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SEACC: THE SYSTEMS ENGINEERING AND ANALYSIS COMPUTER CODE FOR SMALL WIND SYSTEMS

March 1983

P.K.C. Tu
V. Kertesz

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Rocky Flats
Wind Energy Research Center

Prepared by
Rockwell International Corporation
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As a part of the
UNITED STATES DEPARTMENT OF ENERGY
WIND ENERGY TECHNOLOGY DIVISION
FEDERAL WIND ENERGY PROGRAM

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ABSTRACT

The systems engineering and analysis (SEA) computer program (code) evaluates complete horizontal-axis SWECS performance. Rotor power output as a function of wind speed and energy production at various wind regions are predicted by the code. Efficiencies of components such as gearbox, electric generators, rectifiers, electronic inverters, and batteries can be included in the evaluation process to reflect the complete system performance. Parametric studies can be carried out for blade design characteristics such as airfoil series, taper rate, twist degrees and pitch setting; and for geometry such as rotor radius, hub radius, number of blades, coning angle, rotor rpm, etc. Design tradeoffs can also be performed to optimize system configurations for constant rpm, constant tip speed ratio and rpm-specific rotors. SWECS energy supply as compared to the load demand for each hour of the day and during each season of the year can be assessed by the code if the diurnal wind and load distributions are known. Also available during each run of the code is blade aerodynamic loading information.

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NOMENCLATURE

a	- axial interference factor, Eq. 24 and Ref. 13
a'	- circumferential interference factor, Eq. 25 and Ref. 13
A	- SWECS rotor cross section area, ft^2
A_b	- blade planform area, ft^2
B	- number of blades
C	- Weibull wind speed distribution scale parameter, Eq. 2
C_b	- blade chord length, ft
C_D	- airfoil drag coefficient
C_L	- airfoil lift coefficient
C_N	- blade normal force coefficient, Eq. 20
C_T	- blade tangential force coefficient, Eq. 21
C_p	- rotor power coefficient, Eq. 26
$(C_p)_m$ or $(C_p)_{\max}$	- maximum C_p , Fig. 10
E_w	- available wind energy, kWh
$f(v)$	- Weibull wind speed frequency distribution, Eq. 2
$F(\geq V)$	- Weibull accumulative wind speed distribution, Eq. 3
$H(\geq V)$	- Weibull wind speed duration curve, Eq. 4
H	- hour of day
K	- Weibull wind speed distribution shape factor, Eq. 2
N	- numerical number to define wind shear profile, Eq. 1
$(P)_{\max}$	- rotor maximum power output, kW
P_w	- available wind power, watts
R	- rotor radius, ft.
R_N	- Reynolds number, Eq. 16

NOMENCLATURE - Contd.

U	- velocity component (wind velocity through rotor plane) mph, Fig. 4
V	- instantaneous wind speed, mph
$\bar{V}$	- annual average (or mean) wind speed, mph
V_{in}	- cut-in (SWECS starts) wind speed, mph
V_{out}	- cut-out (SWECS stops) wind speed, mph
$(V)_{rated}$	- rated wind speed (where rotor power becomes constant) mph
V_t	- a wind speed where $C_p = (C_p)_{max}$ for two rotor configurations, mph, Fig. 19
W	- local wind velocity, mph
χ	- inverse of Weibull shape factor
Y	- vertical axis distance, ft
α	- airfoil angle of attack, degrees, Fig. 4
Γ	- gamma function, Eq. 8
θ	- blade pitch angle, degrees, Fig. 4
λ	- blade tip speed ratio, Eq. 27
$(\lambda)_{opt}$	- optimum λ where $C_p = (C_p)_m$
ρ	- air density, slugs/ft ³
ϕ	- $\theta + \alpha$, degree, Fig. 4
ω	- rotor shaft speed, rpm
ω'	- angular velocity defined by Eq. 25

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1. INTRODUCTION

Since 1976, the Rocky Flats Wind Systems Program, in its role of providing technical and management support to the Department of Energy, has established goals of assisting private industry through the research and development of small wind energy conversion systems (SWECS) and associated technologies. During the course of developing SWECS, it was found that system parametric tradeoffs and configuration optimization were necessary during preliminary system engineering and analysis, and that such a procedure was difficult and tedious without the aid of a computer. It was also felt that a SWECS performance model should be developed as a research tool for in-house R&D projects. Therefore an effort to establish a system engineering and analysis computer code (SEACC) was put forward by the author with the following goals in mind:

1. Develop a viable SWECS performance model so that rotor/power and energy output can be accurately predicted from basic airfoil data and rotor geometry.
2. Include as many variables in configurations and wind characteristics as possible so that a thorough parametric study can be carried out.
3. Conduct system design tradeoff evaluations for such features as constant rpm, constant tip-speed ratio, and rpm-specific rotors (Ref. 1-5).
4. Carry out studies of power train efficiency influence on SWECS power and energy output, and the energy supply versus demand mismatch for potential applications.

The SEACC was first developed in Fortran on a CDC 720 computer. The code was later transferred to a Data General "Eclipse" computer. The two versions of code are not interchangeable (i.e., one can not be run on the machine used for the other). The version utilizing the Data General machine is listed in Appendix A .

This report is intended as a brief description and outline of basic terminology, theoretical equations, input and output files, and options for various design features. A limited parametric study is presented for illustration purposes. A user's manual and a complete listing of the program are included in the appendices.

2. TERMINOLOGY AND EQUATIONS

The terminology and equations which are relevant and important to the SEA program are introduced in this section. Some theoretical material has been omitted because it can be found in the references listed.

2.1 THE WIND

2.1.1 Instantaneous Wind Speed (V)

This is the horizontal instantaneous wind speed measured by an anemometer and expressed in miles per hour (mph). The Rocky Flats data collection system samples the wind data every 15 seconds. Therefore, V is defined as the average value of 15 seconds. However, this averaging method may vary with test systems or projects. Neither instantaneous wind turbulence nor wind gusting is considered in the analysis.

2.1.2 Annual Average Wind Speed ($\bar{V}$)

This is the average value of V for a year at an elevation of 10 meters (30 ft) from the ground. If $\bar{V}$ is measured at a height other than 10 meters, it should be interpolated (or extrapolated) by a power-law equation (see 2.1.3) to represent the wind site.

2.1.3 Wind Shear

A power-law equation is used to express the wind shear along the vertical axis, such as:

$$\frac{V \text{ (or } \bar{V})}{[V \text{ (or } \bar{V})]_{\text{ref.}}} = \left(\frac{Y}{Y_{\text{ref.}}} \right)^{1/N} \quad (1)$$

where:

Y is the distance from the ground.

$N = 7$ is used in the SEACC based on the classic velocity profile of a turbulent boundary layer in a smooth pipe. When the site wind shear profile is known, "N" should be derived from the profile and used in the analysis.

2.1.4 Wind Speed Statistics

The Weibull wind speed frequency distribution is used in SEA:

$$f(V) = \frac{K}{C} \left(\frac{V}{C}\right)^{K-1} e^{-\left(\frac{V}{C}\right)^K} \quad (2)$$

where:

K is the distribution dispersion parameter, C is the scale parameter of the annual average wind speed ($\bar{V}$).

$f(V)$ is also called the probability density function.

The accumulative wind speed distribution curve is given as:

$$F(\underline{\geq}V) = \int_V^{\infty} f(V)dV = [1 - e^{-\left(\frac{V}{C}\right)^K}]_V^{\infty} = e^{-\left(\frac{V}{C}\right)^K} \quad (3)$$

The wind speed duration curve is defined as when the $F(\underline{\geq}V)$ is expressed in hours per year. That is:

$$H(\underline{\geq}V) = 8766 \cdot F(\underline{\geq}V) \quad (4)$$

$$V \text{ or } H(\geq V) = 8766 \cdot e^{-\left(\frac{V}{C}\right)^K} \quad (5)$$

The annual wind speed ($\bar{V}$) and the Weibull scale parameter (C) are related as (Ref. 6):

$$\bar{V} = C \Gamma(1 + 1/K) \quad (6)$$

$\Gamma(1 + 1/K)$ is a Gamma function (Ref. 7) and can be expressed as:

$$\Gamma(1 + 1/K) = \Gamma(1 + \chi) = \chi \Gamma(\chi) \quad (7)$$

where $\chi = 1/K$, and

$$\Gamma(\chi) = \int_0^{\infty} u^{\chi-1} e^{-u} du, \quad \chi > 0 \quad (8)$$

An asymptotic series is used to express $\Gamma(\chi)$, such as:

$$\Gamma(\chi) \approx \chi^\chi e^{-\chi} \frac{2\pi}{\chi} \left(1 + \frac{1}{12\chi} + \frac{1}{288\chi^2} - \frac{139}{51840\chi^3} \dots\right) \quad (9)$$

It was pointed out in Reference 6 that C and $\bar{V}$ are very nearly proportional since for $1.5 < K < 3.2$ the $C/\bar{V}$ ratio varies only between 1.11 and 1.13. The reader can simplify the computation by using the relation:

$$C = 1.12\bar{V} \quad (10)$$

The computer program provided an option in choosing a wind speed distribution curve used by the NASA-Lewis Research Center, which defined $K = 2.27$ (Ref. 8). This is very close to the Rayleigh Distribution which defines $K = 2.0$.

Diurnal (hourly) wind distribution data on the American continent was published in Reference 9. A typical distribution is shown in Figure 1 in which seasonal changes in the distribution are indicated. This kind of data is needed in the energy supply/demand mismatch estimate.

2.1.5 Available Wind Energy

The power produced by wind speed V across an area A is given as the following:

$$P_W = \frac{1}{2} \rho V^3 A, \text{ watts} \quad (11)$$

where:

ρ is the air density, kg/m^3
 V is the wind speed, m/sec
 A is the cross section area, m^2

The available wind energy is defined as:

$$E_W = \frac{1}{1000} \int_0^{\infty} P_W \cdot f(V) dV, \text{ kWh (kilowatt-hour)} \quad (12)$$

For British units, where ρ is in slugs/ft^3 , V is in ft/sec and A is in ft^2 , Equation 11 becomes:

$$P_W = 0.678 \rho V^3 A, \text{ watts} \quad (13)$$

2.2 THE ROTOR

The rotor commonly consists of blades, hub, and blade pitch control devices. There are downwind rotors and upwind rotors. A downwind rotor is defined as a rotor that operates behind the tower with respect to the

Figure 1
 Typical Measured Diurnal Wind Speed Distributions by Season (Ref. 9)

incoming wind. This section offers a brief explanation of how rotor elements are represented in the SEACC.

2.2.1 Blades

Blade configurations being considered by this analysis include airfoil design, taper and twist, pitch angle, coning angle, and feather and stall.

2.2.1.1 Airfoil Design

Various performance characteristics data of airfoil design can be found in References 10 and 11. As an example, airfoil series NACA 4415 (Ref. 11) is shown in Figure 2 and Table 1 and its aerodynamic lift and drag coefficients (C_L and C_D) as a function of angles of attack (α°) is shown in Figure 3. The lift and drag coefficients are defined as:

$$C_L = \text{lift force} / (1/2 \rho V^2 A_b) \quad (14)$$

$$C_D = \text{drag force} / (1/2 \rho V^2 A_b) \quad (15)$$

where:

A_b is defined as the blade planform area which is the product of the chord length and the lateral span of the blade (Ref. 11).

The angle of attack (α°) is defined as the angle between the direction of the wind and the airfoil chord line.

Reference 11 also tabulated the C_L and C_D as a function of α° and Reynolds number as shown in Table 2 for the NACA 4415 series. Values listed in Table 2 can be used directly as an input file data for SEACC.

The Reynolds number (R_N) of the rotor blade at .75R should be calculated and used to determine appropriate airfoil data values. In general terms R_N is defined as:

NACA 4415

NACA 4415

Reference: (A2)

Wind Tunnel: NACA VDT

Date: 1937

Type of Test: Three-Dimensional

Wind Tunnel Turbulence: 2.0%

Airfoil Surface: Smooth

Reynolds Number: 4.2×10^4 - 3.0×10^6

Reference: (A3)

Wind Tunnel: NACA LTT

Date: 1945

Type of Test: Two-Dimensional

Wind Tunnel Turbulence: 0.03%

Airfoil Surface: Smooth

Reynolds Number: 7.0×10^5 - 3.0×10^6

Airfoil Surface: Rough

Reynolds Number: 7.0×10^5 - 2.0×10^6

Reference: (A4)

Wind Tunnel: IAG Stuttgart #1

Date: 1962-1972

Type of Test: Two-Dimensional

Wind Tunnel Turbulence: 0.02%

Airfoil Surface: Smooth

Reynolds Number: 7.0×10^5 - 3.0×10^6

Figure 2

Airfoil NACA 4415 Test Conditions and Profile Contour (Ref. 11)

TABLE 1
AIRFOIL NACA 4415 SECTION COORDINATES (Reference 11)

NACA 4415		X, Y Coordinates	
X(upper)	Y(upper)	X(lower)	Y(lower)
.00000	.00000	.00000	.00000
.01250	.03070	.01250	-.01790
.02500	.04170	.02500	-.02480
.05000	.05740	.05000	-.03270
.07500	.06910	.07500	-.03710
.10000	.07840	.10000	-.03980
.15000	.09270	.15000	-.04180
.20000	.10250	.20000	-.04150
.25000	.10920	.25000	-.03980
.30000	.11250	.30000	-.03750
.40000	.11250	.40000	-.03250
.50000	.10530	.50000	-.02720
.60000	.09300	.60000	-.02140
.70000	.07630	.70000	-.01550
.80000	.05550	.80000	-.01030
.90000	.03080	.90000	-.00570
.95000	.01670	.95000	-.00360
1.00000	.00000	1.00000	.00000

leading edge radius = 2.48

slope of radius = 0.20

NACA 4415 Airfoil

Figure 3
Graphical Presentation of C_L and C_D as a Function of α° and Reynolds No.

TABLE 2
TABULATED LIFT AND DRAG COEFFICIENTS AS A FUNCTION OF
ANGLE OF ATTACK AND REYNOLDS NUMBER (REF. 11)

NACA 4415

Tunnel: NACA VDT / Date: 1937 / Test: 3-D / Turbulence: 2.0% / Surface: Smooth

RN	4.2×10^4		8.3×10^4		1.6×10^5		3.3×10^5			6.5×10^5		
AOA	CL	CD	CL	CD	CL	CD	CL	CD	CM	CL	CD	CM
-7.0	-	-	-.33	-	-.28	-	-.27	.0160	-	-.31	-	-
-6.0	-.40	.0485	-.23	.0346	-.15	.0213	-.17	.0157	-.10	-.20	.0143	-
-5.0	-.27	.0425	-.13	.0318	-.03	.0196	-.07	.0151	-.10	-.09	.0134	-.09
-4.0	-.15	.0385	-.03	.0295	.08	.0172	.03	.0141	-.10	.02	.0128	-.09
-3.0	-.03	.0364	.07	.0275	.19	.0155	.13	.0128	-.10	.13	.0125	-.09
-2.0	.09	.0356	.18	.0259	.29	.0159	.22	.0124	-.10	.24	.0123	-.10
-1.0	.21	.0345	.28	.0250	.38	.0164	.32	.0129	-.10	.35	.0121	-.09
.0	.32	.0335	.38	.0244	.47	.0166	.41	.0134	-.10	.46	.0119	-.09
1.0	.44	.0327	.48	.0240	.54	.0170	.50	.0139	-.10	.56	.0117	-.09
2.0	.54	.0322	.57	.0239	.62	.0173	.59	.0145	-.10	.66	.0117	-.09
3.0	.64	.0322	.66	.0239	.68	.0175	.68	.0152	-.10	.75	.0120	-.09
4.0	.74	.0328	.74	.0242	.75	.0177	.75	.0159	-.10	.83	.0125	-.09
5.0	.82	.0338	.82	.0249	.81	.0181	.83	.0166	-.10	.91	.0135	-.09
6.0	.90	.0352	.89	.0262	.87	.0189	.90	.0174	-.10	.98	.0148	-.10
7.0	.97	.0372	.96	.0281	.94	.0201	.96	.0181	-.10	1.05	.0166	-.10
8.0	1.04	.0398	1.03	.0311	1.00	.0221	1.03	.0191	-.10	1.11	.0189	-.10
9.0	1.09	.0431	1.09	.0354	1.06	.0250	1.09	.0209	-.10	1.16	.0221	-.11
10.0	1.13	.0479	1.15	.0417	1.11	.0293	1.14	.0245	-.10	1.21	.0262	-.11
11.0	1.16	.0552	1.21	.0507	1.17	.0356	1.20	.0316	-.11	1.26	.0317	-.12
12.0	1.18	-	1.26	-	1.22	.0450	1.26	.0452	-.12	1.30	.0394	-.12
13.0	1.18	-	1.30	-	1.28	-	1.31	-	-.12	1.34	-	-.12
14.0	1.15	-	1.30	-	1.32	-	1.35	-	-.11	1.37	-	-.13
15.0	1.09	-	1.24	-	1.32	-	1.36	-	-.14	1.40	-	-.13
16.0	1.00	-	1.13	-	1.30	-	1.35	-	-.18	1.41	-	-.14
17.0	.92	-	1.04	-	1.25	-	1.33	-	-.19	1.40	-	-.14
18.0	.87	-	.97	-	1.18	-	1.30	-	-.20	1.37	-	-.14
19.0	.83	-	.94	-	1.10	-	1.26	-	-.19	1.34	-	-.15
20.0	.82	-	.91	-	1.02	-	1.21	-	-.17	-	-	-
21.0	.81	-	.90	-	-	-	-	-	-	-	-	-

$$R_N = \frac{(\text{velocity}) (\text{density}) (\text{length})}{(\text{viscosity})} \quad (16)$$

For small wind systems, the following relationships are used to calculate R_N :

$$\text{Velocity} = (.75R) \cdot \omega \cdot 2\pi/60, \text{ ft/sec} \quad (17)$$

$$\text{Length} = \text{chord length at 75\% of rotor radius} \quad (18)$$

where:

R = rotor radius, ft

ω = rotor rotating speed, rpm

For most small wind systems, R_N is below a conventional aircraft's R_N by an order of magnitude (see Ref. 11). Since airfoil data is often affected by the Reynolds number, the input data file should include airfoil data measured under those Reynolds numbers which cover the expected operating range.

