The distance from the tower centerline or yaw axis to the center of the hub (point where the two blades intersect) is 6.79 ft.

ALPHAϕ (deg)

This variable represents the angle from the chord line to the zero lift line. This angle can be found from examination of the lift curve for the LS(1) airfoil shown in Figure 4-5 and represents the angle of attack at which C_L is equal to zero. It is equal to -4 deg for this airfoil. We assume a constant ALPHϕ for the entire blade span. Provisions for changing ALPHϕ with blade span are not provided in this version of FLAP.

CHI (deg)

The angle CHI is the rotor shaft tilt, set equal to zero for this turbine. See Wright, Buhl, and Thresher (1988) for more details.

CSUBMA

This variable represents the airfoil pitching moment coefficient, set equal to 0.015 for this airfoil. For more details, see Wright, Buhl, and Thresher (1988), page 13. This input is not very important for calculation of flap-bending moments.

DRGFRM

This input variable is used in the calculation of airfoil drag coefficient, as given in Wright, Buhl, and Thresher (1988), equation 4-7, page 85. It can be found by fitting a second-order equation of the form given in Wright, Buhl, and Thresher (1988) to the airfoil C_D versus C_L curve. For this airfoil, the value for DRGFRM was calculated as 0.0032.

HUBHT (ft)

The hub height of this turbine is 80 ft.

BETAϕ (deg)

The precone angle for this rotor is 7 deg.

BLSHNK (ft)

BLSHNK is defined as the length of blade shank measured from the blade root to the point where the airfoil section begins. A nonzero value for BLSHNK must always be input to this code. If the particular rotor being analyzed has a zero blade shank, set BLSNK to some small number (.01). Figure 5-1 clarifies the definition of this variable. The main purpose of this variable is to identify the portion of the blade

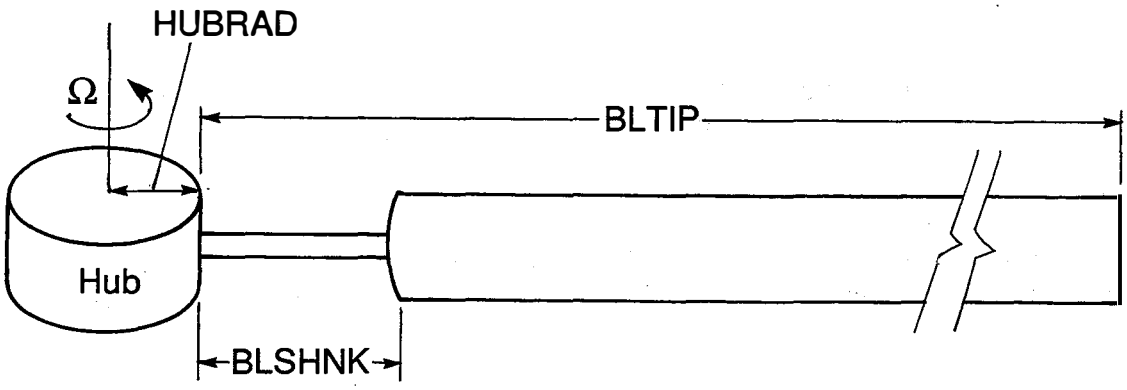

Figure 5-1. Illustration of rotor geometry

not producing aerodynamic lift. For this case, BLSHNK = 0.8 ft. **Input of a zero for BLSHNK will cause an error in code execution.**

BLTIP (ft)

This variable is the blade length, as measured from the blade root to the tip. This value will not, in general, be equal to the rotor radius (see Figure 5-1). For this turbine, BLTIP is set equal to 38 ft because we have a hub radius of 2 ft. The hub is not considered as part of the blade.

HUBRAD (ft)

HUBRAD is the distance from the axis of rotation to the blade root. For this rotor, HUBRAD is set equal to 2 ft. Figure 5-1 clarifies this input variable.

KSHADW

This variable is used in the tower shadow model (see Wright, Buhl, and Thresher, 1988, pages 7, 88). It represents the number of oscillations in the tower shadow region. For this turbine, it is set to 3 because we have a three-legged truss tower.

NBLADS

The number of blades is set to 2.

NPANEL

This variable represents the number of points on the blade, beginning at the root and ending at the tip, in which distributed blade properties are input. We input properties at 11 points along the blade. The maximum value for NPANEL is 11.

OMEGA (RPM)

The rotor speed is 60 RPM.

PHIAMP (deg)

This variable is set to zero because we are not performing a yaw motion solution. See Ref. 2 for more details. This variable defines the yaw-motion amplitude in the time-dependent yaw solution.

PHIOMG (deg/sec)

This variable is also set to zero. This variable defines the steady yaw rate in the trim solution or the maximum yaw rate in a yaw-motion, time-dependent solution. (See Wright, Buhl, and Thresher, 1988).

PHIϕ (deg)

This variable is set to +13 deg because the steady yaw error for this data case was 13 deg (see Wright, Buhl, and Thresher, 1988). See Wright and Butterfield (1992) for yaw error definition.

PSIZER

This variable represents the tower shadow half-width. The tower shadow is modeled as a pie-shaped sector centered about the tower centerline. The value of PSIZER was arbitrarily selected as 20 deg for this machine. For more details, see Wright, Buhl, and Thresher (1988), page 7.

SHERXP

The power law windshear relation given in Wright, Buhl, and Thresher (1988), page 7, had an exponent equal to 0.164 for this case. This value was determined from analysis of anemometer data at three heights, as described in Wright and Butterfield (1992).

THETAP

This variable represents the angle between the principal flapwise bending plane and the cone of rotor rotation. If the blade elastic flapping motion is considered to occur perpendicular to the rotor plane, then THETAP should be set to zero. If flapping motion is considered to occur about the section chord line at the blade root, then THETAP should be set to the angle between this chord line and the rotor cone of rotation.

For a single code run, the orientation of flapping is constant; it does not change from blade station to station because of changes in pretwist. To change the flapping direction for other stations, the code must be rerun with appropriate values of THETAP. All load and deflection results are referenced to this one axis system (the X_p, Y_p, Z_p axes [Wright, Buhl, and Thresher, 1988]). For this case, we set THETAP to 2 deg to reflect flapping about the root chord line. For more details, see Wright, Buhl, and Thresher (1988), pages 13 and 86.

THETAT

This variable represents the difference in twist between the reference station and the tip. Because the reference station was selected at the root, this twist difference is 4 deg.

TSUBP and TSUBϕ

For formal definitions of these variables, see Wright, Buhl, and Thresher (1988), equation 3-3. These two parameters are used to set the shape and magnitude of the velocity profile in the tower shadow region.

Setting both these inputs equal to .05 gives us a cosine squared velocity deficit. The magnitude of the deficit is 10% of the hub height windspeed. If we set TSUBϕ = 0.1 and TSUBP = 0, then we have a square wave-shaped velocity profile with a deficit of 10% of the free-stream windspeed. For more information, see Wright, Buhl, and Thresher (1988).

VHUB (ft/s)

The hub height free-stream windspeed for this case was 33.64 ft/sec.

XLEFT

We used 11 points to input distributed property data. The first point XLEFT(1) is located at the blade root. The last point XLEFT(11) is located at the blade tip. The other points are chosen to help approximate the blade's mass, stiffness, twist, and chord distributions.

WEIGHT

We wanted to include the 42-lb tip weight in the blade's distributed weight input (provisions for inputting a concentrated tip weight are not included). We placed points at 36.0, 36.2, and 38.0 ft.

Distributed property data are interpolated in Module 1 to form a set of evenly spaced data. Between each value of XLEFT, the property data are being linearly interpolated. The point 36.2 was chosen to allow the weight to change rapidly in order to model the tip weight.

The other values chosen for WEIGHT were based on the blade's weight distribution, shown in Figure 4-4.

AEIARE ($\times 10^6$ lb-ft^2)

Figure 4-3 shows the stiffness distributions for this airfoil. Input of values from this plot result in overprediction of the blade's flapwise bending frequencies. We deliberately reduced these values uniformly along the blade so that the predicted flapwise frequencies will agree with test data. It is known that the first symmetric flapwise frequency is approximately 2 Hz. Values taken directly from Figure 4-3 result in overprediction of the frequencies. The user can now try different mass and stiffness distributions, run Module 1, and see what effect these changes have on predicted frequencies. We deliberately reduced the blade's stiffness distribution.

We did not adjust the blade's weight distribution because this parameter is so important for correct calculation of blade centrifugal and gravitational loads.

AIEMASS, AIFMASS, AOFFST, AESBAC

These input variables are set to zero. We did not perform a thorough investigation of the effects of these parameters on blade loads and response. The variables AOFFST and AESBAC may have some effect on the torsional moments predicted by FLAP. We do not think these input parameters have a big effect on flapwise bending moments, however.

ACHORD

This variable is input directly from the information given in Figure 4-2.

ATWIST

This variable represents the blade's built-in twist distribution. It is input from the information given in Figure 4-2. It is important to note that these values must be adjusted in order to obtain zero twist at the tip; i.e., ATWIST(11) = 0. The input variable ATWIST has the blade tip as its zero reference point instead of the 75% span, as seen in Figure 4-2.

ACLALF, ACDZER

ACLALF is the lift curve slope. It is allowed to vary along the span. These values were input from information on the LS(1) airfoil.

ACDZER is the drag coefficient at zero lift. It is used in the calculation of drag coefficient (Wright, Buhl, and Thresher, 1988). It is also allowed to vary along the span.

NUMSCN, TIMINC, MSTAT, STA

These four variables provide information necessary for input of turbulent wind fluctuations to FLAP. NUMSCN was input as 8,192 to reflect 8,192 lines of data in the turbulent windspeed file. TIMINC is set to .041667 because the wind data are sampled at 24 Hz. The number of blade stations at which windspeed data are input is two. Note: The hub center windspeed data will be read in also. MSTAT represents the number of blade stations outboard of the hub center at which turbulent wind input are to be read. STA gives the positions (as measured from the center of rotor rotation) of these points, here set to 20 and 40 ft., which is 50% and 100% of the rotor radius. These inputs are seen in the input file of Appendix A.

6.0 Preparation of Turbulent Wind Input Data

If the user is not interested in running a case with turbulent windspeed input, then this section can be skipped. The FLAP code can be run for deterministic cases only by simply choosing the (Q) option after the trim solution.

In order to run a turbulent windspeed case, a separate file of turbulent windspeed data is needed for input to FLAP. It is assumed that the user must run a separate turbulence wind simulation model such as Veers (1988). Some specific details on the VEERS model will now be given as well as the structure of the turbulence input file to FLAP.

We recommend the use of Veers (1988) for generation of turbulent windspeed input for this rotor. We will henceforth refer to Veers (1988) as the VEERS Three-Dimensional Wind Simulation or, simply, the VEERS model. The reason we recommend this code is that it can be used to generate turbulent windspeed data needed for several points on a blade. With this model, a full three-component field of turbulence is not calculated, only the longitudinal, "along wind," component (in spite of the name "Three-Dimensional . . .").

This simulation method is used to obtain rotationally sampled windspeeds (Veers, 1988). We simulate the windspeed at three points of the rotating blade: the 50% rotor radius location on the blade, the 100% rotor radius on the blade, and the windspeed for the center of rotor rotation.

In the VEERS code, various spectral models for the fixed-point power spectral density calculations can be chosen (Veers, 1988). We usually choose the Solari model. The coherence model is the exponential model with some modifications (Veers, 1988). Input to the model include mean windspeed, rotor speed, number of blades, turbulence intensity, terrain surface roughness, and coherence decrement. For more information, see Veers (1988).

Another input to this model is the number of equally spaced azimuth points in which windspeed data are to be simulated. This parameter will dictate the sampling rate of the generated, rotationally sampled windspeed data. From information that we have obtained from Winkelaar (1991), we usually set this parameter to a high value, in our case, 24 points around the azimuth. This will result in a turbulent windspeed file consisting of four columns of data generated at 24 Hz. The time increment between digitized data is, thus, approximately 0.0417 sec.

In the output file from the VEERS model, the first column is rotor azimuth angle (deg), the second is windspeed at 50% rotor radius, the third is windspeed at 100% rotor radius, and the fourth is the center of hub windspeed. The file contains 8,192 lines of data sampled at 24 Hz. This file represents 341 seconds of real-time wind data. The number of lines of data in the file can be set in the VEERS model input file. We usually want this number to be some power of two (2^{13} in this case) so that we can later perform power spectral density calculations on the computed loads and response output. The FLAP code will generate corresponding loads and response output corresponding to each line of windspeed data. An example output file from VEERS is shown in Appendix F.

7.0 Input of Turbulence Data to FLAP

At this time, we will describe how these turbulent windspeed data are read into FLAP and how they are used.

In order to run a turbulent windspeed case, the FLAP code must first be run in order to determine a trim solution. The code then uses the computed values of blade deflection and velocity at zero azimuth (blade at 12 o'clock) as initial conditions for this process. An example interactive execution will be shown in the next section.

One major change included in FLAP, Version 2.20, and not included in version 2.01, is a subroutine named TRBCLC. After the code finishes with its trim solution calculations, it enters this subroutine, if so chosen by the user. It is in this subroutine that the turbulent windspeed data generated by VEERS is read into FLAP.

We must now describe the two types of interpolation of this windspeed data that are occurring in FLAP. One type is with respect to rotor azimuth, and the other is along the blade radial station locations.

To describe the first type, we must remember that the FLAP code does not increment the rotor azimuth angle in equal azimuth steps. They can vary from point to point because of the use of the Euler Predictor Corrector numeric integration procedure (Wright, Buhl, and Thresher, 1988). The windspeed data generated from VEERS (Veers, 1988) is generated at equal time steps. The main purpose of subroutine TRBCLC is to interpolate the data in order to provide approximate wind input at intermediate rotor azimuth locations. Linear interpolation is used in this subroutine.

Appendix D gives a listing of FLAP2. Subroutine TRBCLC is on page D-112. Upon entering this subroutine, the user will be prompted for the name of the windspeed input file and asked whether the windspeed data are in English (ft/sec) or metric (m/sec) units. He or she is then asked for a file name that contains load and response predictions. These predictions are not written in the RESULTS.DAT file formed previously.

The code then reads one line of wind input data at a time. For the first pass through this subroutine, before the first line of windspeed data is read, the initial azimuth angle is set to zero degrees, and the initial values for the two windspeeds on each blade and the hub center windspeed are set equal to VHUB. The first line of data is then read. The azimuth angle is then incremented, and wind input are then determined by linear interpolation for this intermediate azimuth angle. The values calculated at this intermediate azimuth are stored in the variables VYNOW1(1), VYNOW1(2), and VYNOWH. These variables represent the interpolated values of the two velocities on the blade and the hub center wind velocity at the present azimuth angle. The two end-point values, used in the linear interpolation process, represent the last and most recent values of windspeed read from the input file. These values are represented by the variables VYSAV1(I,J) and VYSAVH(I). The integer I can be either 0 or 1, corresponding to old or new. The integer J is equal to 1 or 2, corresponding to windspeed at the 50% or 100% radial location. The variable VYSAVH(I) is the hub center windspeed.

The three interpolated windspeeds are ultimately passed to a subroutine name WINDVL. In this subroutine, values of turbulent windspeed are calculated for intermediate blade radial stations.

The FLAP code calculates blade aerodynamic forces at 21 equally spaced blade stations, beginning at the root and ending at the tip. In this subroutine, we take the three values of windspeed passed from subroutine TRBCLC and calculate interpolated values for intermediate blade radial stations. We then have

an array containing 21 equally spaced windspeed inputs for a blade. These values are saved in the array DELTVY(I); see Appendix D, page D-108 for Subroutine WINDVL.

This process of azimuth interpolation in subroutine TRBCLC and blade radial station interpolation in WINDVL is continued for each iteration in the numeric process. The code will calculate elastic flap deflections, velocity, and accelerations at every single iteration point. The code calculates and saves loads only at those azimuth positions corresponding to the azimuth values read in from the turbulent windspeed file.

Results written to the user-designated output file include azimuth angle, blade loads, and deflection information. The user can modify the write statement in subroutine TRBCLC to write out all or part of these results. This file will contain the same number of lines of output results as the number of lines of data in the windspeed input file.

Some remarks should be made on proper execution of the trim solution portion of this process. The file produced by the VEERS model contains windspeed data derived from three parts: (1) the mean hub height windspeed, (2) the variation of windspeed as a result of windshear, and (3) the variation as a result of stochastic effects. The second part may be zero if the VEERS model is run with a zero windshear exponent.

Care must be taken to run the trim solution in FLAP using the correct values of VHUB and SHERXP. The variable VHUB, in Module 2 of FLAP, should be set to the value of hub height windspeed as calculated in the VEERS model. The mean windspeed input to the VEERS model is the mean windspeed at a 10-m height (Veers, 1988). This will not necessarily be equal to the hub height windspeed. Hub height may be at a different level. The equivalent hub height windspeed from the VEERS model can be calculated from a knowledge of the windspeed input at 10 m and the power law shear exponent. Once this value is known, FLAP SHOULD BE RUN WITH VHUB SET TO THIS VALUE IN FEET/SECOND.

If the VEERS model is run with a nonzero shear exponent, then the FLAP code should be run with SHERXP set to zero. The wind data generated by the VEERS model already contain the effect of windshear. Input of a nonzero SHERXP in FLAP will result in windshear overprediction. To be safe, we set SHERXP, at the beginning of subroutine TRBCLC, to zero.

An example interactive run of Modules 1 and 2 will now be given.

8.0 Example Interactive Run

8.1 Module 1—FLAP1

Please see Appendix A for a printout of this interactive run. Upon code execution, the user is first prompted for the input file name, here referred to as TURBN.DAT. Upon typing in the input file name, the user is prompted for the name of the run-data file name. This file is written by FLAP1 and contains the data to be read by FLAP2.

All the input data are echoed out to allow the user to check all inputs. At this point, the user is not able to change input during execution of Module 1. The changes must be made to the input file and then rerun.

After all the input data have been echoed out, the user is prompted for the name of a file for writing the blade's modeshape and natural frequency data. This file is different than the run-data file. The purpose of this modeshape file is to allow the user to examine resulting flapwise natural frequencies and mode-shapes. It is not read by FLAP2, and its only purpose is to examine frequency results.

Finally, the user is asked if he or she wants to process another data file; in which case, he or she answers yes or no. The code then responds by repeating the previous steps or stating "FLAP Terminated Normally." This signals the end of FLAP1 execution. A listing of this interactive session is shown in Appendix A. A listing of the run-data file and the modeshape file is also shown.

8.2 Module 2—FLAP2

Upon executing FLAP2, the user is presented with a menu of options shown in the interactive run listing in Appendix B. The options include (R)ead in a data file, (S)et up and run the model, (D)iagnostic run, (T)urbulence run, and (Q)uit.

The user first chooses the (R) option and reads in the run-data file produced by Module 1 (FLAP1). After this step, the user selects option (S). Upon selecting (S), a list of free variables will be given. The user is free to change any of these variables. At this stage, the user selects the number of degrees of freedom to be included in the analysis. The variable NSHAPS sets the number of modes (from 1 to 4) to be used in the analysis. We suggest that NSHAPS be set to 1 so that the first mode is used. For the example turbine described earlier, final code runs should use a value of 2 for NSHAPS because the second bending mode at a frequency of 8 Hz (8 times the rotor rotation speed) gets highly excited by windshear, tower shadow, and turbulence (Wright and Butterfield, 1992).

After changing any of the free variables, the user is given the option of changing the run parameters. We suggest changing the variables STEPMX and EUERR under certain conditions. See Wright, et al. (1988) for the definition of these two variables. The default parameters (STEPMX = 10, EUERR = 10) can be used for initial runs, when only one or two modes are used, at low windspeeds in nonstalled conditions. When more modes are used or in cases involving high angles of attack (stalled flow) or severe tower shadow input, these parameters should be set to 1. Although the code will take longer to run, decreasing these input parameters will help the code to converge to a solution. The small step size is necessary when the blade is encountering highly nonlinear operating conditions, such as stalled flow, and abrupt changes because of tower shadow.

For high-windspeed cases, the code may take 20 to 30 trim iterations before a solution is reached. This occurs because of the decrease in blade aerodynamic damping that result from high angle-of-attack conditions.

We also suggest setting the Trace Flag in the set of run parameters to TRUE. This allows printout of blade deflection, velocity, acceleration, and other items in the RESULTS.DAT file. From this information, the user can monitor problems that may be occurring during code execution.

Another variable in this list of parameters is NYAW. If the user wants to run a time-dependent yaw solution, NYAW should be set to some integer number greater than zero. The variable PHIAMP in the free variable list must also be greater than zero (see Wright, Buhl, and Thresher, 1988).

NYAW represents the number of rotor revolutions to be performed during the yaw solution. The code will first compute a trim solution and then perform a transient analysis using the time-dependent yaw solution. The solution is completed at the end of NYAW revolutions.

After reviewing and/or changing the set of run parameters, the user is prompted for the name of the RESULTS.DAT file. This file will contain blade deflection, slope, and velocity results as well as all the blade's force and moment values. These results are given as a function of blade azimuth angle as well as blade radial station.

Once the code obtains a satisfied trim condition, the code prompts the user for a Fourier analysis of result data. The nine result items are then listed, and the user chooses which item (one at a time) to be Fourier analyzed. The code then determines Fourier cosine and sine coefficients and writes them in table form to the RESULTS.DAT file. A RESULTS.DAT file corresponding to the interactive run is shown in Appendix B.

After this, the name of a shaft load output file is asked for. The shaft loads for the trim runs are written to a separate file. A printout of this file for this interactive run is also shown in Appendix B.

After this, the user is asked if he or she wants to make another run with these data. If the answer is yes, the previous steps are repeated. If the answer is no, the user is returned to the operations menu.

One option that has not been described is (D). This option can only be performed after a trim solution has been performed. Upon execution of this option, items such as angle of attack, lift, and drag will be written to a file named DIAGNOS.DAT. This information is presented for various blade stations as well as rotor azimuth positions.

The other option to be described is (T). This option must also be chosen only after a trim solution has been performed. In this case, we can see that a turbulence analysis was performed. The turbulent windspeed input file was named WIND-2.DAT. These windspeed data were in metric units (meters/ seconds). The turbulence load output file was named LOADS-2.DAT. If the user wants to bypass the turbulence analysis, then the (Q) option should be chosen before the (T) option. This will halt code execution.

9.0 Conclusions

An overview of the NREL Force and Loads Analysis Program (FLAP, Version 2.2) has been given. New input to the code have been described. An example two-bladed rigid-hub wind turbine was described. Preparation of code input and an example code interactive run for this turbine were shown. Code and interactive run listings are given in the appendices.

10.0 References

Veers, P. S., 1988, *Three-Dimensional Wind Simulation*, SAND 88-0152, Sandia National Laboratories, Albuquerque, New Mexico.

Winkelaar, D., 1991, *First Three-Dimensional Wind Simulation and the Predictions of Stochastic Blade Loads*, presented at the Tenth ASME Wind Energy Symposium, Houston, Texas.

Wright, A. D., and Butterfield, C. P., 1992, *The NREL Teetering Hub Rotor Code: Final Results and Conclusions*, presented at the Eleventh ASME Wind Symposium, Houston, Texas.

Wright, A. D., Buhl, M. L., and Thresher, R. W., 1988, *FLAP Code Development and Validation*, SERI/TR-217-3125, National Renewable Energy Laboratory, Golden, Colorado.

11.0 Acknowledgments

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Appendix A

Module 1 Input File, Interactive Run Listing, and Output Files

```
TURBN.DAT
DATA INPUT FOR THE EXAMPLE TWO BLADED, DOWNWIND
80  FT DIAM. RIGID HUB ROTOR
ALENTH        6.79
ALPHAO       -4.0
BETAO         7.0
BLSHNK        0.80
BLTIP        38.00
CHI           0.
CSBMAC        0.015
DRGFRM        0.0032
HUBHT        80.
HUBRAD        2.0
KSHADW        1
NBLADS        2
NPANEL       11
OMEGA        60.
PHIAMP        0.0
PHIOMG        0.0
PHIO         13.0
PSIZER       20.
SHERXP        0.164
THETAP        2.00
THETAT        4.0
TSUBP         0.05
TSUBO         0.05
VHUB         33.64
XLEFT         0.0      0.80     1.00     4.00     10.00    18.00    22.00    26.00    36.00    36.20
WEIGHT       50.0     50.00    50.00    43.3     31.6     19.3     14.0      9.35     5.39    28.30
AEIARE       38.90    38.90    38.89    22.50    13.33     4.22     2.48     1.45     0.289    0.280
AIEMAS        0.0      0.0      0.0      0.0      0.0      0.0      0.0      0.0      0.0      0.0
AIFMAS        0.0      0.0      0.0      0.0      0.0      0.0      0.0      0.0      0.0      0.0
AOFFST        0.       0.       0.       0.       0.       0.       0.       0.       0.       0.
ACHORD        1.00     1.00     2.083    2.333    2.916    2.464    2.238    2.012    1.560    1.549
ATWIST        0.0      0.0      4.0      3.9      3.8      3.2      2.8      2.1      0.20     0.10
ACLALF        0.0      0.0      4.55     4.75     4.85     4.95     4.95     5.20     5.18     5.18
ACLMAX        0.0      0.0      1.0      1.1      1.2      1.3      1.5      1.6      1.6      1.6
ACDZER        0.0      0.0      0.0083   0.0083   0.0083   0.0083   0.0083   0.0083   0.0083   0.0083
AESBAC        0.0      0.0      0.0      0.0      0.0      0.0      0.0      0.0      0.0      0.0
NUMSCN      100
TIMINC        0.041667
MSTAT         2
STA          20.      40.
```

```
THIS IS THE INTERACTIVE RUN LISTING FOR MODULE 1:


  Program For Analysis Of Horizontal Axis Wind Turbine
              Response To Dynamic Loads

                    - MODULE 1


Subroutine INPUT: Input and process new blade
                  and turbine data.

Enter name of input data file >

Enter name of output data file >


TURBN.DAT
DATA INPUT FOR THE EXAMPLE TWO BLADED, DOWNWIND
80  FT DIAM. RIGID HUB ROTOR

Parameter values:

ALENTH =     6.79000          NPANEL =    11
ALPHAO =    -4.00000          OMEGA  =    60.00000
BETAO  =     7.00000          PHIO   =    13.00000
BLSHNK =     0.80000          PHIAMP =     0.00000
BLTIP  =    38.00000          PHIOMG =     0.00000
CHI    =     0.00000          PSIZER =    20.00000
CSUBMA =     0.01500          SHERXP =     0.16400
DRGFRM =     0.00320          THETAP =     2.00000
HUBHT  =    80.00000          THETAT =     4.00000
HUBRAD =     2.00000          TSUBO  =     0.05000
KSHADW =     1                TSUBP  =     0.05000
NBLADS =     2                VHUB   =    33.64000
NUMSCN =   100
TIMINC =     0.04166
MSTAT  =     2

Hit <Enter> to continue...
    XLEFT        WEIGHT       AEIARE       AIEMAS       AIFMAS       AOFFST

   0.00000      50.00000     38.90000      0.00000      0.00000      0.00000
   0.80000      50.00000     38.90000      0.00000      0.00000      0.00000
   1.00000      50.00000     38.89000      0.00000      0.00000      0.00000
   4.00000      43.30000     22.50000      0.00000      0.00000      0.00000
  10.00000      31.60000     13.33000      0.00000      0.00000      0.00000
  18.00000      19.30000      4.22000      0.00000      0.00000      0.00000
  22.00000      14.00000      2.48000      0.00000      0.00000      0.00000
  26.00000       9.35000      1.45000      0.00000      0.00000      0.00000
  36.00000       5.39000      0.28900      0.00000      0.00000      0.00000
  36.20000      28.30000      0.28000      0.00000      0.00000      0.00000
  38.00000      28.20000      0.13500      0.00000      0.00000      0.00000


Hit <Enter> to continue...

    ACHORD       ATWIST       ALCALF       ACLMAX       ACDZER       AESBAC
```

```
   1.00000      0.00000      0.00000      0.00000      0.00000      0.00000
   1.00000      0.00000      0.00000      0.00000      0.00000      0.00000
   2.08300      4.00000      4.55000      1.00000      0.00830      0.00000
   2.33300      3.90000      4.75000      1.10000      0.00830      0.00000
   2.91600      3.80000      4.85000      1.20000      0.00830      0.00000
   2.46400      3.20000      4.95000      1.30000      0.00830      0.00000
   2.23800      2.80000      4.95000      1.50000      0.00830      0.00000
   2.01200      2.10000      5.20000      1.60000      0.00830      0.00000
   1.56000      0.20000      5.18000      1.60000      0.00830      0.00000
   1.54900      0.10000      5.18000      1.60000      0.00830      0.00000
   1.33300      0.00000      5.24000      1.60000      0.00830      0.00000


Hit <Enter> to continue...

STA-
   20.000
   40.000


Hit <Enter> to continue...
Enter name of modeshape and frequency output filedone.

Data for MODULE 2 have been written to RUNB.DAT.


Do you want to process another data file? (Y,=N) >

FLAP terminated normally.
```

THIS IS THE MODESHAPE AND FREQUENCY FILE

FREQUENCIES =

15.4516	50.6140	147.366	473.919	
Modeshapes:				
1	0.000000	0.000000	0.000000	0.000000
11	0.479990E-03	-0.470760E-03	0.152273E-03	-0.453987E-03
21	0.226373E-02	-0.172893E-02	0.811213E-03	-0.116018E-02
31	0.560398E-02	-0.376290E-02	0.195616E-02	-0.155346E-02
41	0.105679E-01	-0.668386E-02	0.330836E-02	-0.146922E-02
51	0.171897E-01	-0.105695E-01	0.450120E-02	-0.981423E-03
61	0.255666E-01	-0.153675E-01	0.519992E-02	-0.279214E-03
71	0.359055E-01	-0.208500E-01	0.517710E-02	0.422401E-03
81	0.485312E-01	-0.266104E-01	0.435051E-02	0.942064E-03
91	0.638611E-01	-0.320938E-01	0.278973E-02	0.116603E-02
101	0.823587E-01	-0.366515E-01	0.698037E-03	0.106098E-02
111	0.104471	-0.396127E-01	-0.162388E-02	0.669985E-03
121	0.130561	-0.403623E-01	-0.382617E-02	0.957751E-04
131	0.160841	-0.384173E-01	-0.556326E-02	-0.524056E-03
141	0.195319	-0.334936E-01	-0.654618E-02	-0.104599E-02
151	0.233762	-0.255528E-01	-0.658726E-02	-0.134900E-02
161	0.275687	-0.148218E-01	-0.563072E-02	-0.135829E-02
171	0.320391	-0.177524E-02	-0.376279E-02	-0.106016E-02
181	0.367023	0.129271E-01	-0.119463E-02	-0.503351E-03
191	0.414711	0.285568E-01	0.178793E-02	0.216767E-03
201	0.462746	0.444972E-01	0.491525E-02	0.996658E-03

```
THIS IS THE RUN DATA FILE PRODUCED BY MODULE 1 AND READ
BY MODULE 2:

TURBN.DAT
DATA INPUT FOR THE EXAMPLE TWO BLADED, DOWNWIND
80  FT DIAM. RIGID HUB ROTOR


        ALENTH                 ALPHAO                 BETAO
 6.7900000000E+00       -4.0000000000E+00       7.0000000000E+00

        BLSHNK                  BLTIP                   CHI
 8.0000000000E-01       3.8000000000E+01       0.0000000000E+00

        CSUBMA                 DRGFRM                  HUBHT
 1.5000000000E-02       3.2000000000E-03       8.0000000000E+01

        HUBRAD                  OMEGA                   PHIO
 2.0000000000E+00       6.0000000000E+01       1.3000000000E+01

        PHIAMP                 PHIOMG                 PSIZER
 0.0000000000E+00       0.0000000000E+00       2.0000000000E+01

        SHERXP                 THETAP                 THETAT
 1.6400000000E-01       2.0000000000E+00       4.0000000000E+00

         TSUBO                  TSUBP                   VHUB
 5.0000000000E-02       5.0000000000E-02       3.3640000000E+01

   KSHADW          NBLADS          NSHAPS           NPTS
     1               2               2              21

   NUMSCN=   100

   TIMINC=   0.04166

   MSTAT =  2

STA(I)-
    2.000E+01     4.000E+01

CLALFA-
    0.0000000E+00     4.6100000E+00     4.7366670E+00     4.7783330E+00
    4.8100000E+00     4.8416670E+00     4.8675000E+00     4.8912500E+00
    4.9150000E+00     4.9387500E+00     4.9500000E+00     4.9500000E+00
    5.0000000E+00     5.1187500E+00     5.1988000E+00     5.1950000E+00
    5.1912000E+00     5.1874000E+00     5.1836000E+00     5.1800000E+00
    5.2400000E+00

CLMAX -
    0.0000000E+00     1.0300000E+00     1.0933330E+00     1.1283330E+00
    1.1600000E+00     1.1916670E+00     1.2175000E+00     1.2412500E+00
    1.2650000E+00     1.2887500E+00     1.3500000E+00     1.4450000E+00
    1.5200000E+00     1.5675000E+00     1.6000000E+00     1.6000000E+00
    1.6000000E+00     1.6000000E+00     1.6000000E+00     1.6000000E+00
    1.6000000E+00

CDZERO-
    0.0000000E+00     8.3000000E-03     8.3000000E-03     8.3000000E-03
    8.3000000E-03     8.3000000E-03     8.3000000E-03     8.3000000E-03
    8.3000000E-03     8.3000000E-03     8.3000000E-03     8.3000000E-03
    8.3000000E-03     8.3000000E-03     8.3000000E-03     8.3000000E-03
    8.3000000E-03     8.3000000E-03     8.3000000E-03     8.3000000E-03
    8.3000000E-03

CHORD-
    1.0000000E+00     2.1580000E+00     2.3163330E+00     2.4981830E+00
    2.6828000E+00     2.8674160E+00     2.8369000E+00     2.7295500E+00
    2.6222010E+00     2.5148510E+00     2.4075010E+00     2.3001500E+00
    2.1928000E+00     2.0854490E+00     1.9848790E+00     1.8989990E+00
    1.8131190E+00     1.7272390E+00     1.6413590E+00     1.5545000E+00
    1.3330000E+00

ECNTFN-
    0.0000000E+00     0.0000000E+00     0.0000000E+00     0.0000000E+00
    0.0000000E+00     0.0000000E+00     0.0000000E+00     0.0000000E+00
    0.0000000E+00     0.0000000E+00     0.0000000E+00     0.0000000E+00
```

```
    0.0000000E+00     0.0000000E+00     0.0000000E+00     0.0000000E+00
    0.0000000E+00     0.0000000E+00     0.0000000E+00     0.0000000E+00
    0.0000000E+00

ESUBAC-
    0.0000000E+00     0.0000000E+00     0.0000000E+00     0.0000000E+00
    0.0000000E+00     0.0000000E+00     0.0000000E+00     0.0000000E+00
    0.0000000E+00     0.0000000E+00     0.0000000E+00     0.0000000E+00
    0.0000000E+00     0.0000000E+00     0.0000000E+00     0.0000000E+00
    0.0000000E+00     0.0000000E+00     0.0000000E+00     0.0000000E+00
    0.0000000E+00

THETAO-
    1.3962630E-01     7.0336770E-02     7.1442140E-02     7.2053010E-02
    7.2605690E-02     7.3158380E-02     7.5136420E-02     7.7623500E-02
    8.0110590E-02     8.2597690E-02     8.5521120E-02     8.8837260E-02
    9.3200590E-02     9.9003830E-02     1.0496420E-01     1.1126480E-01
    1.1756550E-01     1.2386610E-01     1.3016670E-01     1.3700830E-01
    1.3962630E-01

CKBEND-
    1.0083390E+02    -4.0322250E+00     9.9915050E-02    -4.0335320E-02
   -4.0322250E+00     2.8433650E+01    -2.5780500E-01     3.1327550E-02
    9.9915050E-02    -2.5780500E-01     6.7112550E+00    -1.9452040E-02
   -4.0335320E-02     3.1327550E-02    -1.9452040E-02     5.5040870E+00

CKTOMG-
    9.4809340E-01     1.0213810E-01    -2.5309020E-03     1.0220290E-03
    1.0213810E-01     7.1425090E-02     6.5302360E-03    -7.9456660E-04
   -2.5309020E-03     6.5302360E-03     4.4022620E-03     4.9147420E-04
    1.0220290E-03    -7.9456660E-04     4.9147420E-04     6.0389170E-04

CKTGRV-
    2.7604020E-02     1.9881190E-03    -1.2441410E-04     4.4409070E-05
    1.9881190E-03     2.2382840E-03     1.3956390E-04    -4.0216200E-05
   -1.2441410E-04     1.3956390E-04     1.5335550E-04     1.1202700E-05
    4.4409070E-05    -4.0216200E-05     1.1202700E-05     2.5997140E-05

CKQLOO-
    0.0000000E+00     0.0000000E+00     0.0000000E+00     0.0000000E+00
    0.0000000E+00     0.0000000E+00     0.0000000E+00     0.0000000E+00
    0.0000000E+00     0.0000000E+00     0.0000000E+00     0.0000000E+00
    0.0000000E+00     0.0000000E+00     0.0000000E+00     0.0000000E+00

CMMASS-
    5.7911190E-01     4.1807690E-07     5.0681800E-07     6.3668550E-07
    4.1807690E-07     1.2199980E-02     2.1859380E-07     2.5996100E-07
    5.0681800E-07     2.1859380E-07     3.1734160E-04     3.0884490E-07
    6.3668550E-07     2.5996100E-07     3.0884490E-07     2.4889670E-05

CKTCRL( 1,K,L)-
    9.3012170E-03     1.3157830E-03     1.3310280E-05     7.8709800E-06
    1.3157830E-03     6.7067570E-04     7.5045650E-05    -1.5799920E-06
    1.3310280E-05     7.5045650E-05     3.7128080E-05     5.1852320E-06
    7.8709800E-06    -1.5799920E-06     5.1852320E-06     4.2657200E-06

CKTCRL( 2,K,L)-
    2.8308130E-04     1.4827730E-04     1.9014220E-05     6.6901930E-07
    1.4827730E-04     1.5741480E-05     5.2289370E-06     2.0837360E-06
    1.9014220E-05     5.2289370E-06    -5.9275360E-07     2.0192700E-07
    6.6901930E-07     2.0837360E-06     2.0192700E-07    -2.7655570E-07

CKTCRL( 3,K,L)-
    3.3599220E-06     6.4080110E-06     3.0212620E-06     6.1850270E-07
    6.4080110E-06     2.3025510E-06     4.3411470E-08     7.3307340E-08
    3.0212620E-06     4.3411470E-08     2.3791120E-08    -1.0719060E-08
    6.1850270E-07     7.3307340E-08    -1.0719060E-08     2.2584170E-08

CKTCRL( 4,K,L)-
    5.6055080E-07     4.5585320E-07     2.9808030E-07     1.4599310E-07
    4.5585320E-07     4.1657040E-07     8.5431540E-08    -8.5354440E-09
    2.9808030E-07     8.5431540E-08    -2.9392540E-09     3.6502860E-09
    1.4599310E-07    -8.5354440E-09     3.6502860E-09    -2.2649680E-09

CMRIGO-
    6.4966190E+01    -4.2173530E+00     3.2205240E-01    -5.5928610E-02

CMBLNC-
```

```
    0.0000000E+00    0.0000000E+00    0.0000000E+00    0.0000000E+00

CMGRAV-
    2.1128080E+00   -2.8395860E-01    3.6795370E-02   -1.0032110E-02

TCORLS(1,I)-
    2.1128270E+00    2.1123900E+00    2.1090430E+00    2.0997130E+00
    2.0819000E+00    2.0540900E+00    2.0154400E+00    1.9650790E+00
    1.9030750E+00    1.8301280E+00    1.7474600E+00    1.6558360E+00
    1.5577070E+00    1.4553350E+00    1.3524730E+00    1.2420960E+00
    1.1222820E+00    9.9525940E-01    8.6397670E-01    7.1791740E-01
    0.0000000E+00

TCORLS(2,I)-
   -2.8395640E-01   -2.8348530E-01   -2.8069860E-01   -2.7412010E-01
   -2.6258720E-01   -2.4528320E-01   -2.2179010E-01   -1.9201140E-01
   -1.5697290E-01   -1.1860560E-01   -7.9414780E-02   -4.1653340E-02
   -7.8960160E-03    2.0126780E-02    4.1191160E-02    5.6578030E-02
    6.6237290E-02    6.9901270E-02    6.7864180E-02    5.9955730E-02
    0.0000000E+00

TCORLS(3,I)-
    3.6795990E-02    3.6668530E-02    3.5503340E-02    3.2182650E-02
    2.6285470E-02    1.8311840E-02    9.3658650E-03    6.8247090E-04
   -6.4783800E-03   -1.1240590E-02   -1.3291510E-02   -1.2868800E-02
   -1.0585390E-02   -7.2509280E-03   -3.7036940E-03   -2.7365720E-04
    2.6483120E-03    4.6901670E-03    5.6660960E-03    5.5238120E-03
    0.0000000E+00

TCORLS(4,I)-
   -1.0031950E-02   -9.5433580E-03   -7.3454120E-03   -3.9081030E-03
   -4.1554330E-04    2.1385500E-03    3.3167530E-03    3.1949230E-03
    2.1617970E-03    7.5138850E-04   -5.4787870E-04   -1.4270480E-03
   -1.7638520E-03   -1.6178210E-03   -1.1591070E-03   -5.3110440E-04
    1.1922440E-04    6.4708220E-04    9.5514920E-04    1.0020020E-03
    0.0000000E+00

TGRAV-
    2.6713120E+01    2.3788780E+01    2.1080080E+01    1.8609220E+01
    1.6357350E+01    1.4324270E+01    1.2497370E+01    1.0844640E+01
    9.3644120E+00    8.0567000E+00    6.9181700E+00    5.9310100E+00
    5.0908870E+00    4.3842720E+00    3.8037450E+00    3.2878390E+00
    2.8163650E+00    2.3893230E+00    2.0067140E+00    1.6345970E+00
    0.0000000E+00

TOMGA-
    4.0749440E+02    3.9888640E+02    3.8578960E+02    3.6914690E+02
    3.4970350E+02    3.2828990E+02    3.0557420E+02    2.8188530E+02
    2.5785960E+02    2.3415240E+02    2.1135070E+02    1.8970650E+02
    1.6969250E+02    1.5151820E+02    1.3548440E+02    1.2024650E+02
    1.0542580E+02    9.1191170E+01    7.7711350E+01    6.3862130E+01
    0.0000000E+00

CIFMOM(1,I)-
    0.0000000E+00    0.0000000E+00    0.0000000E+00    0.0000000E+00
    0.0000000E+00    0.0000000E+00    0.0000000E+00    0.0000000E+00
    0.0000000E+00    0.0000000E+00    0.0000000E+00    0.0000000E+00
    0.0000000E+00    0.0000000E+00    0.0000000E+00    0.0000000E+00
    0.0000000E+00    0.0000000E+00    0.0000000E+00    0.0000000E+00
    0.0000000E+00

CIFMOM(2,I)-
    0.0000000E+00    0.0000000E+00    0.0000000E+00    0.0000000E+00
    0.0000000E+00    0.0000000E+00    0.0000000E+00    0.0000000E+00
    0.0000000E+00    0.0000000E+00    0.0000000E+00    0.0000000E+00
    0.0000000E+00    0.0000000E+00    0.0000000E+00    0.0000000E+00
    0.0000000E+00    0.0000000E+00    0.0000000E+00    0.0000000E+00
    0.0000000E+00

CIFMOM(3,I)-
    0.0000000E+00    0.0000000E+00    0.0000000E+00    0.0000000E+00
    0.0000000E+00    0.0000000E+00    0.0000000E+00    0.0000000E+00
    0.0000000E+00    0.0000000E+00    0.0000000E+00    0.0000000E+00
    0.0000000E+00    0.0000000E+00    0.0000000E+00    0.0000000E+00
    0.0000000E+00    0.0000000E+00    0.0000000E+00    0.0000000E+00
    0.0000000E+00

CIFMOM(4,I)-
```

```
    0.0000000E+00     0.0000000E+00     0.0000000E+00     0.0000000E+00
    0.0000000E+00     0.0000000E+00     0.0000000E+00     0.0000000E+00
    0.0000000E+00     0.0000000E+00     0.0000000E+00     0.0000000E+00
    0.0000000E+00     0.0000000E+00     0.0000000E+00     0.0000000E+00
    0.0000000E+00     0.0000000E+00     0.0000000E+00     0.0000000E+00
    0.0000000E+00

DELTIM-
    0.0000000E+00     0.0000000E+00     0.0000000E+00     0.0000000E+00
    0.0000000E+00     0.0000000E+00     0.0000000E+00     0.0000000E+00
    0.0000000E+00     0.0000000E+00     0.0000000E+00     0.0000000E+00
    0.0000000E+00     0.0000000E+00     0.0000000E+00     0.0000000E+00
    0.0000000E+00     0.0000000E+00     0.0000000E+00     0.0000000E+00
    0.0000000E+00

OFFMAS-
    0.0000000E+00     0.0000000E+00     0.0000000E+00     0.0000000E+00
    0.0000000E+00     0.0000000E+00     0.0000000E+00     0.0000000E+00
    0.0000000E+00     0.0000000E+00     0.0000000E+00     0.0000000E+00
    0.0000000E+00     0.0000000E+00     0.0000000E+00     0.0000000E+00
    0.0000000E+00     0.0000000E+00     0.0000000E+00     0.0000000E+00
    0.0000000E+00
  0.704375E-01   -0.109351        0.105763E-01   -0.135159
  0.396756        0.195642        0.313000        0.557743
 -0.649376       -0.709698       -0.811690       -0.750139
  0.644929        0.667904        0.493030        0.328551
```

Appendix B

Module 2 Interactive Run Listing and Output Files

```
THIS IS THE INTERACTIVE RUN LISTING FOR MODULE 2:


  Program For Analysis Of Horizontal Axis Wind Turbine
              Response To Dynamic Loads

                      MODULE 2

Operations Menu
---------------

(R)ead in a data file
(S)et up and run the model
(D)iagnostic run
(T)urbulence analysis
(Q)uit

Enter Option (R,S,D,T,Q) >

Enter the name of the file that contains run-data >
Reading in new data...done.

Operations Menu
---------------

(R)ead in a data file
(S)et up and run the model
(D)iagnostic run
(T)urbulence analysis
(Q)uit

Enter Option (R,S,D,T,Q) >

Current values for the 'free' variables:

 1  ALENTH =     6.7900 feet          12  PHIAMP =     0.0000 degrees
 2  ALPHAO =    -4.0000 degrees       13  PHIOMG =     0.0000 degrees/sec
 3  BETAO  =     7.0000 degrees       14  PSISHD =   180.0000 degrees
 4  CHI    =     0.0000 degrees       15  PSIZER =    20.0000 degrees
 5  GRAV   =    32.1740 feet/sec^2    16  RHOAIR =     0.0020 Slugs/feet^3
 6  HUBHT  =    80.0000 feet          17  SHERXP =     0.1640
 7  KSHADW =           1              18  THETAP =     2.0000 degrees
 8  NBLADS =           2              19  THETAT =     4.0000 degrees
 9  NSHAPS =           2              20  TSUBO  =     0.0500
10  OMEGA  =    60.0000 RPM           21  TSUBP  =     0.0500
11  PHIO   =    13.0000 degrees       22  VHUB   =    33.6400 feet/second
23  TIMINC =  0.041660 seconds        24  NUMSCN =         100
Would you like to change any values? (Y,=N) >

The current values of the run parameters are:

 1  STEPMX =   10.000 degrees   Maximum Step Size
 2  STEPMN =    0.001 degrees   Minimum Step Size
 3  PRINT1 =   10.000 degrees   Printout Interval in Region 1
 4  PRINT2 =   10.000 degrees   Printout Interval in Region 2
 5  BEGIN2 =  180.000 degrees   Beginning of Print Region 2
 6  END2   =  270.000 degrees   End of Print Region 2
 7  EUERR  =   10.000 percent   Max value of Euler error function
 8  TRMERR =   10.000 percent   Convergence Criterion for Trim Solution
```

```
 9  NYAW   =    0              No. of Disk Revolutions for Yawing Soln.
10  TRACEF = .FALSE.           Trace Flag

Do you want to change any of these values? (Y,=N) >

Enter number of variable you wish to change >
Enter new REAL value for STEPMX >


The current values of the run parameters are:

 1  STEPMX =    5.000 degrees   Maximum Step Size
 2  STEPMN =    0.001 degrees   Minimum Step Size
 3  PRINT1 =   10.000 degrees   Printout Interval in Region 1
 4  PRINT2 =   10.000 degrees   Printout Interval in Region 2
 5  BEGIN2 =  180.000 degrees   Beginning of Print Region 2
 6  END2   =  270.000 degrees   End of Print Region 2
 7  EUERR  =   10.000 percent   Max value of Euler error function
 8  TRMERR =   10.000 percent   Convergence Criterion for Trim Solution
 9  NYAW   =    0              No. of Disk Revolutions for Yawing Soln.
10  TRACEF = .FALSE.           Trace Flag

Do you want to change any of these values? (Y,=N) >

Enter number of variable you wish to change >
Enter new REAL value for EUERR >


The current values of the run parameters are:

 1  STEPMX =    5.000 degrees   Maximum Step Size
 2  STEPMN =    0.001 degrees   Minimum Step Size
 3  PRINT1 =   10.000 degrees   Printout Interval in Region 1
 4  PRINT2 =   10.000 degrees   Printout Interval in Region 2
 5  BEGIN2 =  180.000 degrees   Beginning of Print Region 2
 6  END2   =  270.000 degrees   End of Print Region 2
 7  EUERR  =    5.000 percent   Max value of Euler error function
 8  TRMERR =   10.000 percent   Convergence Criterion for Trim Solution
 9  NYAW   =    0              No. of Disk Revolutions for Yawing Soln.
10  TRACEF = .FALSE.           Trace Flag

Do you want to change any of these values? (Y,=N) >

Enter number of variable you wish to change >
Enter new REAL value for TRMERR >


The current values of the run parameters are:

 1  STEPMX =    5.000 degrees   Maximum Step Size
 2  STEPMN =    0.001 degrees   Minimum Step Size
 3  PRINT1 =   10.000 degrees   Printout Interval in Region 1
 4  PRINT2 =   10.000 degrees   Printout Interval in Region 2
 5  BEGIN2 =  180.000 degrees   Beginning of Print Region 2
 6  END2   =  270.000 degrees   End of Print Region 2
 7  EUERR  =    5.000 percent   Max value of Euler error function
 8  TRMERR =    5.000 percent   Convergence Criterion for Trim Solution
 9  NYAW   =    0              No. of Disk Revolutions for Yawing Soln.
10  TRACEF = .FALSE.           Trace Flag
```

```
Do you want to change any of these values? (Y,=N) >

Product of CMMASS premultiplied by its inverse:

   1.0000000   0.0000000
   0.0000000   1.0000000

Are you ready to run the model? (=Y,N) >
Enter name of results file [=RESULTS.DAT] >
  >>>  File already exists  <<<

Do you want to overwrite the old data? (Y,N) >

Trim test #01 completed.  The trim condition was not satisfied.

Trim test #02 completed.  The trim condition was not satisfied.

Trim test #03 completed.  The trim condition was satisfied.

Do you want to perform fourier analysis of
any of the results data?

 note: shaft loads harmonics will appear in
 the shaft loads file.

Read in the result data item #
that you want analyzed

1 = flapwise displacement
2 = flapwise slope
3 = flapwise segment velocity
4 = blade tension
5 = blade edgewise shear
6 = blade flapwise shear
7 = blade flapwise moment
8 = blade edgewise moment
9 = blade torsional moment

Read in the highest order harmonic desired
Do you want to perform fourier analysis of
any of the results data?

 note: shaft loads harmonics will appear in
 the shaft loads file.

Read in name of shaft loads output file <
SHAFTB.DAT

Do you want to do another run with this data? (Y,=N) >

Operations Menu
---------------

(R)ead in a data file
(S)et up and run the model
(D)iagnostic run
(T)urbulence analysis
(Q)uit

Enter Option (R,S,D,T,Q) >
```

```
Turbulence Analysis Run Set-up

Read in the name of the wind residual time series file
WIND-2B.DAT
Is the wind data in metric units (meters/sec)?
Y

Read in the name of the file for loads output
turblodb.dat

Operations Menu
---------------

(R)ead in a data file
(S)et up and run the model
(D)iagnostic run
(T)urbulence analysis
(Q)uit

Enter Option (R,S,D,T,Q) >

Invalid response.  Please try again.

Enter Option (R,S,D,T,Q) >

FLAP terminated normally.
```

Analysis of Wind Turbine Blade Loads
National Renewable Energy Lab

TURBN.DAT

DATA INPUT FOR THE EXAMPLE TWO BLADED, DOWNWIND

80 FT DIAM. RIGID HUB ROTOR

ALENTH =	6.790 feet	HUBHT =	80.000 feet	STEPMX =	5.000 degrees
ALPHA0 =	-4.000 degrees	HUBRAD =	2.000 feet	STEPMN =	0.001 degrees
BETA0 =	7.000 degrees	OMEGA =	60.000 RPM	TSUBP =	0.050
BLSHNK =	0.800 feet	PHIAMP =	0.000 degrees	TSUB0 =	0.050
BLTIP =	38.000 feet	PHIOMG =	0.000 degrees/sec	THETAP =	2.000 degrees
CHI =	0.000 degrees	PHI0 =	13.000 degrees	THETAT =	4.000 degrees
CSUBMA =	0.015	PSIZER =	20.000 degrees	TRMERR =	5.000 percent
DRGFRM =	0.003	RHOAIR =	0.002 slugs/ft^3	VHUB =	33.640 feet/second
EUERR =	5.000 percent	SHERXP =	0.164		

KSHADW =	1	NBLADS =	2	NSHAPS =	2	NYAW =	0

Blade section flap displacement (feet) Trim Solution

Psi	Time	Phi	Phi-D	Phi-DD	X / R									
deg	sec	deg	deg/s	deg/s^2	.0	.1	.2	.3	.4	.5	.6	.7	.8	.9	1.0
0	0.00	13.0	0.00	0.00	0.00	1.86E-3	8.52E-3	2.05E-2	3.87E-2	6.48E-2	0.10	0.15	0.21	0.27	0.34
10	0.00	13.0	0.00	0.00	0.00	1.85E-3	8.52E-3	2.05E-2	3.88E-2	6.49E-2	0.10	0.15	0.21	0.27	0.34
20	0.00	13.0	0.00	0.00	0.00	2.04E-3	9.26E-3	2.22E-2	4.18E-2	6.93E-2	0.11	0.15	0.21	0.28	0.34
30	0.00	13.0	0.00	0.00	0.00	2.14E-3	9.68E-3	2.32E-2	4.36E-2	7.21E-2	0.11	0.16	0.22	0.28	0.35
40	0.00	13.0	0.00	0.00	0.00	2.06E-3	9.41E-3	2.26E-2	4.26E-2	7.11E-2	0.11	0.16	0.22	0.29	0.36
50	0.00	13.0	0.00	0.00	0.00	2.01E-3	9.25E-3	2.23E-2	4.21E-2	7.06E-2	0.11	0.16	0.23	0.30	0.37
60	0.00	13.0	0.00	0.00	0.00	2.12E-3	9.71E-3	2.34E-2	4.40E-2	7.33E-2	0.11	0.17	0.23	0.30	0.37
70	0.00	13.0	0.00	0.00	0.00	2.23E-3	1.01E-2	2.43E-2	4.56E-2	7.55E-2	0.12	0.17	0.23	0.30	0.37
80	0.00	13.0	0.00	0.00	0.00	2.14E-3	9.75E-3	2.34E-2	4.40E-2	7.32E-2	0.11	0.16	0.23	0.30	0.37
90	0.00	13.0	0.00	0.00	0.00	1.97E-3	9.05E-3	2.18E-2	4.11E-2	6.88E-2	0.11	0.16	0.22	0.29	0.36
100	0.00	13.0	0.00	0.00	0.00	1.92E-3	8.78E-3	2.11E-2	3.98E-2	6.66E-2	0.10	0.15	0.21	0.28	0.34
110	0.00	13.0	0.00	0.00	0.00	1.93E-3	8.77E-3	2.11E-2	3.96E-2	6.56E-2	0.10	0.15	0.20	0.26	0.32
120	0.00	13.0	0.00	0.00	0.00	1.83E-3	8.30E-3	1.99E-2	3.74E-2	6.20E-2	9.51E-2	0.14	0.19	0.24	0.30
130	0.00	13.0	0.00	0.00	0.00	1.62E-3	7.41E-3	1.78E-2	3.36E-2	5.60E-2	8.68E-2	0.13	0.18	0.23	0.29
140	0.00	13.0	0.00	0.00	0.00	1.49E-3	6.84E-3	1.65E-2	3.10E-2	5.19E-2	8.07E-2	0.12	0.16	0.22	0.27
150	0.00	13.0	0.00	0.00	0.00	1.49E-3	6.77E-3	1.63E-2	3.05E-2	5.06E-2	7.79E-2	0.11	0.15	0.20	0.25
160	0.00	13.0	0.00	0.00	0.00	1.47E-3	6.63E-3	1.59E-2	2.98E-2	4.92E-2	7.51E-2	0.11	0.15	0.19	0.24
170	0.00	13.0	0.00	0.00	0.00	1.33E-3	6.05E-3	1.45E-2	2.73E-2	4.54E-2	7.01E-2	0.10	0.14	0.18	0.23
180	0.00	13.0	0.00	0.00	0.00	1.06E-3	4.95E-3	1.20E-2	2.27E-2	3.85E-2	6.10E-2	9.12E-2	0.13	0.17	0.22
190	0.00	13.0	0.00	0.00	0.00	8.53E-4	4.03E-3	9.79E-3	1.87E-2	3.20E-2	5.13E-2	7.78E-2	0.11	0.15	0.19
200	0.00	13.0	0.00	0.00	0.00	9.74E-4	4.40E-3	1.06E-2	1.98E-2	3.27E-2	4.99E-2	7.19E-2	9.81E-2	0.13	0.16
210	0.00	13.0	0.00	0.00	0.00	1.17E-3	5.14E-3	1.22E-2	2.26E-2	3.63E-2	5.33E-2	7.32E-2	9.54E-2	0.12	0.14
220	0.00	13.0	0.00	0.00	0.00	1.08E-3	4.82E-3	1.15E-2	2.15E-2	3.51E-2	5.28E-2	7.48E-2	0.10	0.13	0.16
230	0.00	13.0	0.00	0.00	0.00	9.47E-4	4.41E-3	1.07E-2	2.02E-2	3.43E-2	5.42E-2	8.09E-2	0.11	0.15	0.19
240	0.00	13.0	0.00	0.00	0.00	1.20E-3	5.52E-3	1.33E-2	2.52E-2	4.23E-2	6.63E-2	9.79E-2	0.14	0.18	0.23
250	0.00	13.0	0.00	0.00	0.00	1.66E-3	7.49E-3	1.80E-2	3.36E-2	5.53E-2	8.42E-2	0.12	0.16	0.21	0.26
260	0.00	13.0	0.00	0.00	0.00	1.89E-3	8.51E-3	2.04E-2	3.82E-2	6.30E-2	9.62E-2	0.14	0.19	0.24	0.30
270	0.00	13.0	0.00	0.00	0.00	1.83E-3	8.45E-3	2.04E-2	3.84E-2	6.45E-2	0.10	0.15	0.21	0.27	0.34
280	0.00	13.0	0.00	0.00	0.00	1.89E-3	8.75E-3	2.11E-2	4.00E-2	6.75E-2	0.11	0.16	0.22	0.29	0.37
290	0.00	13.0	0.00	0.00	0.00	2.15E-3	9.83E-3	2.37E-2	4.45E-2	7.42E-2	0.11	0.17	0.23	0.30	0.38
300	0.00	13.0	0.00	0.00	0.00	2.30E-3	1.04E-2	2.50E-2	4.70E-2	7.77E-2	0.12	0.17	0.24	0.31	0.38
310	0.00	13.0	0.00	0.00	0.00	2.15E-3	9.81E-3	2.36E-2	4.45E-2	7.41E-2	0.11	0.17	0.23	0.30	0.38
320	0.00	13.0	0.00	0.00	0.00	1.95E-3	9.01E-3	2.17E-2	4.11E-2	6.92E-2	0.11	0.16	0.22	0.30	0.37
330	0.00	13.0	0.00	0.00	0.00	1.98E-3	9.08E-3	2.19E-2	4.12E-2	6.90E-2	0.11	0.16	0.22	0.29	0.36
340	0.00	13.0	0.00	0.00	0.00	2.10E-3	9.50E-3	2.28E-2	4.28E-2	7.07E-2	0.11	0.16	0.21	0.28	0.34
350	0.00	13.0	0.00	0.00	0.00	2.03E-3	9.22E-3	2.21E-2	4.15E-2	6.88E-2	0.11	0.15	0.21	0.27	0.34
360	0.00	13.0	0.00	0.00	0.00	1.86E-3	8.52E-3	2.05E-2	3.87E-2	6.48E-2	0.10	0.15	0.21	0.27	0.34

