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Wind-II Users Manual

Melvin H. Snyder and David L. Staples

*Wichita State University*

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WIND-II

Users Manual

By
Melvin H. Snyder
and
David L. Staples
Wind Energy Laboratory
Wichita State University
Wichita, Kansas 67208

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Computer code WIND-II is a program designed to calculate the performance of a wind-axis wind turbine. This guide is intended to assist users in effectively utilizing the program.

History

The computer program WIND resulted from modifying the well-known program, PROP, which was written by Stel N. Walker and Robert E. Wilson at Oregon State University. PROP was installed at the Lewis Research Center of NASA and altered to accommodate the IBM 360 system. A copy of the code was supplied to Wichita State University to facilitate a feasibility study of aileron and spoiler control systems for the Mod-0 wind turbine.

Further modifications were made to accommodate the WSU system 370 and to permit output options displaying either local values or integrated results. To accommodate the use of spoilers, ailerons, or other airfoil modifications, two additional subroutines were added. Then, to simplify input, particularly when computing in the interactive mode at a terminal, additional changes were made. The result of these modifications was a computer code titled WIND.

WIND is loaded on Lewis Research Center computer system 370 and it has been used by the NASA Wind Power Office for the past two years. WIND has been supplied in the form of card decks to several users by the Wind Energy
Laboratory at Wichita State University. Also it has been distributed through references 1 and 2.

Problems

Experience obtained in using WIND indicated three areas in which additional improvement was desirable:

1. WIND consistently under-predicted torque and power output in the region of maximum output of the turbine. A reason for this problem was that subroutine CALC, which derives axial and angular interference factors at each spanwise station, was found to yield questionable values for low wind speeds. It was therefore decided to re-write CALC to incorporate a choice of two empirical interference models, developed by Larry Viterna of NASA-Lewis and Robert Wilson of Oregon State, respectively.

2. Options are available for arbitrary limits to be placed on the values of "a," the axial slowdown factor. Recent experimental flow visualization studies conducted on the Mod-0 turbine indicate that actual values of "a" can exceed those arbitrary limits. Further, the WIND code failed to converge, in some cases, within the 50 iterations permitted.
3. All of the airfoil section coefficient data used by WIND are generated internally by Subroutine NACAXX. This is essentially a canned curve-fit of $\alpha/C_1/C_d$ data for the NACA 23024 for angles of attack from zero degrees to one hundred eighty degrees. This 23024 "half-rough" section is used in the NASA Mod-0 wind machine, and it was the only section provided with the basic WIND program. WIND has been used with other airfoils (notably, GA(W)-1 and GA(W)-2 airfoils; see ref. 3). In each case it was necessary to write a new subroutine containing empirical equations which fit the airfoil data. It was felt that alternative sources of aerodynamic section coefficients within the program were needed. These would involve new models for the performance of the 23024 section, as well as the inclusion of the capability of utilizing tabulated 2-D data for any airfoil section.

Modifications

WIND-II incorporates solutions to these problems. A new NASA-coded calculation of "a" is used, which invariably converges to a value. Arbitrary limits have been eliminated. It is possible to change airfoil section across the span of the turbine blade; as many as ten different airfoils may be specified for any given blade.
The airfoil data is entered in the form of a table of values of lift and drag coefficients. At present, this table look-up system is used from negative stall to positive stall; coefficients of lift and drag corresponding to as many as 25 angles of attack for each airfoil section are entered as data. It is recommended that smooth 2-D airfoil data be used. Beyond the stall NACAXX subroutine is used. Improvements have been made in the equations of this subroutine. This subroutine may be used as previously, but much better results are obtained by using actual airfoil data with subroutine AFOIL which is called by setting IRC = 2.

Blade twist and planform are accommodated by specifying the local chord, twist angle, and airfoil section at up to 25 radial stations.

An additional optimal calculation has been added which permits computation of annual energy produced. Information about the peak output of the turbine, the cut-out wind speed, number of hours expected to operate per year [8760 - (hours down for maintenance, etc.)], average wind speed (hub high) at the turbine site, and the Weibull distribution shape factor are always supplied as data, but the computation is only made if IQUERY is set equal to 1.
Program Organization

This computer program consists of a main program and several subroutines.

Main Program

WIND - The program will calculate performance of a wind turbine which employs any of the control systems:
1. Pitching of the tip section
2. Deflection of ailerons on the blades
3. Deflection of spoiler on the blades
4. Pitching of the entire blade

To operate the program the type of control system and its configuration (deflection angle, chord, span) are fixed and each computer run is made for a series of wind speeds at a fixed rotational speed or for a series of turbine speeds at a given wind speed. A fixed-pitch turbine is calculated using option 4 with the pitch angle maintained at a constant angle.

Subroutines

SEARCH - This subroutine interpolates between data input for specific blade radial positions to determine the local chord and pitch angle at any radial station.

CALC - At each station, this subroutine determines the induced flow factors, the angle of attack and calls the subroutines which determine the lift, drag and hinge moment coefficients.

NACAXX - This subroutine calculates lift and drag coefficients for the NACA 23024 "half-rough" airfoil. This subroutine may be used for the entire range of angles of attack experienced by any blade section, or, if uninstalled 2-D airfoil data is supplied, it will be only used at angles of attack outside the range of data available.

AFOIL - This subroutine interpolates within the airfoil data table, supplied as data, to determine lift and drag coefficients at a local angle of attack.
INCREM - This subroutine calculates increments of lift coefficient and drag coefficient due to deflection of aileron or spoiler. Hinge moment coefficient is also calculated.

TIPLOS - This subroutine determines tip and hub losses depending on the model specified.

GAMMA - This subroutine calculates the value of the gamma function needed for calculation of annual energy in the main program. Method of calculation is six-point Gaussian-Legendre quadrature.

**Basis for Computation and Methods of Calculation**

This program is one which calculates performance of a given turbine geometry, rather than a scheme for evaluating geometric parameters. The approach is based on principles outlined in Reference 3.

For each computer run, input data is required, including: run number and date; type of run, i.e., method of control, velocity or velocity range, rotational speed(s), type of print out required; and the geometry of the rotor and blades. Input specifications are detailed in a later section.

The operator has the option of specifying either "long printout" or "short printout." The "short printout" lists performance parameters at each velocity, rotational speed, and control setting for the complete wind turbine. In addition to these integrated values, the long printout lists, for each condition, local angle of attack, coefficients of lift and drag, increments of thrust, torque and power produced, and local induced effect at each station across blade length from tip to hub. Both types of
printout list the geometric dimensions, including airfoil sections. The aerodynamic characteristics of each airfoil section used are listed if AFOIL subroutine is used. For convenience of the user, a complete list of input variables is printed together with the meaning of these parameters. This list is printed preceding the "answer" sheets.

Following the integrated values, at each operating condition, is the contribution to annual energy production. A final page summarizes the annual energy produced.

A wind turbine operates in an environment affected by (1) removal of energy from the wind stream and (2) flow around the blade tip inducing secondary flow. Effects of these actions can be sketched below:

\[ V(1-a) \]

Attenuation of axial velocity in streamtube through turbine.

\[ rw(1+a') = 2 \pi r n(1+a') \]

Relative wind components at a blade section.
a and a' are induced flow correction factors. "a," the axial velocity attenuation factor, expresses slowdown of the air flow through the rotor plane. From the point of view of the momentum equation and the upper sketch above, "a" appears to be a single value across the rotor plane. However, the value of "a" varies across the rotor, from tip to hub, depending on the mode of operation. Local "a" is a function of local $c$, and $c_d$ (detailed in a latter section of this guide). The "average a" is a weighted average. Local values of "a" are multiplied by the square of the local velocity so as to weight the values proportional to the area swept through.

"a'" expresses rotation imparted to the air as it passes through the plane of the rotor. Wilson states that most desirable value of "a" (for max $c_p$) is $a = 1/3$ (Reference 3). "a'" is usually an order of magnitude smaller than a, and error due to assuming $a' = 0$ is quite small.

In the second sketch, above, relationships between angles at any radial blade station are shown.

Angle of attack = $\alpha = \Phi - \Theta$

Wind angle = $\Phi = \tan^{-1} \left( \frac{V}{rw \ (1-a)} \right)$

Blade angle = $\Theta$

$\Theta$ results from two factors, the twist angle built into the blade plus the amount that the blade is pitched. In case of twisted blade--local blade angle, when the blade is
in flat pitch ($\beta = 0$ -- probably at $r = (3/4)R$), is given by $\theta_{\text{twist}}$. The usual twist is such that $\theta$ is positive inboard toward the root, and zero or slightly negative at the tip. In program input, $\theta_{\text{twist}}$ is THETI(I).

In changing pitch of a rotor blade, NASA convention is such that moving the leading-edge into the wind, i.e., feathering, is negative pitch. Full feather is a pitch angle of $-90^\circ$ ($\beta = -90^\circ$).

Pitch angle = $\beta$

$\theta = \theta_{\text{twist}} - \beta$

At any operational wind speed and rotational speed, decreasing pitch decreases angle of attack. To start, blade is rotated to negative pitch (decreasing $\alpha$ to less than stall); as rotational speed increases (decreasing $\Phi$) the pitch is increased toward zero (decreasing $\theta$).

At zero pitch ($\beta = 0$), for an untwisted blade, $\alpha = \Phi$.

The technique used in the solution is to divide the length of the blade from tip to hub into a specified number of elements. For each element, values of local radius, $\theta$, 

\[
\theta = \theta_{\text{twist}} - \beta
\]
chord, and control chord and deflection (if appropriate) are determined at the outboard edge, the center, and inboard edge of the element.

The values at the outboard edge are those at the inboard edge of the previous element and saved from those calculations. Values at center and inboard edge are obtained by calling subroutine SEARCH twice. SEARCH determines the values by interpolation.

Then, at those three stations in each element, $c_a$, $c_l$, $c_d$ are determined. From them, values of torque per unit span, thrust per unit span, power per unit span, and, if appropriate, hinge moment per unit span are calculated.
These values are integrated across the element using Simpson's Rule:

\[
\int f(x)dx = \frac{h}{6} \left[ f(x_0) + 4f(x_i) + f(x_2) \right]
\]

for example:

\[
\begin{bmatrix}
\text{Element} \\
\text{Torque}
\end{bmatrix} = \frac{DR}{6} \left[ (\text{Torque})_0 + 4(\Delta \text{Torque})_1 + (\Delta \text{Torque})_2 \right]
\]

\[QYX = DT6*(QX 4.*QXP1 + QXP)\]

Integrated values of thrust and torque for each element are added together across the blade span to get total thrust and torque. Power and coefficients are calculated from these totals.

