WIND ENERGY REPORT NO.12

WIND
Users Manual

by
Melvin H. Snyder

WIND ENERGY LABORATORY
WICHITA STATE UNIVERSITY

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Wind Energy Laboratory
Wichita State University
Wichita, Kansas 67208

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Computer code WIND 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

WIND is a modification of 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-O 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 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 is a computer code which has been titled WIND. A copy of WIND is loaded on Lewis Research Center computer system 370. The Wind Energy Laboratory at Wichita State University is maintaining WIND. Copies of the code in the form of a card deck can be supplied by the Wind Energy Laboratory to qualified users. Requests for card decks or questions regarding use of WIND should be addressed to Prof. M. H. Snyder at W.S.U.

Program Organization

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

Main Program

WIND - The program will calculate performance of wind turbines which employ any of the control systems:

1. Pitching of the tip section
2. Deflection of ailerons on the blades
3. Deflection of spoilers 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.

**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.

INCREM - This subroutine calculates increments of lift coefficient and drag coefficient due to deflection of aileron or spoiler. Hinge moment coefficient is also calculated.

MUTANT - This subroutine modifies lift and drag coefficients because of change in the NACA 23024 section. The form of the subroutine on 15 July 1980 was such that responding to an input value of MUT = 1, calculation of lift and drag coefficients are made for an NACA 23024 airfoil with leading-edge slots. Other options corresponding to other positive values of MUT may be added.

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

BESSEL - Subroutine BESSEL is referred to in subroutine TIPLØS, but it is not supplied and should not be called. The Goldstein tip model is not available.

**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 1.

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 short printout lists, for each condition, local angle of attack, coefficients of lift and drag, increments of thrust, torque and power produced, and local induced effects at each station across blade length from tip to hub.

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:

\[ V \rightarrow V(1-\alpha) \rightarrow V(1-2\alpha) \]

Attenuation of axial velocity in streamtube through turbine.

\[ r\omega(1+\alpha') = 2\pi r n(1+\alpha') \]

Relative wind components at a blade section.

\( \alpha \) and \( \alpha' \) are induced flow correction factors. \( \alpha \), 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, \( \alpha \) appears to be a single value across the rotor plane. However, the value of \( \alpha \) varies across the rotor, from tip to hub, depending on the mode of operation. Local \( \alpha \) is a function of local \( c_{\alpha} \), and \( c_{d} \) (detailed in a latter section of this guide).

\( \alpha' \) expresses rotation imparted to the air as it passes through the plane of the rotor. Wilson states that most desirable value of \( \alpha \) (for max \( c_{p} \)) is \( \alpha = 1/3 \) (reference 1). \( \alpha' \) is usually an order of magnitude smaller than \( \alpha \), and error due to assuming \( \alpha' = 0 \) 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 = \( \theta = \tan^{-1} \left( \frac{V}{r\omega} \frac{1 - a}{1 + a} \right) \)

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 \( \theta_{\text{twist}} \) with positive \( \theta \) toward root and negative \( \theta \) toward 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, \( \theta \), 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 subroutines SEARCH twice. SEARCH determines the values by interpolation.
Then, at those three stations in each element, $\alpha$, $c_l$, $c_d$ are determined and from them, the values of torque per unit span, thrust per unit span, power per unit span, and, if appropriate, hinge moment per unit span. 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:

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

$$
QYX = DT6*(QX + 4.*QXP1 + QXP)
$$

Then the 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 \( \alpha \), these terms are evaluated by subroutine CALC. Interdependence of the terms is indicated by the determining equations:

\[
\tan \phi = \left( \frac{1-\alpha'}{1+\alpha'} \right) \frac{V}{ru}
\]

\[
\alpha = \phi - \Theta
\]

c\(_l\) and c\(_d\) are functions of \( \alpha \)

(Defined by algebraic equations in subroutines NACAXX, plus INCREM and/or MUTANT, if appropriate.)

\[
C_y = c_l \cos \phi + c_d \sin \phi
\]

\[
\frac{\alpha}{1-\alpha} = BC \frac{C_y}{8 \pi r \sin^2 \phi}
\]

\[
c_x = c_l \sin \phi - c_d \cos \phi
\]

\[
\frac{\alpha'}{1+\alpha'} = BC \frac{C_x}{4 \pi r \sin 2 \phi}
\]

Subroutine CALC performs this series of calculations within a DO-loop until the values of \( \alpha \) and \( \alpha' \) converge or until 50 cycles have been completed. In some cases, the value of \( \alpha \) will not converge; to prevent use of an unrealistic value of \( \alpha \) an option is available which will limit the value of \( \alpha \). The input variable KFLAG provides the desired boundary.

If KFLAG = 1, \( \alpha = 0 \)
If KFLAG = 2, \(-0.5 \leq \alpha \leq +0.5 \)
If KFLAG = 3, \( \alpha \) is not limited

Good results have been obtained from KFLAG = 2.

Input

In order to use WIND a set of formatted input must be provided, either on data cards or through the terminal with an interactive system.
.. READ INPUT DATA ..