Blade section flapwise slope (feet/foot) Trim Solution

Psi	Time	Phi	Phi-D	Phi-DD	X / R									
deg	sec	deg	deg/s	deg/s^2	.0	.1	.2	.3	.4	.5	.6	.7	.8	.9	1.0
0	0.00	13.0	0.00	0.00	0.00	1.08E-3	2.44E-3	3.91E-3	5.73E-3	8.10E-3	1.10E-2	1.39E-2	1.63E-2	1.76E-2	1.79E-2
10	0.00	13.0	0.00	0.00	0.00	1.08E-3	2.44E-3	3.92E-3	5.75E-3	8.14E-3	1.10E-2	1.40E-2	1.65E-2	1.78E-2	1.81E-2
20	0.00	13.0	0.00	0.00	0.00	1.17E-3	2.64E-3	4.23E-3	6.11E-3	8.46E-3	1.12E-2	1.40E-2	1.62E-2	1.74E-2	1.77E-2
30	0.00	13.0	0.00	0.00	0.00	1.23E-3	2.76E-3	4.41E-3	6.35E-3	8.73E-3	1.15E-2	1.42E-2	1.64E-2	1.76E-2	1.79E-2
40	0.00	13.0	0.00	0.00	0.00	1.19E-3	2.69E-3	4.31E-3	6.28E-3	8.80E-3	1.18E-2	1.48E-2	1.73E-2	1.87E-2	1.90E-2
50	0.00	13.0	0.00	0.00	0.00	1.17E-3	2.65E-3	4.26E-3	6.25E-3	8.87E-3	1.21E-2	1.53E-2	1.80E-2	1.95E-2	1.98E-2
60	0.00	13.0	0.00	0.00	0.00	1.23E-3	2.78E-3	4.45E-3	6.48E-3	9.08E-3	1.22E-2	1.53E-2	1.79E-2	1.93E-2	1.96E-2
70	0.00	13.0	0.00	0.00	0.00	1.28E-3	2.88E-3	4.61E-3	6.66E-3	9.19E-3	1.21E-2	1.51E-2	1.75E-2	1.88E-2	1.90E-2
80	0.00	13.0	0.00	0.00	0.00	1.24E-3	2.78E-3	4.46E-3	6.46E-3	8.99E-3	1.20E-2	1.50E-2	1.74E-2	1.88E-2	1.90E-2
90	0.00	13.0	0.00	0.00	0.00	1.15E-3	2.59E-3	4.16E-3	6.09E-3	8.61E-3	1.16E-2	1.48E-2	1.73E-2	1.87E-2	1.90E-2
100	0.00	13.0	0.00	0.00	0.00	1.11E-3	2.51E-3	4.03E-3	5.89E-3	8.29E-3	1.12E-2	1.41E-2	1.65E-2	1.78E-2	1.81E-2
110	0.00	13.0	0.00	0.00	0.00	1.11E-3	2.50E-3	4.00E-3	5.78E-3	8.00E-3	1.06E-2	1.32E-2	1.52E-2	1.64E-2	1.66E-2
120	0.00	13.0	0.00	0.00	0.00	1.05E-3	2.37E-3	3.79E-3	5.46E-3	7.53E-3	9.93E-3	1.23E-2	1.43E-2	1.53E-2	1.55E-2
130	0.00	13.0	0.00	0.00	0.00	9.39E-4	2.12E-3	3.40E-3	4.95E-3	6.94E-3	9.31E-3	1.17E-2	1.37E-2	1.48E-2	1.50E-2
140	0.00	13.0	0.00	0.00	0.00	8.67E-4	1.96E-3	3.14E-3	4.59E-3	6.47E-3	8.72E-3	1.10E-2	1.29E-2	1.40E-2	1.42E-2
150	0.00	13.0	0.00	0.00	0.00	8.58E-4	1.93E-3	3.09E-3	4.47E-3	6.18E-3	8.18E-3	1.02E-2	1.18E-2	1.27E-2	1.29E-2
160	0.00	13.0	0.00	0.00	0.00	8.41E-4	1.89E-3	3.01E-3	4.33E-3	5.93E-3	7.75E-3	9.56E-3	1.10E-2	1.18E-2	1.20E-2
170	0.00	13.0	0.00	0.00	0.00	7.67E-4	1.73E-3	2.76E-3	4.01E-3	5.58E-3	7.42E-3	9.30E-3	1.08E-2	1.16E-2	1.18E-2
180	0.00	13.0	0.00	0.00	0.00	6.27E-4	1.43E-3	2.30E-3	3.42E-3	4.97E-3	6.91E-3	8.95E-3	1.06E-2	1.16E-2	1.18E-2
190	0.00	13.0	0.00	0.00	0.00	5.10E-4	1.17E-3	1.88E-3	2.85E-3	4.23E-3	6.00E-3	7.89E-3	9.47E-3	1.04E-2	1.05E-2
200	0.00	13.0	0.00	0.00	0.00	5.58E-4	1.25E-3	2.00E-3	2.88E-3	3.94E-3	5.16E-3	6.37E-3	7.34E-3	7.87E-3	7.97E-3
210	0.00	13.0	0.00	0.00	0.00	6.54E-4	1.45E-3	2.29E-3	3.17E-3	4.04E-3	4.87E-3	5.58E-3	6.09E-3	6.35E-3	6.39E-3
220	0.00	13.0	0.00	0.00	0.00	6.11E-4	1.37E-3	2.18E-3	3.08E-3	4.11E-3	5.23E-3	6.31E-3	7.15E-3	7.60E-3	7.68E-3
230	0.00	13.0	0.00	0.00	0.00	5.59E-4	1.27E-3	2.04E-3	3.04E-3	4.41E-3	6.12E-3	7.92E-3	9.40E-3	1.02E-2	1.04E-2
240	0.00	13.0	0.00	0.00	0.00	7.00E-4	1.58E-3	2.55E-3	3.75E-3	5.35E-3	7.30E-3	9.33E-3	1.10E-2	1.19E-2	1.21E-2
250	0.00	13.0	0.00	0.00	0.00	9.51E-4	2.13E-3	3.40E-3	4.87E-3	6.62E-3	8.60E-3	1.06E-2	1.21E-2	1.29E-2	1.31E-2
260	0.00	13.0	0.00	0.00	0.00	1.08E-3	2.42E-3	3.87E-3	5.55E-3	7.58E-3	9.90E-3	1.22E-2	1.40E-2	1.50E-2	1.52E-2
270	0.00	13.0	0.00	0.00	0.00	1.07E-3	2.42E-3	3.89E-3	5.71E-3	8.12E-3	1.10E-2	1.41E-2	1.65E-2	1.79E-2	1.82E-2
280	0.00	13.0	0.00	0.00	0.00	1.11E-3	2.51E-3	4.04E-3	5.99E-3	8.62E-3	1.19E-2	1.53E-2	1.81E-2	1.96E-2	1.99E-2
290	0.00	13.0	0.00	0.00	0.00	1.25E-3	2.81E-3	4.50E-3	6.56E-3	9.19E-3	1.23E-2	1.55E-2	1.81E-2	1.95E-2	1.98E-2
300	0.00	13.0	0.00	0.00	0.00	1.32E-3	2.97E-3	4.75E-3	6.85E-3	9.43E-3	1.24E-2	1.54E-2	1.78E-2	1.91E-2	1.94E-2
310	0.00	13.0	0.00	0.00	0.00	1.24E-3	2.81E-3	4.50E-3	6.55E-3	9.18E-3	1.23E-2	1.55E-2	1.81E-2	1.95E-2	1.98E-2
320	0.00	13.0	0.00	0.00	0.00	1.14E-3	2.59E-3	4.15E-3	6.13E-3	8.78E-3	1.20E-2	1.54E-2	1.82E-2	1.97E-2	2.00E-2
330	0.00	13.0	0.00	0.00	0.00	1.15E-3	2.60E-3	4.17E-3	6.10E-3	8.61E-3	1.16E-2	1.47E-2	1.73E-2	1.87E-2	1.89E-2
340	0.00	13.0	0.00	0.00	0.00	1.21E-3	2.71E-3	4.33E-3	6.23E-3	8.57E-3	1.13E-2	1.39E-2	1.61E-2	1.73E-2	1.75E-2
350	0.00	13.0	0.00	0.00	0.00	1.17E-3	2.63E-3	4.20E-3	6.06E-3	8.36E-3	1.10E-2	1.37E-2	1.58E-2	1.70E-2	1.72E-2
360	0.00	13.0	0.00	0.00	0.00	1.08E-3	2.44E-3	3.91E-3	5.73E-3	8.10E-3	1.10E-2	1.39E-2	1.63E-2	1.76E-2	1.79E-2

Blade section flap velocity (feet/second) Trim Solution

Psi	Time	Phi	Phi-D	Phi-DD	X / R									
deg	sec	deg	deg/s	deg/s^2	.0	.1	.2	.3	.4	.5	.6	.7	.8	.9	1.0
0	0.00	13.0	0.00	0.00	0.00	-4.54E-3	-1.76E-2	-4.04E-2	-7.00E-2	-9.67E-2	-0.11	-9.03E-2	-4.29E-2	2.79E-2	0.11
10	0.00	13.0	0.00	0.00	0.00	4.45E-3	1.78E-2	4.15E-2	7.33E-2	0.11	0.13	0.14	0.13	0.10	6.67E-2
20	0.00	13.0	0.00	0.00	0.00	6.69E-3	2.70E-2	6.28E-2	0.11	0.16	0.20	0.22	0.21	0.18	0.14
30	0.00	13.0	0.00	0.00	0.00	-2.04E-4	5.25E-4	2.13E-3	6.76E-3	2.05E-2	5.15E-2	0.11	0.18	0.28	0.38
40	0.00	13.0	0.00	0.00	0.00	-3.86E-3	-1.37E-2	-3.06E-2	-5.01E-2	-5.85E-2	-3.72E-2	2.83E-2	0.14	0.29	0.45
50	0.00	13.0	0.00	0.00	0.00	1.38E-3	6.20E-3	1.49E-2	2.78E-2	4.58E-2	6.97E-2	0.10	0.14	0.18	0.22
60	0.00	13.0	0.00	0.00	0.00	5.52E-3	2.16E-2	4.99E-2	8.71E-2	0.12	0.14	0.13	8.81E-2	1.99E-2	-5.90E-2
70	0.00	13.0	0.00	0.00	0.00	5.85E-4	1.83E-3	3.91E-3	5.77E-3	4.29E-3	-4.69E-3	-2.44E-2	-5.55E-2	-9.50E-2	-0.14
80	0.00	13.0	0.00	0.00	0.00	-6.01E-3	-2.44E-2	-5.69E-2	-0.10	-0.15	-0.19	-0.21	-0.22	-0.20	-0.18
90	0.00	13.0	0.00	0.00	0.00	-4.68E-3	-1.99E-2	-4.71E-2	-8.59E-2	-0.13	-0.19	-0.24	-0.30	-0.35	-0.41
100	0.00	13.0	0.00	0.00	0.00	3.94E-4	-8.36E-4	-3.57E-3	-1.17E-2	-3.63E-2	-9.18E-2	-0.19	-0.33	-0.50	-0.69
110	0.00	13.0	0.00	0.00	0.00	-6.87E-4	-5.37E-3	-1.42E-2	-3.10E-2	-6.59E-2	-0.13	-0.24	-0.39	-0.57	-0.76
120	0.00	13.0	0.00	0.00	0.00	-6.58E-3	-2.83E-2	-6.70E-2	-0.12	-0.19	-0.28	-0.37	-0.46	-0.55	-0.65
130	0.00	13.0	0.00	0.00	0.00	-7.12E-3	-3.03E-2	-7.16E-2	-0.13	-0.20	-0.28	-0.37	-0.45	-0.53	-0.61
140	0.00	13.0	0.00	0.00	0.00	-1.83E-3	-9.58E-3	-2.38E-2	-4.70E-2	-8.62E-2	-0.15	-0.24	-0.37	-0.52	-0.67
150	0.00	13.0	0.00	0.00	0.00	5.66E-4	7.79E-5	-1.30E-3	-7.19E-3	-2.79E-2	-7.71E-2	-0.17	-0.29	-0.45	-0.62
160	0.00	13.0	0.00	0.00	0.00	-2.84E-3	-1.26E-2	-3.01E-2	-5.59E-2	-9.08E-2	-0.14	-0.19	-0.25	-0.32	-0.39
170	0.00	13.0	0.00	0.00	0.00	-7.40E-3	-3.02E-2	-7.07E-2	-0.13	-0.19	-0.24	-0.28	-0.29	-0.29	-0.28
180	0.00	13.0	0.00	0.00	0.00	-1.06E-2	-4.42E-2	-0.10	-0.19	-0.29	-0.39	-0.49	-0.57	-0.63	-0.69
190	0.00	13.0	0.00	0.00	0.00	-2.17E-3	-1.27E-2	-3.21E-2	-6.56E-2	-0.13	-0.23	-0.40	-0.62	-0.89	-1.2
200	0.00	13.0	0.00	0.00	0.00	9.03E-3	3.25E-2	7.30E-2	0.12	0.15	0.11	-2.89E-2	-0.27	-0.58	-0.93
210	0.00	13.0	0.00	0.00	0.00	2.32E-3	9.21E-3	2.13E-2	3.75E-2	5.35E-2	6.40E-2	6.40E-2	5.21E-2	3.08E-2	5.57E-3
220	0.00	13.0	0.00	0.00	0.00	-7.17E-3	-2.50E-2	-5.56E-2	-9.00E-2	-0.10	-5.19E-2	8.63E-2	0.32	0.62	0.96
230	0.00	13.0	0.00	0.00	0.00	1.11E-3	8.94E-3	2.38E-2	5.21E-2	0.11	0.22	0.41	0.66	0.97	1.3
240	0.00	13.0	0.00	0.00	0.00	1.57E-2	6.62E-2	0.16	0.28	0.44	0.61	0.78	0.94	1.1	1.2
250	0.00	13.0	0.00	0.00	0.00	1.45E-2	6.18E-2	0.15	0.27	0.42	0.59	0.78	0.96	1.1	1.3
260	0.00	13.0	0.00	0.00	0.00	1.37E-3	1.07E-2	2.84E-2	6.20E-2	0.13	0.26	0.48	0.78	1.1	1.5
270	0.00	13.0	0.00	0.00	0.00	-2.21E-3	-4.25E-3	-6.76E-3	-1.61E-3	3.46E-2	0.13	0.32	0.59	0.93	1.3
280	0.00	13.0	0.00	0.00	0.00	6.78E-3	2.90E-2	6.88E-2	0.13	0.20	0.28	0.37	0.46	0.55	0.64
290	0.00	13.0	0.00	0.00	0.00	9.83E-3	3.93E-2	9.13E-2	0.16	0.23	0.28	0.30	0.27	0.20	0.12
300	0.00	13.0	0.00	0.00	0.00	-4.23E-4	-1.71E-3	-3.97E-3	-7.04E-3	-1.03E-2	-1.29E-2	-1.40E-2	-1.35E-2	-1.17E-2	-9.23E-3
310	0.00	13.0	0.00	0.00	0.00	-8.76E-3	-3.49E-2	-8.10E-2	-0.14	-0.21	-0.25	-0.26	-0.22	-0.16	-7.80E-2
320	0.00	13.0	0.00	0.00	0.00	-3.50E-3	-1.51E-2	-3.59E-2	-6.58E-2	-0.10	-0.15	-0.20	-0.25	-0.31	-0.37
330	0.00	13.0	0.00	0.00	0.00	4.64E-3	1.63E-2	3.63E-2	5.89E-2	6.69E-2	3.71E-2	-4.89E-2	-0.20	-0.39	-0.60
340	0.00	13.0	0.00	0.00	0.00	1.84E-3	5.78E-3	1.24E-2	1.82E-2	1.36E-2	-1.46E-2	-7.66E-2	-0.17	-0.30	-0.43
350	0.00	13.0	0.00	0.00	0.00	-6.01E-3	-2.40E-2	-5.57E-2	-9.82E-2	-0.14	-0.17	-0.18	-0.16	-0.11	-6.09E-2
360	0.00	13.0	0.00	0.00	0.00	-4.58E-3	-1.77E-2	-4.08E-2	-7.07E-2	-9.76E-2	-0.11	-9.14E-2	-4.39E-2	2.72E-2	0.11

Blade tension (Lb)

Trim Solution

Psi	Time	Phi	Phi-D	Phi-DD	X / R									
deg	sec	deg	deg/s	deg/s^2	.0	.1	.2	.3	.4	.5	.6	.7	.8	.9	1.0
0	0.00	13.0	0.00	0.00	1.52E+4	1.46E+4	1.33E+4	1.17E+4	9.88E+3	8.12E+3	6.54E+3	5.23E+3	4.07E+3	3.00E+3	0.00
10	0.00	13.0	0.00	0.00	1.52E+4	1.46E+4	1.33E+4	1.17E+4	9.88E+3	8.12E+3	6.54E+3	5.23E+3	4.07E+3	3.00E+3	0.00
20	0.00	13.0	0.00	0.00	1.53E+4	1.46E+4	1.33E+4	1.17E+4	9.90E+3	8.14E+3	6.55E+3	5.23E+3	4.08E+3	3.01E+3	0.00
30	0.00	13.0	0.00	0.00	1.53E+4	1.46E+4	1.34E+4	1.17E+4	9.92E+3	8.15E+3	6.56E+3	5.24E+3	4.08E+3	3.01E+3	0.00
40	0.00	13.0	0.00	0.00	1.54E+4	1.47E+4	1.34E+4	1.18E+4	9.95E+3	8.17E+3	6.57E+3	5.26E+3	4.09E+3	3.02E+3	0.00
50	0.00	13.0	0.00	0.00	1.55E+4	1.48E+4	1.35E+4	1.18E+4	9.99E+3	8.20E+3	6.59E+3	5.27E+3	4.10E+3	3.03E+3	0.00
60	0.00	13.0	0.00	0.00	1.57E+4	1.49E+4	1.35E+4	1.19E+4	1.00E+4	8.23E+3	6.62E+3	5.29E+3	4.12E+3	3.04E+3	0.00
70	0.00	13.0	0.00	0.00	1.58E+4	1.50E+4	1.36E+4	1.19E+4	1.01E+4	8.27E+3	6.64E+3	5.31E+3	4.13E+3	3.05E+3	0.00
80	0.00	13.0	0.00	0.00	1.59E+4	1.51E+4	1.37E+4	1.20E+4	1.01E+4	8.30E+3	6.67E+3	5.33E+3	4.15E+3	3.06E+3	0.00
90	0.00	13.0	0.00	0.00	1.61E+4	1.52E+4	1.38E+4	1.21E+4	1.02E+4	8.34E+3	6.70E+3	5.35E+3	4.16E+3	3.07E+3	0.00
100	0.00	13.0	0.00	0.00	1.62E+4	1.53E+4	1.39E+4	1.21E+4	1.02E+4	8.38E+3	6.73E+3	5.37E+3	4.18E+3	3.08E+3	0.00
110	0.00	13.0	0.00	0.00	1.64E+4	1.55E+4	1.40E+4	1.22E+4	1.03E+4	8.42E+3	6.75E+3	5.39E+3	4.19E+3	3.09E+3	0.00
120	0.00	13.0	0.00	0.00	1.65E+4	1.56E+4	1.41E+4	1.23E+4	1.03E+4	8.45E+3	6.78E+3	5.41E+3	4.21E+3	3.10E+3	0.00
130	0.00	13.0	0.00	0.00	1.66E+4	1.57E+4	1.41E+4	1.23E+4	1.04E+4	8.49E+3	6.80E+3	5.43E+3	4.22E+3	3.11E+3	0.00
140	0.00	13.0	0.00	0.00	1.67E+4	1.57E+4	1.42E+4	1.24E+4	1.04E+4	8.51E+3	6.82E+3	5.44E+3	4.23E+3	3.12E+3	0.00
150	0.00	13.0	0.00	0.00	1.68E+4	1.58E+4	1.43E+4	1.24E+4	1.04E+4	8.54E+3	6.84E+3	5.45E+3	4.24E+3	3.12E+3	0.00
160	0.00	13.0	0.00	0.00	1.69E+4	1.59E+4	1.43E+4	1.24E+4	1.05E+4	8.55E+3	6.85E+3	5.46E+3	4.25E+3	3.13E+3	0.00
170	0.00	13.0	0.00	0.00	1.69E+4	1.59E+4	1.43E+4	1.25E+4	1.05E+4	8.56E+3	6.86E+3	5.47E+3	4.25E+3	3.13E+3	0.00
180	0.00	13.0	0.00	0.00	1.69E+4	1.59E+4	1.43E+4	1.25E+4	1.05E+4	8.56E+3	6.86E+3	5.47E+3	4.25E+3	3.13E+3	0.00
190	0.00	13.0	0.00	0.00	1.69E+4	1.59E+4	1.43E+4	1.25E+4	1.05E+4	8.56E+3	6.86E+3	5.47E+3	4.25E+3	3.13E+3	0.00
200	0.00	13.0	0.00	0.00	1.69E+4	1.59E+4	1.43E+4	1.24E+4	1.05E+4	8.55E+3	6.85E+3	5.46E+3	4.25E+3	3.13E+3	0.00
210	0.00	13.0	0.00	0.00	1.68E+4	1.58E+4	1.43E+4	1.24E+4	1.04E+4	8.54E+3	6.84E+3	5.45E+3	4.24E+3	3.12E+3	0.00
220	0.00	13.0	0.00	0.00	1.67E+4	1.58E+4	1.42E+4	1.24E+4	1.04E+4	8.52E+3	6.83E+3	5.44E+3	4.23E+3	3.12E+3	0.00
230	0.00	13.0	0.00	0.00	1.66E+4	1.57E+4	1.41E+4	1.23E+4	1.04E+4	8.49E+3	6.81E+3	5.43E+3	4.22E+3	3.11E+3	0.00
240	0.00	13.0	0.00	0.00	1.65E+4	1.56E+4	1.41E+4	1.23E+4	1.03E+4	8.46E+3	6.78E+3	5.41E+3	4.21E+3	3.10E+3	0.00
250	0.00	13.0	0.00	0.00	1.64E+4	1.55E+4	1.40E+4	1.22E+4	1.03E+4	8.42E+3	6.76E+3	5.39E+3	4.19E+3	3.09E+3	0.00
260	0.00	13.0	0.00	0.00	1.62E+4	1.54E+4	1.39E+4	1.21E+4	1.02E+4	8.38E+3	6.73E+3	5.37E+3	4.18E+3	3.08E+3	0.00
270	0.00	13.0	0.00	0.00	1.61E+4	1.52E+4	1.38E+4	1.21E+4	1.02E+4	8.35E+3	6.70E+3	5.35E+3	4.16E+3	3.07E+3	0.00
280	0.00	13.0	0.00	0.00	1.59E+4	1.51E+4	1.37E+4	1.20E+4	1.01E+4	8.31E+3	6.67E+3	5.33E+3	4.15E+3	3.06E+3	0.00
290	0.00	13.0	0.00	0.00	1.58E+4	1.50E+4	1.36E+4	1.19E+4	1.01E+4	8.27E+3	6.64E+3	5.31E+3	4.13E+3	3.05E+3	0.00
300	0.00	13.0	0.00	0.00	1.57E+4	1.49E+4	1.35E+4	1.19E+4	1.00E+4	8.23E+3	6.62E+3	5.29E+3	4.12E+3	3.04E+3	0.00
310	0.00	13.0	0.00	0.00	1.55E+4	1.48E+4	1.35E+4	1.18E+4	9.99E+3	8.20E+3	6.59E+3	5.27E+3	4.10E+3	3.03E+3	0.00
320	0.00	13.0	0.00	0.00	1.54E+4	1.47E+4	1.34E+4	1.18E+4	9.95E+3	8.17E+3	6.57E+3	5.25E+3	4.09E+3	3.02E+3	0.00
330	0.00	13.0	0.00	0.00	1.53E+4	1.46E+4	1.33E+4	1.17E+4	9.92E+3	8.15E+3	6.56E+3	5.24E+3	4.08E+3	3.01E+3	0.00
340	0.00	13.0	0.00	0.00	1.53E+4	1.46E+4	1.33E+4	1.17E+4	9.90E+3	8.13E+3	6.54E+3	5.23E+3	4.08E+3	3.01E+3	0.00
350	0.00	13.0	0.00	0.00	1.52E+4	1.46E+4	1.33E+4	1.17E+4	9.88E+3	8.12E+3	6.54E+3	5.23E+3	4.07E+3	3.00E+3	0.00
360	0.00	13.0	0.00	0.00	1.52E+4	1.46E+4	1.33E+4	1.17E+4	9.88E+3	8.12E+3	6.54E+3	5.23E+3	4.07E+3	3.00E+3	0.00

Blade edgewise shear (Lb) Trim Solution

Psi	Time	Phi	Phi-D	Phi-DD	X / R										
deg	sec	deg	deg/s	deg/s^2	.0	.1	.2	.3	.4	.5	.6	.7	.8	.9	1.0
0	0.00	13.0	0.00	0.00	3.29E+2	3.19E+2	2.99E+2	2.70E+2	2.34E+2	1.93E+2	1.52E+2	1.14E+2	77.	42.	0.00
10	0.00	13.0	0.00	0.00	4.76E+2	4.34E+2	3.88E+2	3.37E+2	2.84E+2	2.30E+2	1.79E+2	1.34E+2	92.	53.	0.00
20	0.00	13.0	0.00	0.00	6.18E+2	5.46E+2	4.74E+2	4.03E+2	3.32E+2	2.65E+2	2.05E+2	1.53E+2	1.07E+2	64.	0.00
30	0.00	13.0	0.00	0.00	7.53E+2	6.53E+2	5.57E+2	4.65E+2	3.79E+2	2.99E+2	2.30E+2	1.71E+2	1.20E+2	73.	0.00
40	0.00	13.0	0.00	0.00	8.75E+2	7.48E+2	6.30E+2	5.21E+2	4.20E+2	3.29E+2	2.52E+2	1.88E+2	1.32E+2	82.	0.00
50	0.00	13.0	0.00	0.00	9.77E+2	8.28E+2	6.91E+2	5.67E+2	4.54E+2	3.54E+2	2.70E+2	2.01E+2	1.42E+2	89.	0.00
60	0.00	13.0	0.00	0.00	1.06E+3	8.92E+2	7.40E+2	6.03E+2	4.80E+2	3.73E+2	2.84E+2	2.12E+2	1.50E+2	96.	0.00
70	0.00	13.0	0.00	0.00	1.12E+3	9.40E+2	7.77E+2	6.30E+2	5.00E+2	3.87E+2	2.93E+2	2.19E+2	1.56E+2	9.97E+1	0.00
80	0.00	13.0	0.00	0.00	1.16E+3	9.68E+2	7.97E+2	6.45E+2	5.10E+2	3.94E+2	2.98E+2	2.23E+2	1.58E+2	1.02E+2	0.00
90	0.00	13.0	0.00	0.00	1.17E+3	9.74E+2	8.01E+2	6.47E+2	5.10E+2	3.93E+2	2.97E+2	2.22E+2	1.58E+2	1.02E+2	0.00
100	0.00	13.0	0.00	0.00	1.15E+3	9.58E+2	7.87E+2	6.35E+2	5.00E+2	3.85E+2	2.91E+2	2.17E+2	1.55E+2	1.00E+2	0.00
110	0.00	13.0	0.00	0.00	1.10E+3	9.22E+2	7.58E+2	6.11E+2	4.81E+2	3.70E+2	2.80E+2	2.09E+2	1.49E+2	96.	0.00
120	0.00	13.0	0.00	0.00	1.04E+3	8.67E+2	7.14E+2	5.77E+2	4.54E+2	3.49E+2	2.64E+2	1.97E+2	1.40E+2	90.	0.00
130	0.00	13.0	0.00	0.00	9.45E+2	7.94E+2	6.57E+2	5.32E+2	4.19E+2	3.22E+2	2.44E+2	1.81E+2	1.28E+2	83.	0.00
140	0.00	13.0	0.00	0.00	8.33E+2	7.05E+2	5.86E+2	4.76E+2	3.76E+2	2.90E+2	2.19E+2	1.63E+2	1.15E+2	74.	0.00
150	0.00	13.0	0.00	0.00	7.06E+2	6.04E+2	5.06E+2	4.14E+2	3.29E+2	2.54E+2	1.92E+2	1.43E+2	1.01E+2	63.	0.00
160	0.00	13.0	0.00	0.00	5.67E+2	4.94E+2	4.20E+2	3.47E+2	2.78E+2	2.16E+2	1.64E+2	1.21E+2	85.	52.	0.00
170	0.00	13.0	0.00	0.00	3.93E+2	3.51E+2	3.04E+2	2.54E+2	2.04E+2	1.60E+2	1.21E+2	89.	62.	38.	0.00
180	0.00	13.0	0.00	0.00	2.18E+2	2.08E+2	1.89E+2	1.63E+2	1.33E+2	1.06E+2	81.	60.	40.	24.	0.00
190	0.00	13.0	0.00	0.00	97.	1.17E+2	1.23E+2	1.16E+2	1.02E+2	85.	67.	49.	32.	16.	0.00
200	0.00	13.0	0.00	0.00	-22.	28.	58.	71.	71.	63.	52.	38.	23.	8.7	0.00
210	0.00	13.0	0.00	0.00	-1.57E+2	-78.	-24.	8.3	24.	28.	26.	18.	7.9	-2.3	0.00
220	0.00	13.0	0.00	0.00	-2.78E+2	-1.73E+2	-97.	-47.	-17.	-2.5	2.6	2.08E-2	-5.7	-12.	0.00
230	0.00	13.0	0.00	0.00	-3.83E+2	-2.55E+2	-1.61E+2	-95.	-53.	-29.	-17.	-14.	-16.	-20.	0.00
240	0.00	13.0	0.00	0.00	-4.67E+2	-3.22E+2	-2.12E+2	-1.34E+2	-82.	-49.	-31.	-25.	-24.	-25.	0.00
250	0.00	13.0	0.00	0.00	-5.25E+2	-3.66E+2	-2.45E+2	-1.58E+2	-98.	-61.	-39.	-31.	-28.	-29.	0.00
260	0.00	13.0	0.00	0.00	-5.56E+2	-3.88E+2	-2.60E+2	-1.67E+2	-1.04E+2	-64.	-41.	-32.	-30.	-31.	0.00
270	0.00	13.0	0.00	0.00	-5.61E+2	-3.91E+2	-2.60E+2	-1.66E+2	-1.01E+2	-60.	-38.	-30.	-28.	-30.	0.00
280	0.00	13.0	0.00	0.00	-5.42E+2	-3.75E+2	-2.46E+2	-1.54E+2	-90.	-51.	-30.	-23.	-23.	-27.	0.00
290	0.00	13.0	0.00	0.00	-4.97E+2	-3.38E+2	-2.16E+2	-1.29E+2	-70.	-35.	-17.	-13.	-16.	-22.	0.00
300	0.00	13.0	0.00	0.00	-4.26E+2	-2.80E+2	-1.69E+2	-91.	-40.	-11.	0.90	0.53	-6.2	-16.	0.00
310	0.00	13.0	0.00	0.00	-3.34E+2	-2.06E+2	-1.10E+2	-44.	-3.3	17.	22.	16.	5.0	-8.7	0.00
320	0.00	13.0	0.00	0.00	-2.26E+2	-1.19E+2	-42.	8.1	37.	47.	45.	34.	18.	0.31	0.00
330	0.00	13.0	0.00	0.00	-1.02E+2	-22.	34.	67.	81.	81.	70.	53.	32.	10.	0.00
340	0.00	13.0	0.00	0.00	35.	87.	1.19E+2	1.32E+2	1.31E+2	1.17E+2	97.	73.	47.	21.	0.00
350	0.00	13.0	0.00	0.00	1.81E+2	2.03E+2	2.09E+2	2.01E+2	1.83E+2	1.56E+2	1.25E+2	93.	62.	31.	0.00
360	0.00	13.0	0.00	0.00	3.29E+2	3.19E+2	2.99E+2	2.70E+2	2.34E+2	1.93E+2	1.52E+2	1.14E+2	77.	42.	0.00

Blade flapwise shear (Lb) Trim Solution

Psi	Time	Phi	Phi-D	Phi-DD	X / R									
deg	sec	deg	deg/s	deg/s^2	.0	.1	.2	.3	.4	.5	.6	.7	.8	.9	1.0
0	0.00	13.0	0.00	0.00	-73.	3.5	1.37E+2	2.78E+2	3.94E+2	4.54E+2	4.43E+2	3.55E+2	2.03E+2	-1.2	0.00
10	0.00	13.0	0.00	0.00	-70.	5.7	1.38E+2	2.78E+2	3.94E+2	4.54E+2	4.44E+2	3.57E+2	2.06E+2	1.8	0.00
20	0.00	13.0	0.00	0.00	2.8	78.	2.06E+2	3.36E+2	4.36E+2	4.77E+2	4.50E+2	3.52E+2	1.95E+2	-10.	0.00
30	0.00	13.0	0.00	0.00	35.	1.11E+2	2.37E+2	3.64E+2	4.58E+2	4.92E+2	4.58E+2	3.55E+2	1.94E+2	-12.	0.00
40	0.00	13.0	0.00	0.00	-8.0	69.	2.00E+2	3.34E+2	4.39E+2	4.85E+2	4.64E+2	3.69E+2	2.12E+2	4.8	0.00
50	0.00	13.0	0.00	0.00	-38.	41.	1.75E+2	3.14E+2	4.26E+2	4.81E+2	4.69E+2	3.80E+2	2.26E+2	18.	0.00
60	0.00	13.0	0.00	0.00	4.9	86.	2.18E+2	3.51E+2	4.52E+2	4.95E+2	4.73E+2	3.77E+2	2.19E+2	10.	0.00
70	0.00	13.0	0.00	0.00	47.	1.30E+2	2.61E+2	3.88E+2	4.78E+2	5.07E+2	4.74E+2	3.70E+2	2.09E+2	-0.17	0.00
80	0.00	13.0	0.00	0.00	10.	97.	2.31E+2	3.62E+2	4.59E+2	4.95E+2	4.69E+2	3.70E+2	2.12E+2	3.7	0.00
90	0.00	13.0	0.00	0.00	-56.	34.	1.74E+2	3.13E+2	4.21E+2	4.70E+2	4.58E+2	3.70E+2	2.17E+2	11.	0.00
100	0.00	13.0	0.00	0.00	-68.	26.	1.67E+2	3.06E+2	4.11E+2	4.58E+2	4.46E+2	3.58E+2	2.08E+2	4.0	0.00
110	0.00	13.0	0.00	0.00	-44.	53.	1.93E+2	3.26E+2	4.19E+2	4.55E+2	4.33E+2	3.39E+2	1.86E+2	-14.	0.00
120	0.00	13.0	0.00	0.00	-75.	26.	1.69E+2	3.03E+2	3.98E+2	4.35E+2	4.16E+2	3.25E+2	1.75E+2	-22.	0.00
130	0.00	13.0	0.00	0.00	-1.48E+2	-44.	1.04E+2	2.46E+2	3.52E+2	4.03E+2	3.98E+2	3.17E+2	1.75E+2	-19.	0.00
140	0.00	13.0	0.00	0.00	-1.86E+2	-79.	72.	2.17E+2	3.25E+2	3.81E+2	3.81E+2	3.05E+2	1.67E+2	-22.	0.00
150	0.00	13.0	0.00	0.00	-1.73E+2	-63.	87.	2.28E+2	3.28E+2	3.75E+2	3.68E+2	2.88E+2	1.50E+2	-37.	0.00
160	0.00	13.0	0.00	0.00	-1.73E+2	-61.	90.	2.29E+2	3.25E+2	3.68E+2	3.58E+2	2.76E+2	1.37E+2	-47.	0.00
170	0.00	13.0	0.00	0.00	-2.11E+2	-96.	56.	1.95E+2	2.93E+2	3.45E+2	3.43E+2	2.69E+2	1.39E+2	-37.	0.00
180	0.00	13.0	0.00	0.00	-2.98E+2	-1.81E+2	-25.	1.21E+2	2.33E+2	3.05E+2	3.21E+2	2.64E+2	1.46E+2	-22.	0.00
190	0.00	13.0	0.00	0.00	-3.73E+2	-2.55E+2	-94.	63.	1.89E+2	2.74E+2	3.03E+2	2.53E+2	1.38E+2	-33.	0.00
200	0.00	13.0	0.00	0.00	-3.12E+2	-1.95E+2	-37.	1.12E+2	2.22E+2	2.83E+2	2.90E+2	2.25E+2	9.97E+1	-74.	0.00
210	0.00	13.0	0.00	0.00	-2.20E+2	-1.04E+2	47.	1.82E+2	2.71E+2	3.05E+2	2.87E+2	2.04E+2	71.	-1.01E+2	0.00
220	0.00	13.0	0.00	0.00	-2.72E+2	-1.56E+2	-1.3	1.43E+2	2.48E+2	2.98E+2	2.94E+2	2.20E+2	91.	-81.	0.00
230	0.00	13.0	0.00	0.00	-3.51E+2	-2.36E+2	-75.	85.	2.13E+2	2.91E+2	3.12E+2	2.54E+2	1.32E+2	-43.	0.00
240	0.00	13.0	0.00	0.00	-2.76E+2	-1.64E+2	-6.5	1.47E+2	2.66E+2	3.32E+2	3.43E+2	2.76E+2	1.47E+2	-33.	0.00
250	0.00	13.0	0.00	0.00	-1.19E+2	-10.	1.38E+2	2.74E+2	3.68E+2	4.02E+2	3.80E+2	2.90E+2	1.46E+2	-41.	0.00
260	0.00	13.0	0.00	0.00	-65.	40.	1.86E+2	3.21E+2	4.14E+2	4.43E+2	4.15E+2	3.18E+2	1.67E+2	-27.	0.00
270	0.00	13.0	0.00	0.00	-1.19E+2	-16.	1.34E+2	2.82E+2	3.96E+2	4.50E+2	4.42E+2	3.57E+2	2.09E+2	9.7	0.00
280	0.00	13.0	0.00	0.00	-1.17E+2	-17.	1.32E+2	2.83E+2	4.03E+2	4.64E+2	4.62E+2	3.80E+2	2.31E+2	27.	0.00
290	0.00	13.0	0.00	0.00	-15.	80.	2.22E+2	3.60E+2	4.61E+2	5.01E+2	4.77E+2	3.79E+2	2.21E+2	12.	0.00
300	0.00	13.0	0.00	0.00	47.	1.38E+2	2.75E+2	4.04E+2	4.95E+2	5.22E+2	4.83E+2	3.75E+2	2.10E+2	-0.77	0.00
310	0.00	13.0	0.00	0.00	-12.	77.	2.15E+2	3.53E+2	4.59E+2	5.03E+2	4.79E+2	3.81E+2	2.20E+2	9.5	0.00
320	0.00	13.0	0.00	0.00	-81.	4.5	1.45E+2	2.92E+2	4.13E+2	4.76E+2	4.70E+2	3.83E+2	2.30E+2	20.	0.00
330	0.00	13.0	0.00	0.00	-51.	32.	1.68E+2	3.08E+2	4.21E+2	4.75E+2	4.61E+2	3.70E+2	2.15E+2	6.0	0.00
340	0.00	13.0	0.00	0.00	16.	95.	2.25E+2	3.55E+2	4.51E+2	4.87E+2	4.54E+2	3.51E+2	1.91E+2	-17.	0.00
350	0.00	13.0	0.00	0.00	-2.6	75.	2.05E+2	3.36E+2	4.37E+2	4.77E+2	4.48E+2	3.47E+2	1.89E+2	-17.	0.00
360	0.00	13.0	0.00	0.00	-73.	3.9	1.37E+2	2.78E+2	3.94E+2	4.54E+2	4.43E+2	3.55E+2	2.03E+2	-1.3	0.00

Blade flapwise moment (ft-Lbs

Trim Solution

Psi	Time	Phi	Phi-D	Phi-DD	X / R										
deg	sec	deg	deg/s	deg/s^2	.0	.1	.2	.3	.4	.5	.6	.7	.8	.9	1.0
0	0.00	13.0	0.00	0.00	-6.45E+3	-6.63E+3	-6.46E+3	-5.82E+3	-4.73E+3	-3.33E+3	-1.88E+3	-6.16E+2	1.91E+2	3.61E+2	0.00
10	0.00	13.0	0.00	0.00	-6.50E+3	-6.67E+3	-6.49E+3	-5.85E+3	-4.76E+3	-3.36E+3	-1.90E+3	-6.38E+2	1.76E+2	3.54E+2	0.00
20	0.00	13.0	0.00	0.00	-7.49E+3	-7.39E+3	-6.95E+3	-6.08E+3	-4.81E+3	-3.30E+3	-1.80E+3	-5.37E+2	2.46E+2	3.83E+2	0.00
30	0.00	13.0	0.00	0.00	-8.02E+3	-7.79E+3	-7.24E+3	-6.26E+3	-4.91E+3	-3.34E+3	-1.80E+3	-5.22E+2	2.60E+2	3.89E+2	0.00
40	0.00	13.0	0.00	0.00	-7.60E+3	-7.53E+3	-7.13E+3	-6.28E+3	-5.02E+3	-3.50E+3	-1.96E+3	-6.58E+2	1.72E+2	3.53E+2	0.00
50	0.00	13.0	0.00	0.00	-7.33E+3	-7.37E+3	-7.07E+3	-6.30E+3	-5.10E+3	-3.62E+3	-2.09E+3	-7.61E+2	1.05E+2	3.27E+2	0.00
60	0.00	13.0	0.00	0.00	-7.94E+3	-7.82E+3	-7.35E+3	-6.44E+3	-5.13E+3	-3.58E+3	-2.02E+3	-6.99E+2	1.49E+2	3.45E+2	0.00
70	0.00	13.0	0.00	0.00	-8.52E+3	-8.23E+3	-7.61E+3	-6.55E+3	-5.13E+3	-3.51E+3	-1.93E+3	-6.11E+2	2.08E+2	3.69E+2	0.00
80	0.00	13.0	0.00	0.00	-8.03E+3	-7.88E+3	-7.37E+3	-6.41E+3	-5.06E+3	-3.50E+3	-1.95E+3	-6.41E+2	1.85E+2	3.59E+2	0.00
90	0.00	13.0	0.00	0.00	-7.10E+3	-7.19E+3	-6.90E+3	-6.13E+3	-4.94E+3	-3.49E+3	-1.99E+3	-7.00E+2	1.38E+2	3.38E+2	0.00
100	0.00	13.0	0.00	0.00	-6.81E+3	-6.94E+3	-6.68E+3	-5.94E+3	-4.77E+3	-3.35E+3	-1.90E+3	-6.38E+2	1.72E+2	3.50E+2	0.00
110	0.00	13.0	0.00	0.00	-6.95E+3	-6.98E+3	-6.62E+3	-5.79E+3	-4.57E+3	-3.13E+3	-1.70E+3	-4.85E+2	2.66E+2	3.86E+2	0.00
120	0.00	13.0	0.00	0.00	-6.37E+3	-6.51E+3	-6.24E+3	-5.49E+3	-4.34E+3	-2.97E+3	-1.59E+3	-4.19E+2	2.98E+2	3.96E+2	0.00
130	0.00	13.0	0.00	0.00	-5.25E+3	-5.65E+3	-5.63E+3	-5.09E+3	-4.12E+3	-2.88E+3	-1.58E+3	-4.43E+2	2.70E+2	3.81E+2	0.00
140	0.00	13.0	0.00	0.00	-4.57E+3	-5.12E+3	-5.21E+3	-4.79E+3	-3.91E+3	-2.75E+3	-1.51E+3	-4.10E+2	2.81E+2	3.82E+2	0.00
150	0.00	13.0	0.00	0.00	-4.58E+3	-5.07E+3	-5.11E+3	-4.63E+3	-3.72E+3	-2.56E+3	-1.34E+3	-2.88E+2	3.53E+2	4.08E+2	0.00
160	0.00	13.0	0.00	0.00	-4.46E+3	-4.94E+3	-4.97E+3	-4.48E+3	-3.57E+3	-2.42E+3	-1.23E+3	-2.06E+2	4.00E+2	4.25E+2	0.00
170	0.00	13.0	0.00	0.00	-3.84E+3	-4.45E+3	-4.60E+3	-4.23E+3	-3.44E+3	-2.38E+3	-1.25E+3	-2.62E+2	3.39E+2	3.88E+2	0.00
180	0.00	13.0	0.00	0.00	-2.48E+3	-3.43E+3	-3.88E+3	-3.78E+3	-3.23E+3	-2.34E+3	-1.31E+3	-3.62E+2	2.48E+2	3.41E+2	0.00
190	0.00	13.0	0.00	0.00	-1.26E+3	-2.49E+3	-3.21E+3	-3.33E+3	-2.95E+3	-2.18E+3	-1.22E+3	-3.00E+2	2.96E+2	3.70E+2	0.00
200	0.00	13.0	0.00	0.00	-1.80E+3	-2.79E+3	-3.29E+3	-3.22E+3	-2.68E+3	-1.83E+3	-8.57E+2	7.5	5.08E+2	4.63E+2	0.00
210	0.00	13.0	0.00	0.00	-2.87E+3	-3.52E+3	-3.69E+3	-3.34E+3	-2.59E+3	-1.61E+3	-6.01E+2	2.29E+2	6.53E+2	5.19E+2	0.00
220	0.00	13.0	0.00	0.00	-2.34E+3	-3.18E+3	-3.54E+3	-3.35E+3	-2.71E+3	-1.79E+3	-7.86E+2	75.	5.51E+2	4.77E+2	0.00
230	0.00	13.0	0.00	0.00	-1.64E+3	-2.78E+3	-3.43E+3	-3.49E+3	-3.02E+3	-2.18E+3	-1.17E+3	-2.36E+2	3.51E+2	3.97E+2	0.00
240	0.00	13.0	0.00	0.00	-3.00E+3	-3.87E+3	-4.26E+3	-4.09E+3	-3.43E+3	-2.44E+3	-1.32E+3	-3.17E+2	3.14E+2	3.86E+2	0.00
250	0.00	13.0	0.00	0.00	-5.46E+3	-5.75E+3	-5.59E+3	-4.94E+3	-3.88E+3	-2.60E+3	-1.32E+3	-2.49E+2	3.83E+2	4.19E+2	0.00
260	0.00	13.0	0.00	0.00	-6.60E+3	-6.70E+3	-6.37E+3	-5.55E+3	-4.34E+3	-2.92E+3	-1.53E+3	-3.69E+2	3.24E+2	4.00E+2	0.00
270	0.00	13.0	0.00	0.00	-6.32E+3	-6.62E+3	-6.49E+3	-5.85E+3	-4.75E+3	-3.37E+3	-1.93E+3	-6.75E+2	1.37E+2	3.30E+2	0.00
280	0.00	13.0	0.00	0.00	-6.58E+3	-6.89E+3	-6.77E+3	-6.14E+3	-5.03E+3	-3.62E+3	-2.13E+3	-8.18E+2	56.	3.02E+2	0.00
290	0.00	13.0	0.00	0.00	-8.00E+3	-7.92E+3	-7.46E+3	-6.53E+3	-5.18E+3	-3.61E+3	-2.04E+3	-7.07E+2	1.43E+2	3.42E+2	0.00
300	0.00	13.0	0.00	0.00	-8.80E+3	-8.50E+3	-7.83E+3	-6.72E+3	-5.24E+3	-3.57E+3	-1.95E+3	-6.10E+2	2.15E+2	3.74E+2	0.00
310	0.00	13.0	0.00	0.00	-7.96E+3	-7.88E+3	-7.44E+3	-6.53E+3	-5.20E+3	-3.63E+3	-2.04E+3	-6.99E+2	1.56E+2	3.50E+2	0.00
320	0.00	13.0	0.00	0.00	-6.91E+3	-7.10E+3	-6.92E+3	-6.25E+3	-5.11E+3	-3.66E+3	-2.13E+3	-7.92E+2	89.	3.24E+2	0.00
330	0.00	13.0	0.00	0.00	-7.10E+3	-7.18E+3	-6.91E+3	-6.16E+3	-4.97E+3	-3.50E+3	-1.98E+3	-6.77E+2	1.62E+2	3.53E+2	0.00
340	0.00	13.0	0.00	0.00	-7.77E+3	-7.61E+3	-7.11E+3	-6.17E+3	-4.84E+3	-3.29E+3	-1.76E+3	-4.92E+2	2.83E+2	4.01E+2	0.00
350	0.00	13.0	0.00	0.00	-7.42E+3	-7.33E+3	-6.90E+3	-6.03E+3	-4.76E+3	-3.25E+3	-1.75E+3	-4.89E+2	2.80E+2	3.98E+2	0.00
360	0.00	13.0	0.00	0.00	-6.45E+3	-6.63E+3	-6.46E+3	-5.82E+3	-4.73E+3	-3.33E+3	-1.88E+3	-6.15E+2	1.92E+2	3.61E+2	0.00

Average Flapwise Moment = -6020.8 (ft-Lbs) at the 20% station

Blade edgewise moment (ft-Lbs) Trim Solution

Psi	Time	Phi	Phi-D	Phi-DD	X / R										
deg	sec	deg	deg/s	deg/s^2	.0	.1	.2	.3	.4	.5	.6	.7	.8	.9	1.0
0	0.00	13.0	0.00	0.00	7.10E+3	5.87E+3	4.69E+3	3.61E+3	2.65E+3	1.84E+3	1.18E+3	6.74E+2	3.13E+2	87.	0.00
10	0.00	13.0	0.00	0.00	9.01E+3	7.28E+3	5.72E+3	4.34E+3	3.16E+3	2.19E+3	1.41E+3	8.19E+2	3.90E+2	1.15E+2	0.00
20	0.00	13.0	0.00	0.00	1.09E+4	8.66E+3	6.72E+3	5.06E+3	3.66E+3	2.53E+3	1.64E+3	9.57E+2	4.64E+2	1.42E+2	0.00
30	0.00	13.0	0.00	0.00	1.26E+4	9.97E+3	7.67E+3	5.73E+3	4.13E+3	2.85E+3	1.84E+3	1.08E+3	5.31E+2	1.66E+2	0.00
40	0.00	13.0	0.00	0.00	1.42E+4	1.11E+4	8.52E+3	6.34E+3	4.55E+3	3.13E+3	2.03E+3	1.20E+3	5.92E+2	1.88E+2	0.00
50	0.00	13.0	0.00	0.00	1.55E+4	1.21E+4	9.22E+3	6.84E+3	4.90E+3	3.37E+3	2.19E+3	1.30E+3	6.46E+2	2.07E+2	0.00
60	0.00	13.0	0.00	0.00	1.66E+4	1.29E+4	9.78E+3	7.23E+3	5.17E+3	3.56E+3	2.31E+3	1.38E+3	6.89E+2	2.23E+2	0.00
70	0.00	13.0	0.00	0.00	1.73E+4	1.34E+4	1.02E+4	7.51E+3	5.36E+3	3.69E+3	2.40E+3	1.43E+3	7.17E+2	2.34E+2	0.00
80	0.00	13.0	0.00	0.00	1.78E+4	1.37E+4	1.04E+4	7.65E+3	5.46E+3	3.75E+3	2.44E+3	1.45E+3	7.31E+2	2.39E+2	0.00
90	0.00	13.0	0.00	0.00	1.78E+4	1.38E+4	1.04E+4	7.65E+3	5.45E+3	3.74E+3	2.44E+3	1.45E+3	7.33E+2	2.40E+2	0.00
100	0.00	13.0	0.00	0.00	1.75E+4	1.35E+4	1.02E+4	7.49E+3	5.34E+3	3.67E+3	2.39E+3	1.43E+3	7.20E+2	2.36E+2	0.00
110	0.00	13.0	0.00	0.00	1.68E+4	1.30E+4	9.80E+3	7.21E+3	5.13E+3	3.52E+3	2.29E+3	1.37E+3	6.91E+2	2.27E+2	0.00
120	0.00	13.0	0.00	0.00	1.59E+4	1.22E+4	9.24E+3	6.79E+3	4.84E+3	3.32E+3	2.16E+3	1.29E+3	6.48E+2	2.13E+2	0.00
130	0.00	13.0	0.00	0.00	1.46E+4	1.13E+4	8.52E+3	6.26E+3	4.46E+3	3.05E+3	1.98E+3	1.18E+3	5.94E+2	1.94E+2	0.00
140	0.00	13.0	0.00	0.00	1.30E+4	1.01E+4	7.64E+3	5.62E+3	4.01E+3	2.74E+3	1.78E+3	1.06E+3	5.30E+2	1.73E+2	0.00
150	0.00	13.0	0.00	0.00	1.13E+4	8.77E+3	6.66E+3	4.91E+3	3.50E+3	2.40E+3	1.55E+3	9.20E+2	4.58E+2	1.48E+2	0.00
160	0.00	13.0	0.00	0.00	9.36E+3	7.35E+3	5.61E+3	4.15E+3	2.97E+3	2.03E+3	1.31E+3	7.70E+2	3.80E+2	1.21E+2	0.00
170	0.00	13.0	0.00	0.00	6.77E+3	5.35E+3	4.11E+3	3.05E+3	2.18E+3	1.49E+3	9.59E+2	5.60E+2	2.74E+2	86.	0.00
180	0.00	13.0	0.00	0.00	4.24E+3	3.43E+3	2.67E+3	2.00E+3	1.44E+3	9.85E+2	6.30E+2	3.64E+2	1.75E+2	53.	0.00
190	0.00	13.0	0.00	0.00	2.88E+3	2.47E+3	2.01E+3	1.56E+3	1.14E+3	7.87E+2	4.99E+2	2.79E+2	1.24E+2	32.	0.00
200	0.00	13.0	0.00	0.00	1.55E+3	1.53E+3	1.36E+3	1.11E+3	8.37E+2	5.81E+2	3.61E+2	1.89E+2	72.	11.	0.00
210	0.00	13.0	0.00	0.00	-2.58E+2	1.82E+2	3.70E+2	3.95E+2	3.31E+2	2.30E+2	1.27E+2	44.	-5.3	-16.	0.00
220	0.00	13.0	0.00	0.00	-1.85E+3	-1.00E+3	-4.95E+2	-2.28E+2	-1.11E+2	-76.	-78.	-85.	-74.	-40.	0.00
230	0.00	13.0	0.00	0.00	-3.23E+3	-2.02E+3	-1.24E+3	-7.58E+2	-4.80E+2	-3.27E+2	-2.42E+2	-1.85E+2	-1.27E+2	-59.	0.00
240	0.00	13.0	0.00	0.00	-4.31E+3	-2.82E+3	-1.81E+3	-1.16E+3	-7.56E+2	-5.11E+2	-3.61E+2	-2.57E+2	-1.66E+2	-73.	0.00
250	0.00	13.0	0.00	0.00	-4.99E+3	-3.31E+3	-2.16E+3	-1.40E+3	-9.18E+2	-6.20E+2	-4.33E+2	-3.02E+2	-1.91E+2	-83.	0.00
260	0.00	13.0	0.00	0.00	-5.28E+3	-3.50E+3	-2.28E+3	-1.48E+3	-9.66E+2	-6.53E+2	-4.57E+2	-3.21E+2	-2.03E+2	-88.	0.00
270	0.00	13.0	0.00	0.00	-5.24E+3	-3.44E+3	-2.22E+3	-1.41E+3	-9.15E+2	-6.14E+2	-4.32E+2	-3.07E+2	-1.98E+2	-88.	0.00
280	0.00	13.0	0.00	0.00	-4.88E+3	-3.15E+3	-1.98E+3	-1.23E+3	-7.72E+2	-5.09E+2	-3.59E+2	-2.62E+2	-1.76E+2	-81.	0.00
290	0.00	13.0	0.00	0.00	-4.17E+3	-2.60E+3	-1.55E+3	-9.06E+2	-5.35E+2	-3.41E+2	-2.47E+2	-1.94E+2	-1.41E+2	-70.	0.00
300	0.00	13.0	0.00	0.00	-3.12E+3	-1.79E+3	-9.41E+2	-4.54E+2	-2.11E+2	-1.19E+2	-1.03E+2	-1.08E+2	-98.	-56.	0.00
310	0.00	13.0	0.00	0.00	-1.80E+3	-7.87E+2	-1.95E+2	92.	1.78E+2	1.47E+2	71.	-4.0	-45.	-38.	0.00
320	0.00	13.0	0.00	0.00	-3.06E+2	3.42E+2	6.42E+2	7.01E+2	6.11E+2	4.47E+2	2.69E+2	1.18E+2	19.	-16.	0.00
330	0.00	13.0	0.00	0.00	1.37E+3	1.59E+3	1.57E+3	1.37E+3	1.08E+3	7.73E+2	4.85E+2	2.51E+2	89.	8.2	0.00
340	0.00	13.0	0.00	0.00	3.21E+3	2.97E+3	2.57E+3	2.09E+3	1.59E+3	1.12E+3	7.11E+2	3.89E+2	1.62E+2	34.	0.00
350	0.00	13.0	0.00	0.00	5.15E+3	4.42E+3	3.63E+3	2.85E+3	2.12E+3	1.48E+3	9.43E+2	5.29E+2	2.36E+2	60.	0.00
360	0.00	13.0	0.00	0.00	7.10E+3	5.87E+3	4.69E+3	3.61E+3	2.65E+3	1.84E+3	1.18E+3	6.74E+2	3.13E+2	87.	0.00

Blade torsion (ft-Lbs) Trim Solution

Psi	Time	Phi	Phi-D	Phi-DD											
deg	sec	deg	deg/s	deg/s^2	.0	.1	.2	.3	.4	.5	.6	.7	.8	.9	1.0
0	0.00	13.0	0.00	0.00	-16.	-15.	-14.	-11.	-8.0	-4.4	-0.82	2.2	3.8	3.2	0.00
10	0.00	13.0	0.00	0.00	-25.	-24.	-22.	-18.	-14.	-9.2	-4.4	-0.27	2.4	2.7	0.00
20	0.00	13.0	0.00	0.00	-35.	-34.	-30.	-26.	-20.	-14.	-7.6	-2.3	1.3	2.3	0.00
30	0.00	13.0	0.00	0.00	-44.	-43.	-39.	-33.	-26.	-18.	-11.	-4.5	7.61E-2	1.9	0.00
40	0.00	13.0	0.00	0.00	-53.	-51.	-47.	-40.	-32.	-24.	-15.	-7.4	-1.5	1.3	0.00
50	0.00	13.0	0.00	0.00	-60.	-58.	-53.	-46.	-38.	-28.	-19.	-9.9	-3.0	0.78	0.00
60	0.00	13.0	0.00	0.00	-66.	-65.	-59.	-51.	-41.	-31.	-21.	-11.	-3.6	0.56	0.00
70	0.00	13.0	0.00	0.00	-71.	-68.	-62.	-53.	-43.	-32.	-21.	-11.	-3.7	0.51	0.00
80	0.00	13.0	0.00	0.00	-70.	-68.	-62.	-53.	-43.	-32.	-21.	-12.	-3.9	0.45	0.00
90	0.00	13.0	0.00	0.00	-66.	-65.	-59.	-51.	-41.	-31.	-21.	-11.	-3.8	0.47	0.00
100	0.00	13.0	0.00	0.00	-61.	-59.	-54.	-46.	-37.	-28.	-18.	-9.5	-2.8	0.80	0.00
110	0.00	13.0	0.00	0.00	-54.	-52.	-47.	-40.	-31.	-23.	-14.	-6.8	-1.3	1.3	0.00
120	0.00	13.0	0.00	0.00	-45.	-43.	-39.	-32.	-25.	-17.	-10.	-4.2	0.14	1.8	0.00
130	0.00	13.0	0.00	0.00	-34.	-33.	-29.	-24.	-18.	-12.	-6.7	-1.9	1.4	2.3	0.00
140	0.00	13.0	0.00	0.00	-24.	-23.	-20.	-16.	-12.	-7.0	-2.8	0.70	2.8	2.8	0.00
150	0.00	13.0	0.00	0.00	-15.	-14.	-12.	-8.7	-5.1	-1.6	1.4	3.5	4.3	3.3	0.00
160	0.00	13.0	0.00	0.00	-6.7	-6.1	-4.3	-1.9	0.69	3.1	4.9	6.0	5.7	3.8	0.00
170	0.00	13.0	0.00	0.00	3.6	3.9	4.9	6.2	7.4	8.3	8.7	8.4	7.0	4.2	0.00
180	0.00	13.0	0.00	0.00	13.	13.	13.	14.	13.	13.	12.	11.	8.1	4.6	0.00
190	0.00	13.0	0.00	0.00	18.	18.	18.	17.	17.	15.	14.	12.	8.8	4.9	0.00
200	0.00	13.0	0.00	0.00	21.	21.	21.	20.	19.	18.	16.	13.	9.5	5.1	0.00
210	0.00	13.0	0.00	0.00	25.	25.	24.	23.	22.	20.	17.	14.	10.	5.3	0.00
220	0.00	13.0	0.00	0.00	29.	28.	27.	26.	24.	21.	18.	15.	11.	5.5	0.00
230	0.00	13.0	0.00	0.00	32.	31.	30.	28.	26.	23.	20.	16.	11.	5.8	0.00
240	0.00	13.0	0.00	0.00	36.	35.	34.	31.	28.	25.	21.	17.	12.	6.0	0.00
250	0.00	13.0	0.00	0.00	40.	39.	37.	34.	31.	27.	22.	18.	12.	6.2	0.00
260	0.00	13.0	0.00	0.00	43.	42.	39.	36.	32.	28.	23.	18.	13.	6.4	0.00
270	0.00	13.0	0.00	0.00	43.	42.	40.	36.	33.	28.	24.	19.	13.	6.6	0.00
280	0.00	13.0	0.00	0.00	42.	41.	38.	35.	31.	27.	23.	18.	13.	6.6	0.00
290	0.00	13.0	0.00	0.00	39.	38.	35.	32.	28.	25.	21.	17.	12.	6.3	0.00
300	0.00	13.0	0.00	0.00	33.	32.	30.	27.	24.	21.	19.	15.	11.	6.0	0.00
310	0.00	13.0	0.00	0.00	25.	25.	23.	21.	19.	18.	16.	13.	10.	5.6	0.00
320	0.00	13.0	0.00	0.00	17.	17.	16.	15.	14.	13.	12.	11.	9.0	5.2	0.00
330	0.00	13.0	0.00	0.00	9.2	9.0	8.7	8.5	8.6	8.8	9.1	8.9	7.6	4.7	0.00
340	0.00	13.0	0.00	0.00	0.72	0.75	1.2	2.0	3.2	4.7	6.1	6.9	6.5	4.2	0.00
350	0.00	13.0	0.00	0.00	-7.7	-7.4	-6.3	-4.5	-2.2	0.41	2.9	4.8	5.3	3.8	0.00
360	0.00	13.0	0.00	0.00	-16.	-15.	-14.	-11.	-8.0	-4.4	-0.81	2.2	3.8	3.2	0.00