A crucial step in this process is determination of angle of attack, \( \alpha \), and lift and drag coefficients at each station of each element. Because of the interdependence of \( \alpha \), \( c_l \), \( c_d \), and \( a \), these terms are evaluated by subroutine CALC. Interdependence of the terms is indicated by the determining equations:

\[
\tan \phi = \left( \frac{1-a}{1+a} \right) \frac{V}{r \omega}
\]

\[\alpha = \phi - \theta\]

\( c_l \) and \( c_d \) are functions of \( \alpha \).

Lift and drag coefficients may be determined by algebraic equations in subroutine NACAXX or by
interpolation in a table of data, controlled by subroutine AFOIL. In each case, the coefficients are corrected by INCREM, if appropriate (i.e., if ailerons or spoilers are used).

IF IRC = 1, subroutine NACAXX is used for all angles of attack.

IF IRC = 2, Table look-up (AFOIL) is used for unstalled blade sections; NACAXX is used for other angles of attack.

\[
C_y = C_z \cos \phi + C_d \sin \phi
\]

\[
\frac{a}{1-a} = \frac{B_cc_y}{8\pi r \sin^2 \phi}
\]

\[
C_x = C_z \sin \phi - C_d \cos \phi
\]

\[
\frac{a}{1+a'} = \frac{B_cc_x}{4\pi r \sin 2\phi}
\]

Subroutine CALC-performs this series of calculations within a DO-loop until the values of a and a' converge or until 50 cycles have been completed.

OPT = 1.0, Wilson model is used.

OPT = 2.0, NASA (Viterna) model is used.
Input

In order to use WIND-II a set of formatted input (a data file) must be provided, either on data cards or through the terminal with an interactive system.

 .........READ INPUT DATA..........

READ (KR,265) NORUN,JOUR,MONTH,JAHR
READ (KR,270) MODE,NINC,VMPH,INCVEL,RPM,INCRPM
READ (KR,275) MON1,IPRINT,NF,DR,KONTRL,OPT
READ (KR,280) APP,B,BO,GO,HL,SIDEH,NN,RT,HEH,IRC,UNS,QUERY
READ (KR,285) TIPICH,TIPL,DEPL,PITCH
READ (KR,290) (RR(I),CIM(I),THETI(I),CC(I),DD(I),ISEC(I),11(I),
             *  I2(I),I3(I),I4(I),I5(I)),I=1,NF)
READ (KR,305) VBAR,SHAPE, QHOURS,P MAX,V MAX

IF (IRC.EQ.1) GO TO 15

MULTIPLE AIRFOIL READ-IN. NAS=NO. SECTIONS, NLD=NO. DATA POINTS.

DO 10 K=1,NAS
     READ (KR,295) NLD(K)
     NLEX = NLD(K)
     DO 5 J=1,NLEX
          READ (KR,300) ANGL(K,J),CLY(K,J),CDY(K,J)
      5 CONTINUE

       "                    
       265 FORMAT (215,A4,I6)
       270 FORMAT (2110,F10.2,I10,F10.2,I10)
       275 FORMAT (3110,F10.3,I10,F10.1)
       280 FORMAT (2F5.1,F5.3,2F5.1,F5.2,F10.1,2F10.3,F15)
       285 FORMAT (4F10.3)
       290 FORMAT (5F10.5,I2,5A3)
       295 FORMAT (I2)
       300 FORMAT (F10.2,2F10.6)

Input Variables

First card (or line in data set):

<table>
<thead>
<tr>
<th>Variable</th>
<th>Description</th>
<th>Columns</th>
</tr>
</thead>
<tbody>
<tr>
<td>NORUN</td>
<td>Computer run number</td>
<td>1 - 5</td>
</tr>
<tr>
<td>JOUR</td>
<td>Date (day of the month)</td>
<td>9 - 10</td>
</tr>
<tr>
<td>MONTH</td>
<td>Month (4 letters--spelled out or abbr.)</td>
<td>11 - 14</td>
</tr>
<tr>
<td>JAHR</td>
<td>Year number</td>
<td>17 - 20</td>
</tr>
</tbody>
</table>
Second card

<table>
<thead>
<tr>
<th>MODE</th>
<th>Calculating mode: 1 velocity varied 10</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>2 rpm varied</td>
</tr>
<tr>
<td>NINC</td>
<td>Number of increments of either velocity</td>
</tr>
<tr>
<td></td>
<td>or rpm</td>
</tr>
<tr>
<td>VMPP</td>
<td>Freestream wind velocity (mph)</td>
</tr>
<tr>
<td></td>
<td>(for MODE=1, ( \text{V}_{\text{min}} = \text{VMPP} + \text{INCVEL} ))</td>
</tr>
<tr>
<td></td>
<td>(for MODE=2, Velocity = VMPP)</td>
</tr>
<tr>
<td>INCVEL</td>
<td>Size of velocity increment (mph)</td>
</tr>
<tr>
<td>RPM</td>
<td>Rotational speed for MODE=1;</td>
</tr>
<tr>
<td></td>
<td>(for MODE=2, ( \Omega_{\text{min}} = \text{RPM} + \text{INCRPM} ) (rpm))</td>
</tr>
<tr>
<td>INCRPM</td>
<td>Size of rotational speed increments (rpm)</td>
</tr>
</tbody>
</table>

Third card

<table>
<thead>
<tr>
<th>MCON</th>
<th>Code for method of turbine control</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>MCON=1 Tip section pitch</td>
</tr>
<tr>
<td></td>
<td>MCON=2 Ailerons</td>
</tr>
<tr>
<td></td>
<td>MCON=3 Spoilers</td>
</tr>
<tr>
<td></td>
<td>MCON=4 Blade pitch</td>
</tr>
<tr>
<td>IPRINT</td>
<td>Code for type of printout</td>
</tr>
<tr>
<td></td>
<td>1 long printout</td>
</tr>
<tr>
<td></td>
<td>2 short printout</td>
</tr>
<tr>
<td>NF</td>
<td>Number of stations at which blade geometry are defined</td>
</tr>
<tr>
<td>DR</td>
<td>Size of radial increments (in fraction of R)</td>
</tr>
<tr>
<td></td>
<td>for which element loads are calculated</td>
</tr>
<tr>
<td></td>
<td>(recommend .02)</td>
</tr>
<tr>
<td>KONTROL</td>
<td>Number of stations at which control geometry (MODE=1, 2, or 3) is defined (for MODE=4, KONTROL=0)</td>
</tr>
<tr>
<td>OPT</td>
<td>Model for calculation of &quot;a&quot;</td>
</tr>
<tr>
<td></td>
<td>OPT=1.0, Wilson model</td>
</tr>
<tr>
<td></td>
<td>OPT=2.0, NASA model</td>
</tr>
</tbody>
</table>

Fourth card

<table>
<thead>
<tr>
<th>APF</th>
<th>Angular interference lockout:</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>APF=0.0, a' calculated</td>
</tr>
<tr>
<td></td>
<td>APF=1.0, a'=0</td>
</tr>
<tr>
<td>B</td>
<td>Number of blades</td>
</tr>
<tr>
<td></td>
<td>6 - 10</td>
</tr>
<tr>
<td>BO</td>
<td>Tip loss factor for NASA tip loss model</td>
</tr>
<tr>
<td>GO</td>
<td>Code for tip loss model used:</td>
</tr>
<tr>
<td></td>
<td>GO=0.0 Prandtl</td>
</tr>
<tr>
<td></td>
<td>GO=2.0 None</td>
</tr>
<tr>
<td></td>
<td>GO=3.0 NASA</td>
</tr>
<tr>
<td>HL</td>
<td>Hub loss model controller:</td>
</tr>
<tr>
<td></td>
<td>0.0 None</td>
</tr>
<tr>
<td></td>
<td>1.0 Prandtl</td>
</tr>
</tbody>
</table>
Fourth Card Continued

SIDEG, coning angle (degrees) 26 - 30
HM Altitude of wind turbine above sea-level (m) 31 - 40
RM Radius of the blades (m) 41 - 50
HBM Hub radius (m) 51 - 60
IRC Airfoil characteristics selector:
IRC=1 Subroutine NACAXX is used for all angles of attack
IRC=2 Subroutine AFOIL (table look-up) is used at unstalled angles of attack; NACAXX for other angles
NAS Number of airfoil sections defined for this blade 66 - 70
IQUERY Will Annual Energy be calculated and printed?
1=Yes
2=No 75

Fifth Card

TIPICH Pitch of tip section (deg.) 1 - 10
TIPL Length of movable tip section (m) 11 - 20
DEFL Angular deflection of ailerons (pos. down) or of spoilers (pos. up) (deg.) 21 - 30
PITCH Pitch angle of basic blade (deg.) 31 - 40

Sixth Card (a set of NF cards or lines of data)

RR(I) Local radius in percent of tip radius 1 - 10
CIM(I) Local chord (m) 11 - 20
THETI(I) Local twist angle, at zero pitch (deg.) 21 - 30
CC(I) Local aileron or spoiler chord (m) 31 - 40
DD(I) Deflection of aileron or spoiler (deg.) 41 - 50
ISEC(I) Code designating airfoil (e.g., 1,2,...) 51 - 52
I1(I) I2(I) I3(I) I4(I) I5(I)
Airfoil name or other designation 53 - 68

Seventh Card

VBAR Average wind speed at turbine site (mph) 1 - 10
SHAPER Shape factor for Weibull wind distribution 11 - 20
QHOURS Expected number of operating hours per year (hours/year) 21 - 30
PMAX Rated maximum turbine output (kW) 31 - 40
VMAX Cut-out wind speed (mph) 41 - 50
Eighth Data set (Note: These cards (or lines of data) are omitted if IRC=1, i.e., if airfoil data is assumed to be that in NACAXX and no table look-up is used.)—There are NAS number of sets of data.