2.2.1.2 Blade Taper and Twist

The blade taper is defined as the chord length change from blade root to tip. Constant chord (zero taper) blades would reduce manufacturing cost but also give poorer performance than tapered ones. This is also true for untwisted blades. The blade twist is defined as the angular change of the airfoil chord line from root to tip. Theories for optimum blade taper and twist can be found in Reference 12.

2.2.1.3 Blade Pitch Angle

This is the angle between the airfoil chord line and the plane of rotation at 75 percent rotor radius section. Positive value is defined as the pitch angles measured towards the wind speed direction.

2.2.1.4 Coning Angle

This is the angle between the blade span center line and the plane of rotation. Positive value indicates the blades are coned downwind.

2.2.1.5 Feather and Stall

A blade is feathered when the airfoil is parallel to the free wind speed (or the pitch angle is approaching (+) 90°). The opposite of the feathering is defined as stalling (i.e., the pitch angle is greater than the airfoil stall angle).

2.2.2 Rotor Force and Velocity

A diagram of rotor force and velocity is shown in Figure 4. Lift force coefficient (C_L) and drag force coefficient (C_D) are produced by the airfoil in a stream (W) at an angle of attack α° . The pitch angle of the blade is θ° . Therefore:

$$\phi^\circ = \theta^\circ + \alpha^\circ \quad (19)$$

Normal and tangential force coefficients assuming no coning angle, therefore are defined as:

$$C_N = C_L \cos\phi + C_D \sin\phi \quad (20)$$

$$C_T = C_L \sin\phi - C_D \cos\phi \quad (21)$$

Rotor torque and thrust are the integral of C_N and C_T along the blade, respectively:

$$\text{Thrust} = \int_0^R (B \times C_b) \times C_N (1/2 \rho W^2) \times dr \quad (22)$$

Figure 4
Rotor Force and Velocity Diagram

$$\text{Torque} = \int_0^R (B \times C_b) \cdot C_T (1/2 \rho W^2) \cdot r dr \quad (23)$$

where:

B is the number of blades
 C_b is the blade chord length, ft
W is the resultant velocity, ft/sec
R is the rotor radius, ft
 ρ is the air density, slugs/ft³

Velocity component u and $r\omega'$ are defined as (Ref. 13):

$$u = V (1 - a) \quad (24)$$

$$r\omega' = r\omega (1 + a') \quad (25)$$

where:

V is the free air (wind) speed, ft/sec
 ω is the rotor shaft speed, rpm
a is the axial interference factor (or axial induction factor) at the plane of the rotor
a' is the circumferential interference factor (or angular induction factor) at the rotor plane.

In the SEACC, a and a' are solved based on the propeller theory from the PROP computer code (see Section 3.1 for a discussion of this code).

2.2.3 Rotor Power Coefficient and Tip Speed Ratio

Rotor power coefficient and rotor tip-speed ratio are defined as:

$$C_p = \frac{\text{Rotor Power}}{1/2 \rho V^3 A} = \frac{\text{Torque} \times (\text{Rotor Speed})}{1/2 \rho V^3 A} \quad (26)$$

$$\lambda = \frac{R\omega}{V} \quad (27)$$

where ω is in radians/sec., R in ft, and V in ft/sec.

C_p can be predicted by knowing "Torque" from Equation 23.

The rotor performance curve, C_p vs. λ , is the data base for the rest of the calculations in this systems analysis.

2.3 THE POWER TRAIN SUBSYSTEMS

The power train subsystems have a significant influence on power output and annual energy production. A machine with a constant rpm rotor may have a power train consisting of a gearbox and induction generator, whereas one with a variable rpm rotor may have a direct drive ac alternator, a rectifier, and an electronic inverter. Small wind systems analysts and designers are often confronted with the task of estimating the subsystem efficiency as a function of power ratio. Efficiencies in the manufacturer's specifications are often not sufficiently accurate for wind system applications. More reliable data can be obtained from dynamometer tests, but this method is often too expensive for preliminary wind system design and analysis.

Typical power train subsystem efficiency curves for a constant rpm rotor and a variable rpm rotor are shown in Figures 5 and 6, respectively.

Figure 5 indicates a two-dimensional efficiency curve where power train efficiencies are expressed as a function of power ratio, which is defined as:

$$\text{Power Ratio} = \frac{\text{Output Power}}{\text{Generator Rated Power}} \quad (28)$$

Figure 6 shows a three-dimensional efficiency curve where power train efficiencies are expressed as a function of power ratio and rpm ratio. The rpm ratio is defined as:

CONSTANT RPM ROTOR SWECS DYNAMOMETER TEST RESULTS

Figure 5
Power Train Efficiency of a Constant rpm Rotor SWECS

Figure 6
Power Train Efficiency of a Constant λ Rotor SWECS

$$\text{rpm Ratio} = \frac{\text{Generator rpm}}{\text{Generator rpm at Rated Power}} \quad (29)$$

The subsystem efficiency curves are applied to the rotor performance curve to obtain final power and energy output.

3. COMPUTER PROGRAM DESCRIPTION AND FLOW CHARTS

The SEACC consists of three major subprograms: 1) the PROP code, 2) the POWER code, and 3) the ENERGY code. Rotor power coefficient as a function of blade tip-speed ratio is the major output of the "PROP" code. Likewise, the power output (kW) as function of wind speed (V) and annual energy production (kWh) as a function of annual average wind speed ($\bar{V}$) are the major outputs of the "POWER" and "ENERGY" codes, respectively.

A summary of the SEACC is shown in Figure 7, which also indicates input and output information required for each subprogram.

3.1 THE PROP CODE

The PROP computer program (Ref. 13) utilizes blade element and momentum theory to compute a and a' . By equating the thrust force from blade element theory to the change in axial momentum, the unknown a can be determined through an iterative process. Likewise, by equating the torque force from blade element theory to the change in angular momentum, the unknown a' can be iteratively calculated. In addition, the PROP code utilizes several tip loss options to account for the three-dimensional flow near the blade tip.

The PROP code has been widely used by the wind energy industry since its publication in June 1976. However, several modifications have been made in the code by the Rocky Flats Wind Systems Program, as follows:

1. The inclusion of Glauert's empirical formula describing the windmill brake and vortex ring state performance; i.e., the flow field at high tip speed ratios (Ref. 14). Although this idea was suggested by Reference 13 it was not implemented in that version.
2. The inclusion of a subroutine which synthesizes post-stall airfoil data based on an empirical formulation (Ref. 15).

SWECS SYSTEMS ENGINEERING & ANALYSIS

Figure 7

A Summary of the SEA Computer Program
with Input and Output Information

3. The inclusion of a method to interpolate between aerodynamic data input at various Reynolds numbers for each radial blade station.
4. An improvement on the code so that the hub losses can be calculated simultaneously with any of the tip loss models.

The input parameters required by the PROP code are the following:

1. Rotor configuration - rotor radius, hub radius, coning angle, rotor rpm, number of blades, etc.
2. Blade configuration - airfoil data (C_L and C_D vs. α°), rates of taper and twist, pitch angle, etc.
3. Systems and site information - hub height, site altitude, wind shear power law exponent, etc.

The major output data of the PROP code used in the analysis is the rotor power coefficient curve (i.e., C_p vs. λ). However other computational results contained in PROP are readily available at the user's command when each run is made. Users who are interested in those results should consult Reference 13 for details.

3.2 POWER CODE

The POWER code is so defined because this subprogram calculates rotor power output as a function of wind speed from the power coefficient curve given by PROP code.

The POWER code contains three major options in choosing rotor rpm design. The flow chart (Figure 8) indicates that after taking in C_p vs. λ table from the PROP code three options, numbered as 1, 2, and 3, are offered:

Figure 8. The Computer Flow Chart of POWER Code

1. Choose 1 for a constant rpm rotor design. This design requires the rotor to maintain a constant shaft speed for all wind speeds up to the cut-out condition. The user must specify an rpm for the rotor and the cut-out wind speed. In this subroutine the computer will ask the user to decide whether a maximum power limitation should be imposed on the rotor. If the answer is YES, the user has the option to specify a power limitation or let the computer seek and maintain a maximum power. A constant rpm rotor is often used for an induction generator or a synchronous generator which produces constant frequency and voltage ac electricity at 1800 rpm, with a maximum rpm fluctuation of +10%.
2. Choose 2 for a constant λ (or variable rpm) rotor design. This design requires the rotor rpm to vary with wind speed so that an optimum λ (where C_p is maximum) can be maintained in all wind speeds. The user needs to specify cut-in and cut-out wind speeds, the maximum C_p and the corresponding λ . A rotor maximum power limitation option, as described above, is also provided here. Furthermore, the user is given an additional choice of using the rated wind speed to limit the maximum rotor power output. This design is often used with a power train subsystem consisting of an ac alternator and a rectifier (for a dc current application) or an ac alternator, a rectifier, and an inverter (for an ac house current application).
3. Choose 3 for a rotor rpm-specific design. This design requires the rotor rpm to follow a certain rpm schedule specified by the user. The user needs to create an input file for this particular design. The input file should contain an rpm vs. wind speed table to cover operating conditions between cut-in and cut-out wind speeds.

When one of the above-mentioned options is selected, the computer will pose the following questions before the final power curve is calculated:

1. Should the subsystem's efficiency be applied to the rotor power curve?
2. If the answer is yes, then which efficiency table should be used? A 2-D or 3-D table? The user should be aware that a 2-D table is selected for a constant rpm rotor design only. Whereas a 3-D table is for the constant λ rotor design.

3.3 ENERGY CODE

In this subprogram, SWECS annual energy production will be calculated based on the power curve produced by the previous code (Figure 9). The user is required to specify a hub height and make a choice on the wind speed distribution - a Weibull distribution or a NASA distribution. When a Weibull distribution is selected, the shape factor (K) is requested by the computer. The computer sets $K = 2.27$ for a NASA distribution. Options for a quick summary report or a detailed energy report are also provided. The quick summary report lists energy yield in kWh as a function of annual average wind speed ranging from 5 to 18 mph at an interval of 1 mph. The detailed report will list, in addition to the energy kWh, the most probable wind speed, most probable power output and wind speed for maximum energy density for each annual average wind speed.

Energy supply/demand mismatch can be estimated by the ENERGY code. To accomplish the mismatch estimate the user is required to prepare diurnal wind speed and load distributions for four seasons (winter, spring, summer, and fall). The code will then combine the diurnal distribution and the power curve to summarize the net or total energy mismatch for the four seasons separately and for the entire year. Diurnal SWECS power output superimposed on the load profile can be plotted by the code. Choices for constructing a diurnal wind distribution are also provided by the code.

Figure 9. The Computer Flow Chart of the ENERGY Code

4. PARAMETRIC STUDY

The effect of SWECS configuration parameters on rotor and system performance can be evaluated with the SEACC. If enough runs are carried out, optimum conditions can be pinpointed. A case study was carried out to demonstrate the effectiveness of the code (Ref. 16).

A model SWECS for the case study is selected and listed as shown in Table 3.

The design parameters under study are pitch angle setting for a fixed-pitch rotor and rotor rpm for a constant rpm rotor. In addition, comparisons were made between an optimized constant rpm rotor and constant λ rotor systems. The effect of power train efficiency on such comparisons is also included.

A total of five cases have been studied. A summary of the variables used in the case studies is shown in Table 4 and described in the following.

- Case 1 - The purpose of this case study is to investigate the pitch angle effects on SWECS rotor performances. The pitch angle was varied from 15° to -2° . The rotor rpm option was selected as a constant shaft speed rotor at 346 rpm. No power train efficiency was used to discount the rotor power or energy output. Results of this case study are shown in Section 4.1.
- Case 2 - The purpose of this case study is to investigate the rotor rpm effects on SWECS rotor performance. The rotor rpm was varied from 50 percent to 150 percent of 346 rpm, which was used as the target rpm in Case 1. The pitch angle was fixed at an optimum angle found in Case 1. Results of the rpm effects are listed in Section 4.2.
- Case 3 - The rotor rpm option was selected as a variable rpm rotor at an optimum λ found in Case 2 and an optimum θ° from Case 1. Rotor maximum power output was made to match the one calculated in Case 2 (in this case, five different power levels

TABLE 3
CONFIGURATION OF MODEL SWECS

Rotor configuration	- horizontal-axis and downwind
Number of blades	- 2
Rotor diameter	- 10 ft
Blade pitch control design	- Active controls with actuators
Blade geometry	- Airfoil series NACA 0012 (Ref. 11) whose lift and drag coefficients are listed in Table 2
Performance goals	- The SWECS will produce 1.5 kW household electricity (120 volts, 60 Hz ac) at 25 mph wind speed
Rotor rpm options	- 1) Constant rpm rotor with a target rpm at 346 2) Variable rpm rotor at an optimum tip speed ratio
Cut-out wind speed	- 40 mph
Tower height	- 50 ft
Site altitude	- At sea level
Wind speed distribution	- NASA definition

TABLE 4

A SUMMARY OF THE VARIABLES USED IN THE PARAMETRIC STUDY

Case Study No.	Power Train Efficiency Used	Rotor Design Options	Rotor rpm or (rpm) max.	λ	Pitch Angle θ°	Wind Speed V (mph)	Annual Average Wind Speed $\bar{V}$ (mph)
1	No	constant rpm rotor	346 (design value)	calculated by code	15°, 10°, 5°, 3°, 2°, 1°, -1°, -2°	(V)in by code (V)out = 40	10 - 18
2	No	constant rpm rotor	50%, 75% 100%(=346) 125%, 150%	calculated by code	optimum θ° from Case 1 ($=2^\circ$)	same as above	same as above
3	No	constant λ rotor	(rpm)max. calculated by code	optimum λ ($= 10$)	same as above	(V)in = 7 (V)out = 40	same as above
4	Yes	← SAME AS CASE 2 →					
5	Yes	← SAME AS CASE 3 →					

TABLE 5
AIRFOIL DATA OF SERIES NACA 0012 AT A REYNOLDS NUMBER 330,000

α°	C_L	C_D
-4.0	-.40	.011
-3.0	-.30	.010
-2.0	-.20	.009
-1.0	-.10	.008
0.0	0.00	.008
1.0	.11	.008
2.0	.21	.009
3.0	.31	.010
4.0	.41	.011
5.0	.51	.012
6.0	.60	.013
7.0	.69	.015
8.0	.77	.019
9.0	.83	.024
10.0	.84	.025
11.1	.86	.084

were made according to the five rpm's used in Case 2). The $(rpm)_{max}$ based on each maximum power output was calculated by the code. No power train efficiencies were used in this case. Results of this case as compared to Case 2 are shown in Section 4.3.

Case 4 & 5 - The purpose of these case studies was to show the effect of power train efficiency on rotor performance. Therefore, Cases 2 and 3 were repeated but with power train efficiencies applied to each output, respectively. Results of Case 4 and 5 are included in Section 4.4.