Blade flapwise moment expansion coefficients Trim Solution

X / R

	.0	.1	.2	.3	.4	.5	.6	.7	.8	.9	1.
A0=	-5.89E+3	-6.16E+3	-6.02E+3	-5.39E+3	-4.33E+3	-3.01E+3	-1.65E+3	-4.73E+2	2.60E+2	3.79E+2	0.00
B0=	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
A1=	-2.46E+3	-2.00E+3	-1.62E+3	-1.29E+3	-9.83E+2	-6.88E+2	-4.41E+2	-2.50E+2	-1.13E+2	-29.	0.00
B1=	-7.25E+2	-5.68E+2	-4.37E+2	-3.29E+2	-2.40E+2	-1.67E+2	-1.09E+2	-63.	-29.	-7.8	0.00
A2=	1.14E+3	9.54E+2	7.77E+2	6.09E+2	4.51E+2	3.16E+2	2.08E+2	1.23E+2	61.	19.	0.00
B2=	7.40E+2	6.26E+2	5.17E+2	4.15E+2	3.20E+2	2.34E+2	1.59E+2	98.	49.	15.	0.00
A3=	3.60E+2	3.11E+2	2.64E+2	2.21E+2	1.82E+2	1.45E+2	1.10E+2	77.	46.	18.	0.00
B3=	-3.51E+2	-2.94E+2	-2.40E+2	-1.90E+2	-1.45E+2	-1.06E+2	-75.	-50.	-30.	-12.	0.00
A4=	-1.03E+2	-93.	-84.	-77.	-70.	-63.	-54.	-43.	-29.	-13.	0.00
B4=	59.	49.	39.	31.	23.	17.	12.	9.1	6.3	3.2	0.00
A5=	-3.3	7.2	17.	27.	36.	41.	40.	35.	25.	12.	0.00
B5=	-24.	-19.	-15.	-10.	-7.0	-4.5	-3.0	-2.3	-2.0	-1.3	0.00
A6=	76.	49.	24.	0.80	-19.	-32.	-36.	-33.	-24.	-11.	0.00
B6=	18.	14.	9.8	6.0	2.8	0.66	-0.29	-0.29	0.18	0.44	0.00
A7=	-1.65E+2	-1.14E+2	-66.	-23.	12.	35.	43.	40.	29.	13.	0.00
B7=	-42.	-31.	-20.	-10.	-2.5	2.7	5.0	4.8	3.0	0.92	0.00
A8=	4.35E+2	3.05E+2	1.81E+2	72.	-12.	-63.	-81.	-75.	-53.	-23.	0.00
B8=	5.58E+2	3.94E+2	2.39E+2	1.02E+2	-3.1	-69.	-94.	-86.	-59.	-24.	0.00
A9=	2.01E+2	1.41E+2	85.	36.	0.32	-21.	-27.	-23.	-14.	-4.7	0.00
B9=	-42.	-29.	-17.	-5.8	1.9	5.8	6.6	5.4	3.4	1.3	0.00
A*=	-95.	-66.	-39.	-16.	-0.50	8.4	11.	8.5	4.4	0.96	0.00
B*=	14.	10.	5.8	2.3	-7.40E-2	-1.2	-1.4	-1.1	-0.58	-0.18	0.00

Mean Rotor Torque	=	13993.57 ft-Lbs
Mean Rotor Power	=	119.21 KW
No. of Data Points	=	36

Low-Speed Shaft Loads in Rotor coordinates

Azimuth Angle	Fxr	Fyr	Fzr	Mxr	Myr	Mzr
0.000	118.669	3533.737	-1731.120	-3878.388	12628.680	-394.485
10.000	389.462	3460.918	-1712.961	-5178.290	13183.030	-811.221
20.000	650.965	3594.173	-1637.488	-5548.472	13814.660	-1216.224
30.000	918.805	3717.303	-1504.489	-4769.990	13839.520	-1662.392
40.000	1160.662	3622.955	-1334.563	-4817.126	13784.990	-2060.046
50.000	1370.130	3515.534	-1130.519	-5286.656	13678.690	-2400.547
60.000	1536.050	3632.255	-883.760	-4450.380	13718.360	-2666.971
70.000	1650.852	3829.759	-600.329	-2344.472	13919.000	-2843.988
80.000	1714.129	3845.875	-301.410	-575.671	14090.920	-2926.976
90.000	1727.833	3726.644	-3.021	23.525	14136.820	-2921.154
100.000	1690.108	3717.043	294.845	498.060	14165.760	-2828.482
110.000	1598.671	3841.529	591.435	1799.442	14282.210	-2646.024
120.000	1456.907	3872.376	872.473	3216.859	14378.260	-2378.178
130.000	1273.284	3741.077	1118.143	3372.287	14329.000	-2041.760
140.000	1054.319	3634.080	1324.006	2757.436	14193.750	-1652.779
150.000	803.006	3677.928	1495.436	2797.454	14112.910	-1217.490
160.000	524.975	3743.789	1628.063	3540.189	14086.620	-742.866
170.000	204.368	3689.524	1705.965	3651.546	13348.490	-170.365
180.000	-118.669	3533.737	1731.120	3878.388	12628.680	394.485
190.000	-389.462	3460.918	1712.961	5178.290	13183.030	811.221
200.000	-650.965	3594.173	1637.488	5548.472	13814.660	1216.224
210.000	-918.805	3717.303	1504.489	4769.990	13839.520	1662.392
220.000	-1160.662	3622.955	1334.563	4817.126	13784.990	2060.046
230.000	-1370.130	3515.534	1130.519	5286.656	13678.690	2400.547
240.000	-1536.050	3632.255	883.760	4450.380	13718.360	2666.971
250.000	-1650.852	3829.759	600.329	2344.472	13919.000	2843.988
260.000	-1714.129	3845.875	301.410	575.671	14090.920	2926.976
270.000	-1727.833	3726.644	3.021	-23.525	14136.820	2921.154

280.000	-1690.108	3717.043	-294.845	-498.060	14165.760	2828.482
290.000	-1598.671	3841.529	-591.435	-1799.442	14282.210	2646.024
300.000	-1456.907	3872.376	-872.473	-3216.859	14378.260	2378.178
310.000	-1273.284	3741.077	-1118.143	-3372.287	14329.000	2041.760
320.000	-1054.319	3634.080	-1324.006	-2757.436	14193.750	1652.779
330.000	-803.006	3677.928	-1495.436	-2797.454	14112.910	1217.490
340.000	-524.975	3743.789	-1628.063	-3540.189	14086.620	742.866
350.000	-204.368	3689.524	-1705.965	-3651.546	13348.490	170.365
360.000	118.669	3533.737	-1731.120	-3878.388	12628.680	-394.485

Hub loads in fixed frame hub coordinates

Azimuth Angle	Fxh	Fyh	Fzh	Mxh	Myh	Mzh
0.000	118.669	3533.737	-1731.120	-3878.388	12628.680	-394.485
10.000	86.093	3460.918	-1754.567	-5240.487	13183.030	100.304
20.000	51.653	3594.173	-1761.379	-5629.832	13814.660	754.813
30.000	43.464	3717.303	-1762.328	-4962.129	13839.520	945.321
40.000	31.278	3622.955	-1768.393	-5014.305	13784.990	1518.302
50.000	14.675	3515.534	-1776.264	-5237.123	13678.690	2506.772
60.000	2.666	3632.255	-1772.138	-4534.854	13718.360	2520.657
70.000	0.500	3829.759	-1756.618	-3474.331	13919.000	1230.382
80.000	0.824	3845.875	-1740.426	-2982.472	14090.920	58.661
90.000	-3.022	3726.644	-1727.833	-2921.154	14136.820	-23.525
100.000	-3.119	3717.043	-1715.630	-2871.998	14165.760	0.668
110.000	8.989	3841.529	-1704.542	-3101.895	14282.210	-785.929
120.000	27.130	3872.376	-1697.955	-3667.992	14378.260	-1596.792
130.000	38.095	3741.077	-1694.121	-3731.744	14329.000	-1270.904
140.000	43.399	3634.080	-1691.951	-3174.704	14193.750	-506.344
150.000	52.295	3677.928	-1696.588	-3031.411	14112.910	-344.350
160.000	63.515	3743.789	-1709.430	-3580.765	14086.620	-512.750
170.000	94.974	3689.524	-1715.536	-3625.655	13348.490	-466.308

180.000	118.669	3533.737	-1731.120	-3878.388	12628.680	-394.485
190.000	86.093	3460.918	-1754.567	-5240.487	13183.030	100.304
200.000	51.653	3594.173	-1761.379	-5629.832	13814.660	754.813
210.000	43.464	3717.303	-1762.328	-4962.129	13839.520	945.321
220.000	31.278	3622.955	-1768.393	-5014.305	13784.990	1518.302
230.000	14.675	3515.534	-1776.264	-5237.123	13678.690	2506.772
240.000	2.666	3632.255	-1772.138	-4534.854	13718.360	2520.657
250.000	0.500	3829.759	-1756.618	-3474.331	13919.000	1230.382
260.000	0.824	3845.875	-1740.426	-2982.472	14090.920	58.661
270.000	-3.022	3726.644	-1727.833	-2921.154	14136.820	-23.525
280.000	-3.119	3717.043	-1715.630	-2871.998	14165.760	0.668
290.000	8.989	3841.529	-1704.542	-3101.895	14282.210	-785.929
300.000	27.130	3872.376	-1697.955	-3667.992	14378.260	-1596.793
310.000	38.096	3741.077	-1694.120	-3731.743	14329.000	-1270.904
320.000	43.399	3634.080	-1691.951	-3174.704	14193.750	-506.344
330.000	52.295	3677.928	-1696.588	-3031.411	14112.910	-344.351
340.000	63.516	3743.789	-1709.430	-3580.765	14086.620	-512.751
350.000	94.974	3689.524	-1715.536	-3625.655	13348.490	-466.309
360.000	118.669	3533.737	-1731.120	-3878.388	12628.680	-394.484

Harmonics of Rotor Shaft Loads

	Fxr	Fyr	Fzr	Mxr	Myr	Mzr
cos(0*PSI)	0.000	3688.695	0.000	0.000	13871.760	0.000
sin(0.*PSI)	0.000	0.000	0.000	0.000	0.000	0.000
cos(PSI)	80.548	0.000	-1737.332	-4941.545	0.000	-291.948
sin(PSI)	1726.760	0.000	-5.872	-706.891	0.000	-2909.703
cos(2.*PSI)	0.000	-98.942	0.000	0.000	-381.793	0.000
sin(2.*PSI)	0.000	-60.532	0.000	0.000	-260.192	0.000
cos(3.*PSI)	7.620	0.000	4.263	778.822	0.000	-18.037
sin(3.*PSI)	-2.633	0.000	-2.543	-766.651	0.001	16.298

cos(4.*PSI)	0.000	5.500	0.000	0.000	-239.641	0.000
sin(4.*PSI)	0.000	-5.569	0.000	0.000	49.886	0.000
cos(5.*PSI)	10.199	0.000	-0.545	-8.898	0.000	-27.590
sin(5.*PSI)	-0.878	0.000	0.016	-54.854	0.000	2.769

Harmonics of Hub loads in Fixed Coordinates

	Fxh	Fyh	Fzh	Mxh	Myh	Mzh
cos(0*PSI)	37.338	3688.695	-1732.046	-3925.625	13871.760	207.472
sin(0.*PSI)	0.000	0.000	0.000	0.000	0.000	0.000
cos(PSI)	0.000	0.000	0.000	0.000	0.000	0.000
sin(PSI)	0.000	0.000	0.000	0.000	0.000	0.000
cos(2.*PSI)	45.748	-98.942	-1.838	-618.361	-381.794	-125.112
sin(2.*PSI)	-8.734	-60.532	-40.672	-873.727	-260.192	1413.482
cos(3.*PSI)	0.000	0.000	0.000	0.000	-0.001	0.000
sin(3.*PSI)	0.000	0.000	0.000	0.000	0.001	0.000
cos(4.*PSI)	10.189	5.500	0.982	378.198	-239.642	-378.712
sin(4.*PSI)	0.649	-5.569	0.026	-405.975	49.886	-384.327
cos(5.*PSI)	0.000	0.000	0.000	0.000	-0.001	0.000
sin(5.*PSI)	0.000	0.000	0.000	0.000	0.000	0.000

THIS IS THE FILE OF TURBULENT WINDSPEED DATA AS READ
BY MODULE 2 DURING A TURBULENT LOAD CALCULATION (Meters/sec).

15.0000	11.4375	12.1721	9.8636
30.0000	11.2795	11.4703	9.6749
45.0000	10.5139	10.3868	9.5616
60.0000	10.6547	10.4691	9.2097
75.0000	10.1082	10.4514	9.2604
90.0000	9.8202	10.5176	9.7193
105.0000	9.8885	9.7964	9.6447
120.0000	10.1578	8.9342	9.3867
135.0000	9.9126	8.5892	9.2205
150.0000	9.8776	8.2925	9.3452
165.0000	9.1952	9.3958	9.8515
180.0000	9.4681	8.5594	9.9078
195.0000	8.5003	9.1422	9.9595
210.0000	9.3399	8.3813	9.5617
225.0000	9.0926	7.1986	9.5399
240.0000	7.9973	7.8164	9.5954
255.0000	8.1461	9.0605	9.4897
270.0000	8.6887	9.2447	8.9503
285.0000	9.0807	9.1259	8.9510
300.0000	9.3613	10.0571	8.8075
315.0000	10.4193	11.3491	8.4452
330.0000	10.4663	12.0937	8.4692
345.0000	10.2636	12.1379	8.8571
360.0000	10.4984	12.1172	9.0080
15.0000	11.3167	11.9926	9.1126
30.0000	11.7563	11.1521	8.9411
45.0000	11.8934	10.6483	8.7469
60.0000	10.8782	10.9209	8.8334
75.0000	9.7996	10.4784	8.8542
90.0000	10.0067	9.8132	9.0214
105.0000	9.9229	9.7753	8.9829
120.0000	9.7480	9.1833	9.0527
135.0000	10.2449	9.4676	8.9647
150.0000	9.2852	9.5491	8.4993
165.0000	9.0427	8.0110	9.1352
180.0000	8.8864	8.0518	9.1892
195.0000	9.0984	7.4229	9.4032
210.0000	8.2008	7.6567	9.2803
225.0000	7.9738	7.2738	8.7864
240.0000	8.0416	6.9329	8.5786
255.0000	8.3663	8.6349	8.7668
270.0000	8.5202	8.2866	9.2442
285.0000	9.2680	8.9515	9.0515
300.0000	9.5274	9.8538	9.6445
315.0000	9.8669	10.5504	9.5061
330.0000	9.8349	11.3884	9.3152
345.0000	9.7656	11.8374	9.7763
360.0000	10.2332	11.0562	9.8647
15.0000	10.6885	10.3335	9.8093
30.0000	11.1781	10.5074	9.5484
45.0000	10.9226	10.4468	9.7127
60.0000	10.4891	10.6511	9.6241
75.0000	9.3743	10.1225	9.4663
90.0000	9.0496	9.5442	9.2864
105.0000	9.2474	9.1924	9.2707
120.0000	9.0530	9.4338	9.6475
135.0000	9.1471	8.8096	9.5353

150.0000	8.5220	8.6550	9.5515
165.0000	7.8419	7.8843	9.7655
180.0000	8.5828	6.9766	9.3817
195.0000	8.3854	7.8903	9.5150
210.0000	8.1869	7.0015	9.2821
225.0000	7.8609	6.2604	9.1465
240.0000	8.9282	7.9758	9.2703
255.0000	8.8671	8.3891	9.3725
270.0000	8.9678	8.0585	9.2055
285.0000	10.1328	9.4557	9.3929
300.0000	9.9143	9.9891	9.3575
315.0000	9.7722	9.9394	9.3916
330.0000	10.4391	10.6427	9.1462
345.0000	10.0804	10.3252	8.8188
360.0000	10.7110	10.1753	8.7808
15.0000	11.0008	10.9421	8.5497
30.0000	10.2920	10.8820	8.5737
45.0000	10.0779	10.7198	8.4824
60.0000	8.9733	10.2688	8.5000
75.0000	8.4847	10.0147	8.5795
90.0000	8.2959	8.8401	8.9199
105.0000	8.0646	10.2595	8.8030
120.0000	8.4317	9.1840	8.6205
135.0000	8.7602	9.2067	8.7841
150.0000	9.1933	8.6731	9.1407
165.0000	8.4096	8.7849	9.3633
180.0000	7.7077	8.3820	9.4672
195.0000	7.8242	7.6489	9.7056
210.0000	8.4655	7.3910	9.7025
225.0000	8.2551	7.3215	9.4254
240.0000	9.1701	8.0362	9.3822
255.0000	9.0610	9.0985	9.5409
270.0000	9.2662	9.6007	9.1374
285.0000	10.0148	10.3568	9.1824
300.0000	10.1570	9.6240	8.7583
315.0000	9.9560	10.5797	8.4523
330.0000	10.0334	10.3203	8.7834
345.0000	9.8394	9.7610	8.7382
360.0000	9.5330	10.2365	8.6937
15.0000	10.3205	9.6960	9.0034
30.0000	10.0801	10.2417	9.0482
45.0000	9.4649	9.7643	9.0773
60.0000	9.3237	10.1505	9.5303

THIS IS THE TURBULENCE BLADE LOD FILE PRODUCED
BY MODULE 1 UPON EXECUTION OF TURBULENT WIND INPUTS:

15.0000	-6870.64	-1754.82
30.0000	-9219.37	-1513.41
45.0000	-6966.43	-2087.61
60.0000	-6965.40	-2078.88
75.0000	-8878.00	-1603.94
90.0000	-5958.20	-1899.76
105.000	-5835.08	-1796.18
120.000	-6500.60	-1539.25
135.000	-3568.18	-1804.07
150.000	-3562.13	-1538.94
165.000	-3891.07	-1219.88
180.000	-1950.84	-1462.31
195.000	-224.362	-1411.70
210.000	-3380.40	-822.724
225.000	-910.911	-1392.49
240.000	370.476	-1678.88
255.000	-3879.93	-994.851
270.000	-2914.81	-1338.81
285.000	-2345.39	-1721.53
300.000	-5984.54	-1331.77
315.000	-6167.66	-1539.08
330.000	-6710.77	-1834.00
345.000	-9804.19	-1786.35
0.000000	-9460.19	-2218.77
15.0000	-9683.75	-2352.34
30.0000	-10878.6	-2078.04
45.0000	-8127.20	-2187.45
60.0000	-7040.91	-1853.10
75.0000	-7240.04	-1404.34
90.0000	-4382.79	-1657.15
105.000	-4599.84	-1539.14
120.000	-5929.41	-1372.80
135.000	-3912.39	-1784.05
150.000	-5587.50	-1613.26
165.000	-5637.56	-1700.58
180.000	-1280.76	-2121.36
195.000	-1169.14	-1313.54
210.000	-562.606	-629.670
225.000	3470.42	-987.674
240.000	1992.93	-829.895
255.000	-445.353	-728.751
270.000	-1215.53	-1255.45
285.000	-3013.93	-1601.81
300.000	-6249.89	-1548.91
315.000	-6474.73	-1847.32
330.000	-7150.70	-1936.11
345.000	-8995.94	-1761.92
0.000000	-8066.10	-2031.38
15.0000	-7321.76	-2101.23
30.0000	-7809.90	-1735.84
45.0000	-6444.73	-1644.52
60.0000	-5397.44	-1599.95
75.0000	-6274.38	-1436.30
90.0000	-5018.62	-1725.02
105.000	-4844.32	-1799.77
120.000	-5818.93	-1574.23
135.000	-4550.95	-1719.95

150.000	-3557.26	-1735.71
165.000	-3540.32	-1526.01
180.000	-218.966	-1665.92
195.000	2086.84	-1190.38
210.000	-166.088	-308.557
225.000	4137.32	-956.682
240.000	3164.02	-992.530
255.000	-3591.60	-430.915
270.000	-931.020	-1641.58
285.000	-2849.34	-1915.06
300.000	-9527.41	-1215.55
315.000	-5190.82	-2179.24
330.000	-5425.48	-2136.38
345.000	-9951.77	-1247.07
0.000000	-4289.08	-1994.31
15.0000	-4724.21	-1726.38
30.0000	-9099.45	-968.104
45.0000	-4231.59	-1943.99
60.0000	-5840.88	-1919.43
75.0000	-9037.01	-1499.94
90.0000	-4323.04	-2258.23
105.000	-4454.21	-1909.52
120.000	-7586.31	-1144.96
135.000	-1855.49	-1896.87
150.000	-3237.65	-1572.22
165.000	-5433.71	-1120.20
180.000	61.2371	-1909.10
195.000	486.885	-1520.81
210.000	-2290.40	-606.445
225.000	2505.84	-1206.53
240.000	1283.89	-1079.95
255.000	-3723.65	-588.338
270.000	-1946.85	-1525.89
285.000	-4781.84	-1768.85
300.000	-9408.44	-1608.74
315.000	-5918.70	-2400.94
330.000	-7728.17	-2032.73
345.000	-8395.31	-1592.44
0.000000	-3438.64	-1938.45
15.0000	-5061.17	-1297.51
30.0000	-5187.46	-1055.51
45.0000	-2739.37	-1570.89
60.0000	-5200.60	-1416.06

Appendix C

Module 1 Listing

```
      PROGRAM FLAP1
```

```
C              *********************************************
C              *                                           *
C              *   OOOOOOO  O            OO      OOOOOO    *
C              *   O        O          O  O     O     O   *
C              *   OOOO     O          OOOOOO   OOOOOO    *
C              *   O        O         O      O  O         *
C              *   O        OOOOOOO  O        O O         *
C              *                                           *
C              *   Forces & Loads    Analysis    Program   *
C              *                                           *
C              *                Module  1                  *
C              *                                           *
C              *              Version  2.2                 *
C              *                                           *
C              *********************************************
```

```
C  ************************************************************
C  *   CHANGES MADE IN FLAP SINCE THE MARCH 1988 VERSION       *
C  *   2.01 RELEASE.  FOR MORE DETAILS SEE THE USER'S MANUAL.  *
C  ************************************************************

C              This version of FLAP is for analysis of three
C              bladed or two bladed rigid hub rotors only.
C              The teetering option has been removed from this
C              version and reformulated in the new teetering
C              rotor analysis: STRAP ( SERI TEETERING ROTOR
C              ANALYSIS PROGRAM).  User's wishing to run analyses
C              for 2-bladed teetering hub rotors should consult
C              that code and user's manual.


C               This version of FLAP has been modified from
C               version 2.01 in several ways.  First, in
C               Module1 modifications have been made in order
C               to calculate blade flap-wise frequencies and
C               modeshapes directly in the code and to output
C               these to a user designated file.  This file is
C               designated during execution of Module1.  The
C               user can examine results in this file in order
C               to gain knowledge about the blade's frequencies
```

```
C               and modeshapes.  The user no longer needs to
C               calculate these frequencies by hand. In addi-
C               tion these calculated modeshapes get passed
C               to module2 (via the RESULTS.DAT file) in order
C               to calculate generalized forces.  They also get
C               used in calculation of the blade's mass, stiffness
C               and other matrices.

C               The second major change, contained in the second
C               module is the ability to read in turbulent wind-
C               speed fluctuations (in subroutine TRBCLC) and
C               calculate loads and response on a single blade
C               due to turbulence (note: the shaft loads are not
C               calculated during the turbulence execution because
C               only one blade is being analyzed).

C               Another change is the ability to calculate the rotor
C               shaft loads during a trim (steady state) solution.
C               The code does this either for a three-bladed or a
C               two bladed rigid hub rotor.


C       ************************************************************
C       *                                                          *
C       *                       DISCLAIMER                         *
C       *                                                          *
C       *   Neither  the  United States Department of Energy,  the *
C       *   National Renewable Energy Laboratory,                  *
C       *   the Midwest Research Institute nor anyone              *
C       *   else who has been involved in the                      *
C       *   creation, production or delivery of this program shall *
C       *   be liable for any direct, indirect, consequential,  or *
C       *   incidental damages arising out of the use, the results *
C       *   of use,  or  inability to use this program even if the *
C       *   United States Department of Energy has been advised of *
C       *   the possibility of such damages or claim.  Some states *
C       *   do not allow the  exclusion or limitation of liability *
C       *   for consequential or incidental damages,  so the above *
C       *   limitation may not apply to you.                       *
C       *                                                          *
C       ************************************************************


C       ************************************************************
C       *                                                          *
C       *                      The FLAP Code                       *
C       *                                                          *
C       *   FLAP calculates the  forces and moments  on a wind tur-*
C       *   bine blade  due to  aerodynamic,  inertial and gravita-*
C       *   tional forces.  The  aerodynamic  effects include wind *
C       *   shear, tower shadow and the induced velocity due to the*
C       *   change in momentum of the air stream as it  passes over*
C       *   the blade.  In addition, this version includes the     *
C       *   ability to input and calculate  response               *
C       *   and loads due to turbulence.                           *
C       ************************************************************

C       ************************************************************
```

```
C     *
C     *                        Module 1                              *
C     *                                                              *
C     *   This program  is  the first of two modules that consti-    *
C     *   tute the FLAP code.  This first module interpolates the    *
C     *   input  data  into a form  usable  by the  second module    *
C     *   which does the actual modeling.   This module also com-
C     *   putes the coefficient matrix used for solving the blade
C     *   flaps equation of motion. It also calculated the blade's   *
C     *   frequency and modeshapes.                                  *
C     ****************************************************************

C     ****************************************************************
C     *                                                              *
C     *   Questions about the original formulation, theory, meth-
C     *   od of solution and programming should be addressed to:     *
C     *
C     *                Alan D. Wright
C     *                National Renewable Energy Laboratory          *
C     *                1617 Cole Blvd.                               *
C     *                Golden, CO  80401                             *
C     *                 303-231-7651                                 *
C     ****************************************************************

C     ****************************************************************
C     *                                                              *
C     *   I/O Conventions:                                           *
C     *
C     *      Unit 1 - Input data file
C     *      Unit 2 - Output data file
C     *      Unit 5 - Keyboard                                       *
C     *      Unit * - Monitor or keyboard
C     *                                                              *
C     ****************************************************************

C     ****************************************************************
C     *                                                              *
C     *   External references in this routine:                       *
C     *                                                              *
C     *      COEFFS - Subroutine  that computes the K and M coef-    *
C     *               ficients  used in solving  the equations of    *
C     *               blade motion.                                  *
C     *                                                              *
C     *      INPUT  - Subroutine that reads in a set of blade and    *
C     *               machine data  and  converts them  to a form    *
C     *               needed by the COEFFS subroutine.               *
C     *                                                              *
C     *      PRNCOE - Subroutine that creates the input data file    *
C     *               for the second module.                         *
C     *                                                              *
C     ****************************************************************

C     ****************************************************************
C                                                                    *
C     *   Local and dummy variables used in this routine:            *
C     *                                                              *
C     *      ANS    - Used to store input responses from the key-    *
C     *               board.                                         *
C     *      FILOUT - String  that contains the name  of the out-    *
C     *               put file.  It is defined in INPUT.             *
```

```
C       *      NP     - Number of blade property values used in  *
C       *               performing composite Simpson's integration *
C       *               for the K and M coefficient arrays.  This  *
C       *               number is approximately 10 times the NPTS  *
C       *               value.                                     *
C       *      NPTS   - Number of points along the blade used to  *
C       *               perform Simpson's integration for calcu-   *
C       *               lating the moments and forces at the blade *
C       *               root                                       *
C       *      NSIMP  - Order of the composite Simpson's integra- *
C       *               tion used in the run.  Parameter is set to *
C       *               10 in order to make 21 blade property sta- *
C       *               ions.                                      *
C       *                                                          *
C       ************************************************************


      INTEGER         NP
      INTEGER         NPTS
      INTEGER         NSIMP

      CHARACTER*1     ANS
      CHARACTER*50    FILOUT

      PARAMETER     ( NSIMP = 10 )

  100 FORMAT (
     &   // '   Program For Analysis Of Horizontal Axis Wind Turbine'
     &    / '                Response To Dynamic Loads'
     &    // '                       MODULE 1' )
  110 FORMAT ( / )
  120 FORMAT ( A )
  130 FORMAT ( / ' FLAP terminated normally.' / )



C       Calculate the number of blade property stations and interpola-
C       tion points.

      NPTS =  2*NSIMP + 1
      NP   = 20*NSIMP + 1


C       Print title.

      PRINT 100


C       Get input responses, generate coefficients, and write to output
C       file.

   10 PRINT 110

      CALL INPUT  ( NP , NPTS , FILOUT )
      CALL MODES (NP)
      CALL COEFFS ( NP , NPTS )
      CALL PRNCOE ( FILOUT , NPTS )


C       Check to see if user wants to process another data file.
```

```
   20 PRINT *,  ' '
      PRINT *,  'Do you want to process another data file? (Y,=N) > '
      READ 120,  ANS

      IF ( ( ANS .EQ. 'Y' ) .OR.  ( ANS .EQ. 'y' ) )  GO TO 10

      IF ( ( ANS .NE. 'N' ) .AND. ( ANS .NE. 'n' )
     &                      .AND. ( ANS .NE. ' ' ) )  THEN
         PRINT *,  'Invalid response.  Please try again...'
         GO TO 20
      END IF


C        Processing complete.

      PRINT 130


  999 STOP
      END
      BLOCK DATA


C     ****************************************************************
C     *                                                              *
C     *   This module is used to initialize the COMMON blocks.       *
C     *                                                              *
C     ****************************************************************

C     ****************************************************************
C     *                                                              *
C     *   Named COMMON blocks used in this routine:                  *
C     *                                                              *
C     *      AERO   - Aerodynamic blade properties  derived  from    *
C     *               input aerodynamic data.                        *
C     *      BLADE  - Blade position  dependent  values  that are    *
C     *               computed by linear interpolation of the in-    *
C     *               put property data.                             *
C     *      LITERL - Data file titles used for printed output.      *
C     *      LODVAL - Holds components  used in calculating blade    *
C     *               loads and deflections.                         *
C     *      MATRX1 - Holds some of the  coefficient  matrices of    *
C     *               the governing equation of motion.              *
C     *      MATRX2 - Holds some of the  coefficient  matrices of    *
C     *               the governing equation of motion.              *
C     *      PANELS - Used to communicate with the  interpolation    *
C     *               subroutine INTERP.                             *
C     *      TENSIN - Holds  tension  components of the stiffness   *
C     *               functions.                                     *
C     *      TURBN  - Turbine related variables.                     *
C     *      WIND   - Wind related variables.                        *
C     *                                                              *
C     ****************************************************************

C     ****************************************************************
C     *                                                              *
C     *   External references in this routine:                       *
C     *                                                              *
C     *      none                                                    *
```

```
C       *                                                               *
C       *****************************************************************

C       *****************************************************************
C       *                                                               *
C       *   COMMON variables used in Module 1 of FLAP:                  *
C       *                                                               *
C       *      ALENTH - Distance from  the tower axis  to the rotor     *
C       *               hub.  (feet)                                    *
C       *      ALPHA0 - The angle  from the  zero-lift line  to the     *
C       *               section-chord line.  (Generally negative)       *
C       *      BETA0  - Blade coning angle.  The value is input in      *
C       *               degrees and converted to radians. (radians)     *
C       *      BLSHNK - Length of  blade  shank  measured  from the     *
C       *               blade root to the start of the airfoil sec-     *
C       *               tion.   If airfoil begins at the root, then     *
C       *               BLSHNK=0.  (feet)                               *
C       *      BLTIP  - Blade length  measured from the  blade root     *
C       *               to the blade tip.    Note - rotor radius is     *
C       *               HUBRAD + BLTIP.  (feet)                         *
C       *      CDZERO - Drag  coefficient  values  at  equidistant      *
C       *               points  along  the  blade.   Derived  from      *
C       *               ACDZER values.  (dimensionless)                 *
C       *      CHI    - Rotor  tilt  angle.  Input in degrees  and      *
C       *               converted  to  radians.  (radians)              *
C       *      CHORD  - Blade chord at equidistant points along the     *
C       *               blade.  Derived from ACHORD.  (feet)            *
C       *      CIFMOM   Integral of DIFMOM.                             *
C       *      CKBEND - Bending stiffness matrix.                       *
C       *      CKQLOD - Inertial moment stiffening matrix.              *
C       *      CKTCRL - Coriolis stiffening matrix.                     *
C       *      CKTGRV - Gravity stiffening matrix.                      *
C       *      CKTOMG - Centrifugal stiffening matrix.                  *
C       *      CLALFA - Slope  of  the  lift  curve  at equidistant     *
C       *               points along the blade. Derived from ACLALF     *
C       *               values.  (radians^-1)                           *
C       *      CLMAX  - The maximum or stall value  of the lift co-     *
C       *               efficient.  Derived from ACLMAX values.         *
C       *      CMBLNC - Coefficient  associated with the blade mass     *
C       *               imbalance (OFFSET).                             *
C       *      CMGRAV - Mass coefficients  associated with gravita-     *
C       *               tional loads.                                   *
C       *      CMMASS - Blade mass matrix.   It is also used in the     *
C       *               inertia force stiffening term.                  *
C       *      CMRIGD - Mass coefficients associated with rigid bo-     *
C       *               dy motion.                                      *
C       *      CSUBMA - Pitching moment coefficient.                    *
C       *      DELTIM - Integral of DDELTI.                             *
C       *      DRGFRM - Drag coefficient form constant.                 *
C       *      ECNTFN - Complicated term.                               *
C       *      EIAREA - Moment  of  inertia  values  at equidistant     *
C       *               points  along  the  blade.   Derived  from      *
C       *               AEIARE data values.  (Lb-Ft**2)                 *
C       *      ESUBAC - Distance from the blade elastic axis to the     *
C       *               aerodynamic  center.  Positive  if elastic      *
C       *               axis  is forward  (toward leading edge)  of     *
C       *               aerodynamic  center.  Derived from  AESBAC      *
C       *               values.  (feet)                                 *
C       *       HUBHT  - Hub  reference  height  above  the  ground.    *
C       *               (feet)                                          *
```

```
C       *     HUBRAD - Radius of rotor hub.  (feet)                    *
C       *     IEMASS - Edgewise mass moment of inertia at equidis-     *
C       *              tant points along the blade section.  Der-      *
C       *              ived from AIEMAS values.  (Lb-sec^2)            *
C       *     IFMASS - Flapwise mass moment of inertia at equidis-     *
C       *              tant points along the blade section.  Der-      *
C       *              ived from AIFMAS values.  (Lb-sec^2)            *
C       *     KSHADW - Number of tower shadow peaks within the         *
C       *              tower shadow zone.                              *
C       *     MASS   - Blade mass per unit length at equidistant      *
C       *              points along the blade.  Input in Lbf/ft,       *
C       *              via the input variable WEIGHT, and convert-     *
C       *              ed to slugs/ft.  (slugs/ft)                     *
C       *     NBLADS - Number of turbine blades.                       *
C       *     NSHAPS - Number of blade shape functions, 4 maximum.     *
C       *                                                              *
C       *     OFFMAS - Integral of DOFFMS.                             *
C       *     OFFSET - Distance from the elastic axis to the mass      *
C       *              axes of blade section.  Positive towards        *
C       *              the leading edge.  Derived from AOFFST val-     *
C       *              ues.  Called E-sub-eta in the formulation.      *
C       *              (feet)                                          *
C       *     OMEGA  - Rotor speed.  Input in RPM and converted to     *
C       *              radians/second.  (rad/sec)                      *
C       *     PHI0   - Rotor mean yaw angle.  (radians)                *
C       *     PHIAMP - Amplitude of periodic yaw motion about mean     *
C       *              yaw angle.  Input as degrees and converted      *
C       *              to radians.  (radians)                          *
C       *     PHIOMG - Maximum yaw rate.  Used internally to com-      *
C       *              pute the yaw period.  It can be used to in-     *
C       *              put a turbine steady yaw rate.  Input as        *
C       *              degrees/sec and converted to radians/sec-       *
C       *              ond.  (radians/sec)                             *
C       *     PSIZER - Half angle width of the tower shadow re-        *
C       *              gion.  (degrees)                                *
C       *     SHERXP - Wind shear power exponent.                      *
C       *     STEP   - Distance between the equidistant data           *
C       *              points along the blade.  (feet)                 *
C       *     TCORLS - Blade tension coefficient due to coriolis       *
C       *              effects.                                        *
C       *     TGRAV  - Blade tension coefficient due to gravity        *
C       *              effects.                                        *
C       *     THETA0 - Orientation of the zero lift line with re-      *
C       *              spect to the blade principal bending axis.      *
C       *     THETAP - The blade pitch angle.  That is, the angle      *
C       *              from the bending axis, XP, to the cone of       *
C       *              rotation, X-axis, for the reference sta-        *
C       *              tion.  THETAP establishes the orientation       *
C       *              of the flapping displacements.  Positive        *
C       *              angles are toward feather.  Generally, the      *
C       *              reference station section-chord line is         *
C       *              taken as the bending (flapping) axis.           *
C       *              (radians)                                       *
C       *     THETAT - The built-in blade twist angle from the         *
C       *              section-chord line at the reference station     *
C       *              to the section-chord line at the tip of the     *
C       *              rotor.  Positive towards feather.               *
C       *     TITLE1 - First line of the data file title.              *
C       *     TITLE2 - Second line of the data file title.             *
C       *     TITLE3 - Third line of the data file title.              *
```

```
C       *     TOMGA  - Blade tension coefficient associated with  *
C       *              centrifugal force effects.                 *
C       *     TSUBO  - Tower shadow wind speed offset component.  *
C       *     TSUBP  - Tower shadow sinusoidal component.         *
C       *     VHUB   - Air speed at the height of the hub.        *
C       *              (ft/sec)                                   *
C       *     XLEFT  - Radial positions of the blade property data *
C       *              points.  These are monotonically increasing *
C       *              values from 0.0 at the root to R at the    *
C       *              tip.  (feet)                               *
C       *                                                         *
C       ***********************************************************

      INCLUDE       'C:INCLUDE\AERO.INC'

      INCLUDE       'C:INCLUDE\BLADE.INC'

      INCLUDE       'C:INCLUDE\LITERL.INC'

      INCLUDE       'C:INCLUDE\LODVAL.INC'

      INCLUDE       'C:INCLUDE\MATRX1.INC'

      INCLUDE       'C:INCLUDE\MATRX2.INC'

      INCLUDE       'C:INCLUDE\PANELS.INC'

      INCLUDE       'C:INCLUDE\TENSIN.INC'

      INCLUDE       'C:INCLUDE\TURBN.INC'

      INCLUDE       'C:INCLUDE\WIND.INC'

      END
      SUBROUTINE CAPS ( STRING )

C       ************************************************************
C       *                                                          *
C       *  Subroutine CAPS is used to convert alphabetic charac-   *
C       *  ters into upper case.  It assumes that all the lower    *
C       *  case letters are in one contiguous block and all the    *
C       *  upper case letters are in another contiguous block.     *
C       *  This routine will need to be changed to work with a     *
C       *  noncontiguous character set like IBM's EBCDIC.  It is   *
C       *  not needed for an upper case only character set like    *
C       *  CDC's Display Code.                                     *
C       *                                                          *
C       ************************************************************

C       ************************************************************
C       *                                                          *
C       *  Named COMMON blocks used in this routine:               *
C       *                                                          *
C       *     none                                                 *
C       *                                                          *
C       ************************************************************
```

```
C       ************************************************************
C       *                                                          *
C       *   External references in this routine:                   *
C       *                                                          *
C       *      none                                                *
C       *                                                          *
C       ************************************************************

C       ************************************************************
C       *                                                          *
C       *   Local and dummy variables used in this routine:        *
C       *                                                          *
C       *      DIFF   - Numerical difference between 'A' and 'a'.  *
C       *      I      - Generic index.                             *
C       *      LENGTH - The declared length of the given string.   *
C       *      STRING - The string needing to be converted to upper*
C       *               case.                                      *
C       *                                                          *
C       ************************************************************

      INTEGER         DIFF
      INTEGER         I
      INTEGER         LENGTH

      CHARACTER*(*)   STRING



C       Compute the numerical difference between 'A' and 'a'.

      DIFF = ICHAR( 'a' ) - ICHAR( 'A' )


C       Get the length of the string.

      LENGTH = LEN( STRING )


C       Look for lower case letters.  Convert them to upper case.

      DO 100 I=1,LENGTH

         IF ( ( STRING(I:I) .GE. 'a' ) .AND.
     &        ( STRING(I:I) .LE. 'z' ) )  THEN

            STRING(I:I) = CHAR( ICHAR( STRING(I:I) ) - DIFF )

         END IF

  100 CONTINUE


      RETURN
      END
      SUBROUTINE COEFFS ( NP , NPTS )


C       ************************************************************
C       *                                                          *
C       *   This subroutine computes the coefficient matrices  used  *
```

```
C       *   in the solution of the blade equations of motion.  *
C       *   Since these coefficients are independent of the posi-  *
C       *   tion or state of the blade, and are only dependent upon  *
C       *   the blade properties, they are calculated independently  *
C       *   of the solution to the equations of motion and are made  *
C       *   available to the rest of the program through the COMMON  *
C       *   blocks MATRX1 and MATRX2.                               *
C       *                                                           *
C       *************************************************************

C       *************************************************************
C       *                                                           *
C       *   Named COMMON blocks used in this routine:               *
C       *                                                           *
C       *      AERO   - Aerodynamic blade properties derived from  *
C       *               input aerodynamic data.                     *
C       *      BLADE  - Blade position dependent values that are   *
C       *               computed by linear interpolation of the in- *
C       *               put property data.                          *
C       *      LODVAL - Holds components used in calculating blade  *
C       *               loads and deflections.                      *
C       *      MATRX1 - Holds some of the coefficient matrices of  *
C       *               the governing equation of motion.           *
C       *      MATRX2 - Holds some of the coefficient matrices of  *
C       *               the governing equation of motion.           *
C       *      TENSIN - Holds tension components of the stiffness  *
C       *               functions.                                  *
C       *                                                           *
C       *************************************************************

C       *************************************************************
C       *                                                           *
C       *   External references in this routine:                    *
C       *                                                           *
C       *      SIMPSN - Function that performs the composite Simp-  *
C       *               son's integration on the input data arrays.  *
C       *      TRPZOD - Function that performs composite trapezoi-  *
C       *               dal integration.                            *
C       *                                                           *
C       *************************************************************

C       *************************************************************
C       *                                                           *
C       *   Local and dummy variables used in this routine:         *
C       *                                                           *
C       *      BLTBLT - Square of BLTIP.  (feet**2)                 *
C       *      DDELTI - IEMASS - IFMASS.                            *
C       *      DIFMOM - Complicated term.                           *
C       *      DKBEND - Used to compute the integrals associated    *
C       *               with the coefficient matrices.              *
C       *      DKMASS - Used to compute the integrals associated    *
C       *               with the coefficient matrices.              *
C       *      DKQLD  - Used to compute the integrals associated    *
C       *               with the coefficient matrices.              *
C       *      DKTCRL - Used to compute the integrals associated    *
C       *               with the coefficient matrices.              *
C       *      DKTGRA - Used to compute the integrals associated    *
C       *               with the coefficient matrices.              *
C       *      DKTOMG - Used to compute the integrals associated    *
C       *               with the coefficient matrices.              *
```

```
C       *     DMBALN - Used to compute the integrals associated  *
C       *              with the coefficient matrices.            *
C       *     DMGRAV - Used to compute the integrals associated  *
C       *              with the coefficient matrices.            *
C       *     DMRIGD - Used to compute the integrals associated  *
C       *              with the coefficient matrices.            *
C       *     DOFFMS - OFFSET*MASS.                              *
C       *     DTCOR1 - Used to compute the integrals associated  *
C       *              with the tension components.              *
C       *     DTCOR2 - Used to compute the integrals associated  *
C       *              with the tension components.              *
C       *     DTCOR3 - Used to compute the integrals associated  *
C       *              with the tension components.              *
C       *     DTCOR4 - Used to compute the integrals associated  *
C       *              with the tension components.              *
C       *     DTOMGA - Used to compute the integrals associated  *
C       *              with the tension components.              *
C       *     I      - Generic index.                            *
C       *     IPT    - Array index used for trapezoidal integra- *
C       *              tion.                                     *
C       *     K      - Generic index.                            *
C       *     L      - Generic index.                            *
C       *     N      - Generic index.                            *
C       *     NP     - Number of blade property values used in   *
C       *              performing composite Simpson's integration *
C       *              for the M and K coefficient arrays. This  *
C       *              number is approximately 10 times the NPTS *
C       *              value. (passed from FLAP1)                *
C       *     NPTS   - Number of points along the blade used to  *
C       *              perform Simpson's integration for calculat- *
C       *              ing the moments and forces at the blade   *
C       *              root. (passed from FLAP1)                 *
C       *     SHP  - Array containing shape functions evaluated  *
C       *              at regular intervals.                     *
C       *     SHPDD  - First derivative of SHP with respect to   *
C       *              location along the blade.                 *
C       *     SHPDOT - Second derivative of SHP with respect to  *
C       *              location along the blade.                 *
C       *     X      - Dummy variable used to indicate location  *
C       *              along the blade for use by the internal   *
C       *              shape functions.                          *
C       *                                                        *
C       **********************************************************

      REAL           DDELTI (201)
      REAL           DIFMOM (201)
      REAL           DKBEND (201)
      REAL           DKMASS (201)
      REAL           DKQLD  (201)
      REAL           DKTCRL (201)
      REAL           DKTGRA (201)
      REAL           DKTOMG (201)
      REAL           DMBALN (201)
      REAL           DMGRAV (201)
      REAL           DMRIGD (201)
      REAL           DOFFMS (201)
      REAL           DTCOR1 (201)
      REAL           DTCOR2 (201)
      REAL           DTCOR3 (201)
      REAL           DTCOR4 (201)
```

```
      REAL            DTOMGA (201)
      REAL            SIMPSN
      REAL            STEP
      REAL            TRPZOD

      INTEGER         I
      INTEGER         IPT
      INTEGER         K
      INTEGER         L
      INTEGER         N
      INTEGER         NP
      INTEGER         NPTS

      INCLUDE        'C:INCLUDE\AERO.INC'

      INCLUDE        'C:INCLUDE\BLADE.INC'

      INCLUDE        'C:INCLUDE\LODVAL.INC'

      INCLUDE        'C:INCLUDE\MATRX1.INC'

      INCLUDE        'C:INCLUDE\MATRX2.INC'

      INCLUDE        'C:INCLUDE\TENSIN.INC'

      INCLUDE        'C:INCLUDE\MODAL.INC'


 1000 FORMAT ( / ' Generating coefficient matrices and property'
     &         , ' arrays...' )
 8000 FORMAT (   '&done.' )



C       ****************************************************************
C       *                                                              *
C       *   Fill the intermediate function arrays which are used to    *
C       *   compute the tension component integrals.                   *
C       *                                                              *
C       ****************************************************************

      STEP = BLTIP/( NP - 1.0)

      DO 200 I=1,NP

          DTOMGA(I) = MASS(I)*( HUBRAD + STEP*( I - 1 ) )
          DTCOR1(I) = MASS(I)*SHP(1,I)
          DTCOR2(I) = MASS(I)*SHP(2,I)
          DTCOR3(I) = MASS(I)*SHP(3,I)
          DTCOR4(I) = MASS(I)*SHP(4,I)

  200 CONTINUE


C       ****************************************************************
C       *                                                              *
C       *   Compute the tension component integrals.   Each tension    *
C       *   component is calculated  by integrating from a specific    *
C       *   position on the blade out to the blade tip.                *
C       *                                                              *
```

```
C       ************************************************************

      DO 300 I=1,NP

         TOMGA(I)    = TRPZOD( DTOMGA , I , NP , BLTIP )
         TGRAV(I)    = TRPZOD( MASS   , I , NP , BLTIP )

         TCORLS(1,I) = TRPZOD( DTCOR1 , I , NP , BLTIP )
         TCORLS(2,I) = TRPZOD( DTCOR2 , I , NP , BLTIP )
         TCORLS(3,I) = TRPZOD( DTCOR3 , I , NP , BLTIP )
         TCORLS(4,I) = TRPZOD( DTCOR4 , I , NP , BLTIP )

  300 CONTINUE


C       ************************************************************
C       *                                                          *
C       *   Compute the coefficient matrices.  Please note that    *
C       *   only the upper triangle elements are computed.         *
C       *                                                          *
C       ************************************************************


      DO 470 K=1,4

         DO 440 L=K,4


C                Fill the intermediate function arrays which are used
C                to compute the stiffness and loading coefficient ma-
C                trices.

               DO 400 I=1,NP

                  DKBEND(I) = EIAREA(I)*SHPDD (K,I)*SHPDD (L,I)
                  DKMASS(I) = MASS  (I)*SHP (K,I)*SHP (L,I)
                  DKQLD (I) = IFMASS(I)*SHPDOT(K,I)*SHPDOT(L,I)
                  DKTOMG(I) = TOMGA (I)*SHPDOT(K,I)*SHPDOT(L,I)

   400            CONTINUE


C                Compute the K,Lth element of the coefficient matrices.

               CKBEND(K,L) = SIMPSN( 0.0 , BLTIP , NP , DKBEND )
               CKTOMG(K,L) = SIMPSN( 0.0 , BLTIP , NP , DKTOMG )
               CKQLOD(K,L) = IFMASS(NP)*SHPDOT(K,NP)*SHP(L,NP)
     &                     - SIMPSN( 0.0 , BLTIP , NP , DKQLD  )
               CMMASS(K,L) = SIMPSN( 0.0 , BLTIP , NP , DKMASS )


               DO 410 I=1,NP
   410         DKTGRA(I) = TGRAV(I)*SHPDOT(K,I)*SHPDOT(L,I)

               CKTGRV(K,L) = SIMPSN( 0.0 , BLTIP , NP , DKTGRA )


C              Index into coefficient matrix for coriolis stiffening.

            DO 430 N=1,4
```

```
                DO 420 I=1,NP
  420           DKTCRL(I) = TCORLS(N,I)*SHPDOT(K,I)*SHPDOT(L,I)

                CKTCRL(N,K,L) = SIMPSN( 0.0 , BLTIP , NP , DKTCRL )


  430       CONTINUE

  440.    CONTINUE


C           Compute elements  of  coefficient matrices  which use only a
C           single index.  Fill intermediate function arrays first, then
C           compute the elements of the matrices.


            DO 450 I=1,NP

               DMRIGD(I) = MASS(I)*( HUBRAD + STEP*( I-1 ) )*SHP(K,I)
               DMBALN(I) = MASS(I)*SHP(K,I)*OFFSET(I)
               DMGRAV(I) = MASS(I)*SHP(K,I)

  450       CONTINUE

            CMRIGD(K) = SIMPSN( 0.0 , BLTIP , NP , DMRIGD )
            CMBLNC(K) = SIMPSN( 0.0 , BLTIP , NP , DMBALN )
            CMGRAV(K) = SIMPSN( 0.0 , BLTIP , NP , DMGRAV )


            DO 460 I=1,NP

               DMRIGD(I) = MASS(I)*( HUBRAD + STEP*( I-1 ) )*SHP(K,I)
               DMBALN(I) = MASS(I)*SHP(K,I)*OFFSET(I)
               DMGRAV(I) = MASS(I)*SHP(K,I)

  460       CONTINUE



  470 CONTINUE


C       ****************************************************************
C       *                                                              *
C       *  Once the  diagonal  and  upper triangular  elements are     *
C       *  computed,  reflect the  upper triangle  onto the  lower     *
C       *  one.                                                        *
C       *                                                              *
C       ****************************************************************

      DO 520 K=1,3

         DO 510 L=K+1,4

            CKBEND(L,K) = CKBEND(K,L)
            CKQLOD(L,K) = CKQLOD(K,L)
            CKTGRV(L,K) = CKTGRV(K,L)
            CKTOMG(L,K) = CKTOMG(K,L)
            CMMASS(L,K) = CMMASS(K,L)
```

```
          DO 500 N=1,4
500       CKTCRL(N,L,K) = CKTCRL(N,K,L)

510     CONTINUE

520 CONTINUE


C       ***************************************************************
C       *                                                             *
C       *   The following arrays  are used to compute the loads and   *
C       *   moments for completion of MODULE 2.                       *
C       *                                                             *
C       ***************************************************************

      DO 600 I=1,NP

         DDELTI(I) = IEMASS(I) - IFMASS(I)
         DOFFMS(I) = OFFSET(I)*MASS(I)

600 CONTINUE

      DO 610 I=1,NPTS

         IPT = 10*( I - 1 ) + 1

         DELTIM(I) = TRPZOD( DDELTI , IPT , NP , BLTIP )
         OFFMAS(I) = TRPZOD( DOFFMS , IPT , NP , BLTIP )

610 CONTINUE

      DO 640 N=1,4

         DO 620 I=1,NP
620      DIFMOM(I) = IFMASS(I)*SHPDOT(N,I)

         DO 630 I=1,NPTS

            IPT = 10*( I - 1 ) + 1

            CIFMOM(N,I) = TRPZOD( DIFMOM , IPT , NP , BLTIP )

630      CONTINUE

640 CONTINUE


C       ***************************************************************
C       *                                                             *
C       *   These tension and property arrays will be used in         *
C       *   MODULE 2 to compute the loads and moments.                *
C       *                                                             *
C       ***************************************************************

      DO 700 I=1,NPTS

         IPT = 10*( I - 1 ) + 1

         CHORD (I) = CHORD(IPT)
```

```
         ECNTFN(I) = OFFSET(IPT)*MASS(IPT)*( HUBRAD
     &             + BLTIP*( I-1 )/( NPTS-1 ) )
         TGRAV (I) = TGRAV(IPT)
         THETAO(I) = THETAO(IPT)
         TOMGA (I) = TOMGA(IPT)

         TCORLS(1,I) = TCORLS(1,IPT)
         TCORLS(2,I) = TCORLS(2,IPT)
         TCORLS(3,I) = TCORLS(3,IPT)
         TCORLS(4,I) = TCORLS(4,IPT)

  700 CONTINUE


C        ****************************************************************
C        *                                                              *
C        *   Generation of  coefficient matrices and property arrays    *
C        *   is complete.                                               *
C        *                                                              *
C        ****************************************************************

      PRINT 8000


      RETURN
      END

      SUBROUTINE MODES(NP)

      REAL ASUM(4,4)
      REAL BSUM(4,4)
      REAL CSUM(4,4)
      REAL DSUM(4,4)
      REAL BLTBLT
      REAL CF1
      REAL CF1DOT
      REAL CF1DD
      REAL CF2
      REAL CF2DOT
      REAL CF2DD
      REAL CF3
      REAL CF3DOT
      REAL CF3DD
      REAL CF4
      REAL CF4DOT
      REAL CF4DD
      REAL EKBEND(201)
      REAL EKMASS(201)
      REAL EKTOMG(201)
      REAL ETOMGA(201)
      REAL MAG(4)
      REAL OMGA2
      REAL SIMPSN
      REAL STEP
      REAL POLY(4,201)
      REAL POLYDT(4,201)
      REAL POLYDD(4,201)
      REAL TTOMGA(201)
      REAL TRPZOD
      REAL X
```

```
      REAL QPRIME(4,4)
      REAL QTRANS(4,4)
      REAL PRDCT1(4,4)
      REAL PRDCT2(4,4)
      REAL VALU(4)
      REAL VECTR1(4,4)
      REAL VECTR2(4,4)
      REAL VECTR3(4,4)


      INTEGER I
      INTEGER K
      INTEGER L
      INTEGER NP
      INTEGER NDIM
      INTEGER NDP

      INCLUDE       'C:INCLUDE\BLADE.INC'
      INCLUDE       'C:INCLUDE\MODAL.INC'
      INCLUDE       'C:INCLUDE\TURBN.INC'

      CHARACTER*20 MODOUT

C     Coordinate shape functions and their derivatives.
C     These functions are polynomials that satisfy the
C     boundary conditions for a cantilever blade, namely
C     zero displacement and zero slope at the root.
C     These functions will be used in linear combinations
C     using a Rayleigh Ritz type procedure to determine the
C     natural frequencies and modeshapes of the blade.

C     First shape function and it's derivatives:

      CF1  (X)  =  X**2*( X*(X-4.0) + 6.)/3.
      CF1DOT(X) = 4.*X*(X*(X-3.)+3.)/3.
      CF1DD(X)  = 4.*(X*(X-2.)+1.)

C     Second shape function and it's derivatives:

      CF2  (X)  =  X**3*(X*(3.*X-10.)+10.)/3.
      CF2DOT(X) = 5.*X**2*(X*(3.*X-8.)+6.)/3.
      CF2DD(X)  = 20.*X*(X*(3.*X-6.)+3.)/3.

C     Third shape function and it's derivatives:

      CF3  (X)  =  X**4*(X*(2.*X - 6.) + 5.)
      CF3DOT(X) = 2.*X**3*(X*(6.*X-15.) + 10.)
      CF3DD(X)  = 60.*X**2*( X*( X-2.) + 1.)

C     Fourth shape function and it's derivatives:

      CF4 (X)  =  X**5*( X*( 10.*X - 28.) + 21.)/3.
      CF4DOT(X) = 7.*X**4*( X*( 10.*X - 24.) + 15.)/3.
      CF4DD(X) = 14.*X**3*(X*(10.*X - 20. ) + 10.)

      STEP = 1./(NP-1.)
      BLTBLT = BLTIP**2
      X     = 0.

      DO 110 I = 1,NP
```

```
        POLY(1,I) = CF1 ( X)
        POLYDT(1,I) = CF1DOT(X)/BLTIP
        POLYDD(1,I)  = CF1DD(X)/BLTBLT

        POLY(2,I) = CF2 ( X)
        POLYDT(2,I) = CF2DOT(X)/BLTIP
        POLYDD(2,I)  = CF2DD(X)/BLTBLT

        POLY(3,I) = CF3(X)
        POLYDT(3,I) = CF3DOT(X)/BLTIP
        POLYDD(3,I)  = CF3DD(X)/BLTBLT

        POLY(4,I) = CF4(X)
        POLYDT(4,I) = CF4DOT(X)/BLTIP
        POLYDD(4,I)  = CF4DD(X)/BLTBLT

        X = X + STEP
  110 CONTINUE

C       Fill the intermediate function arrays which are used to
C       compute the tension component integral for the
C       centrifugal stiffening matrix.

      X = 0.
      STEP = BLTIP/(NP - 1.)

      DO 200 I = 1,NP

         ETOMGA(I) = MASS(I)*( HUBRAD + STEP*( I-1 ))
  200 CONTINUE

C         Compute the tension component integral.

      DO 300 I = 1,NP

        TTOMGA(I) = TRPZOD( ETOMGA, I, NP, BLTIP)
  300 CONTINUE

C         Compute the coefficient matrices: ASUM, BSUM, CSUM.
C         ASUM is the bending stiffness matrix, BSUM is the
C         centrifugal stiffening matrix, and CSUM is the
C         mass matrix.

        DO 470 K = 1,4

           DO 440 L = K,4

              DO 400 I = 1, NP

                EKBEND(I) = EIAREA(I)*POLYDD(K,I)*POLYDD(L,I)
                EKMASS(I) = MASS(I)*POLY(K,I)*POLY(L,I)
                EKTOMG(I) = TTOMGA(I)*POLYDT(K,I)*POLYDT(L,I)
  400          CONTINUE

C .         Compute the K,L th element of the coefficient matrices.

             ASUM(K,L) = SIMPSN(0., BLTIP, NP, EKBEND)
             BSUM(K,L) = SIMPSN(0., BLTIP, NP, EKTOMG)
             CSUM(K,L) = SIMPSN(0., BLTIP, NP, EKMASS)
```

```
  440      CONTINUE
  470   CONTINUE

C          Once the diagonal and upper triangular elements are
C          computed, reflect the upper triangle onto the lower
C          one.

        DO 520 K = 1,3

           DO 510 L = K+1,4

              ASUM(L,K) = ASUM(K,L)
              BSUM(L,K) = BSUM(K,L)
              CSUM(L,K) = CSUM(K,L)
  510      CONTINUE
  520   CONTINUE

      NDIM = 4
      NDP  = 4


C      Add the Centrifugal stiffening term to
C      the bending stiffness terms.
C      Form the new matrix DSUM

      OMGA2 = OMEGA * OMEGA * .0109662271124

      DO 1820 I = 1,NDIM
      DO 1830 J = 1,NDIM
         DSUM(I,J) = ASUM(I,J) + OMGA2* BSUM(I,J)
 1830 CONTINUE
 1820 CONTINUE

      CALL JACOBI(CSUM,NDIM,NDP,VALU,VECTR1)
      CALL EIGSRT(VALU,VECTR1,NDIM,NDP)

      DO 880 I = 1, NDIM
      DO 870 J = 1, NDIM
         SVALU = SQRT(VALU(J))
         QPRIME(I,J) = VECTR1(I,J)/SVALU
  870 CONTINUE
  880 CONTINUE


      DO 900 I = 1,NDIM
      DO 890 J = 1,NDIM
         QTRANS(J,I) = QPRIME(I,J)
  890 CONTINUE
  900 CONTINUE


      CALL MULT(QPRIME,DSUM,PRDCT1,NDIM,NDIM)
      CALL MULT(PRDCT1,QTRANS,PRDCT2,NDIM,NDIM)

      CALL JACOBI(PRDCT2,NDIM,NDP,VALU,VECTR2)
      CALL EIGSRT(VALU,VECTR2,NDIM,NDP)
      CALL MULT(VECTR2,QPRIME,VECTR3,NDIM,NDIM)

C      The frequencies of interest are actually the square roots
C      of the calculated eigenvalues.
```

```
      DO 915 J = 1,NDIM
         SUMSQ = 0.
         DO 910 I = 1,NDIM
            SUMSQ = SUMSQ + VECTR3(I,J)**2
  910    CONTINUE
         MAG(J) = SQRT(SUMSQ)
  915 CONTINUE

      DO 920 I = 1, NDIM
         FREQ(I) = SQRT( VALU(NDIM+1-I))
  920 CONTINUE



      DO 960 I = 1,NDIM
      DO 940 J = 1,NDIM
         LAMDA(I,J) = VECTR3(I,NDIM+1-J)/MAG(NDIM+1-J)
  940 CONTINUE
  960 CONTINUE

      PRINT*, 'Enter name of modeshape and frequency output file'
      READ*, MODOUT

      OPEN(8, FILE = MODOUT, STATUS = 'UNKNOWN')

      WRITE(8,*) 'FREQUENCIES = '
      WRITE(8,*) (FREQ(I), I=1,NDIM)

      DO 670 I = 1,4
        DO 660 J = 1,NP
           SHP(I,J) = 0.
           SHPDOT(I,J) = 0.
           SHPDD(I,J) = 0.
  660   CONTINUE
  670 CONTINUE

      DO 700 I = 1,NP
         DO 690 J = 1,NDIM
            DO 680 K = 1,NDIM
               SHP(J,I) = SHP(J,I) + LAMDA(K,J)*POLY(K,I)
               SHPDOT(J,I)= SHPDOT(J,I) + LAMDA(K,J)*POLYDT(K,I)
               SHPDD(J,I) = SHPDD(J,I) + LAMDA(K,J)*POLYDD(K,I)
  680       CONTINUE
  690    CONTINUE
  700 CONTINUE

      DO 1400 I = 1,NDIM
      TIPDFL = 1.
      DO 1390 J = 1,NP
         SHP(I,J) = SHP(I,J)/TIPDFL
         SHPDOT(I,J) = SHPDOT(I,J)/TIPDFL
         SHPDD(I,J) = SHPDD(I,J)/TIPDFL
 1390 CONTINUE
 1400 CONTINUE

      WRITE(8,*) 'Modeshapes:'
      DO 720 I = 1,NP,10
         WRITE(8,*) I, (SHP(J,I), J = 1,NDIM)
  720 CONTINUE
```

```
      RETURN
      END

      SUBROUTINE JACOBI(A,N,NP,D,V)
      PARAMETER (NMAX=100)
      DIMENSION A(NP,NP),D(NP),V(NP,NP),B(NMAX),Z(NMAX)
      DO 12 IP = 1,N
         DO 11 IQ = 1,N
            V(IP,IQ) = 0.
11       CONTINUE
         V(IP,IP) = 1.
12    CONTINUE

      DO 13 IP = 1,N
         B(IP) = A(IP,IP)
         D(IP) = B(IP)
         Z(IP) = 0.
13    CONTINUE

      NROT = 0

      DO 24 I = 1,50
         SM = 0.
         DO 15 IP = 1,N-1
            DO 14 IQ = IP+1, N
               SM = SM + ABS(A(IP,IQ))
14          CONTINUE
15       CONTINUE

       IF(SM .EQ. 0.) RETURN
       IF(I .LT. 4) THEN
           TRESH = 0.2*SM/N**2
       ELSE
           TRESH = 0.
       ENDIF

       DO 22 IP = 1,N-1
          DO 21 IQ = IP+1,N
             G = 100.*ABS(A(IP,IQ))
             IF( G .LT. 1.0E-08)THEN
             A(IP,IQ)=0.

             ELSEIF( ABS(A(IP,IQ)) .GT. TRESH)THEN
               H = D(IQ)-D(IP)
               IF(ABS(H) + G .EQ. ABS(H))THEN
                 T = A(IP,IQ)/H
               ELSE
                 THETA = 0.5*H/A(IP,IQ)
                 T = 1./(ABS(THETA) + SQRT(1.+ THETA**2))
                 IF(THETA .LT. 0.) T = -1.* T
               ENDIF

               C = 1./SQRT(1+T**2)
               S = T*C
               TAU = S/(1.+C)
               H = T*A(IP,IQ)
               Z(IP) = Z(IP) - H
               Z(IQ) = Z(IQ) + H
               D(IP) = D(IP) - H
```

```
            D(IQ) = D(IQ) + H
            A(IP,IQ) = 0.
            DO 16 J=1, IP-1
               G = A(J,IP)
               H = A(J,IQ)
               A(J,IP) = G-S*(H+G*TAU)
               A(J,IQ) = H+S*(G-H*TAU)
16          CONTINUE

            DO 17 J = IP+1, IQ-1
              G = A(IP,J)
              H = A(J,IQ)
              A(IP,J) = G-S*(H+G*TAU)
              A(J,IQ) = H+S*(G-H*TAU)
17          CONTINUE

            DO 18 J = IQ+1, N
              G = A(IP,J)
              H = A(IQ,J)
              A(IP,J) = G-S*(H+G*TAU)
              A(IQ,J) = H+S*(G-H*TAU)
18          CONTINUE

            DO 19 J = 1,N
               G = V(J,IP)
               H = V(J,IQ)
               V(J,IP) = G-S*(H+G*TAU)
               V(J,IQ) = H+S*(G-H*TAU)
19          CONTINUE

            NROT = NROT + 1
          ENDIF
21        CONTINUE
22        CONTINUE

          DO 23 IP = 1,N
            B(IP) = B(IP) + Z(IP)
            D(IP) = B(IP)
            Z(IP) = 0.
23        CONTINUE
24      CONTINUE

    RETURN
    END

    SUBROUTINE EIGSRT(D,V,N,NP)

    DIMENSION D(NP), V(NP,NP)
    DO 13 I = 1, N-1
       K=I
       P=D(I)
       DO 11 J=I+1,N
          IF(D(J) .GE. P)THEN
             K=J
             P=D(J)
          ENDIF
11     CONTINUE

       IF(K .NE. I) THEN
          D(K) = D(I)
```

```
            D(I) = P
            DO 12 J = 1,N
               P = V(J,I)
               V(J,I) = V(J,K)
               V(J,K) = P
   12       CONTINUE
         ENDIF
   13 CONTINUE
      RETURN
      END


      SUBROUTINE INPUT ( NP , NPTS , FILOUT )


C     ***************************************************************
C     *                                                             *
C     *   Subroutine INPUT performs the following tasks:            *
C     *                                                             *
C     *      1 - Opens input and output data files.                 *
C     *      2 - Reads in blade property and wind turbine data.     *
C     *      3 - Checks validity of input data.                     *
C     *      4 - Performs a linear interpolation between data       *
C     *          points to provide data at the proper points for    *
C     *          the COEFFS subroutine.                             *
C     *      5 - Performs unit conversions.                         *
C     *                                                             *
C     ***************************************************************

C     ***************************************************************
C     *                                                             *
C     *   External references in this routine:                      *
C     *                                                             *
C     *      CAPS   - Converts strings to upper case.               *
C     *      INTERP - Subroutine that performs a linear interpo-    *
C     *               lation of the input data.                     *
C     *                                                             *
C     ***************************************************************

C     ***************************************************************
C     *                                                             *
C     *   Named COMMON blocks used in this routine:                 *
C     *                                                             *
C     *      AERO   - Aerodynamic blade properties derived from     *
C     *               input aerodynamic data.                       *
C     *      BLADE  - Blade position dependent values that are      *
C     *               computed by linear interpolation of the in-   *
C     *               put property data.                            *
C     *      LITERL - Data file titles used for printed output.     *
C     *      PANELS - Used to communicate with the interpolation    *
C     *               subroutine INTERP.                            *
C     *      TURBN  - Turbine related variables.                    *
C     *      WIND   - Wind related variables.                       *
C     *                                                             *
C     ***************************************************************

C     ***************************************************************
C     *                                                             *
C     *   Local and dummy variables used in this routine:           *
C     *                                                             *
```

```
C       *     ACDZER   Drag coefficient at each blade station.  *
C       *              (dimensionless)                          *
C       *     ACHORD - Blade chord at each data station. (feet) *
C       *     ACLALF - Slope of lift curve at each blade station. *
C       *              (radians**-1)                            *
C       *     ACLMAX - The maximum or stall value of the lift co- *
C       *              efficient.                               *
C       *     AEIARE - Moment of inertia of blade at data station. *
C       *              (10**6 Lb-Ft**2)                         *
C       *     AESBAC - Distance from elastic axis to aerodynamic *
C       *              center. Origin is at the elastic axis; It *
C       *              is positive if the elastic axis is forward *
C       *              (toward the leading edge) of the aerodynam- *
C       *              ic center. (feet)                        *
C       *     AIEMAS   Second mass moment of the blade cross sec- *
C       *              tion in the edgewise direction. (Lb-sec^2) *
C       *     AIFMAS - Second mass moment of the blade cross sec- *
C       *              tion in the flapwise direction. (Lb-sec^2) *
C       *     ANS    - Literal containing the answer to a ques- *
C       *              tion.                                    *
C       *     AOFFST - Distance from the elastic axis to the mass *
C       *              axes of blade section. Positive towards  *
C       *              the leading edge. Called E-sub-eta in the *
C       *              formulation. (feet)                      *
C       *     ATWIST - The blade built-in twist angle as a func- *
C       *              tion of position along the blade span. The *
C       *              built-in twist at each of I stations.    *
C       *              ATWIST is the angle from the section-chord *
C       *              line at the Ith station to the section- *
C       *              chord line at the tip. Generally speaking, *
C       *              ATWIST(Reference Station) = THETAT.      *
C       *     ERROR  - Error flag indicating an invalid XLEFT ar- *
C       *              ray.                                     *
C       *     FILEIN - Literal containing the name of the input *
C       *              data file.                               *
C       *     FILOUT - Literal containing the name of the output *
C       *              data file.                               *
C       *     GRAV   - Constant of gravitational acceleration as *
C       *              measured at sea level. (feet/second**2)  *
C       *            - Generic index.                           *
C       *     NP       Number of blade property values used in  *
C       *              performing composite Simpson's integration
C       *              for the M and K coefficient arrays. This *
C       *              number is approximately 10 times the NPTS *
C       *              value.                                   *
C       *     NPANEL - Number of blade property values to be read *
C       *              in from the input data file.             *
C       *     NPTS   - Number of points along the blade used to *
C       *              perform Simpson's integration for calculat- *
C       *              ing the moments and forces at the blade  *
C       *              root.                                    *
C       *     RAD2DG - Degrees to radians conversion factor.    *
C       *     RTWIST - The blade twist angle relative to the zero- *
C       *              lift line. (radians)                     *
C       *     WEIGHT - Blade section weight per unit length. In- *
C       *              put as blade station data. (Lbf/ft)      *
C       *                                                       *
C      *********************************************************
```

```
      REAL            ACDZER (11)
      REAL            ACHORD (11)
      REAL            ACLALF (11)
      REAL            ACLMAX (11)
      REAL            AEIARE (11)
      REAL            AESBAC (11)
      REAL            AIEMAS (11)
      REAL            AIFMAS (11)
      REAL            AOFFST (11)
      REAL            ATWIST (11)
      REAL            GRAV
      REAL            RAD2DG
      REAL            RTWIST (11)
      REAL            WEIGHT (11)

      INTEGER         I
      INTEGER         NP
      INTEGER         NPANEL
      INTEGER         NPTS

      LOGICAL         ERROR

      CHARACTER*50    FILEIN
      CHARACTER*50    FILOUT

      INCLUDE        'C:INCLUDE\AERO.INC'

      INCLUDE        'C:INCLUDE\BLADE.INC'

      INCLUDE        'C:INCLUDE\LITERL.INC'

      INCLUDE        'C:INCLUDE\PANELS.INC'

      INCLUDE        'C:INCLUDE\TRBINF.INC'

      INCLUDE        'C:INCLUDE\TURBN.INC'

      INCLUDE        'C:INCLUDE\WIND.INC'

      DATA            GRAV    / 32.1740 /
      DATA            RAD2DG  / 57.29577951308233 /


1000 FORMAT ( / ' Subroutine INPUT: Input and process new blade'
     &         / '                   and turbine data.' / )
1100 FORMAT ( A )
1200 FORMAT ( / '   ***  Invalid response  ***' / )
1300 FORMAT ( BN , 6X , F16.5 )
1400 FORMAT ( BN , 6X , I10 )
1500 FORMAT ( BN , 12X , 11( F10.5 , : ) )
2000 FORMAT ( // 3( 1X , A / ) / ' Parameter values:' / )
2100 FORMAT ( 1X , A , F12.5 , 10X , A , I6 )
2200 FORMAT ( 1X , A , F12.5 , 10X , A , F12.5 )
2300 FORMAT ( 1X , A , I6    , 16X , A , F12.5)
2400 FORMAT ( '     XLEFT        WEIGHT       AEIARE   '
     &       , '    AIEMAS       AIFMAS       AOFFST' / )
2500 FORMAT ( 11( F11.5 , 5F13.5 / : ) )
2600 FORMAT ( / '     ACHORD       ATWIST       ALCALF   '
     &         , '    ACLMAX       ACDZER       AESBAC' / )
2700 FORMAT ( / ' STA-')
```

```
 2750 FORMAT ( 11( F10.3/:))
 3000 FORMAT ( / '   >>>  Error: Blade data do not start at blade root:'
     &         , '   <<<'
     &         / '   >>>' , 50X , '<<<'
     &         / '   >>>         XLEFT(1) =' , F8.3 , ', but should be'
     &         , ' zero.  <<<')
 3100 FORMAT ( / '   >>>  Error: Blade data do not end at blade tip:'
     &         , '  <<<'
     &         / '   >>>' , 46X , '<<<'
     &         / '   >>>         XLEFT(' , I2.2 , ') =' F8.3
     &         , ', but should be   <<<'
     &         / '   >>>         equal to BLTIP =' , F8.3
     &           , '             <<<' / )
 3200 FORMAT ( / '   >>>  Please correct input file and rerun job  <<<'
     &       /// ' FLAP terminated abnormally due to the error listed'
               , ' above.' / )



C        Initialize the number of shape functions.

      NSHAPS = 4


C        Get input and output data file names.  Open the input file.
C        Determine rotor type.  Read data from input file.

      PRINT 1000
      PRINT    *,  'Enter name of input data file > '
      READ  1100,  FILEIN

      OPEN ( 1 , FILE=FILEIN , STATUS='OLD' )

      PRINT    *,  ' '
      PRINT    *,  'Enter name of output data file > '
      READ  1100,  FILOUT

      CALL CAPS ( FILOUT )

  110 READ (1,1100)  TITLE1
      READ (1,1100)  TITLE2
      READ (1,1100)  TITLE3

      READ (1,1300)  ALENTH
      READ (1,1300)  ALPHAO
      READ (1,1300)  BETAO
      READ (1,1300)  BLSHNK
      READ (1,1300)  BLTIP
      READ (1,1300)  CHI
      READ (1,1300)  CSUBMA
      READ (1,1300)  DRGFRM
      READ (1,1300)  HUBHT
      READ (1,1300)  HUBRAD
      READ (1,1400)  KSHADW
      READ (1,1400)  NBLADS
      READ (1,1400)  NPANEL
      READ (1,1300)  OMEGA
      READ (1,1300)  PHIAMP
      READ (1,1300)  PHIOMG
      READ (1,1300)  PHIO
```

```
      READ (1,1300)  PSIZER
      READ (1,1300)  SHERXP
      READ (1,1300)  THETAP
      READ (1,1300)  THETAT
      READ (1,1300)  TSUBP
      READ (1,1300)  TSUBO
      READ (1,1300)  VHUB

      READ (1,1500)  ( XLEFT (I) , I=1,NPANEL )
      READ (1,1500)  ( WEIGHT(I) , I=1,NPANEL )
      READ (1,1500)  ( AEIARE(I) , I=1,NPANEL )
      READ (1,1500)  ( AIEMAS(I) , I=1,NPANEL )
      READ (1,1500)  ( AIFMAS(I) , I=1,NPANEL )
      READ (1,1500)  ( AOFFST(I) , I=1,NPANEL )
      READ (1,1500)  ( ACHORD(I) , I=1,NPANEL )
      READ (1,1500)  ( ATWIST(I) , I=1,NPANEL )
      READ (1,1500)  ( ACLALF(I) , I=1,NPANEL )
      READ (1,1500)  ( ACLMAX(I) , I=1,NPANEL )
      READ (1,1500)  ( ACDZER(I) , I=1,NPANEL )
      READ (1,1500)  ( AESBAC(I) , I=1,NPANEL )

      READ (1,1400) NUMSCN
      READ (1,1300) TIMINC
      READ (1,1400) MSTAT
      READ (1,1500) ( STA(I), I=1,MSTAT)


C       Close input file.

      CLOSE(1)


C       Echo input data.

      PRINT 2000,  TITLE1 , TITLE2 , TITLE3

      PRINT 2100,  'ALENTH = ' , ALENTH , 'NPANEL = ' , NPANEL
      PRINT 2200,  'ALPHAO = ' , ALPHAO , 'OMEGA  = ' , OMEGA
      PRINT 2200,  'BETAO  = ' , BETAO  , 'PHIO   = ' , PHIO
      PRINT 2200,  'BLSHNK = ' , BLSHNK , 'PHIAMP = ' , PHIAMP
      PRINT 2200,  'BLTIP  = ' , BLTIP  , 'PHIOMG = ' , PHIOMG
      PRINT 2200,  'CHI    = ' , CHI    , 'PSIZER = ' , PSIZER
      PRINT 2200,  'CSUBMA = ' , CSUBMA , 'SHERXP = ' , SHERXP
      PRINT 2200,  'DRGFRM = ' , DRGFRM , 'THETAP = ' , THETAP
      PRINT 2200,  'HUBHT  = ' , HUBHT  , 'THETAT = ' , THETAT
      PRINT 2200,  'HUBRAD = ' , HUBRAD , 'TSUBO  = ' , TSUBO
      PRINT 2300,  'KSHADW = ' , KSHADW , 'TSUBP  = ' , TSUBP
      PRINT 2300,  'NBLADS = ' , NBLADS , 'VHUB   = ' , VHUB
      PRINT 2300,  'NUMSCN = ' , NUMSCN
      PRINT 2200,  'TIMINC = ' , TIMINC
      PRINT 2300,  'MSTAT  = ' , MSTAT


      PRINT *,  ' '
      PRINT *,  'Hit <Enter> to continue...'


  200 PRINT 2400
      PRINT 2500,  (  XLEFT(I) , WEIGHT(I) , AEIARE(I) , AIEMAS(I)
     &             , AIFMAS(I) , AOFFST(I) , I=1,NPANEL )
```

```
      PRINT *,  ' '
      PRINT *,  'Hit <Enter> to continue...'

      READ (*,1100,END=210)  ANS

  210 PRINT 2600
      PRINT 2500,  ( ACHORD(I) , ATWIST(I) , ACLALF(I) , ACLMAX(I)
     &             , ACDZER(I) , AESBAC(I) , I=1,NPANEL )

      PRINT *,  ' '
      PRINT *,  'Hit <Enter> to continue...'

  220 PRINT 2700
      PRINT 2750, ( STA(I), I=1,MSTAT)

      PRINT *,  ' '
      PRINT *,  'Hit <Enter> to continue...'


      READ (*,1100,END=300)  ANS


C        Check validity of XLEFT array.  XLEFT must start at blade root
C        and end at blade tip.

  300 ERROR = .FALSE.

      IF ( XLEFT(1) .NE. 0.0 )  THEN
         PRINT 3000,  XLEFT(1)
         ERROR = .TRUE.
      END IF

      IF ( XLEFT(NPANEL) .NE. BLTIP )  THEN
         PRINT 3100,  NPANEL , XLEFT(NPANEL) , BLTIP
         ERROR = .TRUE.
      END IF

      IF ( ERROR )  THEN
         PRINT 3200
         STOP
      END IF


C        Perform unit conversions - Lbm to slugs, degrees to radians.

      DO 400 I=1,NPANEL
          WEIGHT(I) = WEIGHT(I)/GRAV
          AEIARE(I) = AEIARE(I)*1.E06
          AIEMAS(I) = AIEMAS(I)
          AIFMAS(I) = AIFMAS(I)
          RTWIST(I) = ( THETAT - ATWIST(I) - ALPHAO )/RAD2DG
  400 CONTINUE


C        Perform  linear  interpolation  of blade  properties  to set up
C        arrays of  blade property  data at equidistant points along the
C        blade.  The arrays are used by the COEFFS subroutine to produce
C        the coefficient matricies.
```

```
      STEP = BLTIP/( NP - 1 )

      CALL INTERP ( WEIGHT , MASS   , NPANEL , NP )
      CALL INTERP ( AIEMAS , IEMASS , NPANEL , NP )
      CALL INTERP ( AIFMAS , IFMASS , NPANEL , NP )
      CALL INTERP ( AEIARE , EIAREA , NPANEL , NP )
      CALL INTERP ( AOFFST , OFFSET , NPANEL , NP )
      CALL INTERP ( ACHORD , CHORD  , NPANEL , NP )
      CALL INTERP ( RTWIST , THETA0 , NPANEL , NP )


C        These property arrays will be used by the RUN subroutine for
C        solving the governing equations and for calculation of the
C        loads and moments.

      STEP = BLTIP/( NPTS - 1 )

      CALL INTERP ( ACLALF , CLALFA , NPANEL , NPTS )
      CALL INTERP ( ACDZER , CDZERO , NPANEL , NPTS )
      CALL INTERP ( AESBAC , ESUBAC , NPANEL , NPTS )
      CALL INTERP ( ACLMAX , CLMAX  , NPANEL , NPTS )


      RETURN
      END
      SUBROUTINE INTERP ( GIVEN , CMPUTD , NPANEL , NP )


C        ********** ************************************************
C        *                                                        *
C        *   This subroutine performs a linear interpolation  of the  *
C        *   input data set.   The input blade data contains  NPANEL  *
C        *   data points.  The data are interpolated to provide data  *
C        *   at NP evenly spaced points.                          *
C        *                                                        *
C        **********************************************************

C        ************************************************************
C        *                                                        *
C        *   Local and dummy variables used in this routine:      *
C        *                                                        *
C        *      CMPUTD - Regularly spaced interpolated data.      *
C        *      GIVEN  - Unevenly spaced input data.              *
C        *      IPNL   - Index into the GIVEN array.              *
C        *      JPT      Index into the CMPUTD array.             *
C        *      MOVE   - Flag to see if we've moved to the next pan-  *
C        *               el.                                      *
C        *      NP     - Number of evenly spaced data points.     *
C        *      NPANEL - Number of unevenly spaced data points.   *
C        *      PTR    - Blade position pointer.  It is the location  *
C        *               of the next interpolated value.          *
C        *      SLOPE  - Slope  of the  line  between two GIVEN data  *
C        *               points.                                  *
C        *                                                        *
C        * ********************* ******************************************

      INTEGER         NP
      INTEGER         NPANEL

      REAL            CMPUTD (NP)
```

```
      REAL            GIVEN  (NPANEL)
      REAL            PTR
      REAL            SLOPE

      INTEGER         IPNL
      INTEGER         JPT

      LOGICAL         MOVE

      INCLUDE        'C:INCLUDE\PANELS.INC'


C        Initialize GIVEN index and pointer.

      IPNL = 1
      PTR  = 0.0


C        Compute slope between first two data points.

      SLOPE = ( GIVEN(2) - GIVEN(1) )/XLEFT(2)


C        Compute property at each of the NP evenly spaced points.

      DO 20 JPT=1,NP-1

         CMPUTD(JPT) = GIVEN(IPNL) + SLOPE*( PTR - XLEFT(IPNL) )

         PTR = PTR + STEP


C           Make sure that the new data point is inside the current
C           panel.  Otherwise, move over one step.

         IF ( JPT .LT. NP-1 )  THEN

            MOVE = .FALSE.

   10       IF ( PTR .GT. XLEFT(IPNL+1) )  THEN
               IPNL = IPNL + 1
               MOVE = .TRUE.
               GO TO 10
            END IF

            IF ( MOVE )  SLOPE = ( GIVEN(IPNL+1) - GIVEN(IPNL) )/
     &                           ( XLEFT(IPNL+1) - XLEFT(IPNL) )

         END IF

   20 CONTINUE

      CMPUTD(NP) = GIVEN(NPANEL)


      RETURN
      END
      FUNCTION LNTH ( STRING )
```

```
C       ****************************************************************
C       *                                                              *
C       *   Function LNTH returns the length of a character string.    *
C       *   When using the Lahey F77L compiler, the intrinsic func-    *
C       *   tion  NBLANK  can be used as we do here.  This function    *
C       *   was supplied to make conversion to other compilers eas-    *
C       *   ier.                                                       *
C       *                                                              *
C       ****************************************************************

C       ****************************************************************
C       *                                                              *
C       *   Named COMMON blocks used in this routine:                  *
C       *                                                              *
C       *      none                                                    *
C       *                                                              *
C       ****************************************************************

C       ****************************************************************
C       *                                                              *
C       *   Variables used in this routine:                            *
C       *                                                              *
C       *      IC     - Generic index.                                 *
C       *      LENGTH - The declared length of STRING.                 *
C       *      LNTH   - The location of the last nonblank character    *
C       *               in STRING.                                     *
C       *      STRING - A character string.                            *
C       *                                                              *
C       ****************************************************************

      INTEGER         IC
      INTEGER         LENGTH
      INTEGER         LNTH

      CHARACTER*(*)   STRING



C       Get the declared length of STRING using the FORTRAN 77 intrinsic
C       function LEN.

      LENGTH = LEN( STRING )


C       Find the location of the last nonblank character in STRING.

      DO 100 IC=LENGTH,1,-1

         LNTH = IC

         IF ( STRING(IC:IC) .NE. ' ' )  GO TO 200

  100 CONTINUE


C       STRING is all blanks.

      LNTH = 0
```

```
  200 RETURN
      END
      SUBROUTINE PRNCOE ( FILOUT , NPTS )

C     ***************************************************************
C     *                                                             *
C     *   This subroutine writes the data required to run  MODULE   *
C     *   2 into the run data file.   Variable names are included   *
C     *   in the file for informational purposes only.  All vari-   *
C     *   ables written into the run data file  have been defined   *
C     *   previously.  Named common blocks AERO, BLADE, TURBN and   *
C     *   WIND  first appear  in subroutine INPUT.   Named common   *
C     *   blocks  MATRX1  and  MATRX2  are computed in subroutine   *
C     *   COEFFS.                                                   *
C     *                                                             *
C     ***************************************************************

C     ***************************************************************
C     *                                                             *
C     *   Named COMMON blocks used in this routine:                 *
C     *                                                             *
C     *      AERO   - Aerodynamic blade properties  derived  from   *
C     *               input aerodynamic data.                       *
C     *      BLADE  - Blade position  dependent  values  that are   *
C     *               computed by linear interpolation of the in-   *
C     *               put property data.                            *
C     *      HUBTYP - Holds flag indicating the type of hub  (ri-   *
C     *               gid or teetering).                            *
C     *      LITERL - Data file titles used for printed output.     *
C     *      LODVAL -                                               *
C     *      MATRX1 - Holds some of the  coefficient  matrices of   *
C     *               the governing equation of motion.             *
C     *      MATRX2 - Holds some of the  coefficient  matrices of   *
C     *               the governing equation of motion.             *
C     *      TENSIN - Holds  tension  components of the stiffness  *
C     *               functions.                                    *
C     *      TURBN  - Turbine related variables.                    *
C     *      WIND   - Wind related variables.                       *
C     *                                                             *
C     ***************************************************************

C     ***************************************************************
C     *                                                             *
C     *   Local and dummy variables used in this routine:           *
C     *                                                             *
C     *      COL    - Column index into matrices.                   *
C     *      FILOUT - Literal  containing  the name of the output   *
C     *               data file.                                    *
C     *      I      - Generic index.                                *
C     *      N      - Generic index.                                *
C     *      NPTS   - Number  of  points  along the blade used to   *
C     *               perform Simpson's integration for calculat-   *
C     *               ing the  moments  and  forces  at the blade   *
C     *               root.  (passed from FLAP1)                    *
C     *      NSHPS  - Number of blade shape functions.   Set to 1   *
C     *               for use by MODULE 2.                          *
C     *      ROW    - Row index into matrices.                      *
C     *                                                             *
```

```
C     ************************************************************

      INTEGER         COL
      INTEGER         I
      INTEGER         LNTH
      INTEGER         N
      INTEGER         NPTS
      INTEGER         NSHPS
      INTEGER         ROW

      CHARACTER*50    FILOUT

      INCLUDE        'C:INCLUDE\AERO.INC'

      INCLUDE        'C:INCLUDE\BLADE.INC'

      INCLUDE        'C:INCLUDE\LITERL.INC'

      INCLUDE        'C:INCLUDE\LODVAL.INC'

      INCLUDE        'C:INCLUDE\MATRX1.INC'

      INCLUDE        'C:INCLUDE\MATRX2.INC'

      INCLUDE        'C:INCLUDE\TENSIN.INC'

      INCLUDE        'C:INCLUDE\TRBINF.INC'

      INCLUDE        'C:INCLUDE\TURBN.INC'

      INCLUDE        'C:INCLUDE\WIND.INC'

      INCLUDE        'C:INCLUDE\MODAL.INC'

 2000 FORMAT ( 3( A / ) / )
 2100 FORMAT ( A )
 3000 FORMAT ( / 13X , 'ALENTH' , 18X , 'ALPHA0' , 18X , ' BETA0'
     &         / 3( 1PE24.10 ) )
 3100 FORMAT ( / 13X , 'BLSHNK' , 18X , ' BLTIP' , 18X , '  CHI '
     &         / 3( 1PE24.10 ) )
 3200 FORMAT ( / 13X , 'CSUBMA' , 18X , 'DRGFRM' , 18X , ' HUBHT'
     &         / 3( 1PE24.10 ) )
 3300 FORMAT ( / 13X , 'HUBRAD' , 18X , ' OMEGA' , 18X , ' PHIO '
     &         / 3( 1PE24.10 ) )
 3400 FORMAT ( / 13X , 'PHIAMP' , 18X , 'PHIOMG' , 18X , 'PSIZER'
     &         / 3( 1PE24.10 ) )
 3500 FORMAT ( / 13X , 'SHERXP' , 18X , 'THETAP' , 18X , 'THETAT'
     &         / 3( 1PE24.10 ) )
 3600 FORMAT ( / 13X , ' TSUB0' , 18X , ' TSUBP' , 18X , ' VHUB '
     &         / 3( 1PE24.10 ) )
 3700 FORMAT ( / 10X , 'KSHADW' , 12X , 'NBLADS'
     &         , 12X , 'NSHAPS' , 12X , ' NPTS ' / I14 , 3( I18 ) )
 3860 FORMAT ( / 10X , 'NUMSCN=', I6)
 3870 FORMAT ( / 10X , 'TIMINC=', F10.5)
 3880 FORMAT ( / 10X , 'MSTAT =', I3)
 4000 FORMAT ( / A , 26( / 4( 1PE18.7 , : ) ) )
 5000 FORMAT ( / ' CKTCRL(' , I2 , ',K,L)-' , 4( / 4( 1PE18.7 ) ) )
 6000 FORMAT ( / A / 4( 1PE18.7 ) )
 6100 FORMAT ( / ' TCORLS(' , I1 , ',I)-' , 26( / 4( 1PE18.7 , : ) ) )
```

```
 6050 FORMAT ( / ' STA(I)-' ,  26( / 5( 1PE14.3, : )))
 7000 FORMAT ( / ' CIFMOM(' , I1 , ',I)-' , 26( / 4( 1PE18.7 , : ) ) )
 8000 FORMAT ( / ' Data for MODULE 2 have been written to ' , A , '.'
     &         / )


C        Open output data file.

      OPEN ( 2 , FILE=FILOUT , STATUS='UNKNOWN' )


C        Put titles in run data file.

      WRITE (2,2000)  TITLE1 , TITLE2 , TITLE3


C        Put scalar values into run data file.

      WRITE (2,3000)  ALENTH , ALPHAO , BETAO
      WRITE (2,3100)  BLSHNK , BLTIP  , CHI
      WRITE (2,3200)  CSUBMA , DRGFRM , HUBHT
      WRITE (2,3300)  HUBRAD , OMEGA  , PHIO
      WRITE (2,3400)  PHIAMP , PHIOMG , PSIZER
      WRITE (2,3500)  SHERXP , THETAP , THETAT
      WRITE (2,3600)  TSUBO  , TSUBP  , VHUB

C        Use the value 2 for NSHAPS, which is the preferred value for
C        MODULE 2.   Use the variable name NSHPS to avoid overwriting
C        NSHAPS.

      NSHPS = 2

      WRITE (2,3700)  KSHADW , NBLADS , NSHPS , NPTS

      WRITE (2,3860)  NUMSCN
      WRITE (2,3870)  TIMINC
      WRITE (2,3880)  MSTAT
      WRITE (2,6050)  ( STA(I), I=1, MSTAT)

C        Put vector values into run data file.

      WRITE (2,4000)  ' CLALFA-' , ( CLALFA(I) , I=1,NPTS )
      WRITE (2,4000)  ' CLMAX -' , ( CLMAX (I) , I=1,NPTS )
      WRITE (2,4000)  ' CDZERO-' , ( CDZERO(I) , I=1,NPTS )
      WRITE (2,4000)  ' CHORD- ' , ( CHORD (I) , I=1,NPTS )
      WRITE (2,4000)  ' ECNTFN-' , ( ECNTFN(I) , I=1,NPTS )
      WRITE (2,4000)  ' ESUBAC-' , ( ESUBAC(I) , I=1,NPTS )
      WRITE (2,4000)  ' THETAO-' , ( THETAO(I) , I=1,NPTS )


C        Put matrix coefficient values into run data file.

      WRITE (2,4000)  ' CKBEND-'
     &           , ( ( CKBEND(ROW,COL) , COL=1,4 ) , ROW=1,4 )
      WRITE (2,4000)  ' CKTOMG-'
     &           , ( ( CKTOMG(ROW,COL) , COL=1,4 ) , ROW=1,4 )
      WRITE (2,4000)  ' CKTGRV-'
     &           , ( ( CKTGRV(ROW,COL) , COL=1,4 ) , ROW=1,4 )
      WRITE (2,4000)  ' CKQLOD-'
```

```
     &           , ( ( CKQLOD(ROW,COL) , COL=1,4 ) , ROW=1,4 )
      WRITE (2,4000)  ' CMMASS-'
     &           , ( ( CMMASS(ROW,COL) , COL=1,4 ) , ROW=1,4 )

      DO 500 N=1,4
  500 WRITE (2,5000)  N , ( ( CKTCRL(N,ROW,COL), COL=1,4 ), ROW=1,4 )


C        Put vector coefficient values into run data file.

      WRITE (2,6000)  ' CMRIGD-' , ( CMRIGD(I) , I=1,4 )
      WRITE (2,6000)  ' CMBLNC-' , ( CMBLNC(I) , I=1,4 )
      WRITE (2,6000)  ' CMGRAV-' , ( CMGRAV(I) , I=1,4 )


C        Put matrix tension values into run data file.

      DO 600 N=1,4
  600 WRITE (2,6100)  N , ( TCORLS(N,I) , I=1,NPTS )


C        Put vector gravity and centrifugal stiffening values into run
C        data file.

      WRITE (2,4000)  ' TGRAV-' , ( TGRAV(I) , I=1,NPTS )
      WRITE (2,4000)  ' TOMGA-' , ( TOMGA(I) , I=1,NPTS )


C        Put property values into run data file.

      DO 700 N=1,4
  700 WRITE (2,7000)  N , ( CIFMOM(N,I) , I=1,NPTS )

      WRITE (2,4000)  ' DELTIM-' , ( DELTIM(I) , I=1,NPTS )
      WRITE (2,4000)  ' OFFMAS-' , ( OFFMAS(I) , I=1,NPTS )

      DO 710 I = 1,4
           WRITE(2,*) (LAMDA(I,J),J=1,4)
  710 CONTINUE



C        Run file generation complete.  Print message and close file.

      WRITE (*,8000)  FILOUT(1:LNTH(FILOUT))

      CLOSE ( 2 )


      RETURN
      END
      FUNCTION SIMPSN ( LOWLIM , UPLIM , NPTS , FOFX )


C        ***************************************************************
C        *                                                             *
C        *   This function performs  composite Simpson's integration   *
C        *   on a given set of data points.  The formulation appears   *
C        *   in:                                                       *
```

```
C       *      Carnahan, et al,  Applied Numerical Methods, John      *
C       *      Wiley and Sons, NY, pp. 78-79.                         *
C       *                                                             *
C       ***************************************************************

C       ***************************************************************
C       *                                                             *
C       *   Local and dummy variables used in this routine:           *
C       *                                                             *
C       *     FOFX   - Array of data points to be integrated.  They   *
C       *              are treated as the value of a function eval-   *
C       *              uated at a specific point.                     *
C       *     H        Subinterval size.                             *
C       *     I      - Generic index.                                 *
C       *     LOWLIM - Lower limit of integration.                    *
C       *     UPLIM  - Upper limit of integration.                    *
C       *     NPTS   - Number of base points given by 2*N+1,  where   *
C       *              N is the number of applications of Simpson's   *
C       *              rule.  See NSIMP in the main program.  Note:   *
C       *              When calling  from  subroutine  COEFFS,  the   *
C       *              value of NP is used instead of NPTS.           *
C       *     SIMPSN - Value of the integral from LOWLIM to UPLIM.    *
C       *                                                             *
C       ***************************************************************


      REAL            FOFX   (201)
      REAL            H
      REAL            LOWLIM
      REAL            SIMPSN
      REAL            UPLIM

      INTEGER         I
      INTEGER         NPTS


C       Compute the subinterval size and initialize the integral.

      H      = ( UPLIM - LOWLIM )/( NPTS - 1 )
      SIMPSN = 0.0


C       Add in the intermediate points.   In the formulation, all even
C       numbered points have coefficient of 4. In this case, the index
C       must be shifted to form the proper coefficient.

      DO 10 I=2,NPTS-1,2
   10 SIMPSN = SIMPSN + 4.0*FOFX(I) + 2.0*FOFX(I+1)

      SIMPSN = SIMPSN + FOFX(1) - FOFX(NPTS)

      SIMPSN = H*SIMPSN/3.0


      RETURN
      END
      FUNCTION TRPZOD ( FOF , LOWLIM , NP , BLTIP )
```

```
C       ************************************************************
C       *                                                          *
C       *   Function TRPZOD performs composite trapezoidal integra-*
C       *   tion on  a set of  data  points  transmitted  from  the*
C       *   calling  routine.   For  derivation  of the formula and*
C       *   limitations, see Carnahan, p. 78 (see full reference in*
C       *   comments for function SIMPSN).  For computational effi-*
C       *   ciency,  the interval width is not used in the formula-*
C       *   tion until the end when it is multiplied by the sum.   *
C       *                                                          *
C       ************************************************************

C       ************************************************************
C       *                                                          *
C       *   Local and dummy variables used in this routine:        *
C       *                                                          *
C       *      FOF    - Array of data points to be integrated. They*
C       *               are treated  by this function  as the value*
C       *               of a function evaluated at specific points.*
C       *               (dummy argument)                           *
C       *      H      - Subinterval length given by H=(B-A)/N.     *
C       *      I      - Index into the FOF array.                  *
C       *      LOWLIM - Index of the lower integration limit.  The *
C       *               blade position indexed by  LOWLIM  is given*
C       *               by BLTIP*(LOWLIM-1)/(NP-1).    (dummy argu-*
C       *               ment)                                      *
C       *      NP     - Number of evenly spaced data points. (dummy*
C       *               argument)                                  *
C       *      TRPZOD - Value of the integral from the  blade posi-*
C       *               tion indexed by LOWLIM to BLTIP.           *
C       *                                                          *
C       ************************************************************

      REAL            BLTIP
      REAL            FOF    (201)
      REAL            H
      REAL            TRPZOD

      INTEGER         I
      INTEGER         LOWLIM
      INTEGER         NP



C       Check to see if the lower and upper limits of integration are
C       the same.  If so, the integral is zero.

      IF ( LOWLIM .EQ. NP )  THEN

         TRPZOD = 0.0
         RETURN

      END IF


C       Compute the distance between data points.

      H = BLTIP/( NP - 1 )
```

```
C       Initialize integral to the contribution of the end points.

      TRPZOD = 0.5*( FOF(LOWLIM) + FOF(NP) )


C       If there are only two data points, then we are done.

      IF ( LOWLIM+1 .EQ. NP )  GO TO 20


C       Add in the contribution of the intermediate points.

      DO 10 I=LOWLIM+1,NP-1
   10 TRPZOD = TRPZOD + FOF(I)


C       Multiply by the interval width and return.

   20 TRPZOD = H*TRPZOD


      RETURN
      END

      SUBROUTINE MULT ( AMATRX ,  BMATRX, RESULT, M , N )


C       ***************************************************************
C       *                                                             *
C       *   Subroutine MULT premultiplies two incoming matrices       *
C       *   together.   The result is stored in the RESULT matrix.    *
C       *   All matrices are considered to be square matrices up to   *
C       *   up to order 4.  The matrix AMATRX gets multiplied         *
C       *   by the matrix BMATRX.                                     *
C       ***************************************************************

C       ***************************************************************
C       *                                                             *
C       *   External references in this routine:                      *
C       *                                                             *
C       *      none                                                   *
C       *                                                             *
C       ***************************************************************

C       ***************************************************************
C       *                                                             *
C       *   Named COMMON blocks used in this routine:                 *
C       *                                                             *
C       *    NONE                                                     *
C       *                                                             *
C       ***************************************************************

C       ***************************************************************
C       *                                                             *
C       *   Local and dummy variables used in this routine:           *
C       *                                                             *
C       *      AMATRX - The incoming matrix to be premultiplied by    *
C       *               the inverse CMMASS matrix.                    *
```

```
C       *     BMATRX - The other incoming matrix which does the      *
C       *              multiplying.                                  *
C       *     RESULT - The result matrix of the multiplications      *
C       *     I      - Generic index.                                *
C       *     J      - Generic index.                                *
C       *     K      - Generic index.                                *
C       *     M      - Number of rows in the incoming matrix.        *
C       *     N      - Number of columns in the incoming matrix.     *
C       *                                                            *
C       **************************************************************

      REAL            AMATRX (4,4)
      REAL            BMATRX(4,4)
      REAL            RESULT(4,4)

      INTEGER         I
      INTEGER         J
      INTEGER         K
      INTEGER         M
      INTEGER         N



C       Multiply AMATRX by BMATRX putting the result into RESULT.

      DO 30 I=1,M

         DO 20 J=1,N

            RESULT(I,J) = 0.

            DO 10 K=1,M
   10       RESULT(I,J) = RESULT(I,J) + BMATRX(I,K) * AMATRX(K,J)

   20    CONTINUE

   30 CONTINUE

      RETURN
      END
```