READ (KR,175) NORUN, JOUR, MONTH, JAHR
READ (KR,180) MODE, NINC, V, INCVEL, OMEGA, INCRPM
READ (KR,185) MCON, KFLAG, IPRINT, NF, DR, MUT
READ (KR,190) AMOD, APF, B, BO, GO, HL, SI, H, R, HB
READ (KR,195) AF1, AF2, AF3, TIPICH, TIPL, SPAN, DEFL, PCTSPN, PITCH
READ (KR,200) (RR(I), CI(I), THETI(I), CC(I), DD(I), I=1, NF)

175 FORMAT (2I5, A4, I6)
180 FORMAT (2I10, F10.2, I10, F10.2, I10)
185 FORMAT (4I10, F10.3, I10)
190 FORMAT (10F8.2)
195 FORMAT (3A4, 6F8.3)
200 FORMAT (5F10.5)

Input Variables

First card (or line in data set):

<table>
<thead>
<tr>
<th>Variable</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>NORUN</td>
<td>Computer run number</td>
</tr>
<tr>
<td>JOUR</td>
<td>Date (day of the month)</td>
</tr>
<tr>
<td>MONTH</td>
<td>Month (4 letters—spelled out or abbr.)</td>
</tr>
<tr>
<td>JAHR</td>
<td>Year number</td>
</tr>
</tbody>
</table>

Second card

<table>
<thead>
<tr>
<th>Variable</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>MODE</td>
<td>Calculating mode: 1→velocity varied</td>
</tr>
<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>V</td>
<td>Freestream wind velocity (mph)</td>
</tr>
<tr>
<td></td>
<td>(for MODE = 1, ( V_{\text{min}} = V + \Delta V );</td>
</tr>
<tr>
<td></td>
<td>for MODE = 2, ( V = \text{this velocity} )</td>
</tr>
<tr>
<td>INCVEL</td>
<td>Size of velocity increment (mph)</td>
</tr>
<tr>
<td>OMEGA</td>
<td>Rotational speed for MODE = 1;</td>
</tr>
<tr>
<td></td>
<td>for MODE = 2, ( \Omega_{\text{min}} = \Omega + \Delta \Omega )</td>
</tr>
<tr>
<td>INCRPM</td>
<td>Size of rotational speed increments (rpm)</td>
</tr>
</tbody>
</table>

Third card

<table>
<thead>
<tr>
<th>Variable</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>MCON</td>
<td>Code for method of turbine control</td>
</tr>
<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>KFLAG</td>
<td>Code for convergence boundary for a</td>
</tr>
<tr>
<td></td>
<td>KFLAG = 1 → ( a = 0 )</td>
</tr>
<tr>
<td></td>
<td>KFLAG = 2 → (-0.5 \leq a \leq 0.5)</td>
</tr>
<tr>
<td></td>
<td>KFLAG = 3 → ( a ) is not limited</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</td>
</tr>
<tr>
<td></td>
<td>(chord and blade angle) are defined</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Column</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>1 - 5</td>
<td>NORUN</td>
</tr>
<tr>
<td>9 - 10</td>
<td>JOUR</td>
</tr>
<tr>
<td>11 - 14</td>
<td>MONTH</td>
</tr>
<tr>
<td>17 - 20</td>
<td>JAHR</td>
</tr>
<tr>
<td>10</td>
<td>MODE</td>
</tr>
<tr>
<td>11 - 20</td>
<td>NINC</td>
</tr>
<tr>
<td>21 - 30</td>
<td>V</td>
</tr>
<tr>
<td>31 - 40</td>
<td>INCVEL</td>
</tr>
<tr>
<td>41 - 50</td>
<td>OMEGA</td>
</tr>
<tr>
<td>51 - 60</td>
<td>INCRPM</td>
</tr>
<tr>
<td>10</td>
<td>MCON</td>
</tr>
<tr>
<td>20</td>
<td>KFLAG</td>
</tr>
<tr>
<td>30</td>
<td>IPRINT</td>
</tr>
<tr>
<td>38 - 40</td>
<td>NF</td>
</tr>
</tbody>
</table>
Third card (cont.)

<table>
<thead>
<tr>
<th>Code</th>
<th>Description</th>
<th>Columns</th>
</tr>
</thead>
<tbody>
<tr>
<td>DR</td>
<td>Size of radial increments (in fraction of R) for which element loads are calculated (recommend 0.02)</td>
<td>41 - 50</td>
</tr>
<tr>
<td>MUT</td>
<td>Code for use of subroutine MUTANT: MUT = 0 + subroutine is not called MUT.GE.1 + part of subroutine is used</td>
<td>60</td>
</tr>
</tbody>
</table>

Fourth card

<table>
<thead>
<tr>
<th>Code</th>
<th>Description</th>
<th>Columns</th>
</tr>
</thead>
<tbody>
<tr>
<td>AMOD</td>
<td>Defines model for calculation of axial slowdown factor. At present, use 0.0</td>
<td>5 - 7</td>
</tr>
<tr>
<td>APF</td>
<td>Angular interference lockout: APF = 0.0, a' calculated APF = 1.0, a' = 0</td>
<td>13 - 15</td>
</tr>
<tr>
<td>B</td>
<td>Number of blades</td>
<td>21 - 23</td>
</tr>
<tr>
<td>BO</td>
<td>Tip loss factor for NASA tip loss model</td>
<td>25 - 32</td>
</tr>
<tr>
<td>GO</td>
<td>Code for tip loss model used: GO = 0.0 + Prandtl GO = 2.0 + None GO = 3.0 + NASA</td>
<td>37 - 39</td>
</tr>
<tr>
<td>HL</td>
<td>Hub loss model controller: 0.0 + None 1.0 + Prandtl</td>
<td>45 - 47</td>
</tr>
<tr>
<td>SI</td>
<td>$\Psi$, coning angle, degrees</td>
<td>49 - 56</td>
</tr>
<tr>
<td>H</td>
<td>Altitude of wind turbine above sea-level (ft)</td>
<td>57 - 64</td>
</tr>
<tr>
<td>R</td>
<td>Radius of the blades (in coned position) (ft)</td>
<td>65 - 72</td>
</tr>
<tr>
<td>HB</td>
<td>Hub radius (ft)</td>
<td>73 - 80</td>
</tr>
</tbody>
</table>