This section details the results of the case study.

4.1 CASE 1 - BLADE PITCH ANGLE EFFECTS

As shown in Figure 4, ϕ° is determined by the local wind velocity and the blade tangential velocity. The angle of attack, α° , a determinant of airfoil's C_L and C_D , is the difference of ϕ° and θ° , where θ° is the blade pitch angle and a constant in the case of a fixed-pitch rotor. A proper choice of θ° is necessary for a fixed-pitch rotor SWECS. Figures 10 through 15 show the effects of θ° on rotor C_p , power output, and energy production, respectively. The θ° was varied from 15° to -2° and indicated an optimum θ° of 2° based on the energy production plots (Figure 15). This is the pitch angle a fixed pitch rotor SWECS should have during normal operation. The power curve plots (Figures 12 and 13) also indicate a trend that the maximum possible power output and the cut-in wind speed decrease at lower pitch angles. This family of power curves at various pitch angles can be used as the basic pitch control data for a variable pitch rotor SWECS. In the design of a constant λ rotor machine, Figure 11 indicates the maximum C_p and the corresponding λ (λ_{opt}) to be used for achieving optimum performance. Detailed comparisons between the constant rpm rotors and the constant λ rotors will be addressed later in the report.

Figure 10. Rotor Power Coefficient Characteristics As Affected by Variation of Pitch Angle Ranging | From +15° to 3°

Figure 11. Rotor Power Coefficient Characteristics As Affected by Variation of Pitch Angle Ranging from 2° to -2°

Figure 12. Pitch Angle Effect on Rotor Power for $\angle\theta = 15^\circ$ to 3°

Figure 13. Pitch Angle Effect on Rotor Power for $\angle\theta = 2^\circ$ to -2°

Figure 14. Pitch Angle Effect on Rotor Energy Production for $\angle\theta = 15^\circ$ to 3°

Figure 15. Pitch Angle Effect on Rotor Energy Production for $\angle\theta = 2^\circ$ to -2°

4.2 CASE 2 - ROTOR RPM EFFECTS

The model constant rpm rotor design will have a different λ value whenever wind speed changes as, by definition,

$$\lambda = (\text{rotor radius}) \cdot \omega / (\text{wind speed}) \quad (30)$$

The rotor C_p will then vary accordingly, following the curve shown in Figure 16 from $(\lambda)\text{cut-in}$ to $(\lambda)\text{cut-out}$ as wind speed varies from V_{in} to V_{out} . However, when the rotor has a different rpm value, $(\lambda)\text{cut-in}$ and $(\lambda)\text{cut-out}$ change accordingly. This will produce C_p 's in a different range, and rotor power output and annual energy production will be greatly affected. Figure 17 shows that the maximum rotor power output and its corresponding wind speed increase with rotor rpm. However, in low wind speeds the rotor power decreases with rotor rpm. The cut-in wind speed also increases with rotor rpm as seen in the same figure. This demonstrates the fact that the rotor rpm has to be increased to obtain higher maximum rotor power output without changing rotor size. This may result in high blade root stress or high cut-in wind speed.

Rotor annual energy production, as shown in Figure 18, increases with rotor rpm, reaches a maximum and tapers off at high rpm's. The optimum rotor rpm increases with annual average wind speed. This indicates that it may be desirable for SWECS manufacturers to provide gearbox ratio options for various wind sites to optimize energy output.

4.3 CASE 3 - CONSTANT λ ROTORS VS. CONSTANT RPM ROTORS

When rotor C_p is maintained at maximum in all wind speeds, the rotor is considered most efficient because the rotor power, derived by

$$P = 1/2 \rho A V^3 \cdot (C_p)_{\max}, \quad (31)$$

Figure 16. The Optimum Cp Curve Used for a Constant rpm Rotor SWECS

Figure 17. Rotor rpm Effect on the Power Output

Figure 18
Rotor Energy Production as a Function of $\bar{V}$ and rpm

is at optimum all the time. The rotor rpm has to vary with wind speed so that the optimum λ and maximum C_p can be maintained. As the rotor power increases with the cubic wind speed, a maximum power ceiling which is required by the generator size has to be imposed upon the rotor in high wind speeds.

When this constant λ rotor is compared with a constant rpm rotor, a maximum generator capacity is used as the common point. Both rotors will reach a given maximum power and maintain that level until cut-out wind speed, V_{out} .

Higher power output of a constant λ rotor than that of a constant rpm rotor is seen in the wind speeds below the rated wind speed (Figure 19). V_t is the point where $C_p = (C_p)_{max}$ for both rotors. Figure 19 also indicates that the power difference of two rotors increases with generator maximum power capacity.

The energy production difference of two rotors is expressed in annual percentage and as a function of annual average wind speed and generator maximum power capacity, Figure 20. The difference is very large in low wind speed regions but narrows as wind speed increases. Rotor configuration tradeoffs for a given wind site can now be carried out with both Figures 18 and 20.

4.4 CASES 4 AND 5 - POWER TRAIN EFFICIENCY EFFECT

Components of power train subsystems may vary with rotor type. Constant rpm machines may have a gearbox and an induction generator, whereas constant λ rotor machines may have a direct drive ac alternator, a rectifier, and an electronic inverter. Efficiencies of these power train subsystems are different and this has a decisive influence on annual energy production.

Figure 19. Power Curves of a Constant rpm Rotor and a Constant λ Rotor at Two Different Maximum Power Levels

Figure 20. Rotor Energy Production Comparison Between a Constant rpm Rotor and a Constant λ Rotor SWECS

An illustration of this effect has been made by using efficiency curves taken from dynamometer tests carried out at Rocky Flats. The efficiency curve as a function of power ratio (two-dimensional) of a constant rpm rotor subsystem is plotted in Figure 5. Figure 6 shows the efficiency curve of a constant λ rotor subsystem as a function of power ratio and rpm ratio (three-dimensional). The performance comparison of the two rotor configuration systems is shown in Figure 21. It is seen that the difference in energy production is greatly reduced and mostly diminished in high winds. This is due to much poorer power train efficiency given by a constant λ rotor subsystem. Should a better subsystem be developed, of course, energy production would improve.

Figure 21
Final System Energy Production Comparison Between a
Constant rpm Rotor and a Constant λ Rotor SWECS

5. CONCLUSIONS AND RECOMMENDATIONS

The Systems Engineering Analysis Computer Code has proven to be an efficient SWECS research, development, and design tool. Preliminary configuration design trade-offs and parametric studies now can be carried out with minimum computer costs. With rotor geometry and blade airfoil aerodynamic data, major rotor performance can be calculated by the code. When subsystem efficiencies are known, SWECS system performance can be predicted. The energy matching/mismatching questions between SWECS supply and load demand can be answered when the local diurnal wind and load profiles are available.

The following conclusions regarding the general trends of wind system design parameters have been derived from case study results.

1. Rotor power coefficient curve (C_p vs. λ) is strongly affected by the blade pitch angle for a fixed pitch rotor and indicates that deviation of half a degree from the optimum pitch angle can result in noticeable performance degradation.
2. Rotor maximum power output and cut-in wind speed are a strong function of rotor rpm for a constant rpm rotor SWECS. In general, they increase with rotor rpm.
3. The optimum rotor rpm for a constant rpm rotor SWECS increases with annual average wind speeds.
4. Annual rotor energy production of a constant λ rotor SWECS is found much higher than that of a constant rpm rotor SWECS. The difference decreases with $\bar{V}$.
5. Overall system efficiency is vital to the final determination of SWECS energy yield. While a constant λ rotor is more efficient than a constant rpm rotor, the rectifiers and inverters required to process constant λ rotor output reduce their overall performance advantage. Development of more efficient power conversion equipment for constant λ systems (or use of mechanical loads) would enhance their energy production edge.

The following recommendations are appropriate for the continuation of SEACC work:

1. Component cost sensitivity can be included in the code to evaluate the effects of components on the cost of energy (COE).
2. A component sizing subroutine is needed to accomplish the COE sensitivity study.
3. A rotor and tower dynamics calculation subroutine should be included to ensure vibration-proof SWECS.
4. Economic issues such as life cycle costs, energy credit, insurance cost and tax benefits can be included.
5. The SEACC model can be expanded to allow analysis of wind farm applications.

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APPENDIX A
SEACC USER'S MANUAL

APPENDIX A

SEACC USER'S MANUAL

A.1 Introduction

This manual is intended to help prospective users become familiar with the SWECS Systems Engineering & Analysis Computer Code (SEACC), understand the options provided, and operate the program with minimum guesswork by presenting it with step-by-step illustrations.

A user with a basic knowledge in general engineering, perhaps with some understanding of wind energy terminology, and a little home work in the subject of airfoil characteristics and data tables (Refs. 10, and 11) should be able to use this computer program and perform parametric studies.

The present computer codes (Appendix C) were written for computer model "Eclipse" manufactured by Data General Corp. Users should seek assistance from computer experts in adapting this program to a computer which differs from "Eclipse."

Appendix B shows the computer commands for compiling and integrating code subprograms and establishing a procedure file and output files. Again, these steps should be completed by persons who are familiar with the computer operation and its programming requirements.

Included in the following sections are the input files, program steps, and a sample calculation. Users should prepare their own input files based on the desired designs. However, a sample input file is included so that users can validate the code and become familiar with the options provided by the SEACC.

A.2 Input Files

Before the execution of the computer program, a user needs to prepare input data files, such as: 1) rotor data file, 2) special rotor rpm schedule file, 3) power train efficiency file, either for a constant rpm rotor or for a variable rpm rotor SWECS, 4) data file for local diurnal wind speed distribution of four seasons, and 5) data file for load characteristics of four seasons. Data file 3 is required for the system performance. Those who are interested in the rotor performance only may skip file 3 and data files 4 and 5, which are for energy supply/demand matching investigations only.

A.2.1 Rotor Data File

As explained in the PROP code (Ref. 13), this file should describe blade aerodynamic characteristics (C_D and C_L), rotor geometry, tower height and wind site altitude, etc. Computer statements and names of variables are as follows:

```
READ FREE (9)  XR, XHB, XB, XSI
READ FREE (9)  XDR, NNF
READ FREE (9)  (RR(I), CI(I), THETI(I), I = 1, NNF)
READ FREE (9)  RLO(NNN), XTH, XALO
READ FREE (9)  NFS
READ FREE (9)  (AAT(NNN,I), CLT(NNN, I), CDT(NNN,I), I = 1, NFS)
READ FREE (9)  XAMOD, XHL, XBO, XAPF
READ FREE (9)  XH, XHH
```

where: XR = radius of the rotor in ft.
XHB = the rotor hub radius in ft.
XB = number of rotor blades
XSI = rotor blade coning angle in degrees
XDR = incremented percentage (5% or 0.05 is used)
NNF = number of inputed stations for blade geometry, i.e.,
determined by the number of RR's. If there are 10 RR's
NNF = 10

RR = percent radius for stations (20, 30, 40, ... 100% should use 20.0, 30.0, 40.0 ... 100.0)
 CI = blade chord length for each station in ft.
 THETI = angle of blade twist at each station in degrees
 RLO(NNN) = Reynolds number for each set of airfoil aerodynamic data table, CLT and CDT. If only one Reynolds number available, set RLO = 8888.
 XTH = maximum thickness/chord ratio
 XALO = angle of attack for zero lift (read from the aerodynamic data table), in degrees
 NFS = number of aerodynamic data points
 AAT(NNN,I) = angle of attack (from aerodynamic data table) in degrees
 CLT(NNN,I) = coefficient of lift (from an aerodynamic data table)
 CDT(NNN,I) = coefficient of drag (from an aerodynamic data table)
 XAMOD = axial interference model code. 0.0 - standard; 1.0 - Wilson model (XAMOD = 0.0 is often used)
 XHL = hub loss model controller. 0.0 - none; 1.0 Prandtl model (XHL = 0.0 is often used)
 XBO = MOSTAB tip loss model parameter (XBO = .97 is often used)
 XAPF = angular interference lockout. 0.0 - angular interference factor calculated, 1.0 - angular interference factor set equal to zero (XAPF = 0.0 is often used)
 XH = altitude of hub above sea level in ft.
 XHH = hub height from ground level in ft.

An example of a rotor data file, ROTORIN, is shown in Table A-1 for a rotor design (shown in Table 3) whose dimensions are:

rotor radius = 5.25 ft
 hub radius = 1.3125 ft
 number of blades = 2
 coning angle = 8.0
 airfoil series = NACA 0012 at a Reynolds number of 330,000
 blade taper and twist rates = 0
 blade chord = 0.3542 ft

ROTORIN will be used in the sample calculation later in the text.

TABLE A-1

PROP Code Rotor Input File - ROTORIN

5.25	1.3125	2.0	8.0
0.05	16		
100.0	0.3542	0.0	
95.0	0.3542	0.0	
90.0	0.3542	0.0	
85.0	0.3542	0.0	
80.0	0.3542	0.0	
75.0	0.3542	0.0	
70.0	0.3542	0.0	
65.0	0.3542	0.0	
60.0	0.3542	0.0	
55.0	0.3542	0.0	
50.0	0.3542	0.0	
45.0	0.3542	0.0	
40.0	0.3542	0.0	
35.0	0.3542	0.0	
30.0	0.3542	0.0	
25.0	0.3542	0.0	
8888	0.12	0.0	
16			
-4.0	-.40	.011	
-3.0	-.30	.010	
-2.0	-.20	.009	
-1.0	-.10	.008	
0.0	0.00	.008	
1.0	.11	.008	
2.0	.21	.009	
3.0	.31	.010	
4.0	.41	.011	
5.0	.51	.012	
6.0	.60	.013	
7.0	.69	.015	
8.0	.77	.019	
9.0	.83	.024	
10.0	.84	.026	
11.0	.86	.084	
0.0	1.0	0.97	0.0
0.0	9.0		

A.2.2 Special Rotor rpm Schedule File

This file determines the rotor rpm as a function of wind speed. It is used for a special rotor rpm schedule design. Computer statements for read-in of the file are as follows:

```
      READ FREE* (17) NTESTC, WSPD (1), RPM (1)
17  FORMAT (I5, 5x, F10.3, F10.3)
      DO 56 I = 2, NTESTC
          READ FREE (17) WSPD (I), RPM (I)
57  FORMAT (10x, F10.3, F10.3)
56  CONTINUE
```

where: NTESTC = number of points in the table (maximum of 26)
WSPD(I) = wind speeds
RPM(I) = rotor rpm's

* An optional format is provided for those who wish a formatted read.

The file name of this input file should be "RPMFIL." No other file name will be recognized by the computer. An example is shown in Table A-2.

A.2.3 Power Train Efficiency File

This file includes efficiencies of SWECS components such as gearboxes, electric generators (alternators/induction generators/synchronous generators), electronic inverters, rectifiers, etc. SWECS design requires several different combinations of these components. For instance, a constant rpm rotor SWECS needs a gearbox and induction generator or a low speed, direct drive synchronous generator as its subsystem. A variable rpm rotor SWECS design requires an alternator, a rectifier and an inverter as its power train subsystem. An example efficiency file for a constant rpm rotor is shown in Table A-3. A file for a variable rpm rotor is shown in Table A-4. Table A-3 is a two dimensional table which indicates the power train efficiency as a function of the power ratio which is defined as:

Power ratio = generator output power/generator rated power

TABLE A-2

Special Rotor rpm Input File - RPMFIL

25	7.000	.000
	8.000	15.000
	9.000	40.000
	10.000	80.000
	11.000	100.000
	12.000	105.000
	13.000	110.000
	14.000	110.000
	15.000	110.000
	16.000	110.000
	17.000	110.000
	18.000	110.000
	19.000	110.000
	20.000	110.000
	22.000	110.000
	24.000	110.000
	26.000	110.000
	28.000	110.000
	30.000	110.000
	32.000	80.000
	34.000	60.000
	36.000	40.000
	38.000	20.000
	40.000	10.000
	44.000	1.000

TABLE A-3
Power Train Efficiency Input File (2-Dimensional) - PTEFF1

0.0	0.0
13.1	0.016
50.5	0.129
65.5	0.276
65.1	0.289
67.5	0.334
70.3	0.438
72.6	0.529
72.1	0.557
73.1	0.756
72.9	0.797
72.8	0.812
74.5	0.915
72.5	0.935
72.3	0.948
0.0	0.0

The file name of this table is designated as PTEFF1; no other name is recognized by the computer. Computer statements for read-in are as follows:

```

DO 20 I = 1, 100
  READ FREE (4) EFF (I), POWERAT (I)
10 FORMAT (F5.1, F8.4)
  IF (EFF(I) .EQ. 0.0) GO TO 30
20 CONTINUE
30 IF (I .EQ. 1) GO TO 20
40 CONTINUE

```

Each column of this data file should be ended with zeros to terminate the read loop. The variables are defined as:

```

EFF(I) = power train efficiencies in decimals (for 100%
        efficiency EFF(I) = 1.0) (maximum of 26 points)
POWERAT(I) = power ratios

```

Table A-4 is a three-dimensional table which indicates the power train efficiencies as a function of both power ratios and rpm ratios. The rpm ratios are defined as:

$$\text{rpm ratio} = \text{generator rpm} / \text{generator rated rpm}$$

The file name is designated as TUDEE. No other name will be recognized by the computer.