Appendix D

Module 2 Listing

```
      PROGRAM FLAP2
```

```
C              *******************************************
C              *                                         *
C              *   0000000  0           00      000000   *
C              *   0        0          0  0     0     0  *
C              *   0000     0         000000    000000   *
C              *   0        0        0      0   0        *
C              *   0        0000000  0        0  0        *
C              *                                         *
C              *   Forces & Loads    Analysis    Program *
C              *                                         *
C              *                Module  2                *
C              *                                         *
C              *              Version  2.01              *
C              *                                         *
C              *******************************************
```

```
C       ***********************************************************
C       *                                                         *
C       *                      DISCLAIMER                         *
C       *                                                         *
C       *   Neither  the  United States Department of Energy,  the *
C       *   National Renewable Energy Laboratory,                 *
C       *   the Midwest Research Institute nor anyone             *
C       *   else who has been involved in the                     *
C       *   creation, production or delivery of this program shall *
C       *   be liable for any direct, indirect, consequential,  or *
C       *   incidental damages arising out of the use, the results *
C       *   of use,  or  inability to use this program even if the *
C       *   United States Department of Energy has been advised of *
C       *   the possibility of such damages or claim.  Some states *
C       *   do not allow the  exclusion or limitation of liability *
```

```
C       *   for consequential or incidental damages,  so the above   *
C       *   limitation may not apply to you.                         *
C       *                                                            *
C       ************************************************************

C       ************************************************************
C       *                                                          *
C       *                      The FLAP Code                       *
C       *                                                          *
C       *   FLAP calculates the  forces and moments  on a wind tur-*
C       *   bine blade  due to  aerodynamic,  inertial and gravita-*
C       *   tional forces.  The  aerodynamic  effects include wind *
C       *   shear, tower shadow and the induced velocity due to the*
C       *   change in momentum of the air stream as it  passes over*
C       *   the blade.  A dynamic stall model can be added without *
C       *   substantial revision of the code.                      *
C       *                                                          *
C       ************************************************************

C       ************************************************************
C       *                                                          *
C       *                       Module 2                           *
C       *                                                          *
C       *   This program  is the second of two modules that consti-*
C       *   tute the  FLAP  code.  This second module performs the *
C       *   actual model run, computes the loads and prints the re-*
C       *   sults to an external data file.                        *
C       *                                                          *
C       ************************************************************

C       ************************************************************
C       *                                                          *
C       *   Questions about the original formulation, theory, meth-*
C       *   od of solution and programming should be addressed to: *
C       *                                                          *
C       *           Alan D. Wright                                 *
C       *           Wind Research Branch                           *
C       *           Solar Energy Research Institute                *
C       *           1617 Cole Blvd.                                *
C       *           Golden, CO  80401                              *
C       *           (303)231-7651                                  *
C       *                                                          *
C       ************************************************************

C       ****************************************
```

```
C       *                                   *
C       *   I/O Conventions:                *
C       *                                   *
C       *      Unit 2 - Diagnostics file    *
C       *      Unit 3 - Input run data      *
C       *      Unit 4 - Results file        *
C       *      Unit * - Monitor or keyboard *
C       *                                   *
C       *************************************

C       ****************************************************************
C       *                                                              *
C       *   External references in this routine:                       *
C       *                                                              *
C       *      DATAIN - Reads in a data generated by MODULE 1.         *
C       *      DIAG   - Performs a test run of the aerodynamic rou-    *
C       *               tines.                                         *
C       *      RUN    - Models the rotor blade motion.                 *
C       *                                                              *
C       ****************************************************************

C       ****************************************************************
C       *                                                              *
C       *   Local and dummy variables used in this routine:            *
C       *                                                              *
C       *      ANS    - Used to store input responses from key-       *
C       *               board.                                         *
C       *      HAVDAT - Flag that indicates that some data has been    *
C       *               read in.                                       *
C       *      HAVRUN - Flag that indicates that the model has been    *
C       *               run.  Used for diagnostic runs.                *
C       *      NEWSET - Flag that indicates that a new data set has    *
C       *               been read in.                                  *
C       *      NPTS   - Number of points along the blade used to       *
C       *               perform Simpson's integration for calcu-       *
C       *               lating the moments and forces at the blade     *
C       *               root.                                          *
C       *      NSIMP  - Order of the composite Simpson's integra-      *
C       *               tion used in the run.  Parameter is set to     *
C       *               10 in order to make 21 blade property sta-     *
C       *               ions.                                          *
C       *      TODEGS - Logical variable that indicates the direc-     *
C       *               tion of conversion between degrees and ra-     *
C       *               dians.                                         *
C       *                                                              *
C       ****************************************************************


      INTEGER         NPTS
      INTEGER         NSIMP

      INCLUDE         'C:INCLUDE\TRBINF.INC'

      LOGICAL         HAVDAT
      LOGICAL         HAVRUN
      LOGICAL         NEWSET
      LOGICAL         TODEGS

      CHARACTER*1     ANS
```

```
      DATA            HAVDAT  / .FALSE. /
      DATA            HAVRUN  / .FALSE. /
      DATA            NSIMP   / 10 /
      DATA            TODEGS  / .TRUE. /

  100 FORMAT (
     &    // '   Program For Analysis Of Horizontal Axis Wind Turbine'
     &     / '               Response To Dynamic Loads'
     &    // '                       MODULE 2' )
  110 FORMAT ( / ' Operations Menu'
     &        / ' ---------------'
     &       // ' (R)ead in a data file'
     &        / ' (S)et up and run the model'
     &        / ' (D)iagnostic run'
     &        / ' (T)urbulence analysis'
     &        / ' (Q)uit' )
  120 FORMAT ( / ' Enter Option (R,S,D,T,Q) > ' )
  130 FORMAT ( A )
  140 FORMAT ( / ' You must select option (R) at least once before'
     &        / ' invoking this option.' )
  150 FORMAT ( / ' You must select option (S) at least once before'
     &        / ' invoking this option.' )
  160 FORMAT ( / ' Invalid response.  Please try again.' )
  170 FORMAT ( / ' FLAP terminated normally.' / )



C       Calculate the number of blade property stations.

      NPTS = 2*NSIMP + 1


C       Print title.

      PRINT 100


C       Print menu of options.  Ask for choice.

   10 PRINT 110

   20 PRINT 120
      READ  130,  ANS


C       Which option was chosen?

      IF ( ( ANS .EQ. 'R' ) .OR. ( ANS .EQ. 'r' ) )  THEN


C          Read in a data file.  Convert limits values back to degrees
C          if this isn't the first time we've read in data.

         IF ( HAVDAT )  CALL CONVRT ( TODEGS )
         CALL DATAIN
         HAVDAT = .TRUE.
         NEWSET = .TRUE.
         GO TO 10

      ELSE IF ( ( ANS .EQ. 'S' ) .OR. ( ANS .EQ. 's' ) )  THEN
```

```
C          Set up and run the model.  Option (R) must have been
C          previously selected.

         IF ( HAVDAT )  THEN
            CALL RUN ( NPTS , NEWSET , HAVRUN )
            GO TO 10
         ELSE
            PRINT 140
            GO TO 20
         END IF

      ELSE IF ( ( ANS .EQ. 'D' ) .OR. ( ANS .EQ. 'd' ) )  THEN


C          Run diagnostics.  Option (S) must have been previously
C          selected.

         IF ( HAVRUN )  THEN
            CALL DIAG ( NPTS )
            GO TO 10
         ELSE
            PRINT 150
            GO TO 20
         END IF

      ELSE IF ( ( ANS .EQ. 'T' ) .OR.  ( ANS .EQ. 't' ) )  THEN
C          Run turbulence case.  Option S must have been
C          previously invoked.

         IF ( HAVRUN )  THEN
         ITURB = 1
            CALL TRBCLC( NPTS )
            GO TO 10
         ELSE
            PRINT 150
            GO TO 20
         ENDIF

      ELSE IF ( ( ANS .NE. 'Q' ) .AND. ( ANS .NE. 'q' ) )  THEN


C          Invalid response.

         PRINT 160
         GO TO 20

      END IF


C        Processing complete.

      PRINT 170


      STOP
      END

      BLOCK DATA
```

```
C     ************************************************************
C     *                                                          *
C     *   This module is used to initialize the COMMON blocks.   *
C     *                                                          *
C     ************************************************************

C     ************************************************************
C     *                                                          *
C     *   Named COMMON blocks used in this routine:              *
C     *                                                          *
C     *      AERO1  - Holds coefficients related to aerodynamic  *
C     *               loads calculations such as ClAlpha, CdZero,*
C     *               etc.                                       *
C     *      AIRFRC - Holds values used in aerodynamic calcula-  *
C     *               tions.                                     *
C     *      BLADE    Holds blade property values such as stiff- *
C     *               ness and mass distributions.               *
C     *      CONST  - Turbine and other constants used in load   *
C     *               calculations.                              *
C     *      DELTV  - Holds turbine inputs for possible future   *
C     *               use.  Not currently used.                  *
C     *      FORMS  - Holds blade deflections.                   *
C     *      INV    - Holds the inverse of the mass matrix.      *
C     *      LIMITC - Holds values used in the LIMITS routine.   *
C     *      LITERL - Holds data set titles.                     *
C     *      LODVAL - Holds values used to compute blade loads.  *
C     *      MATRX1 - Holds stiffness coefficient matrices.      *
C     *      MATRX2 - Holds some of the coefficient matrices of  *
C     *               the governing equation of motion.          *
C     *      POSITN - Holds parameters related to blade position *
C     *               such as PHI, PSI, etc.                     *
C     *      SARAYS - Holds new and old values for the general-  *
C     *               ized coordinates.                          *
C     *      SHAPE  - Holds blade coordinate shape functions.    *
C     *      START  - Holds initial blade deflection.            *
C     *      TENSIN - Holds tension components of the stiffness  *
C     *               functions.                                 *
C     *      TURBN  - Holds turbine parameters such as number of *
C     *               blades, rotor speed, etc.                  *
C     *      VINDUC - Holds induced velocity components.         *
C     *      VREL1  - Holds blade section velocity components.   *
C     *      WIND   - Holds wind shear and tower shadow parame-  *
C     *               ters.                                      *
C     *      WNDVEL - Holds values used in wind shear and tower  *
C     *               shadow computations.                       *
C     *                                                          *
C     ************************************************************

C     ************************************************************
C     *                                                          *
C     *   COMMON variables used in Module 2 of FLAP:             *
C     *                                                          *
C     *      ABAR   - Dimensionless form of ALENTH ( ALENTH di-  *
C     *               vided by the rotor radius, RR ).           *
C     *      AINVRS - The inverse CMMASS matrix.                 *
C     *      ALENTH - Distance from the tower axis to the rotor  *
C     *               hub.  (feet)                               *
C     *      ALPHAO - The angle from the zero-lift line to the   *
```

```
C       *              section-chord line.  (Generally negative)     *
C       *     BEGIN2 - Azimuth position  corresponding  to the be-   *
C       *              ginning of print region 2.  (degrees)         *
C       *     BETA0    Blade coning angle.  The value is input in    *
C       *              degrees and converted to radians. (radians)   *
C       *              (input data)                                  *
C       *     BLSHNK - Length of blade shank  measured  from the     *
C       *              blade root to the start of the airfoil sec-   *
C       *              tion.  If airfoil begins at the root, then    *
C       *              BLSHNK=0.  (feet)                             *
C       *     BLTIP  - Blade length  measured from the  blade root   *
C       *              to the blade tip.   Note - rotor radius is    *
C       *              HUBRAD + BLTIP.  (feet)                       *
C       *     CDZERO - Drag  coefficient  values  at  equidistant    *
C       *              points  along  the  blade.   Derived  from    *
C       *              ACDZER values.  (dimensionless)               *
C       *     CHI    - Rotor  pitch angle.  Input in degrees and     *
C       *              converted  to  radians.  (radians)  (input    *
C       *              data)                                         *
C       *     CHORD  - Blade chord at equidistant points along the  *
C       *              blade.  Derived from ACHORD.  (feet)          *
C       *     CIFMOM - Integral of DIFMOM.                           *
C       *     CKBEND - Bending stiffness matrix.                     *
C       *     CKQLOD - Inertial moment stiffening matrix.            *
C       *     CKTCRL - Coriolis stiffening matrix.                   *
C       *     CKTGRV - Gravity stiffening matrix.                    *
C       *     CKTOMG - Centrifugal stiffening matrix.                *
C       *     CLALFA - Slope  of  the  lift  curve  at equidistant   *
C       *              points along the blade. Derived from ACLALF   *
C       *              values.  (radians^-1)                         *
C       *     CLMAX  - The maximum or stall value  of the lift co-   *
C       *              efficient.  Derived from ACLMAX values.       *
C       *     CMBLNC - Coefficient  associated with the blade mass   *
C       *              imbalance (OFFSET).                           *
C       *     CMGRAV - Mass coefficients  associated with gravita-   *
C       *              tional loads.                                 *
C       *     CMMASS - Blade mass matrix.  It is also used in the    *
C       *              inertia force stiffening term.                *
C       *     CMRIGD - Mass coefficients associated with rigid bo-   *
C       *              dy motion.                                    *
C       *     CSUBMA - Pitching moment coefficient.                  *
C       *     CTHP   - Cosine of the pitch angle, THETAP.            *
C       *     DAETA  - Differential aerodynamic forces  on a blade   *
C       *              section in the chordwise direction.           *
C       *     DAZETA - Differential aerodynamic forces  on a blade   *
C       *              section in the flapwise direction.            *
C       *     DELPSI - Delta-Psi.  The amount Psi will change from   *
C       *              this step to the next.  Used in Euler pre-    *
C       *              dictor/corrector routine.                     *
C       *     DELTAT   The incremental  time change  from one step   *
C       *              to the next in the yaw solution (ITRIM=0).    *
C       *     DELTIM - Integral of DDELTI.                           *
C       *     DELTVX - Turbulent wind velocity fluctuations.  Not    *
C       *              currently in use.  (feet/second)              *
C       *     DELTVY - Turbulent wind velocity fluctuations.  Not    *
C       *              currently in use.  (feet/second)              *
C       *     DELTVZ - Turbulent wind velocity fluctuations.  Not    *
C       *              currently in use.  (feet/second)              *
C       *     DRGFRM - Drag coefficient form constant.               *
C       *     DVIND  - The  delta-V-induced  velocity  components.   *
```

```
C       *              Components are of order epsilon.                *
C       *     ECNTFN - Complicated term.                               *
C       *     EIAREA - Moment of inertia values at equidistant         *
C       *              points along the blade.  Derived from           *
C       *              AEIARE data values.  (Lb-Ft**2)                 *
C       *     END2   - Azimuth position corresponding to the end       *
C       *              of print region 2.  (degrees)                   *
C       *     ERROR  - Difference between corrected and predicted      *
C       *              value of the blade tip displacements in the     *
C       *              Euler predictor/corrector routine.              *
C       *     ESUBAC - Distance from the blade elastic axis to the     *
C       *              aerodynamic center.  Positive towards the       *
C       *              leading edge.  Derived from AESBAC values.      *
C       *              (feet)                                          *
C       *     EUERR  - Convergence criterion for computing blade       *
C       *              tip deflections via the Euler predictor/        *
C       *              corrector routine.  (percent)                   *
C       *     FAERO  - Aerodynamic force on the rotor.                 *
C       *     GRAV   - Constant of gravitational acceleration as       *
C       *              measured at sea level.  (feet/second**2)        *
C       *     HUBHT  - Hub reference height above the ground.          *
C       *              (feet)                                          *
C       *     HUBRAD - Radius of rotor hub.  (feet) (input data)       *
C       *     HUBVEL - Wind velocity at rotor hub.  Currently          *
C       *              equal to Vhub.  (feet/second)                   *
C       *     IEMASS - Edgewise mass moment of inertia at equidis-     *
C       *              tant points along the blade section.  Der-      *
C       *              ived from AIEMAS values.  (10^6 Lb-sec^2)       *
C       *     IFMASS - Flapwise mass moment of inertia at equidis-     *
C       *              tant points along the blade section.  Der-      *
C       *              ived from AIFMAS values.  (10^6 Lb-sec^2)       *
C       *     ITRIM  - Flag indicating run status:                     *
C       *                 0 - Run to find yawing solution.             *
C       *                 1 - Run to find trim solution.               *
C       *                 2 - Trim startup run.                        *
C       *     KSHADW - Number of tower shadow peaks within the         *
C       *              tower shadow zone.  (input data)                *
C       *     MASS   - Blade mass per unit length at equidistant      *
C       *              points along the blade.  Input in Lbf/ft,       *
C       *              via the input variable WEIGHT, and convert-     *
C       *              ed to slugs/ft.  (slugs/ft)  (input data)       *
C       *     NBLADS - Number of turbine blades.  (input data)         *
C       *     NSHAPS - Number of blade shape functions, 4 maximum.     *
C       *              (input data)                                    *
C       *     NYAW   - Number of rotor revolutions to be run for       *
C       *              a yawing solution.                              *
C       *     OFFMAS - Integral of DOFFMS.                             *
C       *     OFFSET - Distance from the elastic axis to the mass      *
C       *              axes of blade section.  Positive towards        *
C       *              the leading edge.  Derived from AOFFST val-     *
C       *              ues.  Called E-sub-eta in the formulation.      *
C       *              (feet) (input data)                             *
C       *     OMEGA  - Rotor speed.  Input in RPM and converted to     *
C       *              radians/second.  (rad/sec) (input data)         *
C       *     PHI    - Rotor yaw error angle.  Angle between the       *
C       *              hub axis and the mean wind.  Subscript in-      *
C       *              dicates which time derivative.                  *
C       *     PHIO   - Rotor yaw reference angle.  Measured as the     *
C       *              angle between a horizontal reference line       *
C       *              passing through the tower axis and the hor-     *
```

```
C       *             izontal projection  of the line between the  *
C       *             tower axis and the rotor hub.  Input as de-  *
C       *             grees and converted to radians.  (radians)   *
C       *             (input data)                                 *
C       *     PHIAMP - Amplitude  of periodic yaw motion about yaw *
C       *             reference angle.  Input as degrees and con-  *
C       *             verted to radians.  (radians) (input data)   *
C       *     PHIOMG - Maximum yaw rate.  Used internally to com-  *
C       *             pute the yaw period.  It can be used to in-  *
C       *             put a  turbine steady  yaw rate.  Input as   *
C       *             degrees/sec  and  converted to radians/sec-  *
C       *             ond.  (radians/sec)  (input data)            *
C       *     PI      - The constant 3.141592653589793...          *
C       *     PRINT1 - Printout interval in print region 1.        *
C       *     PRINT2  Printout interval in print region 2.         *
C       *     PSI     Blade azimuth angle.  The zeroth element is  *
C       *             the past value of Psi and the first element  *
C       *             contains the present value.  A value of ze-  *
C       *             ro indicates the blade is straight up.       *
C       *     PSISHD - Azimuth position of the center line  of the *
C       *             tower shadow.  When it is 180 degrees, the   *
C       *             tower shadow center line is oriented verti-  *
C       *             cally downward from the hub.                 *
C       *     PSIZER - Half angle width  of  the  tower shadow re- *
C       *             gion.  (degrees) (input data)                *
C       *     RAD2DG - Radians to degrees conversion factor.       *
C       *     RHOAIR - Air density.  Currently set to sea level.   *
C       *             (Lb-sec^2/feet^4 or slugs/feet^3)            *
C       *     RR      - Rotor radius (BLTIP+HUBRAD).  (feet)       *
C       *     RROMGA - A constant used throughout the  FLAP  code. *
C       *             (RR*OMEGA*PI/30)                             *
C       *     SO      - Initial static blade deflection at the tip.*
C       *             It is set in subroutine STARTUP.             *
C       *     SHAPE  - Array containing shape functions  evaluated *
C       *             at regular intervals.  The second subscript  *
C       *             corresponds to Nth spatial derivative.       *
C       *     SHERXP - Wind shear power exponent.  (input data)    *
C       *     SNEW   - An array  of tip displacement function val- *
C       *             ues for each of the STEPMX stations  around  *
C       *             the disk.  These  are  the results  of  the  *
C       *             current  computation.  The  zeroth element   *
C       *             has the same value  as the 360th element of  *
C       *             SOLD.                                        *
C       *     SOLD   - An array  of tip displacement function val- *
C       *             ues for each of the STEPMX stations  around  *
C       *             the disk.  These  are  the results  of  the  *
C       *             previous computation.  The  360th  element   *
C       *             has the same value as the zeroth element of  *
C       *             SNEW.                                        *
C       *     STEPMN - Minimum allowable  azimuth angle step size. *
C       *             (degrees)                                    *
C       *     STEPMX - Maximum allowable  azimuth angle step size. *
C       *             (degrees)                                    *
C       *     STHP   - Sine of the pitch angle THETAP.             *
C       *     TCORLS - Blade tension  coefficient  due to coriolis *
C       *             effects.                                     *
C       *     TGRAV  - Blade tension  coefficient  due to  gravity *
C       *             effects.                                     *
C       *     THETA0 - Orientation  of the zero lift line with re- *
C       *             spect to the blade principal bending axis.   *
```

```
C       *     THETAP - Blade pitch angle.  The angle from the flap  *
C       *              bending axis (assumed to be the chord line)  *
C       *              at the 3/4 spanwise location.  The assump-   *
C       *              tion  has been made  that the  bending axis  *
C       *              does not vary  with spanwise location.  In   *
C       *              effect,  THETAP  sets the blade pitch angle  *
C       *              and the direction of the flapping displace-  *
C       *              ments.  Input in degrees  and converted to   *
C       *              radians.  (radians) (input data)             *
C       *     THETAT - The  built-in  blade twist  angle  from the  *
C       *              section-chord line at the reference station  *
C       *              to the section-chord line at the tip of the  *
C       *              rotor.  Positive towards feather.            *
C       *     TIME   - Total  elapsed time  from the beginning  of  *
C       *              the yaw solution  run.  The zeroth element   *
C       *              holds the past value of time, and the first  *
C       *              element holds the current value.  (seconds)  *
C       *     TITLE1 - First line of the data file title.           *
C       *     TITLE2 - Second line of the data file title.          *
C       *     TITLE3 - Third line of the data file title.           *
C       *     TOMGA  - Blade tension  coefficient  associated with *
C       *              centrifugal force effects.                   *
C       *     TRACEF - Flag  that causes subroutine TRACE to print *
C       *              the values of various variables  around the  *
C       *              rotor disk.                                  *
C       *     TRMERR - Convergence  criterion  for  computing  the *
C       *              trim solution.  (percent)                    *
C       *     TSHADW - The tower shadow velocity deficit.          *
C       *     TSUBO  - Tower shadow wind speed offset component.   *
C       *     TSUBP  - Tower shadow sinusoidal component.          *
C       *     VETA   - Relative fluid velocity  over the blade  in *
C       *              the edgewise direction.                      *
C       *     VHUB   - Air  speed  at  the  height  of  the  hub.  *
C       *              (ft/sec) (input data)                        *
C       *     VINDO  - An induced velocity rotor term.  It is uni- *
C       *              form over the rotor disk.                    *
C       *     VINDC  - An  induced velocity  component  associated *
C       *              with the Cosine(Psi) term.                   *
C       *     VINDR  - Inflow minus uniform induced velocity.      *
C       *     VV     - The actual tip displacements  computed from *
        *              the relation in subroutine FORM1:            *
        *                    V = Sum of S(I)*GAMMA(I)               *
        *              and                                          *
        *                    VDOT = Sum of SDOT(I)*GAMMA(I),        *
        *              where V is a function of position along the  *
        *              blade and time, S is a function of time and  *
        *              GAMMA  is the  blade coordinate shape func-  *
        *              tion.  The index  I  denotes summation over  *
        *              the coordinate function shapes,  DOT is the  *
        *              first derivative  w.r.t. time.  Thus:        *
        *                   VV(0,I) = V     = displacement          *
        *              and  VV(1,I) = V-DOT = velocity.             *
        *     VWIND  - Resultant wind velocity at the rotor disk.   *
        *     VZETA  - Relative fluid velocity  over the blade  in *
        *              the flapwise direction.                      *
        *     WSHEAR - The harmonic  or  unsteady component of the *
        *              wind shear.                                  *
        *     WSHR   - Individual harmonic components of the total *
        *              unsteady wind shear component.               *
        *     WW     - Resultant windspeed at a blade element.     *
```

```
C       *                                                              *
C       ****************************************************************

      INCLUDE        'C:INCLUDE\AERO1.INC'

      INCLUDE        'C:INCLUDE\AIRFRC.INC'

      INCLUDE        'C:INCLUDE\BLADE2.INC'

      INCLUDE        'C:INCLUDE\CONST2.INC'

      INCLUDE        'C:INCLUDE\DELTV.INC'

      INCLUDE        'C:INCLUDE\FORMS.INC'

      INCLUDE        'C:INCLUDE\INV.INC'

      INCLUDE        'C:INCLUDE\LIMITC.INC'

      INCLUDE        'C:INCLUDE\LITERL.INC'

      INCLUDE        'C:INCLUDE\LODVAL.INC'

      INCLUDE        'C:INCLUDE\MATRX1.INC'

      INCLUDE        'C:INCLUDE\MATRX2.INC'

      INCLUDE        'C:INCLUDE\POSITN.INC'

      INCLUDE        'C:INCLUDE\SARAYS.INC'

      INCLUDE        'C:INCLUDE\SHAPE.INC'

      INCLUDE        'C:INCLUDE\START.INC'

      INCLUDE        'C:INCLUDE\TENSIN2.INC'

      INCLUDE        'C:INCLUDE\TURBN.INC'

      INCLUDE        'C:INCLUDE\VINDUC.INC'

      INCLUDE        'C:INCLUDE\VREL1.INC'

      INCLUDE        'C:INCLUDE\WIND2.INC'

      INCLUDE        'C:INCLUDE\WNDVEL.INC'

C       Initialize COMMON blocks.

      DATA            BEGIN2  /     180.0             /
      DATA            DELPSI  /  2*   0.0             /
      DATA            DELTAT  /  2*   0.0             /
      DATA            DELTVX  / 21*   0.0             /
      DATA            DELTVY  / 21*   0.0             /
      DATA            DELTVZ  / 21*   0.0             /
      DATA            END2    /     270.0             /
      DATA            EUERR   /      10.0             /
      DATA            GRAV    /      32.1740          /
      DATA            KSHADW  /       1               /
```

```
      DATA            NSHAPS  /                       /
      DATA            NYAW    /       0               /
      DATA            PHI     /  3*   0.0             /
      DATA            PHIO    /       0.0             /
      DATA            PI      /       3.141592653589793 /
      DATA            PRINT1  /      10.0             /
      DATA            PRINT2  /      10.0             /
      DATA            PSI     /  2*   0.0             /
      DATA            PSISHD  /     180.0             /
      DATA            PSIZER  /      15.0             /
      DATA            RAD2DG  /      57.29577951308233  /
      DATA            RHOAIR  /       0.002           /
      DATA            SHERXP  /       0.14286         /
      DATA            STEPMN  /       0.001           /
      DATA            STEPMX  /      10.0             /
      DATA            TIME    /  2*   0.0             /
      DATA            TRACEF  /  .FALSE.              /
      DATA            TRMERR  /      10.0             /
      DATA            TSUBO   /      10.0             /
      DATA            TSUBP   /      10.0             /
      DATA            VHUB    /      27.1             /

      END
      SUBROUTINE ACCEL ( DEFLTN , VELCTY , ACCELN , NPTS , STEMP )

C     ***************************************************************
C     *                                                             *
C     *   Subroutine ACCEL computes the solution to the blade       *
C     *   equation of motion.  The coefficient matrices are         *
C     *   available for all four coordinate shape functions, but    *
C     *   the solution is only calculated for the number of func-   *
C     *   tions specified by the value of NSHAPS.                   *
C     *                                                             *
C     ***************************************************************

C     ***************************************************************
C     *                                                             *
C     *   External references in this routine:                      *
C     *                                                             *
C     *     AFORCE - Calculates the value of the aerodynamic        *
C     *              force integral.                                *
C     *     FORM1  - Calculates the values of the blade dis-        *
C     *              placement function.                            *
C     *                                                             *
C     ***************************************************************

C     ***************************************************************
C     *                                                             *
C     *   Named COMMON blocks used in this routine:                 *
C     *                                                             *
C     *     AIRFRC - Holds values used in aerodynamic calcula-      *
C     *              tions.                                         *
C     *     CONST  - Turbine and other constants used in load       *
C     *              calculations.                                  *
C     *     MATRX1 - Holds stiffness coefficient matrices.          *
C     *     MATRX2 - Holds some of the coefficient matrices of      *
C     *              the governing equation of motion.              *
C     *     POSITN - Holds parameters related to blade position     *
```

```
C       *              such as PHI, PSI, etc.                          *
C       *      TENSIN - Holds  tension  components of the stiffness   *
C       *              functions.                                      *
C       *      TURBN  - Holds turbine parameters  such as number of    *
C       *              blades, rotor speed, etc.                       *
C       *                                                              *
C       ****************************************************************


C       ****************************************************************
C       *                                                              *
C       *   Local and dummy variables used in this routine:            *
C       *                                                              *
C       *      AA     - 2.0*Omega*Sine( ThetaP ).                      *
C       *      ACCELN - The solution to the equation of motion.  It    *
C       *               corresponds  to the  S-double dot  value in    *
C       *               the formulation,  and is the  current solu-    *
C       *               tion for the blade tip acceleration.           *
C       *               (feet/second^2)                                *
C       *      BB     - Gravity times  cosine of the blade azimuth.    *
C       *      BLDANG - Blade azimuth position  used in the teeter-    *
C       *               ing rotor option.                              *
C       *      C1     - BetaD*Omega^2.                                 *
C       *      C2     - Omega*Phi*Cosine( Psi ).                       *
C       *      C3     - dPhi/dt*Sine( Psi ).                           *
C       *      C4     - -Chi*Cosine( ThetaP ).                         *
C       *      C5     - Sine( ThetaP )*Sine( Psi ).                    *
C       *      C6     - Beta0*Cosine( ThetaP )*Cosine( Psi ).          *
C       *      C7     - Omega^2.                                       *
C       *      CC     - QUANT1^2.                                      *
C       *      CPSI   - Cosine of the blade angle.                     *
C       *      DD     - Complicated term.                              *
C       *      DEFLTN - The  current value  of the  tip deflection,    *
C       *               corresponding to the S variable in the for-    *
C       *               mulation of the equation of motion.            *
C       *      EE     - QUANT1^2.                                      *
C       *      FF     - Omega*QUANT1*Cosine( ThetaP )                  *
C       *      GG     - Complicated term.                              *
C       *      K      - Generic DO index.                              *
C       *      M      - Generic DO index.                              *
C       *      N      - Generic DO index.                              *
C       *      NPTS   - Number  of  points  along the blade used to    *
C       *               perform Simpson's integration for calculat-    *
C       *               ing the  moments  and  forces  at the blade    *
C       *               root.  (passed from FLAP1)                     *
C       *      P1     - Array used in computing acceleration.          *
C       *      P2     - Array used in computing acceleration.          *
C       *      P3     - Array used in computing acceleration.          *
C       *      Q      - Matrix used in computing acceleration.         *
C       *      QUANT1 - Omega*Sine( ThetaP ).                          *
C       *      SPSI   - Sine of the blade angle.                       *
C       *      STEMP  - Temporary array  holding  the tip displace-    *
C       *               ment  values.   The third dimension repre-     *
C       *               sents the order of the time derivative.        *
C       *      VELCTY - The tip velocity corresponding to the S-dot    *
C       *               value in the formulation of the equation of    *
C       *               motion.                                        *
C       *                                                              *
C       ****************************************************************
```

```
      REAL            AA
      REAL            ACCELN (4)
      REAL            BB
      REAL            BLDANG
      REAL            C7
      REAL            CC
      REAL            CPSI
      REAL            DD
      REAL            DEFLTN (4)
      REAL            EE
      REAL            FF
      REAL            GG
      REAL            P1     (4)
      REAL            P2     (4)
      REAL            P3     (4)
      REAL            Q      (4,4)
      REAL            QUANT1
      REAL            SPSI
      REAL            STEMP  (4,0:1,0:2)
      REAL            VELCTY (4)

      INTEGER         K
      INTEGER         M
      INTEGER         N
      INTEGER         NPTS

      INCLUDE        'C:INCLUDE\AIRFRC.INC'

      INCLUDE        'C:INCLUDE\CONST2.INC'

      INCLUDE        'C:INCLUDE\MATRX1.INC'

      INCLUDE        'C:INCLUDE\MATRX2.INC'

      INCLUDE        'C:INCLUDE\POSITN.INC'

      INCLUDE        'C:INCLUDE\TURBN.INC'



        BLDANG = PSI(1)

        CALL FORM1  ( STEMP , NPTS , NSHAPS )
        CALL AFORCE ( NPTS  , BLDANG )


C       Calculate constant coefficients.

      SPSI   = SIN( BLDANG )
      CPSI   = COS( BLDANG )
      QUANT1 = OMEGA*STHP
      AA     = 2.0*QUANT1
      BB     = GRAV*CPSI
      CC     = QUANT1*QUANT1
      DD     = CTHP*( OMEGA*OMEGA*BETA0 + 2.0*OMEGA*PHI(1)*CPSI
     &             + PHI(2)*SPSI )
      EE     = CC
      FF     = OMEGA*QUANT1*CTHP
```

```
      GG     = GRAV*( -1.0*CHI*CTHP + STHP*SPSI + BETAO*CTHP*CPSI )
      C7     = OMEGA*OMEGA


C        Compute P1 (see formulation notes).


         DO 10 M=1,NSHAPS
   10    P1(M) = FAERO(M) + FF*CMBLNC(M) + GG*CMGRAV(M) - DD*CMRIGD(M)


C        Compute P2 - S(M) product (see formulation notes).

      DO 20 M = 1, NSHAPS
  20  P2(M) = EE*DEFLTN(M)


C        Compute Q(M,K) - S(K) products  (see formulation notes).

      DO 50 M=1,NSHAPS

         P3(M) = 0.0

         DO 40 K=1,NSHAPS

            Q(M,K) = CC*CKQLOD(M,K) - CKBEND(M,K)
     &             - C7*CKTOMG(M,K) + BB*CKTGRV(M,K)

            DO 30 N=1,NSHAPS
   30       Q(M,K) = Q(M,K) - AA*VELCTY(N)*CKTCRL(N,M,K)

            P3(M) = P3(M) + Q(M,K)*DEFLTN(K)

   40    CONTINUE

   50 CONTINUE


C        Compute new value for tip acceleration.

      DO 60 M=1,NSHAPS
   60 ACCELN(M) = P1(M) + P2(M) + P3(M)


      RETURN
      END
      SUBROUTINE AERO ( NPTS , BLDANG )


C        ***************************************************************
C        *                                                             *
C        *   Subroutine AERO  computes the aerodynamic forces on the   *
C        *   blade  as a function of position along the blade.   The   *
C        *   result is an array of values for D-A(ETA) and D-A(ZETA)   *
C        *   for each NPTS station down the blade.                     *
C        *                                                             *
C        ***************************************************************

C        ***************************************************************
C        *                                                             *
```

```
C       *   External references in this routine:                    *
C       *                                                           *
C       *      VREL    - Calculates the relative velocity components *
C       *                for each blade station.                    *
C       *                                                           *
C       ************************************************************

C       ************************************************************
C       *                                                           *
C       *   Named COMMON blocks used in this routine:               *
C       *                                                           *
C       *      AERO1   - Holds coefficients related to aerodynamic  *
C       *                loads calculations such as ClAlpha, CdZero,*
C       *                etc.                                       *
C       *      AIRFRC  - Holds values used in aerodynamic calcula-  *
C       *                tions.                                     *
C       *      BLADE     Holds blade property values such as stiff- *
C       *                ness and mass distributions.               *
C       *      CONST   - Turbine and other constants used in load   *
C       *                calculations.                              *
C       *      TURBN   - Holds turbine parameters such as number of *
C       *                blades, rotor speed, etc.                  *
C       *      VREL1   - Holds blade section velocity components.   *
C       *                                                           *
C       ************************************************************

C       ************************************************************
C       *                                                           *
C       *   Local and dummy variables used in this routine:         *
C       *                                                           *
C       *      ALPHA   - Angle of attack.  Includes blade twist con-*
C       *                tribution.  (radians)                      *
C       *      BLDANG  - Blade azimuth position.                    *
C       *      CD2     - 0.5*AirDensity*ChordLength.                *
C       *      CDRAG   - Drag coefficient.                          *
C       *      CLIFT   - Coefficient of lift.  Equal to angle of at-*
C       *                tack times the lift curve slope.           *
C       *      I       - Generic index.                             *
C       *      INBORD  - The number of blade stations that are not  *
C       *                on the airfoil section.  INBORD is used in *
C       *                other routines to differentiate between    *
C       *                sections of the blade with and without an  *
C       *                airfoil section.                           *
C       *      NPTS    - Number of points along the blade used to   *
C       *                perform Simpson's integration for calculat-*
C       *                ing the moments and forces at the blade    *
C       *                root.  (passed from FLAP1)                 *
C       *                                                           *
        ************************************************************

      REAL            ALPHA
      REAL            BLDANG
      REAL            CD2
      REAL            CDRAG
      REAL            CLIFT

      INTEGER         I
      INTEGER         INBORD
      INTEGER         NPTS
```

```
      INCLUDE       'C:INCLUDE\AERO1.INC'

      INCLUDE       'C:INCLUDE\AIRFRC.INC'

      INCLUDE       'C:INCLUDE\BLADE2.INC'

      INCLUDE       'C:INCLUDE\CONST2.INC'

      INCLUDE       'C:INCLUDE\TURBN.INC'

      INCLUDE       'C:INCLUDE\VREL1.INC'


C        Get the relative fluid velocities from each blade section.

      CALL VREL ( INBORD , NPTS , BLDANG )


C        Clear out the aerodynamic load values for the inboard portion
C        of the blade - that is, the portion of the blade without any
C        airfoil section.  This is related to BLSHNK.

      DO 10 I=1,NPTS

         IF ( I .LT. INBORD )  THEN

            DAETA(I)  = 0.0
            DAZETA(I) = 0.0
            WW(I)     = 0.0

         ELSE


C              See the formulation notes for the derivation of the
C              equations for DAETA, DAZETA and the other values.

            CD2      = 0.5*RHOAIR*CHORD(I)
            WW(I)    = SQRT( VETA(I)*VETA(I) + VZETA(I)*VZETA(I) )
            ALPHA    = ATAN( VZETA(I)/VETA(I) ) + THETA0(I)
            CLIFT    = ALPHA*CLALFA(I)
            CLIFT    = SIGN( AMIN1( ABS( CLIFT ) , CLMAX(I) ) , CLIFT )
            CDRAG    = CDZERO(I) + DRGFRM*CLIFT**2
            DAETA(I) = CD2*WW(I)*( CLIFT*VZETA(I) - CDRAG*VETA(I)  )
            DAZETA(I)= CD2*WW(I)*( CLIFT*VETA(I)  + CDRAG*VZETA(I) )

         END IF

   10 CONTINUE


      RETURN
      END
      SUBROUTINE AFORCE ( NPTS , BLDANG )


C        ************************************************************
C        *                                                          *
C        *   Subroutine  AFORCE  calculates the value of the aerody-   *
```

```
C       *   namic force integral used in solving the blade equation  *
C       *   of motion.  The aerodynamic force, D-A(ZETA), is inte-   *
C       *   grated  along the blade  from the root  of the  airfoil  *
C       *   section  to the blade tip,  and then multiplied  by the  *
C       *   inverse  of the  CMMASS  matrix  that was input  in the  *
C       *   DATAIN routine.  There is one AFORCE value for each of   *
C       *   the  coordinate shape functions  specified by the value  *
C       *   of NSHAPS.                                               *
C       *                                                            *
C       ************************************************************

C       ************************************************************
C       *                                                          *
C       *   External references in this routine:                   *
C       *                                                          *
C       *      AERO   - Calculates  the aerodynamic  forces  on the *
C       *               blade.                                     *
C       *      SIMPSN - Composite Simpson's integration.          *
C       *                                                          *
C       ************************************************************

C       ************************************************************
C       *                                                          *
C       *   Named COMMON blocks used in this routine:              *
C       *                                                          *
C       *      AIRFRC - Holds  values used in  aerodynamic calcula- *
C       *               tions.                                     *
C       *      BLADE  - Holds blade property values  such as stiff- *
C       *               ness and mass distributions.               *
C       *      MATRX1 - Holds stiffness coefficient matrices.      *
C       *      TURBN  - Holds turbine parameters  such as number of *
C       *               blades, rotor speed, etc.                  *
C       *                                                          *
C       ************************************************************

C       ************************************************************
C       *                                                          *
C       *   Local and dummy variables used in this routine:        *
C       *                                                          *
C       *      BLDANG - Blade azimuth position.                    *
C       *      FOFZET - Product  of  the  dA(Zeta)  and  the  shape *
C       *               function.                                  *
C       *      FTEMP  - Temporary array.                           *
C       *      I      - Generic index.                             *
C       *      L      - Generic index.                             *
C       *      M      - Generic index.                             *
C       *      NPTS   - Number  of  points  along the blade used to *
C       *               perform Simpson's integration for calculat- *
C       *               ing the  moments  and  forces  at the blade *
C       *               root.  (passed from FLAP1)                 *
C       *                                                          *
C       ************************************************************

      REAL            BLDANG
      REAL            FOFZET (21)
      REAL            FTEMP  (4)
      REAL            SIMPSN

      INTEGER         I
```

```
      INTEGER         L
      INTEGER         M
      INTEGER         NPTS

      INCLUDE        'C:INCLUDE\AIRFRC.INC'

      INCLUDE        'C:INCLUDE\BLADE2.INC'

      INCLUDE        'C:INCLUDE\MATRX1.INC'

      INCLUDE        'C:INCLUDE\SHAPE.INC'

      INCLUDE        'C:INCLUDE\TURBN.INC'


C        Compute aerodynamic forces.

      CALL AERO ( NPTS , BLDANG )


C         Compute the product of the DAZETA value and the shape
C         function at each blade station for each specified shape
C         function.

      DO 20 M=1,NSHAPS

         DO 10 I=1,NPTS
   10    FOFZET(I) = DAZETA(I)*SHAPE(M,0,I)


C           Compute the integral of dF(Aero) along the blade.

         FAERO(M) = SIMPSN( 0.0 , BLTIP , NPTS , FOFZET )

   20 CONTINUE


C        Multiply the F-AERO integrals by the inverse of the CMMASS
C        coefficient matrix.  This is done for the specified number
C        of shape functions.

      DO 50 M=1,NSHAPS

         FTEMP(M) = 0.0

         DO 40 L=1,NSHAPS
   40    FTEMP(M) = FTEMP(M) + CMMASS(M,L)*FAERO(L)

   50 CONTINUE



C        Replace the F-AERO values by their corresponding values
C        multiplied by the CMMASS inverse coefficient matrix.

      DO 60 M=1,NSHAPS
   60 FAERO(M) = FTEMP(M)
```

```
      RETURN
      END
      SUBROUTINE CAPS ( STRING )

C     ****************************************************************
C     *                                                              *
C     *   Subroutine  CAPS  is used to convert alphabetic charac-    *
C     *   ters into  upper case.   It assumes  that all the lower    *
C     *   case letters  are in  one contiguous block  and all the    *
C     *   upper case  letters  are in  another  contiguous block.    *
C     *   This routine  will need  to be  changed to work  with a    *
C     *   noncontiguous character set like  IBM's  EBCDIC.  It is    *
C     *   not needed  for an upper case only  character set  like    *
C     *   CDC's Display Code.                                        *
C     *                                                              *
C     ****************************************************************

C     ****************************************************************
C     *                                                              *
C     *  Named COMMON blocks used in this routine:                   *
C     *                                                              *
C     *      none                                                    *
C     *                                                              *
C     ****************************************************************

C     ****************************************************************
C     *                                                              *
C     *   External references in this routine:                       *
C     *                                                              *
C     *      none                                                    *
C     *                                                              *
C     ****************************************************************

C     ****************************************************************
C     *                                                              *
C     *   Local and dummy variables used in this routine:            *
C     *                                                              *
C     *      DIFF   - Numerical difference between 'A' and 'a'.      *
C     *      I      - Generic index.                                 *
C     *      LENGTH - The declared length of the given string.       *
C     *      STRING - The string needing to be converted to upper    *
C     *               case.                                          *
C     *                                                              *
C     ****************************************************************

      INTEGER         DIFF
      INTEGER         I
      INTEGER         LENGTH

      CHARACTER*(*)   STRING


C     Compute the numerical difference between 'A' and 'a'.

      DIFF = ICHAR( 'a' ) - ICHAR( 'A' )


C     Get the length of the string.
```

```
      LENGTH = LEN( STRING )


C        Look for lower case letters.  Convert them to upper case.

      DO 100 I=1,LENGTH

         IF ( ( STRING(I:I) .GE. 'a' ) .AND.
     &        ( STRING(I:I) .LE. 'z' ) )  THEN

            STRING(I:I) = CHAR( ICHAR( STRING(I:I) ) - DIFF )

         END IF

  100 CONTINUE


      RETURN
      END
      SUBROUTINE CONVRT ( TODEGS )


C        ************************************************************
C        *                                                          *
C        *   Subroutine CONVRT  performs the units conversion speci-*
C        *   fied by the logical value of TODEGS.   The calling rou-*
C        *   tine sends a value of .TRUE.  to indicate conversion to*
C        *   degrees or  .FALSE.  to indicate conversion to radians.*
C        *   This conversion  back and forth between radians and de-*
C        *   grees is to make the interactive portions of the  SETUP*
C        *   and LIMITS routines more 'User Friendly'.              *
C        *                                                          *
C        ************************************************************

C        ************************************************************
C        *                                                          *
C        *   External references in this routine:                   *
C        *                                                          *
C        *      none                                                *
C        *                                                          *
C        ************************************************************

C        ************************************************************
C        *                                                          *
C        *   Named COMMON blocks used in this routine:              *
C        *                                                          *
C        *      CONST  - Turbine  and  other constants  used in load*
C        *               calculations.                              *
C        *      LIMITC - Holds values used in the LIMITS routine.   *
C        *      TURBN  - Holds turbine parameters  such as number of*
C        *               blades, rotor speed, etc.                  *
C        *      WIND   - Holds wind shear  and tower shadow  parame-*
C        *               ters.                                      *
C        *                                                          *
C        ************************************************************

C        ************************************************************
C        *                                                          *
C        *   Local and dummy variables used in this routine:        *
```

```
C       *                                                             *
C       *     FACT1  - Conversion factor.                             *
C       *     FACT2  - Conversion factor.                             *
C       *     TODEGS - Logical variable  that indicates the direc-    *
C       *              tion of conversion between  degrees and ra-    *
C       *              dians.                                         *
C       *                                                             *
C       ***************************************************************


      REAL            FACT1
      REAL            FACT2

      LOGICAL         TODEGS

      INCLUDE        'C:INCLUDE\CONST2.INC'

      INCLUDE        'C:INCLUDE\LIMITC.INC'

      INCLUDE        'C:INCLUDE\TURBN.INC'

      INCLUDE        'C:INCLUDE\WIND2.INC'



C       For all calls to this routine, set the conversion factors
C       specific to the unit conversion required.  Then perform the
C       conversions and return to calling routine.

      IF ( TODEGS )  THEN


C          Convert from radians and radians/second to degrees and RPM.

         FACT1 = RAD2DG
         FACT2 = 30.0/PI

      ELSE


C          Convert from degrees and RPM to radians and radians/second.

         FACT1 = 1.0/RAD2DG
         FACT2 = PI/30.0

      END IF


C       Convert 'free' variables from the SETUP routine.

      BETA0  = FACT1*BETA0
      ALPHA0 = FACT1*ALPHA0
      CHI    = FACT1*CHI
      PHIAMP = FACT1*PHIAMP
      PHIOMG = FACT1*PHIOMG
      PHI0   = FACT1*PHI0
      PSISHD = FACT1*PSISHD
      PSIZER = FACT1*PSIZER
      THETAP = FACT1*THETAP
      THETAT = FACT1*THETAT
```

```
      OMEGA  = FACT2*OMEGA


C        Convert 'limits' variables from the LIMITS routine.

      BEGIN2 = FACT1*BEGIN2
      END2   = FACT1*END2
      PRINT1 = FACT1*PRINT1
      PRINT2 = FACT1*PRINT2
      STEPMX = FACT1*STEPMX
      STEPMN = FACT1*STEPMN


      RETURN
      END
      SUBROUTINE DATAIN


C     ***************************************************************
C     *                                                             *
C     *   Subroutine  DATAIN  reads the data file produced by the   *
C     *   PRNCOE  routine of Module 1.   The name of the run-data   *
C     *   file is specified interactively.  DATAIN opens the spe-   *
C     *   cified file, reads the data and then closes the file.     *
C     *                                                             *
C     *   Note: If any changes  have been made  to the  format of   *
C     *         the run-data file in PRNCOE of Module 1, then the   *
C     *         same changes MUST be made to DATAIN.                *
C     *                                                             *
C     ***************************************************************

C     ***************************************************************
C     *                                                             *
C     *   External references in this routine:                      *
C     *                                                             *
C     *      CONVRT - Performs units conversions.                   *
C     *                                                             *
C     ***************************************************************

C     ***************************************************************
C     *                                                             *
C     *   Named COMMON blocks used in this routine:                 *
C     *                                                             *
C     *      AERO1  - Holds coefficients  related to  aerodynamic   *
C     *               loads calculations such as ClAlpha, CdZero,   *
C     *               etc.                                          *
C     *      BLADE  - Holds blade property values  such as stiff-   *
C     *               ness and mass distributions.                  *
C     *      LITERL - Holds data set titles.                        *
C     *      LODVAL - Holds values used to compute blade loads.     *
C     *      MATRX1 - Holds stiffness coefficient matrices.         *
C     *      MATRX2 - Holds  other matrices  related to  coriolis   *
C     *               stiffening, gravity, etc.                     *
C     *      TENSIN - Holds tension component integrals.            *
C     *      TURBN  - Holds turbine parameters  such as number of   *
C     *               blades, rotor speed, etc.                     *
C     *      WIND   - Holds wind shear  and tower shadow  parame-   *
C     *               ters.                                         *
C     *                                                             *
```

```
C       ************************************************************

C       ************************************************************
C       *                                                          *
C       *   Local and dummy variables used in this routine:        *
C       *                                                          *
C       *      COL    - Column index into matrices.                *
C       *      I      - Generic index.                             *
C       *      N      - Generic index.                             *
C       *      NPTS   - Number  of  points  along the blade used to *
C       *               perform Simpson's integration for calculat- *
C       *               ing the  moments  and  forces  at the blade *
C       *               root.  (passed from FLAP1)                 *
C       *      ROW    - Row index into matrices.                   *
C       *      RUNDAT - Name of file containing run data.          *
C       *      TORADS - Flag used to tell CONVRT  to convert 'free' *
C       *               variables to radians.                      *
C       *                                                          *
C       ************************************************************


      INTEGER         COL
      INTEGER         I
      INTEGER         N
      INTEGER         NPTS
      INTEGER         ROW

      CHARACTER*50    RUNDAT

      LOGICAL         TORADS

      INCLUDE        'C:INCLUDE\AERO1.INC'

      INCLUDE        'C:INCLUDE\BLADE2.INC'

      INCLUDE        'C:INCLUDE\LITERL.INC'

      INCLUDE        'C:INCLUDE\LODVAL.INC'

      INCLUDE        'C:INCLUDE\MATRX1.INC'

      INCLUDE        'C:INCLUDE\MATRX2.INC'

      INCLUDE        'C:INCLUDE\TENSIN2.INC'

      INCLUDE        'C:INCLUDE\TRBINF.INC'

      INCLUDE        'C:INCLUDE\TURBN.INC'

      INCLUDE        'C:INCLUDE\WIND2.INC'

      INCLUDE        'C:INCLUDE\MODAL.INC'

      SAVE            TORADS

      DATA            TORADS  / .FALSE. /

 2000 FORMAT ( 3( A / ) / )
 2100 FORMAT ( 9X , L7 )
 3000 FORMAT ( // 3( 1PE24.7 ) )
```

```
3100 FORMAT ( // I14 , 3( I18 ) )
3400 FORMAT ( / 18X, I6)
3500 FORMAT ( / 18X, F10.5)
3600 FORMAT ( / 18X, I3)
3700 FORMAT ( / 2( / 5( 1PE14.3 , : ) ) )
4000 FORMAT ( / 6( / 4( 1PE18.7 , : ) ) )
4100 FORMAT ( '&done.' )


C       Get name of run-data file.  Open it.

 100 PRINT *,  ' '
     PRINT *,  'Enter the name of the file that contains run-data > '
     READ (*,'(A)')  RUNDAT

     OPEN ( 3 , FILE=RUNDAT , STATUS='OLD' , ERR=110 )

     PRINT *,  'Reading in new data...'

     GO TO 200


C       Error opening data file.

 110 PRINT *,  ' >>>  Run-data file not found.  Try again.  <<<'
     GO TO 100


C       Read titles .

 200 READ (3,2000)  TITLE1 , TITLE2 , TITLE3


C        Read scalar data.

     READ (3,3000)  ALENTH , ALPHA0 , BETA0
     READ (3,3000)  BLSHNK , BLTIP  , CHI
     READ (3,3000)  CSUBMA , DRGFRM , HUBHT
     READ (3,3000)  HUBRAD , OMEGA  , PHI0
     READ (3,3000)  PHIAMP , PHIOMG , PSIZER
     READ (3,3000)  SHERXP , THETAP , THETAT
     READ (3,3000)  TSUB0  , TSUBP  , VHUB
     READ (3,3100)  KSHADW , NBLADS , NSHAPS , NPTS
     READ (3,3400)  NUMSCN
     READ (3,3500)  TIMINC
     READ (3,3600)  MSTAT
     READ (3,3700)  ( STA(I), I=1,MSTAT)

C       Read in vector values.

     READ (3,4000)  ( CLALFA(I) , I=1,NPTS )
     READ (3,4000)  ( CLMAX (I) , I=1,NPTS )
     READ (3,4000)  ( CDZERO(I) , I=1,NPTS )
     READ (3,4000)  ( CHORD (I) , I=1,NPTS )
     READ (3,4000)  ( ECNTFN(I) , I=1,NPTS )
     READ (3,4000)  ( ESUBAC(I) , I=1,NPTS )
     READ (3,4000)  ( THETA0(I) , I=1,NPTS )
```

```
C       Read in coefficient matrices.

      READ (3,4000)  ( ( CKBEND(ROW,COL) , COL=1,4 ) , ROW=1,4 )
      READ (3,4000)  ( ( CKTOMG(ROW,COL) , COL=1,4 ) , ROW=1,4 )
      READ (3,4000)  ( ( CKTGRV(ROW,COL)   COL=1,4 )   ROW=1,4 )
      READ (3,4000)  ( ( CKQLOD(ROW,COL) , COL=1,4 ) , ROW=1,4 )
      READ (3,4000)  ( ( CMMASS(ROW,COL) , COL=1,4 ) , ROW=1,4 )

      DO 300 N=1,4
  300 READ (3,4000)  ( ( CKTCRL(N,ROW,COL) , COL=1,4 ) , ROW=1,4 )


C       Read in vector coefficients.

      READ (3,4000)  ( CMRIGD(I) , I=1,4 )
      READ (3,4000)  ( CMBLNC(I) , I=1,4 )
      READ (3,4000)  ( CMGRAV(I) , I=1,4 )


C       Read tension arrays.

      DO 400 N=1,4
  400 READ (3,4000)  ( TCORLS(N,I) , I=1,NPTS )

      READ (3,4000)  ( TGRAV(I) , I=1,NPTS )
      READ (3,4000)  ( TOMGA(I) , I=1,NPTS )

      DO 410 N=1,4
  410 READ (3,4000)  ( CIFMOM(N,I) , I=1,NPTS )


C       Read arrays of special load computation functions.

      READ (3,4000)  ( DELTIM(I) , I=1,NPTS )
      READ (3,4000)  ( OFFMAS(I) , I=1,NPTS )

      DO 500 I = 1,4
         READ(3,*) (LAMDA(I,J),J=1,4)
  510 CONTINUE
  500 CONTINUE

C       Processing complete.  Close data file.

      PRINT 4100

      CLOSE ( 3 )

C       The units are converted to radians and radians/second to permit
C       compatibility between newly input data and data being used for
C       consecutive model runs.  Thus the DIAG and RUN routines do not
C       need to know if the data they are using is new or old.

      CALL CONVRT ( TORADS )


      RETURN
      END
      SUBROUTINE DIAG ( NPTS )
```

```
C     ************************************************************
C     *                                                          *
C     *   Subroutine DIAG  performs a test run of the aerodynamic  *
C     *   routines for diagnostic purposes.   It steps around the  *
C     *   rotor disk  in specified increments  and calculates the  *
C     *   aerodynamic forces along the blade, the relative veloc-  *
C     *   ity components, the induced velocity components and the  *
C     *   windspeeds.   These are printed out  in chart form  for  *
C     *   each  specified  azimuth  printout interval  around the  *
C     *   disk.   DIAG can be run  repetitively  for  sensitivity  *
C     *   analyses.                                              *
C     *                                                          *
C     *   The  following parameters  are printed  for each of the  *
C     *   specified positions around the disk:                   *
C     *                                                          *
C     *      DAETA      DAZETA     VETA       VZETA      VWIND    *
C     *      WSHEAR     VINDR      VINDO      DVIND      ALPHA    *
C     *      CDZERO     CLLIFT     VV                             *
C     *                                                          *
C     ************************************************************

C     ************************************************************
C     *                                                          *
C     *   External references in this routine:                   *
C     *                                                          *
C     *      AERO   - Calculates  the aerodynamic  forces  on the  *
C     *               blade.                                     *
C     *      CONVRT - Performs units conversions.               *
C     *      SETUP  - Interactive modification of free variables.  *
C     *                                                          *
C     ************************************************************

C     ************************************************************
C     *                                                          *
C     *   Named COMMON blocks used in this routine:              *
C     *                                                          *
C     *      AERO1  - Holds coefficients  related to  aerodynamic  *
C     *               loads calculations such as ClAlpha, CdZero,  *
C     *               etc.                                       *
C     *      AIRFRC - Holds  values used in  aerodynamic calcula-  *
C     *               tions.                                     *
C     *      BLADE  - Holds blade property values  such as stiff-  *
C     *               ness and mass distributions.               *
C     *      CONST  - Turbine  and  other constants  used in load  *
C     *               calculations.                              *
C     *      DELTV  - Holds  turbine inputs  for possible  future  *
C     *               use.  Not currently used.                  *
C     *      FORMS  - Holds blade deflections.                  *
C     *      POSITN - Holds parameters  related to blade position  *
C     *               such as PHI, PSI, etc.                     *
C     *      SARAYS - Holds  new and old  values for the general-  *
C     *               ized coordinates.                          *
C     *      SHAPE  - Holds blade coordinate shape functions.   *
C     *      TURBN  - Holds turbine parameters  such as number of  *
C     *               blades, rotor speed, etc.                  *
C     *      VINDUC - Holds induced velocity components.        *
C     *      VREL1  - Holds blade section velocity components.  *
C     *      WNDVEL - Holds values  used in wind shear  and tower  *
C     *               shadow computations.                       *
C     *                                                          *
```

```
C     ************************************************************

C     ************************************************************
C     *                                                          *
C     *   Local and dummy variables used in this routine:        *
C     *                                                          *
C     *      ALPHA  - Angle of attack.  Includes blade twist con-*
C     *               tribution.  (radians)                      *
C     *      ANS    - Used  to  store  input responses from key- *
C     *               board.                                     *
C     *      BLDANG - Blade azimuth position.                    *
C     *      CLLIFT - Coefficient of lift.  Equal to angle of at-*
C     *               tack times the lift curve slope.           *
C     *      I      - Generic index.                             *
C     *      ICALL  - Counter to save the number of calls to sub-*
C     *               routine DIAG.  Used to open output file.   *
C     *      IDPSI  - Printout interval  in whole degrees  around*
C     *               the rotor disk.                            *
C     *      IPSI   - Do loop counter for azimuth position.      *
C     *      IPT    - Array index  used for  trapezoidal integra-*
C     *               tion.                                      *
C     *      NPTS   - Number  of  points  along the blade used to*
C     *               perform Simpson's integration for calculat-*
C     *               ing the  moments  and  forces  at the blade*
C     *               root.  (passed from FLAP1)                 *
C     *      NSHP   - Counter  on  DO  loops  for  the coordinate*
C     *               shape function.                            *
C     *      TODEGS - Flag used to tell CONVRT  to convert 'free'*
C     *               variables to degrees.                      *
C     *      TORADS - Flag used to tell CONVRT  to convert 'free'*
C     *               variables to radians.                      *
C     *                                                          *
C     ************************************************************

      REAL           ALPHA  (21)
      REAL           BLDANG
      REAL           CLLIFT (21)

      INTEGER        I
      INTEGER        ICALL
      INTEGER        IDPSI
      INTEGER        IPSI
      INTEGER        IPT
      INTEGER        NPTS
      INTEGER        NSHP

      CHARACTER*1    ANS

      LOGICAL        TODEGS
      LOGICAL        TORADS

      INCLUDE       'C:INCLUDE\AERO1.INC'

      INCLUDE       'C:INCLUDE\AIRFRC.INC'

      INCLUDE       'C:INCLUDE\BLADE2.INC'

      INCLUDE       'C:INCLUDE\CONST2.INC'
```

```
      INCLUDE        'C:INCLUDE\DELTV.INC'

      INCLUDE        'C:INCLUDE\FORMS.INC'

      INCLUDE        'C:INCLUDE\POSITN.INC'

      INCLUDE        'C:INCLUDE\SARAYS.INC'

      INCLUDE        'C:INCLUDE\SHAPE.INC'

      INCLUDE        'C:INCLUDE\TURBN.INC'

      INCLUDE        'C:INCLUDE\VINDUC.INC'

      INCLUDE        'C:INCLUDE\VREL1.INC'

      INCLUDE        'C:INCLUDE\WNDVEL.INC'

      SAVE            ICALL
      SAVE            TODEGS
      SAVE            TORADS

      DATA            ICALL   / 0 /
      DATA            TODEGS  / .TRUE. /
      DATA            TORADS  / .FALSE. /

      CHARACTER *20 WRTAIR

 1000 FORMAT ( '1' //// 10X , 'Test Run of Aerodynamic Routines' /// )
 2000 FORMAT ( ////// 10X , 'Azimuth position:  PSI = ' , I3
     &              , 10X , 'Hub velocity = ' , F10.3
     &              / 48X , 'TSHADW = ' , F10.3 )
 2100 FORMAT ( /// '  I   DAETA(I) DAZETA(I)   VETA(I)  VZETA(I)'
     &               , ' VWIND(I) WSHEAR(I)  VINDR(I)  VINDO(I)'
     &               , ' DVIND(I)  ALPHA(I) CDZERO(I)
     &               , ' CLLIFT(I) VV(1,I)' / )
 2200 FORMAT ( I4 , 13( 1PE10.3 ) )
 3000 FORMAT ( A )


C       If this is the first time DIAG is called, open the output file.

  100 IF ( ICALL .EQ. 0 )  THEN
         OPEN ( 2 , FILE='DIAGNOS.DAT' , STATUS='UNKNOWN'
     &           , CARRIAGECONTROL='FORTRAN' )
         ICALL = 1
      END IF

      PRINT *, 'Read in name of airloads output file'
      READ*, WRTAIR
      OPEN( 20, FILE = WRTAIR, STATUS = 'UNKNOWN')

C       Print heading in diagnostic file.

      WRITE (2,1000)

      PRINT *, ' '
      PRINT *, 'Subroutine DIAG:  Diagnostic run and output'
      PRINT *, ' '
```

```
C       Convert values into degrees.

      CALL CONVRT ( TODEGS )


C       Run setup routine.

      CALL SETUP


C       Convert values back into radians for internal use.

      CALL CONVRT ( TORADS )


C       Ask for printout interval.

      PRINT *,  ' '
      PRINT *,  'Enter printout interval around rotor disk in whole '
     &       ,  'degrees > '
      READ  *,  IDPSI

      DELPSI(1) = IDPSI/RAD2DG
      DELTAT(1) = DELPSI(1)/OMEGA


C       NOTE:  DIAG assumes that time is frozen at time=0.

      PHI(0) = PHI0
      PHI(1) = PHIOMG
      PHI(2) = 0.0


C       Go around the disk in IDPSI increments.

      DO 250 IPSI=0,360,IDPSI


C          Clear the forms array.

         DO 200 I=1,NPTS
            VV(0,I) = 0.0
            VV(1,I) = 0.0
  200    CONTINUE

         PSI(1) = IPSI/RAD2DG
         BLDANG = PSI(1)


C          Set up the forms array.

         DO 220 IPT=1,NPTS

            DO 210 NSHP=1,NSHAPS

               VV(0,IPT) = VV(0,IPT)
     &                   + SHAPE(NSHP,0,IPT)*SNEW(NSHP,0,IPSI)
               VV(1,IPT) = VV(1,IPT)
     &                   + SHAPE(NSHP,0,IPT)*SNEW(NSHP,1,IPSI)
```

```
  210       CONTINUE

  220     CONTINUE


C           Compute the aerodynamic forces on the blade.

          CALL AERO ( NPTS , BLDANG )


          DO 230 I=1,NPTS

             IF ( DAETA(I) .EQ. 0.0 )  THEN
                ALPHA(I) = 0.0
             ELSE
                ALPHA(I) = ATAN( VZETA(I)/VETA(I) ) + THETA0(I)
             END IF

             CLLIFT(I) = AMIN1( CLALFA(I)*ABS( ALPHA(I) ) , CLMAX(I) )
             CLLIFT(I) = SIGN( CLLIFT(I) , ALPHA(I) )

  230     CONTINUE


C           Print out results.

          WRITE (2,2000)  IPSI , HUBVEL , TSHADW

          WRITE (2,2100)

          DO 240 I=1,21
  240     WRITE (2,2200)  I,  DAETA(I), DAZETA(I),   VETA(I),  VZETA(I)
     &                     ,  VWIND(I), WSHEAR(I),  VINDR(I),  VINDO(I)
     &                     ,  DVIND(I),  ALPHA(I), CDZERO(I), CLLIFT(I)
     &                     ,  VV(1,I)


        WRITE(20,*) IPSI, VZETA(17)/12.

  250 CONTINUE


C         Test run completed.  See if user wants more.

        PRINT *,  ' '
        PRINT *,  'Test run completed.  Results written onto file '
       &       ,  'DIAGNOS.DAT'

  300 PRINT   *,  ' '
        PRINT   *,  'Do you want to perform another test run? (Y,=N) > '
        READ 3000,  ANS

        IF ( ( ANS .EQ. 'Y' )  .OR. ( ANS .EQ. 'y' ) )  GO TO 100

        IF ( ( ANS .NE. 'N' ) .AND. ( ANS .NE. 'n' )
       &                      .AND. ( ANS .NE. ' ' ) )  THEN

           PRINT *,  '  >>>  Invalid response.  Please try again.  <<<'
           GO TO 300
```

```
      END IF

      RETURN
      END
      SUBROUTINE DSKREV ( NPTS )

C     ****************************************************************
C     *                                                              *
C     *   Subroutine DSKREV performs a full disk revolution solu-    *
C     *   tion to the blade equations of motion and saves the re-    *
C     *   sulting values.                                            *
C     *                                                              *
C     ****************************************************************

C     ****************************************************************
C     *                                                              *
C     *   External references in this routine:                       *
C     *                                                              *
C     *      EULER  - Self starting modified Euler predictor/cor-    *
C     *               rector integration.                            *
C     *      NXTPHI - Calculates the next values of the yaw vari-    *
C     *               ables.                                         *
C     *      NXTPSI - Calculates  the  next value  of the azimuth    *
C     *               angle, Psi.                                    *
C     *      SAVE1  - Saves tip displacement variables.              *
C     *      STRTUP - Calculates  the  static  deflection  of the    *
C     *               blade at the startup position.                 *
C     *      TRACE  - Traces certain variables.                      *
C     *                                                              *
C     ****************************************************************

C     ****************************************************************
C     *                                                              *
C     *   Named COMMON blocks used in this routine:                  *
C     *                                                              *
C     *      CONST  - Turbine  and  other constants  used in load    *
C     *               calculations.                                  *
C     *      LIMITC - Holds values used in the LIMITS routine.       *
C     *      POSITN - Holds parameters  related to blade position    *
C     *               such as PHI, PSI, etc.                         *
C     *      SARAYS - Holds  new and old  values for the general-    *
C     *               ized coordinates.                              *
C     *      TURBN  - Holds turbine parameters  such as number of    *
C     *               blades, rotor speed, etc.                      *
C     *                                                              *
C     ****************************************************************

C     ****************************************************************
C     *                                                              *
C     *   Local and dummy variables used in this routine:            *
C     *                                                              *
C     *      I      - Generic index.                                 *
C     *      IPSIST - The next STEPMX station in integer degrees.    *
C     *      ISTEP  - STEPMX in integer degrees.                     *
C     *      J      - Generic index.                                 *
C     *      NEW    - Array index for new data.                      *
C     *      NPTS   - Number  of  points  along the blade used to    *
```

```
C       *              perform Simpson's integration for calculat-  *
C       *              ing the moments and forces at the blade      *
C       *              root.  (passed from FLAP1)                   *
C       *      NSHP   - Counter on DO loops for the coordinate     *
C       *               shape function.                             *
C       *      OLD    - Array index for old data.                  *
C       *      STEMP  - Temporary array holding the tip displace-  *
C       *               ment values.  The third dimension repre-    *
C       *               sents the order of the time derivative.     *
C       *      TIMNOW - Current time.                              *
C       *                                                          *
C       ************************************************************

      REAL            STEMP  (4,0:1,0:2)
      REAL            TIMNOW

      INTEGER         I
      INTEGER         IPSIST
      INTEGER         ISTEP
      INTEGER         J
      INTEGER         NEW
      INTEGER         NPTS
      INTEGER         NSHP
      INTEGER         OLD

      INCLUDE        'C:INCLUDE\CONST2.INC'

      INCLUDE        'C:INCLUDE\LIMITC.INC'

      INCLUDE        'C:INCLUDE\POSITN.INC'

      INCLUDE        'C:INCLUDE\SARAYS.INC'

      INCLUDE        'C:INCLUDE\TURBN.INC'

      SAVE            NEW
      SAVE            OLD
      SAVE            STEMP

      DATA            NEW     / 1 /
      DATA            OLD     / 0 /

 1000 FORMAT ( ' Static deflection at startup (MODE' , I2.2 , ') ='
     &         , F8.4 / )


C       Initialize some variables.

      ISTEP = RAD2DG*STEPMX + .001


C       IPSIST is the next STEPMX station.  That is, then next azimuth
C       location at which the deflection, velocity and acceleration
C       values will be saved and the loads will be computed.  Values
C       for azimuth positions intermediate to the loads will not be
C       saved.

      IPSIST = RAD2DG*( PSI(1) + STEPMX ) + 0.001
```

```
C       When the ITRIM flag is set to 2, then this is the first pass
C       through DSKREV for this analysis.  If it is, then compute the
C       static deflection of the blade tip for the startup condition.

      IF ( ITRIM .EQ. 2 )  THEN

         CALL STRTUP ( STEMP , NPTS )


C           This section prints the computed static starting deflection
C           when the program is running in the trace mode.

         IF ( TRACEF )  THEN

            DO 100 I=1,NSHAPS
  100       WRITE (4,1000)  I , STEMP(I,1,0)

         END IF

      END IF


C       Push current values of S, SDOT and SDD onto old values.

      DO 220 NSHP=1,NSHAPS

         DO 200 J=0,360,ISTEP
  200    SOLD(NSHP,J) = SNEW(NSHP,0,J)

         DO 210 I=0,2
  210    SNEW(NSHP,I,0) = SNEW(NSHP,I,360)

  220 CONTINUE


C       Save old values of position variables and error.

  300 DELPSI(0) = DELPSI(1)
      DELTAT(0) = DELTAT(1)
      PSI   (0) = PSI   (1)
      TIME  (0) = TIME  (1)


C       Get next PSI, delta PSI, etc. and next yaw values PHI, PHI dot
C       and PHI dot-dot.

  400 CALL NXTPSI ( IPSIST )

      TIMNOW = TIME(1)

      CALL NXTPHI ( TIMNOW )


C       Solve the equation of motion and compute tip displacements and
C       velocities.  Check error of Euler predictor-corrector solution.
C       If the error condition is satisfied, check for disk station and
C       save the new values if this azimuth is a STEPMX disk station.

      CALL EULER ( STEMP , NSHAPS , NPTS )
```

```
      IF ( (ERROR .GT. EUERR) .AND. (DELPSI(1) .GT. STEPMN) )  GO TO 400


C        The following tests check for the current azimuth location
C        between the STEPMX stations.  If the current position is very
C        close to a STEPMX station, then the deflection, velocity and
C        acceleration values are saved.

      IF ( ABS( PSI(1) - IPSIST/RAD2DG ) .LT. 0.1*STEPMN )  THEN

         CALL SAVE1 ( IPSIST , NSHAPS , STEMP )


C           When the TRACEF flag is set, print out the prescribed
C           values.  See subroutine TRACE for a full description.

         IF ( TRACEF )  CALL TRACE ( STEMP , NPTS )

      END IF


C        Move new temporary values to old.

      DO 510 NSHP=1,NSHAPS

         DO 500 I=0,2
  500    STEMP(NSHP,OLD,I) = STEMP(NSHP,NEW,I)

  510 CONTINUE


C        If we haven't gone all the way around, solve the equation of
C        motion for the next step.

      IF ( IPSIST .LE. 360 )  GO TO 300


      RETURN
      END
      SUBROUTINE EULER ( STEMP , NSHAPS , NPTS )


C        ***************************************************************
C        *                                                             *
C        *   Subroutine  EULER  uses the self starting modified pre-   *
C        *   dictor-corrector  method to compute  the values  of the   *
C        *   blade tip displacement and velocity, given the previous   *
C        *   values  and the solution  to the blade  equation of mo-   *
C        *   tion.  The solution is not iterated for a specified de-   *
C        *   sired accuracy, but is instead run through one computa-   *
C        *   tion  of the predictor-corrector.  The  error function    *
C        *   compares  the percentage change  in tip deflection  be-   *
C        *   tween  two consecutive  azimuth locations  against  the   *
C        *   static tip deflection  computed by the startup routine.   *
C        *   This  error value  is sent back  to the calling routine   *
C        *   (ie. DSKREV).  If the error is too large, a smaller az-   *
C        *   imuth angle  step size  will be used  and  another call   *
C        *   will be made to this routine.                             *
C        *                                                             *
```

```
C     ****************************************************************

C     ****************************************************************
C     *                                                              *
C     *   External references in this routine:                       *
C     *                                                              *
C     *      ACCEL  - Solves the blade equation of motion.           *
C     *                                                              *
C     ****************************************************************

C     ****************************************************************
C     *                                                              *
C     *   Named COMMON blocks used in this routine:                  *
C     *                                                              *
C     *      POSITN - Holds parameters  related to blade position    *
C     *               such as PHI, PSI, etc.                         *
C     *      START  - Holds initial blade deflection.                *
C     *                                                              *
C     ****************************************************************

C     ****************************************************************
C     *                                                              *
C     *   Local and dummy variables used in this routine:            *
C     *                                                              *
C     *      ACCELN - Tip acceleration.                              *
C     *      DEFLTN - Tip displacement.                              *
C     *      NEW    - Array index for new data.                      *
C     *      NPTS   - Number  of  points  along the blade used to    *
C     *               perform Simpson's integration for calculat-    *
C     *               ing the  moments  and  forces  at the blade    *
C     *               root.  (passed from FLAP1)                     *
C     *      NSHAPS - Number of blade shape functions, 4 maximum.    *
C     *      NSHP   - Counter  on  DO  loops  for  the coordinate    *
C     *               shape function.                                *
C     *      OLD    - Array index for old data.                      *
C     *      SCORCT - Corrected values  for  blade tip  accelera-    *
C     *               tion.                                          *
C     *      SPRDCT   Predicted values  for  blade tip  accelera-    *
C     *               tion.                                          *
C     *      STEMP  - Temporary array  holding  the tip displace-    *
C     *               ment  values.  The third dimension repre-      *
C     *               sents the order of the time derivative.        *
C     *      VELCTY - Tip velocity.                                  *
C     *                                                              *
C     ****************************************************************

      REAL            ACCELN (4)
      REAL            DEFLTN (4)
      REAL            SCORCT (4)
      REAL            SPRDCT (4)
      REAL            STEMP  (4,0:1,0:2)
      REAL            VELCTY (4)

      INTEGER         NEW
      INTEGER         NPTS
      INTEGER         NSHAPS
      INTEGER         NSHP
      INTEGER         OLD

      INCLUDE        'C:INCLUDE\POSITN.INC'
```

```
      INCLUDE        'C:INCLUDE\START.INC'

      SAVE           NEW
      SAVE           OLD

      DATA           NEW     / 1 /
      DATA           OLD     / 0 /


C        Calculate predictor values.

      DO 100 NSHP=1,NSHAPS

         STEMP(NSHP,NEW,1) = STEMP(NSHP,OLD,1)
     &                     + STEMP(NSHP,OLD,2)*DELTAT(NEW)
         STEMP(NSHP,NEW,0) = STEMP(NSHP,OLD,0)
     &                     + STEMP(NSHP,OLD,1)*DELTAT(NEW)

         SPRDCT(NSHP) = STEMP(NSHP,NEW,0)

  100 CONTINUE


C        Calculate predicted acceleration values by solving the blade
C        equation of motion with the predicted values of the tip
C        velocity and displacement.

      DO 200 NSHP=1,NSHAPS

         DEFLTN(NSHP) = STEMP(NSHP,NEW,0)
         VELCTY(NSHP) = STEMP(NSHP,NEW,1)

  200 CONTINUE


C         Subroutine ACCEL performs the actual solution of the blade
C         equation of motion.  It uses the previous values of the tip
C         deflection and velocity and the current values of the forces.
C         It returns the new blade tip acceleration values.

      CALL ACCEL ( DEFLTN , VELCTY , ACCELN , NPTS, STEMP )


C        Calculate corrector values.

      DO 300 NSHP=1,NSHAPS

         STEMP(NSHP,NEW,2) = ACCELN(NSHP)

         STEMP(NSHP,NEW,0) = STEMP(NSHP,OLD,0)
     &                     + 0.5*DELTAT(1)*( STEMP(NSHP,OLD,1)
     &                                     + STEMP(NSHP,NEW,1) )
         STEMP(NSHP,NEW,1) = STEMP(NSHP,OLD,1)
     &                     + 0.5*DELTAT(1)*( STEMP(NSHP,OLD,2)
     &                                     + STEMP(NSHP,NEW,2) )

         SCORCT(NSHP) = STEMP(NSHP,NEW,0)
```

```
  300 CONTINUE

C       The error is computed from the sum of the ratios of the tip
C       displacement change from the predicted to the corrected values
C       relative to the initial static blade deflection computed at
C       startup.  Summation is over the number of coordinate shape
C       functions specified in the run.

      ERROR = 0.0

      DO 400 NSHP=1,NSHAPS
  400 ERROR = ERROR + ( SCORCT(NSHP) - SPRDCT(NSHP) )/SO(NSHP)


C       The error value is converted into percent for use in the
C       DSKREV routine.

      ERROR = 100.0*ABS( ERROR )


      RETURN
      END
      SUBROUTINE FORM1 ( STEMP , NPTS , NSHAPS )


C       ***************************************************************
C       *                                                             *
C       *   Subroutine FORM1  computes the values of the blade dis-   *
C       *   placement function  for each of the NPTS stations along   *
C       *   the blade.   The values are produced  solely for use in   *
C       *   computing  the blade relative velocity values  that are   *
C       *   in turn  used to compute  the blade  aerodynamic forces   *
C       *   and  ultimately the aerodynamic force function  used in   *
C       *   the blade equation of motion.                             *
C       *                                                             *
C       ***************************************************************

C       ***************************************************************
C       *                                                             *
C       *   External references in this routine:                      *
C       *                                                             *
C       *      none                                                   *
C       *                                                             *
C       ***************************************************************

C       ***************************************************************
C       *                                                             *
C       *   Named COMMON blocks used in this routine:                 *
C       *                                                             *
C       *      FORMS  - Holds blade deflections.                      *
C       *      POSITN - Holds parameters  related to blade position   *
C       *               such as PHI, PSI, etc.                        *
C       *      SHAPE  - Holds blade coordinate shape functions.       *
C       *                                                             *
C       ***************************************************************