Fifth card

<table>
<thead>
<tr>
<th>Code</th>
<th>Description</th>
<th>Columns</th>
</tr>
</thead>
<tbody>
<tr>
<td>AFL AF2</td>
<td>Name of the blade airfoil section</td>
<td>1 - 12</td>
</tr>
<tr>
<td>AF3</td>
<td></td>
<td></td>
</tr>
<tr>
<td>TIPICH</td>
<td>Pitch of tip section (deg.)</td>
<td>13 - 20</td>
</tr>
<tr>
<td>TIPL</td>
<td>Length of movable tip section (m)</td>
<td>21 - 28</td>
</tr>
<tr>
<td>SPAN</td>
<td>Length of aileron or spoiler (m)</td>
<td>29 - 36</td>
</tr>
<tr>
<td>DEFL</td>
<td>Angular deflection of ailerons (pos. down) or of spoilers (pos. up) (deg.)</td>
<td>37 - 44</td>
</tr>
<tr>
<td>PCTSPN</td>
<td>Percent of span of ailerons or spoilers</td>
<td>45 - 52</td>
</tr>
<tr>
<td>PITCH</td>
<td>Pitch angle of basic blade (deg.)</td>
<td>53 - 60</td>
</tr>
</tbody>
</table>

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

<table>
<thead>
<tr>
<th>Code</th>
<th>Description</th>
<th>Columns</th>
</tr>
</thead>
<tbody>
<tr>
<td>RR(I)</td>
<td>Local radius in percent of tip radius</td>
<td>1 - 10</td>
</tr>
<tr>
<td>CI(I)</td>
<td>Local chord (ft)</td>
<td>11 - 20</td>
</tr>
<tr>
<td>THETI(I)</td>
<td>Local twist angle, at zero pitch (deg.)</td>
<td>21 - 30</td>
</tr>
<tr>
<td>CC(I)</td>
<td>Local control chord (ft)</td>
<td>31 - 40</td>
</tr>
<tr>
<td>DD(I)</td>
<td>Local control deflection (deg)</td>
<td>41 - 50</td>
</tr>
</tbody>
</table>
Sample set of input data:

<p>| | | | | | | | | | |</p>
<table>
<thead>
<tr>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>101</td>
<td>19JUNE 1980</td>
<td>0.0</td>
<td>1.0</td>
<td>4.0</td>
<td>0.0</td>
<td>0.97</td>
<td>3.0</td>
<td>0.02</td>
<td>0.0</td>
</tr>
<tr>
<td>1</td>
<td>2</td>
<td>1</td>
<td>9</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>MACA 23024</td>
<td>-5.0</td>
<td>6.731</td>
<td>0.0</td>
<td>0.0</td>
<td>0.0</td>
<td>0.0</td>
<td>0.0</td>
<td>-5.0</td>
<td>2.0</td>
</tr>
<tr>
<td>100.0</td>
<td>2.08333</td>
<td>0.0</td>
<td>0.0</td>
<td>0.0</td>
<td>0.0</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>70.0</td>
<td>3.717</td>
<td>0.0</td>
<td>0.0</td>
<td>0.0</td>
<td>0.0</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>69.9</td>
<td>3.717</td>
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<td>0.0</td>
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<td>0.0</td>
<td></td>
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<td></td>
<td></td>
</tr>
<tr>
<td>64.6667</td>
<td>4.011</td>
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<td>0.0</td>
<td>0.0</td>
<td>0.0</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>64.6</td>
<td>4.003</td>
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<td>0.0</td>
<td>0.0</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>19.2</td>
<td>6.0</td>
<td>0.0</td>
<td>0.0</td>
<td>0.0</td>
<td>0.0</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>3.2</td>
<td>6.0</td>
<td>0.0</td>
<td>0.0</td>
<td>0.0</td>
<td>0.0</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>3.19</td>
<td>0.0</td>
<td>0.0</td>
<td>0.0</td>
<td>0.0</td>
<td>0.0</td>
<td></td>
<td></td>
<td></td>
<td></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>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Note that the order of specifying stations is from the tip inboard toward the root.

Output

Variable names in the WRITE lists have the following meanings:

**Local Values (long printout)**

- **PCRL**: Blade station (percent of \( \frac{\text{diameter}}{2} \)), tip = 100%
- **RLM**: Local radius (meters)
- **CM**: Local blade section chord (meters)
- **THETDG**: Local blade angle (degrees) measured from plane of rotation
- **ALFA**: Local blade section angle of attack (degrees)
- **WMS**: Local resultant velocity (m/sec)
- **CL**: Local section lift coefficient
- **CD**: Local section drag coefficient
- **CH**: Local hinge moment coefficient (for aileron or spoiler)
- **QYXNM**: Increment of torque produced by local blade element (Newton-meters)
- **THRN**: Thrust increment produced by local blade element (Newtons)
- **A**: Local value of a

**Integrated Values (long and short printouts)**

- **V**: Freestream wind speed (mph)
- **VMS**: Freestream wind speed (m/sec)
- **OMEGA**: Angular speed of rotor (rpm)
- **X**: Tip-speed ratio = \( \frac{\text{Tip speed}}{\text{Wind speed}} = \frac{\pi n D}{V} = \frac{\pi}{(V/nD)} = \frac{C_p}{C_Q} \)
PITCH  Basic blade pitch angle (degrees)
QYNM  Torque delivered to shaft (N-m)
TP    Shaft power (kiloWatts)
CPY   Power coefficient, \( C_p = \frac{\text{power}}{(\rho/2)V^2\pi R^2} \)
TYN   Total thrust (Newtons)
CQ    Torque coefficient, \( C_Q = \frac{Q}{(\rho/2)V^2\pi R^2} \)
HMOM  Hinge moment of aileron or spoiler-single blade (N-m)
AVA   Average value of a