The computer statements are as follows:

```
170 READ FREE (2) XPNT, YPNT
180 FORMAT (2F10.5)
    NXPNT = XPNT
    NYPNT = YPNT
    READ FREE (2) (PDRAT (J), J = 1, NXPNT)
190 FORMAT (8x, 9F6.2, /8x, 9F6.2)
    DO 220 I = 1, NYPNT
        READ (2, 200) SPD(I), (EFFGEN (I, J), J = 1, NXPNT)
200 FORMAT (F6.1, 9F6.1/6x, 9F6.1)
220 CONTINUE
```

where:

- XPNT = total number of points in power ratios
(18 points)
- YPNT = total number of points in RPM ratios
(13 points)
- PDRAT(J) = power ratios
(= input power/generator rated power)
- SPD(I) = rpm ratio
- EFFGEN(I, J) = power train efficiencies

Tables A-3 and A-4 can be derived from either dynamometer test results or manufacturer's specifications. When estimating a system power output or yearly energy yield, the power train efficiency plays a vital role in the final prediction.

TABLE A-4

Power Train Efficiency Input File (3-Dimensional) - TUDEE

18.	0.0	0.04	0.08	0.12	0.23	0.30	0.4	0.5	0.6
13.	0.7	0.3	0.9	1.0	1.1	1.24	1.5	1.95	2.0
0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
0.4	0.0	13.5	15.3	16.7	16.2	14.4	14.4	14.4	14.4
	13.4	13.4	13.5	13.5	12.6	12.6	11.7	7.2	0.0
0.6	0.0	22.5	33.3	38.7	37.8	36.0	34.2	34.2	34.2
	34.2	34.2	33.3	32.4	32.4	31.5	24.3	16.2	0.0
0.8	0.0	27.0	40.5	45.0	60.3	62.1	57.6	57.6	56.7
	56.7	55.8	55.8	54.9	51.3	45.0	34.2	22.5	0.0
0.9	0.0	30.6	45.0	47.7	60.3	61.2	62.1	54.8	54.8
	54.8	64.8	64.8	64.8	63.0	54.0	43.2	27.0	0.0
1.0	0.0	34.2	45.0	48.6	61.2	61.2	61.2	61.2	62.1
	64.8	65.7	66.6	66.6	63.9	63.0	40.5	31.5	0.0
1.1	0.0	37.8	48.6	49.5	61.2	62.1	63.0	63.0	63.0
	63.9	64.8	65.7	65.7	66.6	66.6	54.0	37.8	0.0
1.2	0.0	40.5	52.2	54.0	62.1	63.0	64.8	65.7	65.7
	65.7	65.7	64.8	64.8	63.0	63.0	55.8	38.7	0.0
1.3	0.0	45.0	54.0	55.8	62.1	64.8	66.6	67.5	67.5
	67.5	66.6	65.7	64.8	63.0	62.1	58.5	40.5	0.0
1.4	0.0	49.5	55.8	57.6	63.0	65.7	68.4	69.3	69.3
	69.4	67.5	65.7	64.8	63.9	63.0	58.5	45.0	0.0
1.5	0.0	52.2	56.7	58.5	63.0	67.5	69.3	70.2	70.2
	69.3	68.4	66.6	64.8	63.9	63.0	60.3	49.5	0.0
1.6	0.0	54.0	56.7	58.5	63.0	68.4	71.1	72.0	71.1
	71.1	69.3	67.5	65.7	64.8	63.9	61.2	54.0	0.0
2.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0

A.2.4 Diurnal Wind Speed File

If the local wind site diurnal wind speed distribution is known (Ref. 9), the diurnal power output of a SWECS can be estimated. The result helps the understanding of power mismatch and the sizing of the SWECS in regard to the energy demands.

Computer statements for the diurnal wind speed file are as follows:

```
90 READ (3, 95) MTRHT, WNDAVE
95 FORMAT (16x, F6.1, 23x, F6.1)
  DO 100 J = 1, 25
    READ FREE (3) DAYHR(J), WNDSP(1, J), WNDSP(2, J), WNDSP(3, J),
      WNDSP(4, J)
110 FORMAT (5F10.2)
100 CONTINUE
```

where:

- MTRHT = anemometer height, in meters
- WNDAVE = annual average wind speed measure at MTRHT, in m/s
- DAYHR(J) = hour of the day
- WNDSP(1, J) = diurnal wind speed during spring, m/s
- WNDSP(2, J) = diurnal wind speed during summer, m/s
- WNDSP(3, J) = diurnal wind speed during fall, m/s
- WNDSP(4, J) = diurnal wind speed during winter, m/s

The file name for this input file is designated as WINDDI. No other names will be recognized by the computer. An example is shown in Table A-5.

A.2.5 Diurnal Load Distribution File

This file helps the estimate of energy supply/demand mismatch for SWECS applications. The computer statements for the file are:

```
  DO 330 J = 1, 25
    READ (15, 310) DAYHR(J), LDKW(1, J), LDKW(2, J), LDKW(3, J),
      LDKW(4, J)
310 FORMAT (5F10.2)
330 CONTINUE
```

TABLE A-5
Diurnal Wind Speed Distribution - WINDDI

METER HEIGHT(M)=	17.7	AVERAGE	VELOCITY(M/S)=	5.7
0.00	5.0	4.0	4.2	6.0
1.00	5.1	4.0	4.0	5.3
2.00	5.0	3.9	3.8	5.6
3.00	4.9	3.3	3.8	5.6
4.00	4.7	3.6	3.8	5.6
5.00	4.6	3.4	3.8	5.6
6.00	4.5	3.2	3.8	5.6
7.00	5.0	3.5	3.9	5.6
8.00	5.6	3.3	3.9	5.7
9.00	6.0	4.2	4.2	6.0
10.00	6.8	5.0	5.0	6.8
11.00	7.5	5.6	5.6	7.4
12.00	8.0	6.0	6.4	8.2
13.00	8.2	6.3	6.8	8.6
14.00	8.5	6.7	7.3	9.1
15.0	8.7	7.0	7.2	9.0
16.0	8.5	6.9	6.7	8.5
17.0	8.0	7.0	6.2	8.0
18.0	7.5	7.0	5.2	7.0
19.0	7.0	6.3	4.7	6.5
20.0	6.0	6.0	4.3	6.1
21.0	5.6	5.6	4.2	6.0
22.0	5.2	5.0	4.1	5.9
23.0	5.1	4.5	4.0	5.8
24.0	5.0	4.0	4.2	6.0
	Spring	Summer	Fall	Winter

where: DAYHR(J) = hour of the day
 LDKW(1, J) = diurnal loads during spring, kW
 LDKW(2, J) = diurnal loads during summer, kW
 LDKW(3, J) = diurnal loads during fall, kW
 LDKW(4, J) = diurnal loads during winter, kW

The file is designated as LOADDI. No other names would be recognized by the computer. An example is listed in Table A-6.

TABLE A-6
 Diurnal Load Distribution - LOADDI

0.0	2.75	0.0	2.75	5.50
1.0	2.75	2.35	2.75	5.50
2.0	5.00	2.25	5.00	7.75
3.0	2.75	2.35	2.75	5.50
4.0	5.50	0.0	2.75	5.50
5.0	2.75	2.35	2.75	5.50
6.0	7.25	2.25	5.00	7.75
7.0	5.00	4.60	5.00	10.25
8.0	5.00	4.60	5.00	7.75
9.0	2.75	0.0	0.0	5.50
10.0	0.0	2.35	2.75	5.50
11.0	2.75	2.35	2.75	5.50
12.0	5.00	4.60	5.00	7.75
13.0	0.0	4.70	2.75	5.50
14.0	2.75	4.70	0.0	2.75
15.0	0.0	4.70	2.75	2.75
16.0	2.75	4.70	0.0	2.75
17.0	2.75	4.70	2.75	5.50
18.0	2.75	4.70	2.75	5.50
19.0	5.00	5.25	5.00	7.75
20.0	5.00	6.25	10.25	7.75
21.0	2.75	2.35	2.75	5.50
22.0	4.50	5.35	7.25	10.00
23.0	2.75	2.35	2.75	5.50
24.0	2.75	2.35	2.75	5.50
	Spring	Summer	Fall	Winter

In summary, there is a total of six input files which need to be prepared according to various investigation purposes. These six files are:

1. ROTORIN or other names - "PROP" code input file
2. RPMFIL - special rotor rpm vs. wind speed file
3. PTEFF1 - describe power train efficiency (2-D)
4. TUDEE - describe power train efficiency (3-D)
5. WINDDI - describe seasonal diurnal wind speeds
6. LOADDI - describe seasonal diurnal load profile

A.3 Execution of SEACC

An SEACC execution steps flow chart is given in Table A-7. Prospective users may compare the chart with the step-by-step description set forth in this section. For various rotor system designs, appropriate steps have to be taken to ensure the computational continuity. It is suggested that the user sort the routes from the chart according to the desired SWECS design and run the SEACC accordingly.

STEP 1

Log-on procedures (such as user's name, passwords, user's account, etc.)

STEP 2

To start the SEACC the user enters the following commands to prompt the procedure file "SEACC":

SEACC s ROTOR FILE NAME

where s means space between the words.

STEP 3

Computer: DELETED TUOUT
DELETED WINDOUT
ENTER XMIN, XMAX, DELX, OMEGA, THETP, GO, XETA, BLD

NOTE:

1. Output data files, TUOUT and WINDOUT, are cleared out for new data.
2. XMIN = Minimum value of tip-speed ratios (λ) for the C_p vs. λ table. Usually XMIN = 1.0 is used.

XMAX = Maximum value of λ . Depending upon other variables are used, the XMAX should be large enough to show negative C_p 's where cut-in wind speed can be estimated. Usually XMAX = 15 - 20 is used. User should experiment to find the best value for XMAX.

(Contd. on page 62.)

TABLE A-7

SEACC EXECUTION STEPS FLOW CHART

TABLE A-7 (continued)

TABLE A-7 (continued)

DELX = The increment of λ between XMIN and XMAX. The total number of points created by DELX should not exceed 25. Usually DELX = 1.0 is used.

OMEGA = Rotor shaft speed, rpm.

THETP = Rotor blade pitch angle in degrees, assuming a fixed blade pitch operation.

GO = Tip loss model controller (see Ref. 13)

- 0 = Prandtl
- 1 = Goldstein
- 2 = no tip loss model
- 3 = effective radius tip model
- 4 = finite wind tip model

XETA = Wind velocity distribution profile power law exponent. If wind site XETA is not available, XETA = 1/7, describing a classic turbulent boundary layer on a flat plate may be used.

BLD = Blade element data controller.

- 0 - No blade element data will be printed.
- 1 - Blade element data will be printed. For a quick energy calculation BLD = 0 is recommended.

User: Enters appropriate data for the above variables

STEP 4:

Computer: Stop
Enter the datafile name for prop

User: Enters data file name

Computer: The data file name and a table showing C_p vs. λ will be printed by computer. This table is the result given by PROP code

STEP 5:

Computer: Please select your rotor control options:

1. For constant rpm rotors
2. For constant tip-speed ratio rotors
3. For rotors having a special rpm vs. wind speed schedule

User: Enters 1, 2, or 3

NOTE: When 1 is entered, STEP 6 will be taken
When 2 is entered, STEP 13 will be taken
When 3 is entered, STEP 18 will be taken

STEP 6:

Computer: Do you wish to change prop's rotor rpm?

User: Enters Y (for yes) or N (for no)

NOTE: The user specified a rotor rpm when OMEGA was specified in STEP 3. This step is to enable the user to make a change on the rotor rpm before the calculation which follows. If a N (for no) is prompted, the computer will skip STEP 7 and go to STEP 8 directly.

STEP 7:

Computer: Enter rotor rpm

User: Enters a new rotor rpm

STEP 8:

Computer: Prints a table showing rotor power, tip-speed ratio, power coefficient, and rotor rpm as a function of wind speed.

STEP 9:

Computer: Enter maximum power cutoff wind speed in mph

User: Enters V_{out}

STEP 10:

Computer: Do you want a max. power output limit?

User: Enters Y or N

NOTE: Generator's rated power often determine the max. rotor power output
When Y is entered, STEP 11 will be taken
When N is entered, STEP 23 will be taken

STEP 11:

Computer: Do you wish to specify the limiting power?

User: Enters Y or N

NOTE: When N is entered, the computer will use the calculated max. power as the limiting power and skip STEP 12

STEP 12:

Computer: What is the limiting power?

User: Enters $(P)_{\text{limit}}$

NOTE: The computer will continue on to STEP 23 for this rotor option (constant rpm rotor). However, when a rotor design option of a constant λ SWECS is desired, and 2 is entered by user at STEP 5, STEPS 13-17 will be taken by computer. Please consult Table A-7 for continuity.

STEP 13:

Computer: Enter cut-in and cut-out wind speeds in mph

User: Enters V_{in} and V_{out}

STEP 14:

Computer: Enter tip-speed ratio and power coefficient, C_p

User: Enters $(\lambda)_{\text{opt}}$ and $(C_p)_{\text{m}}$ (these values can be found from C_p vs. λ table printed out previously. The power coefficient is the max C_p and the "tip speed ratio" is the corresponding λ value)

STEP 15:

Computer: Enter your choice of using power (type in 1) or rated wind speed (type in 2) to limit max. power

User: Enters 1 or 2

NOTE: When 1 is entered, STEP 16 will be taken; 2, STEP 17

STEP 16:

Computer: What is the limiting power?

User: Enters a $(P)_{\text{limit}}$ (computer will skip STEP 17 after this)

Computer: What is the rated wind speed?

User: Enters $(V)_{rated}$

NOTE: Computer will continued on to STEP 23 after this step.

STEP 18:

NOTE: The following, STEPS 18-22, is the procedure for rotor option 3 at STEP 5, a SWECS design with special rotor rpm vs. wind speed schedule. The user should have an input file, RPMFIL, prepared.

Computer: Prints the RPMFIL file again (this is a table showing rotor rpm as a function of wind speed)

STEP 19:

Computer: Do you wish to change this table? (Y/N)

User: Enters Y or N

NOTE: When Y is entered, computer will go to STEP 20
When N is entered, computer will go to STEP 22

STEP 20:

Computer: Enter number of lines you wish to change (or enter)

User: Enters $(N)_{line}$

STEP 21:

Computer: Enter I, WSPD(I), RPM(I):

User: Enters appropriate values

STEP 22:

Computer: Prints final rpm table and C_p vs. λ table (the results from PROP)

STEP 23:

Computer: Prints the final rotor performance data showing rotor power (kW), tip-speed ratio, power coefficient, and rotor rpm as a function of wind speed in mph.

STEP 24:

Computer: Do you wish to obtain SWECS performance by adding power train efficiency to the system? (Y/N)

User: Enters Y or N

NOTE: If N is entered the computer will skip all the power train efficiency evaluation procedures and go to the final SWECS performance data table, STEP 23.

If Y is entered, the computer will go to STEP 25. At this step, the user should be aware that a power train efficiency table should be provided either in the computer input file or at hand ready to be entered into computer.

STEP 25:

Computer: Enter 2 for a 2-D table or 3 for a 3-D table

User: Enters 2 or 3

NOTE: A 2-D table is the table showing power train efficiency as a function of power ratio (= output power/generator's rated power). This table is often used for a constant rpm rotor SWECS. Whereas a 3-D table shows the power train efficiency as a function of power ratio and rpm ratio (= generator's rpm/rated generator rpm). This table is often used for a constant tip-speed ratio (or a variable rpm) rotor SWECS or a rpm-specific rotor SWECS. When 2 is entered, STEP 26 will be taken; 3, STEP 35.