Card 8A

\[ \text{NLD}(K) \text{ Number of angles of attack for which } C_L \text{ and } C_D \text{ are input} \]

\[ 1 - 2 \]

Card 8B

\[ \text{ANGL}(K,J) \text{ Angle of attack (deg.)} \]
\[ 1 - 10 \]

\[ \text{CLY}(K,J) \text{ Coefficient of lift} \]
\[ 11 - 20 \]

\[ \text{CDY}(K,J) \text{ Coefficient of drag} \]
\[ 21 - 30 \]

Note: When using table(s) of airfoil data it is necessary to fair the table curve to that of the airfoil (NACAXX) used at angle above and below the table values. This fairing is done by choosing one of two arbitrary coefficient values in the transition alpha range as shown in the sketch below. This adjustment should be done for both \( C_L \) and \( C_D \).
### Sample set of input data:

<p>| | | | | | |</p>
<table>
<thead>
<tr>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>23</td>
<td>27SEP</td>
<td>1982</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>2</td>
<td>25</td>
<td>27.0</td>
<td>0</td>
<td>0.0</td>
<td>10</td>
</tr>
<tr>
<td>4</td>
<td>3.0</td>
<td>0.97</td>
<td>3.0</td>
<td>0.0</td>
<td>6.0</td>
</tr>
<tr>
<td>3.0</td>
<td>0.0</td>
<td>6.0</td>
<td>0.0</td>
<td>3.962</td>
<td>0.3962</td>
</tr>
<tr>
<td>0.0</td>
<td>0.0</td>
<td>0.0</td>
<td>0.0</td>
<td>0.0</td>
<td>0.0</td>
</tr>
<tr>
<td>100.0</td>
<td>0.0</td>
<td>-0.03</td>
<td>0.0</td>
<td>0.0</td>
<td>1.0</td>
</tr>
<tr>
<td>99.0</td>
<td>0.143</td>
<td>0.13</td>
<td>0.0</td>
<td>0.0</td>
<td>1.0</td>
</tr>
<tr>
<td>98.0</td>
<td>0.178</td>
<td>0.27</td>
<td>0.0</td>
<td>0.0</td>
<td>1.0</td>
</tr>
<tr>
<td>96.0</td>
<td>0.209</td>
<td>0.58</td>
<td>0.0</td>
<td>0.0</td>
<td>1.0</td>
</tr>
<tr>
<td>94.0</td>
<td>0.229</td>
<td>0.73</td>
<td>0.0</td>
<td>0.0</td>
<td>1.0</td>
</tr>
<tr>
<td>93.0</td>
<td>0.233</td>
<td>0.82</td>
<td>0.0</td>
<td>0.0</td>
<td>1.0</td>
</tr>
<tr>
<td>92.9</td>
<td>0.233</td>
<td>0.82</td>
<td>0.0</td>
<td>0.0</td>
<td>1.0</td>
</tr>
<tr>
<td>82.5</td>
<td>0.238</td>
<td>2.65</td>
<td>0.0</td>
<td>0.0</td>
<td>2.0</td>
</tr>
<tr>
<td>82.49</td>
<td>0.238</td>
<td>2.65</td>
<td>0.0</td>
<td>0.0</td>
<td>2.0</td>
</tr>
<tr>
<td>67.5</td>
<td>0.238</td>
<td>4.95</td>
<td>0.0</td>
<td>0.0</td>
<td>3.0</td>
</tr>
<tr>
<td>67.49</td>
<td>0.238</td>
<td>4.95</td>
<td>0.0</td>
<td>0.0</td>
<td>3.0</td>
</tr>
<tr>
<td>52.5</td>
<td>0.238</td>
<td>7.25</td>
<td>0.0</td>
<td>0.0</td>
<td>4.0</td>
</tr>
<tr>
<td>52.49</td>
<td>0.238</td>
<td>7.25</td>
<td>0.0</td>
<td>0.0</td>
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| -12.0 | -0.75 | 0.014 |
| -8.0 | -0.40 | 0.011 |
| -4.0 | 0.0 | 0.009 |
| 0.0 | 0.4 | 0.007 |
| 4.0 | 0.8 | 0.007 |
| 8.0 | 1.2 | 0.010 |
| 10.0 | 1.33 | 0.014 |
| 12.0 | 1.38 | 0.020 |
| 13.0 | 1.40 | 0.022 |
| 14.0 | 1.37 | 0.07 |
| 15.0 | 1.32 | 0.136 |
| 16.0 | 1.05 | 0.1855 |

### 17

|   |   |   |   |   |
|---|---|---|---|
| -18.0 | -0.7042 | 0.2818 |
| -16.0 | -0.62 | 0.24 |
| -12.0 | -0.80 | 0.0116 |
| -8.0 | -0.43 | 0.0082 |
| -4.0 | -0.03 | 0.0070 |
| 0.0 | 0.40 | 0.0067 |
| 4.0 | 0.80 | 0.0069 |
| 6.0 | 1.00 | 0.0080 |
| 8.0 | 1.20 | 0.013 |
| 10.0 | 1.34 | 0.0164 |
| 12.0 | 1.46 | 0.0240 |
| 13.0 | 1.52 | 0.032 |
| 14.0 | 1.50 | 0.042 |
Output

Program output consists of various parts:

I. Listing of values of input variables.

II. a. Listing of local parameters at each station across blade (omitted in short printout).

b. Integrated values for complete rotor.

c. Contribution, at the given rotational speed and wind speed, to annual energy production.

d. Summary of annual energy production.
# Samples of Printout of Results

## PART I—(Same for Long or Short Printout)

### Modeling of Wind-Axis Wind Turbine — Using Wind-II Program

**Run Number 29**

**4 Oct. 1982**

#### Turbine Description —

- **B** = 1.0 Number of Blades
- **RM** = 3.96 Radius of rotor in uncrowned position (meters)
- **HH** = 0.40 Hub radius (meters)
- **HM** = 0.0 Altitude of turbine site above sea level (meters)
- **SIDEG** = 62.5 Coming angle (degrees)
- **MCON** = Method of control (1 = tip control, 2 = aileron control, 3 = spoiler control, 4 = pitch of entire blade)
- **TIPCH** = 0.0 Pitch of tip section (degrees)
- **TIPL** = 0.0 Length of tip control section (meters)
- **DEFL** = 0.0 Angular deflection of ailerons (positive down) or of spoilers (positive up) (degrees)
- **PITCH** = 0.0 Pitch of blade (degrees)
- **NF** = 20 Number of stations at which blade geometry is defined. (Max. NF = 25)

#### Blade Configuration — (Defined at the NF Stations) —

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<tr>
<th>Local Radius (Percent)</th>
<th>Airfoil Section</th>
<th>Airfoil Identifier</th>
<th>Chord (m)</th>
<th>Theta (Degrees)</th>
<th>Aileron Chord (m)</th>
<th>Spoiler Chord (m)</th>
<th>Aileron Defl (deg)</th>
<th>Spoiler Defl (deg)</th>
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#### Description of Operation for This Run —

- **MODE** = 1 Calculation mode (1 = velocity is varied, 2 = RPM is varied)
- **NINC** = 15 Number of increments of either wind velocity or of rotational speed
- **VMPH** = 8.0 Freestream wind velocity [for mode 1, min. Vel. = VMPH + INCVEL; for mode 2, Velocity = VMPH] (mph)
- **INCVEL** = 4 Size of velocity increment (mph)
- **RPM** = 200.0 Rotational speed for mode 1. For mode 2, min. rotational speed = RPM + INCRPM (rpm)
- **INCRPM** = 0 Size of rotational speed increments (rpm)
- **VBAR** = 22.0 Annual average wind velocity at turbine site (mph)
- **QMINS** = 50000 Expected number of operating hours per year (hours/year)
- **PMAX** = 22.0 Rated maximum turbine output (kilowatts)
- **VMAX** = 40.0 Cut-out wind speed (mph)

### Mathematical Modeling —

- **OPT** = 2.0 "A" calculation control. (OPT = 1.0, Wilson model; OPT = 2.0, Viterma model)
- **APF** = 1.0 Code for calculating angular induction factor (1.0, "A" prime) not calculated; 1.0, "A" prime calculation
- **DR** = 0.020 Size of radial increments for which element loads are calculated (in fraction of blade span)
- **KONTROL** = 0 Number of stations at which control geometry is defined. Max Kontrol = 10. (If MCON = 4, KONTROL = 0)
- **BD** = 0.97 Tip loss factor for NASA tip loss model
- **GO** = 3.0 Tip loss model used (GO = 1.0, PRANDTL; GO = 2.0, NONE; GO = 3.0, NASA)
- **IRC** = 2 Blade section characteristics selector (IRC = 1, NACA; IRC = 2, FOIL table look-up)
- **NAS** = 7 Number of airfoils used in blade (10 is maximum)
- **IPRINT** = 0 Code for form of answer printout (IPRINT = 1 for long printout, IPRINT = 2 for short printout)
- **IQUERY** = 1 Will annual energy be calculated? (1 = YES; 2 = NO)
- **SHAPEK** = 2.30 Shape factor for Weibull distribution
**RUN NUMBER 29**

**NUMBER OF AIRFOILS USED IN THIS BLADE = 7**

**AIRFOIL CHARACTERISTICS**

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<th>BLADE LENGTH (METERS)</th>
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<td>0.35</td>
<td>0.029</td>
<td>0.00</td>
<td>2.4</td>
<td>0.029</td>
<td>0.007</td>
<td>0.000</td>
<td>2.0</td>
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<td>0.00</td>
<td>2.0</td>
<td>0.029</td>
<td>0.007</td>
<td>0.000</td>
<td>2.6</td>
<td>0.0</td>
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<tr>
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<td>0.39</td>
<td>0.029</td>
<td>0.00</td>
<td>2.4</td>
<td>0.029</td>
<td>0.007</td>
<td>0.000</td>
<td>2.5</td>
<td>0.0</td>
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<td>0.41</td>
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<td>0.00</td>
<td>2.0</td>
<td>0.029</td>
<td>0.007</td>
<td>0.000</td>
<td>2.6</td>
<td>0.0</td>
</tr>
</tbody>
</table>

**INTEGRATED RESULTS**

<table>
<thead>
<tr>
<th>FREESTREAM WIND SPEED (MILES/HOUR)</th>
<th>ANGULAR SPEED (RPM)</th>
<th>TIP-SPEED RATIO</th>
<th>PITCH ANGLE</th>
<th>TORQUE (KW)</th>
<th>POWER (KWE)</th>
<th>POWER COEFF.</th>
<th>THRUST (N-M)</th>
<th>THRUST COEFF.</th>
<th>HINGE MOMENT (N-M)</th>
<th>ROOT BEND (EAVE)</th>
</tr>
</thead>
<tbody>
<tr>
<td>16.0</td>
<td>7.15</td>
<td>200.0</td>
<td>11.538</td>
<td>0.0</td>
<td>140.1</td>
<td>2.93</td>
<td>0.285</td>
<td>1363.9</td>
<td>0.023</td>
<td>0.000</td>
</tr>
</tbody>
</table>

**CONTRIBUTION TO ANNUAL ENERGY AT THIS WIND SPEED**

- **WIND SPEED FOR WEIBULL DISTRIBUTION** = 16.0 MILES/HOUR
- **VELOCITY INCREMENT** = 4 MILES/HOUR
- **WEIBULL PROBABILITY FOR THIS VELOCITY** = 0.036
- **PROBABLE NUMBER OF HOURS OPERATING IN THIS SPEED RANGE** = 179.8 HOURS/YEAR
- **POWER PRODUCED DURING THAT TIME** = 2110.8 KW-HR/YEAR
- **TOTAL POWER PRODUCED AT THIS AND AT LOWER WIND SPEEDS** = 2070.4 KW-HR/YEAR
PRODUCTION OF ANNUAL ENERGY

IF THIS TURBINE OPERATES FOR 5000.0 HOURS DURING THE YEAR AT A SITE HAVING AN AVERAGE WIND SPEED OF 22.0 MPH, AND IF THE TURBINE POWER IS LIMITED TO 22.0 KILOWATTS, AND THE CUT-OFF WIND SPEED IS 40.0 MPH, THE ANNUAL ENERGY PRODUCTION WILL BE 48164.0 KILOWATT-HOURS.