Examples of the answer pages are given on the following pages.
## PERFORMANCE OF A WIND-AXIS WIND TURBINE
### CALCULATED BY WIND PROGRAM
#### BLADE SECTION - NACA 21024
- **NO. BLADES = 2.**
- **RADIUS = 19.05 METERS**
- **COMING ANGLE = 0.0 DEGREES**

#### BLADE SECTION IS MODIFIED

### METHOD OF CONTROL
- **PITCH OF ENTIRE BLADE.**
- **PITCH ANGLE IS -2.0 DEGREES.**

**NOTE:** 0.5 LE. A LE. 0.5

#### RUN NO. 146

### INTEGRATED RESULTS

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<td>15.07</td>
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### Integrated Results

#### Integrated Results

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In the long printout, the general headings are followed by listings of local values.
PROGRAM WIND -- 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, AND CYRUS OSTOWARI OF THE WIND ENERGY LAB AND THE AIRFOIL RESEARCH GROUP AT WICHITA STATE UNIVERSITY, WICHITA, KANSAS.

- - - MODIFICATION DATES - - JUNE 1979 TO PRESENT - - - - - - -
- - - MOST RECENT MODIFICATION WAS JULY 18, 1980 - - - - - - -

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

WIND CALCULATES THE THEORETICAL PERFORMANCE PARAMETERS OF A PROPELLER TYPE WIND TURBINE. IT UTILIZES A SIMPSON'S-RULE METHOD / THREE PASS TECHNIQUE OF NUMERICAL INTEGRATION.

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

REAL CHD(2,50), CIM(50), THETX(2,50), CC(50), DD(50)

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

KR = 5
KP = 6
IOUT = 6

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

READ (KR,175) NORUN,JOUR,MONTH,JAHR
READ (KR,180) MODE,NINC,V,INCVEL,OMEGA,INCRPM
READ (KR,185) MCON,KFLAG,IPRINT,NF,DR,MUT
READ (KR,190) AMOD,APF,B,BO,GO,H,HB,H,MF,KFLAG,MCON,NF
READ (KR,195) AFL,AFL2,AFL3,TIPICH,TIPL,SPAN,DEFL,PCTSPN,PITCH
READ (KR,200) (RR(I),CI(I),THETI(I),CC(I),DD(I),I=1,NF)

BRANCH DEPENDING ON CONTROL TYPE

GO TO (2,4,6,8),MCON
2 DO 3 I=1,4
3 THETI(I) = THETI(I)-TIPICH
GO TO 10
4 DO 5 I=1,NF
5 CAI(I) = CC(I)
GO TO 10
6 DO 7 I=1,NF
7 DSI(I) = CC(I)
GO TO 10
8 CONTINUE

CONVERT BLADE RADIUS TO METERS

10 RM = 0.3048*R
PRINT MAIN AND COLUMN HEADINGS
WRITE (KP,210)
WRITE (KP,215)
WRITE (KP,220) AF1, AF2, AF3, B, RM, SI
IF (MUT.GT.0) WRITE (KP,221)
WRITE (KP,225)
GO TO (12,14,15,17), MCON

12 WRITE (KP,230) TIPICH, TIPL
GO TO 20
14 WRITE (KP,235) SPAN, PCTSPN, DEFL
WRITE (KP,250)
GO TO 20
15 WRITE (KP,240) SPAN, PCTSPN, DEFL
WRITE (KP,245)
GO TO 20
17 WRITE (KP,246) PITCH
CONTINUE
GO TO (25, 30, 35), KFLAG
25 WRITE (KP,300)
GO TO 40
30 WRITE (KP,305)
GO TO 40
35 WRITE (KP,310)
40 WRITE (KP,315) NORM, JOUR, MONTH, JAHR
IF (IPRINT.EQ.1) GO TO 45
WRITE (KP,295)
WRITE (KP,260)
WRITE (KP,280)
WRITE (KP,285)
WRITE (KP,290)
WRITE (KP,260)

45 DO 160 NO=1, MINC
IF (IPRINT.EQ.2) GO TO 50
WRITE (KP,255)
WRITE (KP,265)
WRITE (KP,270)
WRITE (KP,275)
WRITE (KP,255)

50 IF (MODE.EQ.1) GO TO 55
IF (MODE.EQ.2) 165, 60, 165
55 DELV = INCVEL
V = V + DELV
GO TO 65
60 RPMINC = INCRPM
OMEGA = OMEGA + RPMINC
65 PI = 3.141593
RADEG = PI/180.
FPSMPH = 88./60.
ISTOP = 0.
DO 70 J=1, NF
70 CIM(J) = 0.3048*CI(J)

STORE INITIAL VALUES
IREAD = 0
S1 = R
S2 = DR
S3 = HB
S4 = PITCH
S5 = V
S6 = OMEGA
S7 = SI

SI IS CONING ANGLE (PSI)
COSSI = COS(SI*RADEG)
CS2 = COSSI*COSSI
W = RM*COSSI*OMEGA*PI/30.
X = W/V/FPSMPH
INCREMENTAL 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 80

DO 75 K=1,NF
RR(K) = R*RR(K)/100.
75 THETI(K) = THETI(K)*RADEG

SET R LOCAL EQUAL TO RMAX

80 RL = R

NUMERICAL INTEGRATION FROM TIP TO HUB

CAT = 1.
IF (GO.EQ.2.) CAT = 2.
CLFA = 1.
IF (GO.LT.2.) GO TO 90
IF (GO.EQ.3.) CLFA = 0.0
IF (IREAD.GT.0) GO TO 85

CALL SEARCH (RL,CX1,THETX1,CA,CS,DA,DS)
85 C = CX1
THET = THETX1
CALL CALC (RL,C,THET,QX,TX,A,AP,F,CLFA,CAT,CL,CD,ALFA,CH,CA,CS, 
          * DA,DS,MUT)