STEP 26:

Computer: Enter your preference for constructing power train eff. table:

1. For using the existing table
2. For entering a new table
3. For user supplied table (file OWNEFF)

User: Enters 1, 2, or 3

NOTE: When 1 is entered, STEP 27 will be taken
When 2 is entered, STEP 28 will be taken
When 3 is entered, STEP 32 will be taken

STEP 27:

Computer: Prints the power train efficiency table and goes to STEP 31

STEP 28:

Computer: Enter number of lines you wish to change (or enter)

User: Enters (N)line

STEP 29:

Computer: Enter item number, efficiency, power ratio

User: Enters appropriate data

STEP 30:

Computer: Prints the power train efficiency table

STEP 31:

Computer: Do you wish to make change to the above table (Y/N)?

User: Enters Y or N

NOTE: If Y is entered, the computer will go to STEP 28 to repeat the changing process. If N is entered, the computer will go to STEP 33.

STEP 32:

Computer: Prints the user supplied power train efficiency table and goes to STEP 31 to see whether the user wishes to change this table.

STEP 33:

Computer: Prints the final power train efficiency table in two versions: One is based on output power ratio; the other one is based on input power ratio

STEP 34:

Computer: Enter the generator's rated power

User: Enters $(P)_{G.R.}$

NOTE: The computer continues on STEP 38 after this step.

STEP 35:

Computer: Enter the rated power and rpm of the generator

User: Enters $(P)_{G.R.}$ and $(RPM)_{G.R.}$

STEP 36:

Computer: Do you wish to enter the gear ratio (DEFAULT = 1)

User: Enters Y or N

NOTE: If Y is entered, the computer will go to STEP 37, otherwise
STEP 38

STEP 37:

Computer: What is the gear ratio?

User: Enters the gear ratio

STEP 38:

Computer: Prints the final SWECS performance

STEP 39:

Computer: Enter hub height, in ft

User: Enters the hub height value

STEP 40:

Computer: Enter 1 for WEIBULL, 2 for NASA distribution

User: Enters 1 or 2

NOTE: When 1 is entered, the computer goes to STEP 41; 2, STEP 42

STEP 41:

Computer: Enter WEIBULL distribution's k value

User: Enters the K

STEP 42:

Computer: For energy output enter 1 for a quick summary, 2 for a detailed report

User: Enters 1 or 2

NOTE: If 1 is entered, computer goes to STEP 43; 2, STEP 44

STEP 43:

Computer: Prints the annual energy production as a function of annual average wind speed from 5 to 18 mph

STEP 44:

Computer: The computer prints out a detailed report with the following output as a function of annual average wind speed:

- annual energy yield in kWh
- annual average power output in kW (= annual energy yield/8766 hr)
- most probable wind speed (= the most frequently occurring wind speed during the year)
- most probable power output (= the most frequently occurring power during the year)
- wind speed for maximum energy density (= the wind speed contributes the most energy, kWh, during the year)

STEP 45:

Computer: Do you want an energy supply/demand mismatch estimate (Y/N)?

User: Enters Y or N

NOTE: When Y is entered, computer goes to STEP 46; N, STEP 50, the end of the run

STEP 46:

Computer: Select the following options for determining the wind speed distribution

1. For entering a new distribution by the user
2. For using an existing distribution

User: Enters 1 or 2

NOTE: When 1 is entered, computer goes to STEP 48; 2, STEP 47

STEP 47:

Computer: Prints the wind speed distribution and asks:
Do you wish to change this table?

User: Enters Y or N

NOTE: When Y is entered, a change subroutine will be initiated by the computer STEP 48; otherwise, STEP 49 will be taken

STEP 48:

Computer: How many points do you wish to change (or enter)?

User: Enters (N)point

Computer: Enter season - 1 = spr, 2 = summer, etc., hour, wind speed

User: Enters appropriate values.

STEP 49:

Computer: The computer will print the final diurnal wind speed dist. & proceed to make energy supply/demand mismatch estimate to show the total and average values of SWECS' kWh, load kWh, and net kWh during four seasons. A positive net kWh means surplus of energy produced by SWECS. A negative net kWh means that the supplied wind energy may be totally absorbed by the load.

STEP 50:

Computer: Completes this routine and is waiting for new initiation as shown in STEP 2. When a printout (hard copy) of the above results is desired, User can enter the command: RESULTS.

A.4 A Sample Calculation

Included in this section is a sample calculation using input files provided elsewhere in this report, including rotor input file ROTORIN, Table A-1; the power train efficiency input file PTEFF1, Table A-3; the diurnal wind speed distribution file WINDDI, Table A-5; and the diurnal load distribution file LOADDI, Table A-6. Operation of this sample will validate the SEACC when it is installed in a user's computer and demonstrate how some of the design options are provided by the code. Only one route through the computation was taken; i.e., the route for the design of a constant rpm rotor system with a simple 2-D power train efficiency table. The following shows the steps used, the user's input, and computer's output at the computer terminal.

SEACC ROTORIN

ENTER XMIN,XMAX,DELX, OMEGA, THETP, GO, XETA, BLD

1,20,2,346,2,3,0.143,0

STOP

ENTER THE DATAFILE NAME FOR PROP

ROTORIN

THE AIRFOIL DATAFILE USED IS ROTORIN

THE FOLLOWING IS PROP'S ROTOR TIP SPEED RATIO V.S. CP TABLE:

TIP SPEED RATIO	POWER COEF.,CP
.990	.010
2.971	.024
4.951	.141
6.932	.266
8.912	.314
10.893	.305
12.873	.254
14.854	.165
16.835	.047
18.815	-.111

PLEASE SELECT YOUR OPTIONS:

1 FOR CONSTANT RPM ROTORS

2 FOR CONSTANT TIP SPEED RATIO ROTORS

3 FOR ROTORS WITH A SPECIAL RPM VS WIND SPEED FUNCTION

1

DO YOU WISH TO CHANGE PROP'S ROTOR RPM ?

N

ROTOR PERFORMANCE DATA GIVEN BY PROP CODE ARE:

WIND SPEEDS MPH	POWER KW	TIP SPEED RATIOS	POWER COEF CP	ROTOR RPM
130.972	9.822	.990	.010	346.000
43.657	.888	2.971	.024	346.000
26.194	1.123	4.951	.141	346.000
18.710	.777	6.932	.266	346.000
14.552	.431	8.912	.314	346.000
11.907	.230	10.893	.305	346.000
10.075	.117	12.873	.254	346.000
8.731	.050	14.854	.165	346.000
7.704	.011	16.835	.047	346.000
6.893	-.015	18.815	-.111	346.000

ENTER MAXIMUM POWER CUT-OFF WIND SPEED IN MPH

50

DO YOU WANT A MAX. POWER OUTPUT LIMIT?

N

FINAL ROTOR PERFORMANCE DATA ARE AS FOLLOWS:

NO. OF POINTS	WIND SPEEDS MPH	POWER KW	TIP SPEED RATIOS	POWER COEF CP	ROTOR RPM
9	7.704	.011	16.835	.047	346.000
	8.731	.050	14.854	.165	346.000
	10.075	.117	12.873	.254	346.000
	11.907	.230	10.893	.305	346.000
	14.552	.431	8.912	.314	346.000
	18.710	.777	6.932	.266	346.000
	26.194	1.123	4.951	.141	346.000
	43.657	.888	2.971	.024	346.000
	50.000	1.537	2.827	.023	346.000

DO YOU WISH TO OBTAIN SWECS PERFORMANCE BY
ADDING POWER-TRAN EFFICIENCY TO THE SYSTEM?(Y/N)

Y

ENTER 2 FOR A 2-D TABLE OR 3 FOR A 3-D TABLE

2

ENTER YOUR PREFERENCE OF CONSTRUCTING THE POWER-TRAIN EFFICIENCY TABLE
1 FOR USING THE EXISTING TABLE
2 FOR ENTERING A NEW TABLE
3 FOR USER SUPPLIED TABLE (FILE OWNEFF)

1

THIS IS YOUR EXISTING POWER TRAN EFF. TABLE,
BASED ON LOAD POWER RATIOS:

ITEM NO.	EFFICIENCIES	POWER RATIO
1	.0	.0000
2	13.1	.0160
3	50.5	.1290
4	65.5	.2760
5	65.1	.2890
6	67.5	.3340
7	70.3	.4380
8	72.6	.5290
9	72.1	.5570
10	73.1	.7560
11	72.9	.7970
12	72.8	.8120
13	74.5	.9150
14	72.5	.9350
15	72.3	.9480

DO YOU WISH TO MAKE CHANGES TO THE ABOVE TABLE?(Y/N)

N

THIS IS THE POWER TRAN EFF. TABLE

BASED ON INPUT POWER RATIOS:

ITEM NO.	EFFICIENCIES	POWER RATIOS
1	.0	.0000
2	13.1	.1221
3	50.5	.2554
4	65.5	.4214
5	65.1	.4439
6	67.5	.4948
7	70.3	.6230
8	72.6	.7287
9	72.1	.7725
10	73.1	1.0342
11	72.9	1.0933
12	72.8	1.1154
13	74.5	1.2282
14	72.5	1.2897
15	72.3	1.3112

ENTER THE GENERATOR'S RATED POWER

1.5

FINAL SWECS PERFORMANCE DATA ARE AS FOLLOWS:

NO. OF POINTS	WIND SPEEDS MPH	SYSTEM POWER KW	TIP SPEED RATIOS	SYSTEM POWER COEF CP	ROTOR RPM
9	7.704	.000	16.835	.000	346.000
	8.731	.001	14.854	.003	346.000
	10.075	.007	12.873	.015	346.000
	11.907	.055	10.893	.073	346.000
	14.552	.241	8.912	.175	346.000
	18.710	.528	6.932	.181	346.000
	26.194	.812	4.951	.102	346.000
	43.657	.618	2.971	.017	346.000
	50.000	1.124	2.827	.017	346.000

ENTER HUB HEIGHT, IN FT.

55

ENTER 1 FOR WEIBULL, 2 FOR NASA DISTRIBUTION

2

FOR ENERGY OUTPUT ENTER 1 FOR A QUICK SUMMARY,
2 FOR A DETAILED REPORT

AVERAGE WIND SPEED	ENERGY YIELD
MPH	KWH
5.00	23.
6.00	101.
7.00	264.
8.00	515.
9.00	838.
10.00	1207.
11.00	1594.
12.00	1975.
13.00	2332.
14.00	2653.
15.00	2934.
16.00	3175.
17.00	3379.
18.00	3550.

DO YOU WANT THE ENERGY SUPPLY/DEMAND MISMATCH ESTIMATE(Y/N)?

Y

SELECT THE FOLLOWING OPTIONS FOR
DETERMINING THE WIND SPEED DISTRIBUTION

- 1- FOR ENTERING A NEW DISTRIBUTION BY THE USER
- 2- FOR USING THE EXISTING DISTRIBUTION

2

THE FOLLOWING IS THE 4 SEASONS' DIURNAL WIND SPEED DISTRIBUTION TABLE

DAYHR	WINDSPEED IN MPH			
	SPRING	SUMMER	FALL	WINTER
.000	13.065	10.452	10.974	15.678
1.000	13.326	10.452	10.452	15.155
2.000	13.065	10.190	9.929	14.632
3.000	12.803	9.929	9.929	14.632
4.000	12.281	9.407	9.929	14.632
5.000	12.019	8.884	9.929	14.632
6.000	11.758	8.361	9.929	14.632
7.000	13.065	9.145	9.929	14.632
8.000	14.632	9.929	10.190	14.894
9.000	15.678	10.974	10.974	15.678
10.000	17.768	13.065	13.065	17.768
11.000	19.597	14.632	14.632	19.336
12.000	20.903	15.678	16.723	21.426
13.000	21.426	16.461	17.768	22.471
14.000	22.210	17.507	19.074	23.778
15.000	22.733	18.291	18.813	23.516
16.000	22.210	18.029	17.507	22.210
17.000	20.903	18.291	16.200	20.903
18.000	19.597	18.291	13.587	18.291
19.000	18.291	16.461	12.281	16.984
20.000	15.678	15.678	11.236	15.939
21.000	14.632	14.632	10.974	15.678
22.000	13.587	13.065	10.713	15.416
23.000	13.326	11.758	10.452	15.155
24.000	13.065	10.452	10.974	15.678

DO YOU WISH TO CHANGE THE TABLE?

N

THE LOAD DISTRIBUTION TABLE

DAYHOUR	SPRING	SUMMER	FALL	WINTER
.00	2.75	.00	2.75	5.50
1.00	2.75	2.35	2.75	5.50
2.00	5.00	2.25	5.00	7.75
3.00	2.75	2.35	2.75	5.50
4.00	5.50	.00	2.75	5.50
5.00	2.75	2.35	2.75	5.50
6.00	7.25	2.25	5.00	7.75
7.00	5.00	4.60	5.00	10.25
8.00	5.00	4.60	5.00	7.75
9.00	2.75	.00	.00	5.50
10.00	.00	2.35	2.75	5.50
11.00	2.75	2.35	2.75	5.50
12.00	5.00	4.60	5.00	7.75
13.00	.00	4.70	2.75	5.50
14.00	2.75	4.70	.00	2.75
15.00	.00	4.70	2.75	2.75
16.00	2.75	4.70	.00	2.75
17.00	2.75	4.70	2.75	5.50
18.00	2.75	4.70	2.75	5.50
19.00	5.00	6.95	5.00	7.75
20.00	5.00	6.95	10.25	7.75
21.00	2.75	2.35	2.75	5.50
22.00	4.50	6.85	7.25	10.00
23.00	2.75	2.35	2.75	5.50
24.00	2.75	2.35	2.75	5.50

DAILY ENERGY SUPPLY AND DEMAND SUMMARY ARE:

ENERGY TYPE	SPRING	SUMMER	FALL	WINTER	TOTAL	AVERAGE
SWECS KWH	8.62	4.77	3.61	10.41	27.41	6.85
LOAD KWH	83.00	86.05	86.00	152.00	407.05	101.76
NET KWH	-74.38	-81.28	-82.39	-141.59	-379.64	-94.91

77/78

APPENDIX B

Steps for establishing the computer code in a Data General "Eclipse" computer:

B.1 The computer program has to be compiled in Fortran with the following commands:

```
QF0RT MAIN
QF0RT PR0P
QF0RT TITLES
QF0RT SEARCH
QF0RT CALC
QF0RT TIPLOS
QF0RT BESSEL
QF0RT NACATT
QF0RT SOLIDT
QF0RT ACTIVI
QF0RT GOLDST
QF0RT WORK
QF0RT READATA.FR
QF0RT CSTRPM.FR
QF0RT VARIRFM.FR
QF0RT RPMCURV.FR
QF0RT SYSEFF.FR
QF0RT WRITOUT.FR
QF0RT INVERT.FR
QF0RT PWRLIM.FR
QF0RT WINDLIX.FR
QF0RT FTNSR.FR
QF0RT INTERPT.FR
QF0RT INTP2D.FR
QF0RT CHANGE.FR
QF0RT YN.FR
QF0RT MATWORK
QF0RT ENERGI.FR
QF0RT MISMAT.FR
QF0RT WCHANGE.FR
QF0RT MATOUT.FR
```


B.2 After all subprograms are compiled, the following statement should be used to complete the final integration of subprograms:

```
QBIND main/prop/titles/search/calc/tiplos/bessel/nacatt,2
      solidt/activi/goldst
QBIND MATWORK/INPFI/MISMAI/INTERPT/CHANGE/MATOUT,YN
QBIND WORK/READATA/CSTRPM/VARI2PM/RPMCURV/SYSEFF/WPITOUT,2
      INVERT/PARLI/VIOLI/FTNSR/INTERPT/INTP2D/CHANGE,YN
```

B.3 An execution file has to be made as follows:

```
SEACC ----- Procedure file name
del/v tuout
del/v windout
cre tuout
cre windout
data %1%
X MAIN
X WORK
X MATWORK
```

B.4 Finally, the output procedure file may be made as:

```
RESULTS ----- Procedure file name

QPRINT/TIT/NOTIFY TUOUT ]
QPRINT/NOTIFY WINDOUT ]
TY TUOUT ]
TY WINDOUT ]
```

} Prints answers and notifies operator when the job is done

} Shows results on the screen

APPENDIX C

Computer Code Listings

This Systems Engineering and Analysis (SEA) computer program evaluating the performance of a horizontal-axis small wind energy conversion system (HA-SWECS) has been developed by Rockwell International under the U.S. Department of Energy Rocky Flats Wind System Program.

As has been demonstrated the SEA program can be used to determine the effect on HA-SWECS system's performance on the following parameters and configuration changes:

- The last topic to be addressed is the option for determining the wind system user's diurnal energy supply/demand match as a function of local wind distribution characteristics and energy load profile.