PART II - Short Printout Example

PERFORMANCE OF A WIND-AXIS WIND TURBINE CALCULATED BY WIND-II PROGRAM

RUN NUMBER 17 27 SEPT 1982
NUMBER OF BLADES = 3. TURBINE DIAMETER = 7.92 METERS CONTROL IS BLADE PITCH. PITCH ANGLE IS 0.0 DEG.

INTEGRATED RESULTS --
WIND-II Program Listing

WIND

PROGRAM WIND-II -- A MODIFICATION OF PROGRAM "PROP" & "WIND"
WILL RUN PERFORMANCE STUDIES BY VARYING WIND SPEED (MODE=1)
OR ROTATIONAL SPEED (MODE=2).

"PROP" PROGRAM WAS DEVELOPED BY STEL N. WALKER AND
ROBERT E. WILSON, DEPARTMENT OF MECHANICAL ENGINEERING,
OREGON STATE UNIVERSITY.

MODIFIED BY MEL SNYDER, BILL WENTZ, CYRUS OSTOWARI AND DAVID
STAPLES OF THE ENERGY LAB AND THE AIRFOIL RESEARCH GROUP AT
WICHITA STATE UNIVERSITY, WICHITA, KANSAS.

-- MODIFICATION DATES -- JUNE 1979 TO PRESENT --
-- MOST RECENT MODIFICATION WAS SEPTEMBER 3, 1982 --

........ MAIN PROGRAM ........

WIND-II CALCULATES THE THEORETICAL PERFORMANCE PARAMETERS OF A
PROPELLER TYPE WIND TURBINE. IT UTILIZES A SIMPSON'S-RULE
METHOD / THREE PASS TECHNIQUE OF NUMERICAL INTEGRATION. THE NASA
METHOD FOR CONVERGENCE ON "A" WAS DEVELOPED BY LARRY VITERNIA.

METHOD OF CONTROL MAY BE --

(1) PITCHING OF THE TIP SECTION
(2) USE OF AILERONS
(3) USE OF OUTBOARD SPOILERS
(4) PITCH OF ENTIRE BLADE

COMMON ANGL(10,25),APF,B,CAI(25),CDY(10,25),CI(25),CLY(10,25),
* COSSI,CSI(25),DAI(25),DSI(25),GO,HB,HL,HMF,IRC,
* ISEC(25),MCON,NF,NLD(25),OMEGA,PI,R,RHO,
* RR(25),RX,SIRAD,THETI(25),THETP,VFPS,W

DIMENSION CIM(25),CC(25),DD(25),CAM(25),CSM(25),
* IL(25),I2(25),I3(25),I4(25),I5(25)

........ DEFINE INPUT AND OUTPUT INDICES ........

KR = 5
KP = 6

........ READ INPUT DATA ........

PI = 3.141593
HMF = 0.0

READ (KR,265) NORUN,JOUR,MONT,JAHR
READ (KR,270) MODE,NINC,VMPH,INCVEL,RPM,INCRPM
READ (KR,275) MCON,IPRINT,NF,DR,KONTRL,OPT
READ (KR,280) APP,B,BO,GO,HL,SIDEG,HI,K1,HBM,IRC,NAS,QUERY
READ (KR,290) TIPICH,TLPL,LEPL,PITCH
READ (KR,295) (KR(I),CIM(I),THETI(I),CC(I),DD(I),ISEC(I),I1(I),
*I2(I),I3(I),I4(I),I5(I),I=1,NF)
READ (KR,305) VBAR,SHAPEK,QHOURS,PMAX,VMAX
CALL GAMMA (SHAPEK,GAMMAK)
CSHAPE = VBAR/GAMMAK
ANNUAL = 0.0
IF (IRC.EQ.1) GO TO 15
MULTIPLE AIRFOIL READ-IN. NAS=NO. SECTIONS, NLD=NO. DATA POINTS.
      DO 10 K=1,NAS
         READ (KR,295) NLD(K)
         NLX = NLD(K)
         DO 5 J=1,NLX
            READ (KR,300) ANGL(K,J),CLY(K,J),CDY(K,J)
      10 CONTINUE
      15 DO 20 KC=1,NF
         CAI(KC) = 0.
         CSI(KC) = 0.
         DAI(KC) = 0.
         DSI(KC) = 0.
         CI(KC) = CIM(KC)/0.3048
      20 CONTINUE
      BRANCH DEPENDING ON CONTROL TYPE
      GO TO (25,35,45,55), MCON
      25 DO 30 I=1,KONTRL
         THETI(I) = THETI(I) - TIPICH
      30 CONTINUE
      GO TO 55
      35 DO 40 I=1,KONTRL
         CAI(I) = CC(I)/0.3048
         DAI(I) = DD(I)
      40 CONTINUE
      GO TO 55
      45 DO 50 I=1,KONTRL
         CSI(I) = CC(I)/0.3048
         DSI(I) = DD(I)
      50 CONTINUE
      CONVERT BLADE DIMENSIONS FROM METERS TO FEET.
      55 DM = RM*2.
         R = RM/0.3048
         H = HM/0.3048
         HB = HBM/0.3048
DO 60 KC=1,NF
CAM(KC) = 0.3048*CAI(KC)
CSH(KC) = 0.3043*CSI(KC)
60 CONTINUE

LIST INPUT VARIABLES

WRITE (KP,455)
WRITE (KP,335) RUN, JOUR, MONTH, JAHR
WRITE (KP,460)
WRITE (KP,455)
WRITE (KP,470) B
WRITE (KP,475) RC1
WRITE (KP,480) RC2
WRITE (KP,485) HM
WRITE (KP,490) SIDEC
WRITE (KP,495) ACOR
WRITE (KP,500) TIPICH
WRITE (KP,505) TIPL
WRITE (KP,510) DEPL
WRITE (KP,515) PITCH
WRITE (KP,520) NF
WRITE (KP,415)
WRITE (KP,420)
WRITE (KP,425)
WRITE (KP,430)
WRITE (KP,320) (AR(I),IL(I),I2(I),I3(I),I4(I),I5(I),ISEC(I),
* CIN(I),THETI(I),CAM(I),CSH(I),DAI(I),DSI(I),I=1,NF)
WRITE (KP,525)
WRITE (KP,530) MOD
WRITE (KP,535) NINC
WRITE (KP,540) VMPH
WRITE (KP,545) INCVEL
WRITE (KP,550) RPM
WRITE (KP,555) INCRPM
WRITE (KP,560) VBAR
WRITE (KP,565) QHOURS
WRITE (KP,600) PMA
WRITE (KP,610) VMAX
WRITE (KP,560)
WRITE (KP,565) OPT
WRITE (KP,570) APF
WRITE (KP,575) DR
WRITE (KP,580) KONTRL
WRITE (KP,585) BO
WRITE (KP,590) GO
WRITE (KP,595) IRC
WRITE (KP,600) NAS
WRITE (KP,605) IPRINT
WRITE (KP,670) IQUERY
WRITE (KP,675) SHAPEK
IF (IRC.EQ.1) GO TO 75

LIST AIRFOIL CHARACTERISTICS

WRITE (KP,385) NORUN, JOUR, MONTH, JAHR
WRITE (KP, 335) MAS
WRITE (KP, 340)
WRITE (KP, 445)
WRITE (KP, 450)

DO 70 K=1, MAS
    WRITE (KP, 310) K
    NLX = NLD(K)
    DO 65 J=1, NLX
        WRITE (KP, 315) ANGL(K, J), CLY(K, J), CDY(K, J)
    CONTINUE
70 CONTINUE

PRINT ANSWER SHEET HEADING

WRITE (KP, 390)
WRITE (KP, 335) NORUN, JOUR, MONTH, JAHR
WRITE (KP, 610) B, D
GO TO (80, 85, 90, 95), MCON

60 WRITE (KP, 395) TIPICH
    GO TO 100

35 WRITE (KP, 400) DEFL
    GO TO 100

90 WRITE (KP, 405) DEFL
    GO TO 100

95 WRITE (KP, 410) PITCH
100 CONTINUE

IF (IPRINT.EQ.1) GO TO 105
WRITE (KP, 365)
WRITE (KP, 330)
WRITE (KP, 350)
WRITE (KP, 355)
WRITE (KP, 360)
WRITE (KP, 330)

105 DO 240 NO=1, NINC
    IF (IPRINT.EQ.2) GO TO 110
    WRITE (KP, 325)
    WRITE (KP, 335)
    WRITE (KP, 340)
    WRITE (KP, 345)
    WRITE (KP, 325)

240 CONTINUE

110 IF (MODE.EQ.1) GO TO 115
    IF (MODE.EQ.2) 245, 120, 245
115 DELV = INCVEL
    VMPH = VMPH + DELV
    GO TO 125

120 RPMINC = INCRPM
RPM = RPM + RPMINC
RADEG = PI / 180.
FPSMPH = 83. / 60.

STORE INITIAL VALUES
IREAD = 0
S1 = R
S2 = DR
S3 = H
S4 = PITCH
S6 = RPM

SIDEG IS CONING ANGLE (PSI) IN DEGREES
THETP = -PITCH * RADEG
VFPS = VMPH * FPSMPH
OMEGA = RPM * PI / 30.
SIRAD = SIDEG * RADEG

COSSI = COS (SIRAD)
W = R * COSSI * OMEGA
X = W / VFPS

..... INITIALIZATION AND CONSTANT PARAMETER CALCULATIONS ......