C       ***************************************************************
C       *                                                             *
C       *   Local and dummy variables used in this routine:           *
```

```
C       *                                                               *
C       *     BLDANG - Blade azimuth position.                          *
C       *     I      - Generic index.                                   *
C       *     NPTS   - Number of points along the blade used to         *
C       *              perform Simpson's integration for calculat-      *
C       *              ing the moments and forces at the blade          *
C       *              root. (passed from FLAP1)                        *
C       *     NSHAPS - Number of blade shape functions, 4 maximum.      *
C       *     NSHP   - Counter on DO loops for the coordinate           *
C       *              shape function.                                  *
C       *     OLD    - Array index for old data.                        *
C       *     STEMP  - Temporary array holding the tip displace-        *
C       *              ment values. The third dimension repre-          *
C       *              sents the order of the time derivative.          *
C       *                                                               *
C       *****************************************************************


      REAL            STEMP  (4,0:1,0:2)

      INTEGER         I
      INTEGER         NPTS
      INTEGER         NSHAPS
      INTEGER         NSHP
      INTEGER         OLD

      INCLUDE        'C:INCLUDE\CONST2.INC'

      INCLUDE        'C:INCLUDE\FORMS.INC'

      INCLUDE        'C:INCLUDE\POSITN.INC'

      INCLUDE        'C:INCLUDE\SHAPE.INC'

      SAVE            OLD

      DATA            OLD     / 0 /



C       Initialize the VV array.

      DO 100 I=1,NPTS
         VV(0,I) = 0.0
         VV(1,I) = 0.0
  100 CONTINUE


C       Compute the VV values down the blade for each of the specified
C       shape functions.

        DO 210 NSHP=1,NSHAPS

           DO 200 I=1,NPTS
              VV(0,I)=VV(0,I)+SHAPE(NSHP,0,I)*STEMP(NSHP,OLD,0)
              VV(1,I)=VV(1,I)+SHAPE(NSHP,0,I)*STEMP(NSHP,OLD,1)
  200       CONTINUE

  210    CONTINUE
```

```
      RETURN
      END
      SUBROUTINE GAUSSJ ( A , N )

C     ***************************************************************
C     *                                                             *
C     *   Subroutine GAUSSJ  is used to solve linear equations by   *
C     *   Gauss-Jordan  elimination  with full pivoting.   It was   *
C     *   transcribed from the book  "Numerical Recipes"  by Wil-   *
C     *   liam H. Press, et al.  Code for right-hand-side vectors   *
C     *   was not implemented in this routine.   This routine was   *
C     *   hard-wired for matrices of maximum order 4.               *
C     *                                                             *
C     ***************************************************************

C     ***************************************************************
C     *                                                             *
C     *   External references in this routine:                      *
C     *                                                             *
C     *      none                                                   *
C     *                                                             *
C     ***************************************************************

C     ***************************************************************
C     *                                                             *
C     *   Named COMMON blocks used in this routine:                 *
C     *                                                             *
C     *      none                                                   *
C     *                                                             *
C     ***************************************************************

C     ***************************************************************
C     *                                                             *
C     *   Local and dummy variables used in this routine:           *
C     *                                                             *
C     *      A      - Input matrix with NP by NP elements.  After   *
C     *               processing it is replaced with its inverse.   *
C     *      BIG    - The biggest element in the A matrix.          *
C     *      DUM    - Temporary storage.                            *
C     *      I      - Generic index.                                *
C     *      ICOL   - Column.                                       *
C     *      INDXC  - Used for bookkeeping on pivoting.             *
C     *      INDXR  - Used for bookkeeping on pivoting.             *
C     *      IPIV   - Used for bookkeeping on pivoting.             *
C     *      J      - Generic index.                                *
C     *      IROW   - Row.                                          *
C     *      K      - Generic index.                                *
C     *      L      - Generic index.                                *
C     *      LL     - Generic index.                                *
C     *      N      - Order of the square A matrix.                 *
C     *      NMAX   - Dimension of bookkeeping arrays.              *
C     *      PIVINV - Inverse of the current pivot element.         *
C     *                                                             *
C     ***************************************************************

      REAL            A      (4,4)
      REAL            BIG
      REAL            DUM
      REAL            PIVINV
```

```
      INTEGER         I
      INTEGER         ICOL
      INTEGER         INDXC  (4)
      INTEGER         INDXR  (4)
      INTEGER         IPIV   (4)
      INTEGER         J
      INTEGER         IROW
      INTEGER         K
      INTEGER         L
      INTEGER         LL
      INTEGER         N


         Initialize the pivot matrix.

      DO 100 J=1,N
)        IPIV(J) = 0


         This is the main loop over the columns to be reduced.

      DO 260 I=1,N

         BIG = 0.0

            This is the outer loop of the search for a pivot element.

         DO 210 J=1,N

            IF ( IPIV(J) .NE. 1 )  THEN

               DO 200 K=1,N

                  IF ( IPIV(K) .EQ. 0 )  THEN

                     IF ( ABS( A(J,K) ) .GE. BIG )  THEN

                        BIG  = ABS( A(J,K) )
                        IROW = J
                        ICOL = K

                     END IF

                  ELSE IF ( IPIV(K) .GT. 1 )  THEN

                     PRINT *,  ' '
                     PRINT *,  '  >>>  The input matrix to GAUSSJ is '
     &                     ,  'singular.  <<<'
                     PRINT *,  ' '
                     PRINT *,  'FLAP terminated abnormally due to the '
     &                     ,  'the error listed above.'

                     STOP

                  END IF

               CONTINUE
```

```
         END IF

  210    CONTINUE

         IPIV(ICOL)   IPIV(ICOL) + 1


C           We now have the pivot element; so we interchange rows.  If
C           needed, to put the pivot element on the diagonal.  The col-
C           umns are not physically interchanged, only relabeled:
C           INDXC(I), the column of the Ith pivotal element, is the Ith
C           column that is reduced, while INDXR(I) is the row in which
C           that pivot element was originally located.  If INDXR(I) is
C           not equal to INDXC(I), there is an implied column inter-
C           change.  With this form of bookkeeping, the solution Bs will
C           end up in the correct order, and the inverse matrix will be
C           scrambled by columns.

         IF ( IROW .NE. ICOL )  THEN

            DO 220 L=1,N

               DUM       = A(IROW,L)
               A(IROW,L) = A(ICOL,L)
               A(ICOL,L) = DUM

  220       CONTINUE

         END IF


C           We are now ready to divide the pivot row by the pivot
C           element, located at (IROW,ICOL).

         INDXR(I) = IROW
         INDXC(I) = ICOL

         IF ( A(ICOL,ICOL) .EQ. 0.0 )  THEN

            PRINT *,  ' '
            PRINT *,  '  >>>  The input matrix to GAUSSJ is '
     &           ,  'singular.  <<<'
            PRINT *,  ' '
            PRINT *,  'FLAP terminated abnormally due to the '
     &           ,  'the error listed above.'

            STOP

         END IF

         PIVINV = 1.0/A(ICOL,ICOL)

         A(ICOL,ICOL) = 1.0

         DO 230 L=1,N
  230    A(ICOL,L) = PIVINV*A(ICOL,L)


C           Reduce all the rows except the pivot one.
```

```
C       ************************************************************
C       *                                                          *
C       *   Named COMMON blocks used in this routine:              *
C       *                                                          *
C       *      none                                                *
C       *                                                          *
C       ************************************************************

C       ************************************************************
C       *                                                          *
C       *   Local and dummy variables used in this routine:        *
C       *                                                          *
C       *      ANS    - Answer to user question.                   *
C       *      EXISTS - Flag that indicates  whether or not  a file *
C       *               already exists.                            *
C       *      ISOPEN - Flag that indicates  whether or not  unit 4 *
C       *               is already active.                         *
C       *      NEDOPN - Flag that indicates  whether or not we need *
C       *               to open the results file.                  *
C       *      RESFIL - Name of file to store results.             *
C       *      TEMP   - Temporary variable  used to store  the name *
C       *               of the results file.                       *
C       *                                                          *
C       ************************************************************


      INTEGER         LNTH

      LOGICAL         EXISTS
      LOGICAL         ISOPEN
      LOGICAL         NEDOPN

      CHARACTER*1     ANS
      CHARACTER*(*)   RESFIL
      CHARACTER*50    TEMP

 1000 FORMAT ( ' Enter name of results file [=' , A , '] > ' )
 1100 FORMAT ( A )
 1200 FORMAT ( '1' )



C       Get name of results file.

  100 PRINT  1000,  RESFIL(1:LNTH(RESFIL))
      READ   1100,  TEMP

      IF ( TEMP .EQ. ' ' )  THEN


C          The user hit just an <Enter>.  Use the old name.

         TEMP = RESFIL

      ELSE


C          Convert file name to upper case if a name was typed in.

         CALL CAPS ( TEMP )
```

```
      DO 250 LL=1,N

         IF ( LL .NE. ICOL )  THEN

            DUM        = A(LL,ICOL)
            A(LL,ICOL) = 0.0

            DO 240 L=1,N
240         A(LL,L) = A(LL,L) - DUM*A(ICOL,L)

         END IF

250   CONTINUE

260 CONTINUE


C     Unscramble the solution in view of the column interchanges.
C     We do this by interchanging pairs of columns in the reverse
C     order that the permutation was built up.

    DO 310 L=N,1,-1

      IF ( INDXR(L) .NE. INDXC(L) )  THEN

         DO 300 K=1,N

            DUM           = A(K,INDXR(L))
            A(K,INDXR(L)) = A(K,INDXC(L))
            A(K,INDXC(L)) = DUM

300      CONTINUE

      END IF

310 CONTINUE


    RETURN
    END
    SUBROUTINE GETFIL ( RESFIL )


C     ****************************************************************
C     *                                                              *
C     *   Subroutine GETFIL gets the name of the results file and    *
C     *   opens it.   If the  file  already exists,  the user  is    *
C     *   asked if it should be overwritten.                         *
C     *                                                              *
C     ****************************************************************

C     ****************************************************************
C     *                                                              *
C     *   External references in this routine:                       *
C     *                                                              *
C     *      LNTH   - Returns the length of a string.                *
C     *                                                              *
C     ****************************************************************
```

```
      END IF

C        Check to see if unit 4 is already attached.

      INQUIRE (4, OPENED=ISOPEN )

      IF ( ISOPEN )  THEN

         IF ( TEMP .EQ. RESFIL )  THEN


C             Use the same file that's already open.  Eject a page.

            WRITE (4,1200)
            NEDOPN = .FALSE.

         ELSE


C             Use a different file.  Close old one.

            CLOSE ( 4 )
            NEDOPN = .TRUE.

         END IF

      ELSE


C          No open file yet.  We need to open one.

         NEDOPN = .TRUE.

      END IF

      IF ( NEDOPN )  THEN


C          We need to open the new results file.  Does it already
C          exist?

         INQUIRE ( FILE=TEMP , EXIST=EXISTS )

         IF ( EXISTS )  THEN


C             File already exists.  Write over it?

            PRINT   *,  '  >>>  File already exists  <<<'
  110       PRINT   *,  ' '
            PRINT   *,  'Do you want to overwrite the old data?'
     &                 ' (Y,N) > '
            READ 1100,  ANS

            IF ( ( ANS .EQ. 'N' )  .OR. ( ANS .EQ. 'n' ) )  GO TO 100

            IF ( ( ANS .NE. 'Y' ) .AND. ( ANS .NE. 'y' ) )  GO TO 110
```

```
         END IF

C           Open the results file.

         OPEN ( 4 , FILE=TEMP , STATUS='UNKNOWN'
     &           , CARRIAGECONTROL='FORTRAN' )

      END IF


C        Save name of results file.

      RESFIL = TEMP

      RETURN
      END

      SUBROUTINE INDUCD ( INBORD , NPTS , BLDANG )


C     ***************************************************************
C     *                                                             *
C     *   Subroutine INDUCD computes the induced velocities along   *
C     *   the blade.  These are then used to compute the aerody-    *
C     *   namic forces.  The values computed and returned by this   *
C     *   routine are all in non-dimensional form.  That is, they   *
C     *   are divided by R, OMEGA or R*OMEGA where necessary.       *
C     *                                                             *
C     ***************************************************************

C     ***************************************************************
C     *                                                             *
C     *   External references in this routine:                      *
C     *                                                             *
C     *      none                                                   *
C     *                                                             *
C     ***************************************************************

C     ***************************************************************
C     *                                                             *
C     *   Named COMMON blocks used in this routine:                 *
C     *                                                             *
C     *      AERO1  - Holds coefficients  related to  aerodynamic   *
C     *               loads calculations such as ClAlpha, CdZero,   *
C     *               etc.                                          *
C     *      BLADE  - Holds blade property values  such as stiff-   *
C     *               ness and mass distributions.                  *
C     *      CONST  - Turbine  and  other constants  used in load   *
C     *               calculations.                                 *
C     *      POSITN - Holds parameters  related to blade position   *
C     *               such as PHI, PSI, etc.                        *
C     *      TURBN  - Holds turbine parameters  such as number of   *
C     *               blades, rotor speed, etc.                     *
C     *      VINDUC - Holds induced velocity components.           *
C     *      WIND   - Holds wind shear  and tower shadow  parame-   *
C     *               ters.                                         *
C     *      WNDVEL - Holds values  used in wind shear  and tower   *
C     *               shadow computations.                          *
C     *                                                             *
```

```
*****************************************************************

*****************************************************************
*                                                               *
*   Local and dummy variables used in this routine:             *
*                                                               *
*      A2BVL  - Temporary storage.                              *
*      AA     - Temporary storage.                              *
*      ALMP   - Temporary storage.                              *
*      AM2BV  - Temporary storage.                              *
*      AMBV   - Temporary storage.                              *
*      APR    - Temporary storage.                              *
*      APRIME - Temporary storage.                              *
*      ASTAR  - Temporary storage.                              *
*      BB     - Temporary storage.                              *
*      BLDANG - Blade azimuth position.                         *
*      BPRIME - Temporary storage.                              *
*      BVALUE - Temporary storage.                              *
*      CC     - Temporary storage.                              *
*      CPRIME - Temporary storage.                              *
*      CSS    - Temporary storage.                              *
*      DELVSH - Temporary storage.                              *
*      F1     - Temporary storage.                              *
*      F2     - Temporary storage.                              *
*      F3     - Temporary storage.                              *
*      F4     - Temporary storage.                              *
*      I      - Generic index.                                  *
*      INBORD - The number of blade stations that are not       *
*               on the airfoil section.  INBORD is used in      *
*               other routines to differentiate between         *
*               sections of the blade with and without an       *
*               airfoil section.                                *
*      ISUBP  - Temporary storage.                              *
*      ISUBW  - Temporary storage.                              *
*      J      - Generic index.                                  *
*      LAMDAH - Inflow ratio.                                   *
*      MPRIME - Temporary storage.                              *
*      NPTS   - Number of points along the blade used to        *
*               perform Simpson's integration for calculat-     *
*               ing the moments and forces at the blade         *
*               root.  (passed from FLAP1)                      *
*      P      - Temporary storage.                              *
*      RBAR   - Temporary storage.                              *
*      RDCL1  - Temporary storage.                              *
*      RDCL2  - Temporary storage.                              *
*      STEADY - Flag to indicate steady flow.                   *
*      STEP   - Distance between points along the blade.        *
*      TAU    - Temporary storage.                              *
*      TAU4   - Temporary storage.                              *
*      TAUTZL - Temporary storage.                              *
*      THETZL - Temporary storage.                              *
*      TLAM   - Temporary storage.                              *
*      TSUBZR - Temporary storage.                              *
*      VINDPC - Temporary storage.                              *
*      VINDS  - Temporary storage.                              *
*      Z      - Blade position pointer.                         *
*                                                               *
*****************************************************************

REAL            A2BVL
```

```
      REAL            AA
      REAL            ALMP
      REAL            AM2BV
      REAL            AMBV
      REAL            APR
      REAL            APRIME
      REAL            ASTAR
      REAL            BB
      REAL            BLDANG
      REAL            BPRIME
      REAL            BVALUE
      REAL            CC
      REAL            CPRIME
      REAL            CSS    (5)
      REAL            DELVSH
      REAL            F1
      REAL            F2
      REAL            F3
      REAL            F4
      REAL            ISUBP
      REAL            ISUBW
      REAL            LAMDAH
      REAL            MPRIME
      REAL            P
      REAL            RBAR
      REAL            RDCL1
      REAL            RDCL2
      REAL            STEP
      REAL            TAU
      REAL            TAU4
      REAL            TAUTZL
      REAL            THETZL
      REAL            TLAM
      REAL            TSUBZR
      REAL            VINDPC
      REAL            VINDS
      REAL            Z

      INTEGER         I
      INTEGER         INBDRD
      INTEGER         J
      INTEGER         NPTS

      LOGICAL         STEADY

      INCLUDE        'C:INCLUDE\AERO1.INC'

      INCLUDE        'C:INCLUDE\BLADE2.INC'

      INCLUDE        'C:INCLUDE\CONST2.INC'

      INCLUDE        'C:INCLUDE\POSITN.INC'

      INCLUDE        'C:INCLUDE\TURBN.INC'

      INCLUDE        'C:INCLUDE\VINDUC.INC'

      INCLUDE        'C:INCLUDE\WIND2.INC'

      INCLUDE        'C:INCLUDE\WNDVEL.INC'
```

```
 2000 FORMAT ( / '  >>>  Error in steady induced velocity.     <<<'
     &         / '  >>>  Negative value in SQRT was set to 0.  <<<'
     &         / '  >>>  Blade angle   =' , F6.2
     &                                  , '                    <<<'
     &         / '  >>>  Blade station =' , I3.2
     &                                , '                      <<<'
     &         / )



C        Initialize constants.

       INBORD = 1
       LAMDAH = HUBVEL/( RR*OMEGA )
       STEP   = BLTIP/( NPTS - 1 )

       IF ( TSHADW .EQ. 0.0 )  THEN
          TSUBZR = 0.0
       ELSE
          TSUBZR = TSUBO
       END IF

      DO 100 I=1,5
  100 CSS(I) = COS( I*BLDANG )


C        Move blade station pointer to inboard start of airfoil section
C        on blade.

       Z = 0.0

  110 IF ( Z .LT. BLSHNK )  THEN

          Z      = Z + STEP
          INBORD = INBORD + 1

          GO TO 110

       END IF


C        Initialize internal values.

       ASTAR  = 0.20
       MPRIME = 2.40
       BVALUE = 0.16
       Z      = 0.0

       ALMP   = LAMDAH*MPRIME
       AMBV   = MPRIME + BVALUE
       AM2BV  = LAMDAH*( MPRIME + 2.0*BVALUE )
       APR    = 1.0/( 8.0*PI*RR )
       A2BVL  = 2.0*BVALUE*LAMDAH
       TLAM   = LAMDAH*LAMDAH


          Loop through blade stations.

       DO 220 I=1,NPTS
```

```
      IF ( I .LT. INBORD )  THEN

         VINDR(I) = 0.0
         VINDO(I) = 0.0
         DVIND(I) = 0.0

      ELSE

         STEADY  = .TRUE.
         RBAR    = ( Z + HUBRAD )/RR
         THETZL  = THETAP - THETA0(I)
         TAU     = APR*( CLALFA(I)*CHORD(I)*NBLADS )
         TAUTZL  = TAU*THETZL

         AA = RBAR - 0.5*TAUTZL
         BB = RBAR*TAU - LAMDAH*( RBAR
     &                - ( WSHR(0,I) - TSUBZR )*( RBAR   - TAUTZL ) )
         CC = -RBAR*( RBAR*TAUTZL
     &           + LAMDAH*( WSHR(0,I) - TSUBZR )*( LAMDAH - TAU    ) )


C           Compute the induced velocity.  First check to see if the
C           coefficient of the squared term is zero.  If it is, then
C           the equation is linear.  If the radical of the root is
C           less than zero, then the momentum solution is invalid,
C           set the radical to zero and go on.

         IF ( AA .NE. 0.0 )  THEN

            RDCL1 = BB**2 - 4.0*AA*CC

            IF ( RDCL1 .LT. 0.0 )  RDCL1 = 0.0

            VINDR(I) = 0.5*( -BB + SQRT( RDCL1 ) )/AA

         ELSE

            VINDR(I) = -CC/BB

         END IF


C           Check to see if the induced condition is steady or
C           turbulent.  If it is turbulent, compute turbulent
C           intermediate values and recompute the induced velocity.

         IF ( ( 1.0-VINDR(I)/LAMDAH .GT. ASTAR ) .OR.
     &          ( RDCL1 .EQ. 0.0 ) )  THEN

            STEADY = .FALSE.
            TAU4   = 4.0*TAU

            APRIME = 2.0*TAUTZL
            BPRIME = -RBAR*( ALMP + TAU4 )
     &               -  LAMDAH*( WSHR(0,I) - TSUBZR ).
     &                       *( RBAR*MPRIME - 4*TAUTZL )
            CPRIME = RBAR*( 4*RBAR*TAUTZL + AMBV*TLAM
     &                     + LAMDAH*( WSHR(0,I) - TSUBZR )
     &                            *( AM2BV - TAU4 ) )
```

```
C               Compute the induced velocity.  Use same logic as
C               for steady flow.

                IF ( APRIME .NE. 0.0 )  THEN

                   RDCL2 = BPRIME**2 - 4*APRIME*CPRIME

                   IF ( RDCL2 .LT. 0.0 )  THEN

                      PRINT 2000,  BLDANG , I

                      RDCL2 = 0.0

                   END IF

                   VINDR(I) = -0.5*( BPRIME + SQRT( RDCL2 ) )/APRIME

                ELSE

                   VINDR(I) = -CPRIME/BPRIME

                END IF

             END IF

             VINDO(I) = LAMDAH - VINDR(I)


C               Calculate the intermediate components for forming induced
C               velocity terms.

             F1 = TAU*VINDR(I)*( VINDR(I) - 2*RBAR*THETZL )
             F2 = TAU*( RBAR - THETZL*VINDR(I) )
             F3 = RBAR*( VINDR(I) - VINDO(I) ) + F2

             IF ( STEADY )  THEN

                ISUBP = F1/F3
                ISUBW = LAMDAH*( F2 - RBAR*VINDO(I) )/F3

             ELSE

                F4    = RBAR*ALMP + 4*F2
                ISUBP = 4*F1/F4
                ISUBW = LAMDAH*( 4*F2 - RBAR*( A2BVL
     &                                  + MPRIME*VINDO(I) ) )/F4

             END IF


C               Form induced velocity components of order epsilon, etc.

             VINDC(1) = -PHI(0)*ISUBP + WSHR(1,I)*ISUBW
             VINDS    = -CHI*ISUBP

             DO 200 J=2,5
  200        VINDC(J) = WSHR(J,I)*ISUBW
```

```
C             Compute the tower shadow effect if in the tower shadow
C             region.

              IF ( TSHADW .NE. 0.0 )  THEN

                 VINDPC = TSUBP*ISUBW
                 P      = KSHADW*PI/PSIZER
                 DELVSH = VINDPC*COS( P*( BLDANG - PSISHD ) )

              ELSE

                 VINDPC = 0.0
                 DELVSH = 0.0

              END IF


C             Compute the delta-V-induced term.  i.e., the sum of the
C             order epsilon components.

              DVIND(I) = VINDS*SIN( BLDANG ) - DELVSH

              DO 210 J=1,5
  210         DVIND(I) = DVIND(I) + VINDC(J) * CSS( J )


           END IF


C          Increment the blade position pointer and repeat the induced
C          velocity procedure out to the blade tip.

           Z = Z + STEP

    220 CONTINUE


        RETURN
        END
        SUBROUTINE INVERT ( AMAT , AINV , N )


C       ***************************************************************
C       *                                                             *
C       *   Subroutine  INVERT  is a transparent interface  between   *
C       *   the calling routine,  SOLVE,  and  GAUSSJ,  the routine   *
C       *   that performs  the actual inversion.  The incoming ma-    *
C       *   trix is unaffected  by the inversion process.             *
C       *                                                             *
C       ***************************************************************

C       ***************************************************************
C       *                                                             *
C       *   External references in this routine:                      *
C       *                                                             *
C       *      GAUSSJ - Matrix inversion using  Gauss-Jordan elimi-   *
C       *               nation with full pivoting.                    *
C       *                                                             *
C       ***************************************************************
```

```
C       ************************************************************
C       *                                                          *
C       *   Named COMMON blocks used in this routine:              *
C       *                                                          *
C       *      none                                                *
C       *                                                          *
C       ************************************************************

C       ************************************************************
C       *                                                          *
C       *   Local and dummy variables used in this routine:        *
C       *                                                          *
C       *      AINV   - The resulting inverse matrix.              *
C       *      AMAT   - The incoming matrix to be inverted.        *
C       *      I      - Generic index.                             *
C       *      J      - Generic index.                             *
C       *      N      - The order of the incoming square matrix.   *
C       *                                                          *
C       ************************************************************


      REAL            AINV   (4,4)
      REAL            AMAT   (4,4)

      INTEGER         I
      INTEGER         J
      INTEGER         N



C       Load the incoming matrix into the inverse matrix AINV.

      DO 20 I=1,N
         DO 10 J=1,N
            AINV(I,J) = AMAT(I,J)
   10    CONTINUE
   20 CONTINUE


         Invert the matrix.

      CALL GAUSSJ ( AINV , N )


      RETURN
      END
      SUBROUTINE LIMITS


;       ************************************************************
;       *                                                          *
;       *   Subroutine  LIMITS  inputs the run limit values through  *
;       *   interactive dialog.   A set of default values are init-  *
;       *   ialized in the BLOCK DATA subprogram.                  *
;       *                                                          *
;       ************************************************************

;       ************************************************************
;       *                                                          *
```

```
C       *   External references in this routine:                    *
C       *                                                           *
C       *      none                                                 *
C       *                                                           *
C       ************************************************************

C       ************************************************************
C       *                                                           *
C       *   Named COMMON blocks used in this routine:               *
C       *                                                           *
C       *      LIMITC - Holds values used in the LIMITS routine.    *
C       *                                                           *
C       ************************************************************

C       ************************************************************
C       *                                                           *
C       *   Local and dummy variables used in this routine:         *
C       *                                                           *
C       *      ANS    - Answer to user question.                    *
C       *      ERROR  - IOSTAT error value on OPEN statement.  Used *
C       *               to check for existing files.                *
C       *      ICASE  - Number of variable to change.               *
C       *      P1     - Temporary variable  used for testing to see *
C       *               if PRINT1 is a multiple of STEPMX.          *
C       *      P2     - Temporary variable  used for testing to see *
C       *               if PRINT2 is a multiple of STEPMX.          *
C       *      TEMP   - Temporary variable  used to store  the name *
C       *               of the results file.                        *
C       *                                                           *
C       ************************************************************


      REAL            P1
      REAL            P2

      INTEGER         ICASE

      CHARACTER*1     ANS

      INCLUDE        'C:INCLUDE\LIMITC.INC'

 1000 FORMAT ( // ' The current values of the run parameters are:' / )
 1100 FORMAT ( 1X , A , F8.3 ,      A )
 1200 FORMAT ( 1X , A , I4   , 4X , A )
 2000 FORMAT ( A )



C       Print out the current limit values.

  100 PRINT 1000

      PRINT 1100,  ' 1  STEPMX = ' , STEPMX
     &          ,  ' degrees   Maximum Step Size'

      PRINT 1100,  ' 2  STEPMN = ' , STEPMN
     &          ,  ' degrees   Minimum Step Size'

      PRINT 1100,  ' 3  PRINT1 = ' , PRINT1
     &          ,  ' degrees   Printout Interval in Region 1'
```

```
      PRINT 1100,  ' 4  PRINT2 = ' , PRINT2
     &          ,  ' degrees   Printout Interval in Region 2'

      PRINT 1100,  ' 5  BEGIN2 = ' , BEGIN2
     &          ,  ' degrees   Beginning of Print Region 2'

      PRINT 1100,  ' 6  END2   = ' , END2
     &          ,  ' degrees   End of Print Region 2'

      PRINT 1100,  ' 7  EUERR  = ' , EUERR
     &          ,  ' percent   Max value of Euler error function'

      PRINT 1100,  ' 8  TRMERR = ' , TRMERR
     &          ,  ' percent   Convergence Criterion for Trim Solution'

      PRINT 1200,  ' 9  NYAW   = ' , NYAW
     &          ,  '           No. of Disk Revolutions for Yawing Soln.'

      IF ( TRACEF )  THEN
         PRINT *,  '10  TRACEF = .TRUE.            Trace Flag'
      ELSE
         PRINT *,  '10  TRACEF = .FALSE.           Trace Flag'
      END IF


C        Ask user for changes to present values.

  200 PRINT *,  ' '
      PRINT *,  'Do you want to change any of these values? (Y,=N) > '
      READ 2000,  ANS

      IF ( ( ANS .EQ. 'Y' ) .OR. ( ANS .EQ. 'y' ) )  THEN

  210    PRINT *,  ' '
         PRINT *,  'Enter number of variable you wish to change > '
         READ  *,  ICASE

         IF ( ( ICASE .LE. 0 ) .OR. ( ICASE .GT. 10) )  THEN

            PRINT *,  ' >>>  Invalid response.  Please try again.  <<<'
            GO TO 210

         ELSE


C              Change one of the variables.

            GO TO (300,310,320,330,340,350,360,370,380,390),  ICASE


  300       PRINT *,  'Enter new REAL value for STEPMX > '
            READ  *,  STEPMX
            GO TO 100

  310       PRINT *,  'Enter new REAL value for STEPMN > '
            READ  *,  STEPMN
            GO TO 100

  320       PRINT *,  'Enter new REAL value for PRINT1 > '
```

```
          READ  *,  PRINT1
          GO TO 100

 330      PRINT *,  'Enter new REAL value for PRINT2 > '
          READ  *,  PRINT2
          GO TO 100

 340      PRINT *,  'Enter new REAL value for BEGIN2 > '
          READ  *,  BEGIN2
          GO TO 100

 350      PRINT *,  'Enter new REAL value for END2 > '
          READ  *,  END2
          GO TO 100

 360      PRINT *,  'Enter new REAL value for EUERR > '
          READ  *,  EUERR
          GO TO 100

 370      PRINT *,  'Enter new REAL value for TRMERR > '
          READ  *,  TRMERR
          GO TO 100

 380      PRINT *,  'Enter new INTEGER value for NYAW > '
          READ  *,  NYAW
          GO TO 100

 390      PRINT *,  'Enter new LOGICAL value for TRACEF (T,F) > '
          READ  *,  TRACEF
          GO TO 100

        END IF

      ELSE IF ( ( ANS .NE. 'N') .AND. ( ANS .NE. 'n' )
     &                          .AND. ( ANS .NE. ' ' ) )  THEN

        PRINT *,  '  >>>  Invalid response.  Please try again.  <<<'

        GO TO 200

      END IF


C     Check to make sure the values of PRINT1 and PRINT2 are integer
C     multiples of STEPMX.  If they are not, print error message and
C     go back to the change values section.

      P1 = STEPMX*INT( PRINT1/STEPMX + 0.00001 )
      P2 = STEPMX*INT( PRINT2/STEPMX + 0.00001 )

      IF ( ABS( P1 - PRINT1 ) .GT. 0.001 )  THEN

        PRINT *,  ' '
        PRINT *,  '  >>>  PRINT1 must be a multiple of STEPMX  <<<'

        GO TO 100

      END IF

      IF ( ABS( P2 - PRINT2 ) .GT. 0.001 )  THEN
```

```
        PRINT *,  ' '
        PRINT *,     >>>  PRINT2 must be a multiple of STEPMX  <<<'

        GO TO 100

      END IF


      RETURN
      END
      FUNCTION LNTH ( STRING )


C     ***************************************************************
C     *                                                             *
C     *   Function LNTH returns the length of a character string.   *
C     *   When using the Lahey F77L compiler, the intrinsic func-   *
C     *   tion  NBLANK  can be used as we do here.  This function   *
C     *   was supplied to make conversion to other compilers eas-   *
C     *   ier.                                                      *
C     *                                                             *
C     ***************************************************************

C     ***************************************************************
C     *                                                             *
C     *   Named COMMON blocks used in this routine:                 *
C     *                                                             *
C     *      none                                                   *
C     *                                                             *
C     ***************************************************************

C     ***************************************************************
C     *                                                             *
C     *   Variables used in this routine:                           *
C     *                                                             *
C     *      IC     - Generic index.                                *
C     *      LENGTH - The declared length of STRING.                *
C     *      LNTH   - The location of the last nonblank character   *
C     *               in STRING.                                    *
C     *      STRING - A character string.                           *
C     *                                                             *
C     ***************************************************************

      INTEGER         IC
      INTEGER         LENGTH
      INTEGER         LNTH

      CHARACTER*(*)   STRING


C     Get the declared length of STRING using the FORTRAN 77 intrinsic
C     function LEN.

      LENGTH = LEN( STRING )


C     Find the location of the last nonblank character in STRING.
```

```
      DO 100 IC=LENGTH,1,-1

         LNTH = IC

         IF ( STRING(IC:IC) .NE. ' ' )  GO TO 200

  100 CONTINUE


         STRING is all blanks.

      LNTH = 0


  200 RETURN
      END
      SUBROUTINE LODOUT ( NCALLS )


C     ************************************************************
C     *                                                          *
C     *   Subroutine  LODOUT  is used to compute blade loads  and  *
C     *   print them out.                                        *
C     *                                                          *
C     ************************************************************

C     ************************************************************
C     *                                                          *
C     *   External references in this routine:                   *
C     *                                                          *
C     *      AERO   - Calculates  the aerodynamic  forces  on the  *
C     *               blade.                                     *
C     *      CONVRT - Performs units conversions.                *
C     *      LNTH   - Returns the length of a string.           *
C     *      NXTPHI - Calculates the next values of the yaw vari-  *
C     *               ables.                                     *
C     *      SIMPSN - Composite Simpson's integration.          *
C     *      TRPZOD - Composite trapezoidal integration.        *
C     *                                                          *
C     ************************************************************

C     ************************************************************
C     *                                                          *
C     *   Named COMMON blocks used in this routine:              *
C     *                                                          *
C     *      AERO1  - Holds coefficients  related to  aerodynamic  *
C     *               loads calculations such as ClAlpha, CdZero,  *
C     *               etc.                                       *
C     *      AIRFRC - Holds  values used in  aerodynamic calcula-  *
C     *               tions.                                     *
C     *      BLADE  - Holds blade property values  such as stiff-  *
C     *               ness and mass distributions.               *
C     *      CONST    Turbine  and  other constants  used in load  *
C     *               calculations.                              *
C     *      FORMS  - Holds blade deflections.                  *
C     *      LIMITC - Holds values used in the LIMITS routine.  *
C     *      LITERL - Holds data set titles.                    *
C     *      LODVAL - Holds values used to compute blade loads.  *
C     *      POSITN - Holds parameters  related to blade position  *
C     *               such as PHI, PSI, etc.                     *
```

```
C       *     SARAYS - Holds  new and old  values for the general-  *
C       *              ized coordinates.                            *
C       *     SHAPE  - Holds blade coordinate shape functions.      *
C       *     TENSIN - Holds tension component integrals.           *
C       *     TURBN  - Holds turbine parameters  such as number of  *
C       *              blades, rotor speed, etc.                    *
C       *     WIND   - Holds wind shear  and tower shadow  parame-  *
C       *              ters.                                        *
C       *                                                           *
C       *************************************************************

C       *************************************************************
C       *                                                           *
C       *  Local and dummy variables used in this routine:          *
C       *                                                           *
C       *     AVEMOM - Mean flapwise bending moment at 0.2*R.       *
C       *     BLDANG - Blade azimuth position.                      *
C       *     COEF1  - Complicated term.                            *
C       *     COEF2  - Complicated term.                            *
C       *     COEF3  - Complicated term.                            *
C       *     COEF4  - Complicated term.                            *
C       *     COEF5  - Complicated term.                            *
C       *     COEF6  - Complicated term.                            *
C       *     COEF7  - Complicated term.                            *
C       *     COEF8  - Complicated term.                            *
C       *     CPSI   - Cosine of the blade angle.                   *
C       *     DMSBAC - Complicated term.                            *
C       *     ECENGR - Integral of ECNTFN.                          *
C       *     EDGEFN - Edgewise shear force distribution.           *
C       *     EINTGR - Integral of EDGEFN.                          *
C       *     FACTR1 - Complicated term.                            *
C       *     FINTGR - Integral of FLAPFN.                          *
C       *     FLAPFN - Flapwise shear force distribution.           *
C       *     FPS2KW - Factor for converting Ft-Lbs/sec to KW.      *
C       *     I      - Generic index.                               *
C       *     IBEGIN - Azimuth position for beginning of print re-  *
C       *              gion 1.                                      *
C       *     IEND   - Azimuth position for end of print region 1.  *
C       *     ILABEL - Strings used for printout.                   *
C       *     IPRNT1 - Printout interval for results in print re-   *
C       *              gion 1.                                      *
C       *     IPSI   - Integerized disk station azimuth positions.  *
        *     IPSIST - The next STEPMX station in integer degrees.  *
C       *     IPT    - Data point index.                            *
        *     IST    - Station index.                               *
        *     IVALUE - Temporary storage.                           *
        *     J      - Generic index.                               *
        *     LABEL1 - String to hold variable names.               *
        *     LABEL2 - String to hold units for variables.          *
        *     LABEL3 - String to hold variable descriptions.        *
        *     LABEL4 - String.                                      *
        *     LABEL5 - String.                                      *
        *     LL     - Generic index.                               *
        *     M      - Generic index.                               *
        *     NCALLS - Number of calls to LODOUT.                   *
        *     NOWPSI - Current value of azimuth position.           *
        *     NPTS   - Number  of  points  along the blade used to  *
        *              perform Simpson's integration for calculat-  *
        *              ing the  moments  and  forces  at the blade  *
        *              root.  (passed from FLAP1)                   *
```

```
C       *     NSHP   - Counter  on  DO  loops  for  the coordinate   *
C       *              shape function.                                *
C       *     NSTN   - Number of stations around rotor disk.         *
C       *     NTORQS - Number of values used to compute TRQSUM.      *
C       *     NTOT   - NUmber of values used to compute AVEMOM.      *
C       *     OMGASQ - Omega^2.                                      *
C       *     POWER  - Power output of wind turbine.                 *
C       *     PRDCT0 - Temporary storage.                            *
C       *     PRDCT1 - Temporary storage.                            *
C       *     PRDCT2 - Temporary storage.                            *
C       *     PRODCT - Temporary storage.                            *
C       *     PRODD  - Temporary storage.                            *
C       *     PXAERO - Aerodynamic  loads  in the  edgewise direc-   *
C       *              tion.                                         *
C       *     PYAERO - Aerodynamic  loads  in the  flapwise direc-   *
C       *              tion.                                         *
C       *     QZAERO - Integral of QZFCN.                            *
C       *     QZFCN  - Aerodynamic moment  per unit  length  about   *
C       *              the elastic axis.                             *
C       *     RDIST  - Distance out along blade.                     *
C       *     RESLTS - Temporary storage.                            *
C       *     RP0    - Phi in degrees.                               *
C       *     RP1    - Phi-dot in degrees.                           *
C       *     RP2    - Phi-dot-dot in degrees.                       *
C       *     RPHI   - Phi and its derivatives at this disk sta-   *
C       *              tion.                                         *
C       *     RTIME  - Time values in yaw solution.                  *
C       *     SINTGR - The integral of VXFCN.                        *
C       *     SPSI   - Sine of the blade angle.                      *
C       *     STEP1  - Distance between stations along the blade.    *
C       *     TIMNOW - Current time.                                 *
C       *     TINTGR - Integral of TSNFCN.                           *
C       *     TODEGS - Flag used to tell CONVRT  to convert 'free'   *
C       *              variables to degrees.                         *
C       *     TORADS - Flag used to tell CONVRT  to convert 'free'   *
C       *              variables to radians.                         *
C       *     TORQFN - The torque produced by an incremental aero-   *
C       *              dynamic force.                                *
C       *     TRQSUM - Total torque.  Integral of TORQFN.            *
C       *     TSNFCN - Product of the tension force  and the slope   *
C       *              at a blade station.                           *
C       *     VALUE  - Temporary storage.                            *
C       *     VXFCN  - Product of the edgewise shear force and the   *
C       *              blade slope at a blade station.               *
C       *                                                            *
C       **************************************************************

      REAL            AVEMOM
      REAL            BLDANG
      REAL            COEF1
      REAL            COEF2
      REAL            COEF3
      REAL            COEF4
      REAL            COEF5
      REAL            COEF6
      REAL            COEF7
      REAL            COEF8
      REAL            CPSI
      REAL            DMSBAC
```

```
REAL            ECENGR
REAL            EDGEFN (21)
REAL            EINTGR
REAL            FACTR1
REAL            FINTGR
REAL            FLAPFN (21)
REAL            FPS2KW
REAL            OMGASQ
REAL            POWER
REAL            PRDCTO
REAL            PRDCT1
REAL            PRDCT2
REAL            PRODCT (21)
REAL            PRODD
REAL            PXAERO (21)
REAL            PYAERO (21)
REAL            QZAERO
REAL            QZFCN  (21)
REAL            RDIST
REAL            RP0
REAL            RP1
REAL            RP2
REAL            RPHI   (360,0:2)
REAL            RTIME  (360)
REAL            SIMPSN
REAL            SINTGR
REAL            SPSI
REAL            STEP1
REAL            TIMNOW
REAL            TINTGR
REAL            TORQFN (21)
REAL            TRPZOD
REAL            TRQSUM
REAL            TSNFCN (21)
REAL            VALUE  (26)
REAL            VXFCN  (21)
REAL            ACOF   (0:10,21)
REAL            BCOF   (0:10,21)

INTEGER         H
INTEGER         I
INTEGER         IPRNT1
INTEGER         IPSI   (360)
INTEGER         IPSIST
INTEGER         IPT
INTEGER         IST
INTEGER         IVALUE (4)
INTEGER         J
INTEGER         LL
INTEGER         LNTH
INTEGER         M
INTEGER         NCALLS
INTEGER         NOWPSI
INTEGER         NPTS
INTEGER         NSHP
INTEGER         NSTN
INTEGER         NTORQS
INTEGER         NTOT
INTEGER         MITEM
INTEGER         NHARM
```

```
      CHARACTER*10    ILABEL (4)
      CHARACTER*9     LABEL1 (26)
      CHARACTER*11    LABEL2 (26)
      CHARACTER*45    LABEL3 (9)
      CHARACTER*19    LABEL4
      CHARACTER*2     LABEL5
      CHARACTER*1     ANS1
      CHARACTER*50    LABEL6 (9)

      LOGICAL         TODEGS
      LOGICAL         TORADS

      INCLUDE        'C:INCLUDE\AERO1.INC'

      INCLUDE        'C:INCLUDE\AIRFRC.INC'

      INCLUDE        'C:INCLUDE\BLADE2.INC'

      INCLUDE        'C:INCLUDE\CONST2.INC'

      INCLUDE        'C:INCLUDE\FORMS.INC'

      INCLUDE        'C:INCLUDE\LIMITC.INC'

      INCLUDE        'C:INCLUDE\LITERL.INC'

      INCLUDE        'C:INCLUDE\LODVAL.INC'

      INCLUDE        'C:INCLUDE\POSITN.INC'

      INCLUDE        'C:INCLUDE\SARAYS.INC'

      INCLUDE        'C:INCLUDE\SHAPE.INC'

      INCLUDE        'C:INCLUDE\TENSIN2.INC'

      INCLUDE        'C:INCLUDE\TURBN.INC'

      INCLUDE        'C:INCLUDE\RESLTS.INC'

      INCLUDE        'C:INCLUDE\WIND2.INC'


      SAVE            ILABEL
      SAVE            LABEL1
      SAVE            LABEL2
      SAVE            LABEL3
      SAVE            NPTS
      SAVE            TODEGS
      SAVE            TORADS
      SAVE            IPSI

      DATA            FPS2KW  / 0.0013558 /

      DATA            ILABEL  / 'KSHADW = ' , 'NBLADS = '
     &                        , 'NSHAPS = ' , 'NYAW   = ' /

      DATA            LABEL1
     &   / 'ALENTH = ' ,  'ALPHAO = ' ,  'BETAO    ' ,  'BLSHNK = '
```

```
     &   , 'BLTIP  = ' ,  'CHI    = ' ,  'CSUBMA = ' ,  'DRGFRM = '
     &   , 'EUERR  = ' ,  'HUBHT  = ' ,  'HUBRAD = ' ,  'OMEGA  = '
     &   , 'PHIAMP = ' ,  'PHIOMG = ' ,  'PHIO   = ' ,  'PSIZER = '
     &   , 'RHOAIR = ' ,  'SHERXP = ' ,  'STEPMX = ' ,  'STEPMN = '
     &   , 'TSUBP  = ' ,  'TSUBO  = ' ,  'THETAP = ' ,  'THETAT = '
     &   , 'TRMERR = ' ,  'VHUB   = ' /
      DATA            LABEL2
     & / 'feet       ' , 'degrees    ' , 'degrees    ' , 'feet       '
     & , 'feet       ' , 'degrees    ' , '           ' , '           '
     & , 'percent    ' , 'feet       ' , 'feet       ' , 'RPM        '
     & , 'degrees    ' , 'degrees/sec' , 'degrees    ' , 'degrees    '
     & , 'slugs/ft^3 ' , '           ' , 'degrees    ' , 'degrees    '
     & , '           ' , '           ' , 'degrees    ' , 'degrees    '
     & , 'percent    ' , 'feet/second' /
      DATA            LABEL3
     &   / 'Blade section flap displacement  ( feet )      '
     &   , 'Blade section flapwise slope  ( feet/foot )    '
     &   , 'Blade section flap velocity  ( feet/second )   '
     &   , 'Blade tension  ( Lb )                          '
     &   , 'Blade edgewise shear  ( Lb )                   '
     &   , 'Blade flapwise shear  ( Lb )                   '
     &   , 'Blade flapwise moment ( ft-Lbs )               '
     &   , 'Blade edgewise moment ( ft-Lbs )               '
     &   , 'Blade torsion  ( ft-Lbs )                      ' /
      DATA            LABEL6
     &   / 'Blade flap-displacement expansion coefficients '
     &   , 'Blade flapwise slope expansion coefficients    '
     &   , 'Blade flap-velocity expansion coefficients     '
     &   , 'Blade tension force expansion coefficients     '
     &   , 'Blade edgewise shear expansion coefficients    '
     &   , 'Blade flapwise shear expansion coefficients    '
     &   , 'Blade flapwise moment expansion coefficients   '
     &   , 'Blade edgewise moment expansion coefficients   '
     &   , 'Blade torsional moment expansion coefficients  ' /

      DATA            NPTS    / 21 /

      DATA            TODEGS  / .TRUE. /

      DATA            TORADS  / .FALSE. /

 4000 FORMAT ( /// 37X , 'Analysis of Wind Turbine Blade Loads',
     &          / 39X , 'Solar Energy Research Institute' //// )
 4100 FORMAT ( 3( 10X , A // ) )
 4200 FORMAT ( 10X , A , ' Rotor'
     &   //// 7X , 'Run Parameters, blade data and machine data used in'
     &            ' this analysis: ' / )
 4300 FORMAT ( 9X , 3( 1X , A , F7.3 , 1X , A , 5X , : ) // )
 4400 FORMAT ( /// 9X , 4( 1X , A , I3 , 12X ) / )
 4500 FORMAT ( '1' //// 1X , A , 65X , A , A / )
 4600 FORMAT ( ' Psi  Time   Phi   Phi-D Phi-DD' , 38X , 'X  /  R '
     &       / 1X , 131( '-')
     &       / ' deg   sec   deg   deg/s deg/s^2    .0       .1'
     &       , '       .2       .3       .4       .5       .6'
     &       , '       .7       .8       .9      1.0'
     &       / 1X , 131( '-') / )
 4700 FORMAT( I4 , F6.2 , F6.1 , F7.2 , F7.2 , 3X , 11(1X , 1PG8.2E1) )
 4800 FORMAT ( // ' Average Flapwise Moment = ' , F9.1
     &          , ' (ft-Lbs) at the 20% station' / )
 5000 FORMAT ( '1' ///// ' Mean Rotor Torque and Power for ' , 2A // )
```

```
 5100 FORMAT ( 10X , 'Mean Rotor Torque  =' , F13.2 , ' ft-Lbs'
     &      // 10X , 'Mean Rotor Power   =' , F13.2 , ' KW'
     &      // 10X , 'No. of Data Points =' , I13 )

 5200 FORMAT ('1' ///// 1X, A, 65X, A, A/)

 5300 FORMAT (69X, 'X / R ' / 1X, 131('-')/ 131('-')/
     &   12X, '.0         .1         .2         .3         .4'
     &'         .5         .6         .7         .8         .9'
     &'         1.'/
     &   1X, 131('-')/131('_')/)

 5400 FORMAT (1X, 'A',I1,'=',3X, 11(3X,1PG8.2E1))
 5500 FORMAT (1X, 'B',I1,'=',3X, 11(3X,1PG8.2E1))
 5600 FORMAT (1X, 131('-'))



C        Initialize torque count and sum.

       NTORQS = 0
       TRQSUM = 0.0


C         Set some constants that are user to compute tension and shear.

       OMGASQ = OMEGA**2
       COEF1  = 2.0*OMEGA*STHP
       COEF4  = OMGASQ*STHP*CTHP
       COEF6  = OMGASQ*CTHP*CTHP
       COEF7  = OMGASQ*STHP*STHP


C        Fill the IPSI array with PSI disk station values.  This section
C        of code is executed only the first time this routine is called.

       IF( NCALLS .EQ. 0 )  THEN

          IPRNT1 = PRINT1*RAD2DG + 0.001
          NSTN   = 1
          IPSIST = 0
          IPSI(NSTN) = IPSIST

   120    IF ( IPSIST .LT. 360 )  THEN

             IPSIST     = IPSIST + IPRNT1
             NSTN       = NSTN + 1
             IPSI(NSTN) = IPSIST

             GO TO 120
          ENDIF

       ENDIF

          IPSI(NSTN) = 360


C        Initialize the time values in the RTIME array for the trim run.

       IF ( ( NCALLS .EQ. 0 ) .OR. ( PHIAMP .EQ. 0.0 ) )  THEN
```

```
         DO 200 I=1,NSTN
  200    RTIME(I) = 0.0

      ELSE


C           Calculate the time values around the disk stations for the
C           yaw runs.

         RTIME(1) = 2*PI*( NCALLS - 1 )/OMEGA

         DO 210 IST=2,NSTN
  210    RTIME(IST) = RTIME(1) + IPSI(IST)/( RAD2DG*OMEGA )

      END IF


C        Initialize outer computation loop used for going around the disk.

      PRODD = 0.5*RHOAIR*CSUBMA

      DO 370 IST=1,NSTN


C           Compute the PHI values at this disk azimuth.

         TIMNOW = RTIME(IST)

         CALL NXTPHI(TIMNOW)

         RPHI(IST,0) = PHI(0)
         RPHI(IST,1) = PHI(1)
         RPHI(IST,2) = PHI(2)


C           Compute constants used in computing the shear and moment
C           values.

         PSI(1) = IPSI(IST)/RAD2DG
         NOWPSI = IPSI(IST)
         CPSI   = COS( PSI(1) )
         SPSI   = SIN( PSI(1) )
         FACTR1 = OMGASQ*BETA0 + 2*OMEGA*CPSI*PHI(1) + SPSI*PHI(2)
         COEF2  = GRAV*( -CHI*CTHP + STHP*SPSI + BETA0*CTHP*CPSI )
         COEF3  = GRAV*(  CHI*STHP + CTHP*SPSI - BETA0*STHP*CPSI )
         COEF5  = GRAV*CPSI
         COEF8  = GRAV*SPSI*STHP


C           Fill the V arrays.

C              V       = RESLTS( , ,1)
C              V-PRIME = RESLTS( , ,2)
C              V-DOT   = RESLTS( , ,3)

         DO 310 IPT=1,NPTS

            RESLTS(IST,IPT,1) = 0.0
            RESLTS(IST,IPT,2) = 0.0
```

```
            RESLTS(IST,IPT,3) = 0.0

            DO 300 NSHP=1,NSHAPS

               RESLTS(IST,IPT,1) = RESLTS(IST,IPT,1)
     &                           + SHAPE(NSHP,0,IPT)*SNEW(NSHP,0,NOWPSI)

               RESLTS(IST,IPT,2) = RESLTS(IST,IPT,2)
     &                           + SHAPE(NSHP,1,IPT)*SNEW(NSHP,0,NOWPSI)

               RESLTS(IST,IPT,3) = RESLTS(IST,IPT,3)
     &                           + SHAPE(NSHP,0,IPT)*SNEW(NSHP,1,NOWPSI)

  300       CONTINUE


C              The values for VV(0,IPT) and VV(1,IPT) are needed for the
C              AERO and VREL routines.

            VV(0,IPT) = RESLTS(IST,IPT,1)
            VV(1,IPT) = RESLTS(IST,IPT,3)

  310     CONTINUE


C           Compute the aerodynamic force components and the Qz compo-
C           nent form integrals and save them for use in computing the
C           shears and moments.

          BLDANG = PSI(1)

          CALL AERO ( NPTS , BLDANG )


C           This section of code computes the rotor torque component
C           that produces the turbine shaft torque.  The torque is
C           averaged over the disk to give average rotor torque for one
C           rotor revolution.  This does not use weighted values.  All
C           values have equal weight regardless of the azimuth spacing.
C           Thus these results will only be accurate when PRINT1 and
C           PRINT2 have the same value.

          STEP1 = BLTIP/( NPTS - 1 )

          IF ( NOWPSI .LT. 360 )  THEN

             DO 320 I=1,NPTS

                RDIST     = HUBRAD +  STEP1*( I - 1 )
                TORQFN(I) = RDIST*( DAETA(I)*CTHP + DAZETA(I)*STHP )

  320        CONTINUE

             TRQSUM = TRQSUM + SIMPSN( 0 , BLTIP , NPTS , TORQFN )
             NTORQS = NTORQS + 1

          END IF

          DO 330 IPT=1,NPTS
```

```
            DMSBAC     = PRODD*CHORD(IPT)*WW(IPT)**2
            QZFCN(IPT) = DMSBAC + ESUBAC(IPT)*DAZETA(IPT)

  330    CONTINUE

         DO 350 IPT=1,NPTS

            PXAERO(IPT) = TRPZOD( IPT , BLTIP , DAETA ,  NPTS )
            PYAERO(IPT) = TRPZOD( IPT , BLTIP , DAZETA , NPTS )


C              Compute the constants needed to compute tension
C              and shear.

            PRDCTO = 0.0
            PRDCT1 = 0.0
            PRDCT2 = 0.0

            PRODCT(IPT) = 0.0

            DO 340 NSHP=1,NSHAPS

               PRDCTO = PRDCTO + SNEW(NSHP,O,NOWPSI)*TCORLS(NSHP,IPT)
               PRDCT1 = PRDCT1 + SNEW(NSHP,1,NOWPSI)*TCORLS(NSHP,IPT)
               PRDCT2 = PRDCT2 + SNEW(NSHP,2,NOWPSI)*TCORLS(NSHP,IPT)

               PRODCT(IPT) = PRODCT(IPT)
     &                     + SNEW(NSHP,O,NOWPSI)*CIFMOM(NSHP,IPT)

  340       CONTINUE


            RESLTS(IST,IPT,4) = OMGASQ*TOMGA(IPT) + COEF1*PRDCT1
     &                        -  COEF5*TGRAV(IPT)

            RESLTS(IST,IPT,6) = PYAERO(IPT) - FACTR1*CTHP*TOMGA(IPT)
     &                        + COEF7*PRDCTO - PRDCT2
     &                        + COEF2*TGRAV(IPT) + COEF4*OFFMAS(IPT)

            RESLTS(IST,IPT,5) = PXAERO(IPT) + FACTR1*STHP*TOMGA(IPT)
     &                        + COEF4*PRDCTO + COEF3*TGRAV(IPT)
     &                        + COEF6*OFFMAS(IPT)

            EDGEFN(IPT) = RESLTS(IST,IPT,5)
            VXFCN (IPT) = EDGEFN(IPT)*RESLTS(IST,IPT,2)
            TSNFCN(IPT) = RESLTS(IST,IPT,4)*RESLTS(IST,IPT,2)
            FLAPFN(IPT) = RESLTS(IST,IPT,6)

  350    CONTINUE


C           Compute the torsion and moment array values for this
C           azimuth position.

         DO 360 IPT=1,NPTS

            EINTGR = TRPZOD( IPT , BLTIP , EDGEFN , NPTS )
            SINTGR = TRPZOD( IPT , BLTIP , VXFCN  , NPTS )
            TINTGR = TRPZOD( IPT   BLTIP , TSNFCN   NPTS )
            QZAERO = TRPZOD( IPT , BLTIP , QZFCN  , NPTS )
```

```
            FINTGR = TRPZOD( IPT , BLTIP , FLAPFN , NPTS )
            ECENGR = TRPZOD( IPT , BLTIP , ECNTFN , NPTS )

            RESLTS(IST,IPT,7) = TINTGR - FINTGR + COEF7*PRODCT(IPT)

            RESLTS(IST,IPT,8) = EINTGR - OMGASQ*ECENGR
     &                        - COEF4*PRODCT(IPT) + COEF5*OFFMAS(IPT)

            RESLTS(IST,IPT,9) = QZAERO - SINTGR + COEF4*DELTIM(IPT)
     &                        + COEF8*OFFMAS(IPT)

  360    CONTINUE

  370 CONTINUE

        TRQSUM = TRQSUM*NBLADS/NTORQS
        POWER  = TRQSUM*OMEGA*FPS2KW


C       Print out the resulting values with a heading on the first
C       pass only.  Convert values to degrees for the printout.

        CALL CONVRT ( TODEGS )

        IF ( MOD( NCALLS , NYAW+1 ) .EQ. 0 )  THEN

           VALUE( 1) = ALENTH
           VALUE( 2) = ALPHAO
           VALUE( 3) = BETAO
           VALUE( 4) = BLSHNK
           VALUE( 5) = BLTIP
           VALUE( 6) = CHI
           VALUE( 7) = CSUBMA
           VALUE( 8) = DRGFRM
           VALUE( 9) = EUERR
           VALUE(10) = HUBHT
           VALUE(11) = HUBRAD
           VALUE(12) = OMEGA
           VALUE(13) = PHIAMP
           VALUE(14) = PHIOMG
           VALUE(15) = PHIO
           VALUE(16) = PSIZER
           VALUE(17) = RHOAIR
           VALUE(18) = SHERXP
           VALUE(19) = STEPMX
           VALUE(20) = STEPMN
           VALUE(21) = TSUBP
           VALUE(22) = TSUBO
           VALUE(23) = THETAP
           VALUE(24) = THETAT
           VALUE(25) = TRMERR
           VALUE(26) = VHUB

           IVALUE(1) = KSHADW
           IVALUE(2) = NBLADS
           IVALUE(3) = NSHAPS
           IVALUE(4) = NYAW

           WRITE (4,4000)
           WRITE (4,4100)  TITLE1(1:LNTH(TITLE1))
```

```
     &               , TITLE2(1:LNTH(TITLE2))
     &               , TITLE3(1:LNTH(TITLE3)) .

         DO 400 J=1,9
  400    WRITE (4,4300)  ( LABEL1(I), VALUE(I), LABEL2(I), I=J,26,9 )

         WRITE (4,4400)  ( ILABEL(I) , IVALUE(I) , I=1,4 )

       END IF


C        Convert values back to radians for use in internal
C        calculations.

       CALL CONVRT ( TORADS )


C        This section of code computes the mean flapwise moment at the
C        20% blade station for NPTS=21.  If NPTS is changed, the second
C        subscript of RESLTS( , ,7) must be changed also.

C        Programmer note:

C           Changed to what?

       NTOT   = 0
       AVEMOM = 0.0

       DO 410 LL=1,NSTN-1

          AVEMOM = AVEMOM + RESLTS(LL,5,7)
          NTOT   = NTOT   + 1

  410  CONTINUE

       AVEMOM = AVEMOM/NTOT


C        Form the proper chart headings and print out the nine charts
C        of the results from this run.

       IF ( NCALLS .EQ. 0 )  THEN

          LABEL4 = 'Trim Solution
          LABEL5 = '

       ELSE

          LABEL4 = 'Yaw Solution, Rev #'
          WRITE (LABEL5,'(I2.2)')  NCALLS

       END IF

       DO 430 M=1,9

          WRITE (4,4500)  LABEL3(M) , LABEL4 , LABEL5
          WRITE (4,4600)

          DO 420 I=1,NSTN
```

```
            RP0 = RPHI(I,0)*RAD2DG
            RP1 = RPHI(I,1)*RAD2DG
            RP2 = RPHI(I,2)*RAD2DG

            WRITE (4,4700)  IPSI(I) , RTIME(I) , RP0 , RP1 , RP2
     &                    ,  ( RESLTS(I,J,M) , J=1,NPTS,2 )

  420    CONTINUE


C           Print the average flapwise moment at the 20% blade station.

         IF ( M .EQ. 7 )  WRITE (4,4800)  AVEMOM

  430 CONTINUE

         IF( NCALLS .EQ. 0) THEN
            PRINT *, ' '
  500       PRINT *, 'Do you want to perform fourier analysis of'
            PRINT *, 'any of the results data?'
            PRINT *, '    '
            PRINT *, ' note: shaft loads harmonics will appear in'
            PRINT *, ' the shaft loads file.'
            PRINT *, ' '
            READ *, ANS1
            IF ( ANS1 .EQ. 'Y' .OR. ANS1 .EQ. 'y' ) THEN
               PRINT *, 'Read in the result data item # '
               PRINT *, 'that you want analyzed'
               PRINT *, ' '
               PRINT *, '1 = flapwise displacement'
               PRINT *, '2 = flapwise slope'
               PRINT *, '3 = flapwise segment velocity'
               PRINT *, '4 = blade tension'
               PRINT *, '5 = blade edgewise shear'
               PRINT *, '6 = blade flapwise shear'
               PRINT *, '7 = blade flapwise moment'
               PRINT *, '8 = blade edgewise moment'
               PRINT *, '9 = blade torsional moment'
               PRINT *, '   '
               READ *, MITEM
               PRINT *, 'Read in the highest order harmonic desired'
               READ *, NHARM

               CALL SERIES(  MITEM, NHARM, ACOF, BCOF, NSTN,
     &              IPSI, IPRNT1)

               WRITE(4,5200) LABEL6(MITEM), LABEL4, LABEL5
               WRITE(4,5300)

               DO 550 H = 0,NHARM

                  WRITE(4,5400) H, (ACOF(H,J),J=1,NPTS,2)
                  WRITE(4,5500) H, (BCOF(H,J),J=1,NPTS,2)
                  WRITE(4,5600)
  550          CONTINUE

               GO TO 500
            ELSEIF( ANS1 .NE. 'y' .AND. ANS1 .NE. 'Y') THEN
               GO TO 600
            ENDIF
```

```
C       When all the results tables have been printed, print out the
C       average rotor torque and power for this rotor revolution.  This
C       codes gives equal weight to each azimuth position regardless
C       of the azimuth spacing.  Thus the power and torque values are
C       only accurate when PRINT1 and PRINT2 are the same.

  600   WRITE (4,5000)  LABEL4 , LABEL5
        WRITE (4,5100)  TRQSUM , POWER , NTORQS

        IF( NBLADS .EQ. 2) THEN
           CALL SHAFT2(IPSI, IPRNT1, NSTN)
        ELSE
           CALL SHAFT3(IPSI, IPRNT1, NSTN)
        ENDIF

      ENDIF

C       Increment the number of calls to this routine before
C       returning.

      NCALLS = NCALLS + 1

      RETURN
      END
      SUBROUTINE MULT ( AMATRX , M , N )


C       ****************************************************************
C       *                                                              *
C       *   Subroutine MULT premultiplies an incoming matrix by the    *
C       *   inverse CMMASS matrix.   The inverse CMMASS matrix is a    *
C       *   square symmetric matrix  of order 4.   The incoming ma-    *
C       *   trix can be of any size but must have exactly 4 rows.      *
C       *                                                              *
C       ****************************************************************

C       ****************************************************************
C       *                                                              *
C       *   External references in this routine:                       *
C       *                                                              *
C       *      none                                                    *
C       *                                                              *
C       ****************************************************************

C       ****************************************************************
C       *                                                              *
C       *   Named COMMON blocks used in this routine:                  *
C       *                                                              *
C       *      INV    - Holds the inverse of the mass matrix.          *
C       *                                                              *
C       ****************************************************************

C       ****************************************************************
C       *                                                              *
C       *   Local and dummy variables used in this routine:            *
C       *                                                              *
C       *      AMATRX - The incoming matrix to be premultiplied by     *
C       *               the inverse CMMASS matrix.                     *
C       *      I      - Generic index.                                 *
```

```
C       *     J      - Generic index.                                 *
C       *     K      - Generic index.                                 *
C       *     M        Number of rows in the incoming matrix.         *
C       *     N      - Number of columns in the incoming matrix.      *
C       *     TEMP   - Temporary work matrix.                         *
C       *                                                             *
C       ***************************************************************

      REAL            AMATRX (4,4)
      REAL            TEMP   (4,4)

      INTEGER         I
      INTEGER         J
      INTEGER         K
      INTEGER         M
      INTEGER         N

      INCLUDE        'C:INCLUDE\INV.INC'



C       Multiply AINVRS by AMATRX putting the result into TEMP.

      DO 30 I=1,M

         DO 20 J=1,N

            TEMP(I,J) = 0.0

            DO 10 K=1,M
   10       TEMP(I,J) = TEMP(I,J) + AINVRS(I,K) * AMATRX(K,J)

   20    CONTINUE

   30 CONTINUE


C       Move the resulting temporary matrix into the original
C       incoming matrix.

      DO 50 I=1,M

         DO 40 J=1,N
   40    AMATRX(I,J) = TEMP(I,J)

   50 CONTINUE


      RETURN
      END
      SUBROUTINE NXTPHI ( TIMNOW )


C
C       ***************************************************************
C       *                                                             *
C       *   Subroutine  NXTPHI  computes the next values  of the yaw  *
C       *   variables.   If this is a trim run, then the yaw varia-   *
C       *   bles do not change.   If this is a yawing run, then the   *
C       *   yaw variables  are computed  based on the next value of   *
```

```
C       *   the time variable.                                          *
C       *                                                               *
C       *   The basic yaw function used here is:                        *
C       *                                                               *
C       *      Phi = Phi-sub-0 + SIN( Omega-sub-Phi*Time ).             *
C       *                                                               *
C       *   The two derivatives  with respect to time,  Phi-dot and     *
C       *   Phi-double-dot  are derived in a straightforward manner     *
C       *   via differentiation with respect to time.                   *
C       *                                                               *
C       *   The indices of the PHI array correspond to the order of     *
C       *   the derivative of Phi with respect to time.                 *
C       *                                                               *
C       ****************************************************************

C       ****************************************************************
C       *                                                               *
C       *   External references in this routine:                        *
C       *                                                               *
C       *      none                                                     *
C       *                                                               *
C       ****************************************************************

C       ****************************************************************
C       *                                                               *
C       *   Named COMMON blocks used in this routine:                   *
C       *                                                               *
C       *      POSITN - Holds parameters  related to blade position     *
C       *               such as PHI, PSI, etc.                          *
C       *      TURBN  - Holds turbine parameters  such as number of     *
C       *               blades, rotor speed, etc.                       *
C       *                                                               *
C       ****************************************************************

C       ****************************************************************
C       *                                                               *
C       *   Local and dummy variables used in this routine:             *
C       *                                                               *
C       *      OMPHIT - Phase angle of the sinusoidal yaw function.     *
C       *               It corresponds to the Omega-sub-Phi*T  term     *
C       *               of the formulation notes. The Omega-sub-Phi     *
C       *               component  is the  yaw  velocity  amplitude     *
C       *               divided by the yaw angle amplitude.             *
C       *      SOMPHT - Sine of Omega-sub-Phi*T.                        *
C       *      TIMNOW - Current time.  TIMNOW  is  identically zero     *
C       *               for the trim solution computation.              *
C       *                                                               *
C       ****************************************************************

      REAL            OMPHIT
      REAL            SOMPHT
      REAL            TIMNOW

      INCLUDE        'C:INCLUDE\POSITN.INC'

      INCLUDE        'C:INCLUDE\TURBN.INC'


C       Check to see if this is time zero.
```

```
      IF ( TIMNOW .EQ. 0.0 )  THEN

C           Set the yaw function and its derivatives for TIME=0.

         PHI(0) = PHI0
         PHI(1) = PHIOMG
         PHI(2) = 0.0

      ELSE


C           Compute the yaw function and its derivatives for times
C           greater than time zero.

         OMPHIT = TIMNOW*PHIOMG/PHIAMP
         SOMPHT = SIN( OMPHIT )
         PHI(0) = PHI0 + PHIAMP*SOMPHT
         PHI(1) = PHIOMG*COS( OMPHIT )
         PHI(2) = -PHIOMG*PHIOMG*SOMPHT/PHIAMP

      END IF


      RETURN
      END
      SUBROUTINE NXTPSI ( IPSIST )


C     ***************************************************************
C     *                                                             *
C     *   Subroutine  NXTPSI  computes the next value of the azi-   *
C     *   muth angle, Psi,  based on the current value of the Eu-   *
C     *   ler error and the previous delta-Psi value.  If the er-   *
C     *   ror is too large,  a smaller delta-Psi  will be used to   *
C     *   compute the value of  Psi,  unless the delta-Psi is al-   *
C     *   ready at the STEPMN lower limit.   Likewise, if the Eu-   *
C     *   ler error is below a certain limit, the delta-Psi value   *
C     *   is increased for the next Psi computation.                *
C     *                                                             *
C     ***************************************************************

C     ***************************************************************
C     *                                                             *
C     *   External references in this routine:                      *
C     *                                                             *
C     *      none                                                   *
C     *                                                             *
C     ***************************************************************

C     ***************************************************************
C     *                                                             *
C     *   Named COMMON blocks used in this routine:                 *
C     *                                                             *
C     *      CONST  - Turbine  and  other constants  used in load   *
C     *               calculations.                                 *
C     *      LIMITC - Holds values used in the LIMITS routine.      *
C     *      POSITN - Holds parameters  related to blade position   *
C     *               such as PHI, PSI, etc.                        *
C     *      TURBN  - Holds turbine parameters  such as number of   *
```

```
C       *              blades, rotor speed, etc.                  *
C       *                                                         *
C       ***********************************************************

C       ***********************************************************
C       *                                                         *
C       *   Local and dummy variables used in this routine:       *
C       *                                                         *
C       *      IPSIST - The next STEPMX station in integer degrees.  *
C       *      NEW    - Array index for new data.                *
C       *      OLD    - Array index for old data.                *
C       *      PSIST  - The next STEPMX station in radians.      *
C       *                                                         *
C       ***********************************************************

      REAL            PSIST

      INTEGER         IPSIST
      INTEGER         NEW
      INTEGER         OLD

      INCLUDE        'C:INCLUDE\CONST2.INC'

      INCLUDE        'C:INCLUDE\LIMITC.INC'

      INCLUDE        'C:INCLUDE\POSITN.INC'

      INCLUDE        'C:INCLUDE\TURBN.INC'

      SAVE            NEW
      SAVE            OLD

      DATA            NEW     / 1 /
      DATA            OLD     / 0 /



C       Check the error.  If it is too large, decrease delta-Psi by
C       50%.  If it is very small, increase delta-Psi by 50%.  The
C       value of delta-Psi must always be greater than STEPMN.

      IF ( ERROR .GT. EUERR )  THEN

         DELPSI(NEW) = AMAX1( 0.5*DELPSI(NEW) , STEPMN )

      ELSE IF ( ERROR .LT. 0.1*EUERR )  THEN

         DELPSI(NEW) = 1.5*DELPSI(NEW)

      END IF


C       This section of code checks the position of the new Psi against
C       the next STEPMX station.  If the next Psi will go past the
C       STEPMX station, the delta-Psi is adjusted to bring the next Psi
C       directly onto the STEPMX point.  If the next Psi will fall just
C       short of a STEPMX station, the delta-Psi is adjusted to assure
C       that it will not be necessary to use a delta-Psi smaller than
C       STEPMN to reach the next STEPMX station on the next iteration.
```

```
C       Programmer note:

C          The following logic can produce a delta-Psi that is less
C          than STEPMN for two steps.  It would then move back within
C          tolerances.  This case comes up when we are within slightly
C          less than two STEPMNs of the next STEPMX station.  This
C          algorithm cannot produce a delta-Psi that is less than
C          STEPMN/2.                          MLB

      PSIST = IPSIST/RAD2DG

      IF ( PSI(OLD)+DELPSI(NEW) .GT. PSIST )  THEN

         DELPSI(NEW) = PSIST - PSI(OLD)

      ELSE IF ( PSI(OLD)+DELPSI(NEW)+STEPMN .GT. PSIST )  THEN

         IF ( (DELPSI(NEW) .NE. STEPMN) .OR. (ERROR .LE. EUERR) )  THEN

            DELPSI(NEW) = 0.5*( PSIST - PSI(OLD) )

         END IF

      END IF


C       Set new Psi and delta-Time.

      PSI(NEW)    = PSI(OLD) + DELPSI(NEW)
      DELTAT(NEW) = DELPSI(NEW)/OMEGA


C       Get time values if we're working on a yawing solution.

      IF ( ITRIM .EQ. 0 )  TIME(NEW) = TIME(OLD) + DELTAT(NEW)


      RETURN
      END
      SUBROUTINE RUN ( NPTS , NEWSET , HAVRUN )


C       ****************************************************************
C       *                                                              *
C       *   Subroutine RUN performs the modeling of the rotor blade    *
C       *   motion.   The coefficients and data  read in by subrou-    *
C       *   tine  DATAIN  are used along with the run limit and run    *
C       *   setup values input in subroutines LIMITS and SETUP.        *
C       *                                                              *
C       *   There are  two basic steps  to the run solution  -  the    *
C       *   trim solution and the yawing solution.  In the trim so-    *
C       *   lution,  the yaw position  and yaw rate  are kept  at a    *
C       *   fixed value,  and the time is kept fixed at zero.   The    *
C       *   equations are solved  for successive revolutions around    *
C       *   the rotor disk  until the tip displacement functions no    *
C       *   longer change significantly  from one revolution to the    *
C       *   next.  This is the trim solution.   Once the trim solu-    *
C       *   tion is achieved,  the trim solution is completed, with    *
C       *   the yaw angle,  yaw angular velocity  and  acceleration    *
C       *   computed  from a  given  function  and the time elapsed    *
```

```
C       *   since the start of the yaw solution.   After each rotor   *
C       *   disk revolution of the yaw solution, the loads are cal-   *
C       *   culated and printed out.                                  *
C       *                                                             *
C       ***************************************************************

C       ***************************************************************
C       *                                                             *
C       *   External references in this routine:                      *
C       *                                                             *
C       *      CONVRT - Performs units conversions.                   *
C       *      DSKREV - Performs a full disk revolution solution to   *
C       *               the blade equations of motion.                *
C       *      GETFIL - Get the name  of the results file  and open   *
C       *               it.                                           *
C       *      LIMITS - Interactive input of run limits.              *
C       *      LODOUT - Calculates and prints blade loads.            *
C       *      SETUP  - Interactive modification of free variables.   *
C       *      SHAPES - Calculates  the four coordinate shape func-   *
C       *               tions.                                        *
C       *      SOLVE  - Calculates  the inverse  CMMASS  matrix for   *
C       *               premultipling other coefficient matrices.     *
C       *      TRMTST - Compares the results of two consecutive ro-   *
C       *               tor revolutions.                              *
C       *                                                             *
C       ***************************************************************

C       ***************************************************************
C       *                                                             *
C       *   Named COMMON blocks used in this routine:                 *
C       *                                                             *
C       *      CONST  - Turbine  and  other constants  used in load   *
C       *               calculations.                                 *
C       *      LIMITC - Holds values used in the LIMITS routine.      *
C       *      POSITN - Holds parameters  related to blade position   *
C       *               such as PHI, PSI, etc.                        *
C              SARAYS - Holds  new and old  values for the general-   *
C       *               ized coordinates.                             *
C       *      TURBN  - Holds turbine parameters  such as number of   *
C       *               blades, rotor speed, etc.                     *
C       *                                                             *
C       ***************************************************************

C       ***************************************************************
C       *                                                             *
C       *   Local and dummy variables used in this routine:           *
C       *                                                             *
C       *      ANS    - Used  to  store  input responses from key-    *
C       *               board.                                        *
C       *      HAVRUN - Flag that indicates that the model has been   *
C       *               run.  Used for diagnostic runs.               *
C       *             - Generic index.                                *
C       *      ITCNT  - The count of the number of disk revolutions   *
C       *               required to achieve a trim solution.          *
C       *      J      - Generic index.                                *
C       *      NCALLS - Number of calls to LODOUT.                    *
C       *      NEWSET - Flag to control calls to SOLVE.               *
C       *      NPTS   - Number  of  points  along the blade used to   *
C       *               perform Simpson's integration for calculat-   *
C       *               ing the  moments  and  forces  at the blade   *
```

```
C       *              root.  (passed from FLAP1)                 *
C       *      NSHP   - Counter  on  DO  loops  for  the coordinate  *
C       *              shape function.                             *
C       *      RESFIL - Name of file to which results are written.  *
C       *      TODEGS - Flag used to tell CONVRT  to convert 'free'  *
C       *              variables to degrees.                       *
C       *      TORADS - Flag used to tell CONVRT  to convert 'free'  *
C       *              variables to radians.                       *
C       *                                                          *
C       ************************************************************

      INTEGER         I
      INTEGER         ITCNT
      INTEGER         J
      INTEGER         NCALLS
      INTEGER         NPTS
      INTEGER         NSHP

      LOGICAL         HAVRUN
      LOGICAL         NEWSET
      LOGICAL         TODEGS
      LOGICAL         TORADS

      CHARACTER*1     ANS
      CHARACTER*50    RESFIL

      INCLUDE        'C:INCLUDE\CONST2.INC'

      INCLUDE        'C:INCLUDE\LIMITC.INC'

      INCLUDE        'C:INCLUDE\POSITN.INC'

      INCLUDE        'C:INCLUDE\SARAYS.INC'

      INCLUDE        'C:INCLUDE\TURBN.INC'

      SAVE            RESFIL
      SAVE            TODEGS
      SAVE            TORADS

      DATA            RESFIL  / 'RESULTS.DAT' /
      DATA            TODEGS  / .TRUE. /
      DATA            TORADS  / .FALSE. /

 2000 FORMAT ( A )
 4000 FORMAT ( / ' The trim condition is not satisfied after' , I3.2
     &         , ' rotor'
     &         / ' revolutions.  Shall we continue? (=Y,N) > ' )
 4100 FORMAT ( '&  The trim condition was not satisfied.' )
 4200 FORMAT ( / ' Trim test #' , I2.2 , ' completed.' )
 4300 FORMAT ( '&  The trim condition was satisfied.' )
 6000 FORMAT ( / ' Do you want to do another run with this data? (Y,=N)'
     &         , ' > ' )



C       Compute the values of the four coordinate shape functions for
C       for each of the NPTS blade stations along the blade.

      CALL SHAPES ( NPTS )
```

```
C       The main run loop begins here.  The interactive program se-
C       quence starts.

  100 CONTINUE


C
C       Clear NCALLS which represents the number of calls to LOOOUT.
C       It is used to control printing of the title page.  It is
C       incremented in LODOUT just before returning.

      NCALLS = 0


C       Set up a run by first calling the SETUP and LIMITS routines.
C       Temporarily convert the units of the 'free' variables to de-
C       grees and RPM for interactive use.

      CALL CONVRT ( TODEGS )
      CALL SETUP
      CALL LIMITS
      CALL CONVRT ( TORADS )


C       Before starting the model run, check for potential error in the
C       yaw function.  A value of zero for PHIAMP in a yaw solution
C       will cause the program to abort.

      IF ( ( NYAW .GT. 0 ) .AND. ( PHIAMP .EQ. 0.0 ) )  THEN

         PRINT *, ' '
         PRINT *, 'Error in input data.  PHIAMP cannot be zero'
         PRINT *, 'for a yaw solution.  Please review the setup'
         PRINT *, 'and limits values.'

         GO TO 600

      END IF


C       On the first pass through the RUN routine, invert the mass
C       coefficient matrix and premultiply all the coefficient ma-
C       trices by the result.  The is done just once per data set.

      IF ( NEWSET )  THEN

         CALL SOLVE
         NEWSET = .FALSE.

      END IF

  200 PRINT   *,  ' '
      PRINT   *,  'Are you ready to run the model? (=Y,N) > '
      READ 2000,  ANS

      IF ( ( ANS .EQ. 'N' )  .OR. ( ANS .EQ. 'n' ) )  RETURN

      IF ( ( ANS .NE. 'Y' ) .AND. ( ANS .NE. 'y' )
```

```
     &                    .AND. ( ANS .NE. ' ' ) )  THEN

         PRINT *, '  >>>  Invalid response.  Please try again.  <<<'
         GO TO 200

       END IF


C        Open the file that is to contain the results.

       CALL GETFIL ( RESFIL )


C        Zero the blade deflection, velocity and acceleration for the
C        start of the trim solution run.

       DO 320 NSHP=1,NSHAPS
          DO 310 I=0,2
             DO 300 J=0,360

                SNEW(NSHP,I,J) = 0.0
                SOLD(NSHP,J)   = 0.0

  300        CONTINUE
  310     CONTINUE
  320  CONTINUE


C        Start the trim run.  When the ITRIM flag is set to 2, the first
C        pass through DSKREV will also execute the STRTUP startup rou-
C        tine.  STRTUP computes the static deflection of the blade at
C        the 270 degree azimuth position, under the given wind condi-
C        tions.  This static deflection is used to start the actual mo-
C        del run, and helps to assure rapid convergence to the trim so-
C        lution  by removing many of the startup transients  associated
C        with beginning execution without a realistic initial blade tip
C        deflection.

       ITRIM     = 2
       PSI(1)    = 270/RAD2DG
       DELPSI(1) = STEPMN
       ERROR     = 0.0

       CALL DSKREV ( NPTS )

       ITRIM = 1


C         Iterate for the trim solution.  Keep count of the rotor re-
C         volutions and give the user a chance to bail out every ten
C         revolutions.

       ITCNT = 0

  400  IF ( ITRIM .EQ. 1 )  THEN

          IF ( ITCNT .NE. 0 )  THEN

             IF ( MOD( ITCNT , 10 ) .EQ. 0 )  THEN
```

```
            PRINT 4000,  ITCNT
            READ  2000,  ANS

            IF ( ( ANS .EQ. 'N' ) .OR. ( ANS .EQ. 'n' ) )  THEN

               PRINT *,  ' '
               PRINT *,  'FLAP terminated by user.'
               PRINT *,  ' '

               STOP

            END IF

         ELSE

            PRINT 4100

         END IF

      END IF


C        Initialize the azimuth angle and run another revolution.
C        Test the last set of solutions against this set for stabil-
C        ity.  When TRMTST is satisfied, ITRIM will be set to zero
C        the loop will be terminated.

      PSI(1) = 0.0

      CALL DSKREV ( NPTS )

      ITCNT = ITCNT + 1

      CALL TRMTST ( ITRIM )

      PRINT 4200,  ITCNT

      GO TO 400

   END IF


C     Trim solution completed.

   PRINT 4300


C     Calculate results of the trim solution.

   CALL LODOUT ( NCALLS )


C     Initialize the yaw run loop by starting time at zero.  Run yaw
C     solution NYAW times.  Calculate the loads and print out the
C     results after each disk revolution.

   IF ( NYAW .GT. 0 )  THEN

      TIME(1) = 0.0
```

```
         DO 500 I=1,NYAW

            PSI(1) = 0.0

            CALL DSKREV ( NPTS )
            CALL LODOUT ( NCALLS )

  500    CONTINUE

      END IF


C        Run complete.

  600 PRINT 6000
      READ  2000,  ANS

      IF ( ( ANS .EQ. 'Y' ) .OR. ( ANS .EQ. 'y' ) )  THEN

         PRINT *,  ' '
         PRINT *,  'You must not change the number of shapes, NSHAPS!!!'
         PRINT *,  ' '

         GO TO 100

      ELSE IF ( ( ANS .NE. 'N' ) .AND. ( ANS .NE. 'n' )
     &                           .AND. ( ANS .NE. ' ' ) )  THEN

         PRINT *, ' >>>  Invalid response.  Please try again.  <<<'

         GO TO 600

      END IF


C        Set the HAVRUN flag to true to enable diagnostic runs.

      HAVRUN = .TRUE.


      RETURN
      END
      SUBROUTINE SAVE1 ( IPSIST ,  NSHAPS , STEMP )


C        ************************************************************
C        *                                                          *
C        *   Subroutine SAVE1 makes a permanent copy of the tip dis-*
C        *   placement variables at each  STEPMX  station around the*
C        *   rotor disk.  These values are used by the loads routine*
C        *   to calculate  the blade loads  based upon  the tip dis-*
C        *   placements.  Only the values corresponding to the spec-*
C        *   ified number of shape functions are saved.             *
C        *                                                          *
C        ************************************************************

C        ************************************************************
C        *                                                          *
C        *   External references in this routine:                   *
C        *                                                          *
```

```
C       *      none                                                    *
C       *                                                              *
C       ****************************************************************

C       ****************************************************************
C       *                                                              *
C       *   Named COMMON blocks used in this routine:                  *
C       *                                                              *
C       *      CONST  - Turbine and other constants used in load       *
C       *               calculations.                                  *
C       *      LIMITC - Holds values used in the LIMITS routine.       *
C       *      POSITN - Holds parameters related to blade position     *
C       *               such as PHI, PSI, etc.                         *
C       *      SARAYS - Holds new and old values for the general-      *
C       *               ized coordinates.                              *
C       *                                                              *
C       ****************************************************************

C       ****************************************************************
C       *                                                              *
C       *   Local and dummy variables used in this routine:            *
C       *                                                              *
C       *      IPSIST - The next STEPMX station in integer degrees.    *
C       *      NEW    - Array index for new data.                      *
C       *      NSHAPS - Number of blade shape functions, 4 maximum.    *
C       *      NSHP   - Counter on DO loops for the coordinate         *
C       *               shape function.                                *
C       *      STEMP  - Temporary array holding the tip displace-      *
C       *               ment values.  The third dimension repre-       *
C       *               sents the order of the time derivative.        *
C       *                                                              *