★ Developed by: Peter Tu ★
★
★ Written by: Peter Tu ★
★ Veronica Kertesz ★
★
★ Date: April 1982 ★
★

```

C ..... VERSION - SEPT 1981 .....
C ANALYSIS AND PROGRAM MODIFIED BY JAMES L TANGLER
C AND THOMAS E HAUSFELD
C ROCKWELL INTERNATIONAL
C GOLDEN COLORADO

```

```

C ..... ORIGINAL VERSION - 15 MARCH 1976 .....
C ANALYSIS AND PROGRAM DEVELOPED BY STEL N WALKES AND
C ROBERT WILSON, OREGON STATE UNIVERSITY,
C CORVALLIS, OREGON.

```

```

C ..... MAIN PROGRAM .....
C PROP CALCULATES THE THEORETICAL PERFORMANCE PARAMETERS OF A
C PROPELLER TYPE WIND TURBINE. IT UTILIZES A SIMPSON'S-RULE

```

```

C METHOD / THREE PASS TECHNIQUE OF NUMERICAL INTEGRATION.

```

```

    OPEN 55,"SYSDAT"
    OPEN 56,"PWRDAT"
    OPEN 59,"DATAIN"
    OPEN 61,"STOALL"
    OPEN 63,"PERFOR"
    OPEN 62,"POUT"

```

```

C
C DIMENSION RR(35), CI(35), THETI(35), AAT(5,60), CLT(5,60),
+CDT(5,60), VV(25), RLO(5), XX(25), TP(25), CPAV(25),QQY(25)
C COMMON R,DR,HB,B,V,X,THETP,AMOD,H,SI,GO,OMEGA,RHO,VIS,HL,PI,
+RX,W,APF,T1,T2,T3,T4,T5,T6,T7,T8,TEST,XETA,HH,ALO,BO,BLD,NPROF,RLO

```

```

C INPUT PARAMETERS%

```

```

C ....BLD--BLADE ELEMENT DATA CONTROLLER
C .....0 - NONE
C .....1 - BLADE ELEMENT DATA

```

```

C ....XMAX--MAXIMUM TIP SPEED RATIO
C ....XMIN--MINIMUM TIP SPEED RATIO
C ....DELX--TIP SPEED RATIO INCREMENT

```

```

C ....R--RADIUS OF BLADE - FT

```

```

C ....HB--HUB RADIUS - FT

```

```

C ....DR--INCREMENTAL PERCENTAGE

```

```

C ....THETP--PITCH ANGLE - DEGREES

```

```

C ....B--NUMBER OF BLADES

```

```

C ....V--WIND VELOCITY - MPH

```

```

C ....XETA--VELOCITY POWER LAW EXPONENT

```

```

C ....OMEGA--ANGULAR VELOCITY OF PROP - RPM

```

```

C ....AMOD--AXIAL INTERFERENCE MODEL CODE
C ..... 0 -- STANDARD
C ..... 1 -- WILSON

```

```

C .....H--ALTITUDE OF HUB ABOVE SEA LEVEL - FT
C
C .....MH--ALTITUDE OF HUB ABOVE GROUND LEVEL - FT
C
C .....SI--CONING ANGLE - DEGREES
C
C .....NF--NUMBER OF INPUTED STATION"S FOR BLADE GEOMETRY
C
C .....GO--TIP LOSS MODEL CONTROLLER
C .....0 - PRANDTL
C .....1 - GOLDSTEIN
C .....2 - NO TIP LOSS MODEL
C .....3 - EFFECTIVE RADIUS TIP MODEL
C .....4 - FINITE WING TIP MODEL
C
C .....HL--HUB LOSS MODEL CONTROLLER
C .....0 - NONE
C .....1 - PRANDTL
C
C .....BO--MOSTAB TIP LOSS MODEL PARAMETER
C
C .....APF--ANGULAR INTERFERENCE LOCKOUT
C .....0 - ANGULAR INTERFERENCE FACTOR CALCULATED
C .....1 - ANGULAR INTERFERENCE FACTOR SET EQUAL TO 0
C
C .....RR(I)--PERCENT RADIUS FOR STATIONS
C
C .....CI(I)--CHORD FOR STATIONS - FT
C
C .....THET(I)--TWIST ANGLE FOR STATIONS - DEGREES
C
C .....TH--MAX THICKNESS/CHORD RATIO
C
C .....ALO--ANGLE OF ATTACK FOR ZERO LIFT - DEGREES
C
C .....CLT(I)--COEF. OF LIFT DATA
C
C .....CDT(I)--COEF. OF DRAG DATA
C
C .....AAT(I)--ANGLE OF ATTACK - DEGREES
C
C .....RLO(I)--REYNOLDS NUMBER FOR EACH AERODYNAMIC DATA TABLE
C
C .....READ INPUT DATA.....

```

```
REWIND 59
```

```
NNN=1
```

```
NNPROF=8388
```

```
NRLO=1
```

```
READ FREE(9) XR, XHB, XB, XSI
```

```
READ FREE(9) XDR, NNF
```

```
READ FREE(9) (RR(I), CI(I), THETI(I), I=1, NNF)
```

```
READ FREE(9) RLO(NNN), XTH, XALO
```

```
READ FREE(9) NFS
```

```
READ FREE(9) (AAT(NNN, I), CLT(NNN, I), CDT(NNN, I), I=1, NFS)
```

```
CE=CI(NNF)-.8*(CI(NNF)-CI(1))
```

```
AR=XR/CE
```

```
CDMAX=1.11+.018*AR
```

```
B1=CDMAX
```

```

A1=81/2
ATN=AAT(NNN,NFS)*3.141593/180.
SSI=SIN(ATN)
SCO=COS(ATN)
B2=(CDT(NNN,NFS)-B1*SSI**2)/SCO
A2=(CLT(NNN,NFS)-B1*SSI*SCO)*SSI/SCO**2
MMFS=NFS+1
DO 9867 K=MMFS,45
AAT(NNN,K)=AAT(NNN,K-1)+1.0
ATK=AAT(NNN,K)*3.14159/180.
SIK=SIN(ATK)
COK=COS(ATK)
CLT(NNN,K)=2.*A1*SIK*COK+A2*COK**2/SIK
9867 CDT(NNN,K)=B1*SIK**2+B2*COK
READ FREE(9) XAMOD, XHL, XBO, XAPF
IF(XAMOD.LT.10000.) GO TO 1587
NNN=NNN+1
NRLO=NRLO+1
RLO(NNN)=XAMOD
XTH=XHL
XALO=XBO
GO TO 1
1587 READ FREE(9) XH, XHH
TYPE "ENTER XMIN,XMAX,DELX, OMEGA, THETP, GO, XETA, BLD"
ACCEPT XMIN,XMAX,DELX, XOMEGA, XTHETP, XGO, XXETA, XBLD
I=1
GO=XGO
IF(XGO.LT.4.0) GO TO 2
TYPE "ENTER ASPECT RATIO"
ACCEPT AR
2 AI=I
R=XR
HB=XH3
B=XB
SI=XSI
DR=XDR
NF=NNF
NPROF=NNPROF
TH=XTH
ALO=XALO
AMOD=XAMOD
HL=XHL
BO=XBO
APF=XAPF
XETA=XXETA
BLD=XBLD
HH=XHH
OMEGA=XOMEGA
THETP=XTHETP
H=XH
PI = 3.1415926536
X=(XMIN+(AI-1)*DELX)*COS(PI*SI/180.)
IF (X.GT.(XMAX+.01)) GO TO 5
VT=(2*PI*OMEGA*R)/60
V=(VT*3600.)/(X*5280.)
CALL PROP(T,CPV,XMIN,XMAX,DELX,RR,CI,THETI,AAT,CLT,CDT,NF,QY,
+I,KKPRT,NFS,AR,NRLO)
V=V*3600./5280.
VV(I)=V
XX(I)=X

```

```

      TP(I)=T
      CPAV(I)=CPV
      QQY(I)=QY
      I=I+1
      GO TO 2
5     WRITE(63) VV,XX,TP,CPAV
      IF(HL.EQ.0.0) GO TO 1560
      WRITE(62,2731)
2731  FORMAT(1X,///,"F=0.0 FOR THE INNERMOST STATION")
1560  WRITE(62,7)
      WRITE(62,6)(VV(J),XX(J),TP(J),CPAV(J),QQY(J),J=1,I)
7     FORMAT(1H1,///2X,"WIND VEL.",5X,"TIP SPEED RATIO",5X,
+ "POWER",5X,"POWER COEFF.",5X,"TORQUE"/5X,"MPH",30X,"KW",23X,
+ "FT-LBS")
6     FORMAT(//4X,F6.2,11X,F5.2,10X,F6.2,7X,F6.4,8X,F7.1)
      WRITE(55,8)(VV(J),XX(J),TP(J),CPAV(J),J=1,I)
8     FORMAT(4(10X,F10.3))
      WRITE(56,9) R,OMEGA
9     FORMAT(1X,F10.3,5X,F10.3)
      WRITE(56,10)XMIN,XMAX,DELX,XOMEGA,XTHETP,XGO,XXETA,XBLD
10    FORMAT(8F8.3)
12    FORMAT (3F10.5)
41    FORMAT (3F10.3)
39    FORMAT (4F10.3)
53    FORMAT (F10.3,I5)
40    FORMAT (F5.1,5X,F10.5,F10.5)
11    FORMAT (I4)
42    FORMAT (5F10.3)
54    FORMAT (2F10.3)
      CLOSE 55
      CLOSE 56
      CLOSE 59
      CLOSE 61
      CLOSE 63
      CLOSE 62
      STOP
      END

```



```

SUBROUTINE PROP (TP,CPAV,XMIN,XMAX,DELX,RR,CI,THETI,AAT,CLT,
+CDT,NF,QY,IPRT,KKPRT,NFS,AR,NRLO)
  DIMENSION RR(35), CI(35), THETI(35), AAT(5,60), CLT(5,60),
+CDT(5,60),RLO(5)
  COMMON R,DR,HB,B,V,X,THETP,AMOD,H,SI,GO,OMEGA,RHO,VIS,HL,PI,
+RX,W,APF,T1,T2,T3,T4,T5,T6,T7,T8,TEST,XETA,HH,ALO,BO,BLO,NPROF,
+RLO
  CONTINUE
  PI=3.1415926536

```

```

C
C ..... PRINT INPUT AND TITLES FOR OUTPUT .....
C

```

```

  IF (IPRT.EQ.1) GO TO 58
  GO TO 57
58  CALL TITLES (RR,CI,THETI,NF,SOLD,XMIN,XMAX,DELX)
  DO 8969 KLK=1,NRLO
  WRITE (61,60) NFS,RLO(KLK)
8969 WRITE (61,61) (AAT(KLK,I),CLT(KLK,I),CDT(KLK,I),I=1,45)
C
C .....
C

```

```

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

```

```

57  W = 200.
  T1 = 0.0
  T2 = 0.0
  T3 = 0.0
  T4 = 0.0
  T5 = 0.0
  T6 = 0.0
  T7 = 0.0
  T8 = 0.0
  XMXX = 0.0
  XMYX = 0.0
  QX = 0.0
  TX = 0.0
  FXXP1 = 0.0
  FYF = 0.0
  QY = 0.0
  TY = 0.0
  PY = 0.0
  XMYX = 0.0
  XMYX = 0.0
  ASTOP = 0.0
CC *****FINITE WING TIP LOSS*****
  IF(GO.LT.4.0) GO TO 2222
  GO=2.0
  DO 5555 I=1,45
  AAT(I)=AAT(I)+19.24*CLT(I)/AR
5555 CDT(I)=CDT(I)+0.3183*CLT(I)**2/AR
2222 A = 0.0
  AP = 0.0
  CONTROL = 3.0
  V=V*5280./3600.
  SI = SI*PI/180.
  REF = BO*R*COS(SI)
  THETP = THETP*PI/180.
  RHO = 0.0023769199*EXP(-0.297*H/10000.)
  VIS = 0.0000003719-0.00000000204*H/1000.
  OMEGA=V*X/R
  NN=(R-HB)/(R*DR)+2.

```

```

RX = R
RLB = (1.-DR)*RX
DR = (RX-RLB)*COS(SI)
DRO = DR
R = R*COS(SI)
HB = HB*COS(SI)
RL = R

```

```

C
C
C
..... THREE PASS - NUMERICAL INTEGRATION FROM TIP TO HUB .....

```

```

CAT = 1.
IF (GO.EQ.2.) CAT = 2.
CLFA = 1.
IF (GO.EQ.3.) CLFA = 0.0001
IF (GO.LT.2.) GO TO 2
AK = 2.
CALL SEARCH (RL,RR,CI,THETI,NF,C,THET)
CALL CALC (RL,C,THET,FXXP1,FYF,XXMX,XYMX,QX,TX,RE,PHIR,CL,CD,CX,
+CY,A,AP,XL,AK,ALPHA,F,CLFA,CAT,AAT,CLT,CDT,NFS,SOLD,TH,NRLO)

```

```

2  A = 0.0
   CAT = 0.0
   DO 3 L=1,NN
   IF ((RL-HB).GE.DR) GO TO 3
   ASTOP = ASTOP+1.
   IF (ASTOP.GE.2.) GO TO 9
   DR = (RL-HB)
3  IF (GO.LT.3.) GO TO 5
   IF (CONTROL.EQ.0.0) GO TO 5
   TIP = RL-DR
   IF (TIP.GT.REF) GO TO 4
   IF (CONTROL.EQ.2.) GO TO 5
   DR = (RL-REF)
   CLF0 = (REF-TIP)/(RL-TIP)
   CLF = .5*CLF0
   CONTROL = 1.
   GO TO 5
4  CLF = 0.0
5  DR2 = DR/2.
   DT6 = DR/(6.*COS(SI))
   RL = RL-DR2
   IF (CONTROL.EQ.0.0) CLF = 1.
   IF (CONTROL.EQ.2.0) CLF = (CLF0+1.)/2.
   AK = 1.

```

```

CALL SEARCH (RL,RR,CI,THETI,NF,C,THET)
CALL CALC (RL,C,THET,FXXP1,FYF,XXMX,XYMX,QXP1,TXP1,RE,
+ PHIR,CL,CD,CX,CY,A,AP,XL,AK,ALPHA,F,CLF,CAT,AAT,CLT,CDT,NFS,
+ SOLD,TH,NRLO)

```

```

RL = RL-DR2
IF (CONTROL.EQ.0.0) CLF = 1.
IF (CONTROL.EQ.1.0) CLF = CLF0
IF (CONTROL.EQ.2.0) CLF = 1.0
AK = 0.0
IF (HL.EQ.0.0) GO TO 2320
IF ((RL-HB).GT..01) GO TO 2820
XXMX=0.0
XYMX=0.0
QXP=0.0
TXP=0.0
BLD=0.0
GO TO 2850

```

```

2820 CALL SEARCH (RL,RR,CI,THETI,NF,C,THET)
      CALL CALC (RL,C,THET,FX,Y,FYF,XMXXP,XMYXP,QXP,TXP,RE,PHIR,CL,CD,
+ CX,CY,A,AP,XL,AK,ALPHA,F,CLF,CAT,AAT,CLT,COT,NFS,SOLD,TH,NRLO)
2850 QYX = DT6*(QX+4.*QXP1+QXP)
      QY = QY+QYX
      TY = TY+DT6*(TX+4.*TXP1+TXP)
      PY = PY+OMEGA*QYX
      XMX Y = XMX Y+DT6*(XMX X+4.*XMX XP1+XMX XP)

      XMY Y = XMY Y+DT6*(XMY X+4.*XMY XP1+XMY XP)
      TIP=RL-DR
      IF (CONTROL.EQ.2.) CONTROL = 0.0
      IF (CONTROL.EQ.0.0) GO TO 6
      IF ((RL-TIP).EQ.0.0) GO TO 6
      IF (CONTROL.EQ.1.) DR = REF-TIP
      IF (CONTROL.EQ.1.) CONTROL = 2.
      GO TO 7
6     DR = DRO
7     CONTINUE
      QX = QXP
      TX = TXP
      XMX X = XMX XP
      XMY X = XMY XP
      CTY = TY/(.5*RHO*V**2*PI*RX**2)
      CPY = PY/(.5*RHO*V**3*PI*RX**2)
      TP = PY/737.6
      PHIO = PHIR*180./PI
      ALPHA = ALPHA*180./PI
      PR = RL/(RX*COS(SI))
      IF (BLD.EQ.0.0) GO TO 8

      ..... PRINT OUTPUT .....

      WRITE (62,13) RL
      WRITE (61,13) RL
      WRITE (61,14) F
      WRITE (61,15) PHIO
      WRITE (62,15) ALPHA
      WRITE (61,15) ALPHA
      WRITE (62,17) CL
      WRITE (61,17) CL
      WRITE (62,18) CD
      WRITE (61,18) CD
      WRITE (61,19) CX
      WRITE (61,20) CY
      WRITE (61,21) FXY
      WRITE (62,21) FXY
      WRITE (62,22) FYF
      WRITE (61,22) FYF
      WRITE (61,23) XMX Y
      WRITE (61,24) XMY Y
      WRITE (61,25) RE
      WRITE (61,26) W
      WRITE (61,27) QY
      WRITE (61,28) TY
      WRITE (61,29) CTY
      WRITE (61,30) TP
      WRITE (61,31) CPY
      WRITE (61,32)
8     CONTINUE