SUM1 = 0.0
SUM2 = 0.0
QX = 0.0
QY = 0.0
TX = 0.0
TY = 0.0
PY = 0.0
ASTOP = 0.0
THET = 0.0
TSMOM = 0.0

INDUCED VELOCITY FACTORS ARE SET EQUAL TO ZERO TO BEGIN ITERATION
A = 0.0
AP = 0.0
HMOM = 0.0
CONTRL = 3.0

'CONTROL' COUNTS STEP IN 3-STEP SIMPSON RULE INTEGRATION
RHO = 0.0023769199 * EXP (-0.297 * H / 10000.)
RX = R

CORRECT FOR CONING
R = R * COSSI
REF = BO * R
DR = DR * R
DRO = DR
HB = HB*COSSI

'NN' IS THE NUMBER OF STEPS ACROSS THE BLADE SPAN.
IT IS DETERMINED FROM THE INPUT VALUE OF 'DR'.

NN = (R-HB)/DR+3.
IF (IREAD.GT.0) GO TO 135

DO 130 L=1,NN
   RR(L) = R*RR(L)/100.
   THETI(L) = THETI(L)*RADEG
130 CONTINUE

SET R LOCAL EQUAL TO RMAX

135 RL = R

...... NUMERICAL INTEGRATION FROM TIP TO HUB ......

   CAT = 1.
   IF (GO.EQ.2.) CAT = 2.
   CLFA = 1.
   IF (GO.LT.2.) GO TO 145
   IF (GO.EQ.3.) CLFA = 0.0
   IF (IREAD.GT.0) GO TO 140

   CALL SEARCH (RL,C,THET,CA,CS,DA,DS,ISECT)

140 CALL CALC (RL,C,THET,QX,TX,A,AP,CLFA,CAT,CL,CD,ALFA,CH,CA,CS,DA,DS,ISECT,NLX,OPT)

RE-INITIALIZE 'A'

145 A = 0.0
   CAT = 0.0

BEGIN MARCHING ACROSS SPAN FROM TIP TO HUB

DO 195 L=1,NN

DO NOT MARCH INSIDE HUB

   IF ((RL-HB).GE.DR) GO TO 150
   ASTOP = ASTOP+1.
   IF (ASTOP.GE.2.) GO TO 200
   DR = (RL-HB)
150 IF (GO.LT.3.) GO TO 160

TEST FOR STEP IN 3-POINT SIMPSON

   IF (CONTRL.EQ.0.0) GO TO 160
   TIP = RL-DR
   IF (TIP.GT.REF) GO TO 155
   IF (CONTRL.EQ.2.) GO TO 160
   DR = (RL-REF)
$CLFO = (\text{REF-TIP})/(\text{RL-TIP})$
$CLF = .5*CLFO$
$\text{CONTRL} = 1.$
GO TO 160

155  \text{CLF} = 0.0
160  \text{DR2} = \text{DR}/2.$
$\text{JT6} = \text{DR}/(6.*\text{COSI})$

\text{INCREMENT 'R' BY 'DR/2'}

$\text{RL} = \text{RL-DR2}$
$\text{RTAB} = \text{RL}$
\text{IF (CONTRL.EQ.0.0) CLF = 1.}$
\text{IF (CONTRL.EQ.2.0) CLF = (CLFO+1.)/2.}$
\text{IF (IREAD.GT.0) GO TO 165}$

\text{FIND LOCAL CHORDS AND ANGLES}
\text{CALL SEARCH (RL,C,THET,CA,CS,DA,DS,ISECT)}$

\text{CALCULATE VALUES AT R+DR/2 STATION}$

165  \text{CALL CALC (RL,C,THET,QXP1,TXP1,A,AP,CLF,CAT,CL,CD,ALFA,CH,}$
$\text{CA,CS,DA,DS,ISECT,NLX,OPT)}$

\text{INCREMENT R BY DR/2 AGAIN (TOTAL INCREMENT = DR)}$

$\text{RL} = \text{RL-DR2}$
\text{IF (CONTRL.EQ.0.0) CLF = 1.}$
\text{IF (CONTRL.EQ.1.0) CLF = CLFO}$
\text{IF (CONTRL.EQ.2.0) CLF = 1.0}$
\text{IF (IREAD.GT.0) GO TO 170}$

\text{FIND LOCAL CHORDS AND ANGLES}
\text{CALL SEARCH (RL,C,THET,CA,CS,DA,DS,ISECT)}$

\text{CALCULATE VALUES AT R+DR STATION}$

170  \text{CALL CALC (RL,C,THET,QXP,TXP,A,AP,CLF,CAT,CL,CD,ALFA,CH,}$
$\text{CA,CS,DA,DS,ISECT,NLX,OPT)}$

\text{THETA=LOCAL BLADE TWIST ANGLE - PITCH ANGLE}$

\text{THETA = THET+THETP}$
\text{PCRL = (100.)*RTAB/R}$
\text{RLM = 0.3048*RTAB}$
\text{CM = 0.3048*C}$

\text{NEXT 4 STEPS INTEGRATE TORQUE, THRUST AND POWER,}$
\text{USING A THREE-POINT SIMPSON'S RULE.}$

\text{3 POINTS ARE AT R,R+DR/2,AND R+DR}
QYX = DT6*(QX+4.*QXP1+QXP)
QYXNM = JYX*1.35583
QY = QY+QYX
THINCR = DT6*(TX+4.*TXP1+TXP)
TY = TY+THINCR
THRN = THINCR*4.44827
BMINC = THRN*RLM/B
TBHOM = TBHOM+BMINC
PY = PY+OMEGA*QYX
HINC = HINC+HMF*DR/COSI

C
IF (CONTRL.EQ.2.) CONTRL = 0.0
IF (CONTRL.EQ.0.0) GO TO 175
IF ((RL-TIP).EQ.0.0) GO TO 175
   IF (CONTRL.EQ.1.) DR = REF-TIP
   IF (CONTRL.EQ.1.) CONT RL = 2.
   GO TO 180
   C
175
   C
   DR = DRO
130
   JX = QXP
   TX = TXP

C
THE NEXT THREE STEPS CALCULATE TERMS WHICH ARE
USED TO EVALUATE THE AVERAGE VALUE (\'AVA\') OF A.

AREA = 2.*PI*((RL+DR)-RL)
SUM1 = SUM1+AREA
SUM2 = SUM2+AREA*A
IF (IPRINT.EQ.2) GO TO 195
   GO TO (185,190,190,185), XCON
185
   C
   CH = 0.
190
   WMS = W*0.3048
   THETDG = THETA/57.29578
   WRITE (KP,370) PCRL,RLM,CM,THETDG,ALFA,WMS,CL,CD,CH,
   QYXNM,THRN,BMINC,A

   CONTINUE

C
200
   CTY = TY/(.5*RHO*VFPS**2*PI*RX**2)
   CPY = PY/(.5*RHO*VFPS**3*PI*RX**2)
   TP = PY/737.6

C
THE NEXT STATEMENT COMPUTES THE AVERAGE VALUE \"A\"
AVA = SUM2/SUM1

C
RESTORE INITIAL VALUES FOR POSSIBLE RERUN

C
IF (IREAD.EQ.1) GO TO 210

C
DO 205 L=1,NF
   RR(L) = 100.*RR(L)/R
   THETI(L) = THETI(L)/RADEG
205
   CONTINUE
IREAD = 1

210 R = S1
DR = S2
H3 = S3
PITCH = S4
RPM = S6
VMS = 0.447040*VMPH
QYNM = QY*1.355833
TYP = 4.44827*TY
CQ = CPY/X

HMOM = HMOM/.73752
IF (IPRINT.EQ.2) GO TO 215

WRITE (KP,260)
WRITE (KP,365)
WRITE (KP,330)
WRITE (KP,350)
WRITE (KP,355)
WRITE (KP,360)
WRITE (KP,330)

ANNUAL ENERGY CALCULATIONS BEGIN HERE --

215 IF (IQUERY.GT.1) GO TO 230
VTP = VMGH
PTP = TP
IF (MODE.EQ.2) GO TO 235
PROBV = QHOURS*SHAPEK/CSHAPE*((VTP/CSHAPE)**(SHAPEK-1.))
EXP(-(VTP/CSHAPE)**SHAPEK)
IF (TP.GT.PMAX) PTP = PMAX
IF (VMPH.GT.VMAX) GO TO 225
IF (VMPH.LT.VMAX) GO TO 220
DVSPRC = VMAX-(VMPH-FLOAT(INCVEL/2))
PROBTP = (PROBTP/FLOAT(INCVEL))*DVSPRC
GO TO 230

220 PTP = 0.0
225 PROBTP = PTP*PROBV*FLOAT(INCVEL)
IF (NO.EQ.1.OR.NO.EQ.NINC) PROBTP = PROBTP/2.
ANNUAL = ANNUAL+PROBTP

230 WRITE (KP,375) VMGH,VMGH,RPM,X,PITCH,QYNM,TP,CPY,TYP,CQ,
HMOM,TBMOM,AHA
WRITE (KP,330)
IF (IQUERY.GT.1.OR.IPRINT.EQ.2) GO TO 235
PROB = PROBV/QHOURS
WRITE (KP,615)
WRITE (KP,620) VTP
WRITE (KP,625) INCVEL
WRITE (KP,630) PROB
WRITE (KP,635) PROBV
WRITE (KP,640) PROBTP
WRITE (KP,645) ANNUAL

235 IF (IPRINT.EQ.2) GO TO 240
WRITE (KP,260)
CONTINUE
GO TO 250

INVALID MODE

WRITE (KP,380)

***** ANNUAL ENERGY RESULTS *****

IF (IQUERY.GT.1) GO TO 255
WRITE (KP,680)
WRITE (KP,685) QHOURS,VBAR
WRITE (KP,690) PMAX,VMAX
WRITE (KP,695) ANNUAL

WRITE (KP,260)
STOP

....... FORMATS FOR INPUT AND OUTPUT STATEMENTS ......