RE-INITIALIZE 'A'

90 A = 0.0
CAT = 0.0
BEGIN MARCHING ACROSS SPAN FROM TIP TO HUB

DO 135 L=1,NN
DO NOT MARCH INSIDE HUB
IF ((RL-HB).GE.DR) GO TO 95
ASTOP = ASTOP+1.
IF (ASTOP.GE.2.) GO TO 140
DR = (RL-HB)

95 IF (GO.LT.3.) GO TO 105
TEST FOR STEP IN 3-POINT SIMPSON
IF (CTRL.EQ.0.0) GO TO 105
TIP = RL-DR
IF (TIP.GT.REF) GO TO 100
IF (CTRL.EQ.2.0) GO TO 105
DR = (RL-REF)
CLFO = (REF-TIP)/(RL-TIP)
CLF = .5*CLFO
CTRL = 1.
GO TO 105

100 CLF = 0.0
105 DR2 = DR/2.
DT6 = DR/(6.*COSST)
INCREMENT 'R' BY 'DR/2'

RL = RL-DR2
RTAB = RL
IF (CTRL.EQ.0.0) CLF = 1.
IF (CTRL.EQ.2.0) CLF = (CLFO+1.)/2.
IF (IREAD.GT.0) GO TO 110
FIND LOCAL CHORDS AND ANGLES
CALL SEARCH (RL,CHD(1,L),THETX(1,L),CA,CS,DA,DS)

110 C = CHD(1,L)
THET = THETX(1,L)

CALCULATE VALUES AT R+DR/2 STATION
CALL CALC (RL,C,THET,QXP1,TXP1,A,AP,F,CLF,CAT,CL,CD,ALFA,CH,CA,
* CS,DA,DS,MUT)
INCREMENT R BY DR/2 AGAIN(TOTAL INCREMENT = DR)

RL = RL-DR2
IF (CTRL.EQ.0.0) CLF = 1.
IF (CTRL.EQ.1.0) CLF = CLFO
IF (CTRL.EQ.2.0) CLF = 1.0
IF (IREAD.GT.0) GO TO 115
FIND LOCAL CHORDS AND ANGLES
CALL SEARCH (RL,CHD(2,L),THETX(2,L),CA,CS,DA,DS)

115 C = CHD(2,L)
THET = THETX(2,L)

CALCULATE VALUES AT R+DR STATION
CALL CALC (RL,C,THET,QXP,TXP,A,AP,F,CLF,CAT,CL,CD,ALFA,CH,CA,
* DA,DS,MUT)

THETA=LOCAL BLADE TWIST ANGLE - PITCH ANGLE

THETA = THET+THETP
PCRL = (100.)*RTAB/R
RLM = 0.3048*RTAB
CM = 0.3048*C

NEXT 4 STEPS INTEGRATE TORQUE, THRUST AND POWER,
USING A THREE-POINT SIMPSON'S RULE.
3 POINTS ARE AT R,R+DR/2,AND R+DR
QYX = DT6*(QX+4.*QXP1+QXP)
QYXNM = QYX*1.35583
QY = QY+QYX
THINCR = DT6*(TX+4.*TXP1+TXP)
TY = TY+THINCR
THRNM = THINCR*4.44827
PY = PY+OMEGA*QYX
HMOM = HMOM+HMF*DR/COSSI

C IF (CONTRL.EQ.2.) CONTRL = 0.0
C IF (CONTRL.EQ.0.0) GO TO 120
C IF ((RL-TIP).EQ.0.0) GO TO 120
C IF (CONTRL.EQ.1.) DR = REF-TIP
C IF (CONTRL.EQ.1.) CONTRL = 2.
C GO TO 125
C
120 DR = DRO
125 QX = QXP
TX = TXP

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

AREA = DR*(2.*RL+DR)
SUM1 = SUM1+AREA
SUM2 = SUM2+(1.-A)*AREA
IF (IPRINT.EQ.2) GO TO 135
GO TO (129,130,130,129),MCON
C
129 CH = 0.
130 WMS = W*0.447040
C
THETDG = THETA/57.29578
WRITE (KP,320) PCRL,RLM,CM,THETDG,ALFA,WMS,CL,CD,CH,QYXNM,THRNM,A
135 CONTINUE
C
140 CTY = TY/((.5*RHO0*V*2*PI*R*X*2)
CPY = PY/((.5*RHO0*V*3*PI*R*X*2)
TP = TY/737.6
C
THE NEXT STATEMENT COMPUTES THE AVERAGE VALUE OF 'A'