```

```

9  HP=TP*1.3410
   PISTEL = T7/(PI*RX**5)
   PI2STEL = T8*X/(PI*RX**6)
   DCP = (XETA*X*RX**2/(HH*HH))*(XETA*PISTEL+(XETA-1.)*PI2STEL)*8/4.
   CPAV = CPY+DCP
   FYKDE = RX/V*T1
   FYKDG = -T2
   XMCKDE = -RX/V*T3
   XMCKDG = T4
   XMZKDE = RX/V*T3
   XMZKDG = -T4
   CQKDE = -RX/V*T5
   CQKDG = T6
   IF (IPRT.EQ.1) KKPRT = 0
   IF (IPRT.EQ.1) GO TO 10
   IF (X.GT.(XMAX+.01)) GO TO 10
   IF ((IPRT/5).EQ.KKPRT) GO TO 10
   GO TO 56
10  CONTINUE
   KKPRT = KKPRT+1
   WRITE (61,31) CPY
   WRITE (61,32)
   WRITE (61,33)
   WRITE (61,34) TP
   WRITE (61,35) HP
   WRITE (61,36) CPY
   WRITE (61,37) CPAV
   WRITE (61,38) CTY
   WRITE (61,43) FYKDE
   WRITE (61,44) FYKDG
   WRITE (61,45) XMCKDE
   WRITE (61,46) XMCKDG
   WRITE (61,47) XMZKDE
   WRITE (61,48) XMZKDG
   WRITE (61,49) CQKDE
   WRITE (61,50) CQKDG
   WRITE (61,51) PISTEL
   WRITE (61,52) PI2STEL

```

..... FORMATS FOR INPUT AND OUTPUT STATEMENTS

56 RETURN

```

11  FORMAT (I4)
12  FORMAT (3F10.5)
13  FORMAT (/ ,10X,21H LOCAL RADIUS - FT = ,F10.4)
14  FORMAT (/ ,10X,22H TIP LOSS FACTOR, F = ,F7.4)
15  FORMAT (/ ,10X,23H ANGLE PHI - DEGREES = ,F10.4)
16  FORMAT (/ ,10X,36H ANGLE OF ATTACK, ALPHA - DEGREES = ,F10.4)
17  FORMAT (/ ,10X,37H COEFFICIENT OF SECTIONAL LIFT, CL = ,F20.4)
18  FORMAT (/ ,10X,37H COEFFICIENT OF SECTIONAL DRAG, CD = ,F20.4)
19  FORMAT (/ ,10X,43H COEFFICIENT OF FORCE IN X DIRECTION, CX = ,F7.4)
20  FORMAT (/ ,10X,43H COEFFICIENT OF FORCE IN Y DIRECTION, CY = ,F7.4)
21  FORMAT (/ ,10X,43H FORCE IN X DIRECTION PER BLADE, FX - LB = ,F15.4
+)
22  FORMAT (/ ,10X,47H FORCE IN Y DIRECTION PER BLADE, FY - LBS FT =
+15.4)
23  FORMAT (/ ,10X,47H MOMENT IN X DIRECTION PER BLADE, MX - FT-LB = ,
+15.4)

```

```

24  FORMAT (/ ,10X,47H MOMENT IN Y DIRECTION PER BLADE, MY - FT-LB = ,
    +F15.4)
25  FORMAT (/ ,10X,26H REYNOLDS NUMBER, RE NO = ,E10.4)
26  FORMAT (/ ,10X,32H RELATIVE VELOCITY, W - FT/SEC = ,F15.4)
27  FORMAT (/ ,10X,21H TORQUE, Q - FT-LB = ,F15.4)
28  FORMAT (/ ,10X,17H THRUST, T - LB = ,F15.4)
29  FORMAT (/ ,10X,26H THRUST COEFFICIENT, CT = ,F7.4)
30  FORMAT (/ ,10X,24H POWER, P - KILOWATTS = ,F10.2)
31  FORMAT (/ ,10X,25H POWER COEFFICIENT, CP = ,F10.4)
32  FORMAT (1H1)
33  FORMAT (///,21H PERFORMANCE SUMMARY%)
34  FORMAT (///,15X,15H TOTAL POWER = ,F10.2,10H KILOWATTS)
35  FORMAT (/ ,15X,15H TOTAL POWER = ,F10.2,11H HORSEPOWER)
36  FORMAT (/ ,15X,27H TOTAL POWER COEFFICIENT = ,F7.5)
37  FORMAT (/ ,15X,43H AVERAGE POWER COEFFICIENT WITH GRADIENT = ,F10.5)
38  FORMAT (/ ,15X,28H TOTAL THRUST COEFFICIENT = ,F7.4)
39  FORMAT (4F10.3)
40  FORMAT (F5.1,5X,F10.5,F10.5)
41  FORMAT(15,2F10.3)
42  FORMAT (5F10.3)
43  FORMAT(/49H(YAW FORCES DUE TO CONING / BLADE) / (SIN(THETK))=,F9.4)
44  FORMAT(/48H(YAW FORCES DUE TO SHEAR/BLADE)/(SIN(THETK)**2)=,F10.4)
45  FORMAT (/41H(CONING MOMENT DUE TO FLAPPING / BLADE) =,F10.4)
46  FORMAT(/48H(CONING MOMENT DUE TO SHEAR/BLADE)/(SIN(THETK))=,F10.4)
47  FORMAT(/"(YAWING MOMENT DUE TO FLAPPING/BLADE)/(COS(THETK))=,F9.4)
48  FORMAT(/"(YAWING MOMENT DUE TO SHEAR/BLADE)/(SIN(THETK)*COS(THETK)
    $)=,F10.4)
49  FORMAT (/42H(TORQUE VARIATION DUE TO CONING / BLADE) =,F10.4)
50  FORMAT (/"(TORQUE VARIATION DUE TO SHEAR / BLADE) / (SIN(THETK))
    $ =,F10.4)
51  FORMAT (/53H TORQUE VARIATION DUE TO AERODYNAMIC SECOND DERIVATIVE
    $ = ,F15.4)
52  FORMAT (/51H TORQUE VARIATION DUE TO SHEAR SECOND DERIVATIVE = ,
    $F15.4)
53  FORMAT(F10.3,15)
54  FORMAT(2F10.3)
60  FORMAT (1H1,///,10X,"THE NO. OF POINTS = ",I4," REYNOLDS NUMBER=
    +",F10.1)
61  FORMAT (/ ,10X,"AAT",20X,"CLT",20X,"CDT"// (7X,F10.5,
    $12X,F10.6,14X,F13.9))
    END

```

```

C      SUBROUTINE TITLES (RR,CI,THETI,NF,SOLD,XMIN,XMAX,DELX)
C      ..... TITLES - PRINTS OUT INPUT DATA IN A DESCRIPTIVE
C      FORM, AND PRINTS DESCRIPTIONS OF SYMBOLS/TITLES FOR OUTPUT.
C
      DIMENSION RR(35), CI(35), THETI(35), RLO(5)
      COMMON R,DR,HB,B,V,X,THETP,AMOD,H,SI,GO,OMEGA,RHO,VIS,HL,PI,
+RX,W,APF,T1,T2,T3,T4,T5,T6,T7,T8,TEST,XETA,HH,ALO,B0,BLD,NPROF,RLO
      WRITE (62,12)
      WRITE (61,12)
      WRITE (61,13)
      WRITE (61,14)
      WRITE (61,15) V
      WRITE (61,16) XETA
      WRITE (61,17) HH
      WRITE (61,18) H
      WRITE (61,19) OMEGA
      WRITE (61,20) X
      WRITE (61,21) THETP
      RX = R
      CSI = SI
      SI = SI*PI/180.
      CRL = .75*R
      CALL SEARCH (CRL,RR,CI,THETI,NF,C,THET)
      SI = CSI
      BANG = THET*180./PI+THETP
      WRITE (61,22) BANG
      WRITE (61,23) SI
      WRITE (61,24)
      WRITE (61,25) B
      WRITE (61,26) R
      WRITE (61,27) HB
      CALL SOLIDT (RR,CI,NF,B,R,PI,SOLD)
      WRITE (61,28) SOLD
      CALL ACTIVI (RR,CI,NF,B,R,PI,ACF)
      WRITE (61,29) ACF
      WRITE (61,30) NPROF
      WRITE (61,31) NF
      WRITE (61,32)
      WRITE (61,33)
      WRITE (61,34) (RR(I),CI(I),THETI(I),I=1,NF)
      WRITE (61,35)
      WRITE (61,36) DR
      IF (APF.EQ.0.0) GO TO 1
      WRITE (62,37)
      WRITE (61,37)
1     IF (AMOD.EQ.0.0) GO TO 2
      WRITE (62,38)
      WRITE (61,38)
      GO TO 3
2     WRITE (61,39)
      WRITE (62,39)
3     IF (B.GT.2.0) GO TO 4
      IF (GO.EQ.0.0) GO TO 8
      IF (GO.EQ.1.0) GO TO 5
      IF (GO.EQ.2.0) GO TO 6
      IF (GO.EQ.3.0) GO TO 7
      IF (GO.EQ.4.0) GO TO 50
      GO TO 9
4     IF (GO.EQ.2.0) GO TO 6

```

```

      IF (GO.EQ.3.0) GO TO 7
      IF(GO .EQ. 4.0 )GO TO 50
      GO TO 8
5     WRITE (62,41)
      WRITE (61,41)
      GO TO 9
6     WRITE (62,42)
      WRITE (61,42)
      GO TO 9
7     WRITE (62,43)
      WRITE (61,43)
      GO TO 9
50    WRITE(62,51)
      WRITE(61,51)
      GO TO 9

```

```

8     WRITE (61,40)
      WRITE(62,40)
9     IF (HL.EQ.0.0) GO TO 10
      WRITE (62,45)
      WRITE (61,45)
      GO TO 11
10    WRITE (61,44)
      WRITE(62,44)
11    CONTINUE
      WRITE (62,46)
      WRITE (61,46)
      WRITE (61,47)
      RETURN

```

C
C

```

12    FORMAT (1H1)
13    FORMAT("THEORETICAL PERFORMANCE OF A PROPELLER TYPE WIND TURBINE")
14    FORMAT (///,5X,22H OPERATING CONDITIONS%)
15    FORMAT (///,15X,23H WIND VELOCITY - MPH = ,F7.4)
16    FORMAT (/,15X,35H WIND VELOCITY GRADIENT EXPONENT = ,F7.4)
17    FORMAT (/,15X,39H HUB HEIGHT ABOVE GROUND LEVEL - FT = ,F12.4)
18    FORMAT (/,15X,40H ALTITUDE OF HUB ABOVE SEA LEVEL - FT = ,F15.4)
19    FORMAT (/,15X,26H ANGULAR VELOCITY - RPM = ,F10.4)
20    FORMAT (/,15X,19H TIP SPEED RATIO = ,F7.4)
21    FORMAT (/,15X,44H PITCH ANGLE FROM NOMINAL TWIST - DEGREES = ,F10.
+4)
22    FORMAT (/,15X,40H PITCH ANGLE AT 0.75 RADIUS - DEGREES = ,F10.4)
23    FORMAT (/,15X,26H CONING ANGLE - DEGREES = ,F10.4)
24    FORMAT (///,5X,14H BLADE DESIGN%)
25    FORMAT (///,15X,20H NUMBER OF BLADES = ,F3.0)
26    FORMAT (/,15X,19H TIP RADIUS - FT = ,F7.4)
27    FORMAT (/,15X,19H HUB RADIUS - FT = ,F7.4)
28    FORMAT (/,15X,11H SOLIDTY = ,F12.5)
29    FORMAT (/,15X,19H ACTIVITY FACTOR = ,F12.5)
30    FORMAT (/,15X,16H NACA PROFILE = ,I4)
31    FORMAT (/,15X,33H NUMBER OF STATIONS ALONG SPAN = ,I4)
32    FORMAT (///,10X,29H CHORD AND TWIST DISTRIBUTION)
33    FORMAT (///,16X,15H PERCENT RADIUS,5X,8HCHORD-FT,10X,9HTWIST-DEG)
34    FORMAT (/,20X,F5.1,8X,F10.5,10X,F10.5)
35    FORMAT (///,5X,30H PROGRAM OPERATING CONDITIONS%)
36    FORMAT (///,15X,25H INCREMENTAL PERCENTAGE =,F7.4)
37    FORMAT (///,15X,38H ANGULAR INTERFERENCE FACTOR, AP = 0.0)
38    FORMAT (///,15X,38H WILSON AXIAL INTERFERENCE METHOD USED)
39    FORMAT (///,15X,40H STANDARD AXIAL INTERFERENCE METHOD USED)

```

40 FORMAT (///,15X,39H TIP LOSSES MODELED BY PRANDTL'S FORMULA)
41 FORMAT (///,15X,41H TIP LOSSES MODELED BY GOLDSTEIN'S FORMULA)
42 FORMAT (///,15X,18H NO TIP LOSS MODEL)
43 FORMAT (///,15X,31H TIP LOSS MODEL -- NASA VERSION)
44 FORMAT (///,15X,22H NO HUBLOSS MODEL USED)
45 FORMAT (///,15X,29H HUBLOSSES MODELED BY PRANDTL)
46 FORMAT (1H1)
47 FORMAT (///,22H PERFORMANCE ANALYSIS%)
51 FORMAT(///,15X,21H FINITE WING TIP LOSS)
END

SUBROUTINE SEARCH (RL,RR,CI,THETI,NF,C,THET)

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

```

DIMENSION RR(35), CI(35), THETI(35), RLO(5)
COMMON R,DR,HB,B,V,X,THETP,AMOD,H,SI,GO,OMEGA,RHO,VIS,HL,PI,
+RX,W,APF,T1,T2,T3,T4,T5,T6,T7,T8,TEST,XETA,HH,ALO,BO,BLD,NPROF,RLO
DO 1 I=1,NF
  RRV = RL/(RX*COS(SI))*100.
  IF (RRV.EQ.RR(1)) GO TO 4
  IF (RRV.GE.RR(I)) GO TO 2
  IF (I.EQ.NF) GO TO 3
1  CONTINUE
2  J = I+1
  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)
  GO TO 5
3  C = CI(NF)
  THET = THETI(NF)
  GO TO 5
4  C = CI(1)
  THET = THETI(1)
5  THET = THET*PI/180.
  RETURN
END
```

```

SUBROUTINE CALC (RL,C,THET,FXF,FYF,XMFXF,XMFYF,QF,TF,RE,PHIR,CL,CD
+,CX,CY,A,AP,XL,AK,ALPHA,F,CLF,CAT,AAT,CLT,CDT,NFS,SOLD,TH,NRLO)

```

```

..... CALC - DETERMINES THE AXIAL AND ANGULAR INTERFERENCE
FACTORS AT A GIVEN RADIUS AND DETERMINES FUNCTIONS DEPENDENT
UPON THESE PARAMETERS.