C       ****************************************************************

      REAL            STEMP  (4,0:1,0:2)

      INTEGER         IPSIST
      INTEGER         NEW
      INTEGER         NSHAPS
      INTEGER         NSHP

      INCLUDE        'C:INCLUDE\CONST2.INC'

      INCLUDE        'C:INCLUDE\LIMITC.INC'

      INCLUDE        'C:INCLUDE\POSITN.INC'

      INCLUDE        'C:INCLUDE\SARAYS.INC'

      SAVE            NEW

      DATA            NEW     / 1 /



C       Move the values stored in STEMP into SNEW.

      DO 10 NSHP=1,NSHAPS

         SNEW(NSHP,0,IPSIST) = STEMP(NSHP,NEW,0)
```

```
            SNEW(NSHP,1,IPSIST) = STEMP(NSHP,NEW,1)
            SNEW(NSHP,2,IPSIST) = STEMP(NSHP,NEW,2)

         10 CONTINUE


C           Set the STEPMX station pointer, IPSIST, for the next STEPMX
C           location on the rotor disk.

           IPSIST = IPSIST + STEPMX*RAD2DG + 0.001


           RETURN
           END
           SUBROUTINE SETUP


C          ****************************************************************
C          *                                                              *
C          *   Subroutine SETUP allows the user to interactively          *
C          *   change the 'free' variables of FLAP.  The 'free' vari-     *
C          *   ables are those that do not affect the computation of      *
C          *   the coefficient matrices or property arrays and which      *
C          *   are not specifically machine dependent.                    *
C          *                                                              *
C          ****************************************************************

C          ****************************************************************
C          *                                                              *
C          *   External references in this routine:                       *
C          *                                                              *
C          *      none                                                    *
C          *                                                              *
C          ****************************************************************

C          ****************************************************************
C          *                                                              *
C          *   Named COMMON blocks used in this routine:                  *
C          *                                                              *
C          *      BLADE  - Holds blade property values such as stiff-     *
C          *               ness and mass distributions.                   *
C          *      CONST    Turbine and other constants used in load       *
C          *               calculations.                                  *
C          *      LITERL - Holds data set titles.                         *
C          *      TURBN  - Holds turbine parameters such as number of     *
C          *               blades, rotor speed, etc.                      *
C          *      WIND   - Holds wind shear and tower shadow parame-      *
C          *               ters.                                          *
C          *                                                              *
C          ****************************************************************

C          ****************************************************************
C          *                                                              *
C          *   Local and dummy variables used in this routine:            *
C          *                                                              *
C          *      ANS    - Used to store responses to questions.         *
C          *      ICASE  - Number of variable to be changed.             *
C          *                                                              *
C          ****************************************************************
```

```
      INTEGER          ICASE

      CHARACTER*1      ANS

      INCLUDE         'C:INCLUDE\BLADE2.INC'

      INCLUDE         'C:INCLUDE\CONST2.INC'

      INCLUDE         'C:INCLUDE\LITERL.INC'

      INCLUDE         'C:INCLUDE\TRBINF.INC'

      INCLUDE         'C:INCLUDE\TURBN.INC'

      INCLUDE         'C:INCLUDE\WIND2.INC'

 1000 FORMAT ( / ' Current values for the ''free'' variables:'
     &        // '  1  ALENTH = ' , F10.4 , ' feet       '
     &           ' 12  PHIAMP = ' , F10.4 , ' degrees'
     &         / '  2  ALPHAO = ' , F10.4 , ' degrees    '
     &           ' 13  PHIOMG = ' , F10.4 , ' degrees/sec'
     &         / '  3  BETAO  = ' , F10.4 , ' degrees    '
     &           ' 14  PSISHD = ' , F10.4 , ' degrees'
     &         / '  4  CHI    = ' , F10.4 , ' degrees    '
     &           ' 15  PSIZER = ' , F10.4 , ' degrees'
     &         / '  5  GRAV   = ' , F10.4 , ' feet/sec^2 '
     &           ' 16  RHOAIR = ' , F10.4 , ' Slugs/feet^3'
     &         / '  6  HUBHT  = ' , F10.4 , ' feet       '
     &           ' 17  SHERXP = ' , F10.4
     &         / '  7  KSHADW = ' , I10   , 12X
     &           ' 18  THETAP = ' , F10.4 , ' degrees'
     &         / '  8  NBLADS = ' , I10   , 12X
     &           ' 19  THETAT = ' , F10.4 , ' degrees'
     &         / '  9  NSHAPS = ' , I10   , 12X
     &           ' 20  TSUBO  = ' , F10.4
     &         / ' 10  OMEGA  = ' , F10.4 , ' RPM        '
     &           ' 21  TSUBP  = ' , F10.4
     &         / ' 11  PHIO   = ' , F10.4 , ' degrees    '
     &           ' 22  VHUB   = ' , F10.4 , ' feet/second'
     &         / ' 23  TIMINC = ' , F10.6 , ' seconds    '
     &           ' 24  NUMSCN = ' , I10)
 2000 FORMAT ( A )


C        Print the values of the free variables.

  100 PRINT 1000,  ALENTH , PHIAMP
     &           ,  ALPHAO , PHIOMG
     &           ,  BETAO  , PSISHD
     &           ,  CHI    , PSIZER
     &           ,  GRAV   , RHOAIR
     &           ,  HUBHT  , SHERXP
     &           ,  KSHADW , THETAP
     &           ,  NBLADS , THETAT
     &           ,  NSHAPS , TSUBO
     &           ,  OMEGA  , TSUBP
     &           ,  PHIO   , VHUB
     &           ,  TIMINC , NUMSCN
```

```
C       Allow user to change values of the 'free' variables.  Display
C       values of all variables after each change.

  200 PRINT    *,  'Would you like to change any values? (Y,=N) > '
      READ  2000,  ANS

      IF ( ( ANS .EQ. 'Y' ) .OR. ( ANS .EQ. 'y' ) )  THEN

  210 PRINT *,  'Enter the number of the variable you would like'
      PRINT *,  'to change (1-24) > '
      READ  *,  ICASE

      GO TO (300,302,305,310,315,320,325,330,335,340,345
     &      ,350,355,360,365,370,375,380,385,390,392,395
     &      , 403, 404) ICASE

      PRINT *,  '  >>>  Invalid response.  Please try again.  <<<'
      PRINT *,  ' '

      GO TO 210

  300 PRINT *,  'Enter new REAL value for ALENTH > '
      READ  *,  ALENTH
      GO TO 100

  302 PRINT *,  'Enter new REAL value for ALPHA0 > '
      READ  *,  ALPHA0
      GO TO 100

  305 PRINT *,  'Enter new REAL value for BETA0 > '
      READ  *,  BETA0
      GO TO 100

  310 PRINT *,  'Enter new REAL value for CHI > '
      READ  *,  CHI
      GO TO 100

  315 PRINT *,  'Enter new REAL value for GRAV > '
      READ  *,  GRAV
      GO TO 100

  320 PRINT *,  'Enter new REAL value for HUBHT > '
      READ  *,  HUBHT
      GO TO 100

  325 PRINT *,  'Enter new INTEGER value for KSHADW > '
      READ  *,  KSHADW
      GO TO 100

  330 PRINT *,  'Enter new INTEGER value for NBLADS > '
      READ  *,  NBLADS
      GO TO 100

  335 PRINT *,  'Enter new INTEGER value for NSHAPS > '
      READ  *,  NSHAPS
      GO TO 100

  340 PRINT *,  'Enter new REAL value for OMEGA > '
      READ  *,  OMEGA
```

```
      GO TO 100

345   PRINT *,  'Enter new REAL value for PHIO > '
      READ  *,  PHIO
      GO TO 100

350   PRINT *,  'Enter new REAL value for PHIAMP > '
      READ  *,  PHIAMP
      GO TO 100

355   PRINT *,  'Enter new REAL value for PHIOMG > '
      READ  *,  PHIOMG
      GO TO 100

360   PRINT *,  'Enter new REAL value for PSISHD > '
      READ  *,  PSISHD
      GO TO 100

365   PRINT *,  'Enter new REAL value for PSIZER > '
      READ  *,  PSIZER
      GO TO 100

370   PRINT *,  'Enter new REAL value for RHOAIR > '
      READ  *,  RHOAIR
      GO TO 100

375   PRINT *,  'Enter new REAL value for SHERXP > '
      READ  *,  SHERXP
      GO TO 100

380   PRINT *,  'Enter new REAL value for THETAP > '
      READ  *,  THETAP
      GO TO 100

385   PRINT *,  'Enter new REAL value for THETAT > '
      READ  *,  THETAT
      GO TO 100

390   PRINT *,  'Enter new REAL value for TSUBO > '
      READ  *,  TSUBO
      GO TO 100

392   PRINT *,  'Enter new REAL value for TSUBP > '
      READ  *,  TSUBP
      GO TO 100

395   PRINT *,  'Enter new REAL value for VHUB > '
      READ  *,  VHUB
      GO TO 100

403   PRINT *,  'Enter new REAL value for TIMINC>'
      READ *, TIMINC
      PRINT *, TIMINC
      GO TO 100

404   PRINT *,  'Enter new REAL value for NUMSCN>'.
      READ *, NUMSCN
      PRINT *, NUMSCN
      GO TO 100
```

```
      ELSE IF ( ( ANS .NE. 'N' ) .AND. ( ANS .NE. 'n' )
     &                           .AND. ( ANS .NE. ' ' ) )  THEN

         PRINT *,     >>>  Invalid response.  Please try again.  <<<'
         PRINT *,  ' '

         GO TO 200

      END IF


C        Compute commonly used constants.

      RR      = BLTIP + HUBRAD
      ABAR    = ALENTH/RR
      RROMGA  = RR*OMEGA*PI/30.0
      CTHP    = COS( THETAP/RAD2DG )
      STHP    = SIN( THETAP/RAD2DG )


      RETURN
      END
      SUBROUTINE SHAPES ( NPTS )


C     ***************************************************************
C     *                                                             *
C     *   Subroutine  SHAPES  computes the values of the four co-   *
C     *   ordinate shape functions at each of the  NPTS  stations   *
C     *   along the blade.  This is done for all four shape func-   *
C     *   tions  regardless  of the  value  specified  in NSHAPS.   *
C     *   This routine is run  only when the program is first in-   *
C     *   itialized and is not run again for any subsequent iter-   *
C     *   ations of the RUN routine.                                *
C     *                                                             *
C     *   These functions are identical  to those included in the   *
C     *   COEFFS routine of Module 1.                               *
C     *                                                             *
C     ***************************************************************

C     ***************************************************************
C     *                                                             *
C     *   External references in this routine:                      *
C     *                                                             *
C     *      none                                                   *
C     *                                                             *
C     ***************************************************************

C     ***************************************************************
C     *                                                             *
C     *   Named COMMON blocks used in this routine:                 *
C     *                                                             *
C     *      BLADE  - Holds blade property values  such as stiff-   *
C     *               ness and mass distributions.                  *
C     *                                                             *
C     ***************************************************************

C     ***************************************************************
C     *                                                             *
C     *   Local and dummy variables used in this routine:           *
```

```
C       *                                                               *
C       *      I      - Generic index.                                  *
C       *      L      - Blade length, BLTIP.                            *
C       *      LSQRD  - Square of blade length.                         *
C       *      NPTS   - Number of points along the blade used to        *
C       *               perform Simpson's integration for calculat-     *
C       *               ing the moments and forces at the blade         *
C       *               root.                                           *
C       *      STEP   - Distance between points along the blade.        *
C       *      X      - Location along the blade.                       *
C       *      X2     - X^2.                                            *
C       *      X3     - X^3.                                            *
C       *      X4     - X^4.                                            *
C       *                                                               *
C       *****************************************************************

      REAL            L
      REAL            LSQRD
      REAL            STEP
      REAL            X
      REAL            X2
      REAL            X3
      REAL            X4
      REAL            POLY(4,21)
      REAL            POLYDT(4,21)
      REAL            POLYDD(4,21)

      INTEGER         I
      INTEGER         NPTS

      INCLUDE        'C:INCLUDE\BLADE2.INC'

      INCLUDE        'C:INCLUDE\SHAPE.INC'

      INCLUDE        'C:INCLUDE\MODAL.INC'

C       Initialize some constants.

      STEP  = 1.0/( NPTS - 1 )
      L     = BLTIP
      LSQRD = BLTIP**2
      X     = -STEP



         DO 20 I = 1, NPTS

            X  = X + STEP
            X2 = X *X
            X3 = X2*X
            X4 = X3*X

            POLY(1,I)    =     X2*((    X -  4.0 )*X +  6.0)/3
            POLY(2,I)    =     X3*((  3*X - 10.0 )*X + 10.0)/3
            POLY(3,I)    =     X4*((  2*X -  6.0 )*X +  5.0)
            POLY(4,I)    =   X*X4*(( 10*X - 28.0 )*X + 21.0)/3
            POLYDT(1,I)  =   4*X *((    X -  3.0 )*X +  3.0)/( 3*L )
            POLYDT(2,I)  =   5*X2*((  3*X -  8.0 )*X +  6.0)/( 3*L )
            POLYDT(3,I)  =   2*X3*((  6*X - 15.0 )*X + 10.0)/L
            POLYDT(4,I)  =   7*X4*(( 10*X - 24.0 )*X + 15.0)/( 3*L )
```

```
          POLYDD(1,I)  =   4   *((    X -  2.0 )*X +  1.0)/LSQRD
          POLYDD(2,I)  =  20*X *((  3*X -  6.0 )*X +  3.0)/( 3*LSQRD )
          POLYDD(3,I)  =  60*X2*((    X -  2.0 )*X +  1.0)/LSQRD
          POLYDD(4,I)  = 140*X3*((    X -  2.0 )*X +  1.0)/LSQRD

 20    CONTINUE

       DO 670 I = 1,4
          DO 660 J = 1,NPTS
             SHAPE(I,0,J) = 0.
             SHAPE(I,1,J) = 0.
             SHAPE(I,2,J) = 0.
660    CONTINUE
670 CONTINUE

       DO 700 I = 1,NPTS
          DO 690 J = 1,4
             DO 680 K = 1,4
                SHAPE(J,0,I) = SHAPE(J,0,I) + LAMDA(K,J)*POLY(K,I)
                SHAPE(J,1,I) = SHAPE(J,1,I) + LAMDA(K,J)*POLYDT(K,I)
                SHAPE(J,2,I) = SHAPE(J,2,I) + LAMDA(K,J)*POLYDD(K,I)
680       CONTINUE
690    CONTINUE
700 CONTINUE

       DO 703 I = 1,4
            TIPDFL = 1.
            DO 701 K = 1,NPTS
               SHAPE(I,0,K) = SHAPE(I,0,K)/TIPDFL
               SHAPE(I,1,K) = SHAPE(I,1,K)/TIPDFL
               SHAPE(I,2,K) = SHAPE(I,2,K)/TIPDFL
701      CONTINUE
703 CONTINUE

       RETURN
       END
       FUNCTION SIMPSN ( LOWLIM , UPLIM , NPTS , FOFX )


C      ***************************************************************
C      *                                                             *
C      *   Function SIMPSN performs a composite Simpson's integra-   *
C      *   tion of a given data set.  This routine is identical to   *
C      *   the SIMPSN routine used by COEFFS in Module 1.            *
C      *                                                             *
C      ***************************************************************

C      ***************************************************************
C      *                                                             *
C      *   External references in this routine:                      *
C      *                                                             *
C      *      none                                                   *
C      *                                                             *
C      ***************************************************************

C      ***************************************************************
C      *                                                             *
C      *   Named COMMON blocks used in this routine:                 *
C      *                                                             *
C      *      none                                                   *
```

```
C       *                                                             *
C       ***************************************************************

C       ***************************************************************
C       *                                                             *
C       *   Local and dummy variables used in this routine:           *
C       *                                                             *
C       *      FOFX   - Array of data points to be integrated.        *
C       *               They are treated as the value of a function   *
C       *               evaluated at a specific point.                *
C       *      H      - Subinterval size.                             *
C       *      I      - Generic index.                                *
C       *      LOWLIM - Lower limit of integration.                   *
C       *      NPTS   - Number of points along the blade used to      *
C       *               perform Simpson's integration for calculat-   *
C       *               ing the moments and forces at the blade       *
C       *               root.                                         *
C       *      SIMPSN - Value of the integral from LOWLIM to UPLIM.   *
C       *      UPLIM  - Upper limit of integration.                   *
C       *                                                             *
C       ***************************************************************

      REAL            FOFX   (21)
      REAL            H
      REAL            LOWLIM
      REAL            SIMPSN
      REAL            UPLIM

      INTEGER         I
      INTEGER         NPTS


C       Compute the subinterval size and initialize the integral.

      H      = ( UPLIM - LOWLIM )/( NPTS - 1 )
      SIMPSN = 0.0


C       Add in the intermediate points.   In the formulation, all even
C       numbered points have coefficient of 4. In this case, the index
C       must be shifted to form the proper coefficient.

      DO 10 I=2,NPTS-1,2
   10 SIMPSN = SIMPSN + 4.0*FOFX(I) + 2.0*FOFX(I+1)

      SIMPSN = SIMPSN + FOFX(1) - FOFX(NPTS)

      SIMPSN = H*SIMPSN/3.0


      RETURN
      END
      SUBROUTINE SOLVE


C       ***************************************************************
C       *                                                             *
C       *   Subroutine SOLVE computes the inverse of coefficient      *
C       *   matrix CMMASS and then premultiplies all the other co-    *
C       *   efficient matrices by the inverse CMMASS matrix. The      *
```

```
C       *   result of multiplying the inverse CMMASS matrix  by the   *
C       *   CMMASS matrix  is printed  on the screen for diagnostic   *
C       *   purposes.  It should be very close to the Identity mat-   *
C       *   rix.                                                      *
C       *                                                             *
C       ***************************************************************

C       ***************************************************************
C       *                                                             *
C       *   External references in this routine:                      *
C       *                                                             *
C       *      INVERT - Provides an interface to the GAUSS routine.   *
C       *      MULT     Premultiplies  the  incoming matrix  by the   *
C       *               inverse CMMASS matrix.                        *
C       *                                                             *
C       ***************************************************************

C       ***************************************************************
C       *                                                             *
C       *   Named COMMON blocks used in this routine:                 *
C       *                                                             *
C       *      INV    - Holds the inverse of the mass matrix.         *
C       *      MATRX1 - Holds stiffness coefficient matrices.         *
C       *      MATRX2 - Holds  other matrices  related to  coriolis   *
C       *               stiffening, gravity, etc.                     *
C       *      TURBN  - Holds turbine parameters  such as number of   *
C       *               blades, rotor speed, etc.                     *
C       *                                                             *
C       ***************************************************************

C       ***************************************************************
C       *                                                             *
C       *   Local and dummy variables used in this routine:           *
C       *                                                             *
C       *      I .    - Generic index.                                *
C       *      J      - Generic index.                                *
C       *      K      - Generic index.                                *
C       *      TEMP   - A temporary storage array  used  for matrix   *
C       *               manipulation.                                 *
C       *                                                             *
C       ***************************************************************

      REAL            TEMP   (4,4)

      INTEGER         I
      INTEGER         J
      INTEGER         K

      INCLUDE        'C:INCLUDE\INV.INC'

      INCLUDE        'C:INCLUDE\MATRX1.INC'

      INCLUDE        'C:INCLUDE\MATRX2.INC'

      INCLUDE        'C:INCLUDE\TURBN.INC'

 4000 FORMAT ( 1X , 4F12.7 / )
```

```
C       Invert the CMMASS matrix.

      CALL INVERT ( CMMASS , AINVRS , NSHAPS )


C       Premultiply the other coefficient matrices by the inverse
C       CMMASS matrix.

      CALL MULT ( CKBEND , NSHAPS , NSHAPS )
      CALL MULT ( CKTOMG , NSHAPS , NSHAPS )
      CALL MULT ( CKTGRV , NSHAPS , NSHAPS )
      CALL MULT ( CKQLOD , NSHAPS , NSHAPS )


C       The coefficient matrix CKTCRL must be separated into individual
C       2-dimensional matrices for multiplication by the inverse CMMASS
C       matrix.  Then the individual matrices are recombined into the
C       original 3-dimensional form.

      DO 140 I=1,NSHAPS

         DO 110 J=1,NSHAPS

            DO 100 K=J,NSHAPS

               TEMP(J,K) = CKTCRL(I,J,K)
               TEMP(K,J) = CKTCRL(I,K,J)

  100       CONTINUE

  110    CONTINUE

         CALL MULT ( TEMP , NSHAPS , NSHAPS )

         DO 130 J=1,NSHAPS

            DO 120 K=J,NSHAPS

               CKTCRL(I,J,K) = TEMP(J,K)
               CKTCRL(I,K,J) = TEMP(K,J)

  120       CONTINUE

  130    CONTINUE

  140 CONTINUE


C       Load three of the 1-dimensional matrices into a single matrix
C       of order 4 by 3 and premultiply it by the inverse CMMASS ma-
C       trix.  Then move the resulting columns back into the original
C       vectors.

      DO 200 J=1,NSHAPS

         TEMP(J,1) = CMRIGD(J)
         TEMP(J,2) = CMBLNC(J)
         TEMP(J,3) = CMGRAV(J)

  200 CONTINUE
```

```
      CALL MULT ( TEMP , NSHAPS , 3 )

      DO 210 J=1,NSHAPS

         CMRIGD(J) = TEMP(J,1)
         CMBLNC(J) = TEMP(J,2)
         CMGRAV(J) = TEMP(J,3)

  210 CONTINUE


C        Premultiply the CMMASS matrix by its inverse and save for diag-
C        nostic purposes.  Print out the result.

      CALL MULT ( CMMASS , NSHAPS , NSHAPS )

      PRINT *,  ' '
      PRINT *,  'Product of CMMASS premultiplied by its inverse:'
      PRINT *,  ' '

      DO 400 I=1,NSHAPS
  400 PRINT 4000,  ( CMMASS(I,J) , J=1,NSHAPS )


C        CMMASS is replaced by its inverse for use in the RUN routine
         in computing the sclution for the aerodynamic forces.

      DO 500 I=1,NSHAPS

         DO 510 J=1,NSHAPS
  510    CMMASS(I,J) = AINVRS(I,J)

  500 CONTINUE


      RETURN
      END
      SUBROUTINE STRTUP ( STEMP , NPTS )


C        ***************************************************************
C        *                                                             *
C        *   Subroutine STRTUP computes the static deflection of the   *
C        *   blade at the startup position (Psi=270).  This is then    *
C        *   used to compute further values based on an initial de-    *
C        *   flection.  The initial static deflection is computed      *
C        *   based on the blade azimuth and the static (instantane-    *
C        *   ous) aerodynamic loads on the blade.                      *
C        *                                                             *
C        ***************************************************************

C        ***************************************************************
C        *                                                             *
C        *   External references in this routine:                      *
C        *                                                             *
C        *      AFORCE - Calculates the value of the aerodynamic       *
C        *               force integral.                               *
C        *      FORM1  - Calculates the values of the blade dis-       *
C        *               placement function.                           *
```

```
C       *      INVERT - Provides an interface to the GAUSS routine.   *
C       *      NXTPHI - Calculates the next values of the yaw vari-   *
C       *               ables.                                        *
C       *                                                             *
C       ***************************************************************

C       ***************************************************************
C       *                                                             *
C       *   Named COMMON blocks used in this routine:                 *
C       *                                                             *
C       *      AIRFRC - Holds  values used in  aerodynamic calcula-   *
C       *               tions.                                        *
C       *      CONST  - Turbine  and  other constants  used in load   *
C       *               calculations.                                 *
C       *      MATRX1 - Holds stiffness coefficient matrices.         *
C       *      MATRX2 - Holds  other matrices  related to  coriolis   *
C       *               stiffening, gravity, etc.                     *
C       *      POSITN - Holds parameters  related to blade position   *
C       *               such as PHI, PSI, etc.                        *
C       *      SARAYS - Holds  new and old  values for the general-   *
C       *               ized coordinates.                             *
C       *      START  - Holds initial blade deflection.               *
C       *      TURBN  - Holds turbine parameters  such as number of   *
C       *               blades, rotor speed, etc.                     *
C       *                                                             *
C       ***************************************************************

C       ***************************************************************
C       *                                                             *
C       *   Local and dummy variables used in this routine:           *
C       *                                                             *
C       *      BLDANG - Blade azimuth position  used in the teeter-   *
C       *               ing rotor option.                             *
C       *      FSTAR  - Complicated term.                             *
C       *      I      - Generic index.                                *
C       *      IDENT  - The identity matrix.                          *
C       *      K      - Generic index.                                *
C       *      KINVRS - Inverse of KSTAR matrix.                      *
C       *      KSTAR  - Complicated term.                             *
C       *      L      - Generic index.                                *
C       *      M      - Generic index.                                *
C       *      NPTS   - Number  of  points  along the blade used to   *
C       *               perform Simpson's integration for calculat-   *
C       *               ing the  moments  and  forces  at the blade   *
C       *               root.  (passed from FLAP1)                    *
C       *      OMGSQR - Omega^2.                                      *
C       *      STEMP  - Temporary array  holding  the tip displace-   *
C       *               ment  values.  The third dimension repre-     *
C       *               sents the order of the time derivative.       *
C       *      TIMNOW - Current time.                                 *
C       *                                                             *
C       ***************************************************************

      REAL            BLDANG
      REAL            FSTAR  (4)
      REAL            IDENT  (4,4)
      REAL            KINVRS (4,4)
      REAL            KSTAR  (4,4)
      REAL            OMGSQR
      REAL            STEMP  (4,0:1,0:2)
```

```
      REAL            TIMNOW

      INTEGER         I
      INTEGER         K
      INTEGER         L
      INTEGER         M
      INTEGER         NPTS

      INCLUDE        'C:INCLUDE\AIRFRC.INC'

      INCLUDE        'C:INCLUDE\CONST2.INC'

      INCLUDE        'C:INCLUDE\MATRX1.INC'

      INCLUDE        'C:INCLUDE\MATRX2.INC'

      INCLUDE        'C:INCLUDE\POSITN.INC'

      INCLUDE        'C:INCLUDE\SARAYS.INC'

      INCLUDE        'C:INCLUDE\START.INC'

      INCLUDE        'C:INCLUDE\TURBN.INC'


C        Initialize some arrays.

      DO 120 M=1,NSHAPS

         DO 100 I=0,2

            STEMP(M,0,I) = 0.0
            STEMP(M,1,I) = 0.0

  100    CONTINUE

         DO 110 K=1,NSHAPS
  110    IDENT(M,K) = 0.0

         IDENT(M,M) = 1.0

  120 CONTINUE


         Compute the FAERO values for use in calculating the FSTAR
         values.  These are actually FAERO multiplied by the inverse
         CMMASS matrix.

      TIMNOW = TIME(1)

      CALL NXTPHI ( TIMNOW )


         BLDANG = PSI(1)

         CALL FORM1  ( STEMP , NPTS   , NSHAPS )
         CALL AFORCE ( NPTS  , BLDANG )
```

```
         BLDANG = PSI(1)

         CALL FORM1  ( STEMP , NPTS   , NSHAPS )
         CALL AFORCE ( NPTS  , BLDANG )


C        Compute the FSTAR values.

       OMGSQR = OMEGA**2


         DO 310 M=1,NSHAPS

            FSTAR(M) = FAERO(M) - OMGSQR*BETAO*CTHP*CMRIGD(M)
     &               + OMGSQR*STHP*CTHP*CMBLNC(M)
     &               - GRAV*( CHI*CTHP + STHP )*CMGRAV(M)

  310    CONTINUE


C        Compute the KSTAR values.

       DO 410 M=1,NSHAPS

         DO 400 K=1,NSHAPS
  400    KSTAR(M,K) = CKBEND(M,K)
     &             + OMGSQR*( CKTOMG(M,K) - STHP*STHP*CKQLOD(M,K)
     &                      - STHP*STHP*IDENT(M,K) )

  410 CONTINUE


C         Invert the KSTAR matrix.

       CALL INVERT ( KSTAR , KINVRS , NSHAPS )


C        Compute S(K) = S(L) = ( KSTAR - INVERSE(L,M) )*FSTAR(M).

       DO 510 L=1,NSHAPS

         SO(L) = 0.0

         DO 500 M=1,NSHAPS
  500    SO(L) = SO(L) + KINVRS(L,M)*FSTAR(M)

  510 CONTINUE



C        Load the resulting static deflection values into the appropriate
C        tip data array and set all other values to zero.

       DO 610 K=1,NSHAPS

         DO 600 I=0,1

            STEMP(K,I,0) = SO(K)
            STEMP(K,I,1) = 0.0
            STEMP(K,I,2) = 0.0
```

```
600    CONTINUE

610 CONTINUE

    RETURN
    END
    SUBROUTINE TRACE ( STEMP , NPTS )

      ****************************************************************
      *                                                              *
      *   Subroutine TRACE prints out the values of certain vari-    *
      *   ables at each printout interval around the disk.  The      *
      *   printout includes the current values of DELPSI, the        *
      *   blade tip acceleration, velocity and deflection, the       *
      *   error value and the values of the relative fluid veloc-    *
      *   ity in the edgewise and flapwise directions. This is       *
      *   done for each STEPMX station and is part of the diag-      *
      *   nostic features of the code.  It is controlled by the      *
      *   TRACEF flag set in the subroutine LIMITS.                  *
      *                                                              *
      ****************************************************************

      ****************************************************************
      *                                                              *
      *   External references in this routine:                       *
      *                                                              *
      *      none                                                    *
      *                                                              *
      ****************************************************************

      ****************************************************************
      *                                                              *
      *   Named COMMON blocks used in this routine:                  *
      *                                                              *
      *      AIRFRC - Holds values used in aerodynamic calcula-      *
      *               tions.                                         *
      *      CONST    Turbine and other constants used in load      *
      *               calculations.                                  *
      *      POSITN - Holds parameters related to blade position     *
      *               such as PHI, PSI, etc.                         *
      *      TURBN  - Holds turbine parameters such as number of     *
      *               blades, rotor speed, etc.                      *
      *      VREL1  - Holds blade section velocity components.       *
      *                                                              *
      ****************************************************************

      ****************************************************************
      *                                                              *
      *   Local and dummy variables used in this routine:            *
      *                                                              *
      *      JCALLS - Print counter.                                 *
      *      K      - Generic index.                                 *
      *      NEW    - Array index for new data.                      *
      *      NPTS   - Number of points along the blade used to       *
      *               perform Simpson's integration for calculat-    *
      *               ing the moments and forces at the blade        *
      *               root.  (passed from FLAP1)                     *
```

```
C       *      STEMP  - Temporary array  holding  the tip displace-   *
C       *               ment  values.   The third dimension  repre-   *
C       *               sents the order of the time derivative.       *
C       *      X      - Psi in degrees.                               *
C       *      XX     - DeltaPsi in degrees.                          *
C       *                                                             *
C       ***************************************************************

      REAL            STEMP  (4,0:1,0:2)
      REAL            X
      REAL            XX

      INTEGER         JCALLS
      INTEGER         K
      INTEGER         NEW
      INTEGER         NPTS

      INCLUDE        'C:INCLUDE\AIRFRC.INC'

      INCLUDE        'C:INCLUDE\CONST2.INC'

      INCLUDE        'C:INCLUDE\POSITN.INC'

      INCLUDE        'C:INCLUDE\TURBN.INC'

      INCLUDE        'C:INCLUDE\VREL1.INC'

      SAVE            JCALLS
      SAVE            NEW

      DATA            JCALLS  / -1 /
      DATA            NEW     /  1 /

 1000 FORMAT( / '  Psi d-Psi    Accel   Velocity Deflect     Error
     &        , '  FAero  VEta-Tip VZeta-Tip' / )
 1100 FORMAT( F5.0 , F6.2 , 2F10.3 , F8.3 , F11.6 , F10.3 , 2F9.3 )


C       Get Psi and delta-Psi in degrees.

      X  =    PSI(1)*RAD2DG
      XX = DELPSI(1)*RAD2DG


C       JCALLS is used to print column headings every ten lines.

      JCALLS = JCALLS + 1

      IF ( MOD( JCALLS , 10 ) .EQ. 0 )  WRITE (4,1000)

      DO 100 K=1,NSHAPS
  100 WRITE (4,1100)  X , XX , STEMP(K,NEW,2) , STEMP(K,NEW,1)
     &              , STEMP(K,NEW,0) , ERROR , FAERO(K) , VETA(NPTS)
     &              , VZETA(NPTS)


      RETURN
      END
      SUBROUTINE TRMTST ( ITRIM )
```

```
C     ************************************************************
C     *                                                          *
C     *   Subroutine TRMTST compares the results of two consecu- *
C     *   tive rotor revolutions.  The trim error condition is   *
C     *   satisfied if the value of QUANT2 times the trim error  *
C     *   fraction is less than the QUANT1 value.  If any one az-*
C     *   imuth location fails the trim test criterion, control  *
C     *   is returned to the calling routine and another disk    *
C     *   revolution is performed.  If all the STEPMX stations   *
C     *   pass the test, then the trim solution exists and the   *
C     *   loads are computed.                                    *
C     *                                                          *
C     ************************************************************

C     ************************************************************
C     *                                                          *
C     *   External references in this routine:                   *
C     *                                                          *
C     *     none                                                 *
C     *                                                          *
C     ************************************************************

C     ************************************************************
C     *                                                          *
C     *   Named COMMON blocks used in this routine:              *
C     *                                                          *
C     *     CONST  - Turbine and other constants used in load    *
C     *              calculations.                               *
C     *     LIMITC - Holds values used in the LIMITS routine.    *
C     *     SARAYS - Holds new and old values for the general-   *
C     *              ized coordinates.                           *
C     *     START  - Holds initial blade deflection.             *
C     *     TURBN  - Holds turbine parameters such as number of  *
C     *              blades, rotor speed, etc.                   *
C     *                                                          *
C     ************************************************************

C     ************************************************************
C     *                                                          *
C     *   Local and dummy variables used in this routine:        *
C     *                                                          *
C     *     I      - Generic index.                              *
C     *     ISTPMX - STEPMX integerized.                         *
C     *     ITRIM  - Flag that indicates that the trim solution  *
C     *              has been completed when set to 0.           *
C     *     NSHP   - Counter on DO loops for the coordinate      *
C     *              shape function.                             *
C     *     QUANT1 - This contains the sum of the differences    *
C     *              between the blade tip deflections computed  *
C     *              for this rotor revolution and the last rev- *
C     *              olution.  This summation is also over the   *
C     *              coordinate shapes used in this run.         *
C     *     QUANT2 - This contains the sum of the blade tip de-  *
C     *              flections computed by subroutine STRTUP for *
C     *              the static blade deflection of each coordi- *
C     *              nate function used in this run.             *
C     *                                                          *
C     ************************************************************
```

```
      REAL            QUANT1
      REAL            QUANT2

      INTEGER         I
      INTEGER         ISTPMX
      INTEGER         ITRIM
      INTEGER         NSHP

      INCLUDE        'C:INCLUDE\CONST2.INC'

      INCLUDE        'C:INCLUDE\LIMITC.INC'

      INCLUDE        'C:INCLUDE\SARAYS.INC'

      INCLUDE        'C:INCLUDE\START.INC'

      INCLUDE        'C:INCLUDE\TURBN.INC'


C        Integerize the STEPMX interval.

      ISTPMX = RAD2DG*STEPMX + 0.001


C        Compute the sum of the tip deflections that were computed in
C        subroutine STRTUP.

      QUANT2 = 0.0

      DO 100 NSHP=1,NSHAPS
  100 QUANT2 = QUANT2 + SO(NSHP)

      QUANT2 = ABS( QUANT2 )


C        Check each STEPMX station around the disk.

      DO 210 I=ISTPMX,360,ISTPMX

         QUANT1 = 0.0


C           Compute the sum of the differences between tip deflections
C           for this rotor revolution and the last.

         DO 200 NSHP=1,NSHAPS
  200    QUANT1 = QUANT1 + SNEW(NSHP,O,I) - SOLD(NSHP,I)


C           Compare the trim error fraction to the current deflection
C           differences.  If any station fails the test, return for
C           another revolution.

          IF( ABS( QUANT1 ) .GT. ( 0.01*QUANT2*TRMERR ) )  RETURN

  210 CONTINUE
```

```
C       All stations satisfied the trim error criterion.  The trim solution
C       is now complete.  Set the ITRIM flag to zero to signal it.  Loads
C       can now be computed and the yaw run started.

      ITRIM = 0


      RETURN
      END
      FUNCTION TRPZOD ( LOWLIM , BLTIP , FOF , NPTS )


C     ***************************************************************
C     *                                                             *
C     *   Function TRPZOD performs composite trapezoidal integra-   *
C     *   tion on a set of data points transmitted from the         *
C     *   calling routine.  For derivation of the formula and       *
C     *   limitations, see Carnahan, p. 78 (see full reference in   *
C     *   comments for function SIMPSN).  For computational effi-   *
C     *   ciency,  the interval width is not used in the formula-   *
C     *   tion until the end when it is multiplied by the sum.      *
C     *                                                             *
C     *   This function is similar to function  TRAP  in Module 1   *
C     *   of the FLAP code.                                         *
C     *                                                             *
C     ***************************************************************

C     ***************************************************************
C     *                                                             *
C     *   External references in this routine:                      *
C     *                                                             *
C     *      none                                                   *
C     *                                                             *
C     ***************************************************************

C     ***************************************************************
C     *                                                             *
C     *   Named COMMON blocks used in this routine:                 *
C     *                                                             *
C     *      none                                                   *
C     *                                                             *
C     ***************************************************************

C     ***************************************************************
C     *                                                             *
C     *   Local and dummy variables used in this routine:           *
C     *                                                             *
C     *      BLTIP  - Blade length.  All integrations using this    *
C     *               function are performed from the lower limit   *
C     *               indexed by LOWLIM to the upper limit BLTIP.   *
C     *      FOF    - Array of data points to be integrated. They   *
C     *               are treated  by this function  as the value   *
C     *               of a function evaluated at specific points.   *
C     *      H      - Subinterval length given by H=(B-A)/N.        *
C     *      I      - Index into the FOF array.                     *
C     *      LOWLIM - Index of the lower integration limit.  The    *
C     *               blade position indexed by  LOWLIM  is given   *
C     *               by BLTIP*(LOWLIM-1)/(NPTS-1).                 *
C     *      NPTS   - Number  of  points  along the blade used to   *
C     *               perform Simpson's integration for calculat-   *
```

```
C       *              ing the  moments  and  forces  at the blade   *
C       *              root.  (passed from FLAP1)                    *
C       *      TRPZOD - Value of the integral from the  blade posi-  *
C       *              tion indexed by LOWLIM to BLTIP.              *
C       *                                                            *
C       ************************************************************

      REAL            BLTIP
      REAL            FOF    (201)
      REAL            H
      REAL            TRPZOD

      INTEGER         I
      INTEGER         LOWLIM
      INTEGER         NPTS



C       Check to see if the lower and upper limits of integration are
C       the same.  If so, the integral is zero.

      IF ( LOWLIM .EQ. NPTS )  THEN

         TRPZOD = 0.0
         RETURN

      END IF


C       Compute the distance between data points.

      H = BLTIP/( NPTS - 1 )


C       Initialize integral to the contribution of the end points.

      TRPZOD = 0.5*( FOF(LOWLIM) + FOF(NPTS) )


C       If there are only two data points, then we are done.

      IF ( LOWLIM+1 .EQ. NPTS )  GO TO 20


C       Add in the contribution of the intermediate points.

      DO 10 I=LOWLIM+1,NPTS-1
   10 TRPZOD = TRPZOD + FOF(I)


C       Multiply by the interval width and return.

   20 TRPZOD = H*TRPZOD


      RETURN
      END
      SUBROUTINE VREL ( INBORD , NPTS , BLDANG )
```

```
C     ****************************************************************
C     *                                                              *
C     *  Subroutine  VREL  computes the relative velocity compo-     *
C     *  nents for each of the blade stations.  These values are     *
C     *  needed to compute the aerodynamic forces.                   *
C     *                                                              *
C     ****************************************************************

C     ****************************************************************
C     *                                                              *
C     *  External references in this routine:                        *
C     *                                                              *
C     *     INDUCD - Calculates the induced velocities along the     *
C     *              blade.                                          *
C     *     WINDVL - Computes wind velocity components.              *
C     *                                                              *
C     ****************************************************************

C     ****************************************************************
C     *                                                              *
C     *  Named COMMON blocks used in this routine:                   *
C     *                                                              *
C     *     BLADE  - Holds blade property values  such as stiff-     *
C     *              ness and mass distributions.                    *
C     *     CONST    Turbine  and  other constants  used in load     *
C     *              calculations.                                   *
C     *     DELTV  - Holds  turbine inputs  for possible  future     *
C     *              use.  Not currently used.                       *
C     *     FORMS  - Holds blade deflections.                        *
C     *     POSITN - Holds parameters  related to blade position     *
C     *              such as PHI, PSI, etc.                          *
C     *     TURBN  - Holds turbine parameters  such as number of     *
C     *              blades, rotor speed, etc.                       *
C     *     VINDUC - Holds induced velocity components.              *
C     *     VREL1  - Holds blade section velocity components.        *
C     *     WNDVEL - Holds values  used in wind shear  and tower     *
C     *              shadow computations.                            *
C     *                                                              *
C     ****************************************************************

C     ****************************************************************
C     *                                                              *
C     *  Local and dummy variables used in this routine:             *
C     *                                                              *
C     *     BLDANG - Blade azimuth position.                         *
C     *     CPSI   - Cosine of the blade angle.                      *
C     *     I      - Generic index.                                  *
C     *     INBORD - The number  of blade stations  that are not     *
C     *              on the airfoil section.  INBORD is used in      *
C     *              other  routines  to  differentiate  between     *
C     *              sections of the blade  with and without  an     *
C     *              airfoil section.                                *
C     *     NPTS     Number  of  points  along the blade used to     *
C     *              perform Simpson's integration for calculat-     *
C     *              ing the  moments  and  forces  at the blade     *
C     *              root.  (passed from FLAP1)                      *
C     *     PHIDBR - Temporary storage.                              *
C     *     PHIDCT   Temporary storage.                              *
```

```
C       *     PHIDST - Temporary storage.                          *
C       *     QUANT1 - Temporary storage.                          *
C       *     QUANT2 - Temporary storage.                          *
C       *     QUANT3 - Temporary storage.                          *
C       *     QUANT4 - Temporary storage.                          *
C       *     R      - Distance from hub axis.                     *
C       *     ROMEGA - Temporary storage.                          *
C       *     SPSI   - Sine of the blade angle.                    *
C       *     SPSI2  - Temporary storage.                          *
C       *     SPSI3  - Temporary storage.                          *
C       *     STEP   - Distance between points along the blade.    *
C       *     X      - The radial location along the blade (nondi- *
C       *              mensional).                                 *
C       *     Z      - Blade station pointer.  Z goes from zero to *
C       *              the tip.                                    *
C       *                                                          *
C       ************************************************************

      REAL            BLDANG
      REAL            CPSI
      REAL            PHIDBR
      REAL            PHIDCT
      REAL            PHIDST
      REAL            QUANT1
      REAL            QUANT2
      REAL            QUANT3
      REAL            QUANT4
      REAL            R
      REAL            ROMEGA
      REAL            SPSI
      REAL            SPSI2
      REAL            SPSI3
      REAL            STEP
      REAL            X
      REAL            Z

      INTEGER         I
      INTEGER         INBORD
      INTEGER         NPTS

      INCLUDE        'C:INCLUDE\BLADE2.INC'

      INCLUDE        'C:INCLUDE\CONST2.INC'

      INCLUDE        'C:INCLUDE\DELTV.INC'

      INCLUDE        'C:INCLUDE\FORMS.INC'

      INCLUDE        'C:INCLUDE\POSITN.INC'

      INCLUDE        'C:INCLUDE\TURBN.INC'

      INCLUDE        'C:INCLUDE\VINDUC.INC'

      INCLUDE        'C:INCLUDE\VREL1.INC'

      INCLUDE        'C:INCLUDE\WNDVEL.INC'
```

```
C       Compute the wind velocity components and then the induced
C       velocity components.

      CALL WINDVL ( NPTS   , BLDANG )
      CALL INDUCD ( INBORD , NPTS , BLDANG )


C       Set up constants used in this computation.

      CPSI   = COS( BLDANG )
      SPSI   = SIN( BLDANG )
      SPSI2  = -SPSI*STHP
      SPSI3  = -SPSI*CTHP
      PHIDBR = PHI(1)/OMEGA
      PHIDST = PHIDBR*STHP*SPSI
      PHIDCT = PHIDBR*CTHP*SPSI
      ROMEGA = 1.0/RROMGA
      STEP   = BLTIP/( NPTS - 1 )
      Z      = 0.0


C       Compute the velocity components VEta and VZeta.

      DO 100 I=1,NPTS

         R = HUBRAD + Z


C          Clear the velocity components on the nonaerodynamic portion
C          of the blade.

         IF ( I .LT. INBORD )  THEN

            VETA(I)  = 0.0
            VZETA(I) = 0.0

         ELSE

            X       = R/RR
            VETA(I) = -X*CTHP
            VZETA(I)= -X*STHP - VV(1,I)*ROMEGA

            QUANT1  = VINDR(I) + ROMEGA*( VWIND(I) - HUBVEL )
     &                         + ROMEGA*DELTVY(I) - DVIND(I)
            QUANT2  = DELTVX(I)*ROMEGA + PHI(0)*VINDR(I)
            QUANT3  = PHIDBR*( ABAR + BETA0*X )
            QUANT4  = DELTVZ(I)*ROMEGA - CHI*VINDR(I)

            VETA(I)  = VETA(I) - QUANT1*STHP
     &               + CPSI*( CTHP*( QUANT2 + QUANT3 )
     &                     + PHIDBR*VV(0,I)/RR )
     &               + SPSI3*QUANT4 + X*PHIDST
            VZETA(I) = VZETA(I) + QUANT1*CTHP
     &               + CPSI*( (QUANT2 + QUANT3)*STHP )
     &               + SPSI2*QUANT4 + X*PHIDCT


C             Convert the velocity components into dimensional form
C             before returning to the calling routine.  The VEta term
C             is negated to account for the sign convention that pos-
```

```
C              itive velocities are from the leading edge to the trail-
C              ing edge.

            VETA(I)    -VETA(I)*RROMGA
            VZETA(I) = VZETA(I)*RROMGA

         END IF


C           Increment the location along the blade and make another pass.

         Z = Z + STEP

  100 CONTINUE

      RETURN
      END


      SUBROUTINE WINDVL ( NPTS , BLDANG )


C        ***************************************************************
C        *                                                             *
C        *   Subroutine WINDVL computes the wind velocity components   *
C        *   along the blade  for a given time and azimuth position.   *
C        *   Provision  has been made  to include  a  time dependent   *
C        *   function  for the hub velocity,  but none  is  included   *
C        *   now.  Likewise, time dependent functions deltaX, deltaY   *
C        *   and deltaZ can be included in the future in the section   *
C        *   set aside for them here.  They are now set to zero.       *
C        *                                                             *
C        ***************************************************************

C        ***************************************************************
C        *                                                             *
C        *   External references in this routine:                      *
C        *                                                             *
C        *      none                                                   *
C        *                                                             *
C        ***************************************************************

C        ***************************************************************
C        *                                                             *
C        *   Named COMMON blocks used in this routine:                 *
C        *                                                             *
C        *      BLADE  - Holds blade property values  such as stiff-   *
C        *               ness and mass distributions.                  *
C        *      CONST    Turbine  and  other constants  used in load   *
C        *               calculations.                                 *
C        *      DELTV  - Holds  turbine inputs  for possible  future   *
C        *               use.  Not currently used.                     *
C        *      POSITN - Holds parameters  related to blade position   *
C        *               such as PHI, PSI, etc.                        *
C        *      TURBN  - Holds turbine parameters  such as number of   *
C        *               blades, rotor speed, etc.                     *
C        *      WIND   - Holds wind shear  and tower shadow  parame-   *
C        *               ters.                                         *
C        *      WNDVEL - Holds values  used in wind shear  and tower   *
C        *               shadow computations.                          *
```

```
C       *                                                              *
C       ****************************************************************

C       ****************************************************************
C       *                                                              *
C       *   Local and dummy variables used in this routine:            *
C       *                                                              *
C       *      BLDANG - Blade azimuth position  used in the teeter-    *
C       *               ing rotor option.                              *
C       *      HH     - Hub radius divided by its height.             *
C       *      I      - Generic index.                                *
C       *      J      - Generic index.                                *
C       *      NPTS   - Number  of  points  along the blade used to   *
C       *               perform Simpson's integration for calculat-    *
C       *               ing the  moments  and  forces  at the blade    *
C       *               root.                                          *
C       *      P      - Complicated term.                             *
C       *      R      - Location  of  the  current point  along  the  *
C       *               blade.                                         *
C       *      STEP   - Distance between points along the blade.      *
C       *                                                              *
C       ****************************************************************

      REAL             BLDANG
      REAL             HH
      REAL             P
      REAL             R
      REAL             STEP

      INTEGER          I
      INTEGER          J
      INTEGER          NPTS

      INCLUDE         'C:INCLUDE\BLADE2.INC'

      INCLUDE         'C:INCLUDE\CONST2.INC'

      INCLUDE         'C:INCLUDE\DELTV.INC'

      INCLUDE         'C:INCLUDE\POSITN.INC'

      INCLUDE         'C:INCLUDE\TURBN.INC'

      INCLUDE         'C:INCLUDE\WIND2.INC'

      INCLUDE         'C:INCLUDE\WNDVEL.INC'

      INCLUDE         'C:INCLUDE\TRBINF.INC'


C       Compute the wind velocity at the hub.  A time dependent function
C       may be added in the future.

        HUBVEL = VHUB

C       Compute the wind shear components.

      R    = HUBRAD
      STEP = BLTIP/( NPTS - 1 )
```

```
      DO 110 I=1,NPTS

         HH = R/HUBHT

         WSHR(0,I) = 0.25*SHERXP*( SHERXP - 1.0 )*HH**2
         WSHR(1,I) = SHERXP*HH
C        WSHR(2,I) = 0.
         WSHR(2,I) = WSHR(0,I)
         WSHR(3,I) = 0.0
         WSHR(4,I) = 0.0
         WSHR(5,I) = 0.0

         R = R + STEP

         WSHEAR(I) = WSHR(0,I)

         DO 100 J=1,5
  100    WSHEAR(I) = WSHEAR(I) + WSHR(J,I)*COS( J*BLDANG )

  110 CONTINUE


C        Compute tower shadow effects.  When blade #1 is close to 360
C        degrees azimuth, the second blade must know that it is in the
C        tower shadow.

      IF ( ABS( BLDANG - PSISHD ) .LE.  PSIZER  )  THEN

         P      = KSHADW*PI/PSIZER
         TSHADW = TSUBO + TSUBP*COS( P*( BLDANG - PSISHD ) )

      ELSE IF ( ABS( BLDANG - PSISHD - 2*PI ) .LE. PSIZER )  THEN

         P      = KSHADW*PI/PSIZER
         TSHADW = TSUBO + TSUBP*COS( P*( BLDANG - PSISHD - 2*PI ) )

      ELSE

         TSHADW = 0.0

      END IF

         DO 200 I=1,NPTS
  200      VWIND(I) = HUBVEL*( 1.0 + WSHEAR(I) - TSHADW )



C     ********************************************************************
C     *                                                                  *
C     *   This place is reserved for future time dependent functions.    *
C     *                                                                  *
C     ********************************************************************


C     Input the time dependent windspeed fluctuations if
C     working on a turbulent analysis: ITURB .EQ. 1

      R = HUBRAD/(HUBRAD+BLTIP)
      STEP = (1.-R)/(NPTS-1)
```

```
C   Flag for deciding if working on a turbulence analysis.

      IF( ITURB  .EQ. 1 ) THEN


C   Linearly interpolate along the blade span
C   using the three values as interpolation points
C   to get windspeed values along the entire 21
C   set of blade points.

           DO 600 I = 1,NPTS

              IF(R .LE. 0.3333333) THEN
                 DELTVY(I)=(VYNOW1(1)-VYNOWH)*3.*R+VYNOWH
              ELSEIF(R .LE. 0.6666666)THEN
                 DELTVY(I)=(VYNOW1(2)-VYNOW1(1))*3.*(R-.3333333)
     &              + VYNOW1(1)
              ELSE
                 DELTVY(I)=(VYNOW1(3)-VYNOW1(2))*3.*(R-.6666666)
     &              + VYNOW1(2)
              ENDIF
              R=R+STEP
  600       CONTINUE


        ENDIF

        RETURN
        END

        SUBROUTINE SERIES(M,N,A,B,NST,IPS,IPR)
        REAL A(0:10,21)
        REAL B(0:10,21)
        REAL FACTOR
        REAL FI

        INTEGER IPS(360)
        INTEGER M
        INTEGER N
        INTEGER NST
        INTEGER IPR

        INCLUDE        'C:INCLUDE\RESLTS.INC'

        FACTOR = FLOAT(IPR)/180.

        DO 100 I = 0,N

           FI = FLOAT(I)

           DO 80 J = 1,21

             SUMA2 = 0.
             SUMB2 = 0.

             DO 75 IST = 2,NST-1
                PSI = IPS(IST)* .017453293
                SUMA2 = SUMA2 + COS(FI*PSI)*RESLTS(IST,J,M)
                SUMB2 = SUMB2 + SIN(FI*PSI)*RESLTS(IST,J,M)
    75       CONTINUE
```

```
      PSI1 = 0.
      PSIN = 360.0*.017453293

      SUMA = 2.*SUMA2 + COS(FI*PSI1)*RESLTS(1,J,M) +
     &    COS(FI*PSIN)*RESLTS(NST,J,M)

      SUMB = 2.*SUMB2 + SIN(FI*PSI1)*RESLTS(1,J,M) +
     &    SIN(FI*PSIN)*RESLTS(NST,J,M)

      IF( I .EQ. 0) THEN
        A(I,J) = 0.25*FACTOR*SUMA
        B(I,J) = 0.25*FACTOR*SUMB
      ELSE
        A(I,J) = 0.5*FACTOR*SUMA
        B(I,J) = 0.5*FACTOR*SUMB
      ENDIF

   80   CONTINUE
  100 CONTINUE

      RETURN
      END

      SUBROUTINE TRBCLC( NPTS )

C       Subroutine for calculation of turbulence.  We will assume that
C       turbulence is being modeled from rotationally sampled wind data
C       as predicted from the VEERS Wind Simulation model.
C       The file of data must contain 4 columns ( as evidenced in the
C       read statement below.
C       The first column is blade azimuth angle, the second column
C       is the windspeed for blade #1 at the 50% rotor radius station,
C       the third column is the windspeed for blade #1 at the tip,
C       and finally the fifth column is the windspeed at the
C       center of the hub.
C       Before this windspeed data is read in, the user is asked for the
C       name of the file containing the turbulent windspeed data, is asked
C       whether this data is in metric (meters/sec) or english units
C       (ft/s) and is asked for the name of the file to contain the
C       predicted turbulent loads data.  For the structure of this file,
C       see the block of comments near the WRITE statement toward the
C       end of this subroutine.

C       BE SURE TO RUN THE TRIM SOLUTION CORRESPONDING WITH THIS
C       TURBULENCE ANALYSIS WITH A VALUE OF SHERXP EQUAL TO ZERO
C       IF THE VEERS GENERATED WINDSPEED DATA ALREADY HAS THE
C       EFFECTS OF WINDSHEAR.  IF YOU DON'T THEN THE PREDICTIONS
C       WILL HAVE TO MUCH CYCLIC CONTENT, DUE TO TWO TIMES THE
C       DESIRED WINDSHEAR VALUES.

      REAL STEMP  (4, 0:1 , 0:2)
      REAL ANGLE
      REAL AZIDAT
      REAL AZIINC
      REAL AZIOLD
      REAL BLDANG
      REAL DELVY1 (10)
      REAL PSIDIF
      REAL RESLTS (21,9)
```

```
      REAL VY1    (10)
      REAL VYHUB
      REAL VYSAV1 (0:1,10)
      REAL VYSAVH (0:1)

      INTEGER I
      INTEGER J
      INTEGER NEW
      INTEGER NPTS
      INTEGER NSHP
      INTEGER OLD

      CHARACTER *50 WNDFIL
      CHARACTER *50 LODFIL
      CHARACTER * 2 ANS

      INCLUDE       'C:INCLUDE\BLADE2.INC'
      INCLUDE       'C:INCLUDE\LIMITC.INC'
      INCLUDE       'C:INCLUDE\POSITN.INC'
      INCLUDE       'C:INCLUDE\SARAYS.INC'
      INCLUDE       'C:INCLUDE\TURBN.INC '
      INCLUDE       'C:INCLUDE\TRBINF.INC'
      INCLUDE       'C:INCLUDE\CONST2.INC'
      INCLUDE       'C:INCLUDE\DELTV.INC'
      INCLUDE       'C:INCLUDE\WIND2.INC'

      SAVE           NEW
      SAVE           OLD
      SAVE           STEMP


      DATA           NEW   / 1 /
      DATA           OLD   / 0 /

      PRINT *, ' '
      PRINT *, 'Turbulence Analysis Run Set-up'
      PRINT *, ' '

C   Read in the name of the file containing the VEERS generated
C   windspeed data.

      PRINT *, 'Read in the name of the wind residual time series file'
      READ *, WNDFIL
      PRINT *, WNDFIL

C   See if the windspeed data is in metric or english units.

      PRINT *, 'Is the wind data in metric units (meters/sec)?'
      READ *, ANS
      PRINT *, ANS
      PRINT *, ' '

C   Give the name of the file you want to write rotor and blade
C   teeter, loads, shaft-loads, etc. out to.

      PRINT *, 'Read in the name of the file for loads output'
      READ *, LODFIL
      PRINT *, LODFIL

      OPEN (15, FILE = WNDFIL, STATUS = 'UNKNOWN')
```

```
      OPEN (16, FILE = LODFIL, STATUS = 'UNKNOWN')

      NSCN = 1
      AZIDAT = 0.

C     AZIDAT is the azimuth angle read from data,
C     VY1(J) is the windspeed data
C     for blade number 1, and VYHUB is the hubcenter windspeed.
C     Currently MSTAT is limited to 2.  We usually read in windspeed
C     data at the 50% and 100% rotor radius location, for the
C     blade and then the hubcenter windspeed.


C     Set the shear exponent from the trim run to
C     zero, since the file generated from the
C     VEERS model already has the effects of windshear
C     in it.  Failure to do so will result in too much
C     windshear.  Other parameters such as tower shadow
C     inputs are not set to zero unless the user
C     reruns the trim solution with zero values
C     for Tp, T0 - the tower shadow parameters.

C     Initialize values for SHEREXP, PSI(0),
C     AZIOLD, ERROR, DELPSI(1),
C     STEMP, etc.

      SHERXP = 0.
      PSI(0) = 0.
      AZIOLD = -0.0001
      ERROR  = 0.
      DELPSI(1) = STEPMN
      AZIINC = TIMINC*OMEGA


c         set the initial blade deflection, velocity,
c         and acceleration values to what was calculated
c         in the trim solution at zero azimuth angle. This
c         serves to start the solution process.


            DO 260 NSHP = 1, NSHAPS
            DO 250 I    = 0, 2
               STEMP(NSHP,OLD,I)  =  SNEW(NSHP, I , 360)
  250       CONTINUE
  260       CONTINUE

C         Set the left-hand endpoint windspeed value
C         needed in the linear interpolation process
C         equal to VHUB since we have not read in
C         a windspeed data line from the VEERS file yet.
C         The right-hand endpoint value will be the
C         new line of windspeed data read in.
C         These values are necessary in order to have
C         endpoints for interpolation, since the blade
C         azimuth in the numerical integration process
C         will lie between azimuth values read from
C         the data (AZIDAT).  Setting this first left-
C         hand point to VHUB starts the process. I=0
C         stands for the left-hand endpoint value,
C         while I=1 is the right-hand endpoint.
```

```
C         VYSAV1 is for blade 1,
C         and VYSAVH is the hub-center.  J is equal
C         to 1 or 2 depending on whether it's the 50%
C         station or the blade tip.


            DO 300 J = 1,MSTAT
               VYSAV1(0,J) = 0.
  300       CONTINUE
            VYSAVH(0) = 0.

 1000 READ (15,*) AZIDAT, (VY1(J), J=1,MSTAT), VYHUB


      IF (( ANS .EQ. 'Y') .OR. ( ANS .EQ. 'y')) THEN
         DO 220 J = 1,MSTAT
            VY1(J) = 3.28*VY1(J)
  220    CONTINUE
         VYHUB  = 3.28*VYHUB
      ENDIF

C     Convert AZIDAT to radians

      AZIDAT = AZIDAT/RAD2DG

C     Be sure that the windspeed data produced by the VEERS model
C     contains the hubheight or mean windspeed.  If it doesn't then
C     the next 4 lines of code should be commented out.
C     The purpose of the next 4 lines of code is
C     to subtract out the mean windspeed from the data input.

      DO 230 J = 1,MSTAT
         VY1(J) = VY1(J)-VHUB
  230 CONTINUE
      VYHUB  = VYHUB-VHUB

C     We read in one line of windspeed data at a time.
C     We interpolate the windspeed data to get turbulent
C     windspeed fluctuations when the blade azimuth angle
C     lies between successive values in the input file.

C      Set the right-hand endpoint windspeed in the
C      interpolation process equal to the windspeeds
C      just read in.

         DO 350 J = 1, MSTAT
            VYSAV1(1,J) = VY1(J)
  350.   CONTINUE
            VYSAVH(1) = VYHUB

C      If we have passed through 360 degrees
C      then subtract out 360 degrees from
C      PSI.  We are not able to deal with
C      azimuth angles greater than 360 deg.
C      Be sure to convert to radians.

         IF( (AZIDAT - AZIOLD) .LT. 0.) THEN
            PSI(0) = PSI(0) - 360./RAD2DG
            AZIOLD = AZIOLD - 360./RAD2DG
         ENDIF
```

```
C      Find the next azimuth angle in the
C      code numerical solution process ( not
C      the azimuth angle of the next line
C      of wind data. PSI(1) represents
C      this new azimuth angle (radians).
C      PSIDIF represents the difference between
C      this new azimuth location and the last
C      azimuth angle read in from the data.

  400    CALL NXTAZI ( AZIDAT)

         PSIDIF = PSI(1) - AZIOLD

C   Interpolate in order to determine turbulent windspeed
C   data for azimuth angles lying between the previously
C   read in line of data and the new line of data.
C   VYNOW1(J) is interpolated windspeed for blade 1 at
C   this new azimuth angle.  VYNOW2(J) is the interpolated
C   windspeed for blade 2.  VYNOWH is the interpolated
C   hub center windspeed for this azimuth position.
C   These windspeed values are the ones that ultimately
C   get passed into the WINDVL subroutine.
C   The windspeed values for blade radial stations lying
C   between the hub, 50% radial station and blade tip
C   get formed in WINDVL by linear interpolation along
C   the blade span.  If the user wants to read windspeed
C   data at more than
C   these stations then SUBROUTINE WINDVL will have
C   to be changed and more columns of data would have
C   to be read in from the VEERS file.

         DO 450 J = 1, MSTAT
            DELVY1(J) = VYSAV1(1,J) - VYSAV1(0,J)
            VYNOW1(J) = (DELVY1(J)/AZIINC)*PSIDIF + VYSAV1(0,J)
  450    CONTINUE
         DELVYO = VYSAVH(1) - VYSAVH(O)
         VYNOWH = (DELVYO/AZIINC)*PSIDIF + VYSAVH(O)

         CALL EULER ( STEMP, NSHAPS, NPTS)

         IF(( ERROR .GT. EUERR) .AND. ( DELPSI(1) .GT. STEPMN))
     &      GO TO 400


         DO 510 NSHP = 1, NSHAPS
         DO 500 I = 0,2
            STEMP ( NSHP, OLD, I) = STEMP(NSHP, NEW, I)
  500    CONTINUE
  510    CONTINUE

         DELPSI(O) = DELPSI(1)
         DELTAT(O) = DELTAT(1)
         PSI(O)    = PSI(1)

         IF( ABS(PSI(1)-AZIDAT) .GE. 0.1*STEPMN) THEN
             GO TO 400
         ELSE

             ANGLE = AZIDAT*RAD2DG
```

```
 512        IF( ANGLE .LT. 360) GO TO 515
            ANGLE = ANGLE - 360.
            GO TO 512

C    Calculate blade loads and store
C    loads and response results in the
C    array RESLTS


 515        BLDANG = PSI(1)
            CALL LODCLC(BLDANG, STEMP, RESLTS)

C    This is the portion of the subroutine that writes
C    out results to the user designated loads output
C    file.  ANGLE is the azimuth angle, RESLTS(I,J) is the
C    results matrix for blade #1 at the I'th station.
C    J corresponds to the results item to printed out:
C    J=1 to 7.
C    I corresponds to the number of the blade radial
C    station, from 1 to 21, with 1 at the root and
C    21 at the blade tip.
C
C               J=1 BLADE DEFLECTION (FT.)
C               J=2 BLADE SLOPE   (FT./FT.)
C               J=3 BLADE FLAP+TEETER VELOCITY (FT/SEC)
C               J=4 BLADE TENSION (LB.)
C               J=5 BLADE EDGEWISE SHEAR FORCE (LB.)
C               J=6 BLADE FLAPWISE SHEAR FORCE (LB.)
C               J=7 BLADE FLAPWISE MOMENT (FT-LB)
C               J=B BLADE EDGEWISE MOMENT (FT-LB)
C               J=9 BLADE TORSIONAL MOMENT (FT-LB)
C
C
C
C     Here we are printing out azimuth,
C     root flap-bending for blade 1 ,
C     65% span flap-bending for blade 1,
C     This statement will need to be
C     changed by the user to write out items
C     needed.

            WRITE(16,*) ANGLE, RESLTS(1,7),
     &          RESLTS(13,7)


C   Set the left-hand endpoint windspeeds to the right-
C   hand values and read in a new line of windspeed
C   data from the
C   VEERS generated windspeed file, until NSCN is
C   equal to NUMSCN.
C

            DO 520 J = 1,MSTAT
  520         VYSAV1(0,J) = VYSAV1(1,J)
              VYSAVH(O)   = VYSAVH(1)
              NSCN = NSCN + 1
              AZIOLD = AZIDAT
              IF( NSCN .LE. NUMSCN) GO TO 1000
         ENDIF
```

```
      RETURN
      END

      SUBROUTINE NXTAZI ( AZI )

C     ***************************************************************
C     *                                                             *
C     *   Subroutine  NXTAZI  computes the next value of the azi-   *
C     *   muth angle, Psi,  based on the current value of the Eu-   *
C     *   ler error and the previous delta-Psi value.  If the er-   *
C     *   ror is too large,  a smaller delta-Psi  will be used to   *
C     *   compute the value of  Psi,  unless the delta-Psi is al-   *
C     *   ready at the STEPMN lower limit.   Likewise, if the Eu-   *
C     *   ler error is below a certain limit, the delta-Psi value   *
C     *   is increased for the next Psi computation.                *
C     *                                                             *
C     ***************************************************************

C     ***************************************************************
C     *                                                             *
C     *   External references in this routine:                      *
C     *                                                             *
C     *      none                                                   *
C     *                                                             *
C     ***************************************************************

C     ***************************************************************
C     *                                                             *
C     *   Named COMMON blocks used in this routine:                 *
C     *                                                             *
C     *      CONST    Turbine  and  other constants  used in load   *
C     *               calculations.                                 *
C     *      LIMITC - Holds values used in the LIMITS routine.      *
C     *      POSITN - Holds parameters  related to blade position   *
C     *               such as PHI, PSI, etc.                        *
C     *      TURBN  - Holds turbine parameters  such as number of   *
C     *               blades, rotor speed, etc.                     *
C     *                                                             *
C     ***************************************************************

C     ***************************************************************
C     *                                                             *
C     *   Local and dummy variables used in this routine:           *
C     *                                                             *
C     *      AZI    - The next STEPMX station .                     *
C     *      NEW    - Array index for new data.                     *
C     *      OLD    - Array index for old data.                     *
C     *                                                             *
C     ***************************************************************

      REAL           AZI

      INTEGER        NEW
      INTEGER        OLD

      INCLUDE       'C:INCLUDE\CONST2.INC'

      INCLUDE       'C:INCLUDE\LIMITC.INC'
```

```
      INCLUDE        'C:INCLUDE\POSITN.INC'

      INCLUDE        'C:INCLUDE\TURBN.INC'

      SAVE            NEW
      SAVE            OLD

      DATA            NEW     / 1 /
      DATA            OLD     / 0 /


C        Check the error.  If it is too large, decrease delta-Psi by
C        50%.  If it is very small, increase delta-Psi by 50%.  The
C        value of delta-Psi must always be greater than STEPMN.

      IF ( ERROR .GT. EUERR )  THEN

         DELPSI(NEW) = AMAX1( 0.5*DELPSI(NEW) , STEPMN )

      ELSE IF ( ERROR .LT. 0.1*EUERR )  THEN

         DELPSI(NEW) = 1.5*DELPSI(NEW)

      END IF


C        This section of code checks the position of the new Psi against
C        the next STEPMX station.  If the next Psi will go past the
C        STEPMX station, the delta-Psi is adjusted to bring the next Psi
C        directly onto the STEPMX point.  If the next Psi will fall just
C        short of a STEPMX station, the delta-Psi is adjusted to assure
C        that it will not be necessary to use a delta-Psi smaller than
C        STEPMN to reach the next STEPMX station on the next iteration.

C        Programmer note:

C           The following logic can produce a delta-Psi that is less
C           than STEPMN for two steps.  It would then move back within
C           tolerances.  This case comes up when we are within slightly
C           less than two STEPMNs of the next STEPMX station.  This
C           algorithm cannot produce a delta-Psi that is less than
C           STEPMN/2.                          MLB


      IF ( PSI(OLD)+DELPSI(NEW) .GT. AZI )  THEN

         DELPSI(NEW) = AZI - PSI(OLD)

      ELSE IF ( PSI(OLD)+DELPSI(NEW)+STEPMN .GT. AZI )  THEN

         IF ( (DELPSI(NEW) .NE. STEPMN) .OR. (ERROR .LE. EUERR) )  THEN

            DELPSI(NEW) = 0.5*( AZI - PSI(OLD) )

         END IF

      END IF
```

```
C       Set new Psi and delta-Time.

      PSI(NEW)    = PSI(OLD) + DELPSI(NEW)
      DELTAT(NEW) = DELPSI(NEW)/OMEGA


C       Get time values if we're working on a yawing solution.

      IF ( ITRIM .EQ. 0 )  TIME(NEW) = TIME(OLD) + DELTAT(NEW)


      RETURN
      END

      SUBROUTINE LODCLC( BLDANG, STEMP, RESLTS)


C       ***************************************************************
C       *                                                             *
C       *   Subroutine  LODCLC  is used to compute blade flap loads.  *
C       *                                                             *
C       ***************************************************************

C       ***************************************************************
C       *                                                             *
C       *   External references in this routine:                      *
C       *                                                             *
C       *      TRPZOD - Composite trapezoidal integration.            *
C       *                                                             *
C       ***************************************************************

C       ***************************************************************
C       *                                                             *
C       *   Named COMMON blocks used in this routine:                 *
C       *                                                             *
C       *      AERO1  - Holds coefficients  related to  aerodynamic   *
C       *               loads calculations such as ClAlpha, CdZero,   *
C       *               etc.                                          *
C       *      AIRFRC - Holds  values used in  aerodynamic calcula-   *
C       *               tions.                                        *
C       *      BLADE  - Holds blade property values  such as stiff-   *
C       *               ness and mass distributions.                  *
C       *      CONST  - Turbine  and  other constants  used in load   *
C       *               calculations.                                 *
C       *      LIMITC - Holds values used in the LIMITS routine.      *
C       *      LODVAL - Holds values used to compute blade loads.     *
C       *      POSITN - Holds parameters  related to blade position   *
C       *               such as PHI, PSI, etc.                        *
C       *      SHAPE  - Holds blade coordinate shape functions.       *
C       *      TENSIN - Holds tension component integrals.            *
C       *      TURBN  - Holds turbine parameters  such as number of   *
C       *               blades, rotor speed, etc.                     *
C       *      WIND   - Holds wind shear  and tower shadow  parame-   *
C       *               ters.                                         *
C       *                                                             *
C       ***************************************************************

C       ***************************************************************
C       *                                                             *
```

```
C       *   Local and dummy variables used in this routine:          *
C       *                                                            *
C       *     BLDANG - Blade azimuth position.                       *
C       *     COEF1  - Complicated term.                             *
C       *     COEF2  - Complicated term.                             *
C       *     COEF4  - Complicated term.                             *
C       *     COEF7  - Complicated term.                             *
C       *     CPSI   - Cosine of the blade angle.                    *
C       *     FACTR1 - Complicated term.                             *
C       *     FINTGR - Integral of FLAPFN.                           *
C       *     FLAPFN - Flapwise shear force distribution.            *
C       *     I      - Generic index.                                *
C       *     IPT    - Data point index.                             *
C       *     J      - Generic index.                                *
C       *     LL     - Generic index.                                *
C       *     M      - Generic index.                                *
C       *     NPTS   - Number of points along the blade used to      *
C       *              perform Simpson's integration for calculat-   *
C       *              ing the moments and forces at the blade       *
C       *              root. (passed from FLAP1)                     *
C       *     NSHP   - Counter on DO loops for the coordinate        *
C       *              shape function.                               *
C       *     OMGASQ - Omega^2.                                      *
C       *     PRDCTO - Temporary storage.                            *
C       *     PRDCT1 - Temporary storage.                            *
C       *     PRDCT2 - Temporary storage.                            *
C       *     PRODCT - Temporary storage.                            *
C       *     PYAERO - Aerodynamic loads in the flapwise direc-      *
C       *              tion.                                         *
C       *     RESLTS - Temporary storage.                            *
C       *     SPSI   - Sine of the blade angle.                      *
C       *     TINTGR - Integral of TSNFCN.                           *
C       *     TSNFCN - Product of the tension force and the slope    *
C       *              at a blade station.                           *
C       *                                                            *
C       **************************************************************

      REAL            BLDANG
      REAL            COEF1
      REAL            COEF2
      REAL            COEF4
      REAL            COEF7
      REAL            CPSI
      REAL            FACTR1
      REAL            FINTGR
      REAL            FLAPFN (21)
      REAL            EDGEFN (21)
      REAL            TSNFCN (21)
      REAL            VXFCN  (21)
      REAL            OMGASQ
      REAL            PRODD
      REAL            PRDCTO
      REAL            PRDCT1
      REAL            PRDCT2
      REAL            PRODCT (21)
      REAL            PYAERO (21)
      REAL            PXAERO (21)
      REAL            QZFCN  (21)
      REAL            RESLTS (21,9)
```

```
      REAL            SPSI
      REAL            STEMP  (4, 0:1, 0:2)
      REAL            TINTGR
      REAL            TRPZOD

      INTEGER         IPT
      INTEGER         NPTS
      INTEGER         NSHP


      INCLUDE        'C:INCLUDE\AERO1.INC'

      INCLUDE        'C:INCLUDE\AIRFRC.INC'

      INCLUDE        'C:INCLUDE\BLADE2.INC'

      INCLUDE        'C:INCLUDE\CONST2.INC'

      INCLUDE        'C:INCLUDE\LIMITC.INC'

      INCLUDE        'C:INCLUDE\LODVAL.INC'

      INCLUDE        'C:INCLUDE\POSITN.INC'

      INCLUDE        'C:INCLUDE\SHAPE.INC'

      INCLUDE        'C:INCLUDE\TENSIN2.INC'

      INCLUDE        'C:INCLUDE\TURBN.INC'

      INCLUDE        'C:INCLUDE\WIND2.INC'

      SAVE            NPTS
      SAVE            NEW

      DATA            NPTS    / 21 /
      DATA            NEW     / 1 /


C       Initialize some constants

      OMGASQ = OMEGA**2
      COEF1  = 2.0*OMEGA*STHP
      COEF4  = OMGASQ*STHP*CTHP
      COEF6  = OMGASQ*CTHP*CTHP
      COEF7  = OMGASQ*STHP*STHP

      CPSI   = COS( BLDANG )
      SPSI   = SIN( BLDANG )
      FACTR1 = OMGASQ*BETA0 + 2*OMEGA*CPSI*PHI(1) + SPSI*PHI(2)
      COEF2  = GRAV*( -CHI*CTHP + STHP*SPSI + BETA0*CTHP*CPSI )
      COEF3  = GRAV*( CHI*STHP + CTHP*SPSI-BETA0*STHP*CPSI)
      COEF5  = GRAV*CPSI
      COEF8  = GRAV*SPSI*STHP

      PRODD  = 0.5*RHOAIR*CSUBMA

      DO 350  IPT = 1, NPTS

         RESLTS(IPT,1) = 0.
```

```
      RESLTS(IPT,2) = 0.
      RESLTS(IPT,3) = 0.

      DO 300 NSHP = 1, NSHAPS


         RESLTS(IPT,1) = RESLTS(IPT,1)+
     &     SHAPE(NSHP,0,IPT)*STEMP(NSHP,NEW,0)
         RESLTS(IPT,2) = RESLTS(IPT,2)+
     &     SHAPE(NSHP,1,IPT)*STEMP(NSHP, NEW, 0)
         RESLTS(IPT,3) = RESLTS(IPT,3)+
     &     SHAPE(NSHP,0,IPT)*STEMP(NSHP, NEW, 1)
300   CONTINUE

      PYAERO(IPT) = TRPZOD( IPT, BLTIP, DAZETA, NPTS)
      PXAERO(IPT) = TRPZOD( IPT, BLTIP, DAETA, NPTS)
      DMSBAC      = PRODD*CHORD(IPT)*WW(IPT)**2
      QZFCN(IPT) = DMSBAC + ESUBAC(IPT)*DAZETA(IPT)

      PRDCT0 = 0.
      PRDCT1 = 0.
      PRDCT2 = 0.
      PRODCT(IPT) = 0.

      DO 340 NSHP = 1, NSHAPS


            PRDCT0 = PRDCT0 +STEMP(NSHP,NEW,0)*TCORLS(NSHP,IPT)
            PRDCT1 = PRDCT1 +STEMP(NSHP,NEW,1)*TCORLS(NSHP,IPT)
            PRDCT2 = PRDCT2 +STEMP(NSHP,NEW,2)*TCORLS(NSHP,IPT)
            PRODCT(IPT) = PRODCT(IPT) + STEMP(NSHP, NEW, 0)
     &        * CIFMOM(NSHP, IPT)
340   CONTINUE

      RESLTS(IPT,4) = OMGASQ * TOMGA(IPT) + COEF1 * PRDCT1
     &    - COEF5 * TGRAV(IPT)

      RESLTS(IPT,5) = PXAERO(IPT) - FACTR1 * STHP * TOMGA(IPT)
     &    + COEF4 * PRDCT0 + COEF3 * TGRAV(IPT)
     &    + COEF6 * OFFMAS(IPT)

      RESLTS(IPT,6) = PYAERO(IPT) - FACTR1 * CTHP * TOMGA(IPT)
     &    + COEF7 * PRDCT0 - PRDCT2 + COEF2 * TGRAV(IPT)
     &    + COEF4 * OFFMAS(IPT)

      EDGEFN(IPT) = RESLTS(IPT,5)
      VXFCN (IPT) = EDGEFN(IPT)*RESLTS(IPT,2)
      TSNFCN(IPT) = RESLTS(IPT,4) * RESLTS(IPT,2)
      FLAPFN(IPT) = RESLTS(IPT,6)
350 CONTINUE

    DO 360 IPT = 1,NPTS

      EINTGR = TRPZOD(IPT, BLTIP, EDGEFN, NPTS)
      SINTGR = TRPZOD(IPT, BLTIP, VXFCN , NPTS)
      TINTGR = TRPZOD(IPT, BLTIP, TSNFCN, NPTS)
      QZAERO = TRPZOD(IPT, BLTIP, QZFCN , NPTS)
      FINTGR = TRPZOD(IPT, BLTIP, FLAPFN, NPTS)
      ECENGR = TRPZOD(IPT, BLTIP, ECNTFN, NPTS)
```

```
      RESLTS(IPT,7) = TINTGR - FINTGR + COEF7*PRODCT(IPT)
      RESLTS(IPT,8) = EINTGR - OMGASQ*ECENGR
     &     - COEF4*PRODCT(IPT) + COEF5*OFFMAS(IPT)
      RESLTS(IPT,9) = QZAERO - SINTGR + COEF4*DELTIM(IPT)
     &     + COEF8*OFFMAS(IPT)

360 CONTINUE

    RETURN
    END



    SUBROUTINE SHAFT2(IPS,IPR,NSTN)

    INCLUDE         'C:INCLUDE\CONST2.INC'
    INCLUDE         'C:INCLUDE\TURBN.INC'
    INCLUDE         'C:INCLUDE\RESLTS.INC'
    INCLUDE         'C:INCLUDE\SHFLOD.INC'
    INCLUDE         'C:INCLUDE\BLADE2.INC'

    CHARACTER * 50 SHFOUT
    CHARACTER * 15 LABEL1
    CHARACTER * 10 LABEL2(6)
    CHARACTER * 12 LABEL3(0:5)
    CHARACTER * 12 LABEL4(0:5)
    CHARACTER * 10 LABEL5(6)

    INTEGER IPS(360)
    INTEGER IPR
    INTEGER NSTN
    INTEGER NSTN1
    INTEGER NST1
    INTEGER IST
    INTEGER IST2

    REAL A(0:10,6)
    REAL B(0:10,6)
    REAL C(0:10,6)
    REAL D(0:10,6)
    REAL SBETAO
    REAL CBETAO
    REAL FACTOR
    REAL FI
    REAL PSI1
    REAL PSIN

    SAVE LABEL1
    SAVE LABEL2
    SAVE LABEL3
    SAVE LABEL4
    SAVE LABEL5

    DATA       LABEL1
   & / 'Azimuth Angle'/

    DATA       LABEL2
   &   /  'Fxr','Fyr',
   &  'Fzr','Mxr','Myr','Mzr'/
```

```
      DATA       LABEL3
     &  / 'cos(0*PSI)', 'cos(PSI)',
     &  'cos(2.*PSI)','cos(3.*PSI)',
     &  'cos(4.*PSI)','cos(5.*PSI)'/

      DATA       LABEL4
     &  / 'sin(0.*PSI)','sin(PSI)','sin(2.*PSI)',
     &  'sin(3.*PSI)','sin(4.*PSI)','sin(5.*PSI)'/

      DATA       LABEL5
     &  / 'Fxh', 'Fyh','Fzh',
     &    'Mxh', 'Myh','Mzh'/

4000 FORMAT (/, 1X, A, 6( 1X, A))

4200 FORMAT (/, 2X, F10.3, 6(1X, F10.3))

4300 FORMAT (//)

4400 FORMAT (/, 17X, 6(1X, A))

4500 FORMAT (/, 1X, A , 6(1X, F10.3))

      SBETA0 = SIN(BETA0)
      CBETA0 = COS(BETA0)

      PSI1 = 0.
      PSIN = 360.*.017453293

      FACTOR = FLOAT(IPR)/180.

      PRINT *, 'Read in name of shaft loads output file < '
      READ *, SHFOUT
      PRINT *, SHFOUT
      OPEN( 10, FILE = SHFOUT, STATUS = 'UNKNOWN')


      NSTN1 = NSTN - 1
      DO 360 IST = 1,NSTN1

      F(1,1,IST) = RESLTS(IST,1,5)*CTHP + RESLTS(IST,1,6)*STHP

      F(2,1,IST) = RESLTS(IST,1,6)*CBETA0*CTHP +
     &    RESLTS(IST,1,4)*SBETA0 - RESLTS(IST,1,5)*CBETA0*STHP

      F(3,1,IST) = RESLTS(IST,1,5)*SBETA0*STHP -
     &    RESLTS(IST,1,6)*SBETA0*CTHP + RESLTS(IST,1,4)*CBETA0

      F(4,1,IST) = RESLTS(IST,1,7)*CTHP + RESLTS(IST,1,8)*STHP

      F(5,1,IST) = RESLTS(IST,1,8)*CBETA0*CTHP
     &    + RESLTS(IST,1,9)*SBETA0
     &    -RESLTS(IST,1,7)*CBETA0*STHP

      F(6,1,IST) = RESLTS(IST,1,7)*SBETA0*STHP -
     &    RESLTS(IST,1,8)*SBETA0*CTHP + RESLTS(IST,1,9)*CBETA0

  360 CONTINUE

      DO 370 I = 1,6
```

```
      F(I,1,NSTN) = F(I,1,1)
370 CONTINUE


    NST1  = INT(NSTN1/2. + .0001)


    DO 390  IST = 1, NSTN1

       IST2 = IST + NST1

       IF( IST2 .GE. NSTN) THEN
          IST2 = IST - NST1
       ENDIF


       DO 385 I = 1,6

          F(I,2,IST2) = F(I,1,IST)

385    CONTINUE

390 CONTINUE

    DO 400 I = 1,6

       F(I,2,NSTN) = F(I,2,1)

400 CONTINUE



    DO 500 IST = 1,NSTN

       PSI = IPS(IST) * .017453293

       SHFLOD(1,IST) = F(1,1,IST) -F(1,2,IST)

       SHFLOD(2,IST) = F(2,1,IST) + F(2,2,IST)

       SHFLOD(3,IST) = F(3,1,IST) - F(3,2,IST)

       SHFLOD(4,IST) = F(4,1,IST) - F(4,2,IST)
  &     - HUBRAD*( F(2,1,IST) - F(2,2,IST))

       SHFLOD(5,IST) = F(5,1,IST) + F(5,2,IST)
  &     + HUBRAD*( F(1,1,IST) + F(1,2,IST))

       SHFLOD(6,IST) = F(6,1,IST) - F(6,2,IST)

       HUBLOD(1,IST) = SHFLOD(1,IST)*COS(PSI) + SHFLOD(3,IST)
  &     * SIN(PSI)

       HUBLOD(2,IST) = SHFLOD(2,IST)

       HUBLOD(3,IST) = SHFLOD(3,IST)*COS(PSI) - SHFLOD(1,IST)
  &     * SIN(PSI)

       HUBLOD(4,IST) = SHFLOD(4,IST)*COS(PSI) + SHFLOD(6,IST)
  &     * SIN(PSI)
```

```
         HUBLOD(5,IST) = SHFLOD(5,IST)

         HUBLOD(6,IST) = SHFLOD(6,IST)*COS(PSI) -
     &      SHFLOD(4,IST)*SIN(PSI)

  500 CONTINUE

      WRITE(10,*) 'Low-Speed Shaft Loads in Rotor coordinates'

      WRITE(10,4000) LABEL1, ( LABEL2(J), J=1,6)

      DO 420 IST = 1, NSTN
      WRITE(10,4200) IPS(IST), (SHFLOD(J,IST), J=1,6)
  420 CONTINUE

      WRITE(10,4300)

      WRITE(10,*) 'Hub loads in fixed frame hub coordinates'

      WRITE(10,4000) LABEL1, ( LABEL5(J), J=1,6)

      DO 430 IST = 1, NSTN
      WRITE(10,4200) IPS(IST), (HUBLOD(J,IST), J=1,6)
  430 CONTINUE

C  Compute harmonics of rotor shaft loads: Fourier Series expansion.
C  Also compute harmonics of fixed frame hub loads, in hub coordinates.

      DO 800 II = 1,6
      DO 700  I = 0,5

         SUMA2 = 0.
         SUMB2 = 0.
         SUMC2 = 0.
         SUMD2 = 0.

         FI = FLOAT(I)

         DO 650 IST = 2, NSTN1
            PSI = IPS(IST) * .017453293
            SUMA2 = SUMA2 + COS(FI*PSI)*SHFLOD(II,IST)
            SUMB2 = SUMB2 + SIN(FI*PSI)*SHFLOD(II,IST)
            SUMC2 = SUMC2 + COS(FI*PSI)*HUBLOD(II,IST)
            SUMD2 = SUMD2 + SIN(FI*PSI)*HUBLOD(II,IST)

  650    CONTINUE

         SUMA = 2.*SUMA2 + COS(FI*PSI1)*SHFLOD(II,1) +
     &      COS(FI*PSIN)*SHFLOD(II,NSTN)
         SUMB = 2.*SUMB2 + SIN(FI*PSI1)*SHFLOD(II,1) +
     &      SIN(FI*PSIN)*SHFLOD(II,NSTN)
         SUMC = 2.*SUMC2 + COS(FI*PSI1)*HUBLOD(II,1) +
     &      COS(FI*PSIN)*HUBLOD(II,NSTN)
         SUMD = 2.*SUMD2 + SIN(FI*PSI1)*HUBLOD(II,1) +
     &      SIN(FI*PSIN)*HUBLOD(II,NSTN)

         IF( I .EQ. 0) THEN
            A(I,II) = 0.25 * FACTOR*SUMA
            B(I,II) = 0.25 * FACTOR*SUMB
```

```
         C(I,II) = 0.25 * FACTOR*SUMC
         D(I,II) = 0.25 * FACTOR*SUMD

      ELSE
         A(I,II) = 0.50 * FACTOR*SUMA
         B(I,II) = 0.50 * FACTOR*SUMB
         C(I,II) = 0.50 * FACTOR*SUMC
         D(I,II) = 0.50 * FACTOR*SUMD

      ENDIF
700 CONTINUE
800 CONTINUE

    WRITE(10,4300)

    WRITE(10,*) 'Harmonics of Rotor Shaft Loads'
    WRITE(10,4400) ( LABEL2(J), J=1,6)
    DO 900 I = 0,5
       WRITE(10,4500) LABEL3(I),(A(I,II), II=1,6)
       WRITE(10,4500) LABEL4(I),(B(I,II), II=1,6)
900 CONTINUE

    WRITE(10,4300)

    WRITE(10,*) 'Harmonics of Hub loads in Fixed Coordinates'
    WRITE(10,4400) ( LABEL5(J), J=1,6)
    DO 920 I = 0,5
       WRITE(10,4500) LABEL3(I), ( C(I,II), II=1,6)
       WRITE(10,4500) LABEL4(I), ( D(I,II), II=1,6)
920 CONTINUE
    RETURN
    END


    SUBROUTINE SHAFT3(IPS,IPR,NSTN)

    INCLUDE        'C:INCLUDE\CONST2.INC'
    INCLUDE        'C:INCLUDE\TURBN.INC'
    INCLUDE        'C:INCLUDE\RESLTS.INC'
    INCLUDE        'C:INCLUDE\SHFLOD.INC'
    INCLUDE        'C:INCLUDE\BLADE2.INC'

    CHARACTER * 50 SHFOUT
    CHARACTER * 15 LABEL1
    CHARACTER * 10 LABEL2(6)
    CHARACTER * 12 LABEL3(0:5)
    CHARACTER * 12 LABEL4(0:5)
    CHARACTER * 10 LABEL5(6)

    INTEGER IPS(360)
    INTEGER IPR
    INTEGER NSTN
    REAL A(0:10,6)
    REAL B(0:10,6)
    REAL C(0:10,6)
    REAL D(0:10,6)

    REAL FACTOR
    REAL FI
```

```
      SAVE LABEL1
      SAVE LABEL2
      SAVE LABEL3
      SAVE LABEL4
      SAVE LABEL5

      DATA       LABEL1
     & / 'Azimuth Angle'/

      DATA       LABEL2
     &   /  'Fxr','Fyr',
     &  'Fzr','Mxr','Myr','Mzr'/

      DATA       LABEL3
     &  / 'cos(0*PSI)', 'cos(PSI)',
     &  'cos(2.*PSI)','cos(3.*PSI)',
     &  'cos(4.*PSI)','cos(5.*PSI)'/

      DATA       LABEL4
     &  / 'sin(0.*PSI)','sin(PSI)','sin(2.*PSI)',
     &  'sin(3.*PSI)','sin(4.*PSI)','sin(5.*PSI)'/

      DATA       LABEL5
     &  / 'Fxh', 'Fyh','Fzh',
     &    'Mxh', 'Myh','Mzh'/

 4000 FORMAT (/, 1X, A, 6( 1X, A))

 4200 FORMAT (/, 2X, F11.2, 6(1X, F11.2))

 4300 FORMAT (//)

 4400 FORMAT (/, 17X, 6(1X, A))

 4500 FORMAT (/, 1X, A , 6(1X, F11.2))

      SBETA0 = SIN(BETA0)
      CBETA0 = COS(BETA0)

      PSI1 = 0.
      PSIN = 360.*.017453293

      FACTOR = FLOAT(IPR)/180.

      PRINT *, '      '
      PRINT *, '      '
      PRINT *, 'Read in name of shaft loads output file'
      READ *, SHFOUT
      OPEN( 10, FILE = SHFOUT, STATUS = 'UNKNOWN')


      NSTN1 = NSTN - 1
      DO 360 IST = 1,NSTN1

      F(1,1,IST) = RESLTS(IST,1,5)*CTHP + RESLTS(IST,1,6)*STHP

      F(2,1,IST) = RESLTS(IST,1,6)*CBETA0*CTHP + RESLTS(IST,1,4)*SBETA0
     &    - RESLTS(IST,1,5)*CBETA0*STHP

      F(3,1,IST) = RESLTS(IST,1,5)*SBETA0*STHP - RESLTS(IST,1,6)*SBETA0
```