AVA = 1.-SUM2/SUM1
C
RESTORE INITIAL VALUES FOR POSSIBLE RERUN
C
IF (IREAD.EQ.1) GO TO 150
C
DO 145 L=1,NF
RR(L) = 100.*RR(L)/R
145 THETI(L) = THETI(L)/RADEG
C
IREAD = 1
C
150 R = S1
SR = S2
HB = S3
PITCH = S4
V = S5
OMEGA = S6
S1 = S7
S8 = X
VMS = 0.447040*V
QYNM = QY*1.355833
TNY = 4.44827*TY
CQ = CPY/X
C
HMOM = HMOM*.7376
IF (IPRINT.EQ.2) GO TO 155
C
WRITE (KP,330)
WRITE (KP,295)
WRITE (KP,260)
WRITE (KP,280)
WRITE (KP,285)
WRITE (KP,290)
WRITE (KP,260)
155 WRITE (KP,325) V, VMS, OMEGA, X, PITCH, QYNM, TP, CPY, TYN, CQ, HMOM, AVA
C
IF (IPRINT.EQ.2) GO TO 160
WRITE (KP,330)
160 CONTINUE
C
GO TO 170
INVALID MODE
165 WRITE (KP,335)
170 STOP
C
....... FORMATS FOR INPUT AND OUTPUT STATEMENTS ......
175 FORMAT (2I5,A4,I6) 180 FORMAT (2I10,F10.2,I10,F10.2,I10)
185 FORMAT (4I10,F10.3,I10) 190 FORMAT (10F8.2)
195 FORMAT (3A4,6F8.3) 200 FORMAT (5F10.5)
205 FORMAT (2F10.5) 210 FORMAT ('1',40X,'PERFORMANCE OF A WIND-AXIS WIND TURBINE')
215 FORMAT (' ',43X,'CALCULATED BY W I N D  P R O G R A M ') 220 FORMAT ('0',8X,'BLADE SECTION - ',3A4,5X,'NO. BLADES = ',F2.0,7X,
* COMING ANGLE = ',F4.1,' DEGREES') 225 FORMAT ('0',8X,'METHOD OF CONTROL --')
221 FORMAT ('0',25X,'BLADE SECTION IS MODIFIED') 230 FORMAT (' ',30X,'TIP SECTION PITCH, ANGLE OF PITCH = ',F5.1,
* DEGREES TIP SECTION LENGTH = ',F4.1,' METERS')
235 FORMAT (' ',30X,'AILERONS, SPAN = ',F5.1,' METERS (OUTBOARD',
* F5.1,' PERCENT) DEFLECTION = ',F6.1,' DEGREES') 240 FORMAT (' ',30X,'SPIOLERS, SPAN = ',F5.1,' METERS (OUTBOARD',
* F5.1,' PERCENT) DEFLECTION = ',F6.1,' DEGREES')
245 FORMAT ('0',30X,'SPIOLER CHORD IS 10% OF LOCAL CHORD -- HINGED',
* AT 70% CHORD') 246 FORMAT (' ',30X,'PITCH OF ENTIRE BLADE. PITCH ANGLE IS ',F5.1,
* DEGREES.') 250 FORMAT ('0',35X,'AILERON CHORD IS 20% OF LOCAL BLADE CHORD')
255 FORMAT ('0',3X,5'I-------------',5('-------')
* ') 260 FORMAT (' ',3X,3'------------------------',3('|-------------')
* ') 265 FORMAT (' ',3X,'| BLADE | RADIUS | LOCAL | BLADE | ANGLE OF | RE
*SULTANT | COEF. | COEF. | HINGE | TORQUE | THRUST | A |
* ') 270 FORMAT (' ',3X,'| STATION | CHORD | ANGLE | ATTACK | VE
*LICITY | OF | OF | MOMENT | INCREMENT | INCREMENT |
* ') 275 FORMAT (' ',3X,'| PERCENT | (METERS) | (METERS) | (DEG.) | (DEG.) | (|
* M/SEC) | LIFT | DRAG | COEF. | (N-M) | (NEWTONS) |
* ') 280 FORMAT (' ',3X,'| FREESTREAM | ANGULAR | TIP-SPEED | PITCH | TOR
* QUE | POWER | POWER | THRUST | THRUST | HINGE MOM | A |
* ') 285 FORMAT (' ',3X,'| WIND SPEED | SPEED | RATIO | ANGLE | 9X
* ',',9X,1' | COEF. | ',10X,1' | COEF. | FREE BLADE (AVE) | ')
290 FORMAT (' ',3X,1'MPH) | (M/S) | (RPM) | X | (DEG) | (N
* -M) | (KX) | CP | (NEWTON) | CQ | (N-M) |
* ') 295 FORMAT ('0',6X,'INTEGRATED RESULTS --',//) 300 FORMAT ('0',40X,'NOTE: "A" IS ZERO - INDUCED VELOCITIES ARE',
* IGNORED'//)
305 FORMAT ('0',40X,'NOTE: -0.5.LE. A .LE.+0.5'//) 310 FORMAT ('0',40X,'NOTE: "A" IS NOT LIMITED'//) 315 FORMAT (' ',5X,'RUN NO.',I3,8X,I3,2X,A4,16,/)
* F8.3,F10.3,F8.3) 330 FORMAT ('1') 335 FORMAT ('0',2X,'MODE IN ERROR, PROGRAM STOPPED') END
SEARCH

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

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

COMMON AMOD, APF, B, BO, CAI(50), CI(50), COSSI, CSI(50), CS2,
* DA(50), DR, DSI(50), GO, H, HB, HL, HMF, KFLAG, MCON, NF,
* OMEGA, PI, R, RADEG, RHO, RR(50), RX, SI, THETI(50), THETP,
* V, W, X

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*(CAI(J-2)-CAI(J-1))+CAI(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)
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)
RETURN

VALUES REQUIRED AT THE FIRST STATION

20 C = CI(1)
THET = THETI(1)
CA = CAI(1)
CS = CSI(1)
DA = DAI(1)
DS = DSI(1)
RETURN
END
SUBROUTINE CALC (RL,C,THET,QF,TF,A,AP,F,CLF,CAT,CL,CD,ALFA,CH,CA,
CS,DA,DS,MUT)

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

COMMON AMOD, APF, B, BO, CAI(50), CI(50), COSSI, CSI(50), CS2,
DAI(50), DR, DSI(50), GO, H, HB, HL, HMF, KFLAG, MCON, NF,
OMEGA, PI, R, RADEG, RHO, RR(50), RX, SI, THETI(50), THETP,
V, W, X