FORMAT ('I')

FORMAT ('215,A4,I6')

FORMAT ('2110,F10.2,I10,F10.2,I10')

FORMAT ('3110,F10.3,I10,F10.1')

FORMAT ('2F5.1,F5.3,2F5.1,F5.2,F10.1,2F10.3,3I5')

FORMAT ('4F10.3')

FORMAT ('5F10.5,I2,5A3')

FORMAT (I2)

FORMAT (F10.2,2F10.6)

FORMAT (5F10.0)

FORMAT ('0',20X,'AIRFOIL ID: ',I2/)

FORMAT (' ',F54.2,F22.5,F20.5)


FORMAT (' ',3X,3('---------','|------|--------','
* 5('---------','|------|--------','|------|--------')

FORMAT (' ',3X,3('---------','|------|--------','|------|--------',3('---------')

FORMAT (' ',3X,'| BLADE | RADIUS | LOCAL | BLADE ANGLE OF RE
* SULTANT | COEF. | COEF. | HINGE | TORQUE | THRUST | BEND: | M
* | A |

FORMAT (' ',3X,'| STATION | | CHORD | ANGLE | ATTACK | VE
* LOCITY | OF | OF | MOMENT | INCREMENT | INCREMENT | INCREMN
* T | |

FORMAT (' ',3X,'| PERCENT | (METERS) | (METERS) | (DEG.) | (DEG.) | (N-M) | (NEWTONS) | (N-M)
* | |

FORMAT (' ',3X,'| FREESTREAM | ANGULAR | TIP-SPEED | PITCH | TOR
* QUE | POWER | POWER | THRUST | TORQUE | HINGE | MOM | ROOT BEND.
* | A |

FORMAT (' ',3X,'| WIND SPEED | SPEED | RATIO | ANGLE |',
* 3X,'| ','9X,' | COEF. | ','10X',' | COEF. | PER | BLADE | MOMENT | (AVE) |

FORMAT (' ',3X,'| (MPH) | (M/S) | (RPM) | X | (DEG) | (N
* M) | (KW) | CP | (NEWTON) | CQ | (N-M) | (N-M)

FORMAT ('0'//6X,'INTEGRATED RESULTS --'//)
           * F11.1,F210.1,F8.3)
           * F8.3,F10.3,F11.1,F7.3/)
380 FORMAT ('0',2X,'MODE IN ERROR, PROGRAM STOPPED')
385 FORMAT ('0',12X,'RUN NUMBER',I4,76X,I2,1X,A4,15)
390 FORMAT ('1',29X,'PERFORMANCE OF A WIND-AXIS WIND TURBINE',
           * CALCULATED BY WIND-II PROGRAM')
395 FORMAT ('+',T71,'CONTROL IS TIP PITCH. TIP ANGLE IS',F5.1,
           * DEGREES')
400 FORMAT ('+',T71,'CONTROL IS AILERONS. AILERON DEFLECTION IS',F6.1,
           * DEG. ')
405 FORMAT ('+',T71,'CONTROL IS SPOILERS. SPOILER DEFLECTION IS',F5.1,
           * DEG. ')
410 FORMAT ('+',T71,'CONTROL IS BLADE PITCH. PITCH ANGLE IS',F5.1,
           * DEG. ')
415 FORMAT ('0',4X,'BLADE CONFIGURATION - (DEFINED AT THE NF STATIONS)
           * - - )
420 FORMAT ('0',10X,'LOCAL RADIUS AIRFOIL SECTION AIRFOIL CH
           *ORD THE ETA AILERON SPOILER AIRFOIL SPOILER')
425 FORMAT (' ',11X,'(PERCENT)',22X,'IDENTIFIER (M) (DEGREES)
           * CHORD(M) CHORD(M) DEFL(DEG) DEFL(DEG) '
430 FORMAT (' ',10X,'---------------------------
           * ---- -------- --------------- ---- ----
435 FORMAT ('-',7X,'NUMBER OF AIRFOILS USED IN THIS BLADE = ',I2)
440 FORMAT ('-',10X,'AIREFOIL CHARACTERISTICS - - ')
445 FORMAT (' ',44X,'ANGLE OF ATTACK',8X,'COEFFICIENT',8X,
           * 'COEFFICIENT')
450 FORMAT (' ',47X,'(DEGREES)',12X,'OF LIFT',12X,'OF DRAG')
455 FORMAT ('1',MODELING OF WIND-AXIS WIND TURBINE - USING WIND',
           * -II PROGRAM')
460 FORMAT (' ',28X,10(' '),'LISTING OF INPUT VARIABLES ',10(' ')')
465 FORMAT (' ',TURBINE DESCRIPTION - - ')
470 FORMAT ('0',B =',F7.1,' NUMBER OF BLADES')
475 FORMAT (' ',RM =',F8.2,' RADIUS OF ROTOR IN UNCONED',
           * POSITION (METERS) ')
480 FORMAT (' ',HBM =',F8.2,' HUB RADIUS (METERS) ')
485 FORMAT (' ',HM =',F7.1,' ALTITUDE OF TURBINE SITE',
           * ABOVE SEA LEVEL (METERS) ')
490 FORMAT (' ',SIDEG =',F7.1,' CONING ANGLE (DEGREES) ')
495 FORMAT (' ',MCON =',I5,5X,'METHOD OF CONTROL (1=TIP CONTROL,
           *2=AILERON CONTROL, 3=SPOILER CONTROL, 4=PITCH OF ENTIRE BLADE)
500 FORMAT (' ',TIPICH =',F7.1,' PITCH OF TIP SECTION (DEGREES) ')
505 FORMAT (' ',TIPL =',F7.1,' LENGTH OF TIP CONTROL SECTION',
           * (METERS) '
510 FORMAT (' ',DEFL =',F7.1,' ANGULAR DEFLECTION OF AILERONS (*
           *POSITIVE DOWN) OR OF SPOILERS (POSITIVE UP) (DEGREES)' )
515 FORMAT (' ',PITCH =',F7.1,' PITCH OF BLADE (DEGREES)' )
520 FORMAT (' ',NF =',I5,5X,'NUMBER OF STATIONS AT WHICH BLADE
           *GEOMETRY IS DEFINED. (MAX. NF = 25) '
525 FORMAT ('0',DESCRIPTION OF OPERATION FOR THIS RUN - - ')
530 FORMAT ('0',MODE =',I5,5X,'CALCULATION MODE (1=VELOCITY IS',
           * VARIED, 2=RPM IS VARIED) '
535 FORMAT (' ',NINC =',I5,5X,'NUMBER OF INCREMENTS OF EITHER WIN
           *D VELOCITY OR OF ROTATIONAL SPEED)'
540 FORMAT (' ',VMPH =',F7.1,' FREESTREAM WIND VELOCITY (FOR NO
           *DE=1, MIN. VEL.=VMPH+INCVEL; FOR MODE=2, VELOCITY=VMPH) (NPH)' )
545 FORMAT (' ', 'INCVEL = ', 5X, 'SIZE OF VELOCITY INCREMENT (MPH)')
550 FORMAT (' ', 'RPM = ', F7.1, ' ROTATIONAL SPEED FOR NODE = 1.
*FOR MODE = 2, MIN. ROTATIONAL SPEED = RPM + INC RPM (RPM).')
555 FORMAT (' ', 'INCRPM = ', 5X, 'SIZE OF ROTATIONAL SPEED INCREMENT
*S (RPM)')
560 FORMAT ('0', 'MATHEMATICAL MODELING = -1')
565 FORMAT ('0', 'OPT = ', F7.1, ' "A" CALCULATION CONTROL. (OPT =
* 1.0, WILSON MODEL. OPT = 2.0, VITERNA MODEL)')
570 FORMAT (' ', 'AF = ', F7.1, ' CODE FOR CALCULATING ANGULAR IND
*UCTOR FACTOR (0.0, "A PRIME" NOT CALCULATED. 1.0, "A PRIME" CALC
*ATED.)')
575 FORMAT (' ', 'DR = ', F9.3, ' SIZE OF RADIAL INCREMENTS FOR WHIC
* H ELEMENT LOADS ARE CALCULATED (IN FRACTION OF BLADE SPAN)')
580 FORMAT (' ', 'KONTRL = ', 5X, 'NUMBER OF STATIONS AT WHICH CONTR
* L GEOMETRY IS DEFINED. MAX KONTRL = 10. (IF ACON=4, KONTRL=0)'
585 FORMAT (' ', 'BO = ', F8.2, ' TIP LOSS FACTOR FOR NASA TIP LOSS
* MODEL')
590 FORMAT (' ', 'GO = ', F7.1, ' TIP LOSS MODEL USED (GO=1.0, ',
* 'PRAHTL; GO=2.0; NONE; GO=3.0, NASA)')
595 FORMAT (' ', 'IRC = ', 5X, 'BLADE SECTION CHARACTERISTICS',
* 'SELECTOR (IRC=1,NACAXX SUBROUTINE USED. IRC=2, AFoil):
* 'TABLE LOOK-UP) IS USED')
600 FORMAT (' ', 'NAS = ', 5X, 'NUMBER OF AIRFOILS USED IN BLADE
* (10 IS MAXIMUM)')
605 FORMAT ('0', 'IPRINT = ', 5X, 'CODE FOR FORM OF ANSWER PRINTOUT ('
* INPRINT=1 FOR LONG PRINTOUT, INPRINT=2 FOR SHORT PRINTOUT)')
610 FORMAT ('0', '8X, 'NUMBER OF BLADES = ', F3.0, 5X, 'TURBINE DIAMETER =',
* 'F6.2, 'METERS')
615 FORMAT (' ', 'CONTRIBUTION TO ANNUAL ENERGY AT THIS WIND SPEED:')
620 FORMAT (' ', '5X, 'IND SPEED FOR WEIBULL DISTRIBUTION =', F30.1,
* 'MILES/HOUR')
625 FORMAT (' ', '5X, 'VELOCITY INCREMENT = ', I45, ' MILES/HOUR')
630 FORMAT (' ', '5X, 'WEIBULL PROBABILITY FOR THIS VELOCITY =', F30.3)
635 FORMAT (' ', '5X, 'PROBABLE NUMBER OF HOURS OPERATING IN THIS SPEED R
* ANGE = ', F10.1, ' HOURS/YEAR')
640 FORMAT (' ', '5X, 'POWER PRODUCED DURING THAT TIME =', F34.1, ' KW-HR/'
* YEAR')
645 FORMAT (' ', '5X, 'TOTAL POWER PRODUCED AT THIS AND AT LOWER WIND SPE
* ED = ', F11.1, ' KW-HR/YEAR')
650 FORMAT (' ', 'VBAR = ', F7.1, ' ANNUAL AVERAGE WIND VELOCITY AT
* TURBINE SITE (MPH)')
655 FORMAT (' ', 'QHOURS = ', F7.1, ' EXPECTED NUMBER OF OPERATING HOU
* RS PER YEAR (HOURS/YEAR)')
660 FORMAT (' ', 'PMAX = ', F7.1, ' RATED MAXIMUM TURBINE OUTPUT (KI
* LLOWATTS)')
665 FORMAT (' ', 'VMAX = ', F7.1, ' CUT-OUT WIND SPEED (MPH)')
670 FORMAT (' ', 'QUIRY = ', I5, 5X, 'WILL ANNUAL ENERGY BE CALCULATED?
* (1 = YES; 2 = NO)')
675 FORMAT (' ', 'SHAPEK = ', F8.2, ' SHAPE FACTOR FOR WEIBULL DISTRIBUT
* ION')
680 FORMAT ('-', '40X, 5(*)', ' PRODUCTION OF ANNUAL ENERGY ', 5(' *'))
685 FORMAT ('0', '10X, 'IF THIS TURBINE OPERATES FOR ', F6.1, ' HOURS DURIN
* G THE YEAR AT A SITE HAVING AN AVERAGE WIND SPEED OF ', F4.1,
* 'MPH.')
690 FORMAT ('0', '10X, 'AND IF THE TURBINE POWER IS LIMITED TO ', F6.1,
* 'KILOWATTS, AND THE CUT-OFF WIND SPEED IS ', F4.1, 'MPH.')
695 FORMAT ('0', '10X, 'THE ANNUAL ENERGY PRODUCTION WILL BE ', F12.1,
* 'KILOWATT-HOURS')

END
SUBROUTINE CALC (RL,C,THET,QF,TF,A,AP,CLF,CAT,CL,CD,ALFA,CH,CA,
                  CS,DA,DS,ISECT,NLX,OPT)

        CALC - DETERMINES THE AXIAL AND ANGULAR INTERFERENCE
        FACTORS AT A GIVEN RADIUS, AND COMPUTES THE
        FUNCTIONS WHICH ARE DEPENDENT ON THESE FACTORS.