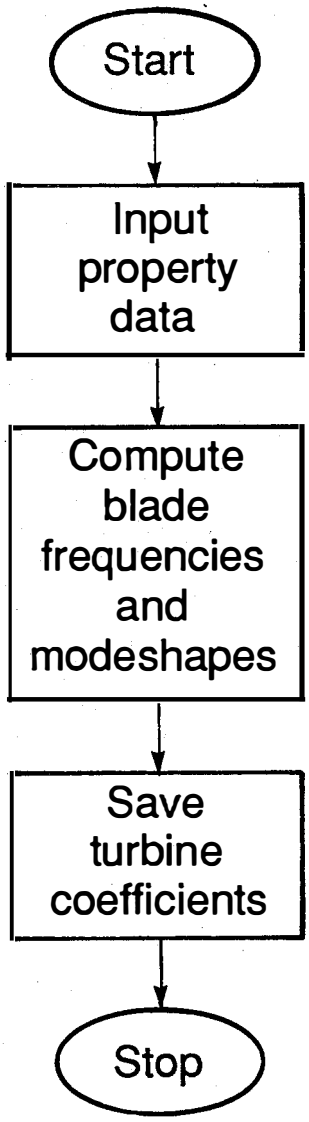
```
     &    *CTHP + RESLTS(IST,1,4)*CBETA0

          F(4,1,IST) = RESLTS(IST,1,7)*CTHP + RESLTS(IST,1,8)*STHP

          F(5,1,IST) = RESLTS(IST,1,8)*CBETA0*CTHP + RESLTS(IST,1,9)*SBETA0
     &    -RESLTS(IST,1,7)*CBETA0*STHP

          F(6,1,IST) = RESLTS(IST,1,7)*SBETA0*STHP - RESLTS(IST,1,8)*SBETA0
     &    *CTHP + RESLTS(IST,1,9)*CBETA0

360  CONTINUE

          DO 370 I = 1,6
             F(I,1,NSTN) = F(I,1,1)
370  CONTINUE


          NST1  = INT(NSTN1/3. + .0001)
          NST2  = INT(2.*NSTN1/3. + .0001)


          DO 390  IST = 1, NSTN1

             IST2 = IST + NST2
             IST3 = IST + NST1

             IF( IST3 .GE. NSTN) THEN
                IST3 = IST - NST2
             ENDIF

             IF( IST2 .GE. NSTN) THEN
                IST2 = IST - NST1
             ENDIF

             DO 385 I = 1,6

                F(I,2,IST2) = F(I,1,IST)
                F(I,3,IST3) = F(I,1,IST)

385          CONTINUE
390  CONTINUE

          DO 400 I = 1,6

             F(I,2,NSTN) = F(I,2,1)
             F(I,3,NSTN) = F(I,3,1)

400  CONTINUE


          FACTR = .86603


          DO 500 IST = 1,NSTN

             PSI = IPS(IST) * .017453293

             SHFLOD(1,IST) = F(1,1,IST) - 0.5*(F(1,2,IST)+F(1,3,IST))
     &     + FACTR*(F(3,2,IST)-F(3,3,IST))
```

```
        SHFLOD(2,IST) = F(2,1,IST) + F(2,2,IST) + F(2,3,IST)

        SHFLOD(3,IST) = F(3,1,IST) - 0.5*(F(3,2,IST)+F(3,3,IST))
     &     - FACTR*(F(1,2,IST)-F(1,3,IST))

        SHFLOD(4,IST) = F(4,1,IST) - 0.5*(F(4,2,IST)+F(4,3,IST))
     &     + FACTR*(F(6,2,IST)-F(6,3,IST))-HUBRAD*F(2,1,IST)
     &     + 0.5*HUBRAD*(F(2,3,IST)+F(2,2,IST))

        SHFLOD(5,IST) = F(5,1,IST) + F(5,2,IST) + F(5,3,IST)
     &     + HUBRAD*(F(1,1,IST)+F(1,2,IST)+F(1,3,IST))

        SHFLOD(6,IST) = F(6,1,IST) - 0.5*(F(6,2,IST)+F(6,3,IST))
     &     - FACTR*(F(4,2,IST)-F(4,3,IST))
     &     + FACTR*HUBRAD*(F(2,2,IST)-F(2,3,IST))

        HUBLOD(1,IST) = SHFLOD(1,IST)*COS(PSI) + SHFLOD(3,IST)
     &     * SIN(PSI)

        HUBLOD(2,IST) = SHFLOD(2,IST)

        HUBLOD(3,IST) = SHFLOD(3,IST)*COS(PSI) - SHFLOD(1,IST)
     &     * SIN(PSI)

        HUBLOD(4,IST) = SHFLOD(4,IST)*COS(PSI) + SHFLOD(6,IST)
     &     * SIN(PSI)

        HUBLOD(5,IST) = SHFLOD(5,IST)

        HUBLOD(6,IST) = SHFLOD(6,IST) * COS(PSI) - SHFLOD(4,IST)
     &     * SIN(PSI)

  500 CONTINUE

      WRITE(10,*) 'Low-Speed Shaft Loads in Rotor coordinates'

      WRITE(10,4000) LABEL1, ( LABEL2(J), J=1,6)

      DO 420 IST = 1, NSTN
      WRITE(10,4200) IPS(IST), (SHFLOD(J,IST), J=1,6)
  420 CONTINUE

      WRITE(10,4300)

      WRITE(10,*) 'Hub loads in fixed frame hub coordinates'

      WRITE(10,4000) LABEL1, ( LABEL5(J), J=1,6)

      DO 430 IST = 1, NSTN
      WRITE(10,4200) IPS(IST), (HUBLOD(J,IST), J=1,6)
  430 CONTINUE

C  Compute harmonics of rotor shaft loads: Fourier Series expansion.
C  Also compute harmonics of fixed frame hub loads, in hub coordinates.

      DO 800 II = 1,6
      DO 700  I = 0,5

         SUMA2 = 0.
         SUMB2 = 0.
```

```
      SUMC2 = 0.
      SUMD2 = 0.

      FI = FLOAT(I)

      DO 650 IST = 2, NSTN1
         PSI = IPS(IST) * .017453293
         SUMA2 = SUMA2 + COS(FI*PSI)*SHFLOD(II,IST)
         SUMB2 = SUMB2 + SIN(FI*PSI)*SHFLOD(II,IST)
         SUMC2 = SUMC2 + COS(FI*PSI)*HUBLOD(II,IST)
         SUMD2 = SUMD2 + SIN(FI*PSI)*HUBLOD(II,IST)

650   CONTINUE

      SUMA = 2.*SUMA2 + COS(FI*PSI1)*SHFLOD(II,1) +
     &     COS(FI*PSIN)*SHFLOD(II,NSTN)
      SUMB = 2.*SUMB2 + SIN(FI*PSI1)*SHFLOD(II,1) +
     &     SIN(FI*PSIN)*SHFLOD(II,NSTN)
      SUMC = 2.*SUMC2 + COS(FI*PSI1)*HUBLOD(II,1) +
     &     COS(FI*PSIN)*HUBLOD(II,NSTN)
      SUMD = 2.*SUMD2 + SIN(FI*PSI1)*HUBLOD(II,1) +
     &     SIN(FI*PSIN)*HUBLOD(II,NSTN)

      IF( I .EQ. 0) THEN
         A(I,II) = 0.25 * FACTOR*SUMA
         B(I,II) = 0.25 * FACTOR*SUMB
         C(I,II) = 0.25 * FACTOR*SUMC
         D(I,II) = 0.25 * FACTOR*SUMD

      ELSE
         A(I,II) = 0.50 * FACTOR*SUMA
         B(I,II) = 0.50 * FACTOR*SUMB
         C(I,II) = 0.50 * FACTOR*SUMC
         D(I,II) = 0.50 * FACTOR*SUMD

      ENDIF
700 CONTINUE
800 CONTINUE

    WRITE(10,4300)

    WRITE(10,*) 'Harmonics of Rotor Shaft Loads'
    WRITE(10,4400) ( LABEL2(J), J=1,6)
    DO 900 I = 0,5
       WRITE(10,4500) LABEL3(I),(A(I,II), II=1,6)
       WRITE(10,4500) LABEL4(I),(B(I,II), II=1,6)
900 CONTINUE

    WRITE(10,4300)

    WRITE(10,*) 'Harmonics of Hub loads in Fixed Coordinates'
    WRITE(10,4400) ( LABEL5(J), J=1,6)
    DO 920 I = 0,5
       WRITE(10,4500) LABEL3(I), ( C(I,II), II=1,6)
       WRITE(10,4500) LABEL4(I), ( D(I,II), II=1,6)
920 CONTINUE
    RETURN
    END
```