DATA ACK /0.5/, KP /6/

SET INITIAL VALUES
XL = RL*OMEGA/V
RH = HB
SIGB = 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 (ABS(A).GT.ACK) A = 0.0
DO 50 J=1,50
SAVE OLD 'A' AND A-PRIME('AP')
BETA = A
DELTA = AP
PHI IS RELATIVE WIND DIRECTION, INCLUDING INDUCED EFFECTS.
PHI = ATAN((1.-A)*COSSI/((1.+AP)*XXL))
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 = V*SQRT((((1.-A)*COSSI)**2+((1.+AP)*XXL)**2)
CALL NACAXX (RL,RX,SI,ALPHA,CL,CD,W)
GO TO (10,5,5,10), MCON

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

10 IF (MUT.GE.1) CALL MUTANT (ALPHA,CL,CD,MUT)
ALFA = ALPHAX57.29578
IF (MCON.EQ.1) CH = 0.
IF(MCON.EQ.4) CH=0
IF (GO.LT.3.) GO TO 15
CL = CLF*CL
F = 1.
GO TO 20

15 IF (CAT.EQ.1.) F = 0.0
IF (CAT.EQ.1.) GO TO 20
XXL = ABS(COSPHI/SINPHI)
XXLO = XXL*R/RL
CALL TIPLOS (XXL, XXLO, F, B, G0, HL, PI, R, RL, PHI, RH)

C 20 CX = CLMXSINPHI-CDXCSINPHI
CY = CLMXCOSPHI+CDXCSINPHI

'A MOD' DETERMINES MODEL FOR 'A'.

IF (AMOD.EQ.0.) GO TO 25
VBR = SIG8*CX*CS2/(SINPHI*X2)
VAR = SIG8*CX/F/SINPHI/COSPHI
CAN = F*X+4.*VBR*F*(1.-F)
IF (CAN.LT.0.0) CAN = 0.0

'A' IS THE INDUCED AXIAL VELOCITY FACTOR.
'AP' IS THE INDUCED ROTATIONAL VELOCITY FACTOR.

A = (2.*VBR+F-SQR(CAN))/(2.*(VBR+F+F))

IF 'APF' IS 1.0, PROGRAM CONVERGES ON 'A', NOT 'AP'.
IF 'APF' IS NOT 1.0, PROGRAM CONVERGES ON 'AP', NOT 'A'.

IF (APF.EQ.1.) GO TO 35
AP = VAR/(1.-VAR)
GO TO 35

25 VBR = SIG8*CX*CS2
VAR = SIG8*CX

IF (KFLAG.EQ.1) A = 0.0
IF (KFLAG.EQ.1) GO TO 30

A = VBR/(F*SINPHI*X2+VBR)

30 IF (APF.EQ.1.) GO TO 35
AP = VAR/(F*SINPHI*COSPHI-VAR)

35 IF (KFLAG.EQ.3) GO TO 40
IF (A.GT.0.5) A = 0.5
IF (A.LT.(-0.5)) A = -0.5

.. DAMPENING OF AXIAL AND ANGULAR INTERFERENCE FACTOR ITERATIONS.

40 A = (A+BETA)*.5
AP = (AP+DELTA)*.5

......... TEST FOR CONVERGENCE ......

IF (APF.EQ.1..) GO TO 45
IF (ABS(AP-DELTA).LE..001) GO TO 55
GO TO 50

45 IF (ABS(A-BETA).LE..001) GO TO 55
CONTINUE

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

WRITE (KP,60)

C COMPUTE FUNCTIONS DEPENDENT ON 'A'

55 W = VSQR((1.-A)*COSI)*X2+((1.+A)*XL)*X2
CT1 = (0.5*RH0*B*C)*(W)*W
QF = CT1*RL*CX
TF = CT1*CX*COSI
IF (MCON.EQ.2) HMF = CH*CT1*CA*X2/C
IF (MCON.EQ.3) HMF = CH*CT1*CS*X2/C
RETURN

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

SUBROUTINE TIPLOS (U, UO, F, Q, GO, HL, PI, R, RL, PHI, RH)

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

SUM2 = 0.0
SUM = 0.0
AK = 1.
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) * ARCOS( (EXP(-(Q*X*(R-RL)))/(2.*RL*X**SQR((SIN(PHI)**2+0.0001)))) )
GO TO 50

15 F = 1.0
GO TO 50
20 IF ((ABS(SIN(PHI))).LT.0.001) GO TO 10

..... GOLDSTEIN'S METHOD......

DO 45 M=1,3
V = (2.*AM+1.)
ZO = UO*V
V2 = VKV
Z = UKV
Z2 = ZKZ

CALL BESSEL(Z,V,A1)
CALL BESSEL(Z0,V,A10)

IF (Z.GE.3.5) GO TO 25
A = 2.*2.
B = 4.*4.
C = 6.*6.
D = 8.*8.

TIVZ = (A-V2)+(Z2*Z2)/(A-V2)*(Z2*3)/(A-V2)*(B-V2) *
*(C-V2)+(Z2*4)/(A-V2)*(B-V2)*(C-V2)*(D-V2) *
CTIVZ = (VPI*A1)/(2.*SIN(5*VPI)) - TIVZ
GO TO 30

25 TO = (UXU)/(1.+UXU)
T2 = 4.*UXUXU(1.-UXU)/(1.+UXU)**4)
T4 = 16.*UXUXU(1.-14.*UXU+21.*UXU+4.-UXU+6.)/(1.+UXU)**7)
T6 = 64.*UXUXU(1.-175.*UXU+603.*UXU+41065.*UXU+6+460.*UXU+8-36.*UXU)**10) *
(1.+UXU)**10)
CTIVZ = TO+T2/V2+T4/(V2**2)+T6/(V2**3)