COMMON ANGL(10,25),APF,B,CAI(25),CDY(10,25),CI(25),CLY(10,25),
        * COSSI,CSI(25),DAI(25),DSI(25),GO,HB,HL,HMF,IRC,
        * ISEC(25),MCON,NF,NLD(25),OMEGA,PI,R,RHO,
        * RR(25),RX,SIRAD,THETI(25),THETP,VFPS,N

KP = 6

SET INITIAL VALUES

CJE = 3.0
ALIMIT = 0.0
ALT = 0.5
AF = 0.0
XL = RL*OMEGA/VFPS
RH = HB
SIG8 = B*C/PI/RL/8.

THETA = THET+THETP

IF LAST VALUE OF 'A' WAS GREATER THAN 0.5, SET INITIAL 'A' EQUAL
TO 0. TO START ITERATION.

IF LAST VALUE OF 'A' WAS EQUAL TO OR LESS THAN 0.5, USE LAST 'A'
TO START ITERATION.

BEGIN ITERATION FOR 'A' AND 'AP'. ITERATION WILL CEASE IF NOT
CONVERGED AT 50TH STEP.

IF (AF.EQ.1.) A = 0.
AJE = SQRT(8./(4.-CJE))+.5
CPR = -2.
ALO = -10.
AHI = 10.
IF (ABS(A).GT.0.5) A = 0.0

DO 85 J=1,50

SAVE OLD 'A' AND A-PRIME('AP')

          BETAS = A
DELTA = AP

Phi is relative wind direction, including induced effects.

       PHI = ATAN(((1.-A)*COSSI/((1.+AP)*XL))
       IF (ABS(PHI).LT.0.0001) PHI = SIGN(0.0001,PHI)
SINPHI = SIN(PHI)
COSPHI = COS(PHI)
ALPHA IS ANGLE OF ATTACK
THETA IS LOCAL BLADE PITCH ANGLE
ALPHA = PHI-THETA

...... CALCULATION OF SECTIONAL LIFT AND DRAG COEFFICIENTS

CALCULATE RESULTANT VELOCITY ("W")

\[ W = VFPS \times \sqrt{((1-A) \times \cos \alpha)^2 + ((1+AP) \times xl)^2} \]
\[ PER = RL/(RX \times \cos(sIRAD)) \]

GO TO (5, 10, IRC)

5 CALL NACAXX (RL, RX, SI, ALPHA, CL, CD, W)
GO TO 15

10 NP = NLD (ISECT)
   IF (ALPHA.GE.ANGL (ISECT, 1) \times PI/180. AND. ALPHA.LE.ANGL (ISECT, NP) \times PI/180.) CALL AFOIL (ALPHA, CL, CD, ISECT)
   IF (ALPHA.LT.ANGL (ISECT, 1) \times PI/180. OR. ALPHA.GT.ANGL (ISECT, NP) \times PI/180.) CALL NACAXX (RL, RX, SI, ALPHA, CL, CD, W)

15 GO TO (25, 20, 20, 25), MCON

CALCULATE CONTROL SURFACE INCREMENTAL CL, INCREMENTAL CD, AND CH

20 CALL INCREM (ALPHA, CL, CD, CH, CA, DA, CS, DS, C)

25 ALFA = ALPHA \times 57.29578
   IF (MCON.EQ.1) CH = 0.
   IF (MCON.EQ.4) CH = 0.
   IF (GO.LT.3.) GO TO 30
   CL = CLF*CL
   F = 1.
   GO TO 35

...... CALCULATION OF TIP AND HUB LOSSES ......

30 IF (CAT.EQ.1.) F = 0.0
   IF (CAT.EQ.1.) GO TO 35
   XXL = ABS(COSPHI/SINPHI)
   XXLO = XXL*R/RL

   CALL TIPLOS (XXL, XXLO, F, B, GO, HL, PI, R, RL, PHI, RH)

35 CX = CL*SINPHI-CD*COSPHI
   CY = CL*COSPHI+CD*SINPHI

NASA-CODED MODIFICATION

\[ CT = 4. \times \text{SIG8} \times CY \times W \times W / VFPS / VFPS \]
\[ A2 = A \]
CT2 = CT/F
IF (J.GT.1) CPR = (CT2-CT1)/(A2-A1)
CZ = CT2-CPR*A2
A1 = A2
CT1 = CT2
IF (OPT.NE.1.) GO TO 40
CRF = CZ+CPR*.38
IF (CRF.GT.0.9424) GO TO 55

.... MOMENTUM THEORY ....

40    CAN = 1.-CPR/4.
    CCC = CAN*CAN-CZ
    IF (CCC.LT.0.0) GO TO 45

    A .LE. 1.0

    A = .5*(CAN-SQRT(CCC))
    GO TO 50

    A .GT. 1.0

45    CAN = 1.+CPR/4.
    CCC = CAN*CAN+CZ
    A = .5*(CAN+SQRT(CCC))
    IF (OPT.EQ.2.0) GO TO 60

WILSON EMPIRICAL ....... OPT = 1. & A .GT. 0.38
55    A = (CZ-.5778)/(.96-CPR)
    GO TO 65

NASA/LERC EMPIRICAL ... OPT = 2. & .5 .LT. A .LT. AJE
60    IF (A.LT.0.5.OR.A.GT.AJE) GO TO 65
    CAN = 1.+CPR/CJE
    CCC = CAN*CAN-1.-4.*(1.-CZ)/CJE
    A = .5*(CAN+SQRT(CCC))

CHECK LIMITS ON A ....
65    IF (ALIMIT.EQ.0.0) GO TO 70
    IF (A.GT.ALT) A = ALT
70    IF (A.GT.A2) ALO = A2
    IF (A.LT.A2) AHI = A2
    IF (A.LE.ALO.OR.A.GE.AHI) A = (A2+ALO+AHI)/3.0
    IF (APP.EQ.1.0) GO TO 75
    VAR = SIG8*CX/SINPHI/COSPHI
    AP = VAR/(F-VAR)

END OF NASA-CODED MODIFICATION ....
75    CONTINUE

        ....... TEST FOR CONVERGENCE .......
IF (APF.EQ.1.) GO TO 80
IF (ABS(AP-DELTA).LE..001) GO TO 90
GO TO 85

30 IF (ABS(A-BETA).LE..001) GO TO 90
95 CONTINUE

IF 'A' DOES NOT CONVERGE IN FIFTY ITERATIONS, PRINT WARNING AND CONTINUE.

WRITE (KP,95)

COMPUTE FUNCTIONS DEPENDENT ON 'A'

90 W = VFPS*SQRT(((1.-A)*COSI)**2+(1.+AP)*XL)**2) 
CT1 = (0.5*RHO*W*C)*(W)*W
QF = CT1*RL*CX
TF = CT1*CY*COSI
IF (NCON.EQ.2) HMF = CH*CT1*CA**2/C
IF (NCON.EQ.3) HMF = CH*CT1*CS**2/C

RETURN

95 FORMAT ('0 VALUE OF SLOWDOWN FACTOR, A , IS NOT CONVERGED/')
END
SEARCH

SUBROUTINE SEARCH (RL, C, THET, CA, CS, DA, DS, ISECT)

....... SEARCH - DETERMINES THE CHORD AND THE TWIST ANGLE AT A GIVEN RADIUS ALONG THE SPAN. IT UTILIZES A LINEAR INTERPOLATION TECHNIQUE.

COMMON ANGL(10, 25), APP, B, CAI(25), CDY(10, 25), CI(25), CLY(10, 25),
* COSSI, CSI(25), DAI(25), DS1(25), GO, HB, HL, HMF, IRC,
* ISEC(25), IMCON, NF, NLD(25), OMEGA, PI, R, RHO,
* RR(25), RX, SIRAD, THETI(25), THETP, VFPS, W

RRV = RL
IF (RRV.EQ.RR(1)) GO TO 20
LOCATE THE FIRST RADIUS IN ARRAY 'RR' WHICH IS LESS THAN RLOCAL, AND THEN BRANCH TO THE INTERPOLATION STEPS.

DO 5 I=2, NF
IF (RRV.GE.RR(I)) GO TO 10
IF RLOCAL IS LESS THAN LAST VALUE IN TABLE, SET R=LAST VALUE IF (I.EQ.NF) GO TO 15
5 CONTINUE

J = I+1

COMPUTE INTERPOLATED VALUE

PER = (RRV-RR(J-1))/(RR(J-2)-RR(J-1))
C = PER*(CI(J-2)-CI(J-1))+CI(J-1)
THET = PER*(THETI(J-2)-THETI(J-1))+THETI(J-1)

CA = PER*(CAI(J-2)-CAI(J-1))+CAI(J-1)
CS = PER*(CSI(J-2)-CSI(J-1))+CSI(J-1)
DA = PER*(DAI(J-2)-DAI(J-1))+DAI(J-1)
DS = PER*(DSI(J-2)-DSI(J-1))+DSI(J-1)
XISECT = PER*(ISEC(J-2)-ISEC(J-1))+ISEC(J-1)
ISECT = XISECT+0.5
RETURN

VALUES REQUIRED AT THE FINAL STATION

15 C = CI(NF)
THET = THETI(NF)
CA = CAI(NF)
CS = CSI(NF)
DA = DAI(NF)
DS = DSI(NF)
ISECT = ISEC(NF)
RETURN

VALUES REQUIRED AT THE FIRST STATION

20 C = CI(1)
THET = THETI(1)
CA = CAI(1)
CS = CSI(1)
SUBROUTINE INCREM (ALPHA, CL, CD, CH, CA, DA, CS, DS, C)

THIS ROUTINE ADJUSTS AIRFOIL COEFFICIENTS
FOR THE DEFLECTION OF SPOILERS OR AILERONS

PI = 3.141593
Y = ALPHA*180./PI

THE VALUE OF CHO DEPENDS ON AIRFOIL CAMBER NEAR TRAILING EDGE.
THIS VALUE OF CHO IS FOR NACA 230 MEAN LINE AILERONS ONLY.