Appendix E

Modules 1 and 2 Flowcharts



BA-G0246404

Fig. E-1. Module 1 Flowchart

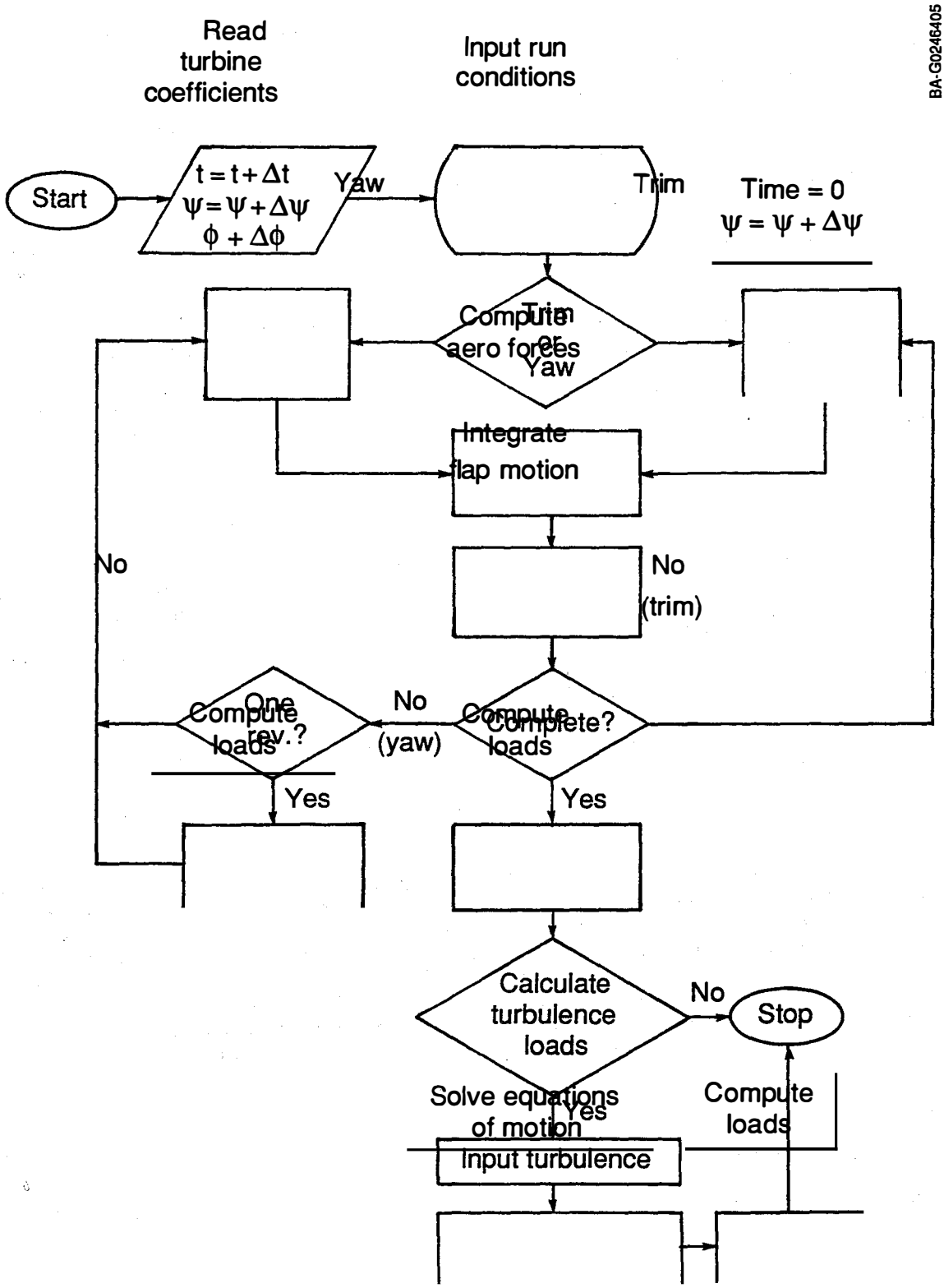


Fig. E-2. Module 2 Flowchart

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16. Abstract (Limit: 200 words)

This report gives the reader an overview of and instructions on the proper use of the National Renewable Energy Laboratory Force and Loads Analysis Program (FLAP, Version 2.2). It is intended as a tool for prediction of rotor and blade loads and response for two- or three-bladed rigid hub wind turbines. The effects of turbulence are accounted for. The objectives of the report are to give an overview of the code and also show the methods of data input and correct code execution steps in order to model an example two-bladed rigid hub turbine. A large portion of the discussion (Sections 6.0, 7.0, and 8.0) is devoted to the subject of inputting and running the code for wind turbulence effects. The ability to include turbulent wind effects is perhaps the biggest change in the code since the release of FLAP version 2.01 in 1988. This report is intended to be a user's guide. It does not contain a theoretical discussion on equations of motion, assumptions, underlying theory, etc.

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