30 FVU = (UXU)/(1.+UXU)-CTIVZ
SUM = SUM+FVU/V2

IF (AM.NE.0.0) GO TO 35
E = -0.098/(UO**0.668)
35 IF (AM.NE.1.0) GO TO 40
E = 0.031/(UO**1.285)

40 IF (AM.GT.1.0) E = 0.0
SUM2 = SUM2+(UXU*UO*AMM)/(1.+UXU-UO)-E*(AM/AI0)
AM = AM+1.
AK = (AM-1.0)*AK/(2.*AM)

45 AMM = AK/(2.*AM+1.)
G = (UXU)/(1.+UXU)-(B./PI*PI)*SUM
CIRC = G-(2./PI)*SUM2
F = ((1.+UXU)/(UXU))*CIRC
C HUBLOSS CALCULATIONS

50 IF (HL.EQ.1.0) GO TO 55
   FI = 1.0
   GO TO 60

55 FI = (2./PI)*ARCCOS(EXP(-(Q*(RL-RH))/(2.*RHSQRT(SIN(PHI)*H)*2
     +0.0001)))

60 F = F*FI

RETURN
END

NACAXX

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 = ALPHA*180./3.1415927
AALPHA = ABS(ALPHA)
X = ABS(Y)

IF (8. < X.AND.X < 13.) CD = X/248.8-0.01675
IF (-9. < Y.AND.Y < 8.) CD = -2.09050E-6*YY*3+7.19578E-5*YY*2
   +2.26766E-6*X+9.99331E-3

IF (13. < X.AND.X < 160.) CD = 2.-1.089*(1.57-AALPHA)*X
IF (160. < X.AND.X < 180.) CD = 0.04+2.8*(AALPHA-3.142)*X
IF (10. < X.AND.X < 16.) CL = -1.25E-3*XX*3+4.55953E-2*XX*2
   -5.47084E-1*X+3.04822

IF (-12. < Y.AND.Y < 10.) CL = 2.64619E-10*YY*8+2.39782E-8*YY*7
   +1.03975E-7*YY*6-5.54091E-6*YY*5
   -2.20717E-5*YY*4+3.11341E-4*YY*3
   +4.59110E-4*YY*2+8.26369E-2*YY
   +1.00579E-1

IF (16. < X.AND.X < 90.) CL = 1.1-1.78*(AALPHA-.7853)*X
IF (10. < Y.AND.Y < 17.8) CL = -.4388+.2233*YY-.00899*YY*2
IF (90. < X.AND.X < 160.) CL = -1.1+1.78*(AALPHA-2.356)*X
IF (160. < X.AND.X < 172.5) CL = -.763
IF (172.5 < X.AND.X < 180.) CL = .10173*X-18.3114

RETURN
END
SUBROUTINE INCREM (ALPHA,CL,CD,CH,CA,DA,CS,DS,C)

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

$PI = 3.141593$
$Y = ALPHA \times 180 / PI$

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) \times SIN(DAR)
SIN2DS = SIN(DSR) \times 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

5 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

10 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) \times CS/C \times SIN2DS
IF (-17..LE.Y.AND.Y.LE.0.) CH = -(6.7-.075 \times Y) \times CS/C \times SIN2DS

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

25 CONTINUE
CALCULATE POST-STALL CONDITIONS FOR AILERON
CONVERT CL AND CD TO CN AND CC
CN = NORMAL FORCE COEFFICIENT
CN = CL*COS(ALPHA)+CD*SIN(ALPHA)
CC = CHORDWISE FORCE COEFFICIENT
CC = CD*COS(ALPHA)-CL*SIN(ALPHA)
CALCULATE CONTRIBUTIONS TO FORWARD ELEMENT
CNI = CN*(1.-CA/C)
CCI = CC*(1.-CA/C)
**CALCULATE AILERON CONTRIBUTIONS**

\[ C_{L}^{2} = \frac{2.27 \times 2 \times \pi \times \sin(\alpha + \Delta r)}{(4 + \pi \times \text{abs}(\sin(\alpha + \Delta r)))} \]

\[ D_{C} = C_{N} \times \cos(\Delta r) \times \cos(\Delta r) \]

\[ C_{H} = -\frac{C_{N} \times 2}{2} \]

\[ C_{S} = C_{N} + D_{C} \]

\[ C_{T} = C_{N} - C_{H} \times \sin(\alpha + \Delta r) \]

\[ C_{D} = C_{N} \times \cos(\alpha + \Delta r) + C_{T} \times \sin(\alpha + \Delta r) \]

**CONVERT TO LIFT AND DRAG COEFFICIENTS**

\[ C_{L} = C_{N} \times \cos(\alpha) - C_{H} \times \sin(\alpha) \]

\[ C_{D} = C_{N} \times \cos(\alpha) + C_{H} \times \sin(\alpha) \]

**MUTANT**

**SUBROUTINE MUTANT (ALPHA, CL, CD, MUT)**

This subroutine calculates lift and drag coefficients for modifications of basic airfoil.

Routine approximates 23024 section with leading-edge slots when MUT = 1. Other modifications may be added with other positive values of MUT.

IF (MUT.GT.1) GO TO 5

ALFA = ALFA X 57.2958

IF (ALFA.LT.20.) CL = 0.199 X ALFA X 0.6522

IF (ALFA.LT.25.) CD = -10.194 + 1.0813 X ALFA - 0.025084 X ALFA X 2

IF (ALFA.LT.22.) CD = 0.01894 X (EXP(.0919 X ALFA))

IF (ALFA.LT.25.) CD = -3.233 + 0.1533 X ALFA

IF (ALFA.LE.8.) CD = CD + 0.024

5 CONTINUE

RETURN

END