CHO = -.0035
CH = 0.
DAR = DA*PI/180.
DSR = DS*PI/180.
SIN2DA = SIN(DAR)*SIN(DAR)
SIN2DS = SIN(DSR)*SIN(DSR)
IF (CA.EQ.0.) GO TO 15

BEGIN AILERON INCREMENT CALCULATIONS
CHECK FOR POST STALL CONDITION

IF (17..LT.Y.OR.Y.LT.-17.) GO TO 25
IF (0..LE.DA.AND.DA.LE.60.) GO TO 5
IF (-60..LE.DA.AND.DA.LT.0.) GO TO 10

DCL = CA/C*(11.5*SIN(DAR)-5.*SIN2DA)
DCD = 1.05*CA/C*SIN2DA
CH = CA/C*(CHO-.0542*Y-2.*SIN(DAR))
GO TO 20
DCL = CA/C*(11.5*SIN(DAR)+3.35*SIN2DA)
DCD = .65*CA/C*SIN2DA
CH = CA/C*(CHO-.0542*Y-2.*SIN(DAR))
GO TO 20

15 IF (CS.EQ.0.) GO TO 30

BEGIN SPOILER INCREMENT CALCULATIONS

IF (17.LT.Y. OR.Y.LT.-17.) GO TO 30

SPOILER IS ASSUMED INEFFECTIVE FOR POST-STALL CASES

DCL = -9.9*CS/C*SIN(DSR)
DCD = .93*CS/C*SIN2DS

IF (0..LT.Y. AND.Y.LE.17.) CH = -(6.7-.175*Y)*CS/C*SIN2DS
IF (-17..LE.Y. AND.Y.LE.0.) CH = -(6.7-.075*Y)*CS/C*SIN2DS

20 CL = CL+DCL
CD = CD+DCD
GO TO 30

CALCULATE POST-STALL CONDITIONS FOR AILERON
CONVERT CL AND CD TO CN AND CC

CN = NORMAL FORCE COEFFICIENT

25 CN = CL*COS(ALPHA)+CD*SIN(ALPHA)

CC = CHORDWISE FORCE COEFFICIENT

CC = CD*COS(ALPHA)-CL*SIN(ALPHA)

CALCULATE CONTRIBUTIONS TO FORWARD ELEMENT

CN1 = CN*(1.-CA/C)
CC1 = CC*(1.-CA/C)

CALCULATE AILERON CONTRIBUTIONS

CN2 = 2.27*2.*PI*SIN(ALPHA+DAR)/(4.+PI*ABS(SIN(ALPHA+DAR)))
DCNA = CN2*CA/C*COS(DAR)
DCCA = CN2*CA/C*SIN(DAR)
CH = -CN2/2.
CN = CN1+DCNA
CC = CC1+DCCA

CONVERT TO LIFT AND DRAG COEFFICIENTS

CL = CN*COS(ALPHA)-CC*SIN(ALPHA)
CD = CC*COS(ALPHA)+CN*SIN(ALPHA)

30 RETURN
END
SUBROUTINE TIPLOS (U, GO, F, Q, GO, HL, PI, R, RL, PHI, RH)

...... TIPLOS - DETERMINES THE TIP AND HUB LOSSES BASED UPON PRANDTL'S THEORY, OR FOR ASSUMPTION OF NO LOSSES.

SUM2 = 0.0
SUM = 0.0
AMM = 1.
AM = 0.0

IF (Q.GT.2.0) GO TO 5
  IF (GO.EQ.0.0) GO TO 10
    IF (GO.EQ.1.0) GO TO 20
      IF (GO.EQ.2.0) GO TO 15
  5 IF (GO.EQ.2.0) GO TO 15

10 F = (2./PI)*ARCCOS(EXP(-(Q*(R-RL)))/(2.*RL*SQRT(SIN(PHI)**2
     * +0.0001)))
  GO TO 25

15 F = 1.0
  GO TO 25

20 WRITE (KP,40)
  GO TO 10

HUBLOSS CALCULATIONS

25 IF (HL.EQ.1.0) GO TO 30
  FI = 1.0
  GO TO 35

30 FI = (2./PI)*ARCCOS(EXP(-(Q*(RL-RH)))/(2.*RH*SQRT(SIN(PHI)**2
    * +0.0001)))
35 F = F*FI

RETURN

40 FORMAT ('-','15('+'),'GOLDSTEIN TIP LOSS MODEL IS NOT AVAILABLE.),'\n  ' SOLUTION ASSUMES NO TIP LOSS.',['15('+')]\nEND
SUBROUTINE NACAXX (RL, RX, SI, ALPHA, CL, CD, W)

THIS SUBROUTINE CALCULATES LIFT AND DRAG COEFFICIENTS
FOR THE NACA 23024 HALF ROUGH AIRFOIL AS A FUNCTION
OF THE ANGLE OF ATTACK ALPHA (IN RADIANS).

\[ Y = \text{ALPHA} \times \frac{180}{3.1415927} \]
\[ \text{AALPHA} = \text{ABS}(\text{ALPHA}) \]
\[ X = \text{ABS}(Y) \]

IF (8. LT. X .AND. X .LT. 13.) CD = X/248.8-.01675
IF (-9. LE. Y .AND. Y .LE. +8.) CD = -2.09050E-6*Y**3+7.19573E-5*Y**2
* +2.26766E-4*X+9.99331E-3
IF (13. LE. X .AND. X .LT. 160.) CD = 2. -1.089*(1.57-AALPHA)**2
IF (160. LE. X .AND. X .LE. 180.) CD = 0.04+2.8*(AALPHA-3.142)**2
IF (10. LE. X .AND. X .LE. 16.) CL = -1.25E-3*X**3+4.55953E-2*X**2
* -5.47084E-1*X+3.04822
IF (-12. LE. Y .AND. Y .LT. 10.) CL = 2.64619E-10*Y**8+2.39782E-3*Y**7
* +1.03975E-7*Y**6-5.54091E-6*Y**5-2.20717E-5*Y**4+3.11341E-4*Y
* **3+4.55110E-4*Y**2+8.26369E-2*Y+1.00579E-1
IF (16. LT. X .AND. X .LE. 90.) CL = 1.1-1.78*(AALPHA-.7853)**2
IF (10. LT. Y .AND. Y .LT. 17.8) CL = -.4388+.2233*Y-.00899*Y**2
IF (90. LT. X .AND. X .LE. 160.) CL = -1.1+1.78*(AALPHA-2.356)**2
IF (160. LT. X .AND. X .LE. 172.5) CL = -.763
IF (172.5. LT. X .AND. X .LE. 180.) CL = .10173*X-18.3114
IF (Y.LT.-12.) CL = -CL

RETURN
END
AFOIL

SUBROUTINE AFOIL (ALPHA, CL, CD, K)

THIS ROUTINE INTERPOLATES LOCAL VALUES OF COEFFICIENTS
OF LIFT AND DRAG FROM AN AIRFOIL CHARACTERISTICS TABLE.

COMMON ANGL(10,25), APF, B, CAI(25), CDY(10,25), CI(25), CLY(10,25),
*    COSSI, CSI(25), DAI(25), DS1(25), GO, HB, HL, HMP, IRC,
*    ISIC(25), HCON, NF, NL0(25), OMEGA, PI, R, RHO,
*    RR(25), RX, SIRAD, THETI(25), THETP, VFPS, W

NOTE - ALPHA IS SECTION ANGLE OF ATTACK IN RADIANS
- ALFA IS SECTION ANGLE OF ATTACK IN DEGREES

ALFA = ALPHA*180./3.141593
NLX = NL0(K)
IF (ALFA-ANGL(K,1)) 25,20,5

5 DO 10 L=2,NLX
   IF (ALFA-ANGL(K,L)) 15,20,10
10 CONTINUE

15 DIF = ANGL(K,L)-ANGL(K,L-1)
   FRACT = (ALFA-ANGL(K,L-1))/DIF
   CL = CLY(K,L-1)+FRACT*(CLY(K,L)-CLY(K,L-1))
   CD = CDY(K,L-1)+FRACT*(CDY(K,L)-CDY(K,L-1))
   GO TO 25

20 CL = CLY(K,L)
   CD = CDY(K,L)

25 RETURN
END
SUBROUTINE GAMMA (SHAPEK, GAMMAK)

THIS ROUTINE OBTAINS THE VALUE OF THE GAMMA FUNCTION FOR THE
QUANTITY (1+1/K) FOR USE IN THE WEIBULL DISTRIBUTION NEEDED BY
THE "EQUIVALENT ANNUAL ENERGY" CALCULATIONS IN THE MAIN
PROGRAM. THE METHOD OF INTEGRATION IS SIX-POINT GAUSSIAN
QUADRATURE. REFERENCE: HEWLETT-PACKARD HP-67/97 MATH PAC 1.

DOUBLE PRECISION Z(6), A(6), X, FX, SUM, SUMI

Z(1) = .2386191861
Z(2) = -Z(1)
Z(3) = .6612093865
Z(4) = -Z(3)
Z(5) = .3324693142
Z(6) = -Z(5)

W(1) = .4679139346
W(2) = W(1)
W(3) = .3607615730
W(4) = W(3)
W(5) = .1713244924
W(6) = W(5)

SUM = 0.
SUMI = 0.

DO 5 I=1,6
   X = Z(I)/(1.+Z(I)) - 1.
   FX = DEXP(-X)*(X**(1./SHAPEK))
   SUMI = W(I)/((1.+Z(I))**2)*FX
   SUM = SUM+SUMI
5 CONTINUE
GAMMAK = SUM*2.

RETURN
END
References