```

```

DIMENSION AAT(5,60), CLT(5,60), CDT(5,60),RLO(5)
COMMON R,DR,H8,B,V,X,THETP,AMOD,H,SI,GO,OMEGA,RHO,VIS,HL,PI,
+RX,W,APF,T1,T2,T3,T4,T5,T6,T7,T8,TEST,XETA,HH,ALO,BO,BLD,NPROF,RLO
XL = RL*OMEGA/V
IF (A.GT..5) A = 0.
IF (A.GT..5) AP = 0.
EPS=0.1
RH = H8
DO 15 J=1,40
BETA = A
DELTA = AP
ADDD=(1.+AP)*XL
IF (ADDD.EQ.0.) GO TO 30
PHI = ATAN((1.-A)*COS(SI)/((1.+AP)*XL))
IF (PHI.EQ.0.0) PHI=0.0001
GO TO 31
30 PHI=PI/2.
31 PHIAA = ABS(PHI)
XXL = COS(PHIAA)/SIN(PHIAA)
XXLO = XXL*R/RL
PHIR = PHI
ALPHA = PHI-THET-THETP
DDTC = ATAN((1.-A)/(XL*(1.+2.*AP)))-ATAN((1.-A)/XL)
DA1 = DDTC/4.
DA2 = ((4./15.)*(SOLD*TH)/X)/((1./X)**2+(RL/R)**2)
DALPHA = DA1+DA2
ALPHA = ALPHA-DALPHA
ALPHAD = ALPHA+0.001
W1=SQRT((V*COS(SI))**2+(RL*OMEGA)**2)
C RE1 APPROXIMATES THE ACTUAL REYNOLDS NUMBER
RE1=RHO*W*C/VIS*.96

```

```

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

```

```

CALL NACATT (RL,RX,SI,ALPHA,CL,CD,ALO,W,AAT,CLT,CDT,NFS,SOLD,RLO,
+NRLO,RE1)
CALL NACATT (RL,RX,SI,ALPHAD,CLD,CDD,ALO,W,AAT,CLT,CDT,NFS,SOLD
+,RLO,NRLO,RE1)
IF (GO.LT.3.) GO TO 6
CL = CLF*CL
CLD = CLF*CLD
F = 1.
GO TO 7

```

```

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

```

```

6 IF (CAT.EQ.1.) F = 0.0
IF (CAT.EQ.1.) GO TO 7
CALL TIPLOS (XXL,XXLO,F,B,GO,HL,PI,R,RL,PHI,RH)
7 CX = CL*SIN(PHI)-CD*COS(PHI)
CY = CL*COS(PHI)+CD*SIN(PHI)
CXX = CL*SIN(PHI)

```

```

CYY = CL*COS(PHI)
SIG = (B*C)/(PI*RL)
IF (AMOD.EQ.0.) GO TO 8
VBR = ((.125*SIG*CYY)*(COS(SI)**2))/(SIN(PHI)**2)
VAR = (0.125*SIG*CXX)/(F*SIN(PHI)*COS(PHI))
CAN = F*F+4.*VBR*F*(1.-F)
IF (CAN.LT.0.0) CAN = 0.0
A = (2.*VBR+F-SQRT(CAN))/(2.*(VBR+F*F))
AP = VAR/((1.-A*F)/(1.-A)-VAR)
34 IF (APF.EQ.1.) AP = 0.0
GO TO 9
8 VBR = 0.125*SIG*CYY*(COS(SI)**2)
VAR = 0.125*SIG*CXX
A=VBR/(F*SIN(PHI)**2+VBR)
IF (A.GT.0.38) GO TO 32
33 AP = VAR/(F*SIN(PHI)*COS(PHI)-VAR)
GO TO 34
32 YTEM=SIG*CL*COS(SI)*(1.+AP)*XL/(2.*SIN(PHI))
A=(YTEM-0.5776*F)/(YTEM+0.96*F)
GO TO 33
9 IF (APF.EQ.1.) AP=0.0
PCR = RL/(RX*COS(SI))
C ..... DAMPENING OF AXIAL AND ANGULAR INTERFERENCE FACTOR
C ITERATIONS.
C
IF (J-4) 13,12,10
10 IF (J-10) 13,12,11
11 IF (J-15) 13,12,100
100 IF (J-20) 13,12,60
60 IF (J-30) 13,61,62
12 A = (A+BETA)*.5
AP = (AP+DELTA)*.5
GO TO 13
61 ODELA=0.1
IF (A.LT.0..OR.A.GT.1.) A=0.3
GO TO 63
62 ODELA=DELA
63 DELA=A-BETA
C .....DELA IS GREAT THAN ZERO.....
65 IF ((DELA*ODELA).LT.0.) EPS=EPS*0.2
A=BETA+EPS
GO TO 13
C .....DELA IS LESS THAN ZERO.....
64 IF ((DELA*ODELA).LT.0.) EPS=EPS*0.2
A=BETA-EPS
13 CONTINUE
C ..... TEST FOR CONVERGENCE .....
C
IF (APF.EQ.1.) GO TO 14
IF (AP.EQ.0.0) GO TO 14
IF (ABS((AP-DELTA)/AP).LE..0001) GO TO 16
GO TO 15
14 IF (ABS((A-BETA)/A).LE..0001) GO TO 16
C
15 CONTINUE
16 IF (AK.GE.1.) GO TO 18
IF (BLD.EQ.0.0) GO TO 18
C FOR OPERATION OF VORTEX RING STATE REPLACE THE FOLLOWINGC CARDS
C

```

C

```

PCCR = RL/RX
WRITE (62,21) PCR
WRITE (61,21) PCR
WRITE (62,22) BETA
WRITE (61,22) BETA
WRITE (62,23) A
WRITE (61,23) A
WRITE (61,81) VAR
WRITE (61,82) AP
WRITE (62,24) DELTA
WRITE (61,24) DELTA
WRITE (62,25) AP
WRITE (61,25) AP
WRITE (61,26) J
IF (J.LT.40) GO TO 17
WRITE (61,27)

```

17 CONTINUE

C
C
C
C

..... CALCULATION OF FUNCTIONS DEPENDENT UPON AXIAL AND
ANGULAR INTERFERENCE FACTORS.

18 CONTINUE

```

W = SQRT(((1.-A)*V*COS(SI))**2+((1.+AP)*RL*OMEGA)**2)
RE = RHO*W*C/VIS
CONST = (0.5*RHO*(W**2)*C)
FXF = CONST*CX
FYF = CONST*CY
XMFXF = FXF*(RL-H3)/COS(SI)
XMFYF = FYF*(RL-H3)/COS(SI)
CT1 = (0.5*RHO*B*C)*(W*W)
QF = CT1*RL*CX
TF = CT1*CY*COS(SI)
DPCR = DR/(2.*RX)
CR = C/RX
CLA = (CLD-CL)/0.001
CDA = (CDD-CD)/0.001
CXP = CLA*SIN(PHI)-CDA*COS(PHI)+CY
CYP = CLA*COS(PHI)+CDA*SIN(PHI)-CX
TAN = SIN(PHI)/COS(PHI)
FT = (2.*CX+CXP/TAN)*(1.-A)*CR*PCR
FN = (2.*CY+CYP/TAN)*(1.-A)*CR*PCR
IF (AK.GE.1.) GO TO 19
TEST = TEST+1.
IF (TEST.EQ.1.) GO TO 19
WRITE (61,23) FN
WRITE (61,29) FT
TEST = 0.

```

C
C

19 CONTINUE

```

T1 = T1+FT*DPCR
T2 = T2+FT*(1.-A)*DPCR
T3 = T3+FN*PCR*DPCR
T4 = T4+FN*(1.-A)*PCR**2*DPCR
T5 = T5+FT*PCR*DPCR
T6 = T6+FT*(1.-A)*PCR*DPCR
T7 = T7+(((2.+COS(PHI))**2)*CL*SIN(PHI)-COS(PHI)**3*CD+2.*COS(PHI)
+CLA)*(1.-A)**2*RL**3*C)*DR/2.
T8 = T8+(((1.+SIN(PHI))**2)/COS(PHI)*CL-CD*SIN(PHI)+CLA*SIN(PHI))*
+(1.+AP)*(1.-A)*RL**4*C)*DR/2.

```

C

RETURN

C
C

```
20  FORMAT ("YOU HAVE SPECIFIED A NACA PROFILE NOT STORED, USE 4418")
21  FORMAT (///,5X,39H STATION - (LOCAL RADIUS/TIP RADIUS) = ,F7.4)
22  FORMAT(/,10X,43H AXIAL INTERFERENCE FACTOR (PREVIOUS), A = ,F12.8)
23  FORMAT (/,10X,32H AXIAL INTERFERENCE FACTOR, A = ,F12.8)
31  FORMAT (/,10X,7H VAR = ,F12.8)
32  FORMAT (/,10X,6H AP = ,F12.8)
24  FORMAT (/,10X,46H ANGULAR INTERFERENCE FACTOR (PREVIOUS), AP = ,
+ F12.8)
25  FORMAT (/,10X,35H ANGULAR INTERFERENCE FACTOR, AP = ,F12.8)
26  FORMAT (/,10X,24H NUMBER OF ITERATIONS = ,I4)
27  FORMAT (//,5X,49H ***** ATTENTION - NO CONVERGENCE AT THIS STATION)
57  FORMAT (/,10X,37H COEFFICIENT OF SECTIONAL LIFT, CL = ,F7.4)
28  FORMAT (/,10X,20H NORMAL FORCE, FN = ,F10.5)
29  FORMAT (/,10X,25H TANGENTIAL FORCE, FT = ,F10.5)
    END
```

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 1

IF (GO.EQ.0.0) GO TO 2

IF (GO.EQ.1.0) GO TO 4

IF (GO.EQ.2.0) GO TO 3

IF (GO.EQ.2.0) GO TO 3

CONTINUE

CCC=-(Q*(R-RL))/(2.*RL*SQRT(SIN(PHI)**2+.0001))

IF (CCC.LT.(-50)) GO TO 3

F = (2./PI)*ACOS(EXP(-(Q*(R-RL))/(2.*RL*SQRT(SIN(PHI)**2+.0001))))

+))

GO TO 5

F = 1.0

GO TO 5

IF ((ABS(SIN(PHI))).LT..0001) GO TO 2

CALL GOLDST (U,UO,F,Q,GO,PI,R,RL,PHI,SUM2,SUM,AK,AMM,AM)

HUBLSS CALCULATIONS

IF (HL.EQ.1.0) GO TO 6

FI = 1.0

GO TO 7

...AVOIDING THE PROBLEM OF UNDERFLOW IN THE EXPRESSION FI,

...BY ADDING AN IF STATEMENT.

DDDD=-(Q*(RL-RH))/(2.*RH*SQRT(SIN(PHI)**2+.0001))

IF (DDDD.LE.(-50.)) GO TO 8

FI = (2./PI)*ACOS(EXP(-(Q*(RL-RH))/(2.*RH*SQRT(SIN(PHI)**2+.0001))))

GO TO 7

FI=1.

CONTINUE

F=F*FI

RETURN

END

SUBROUTINE BESSEL (Z,V,AI)

..... BESSEL CALCULATES BESSEL FUNCTIONS FOR THE GOLDSTEIN
TIP LOSS MODEL.....

S = 0.0

AK = 0.0

C = 1.

DO 3 K=1,10

B = (.25*Z*Z)**AK

D = V+AK

P = 1.

1 TK = D-1.

IF (TK.LE.0.0) GO TO 2

P = D*TK*P

D = D-2.

GO TO 1

2 E = P

S = B/(C+E)+S

AK = AK+1.

C = AK*C

3 CONTINUE

AI = ((.5*Z)**V)*S

RETURN

END

SUBROUTINE NACATT (RL,RX,SI,ALPHA,CL,CD,ALO,W,AAT,CLT,CDT,NFS,SOLD
+,RLO,NRLO,RE)

C
C NACATT - IS AN INTERPOLATING SUBROUTINE TO INTERPOLATE
C AIRFOIL DATA INPUTED IN TABLE FORM.
C

```

        DIMENSION AAT(5,60), CLT(5,60), CDT(5,60),RLO(5)
        A = ALPHA*180./3.141593-ALO
        K=0
        IF (NRLO.EQ.1)GO TO 888
        DO 5 K=1,NRLO
        IF(RE.LT.RLO(1))RE=RLO(1)
6      IF(RE.LE.RLO(K))GO TO 7
        K=K-1
        RE=RLO(K)
7      KK=K
        PERRL=(RE-RLO(KK-1))/(RLO(KK)-RLO(KK-1))
27     DO 1 I=1,45
        IF (A.LE.AAT(KK,1)) GO TO 4
        IF (A.LE.AAT(KK,I)) GO TO 2
1      CONTINUE
2      J = I+1
        PER = (A-AAT(KK,J-1))/(AAT(KK,J-2)-AAT(KK,J-1))
        CLLOW=PER*(CLT(KK-1,J-2)-CLT(KK-1,J-1))+CLT(KK-1,J-1)
        CDLOW=PER*(CDT(KK-1,J-2)-CDT(KK-1,J-1))+CDT(KK-1,J-1)
999    CLHIGH=PER*(CLT(KK,J-2)-CLT(KK,J-1))+CLT(KK,J-1)
        CDHIGH=PER*(CDT(KK,J-2)-CDT(KK,J-1))+CDT(KK,J-1)
        CL=PERRL*(CLHIGH-CLLOW)+CLLOW
        CD=PERRL*(CDHIGH-CDLOW)+CDLOW
        GO TO 5
4      CD = PERRL*(CDT(KK,1)-CDT(KK-1,1))+CDT(KK-1,1)
        CL = PERRL*(CLT(KK,1)-CLT(KK-1,1))+CLT(KK-1,1)
        GO TO 5
888    DO 91 II=1,45
        IF(A.LE.AAT(1,1))GO TO 94
        IF(A.LE.AAT(1,II))GO TO 92
91     CONTINUE
92     JJ=II+1
        PER=(A-AAT(1,JJ-1))/(AAT(1,JJ-2)-AAT(1,JJ-1))
        CL=PER*(CLT(1,JJ-2)-CLT(1,JJ-1))+CLT(1,JJ-1)
        CD=PER*(CDT(1,JJ-2)-CDT(1,JJ-1))+CDT(1,JJ-1)
        GO TO 5
94     CL=CLT(1,1)
        CD=CDT(1,1)
5      RETURN
        END

```


SUBROUTINE SOLIDT (RR,CI,NF,B,R,PI,SOLD)

..... SOLIDT - DETERMINES THE TOTAL SOLIDITY OF THE
WIND TURBINE DESIGN.

DIMENSION RR(35), CI(35)

NFX = NF-1

S1 = 0.

DO 1 I=1,NFX

SOL = ((CI(I+1)+CI(I))/2.)*(RR(I)-RR(I+1))*R/100.

S1 = S1+SOL

CONTINUE

SOLD = 8*S1/(PI*R**2)

RETURN

END

SUBROUTINE ACTIVI (RR,CI,NF,B,R,PI,ACF)

..... ACTIVI - DETERMINES THE ACTIVITY FACTOR OF THE
WIND TURBINE DESIGN.

DIMENSION RR(35), CI(35)

NFX = NF-1

S1 = 0.

DO 1 I=1,NFX

C1 = (CI(I+1)+CI(I))/2.

ROR = ((RR(I)-RR(I+1))/2.+RR(I+1))/100.

DROR = (RR(I)-RR(I+1))/100.

FAC = (C1/(2.*R))*ROR**3*DROR

S1 = S1+FAC

CONTINUE

ACF = S1*100000./16.

RETURN

END

SUBROUTINE GOLDST (U,UO,F,Q,GO,PI,R,RL,PHI,SUM2,SUM,AK,AMM,AM)

..... GOLDST - DETERMINES THE GOLDSTEN TIP LOSS
FACTORS FOR THE 2 BLADED DESIGN CASE. FOR DESIGN CASES
WITH BLADE NUMBERS OTHER THAN TWO THE PRANDTL
MODEL IS USED. THIS CAN BE CHANGED IF NECESSARY, AND
THE GOLDSTEN MODEL FOR ANY NUMBER OF BLADES MAY BE
SUBSTITUTED FOR THIS ROUTINE.

```

DO 5 M=1,3
  V = (2.*AM+1.)
  ZO = UO*V
  V2 = V*V
  Z = U*V
  Z2 = Z*Z
  CALL BESSEL (Z,V,AI)
  CALL BESSEL (ZO,V,AIO)
  IF (Z.GE.3.5) GO TO 1
  A = 2.*2.
  B = 4.*4.
  C = 6.*6.
  D = 8.*8.
  T1VZ = Z2/(A-V2)+(Z2*Z2)/((A-V2)*(B-V2))+(Z2**3)/((A-V2)*(B-V2)
+ *(C-V2))+(Z2**4)/((A-V2)*(B-V2)*(C-V2)*(D-V2))
  CT1VZ = (V*PI*AI)/(2.*SIN(.5*V*PI))-T1VZ
  GO TO 2
1  TO = (U*U)/(1.+U*U)
  T2 = 4.*U*U*(1.-U*U)/((1.+U*U)**4)
  T4 = 16.*U*U*(1.-14.*U*U+21.*U**4-4.*U**6)/((1.+U*U)**7)
  T6 = 64.*U*U*(1.-75.*U*U+603.*U**4-1065.*U**6+460.*U**8-36.*U**
+ 10)/((1.+U*U)**10)
  CT1VZ = TO+T2/V2+T4/(V2**2)+T6/(V2**3)
2  FVU = (U*U)/(1.+U*U)-CT1VZ
  SUM = SUM+FVU/V2
  IF (AM.NE.0.0) GO TO 3
  E = -0.098/(UO**1.668)
3  IF (AM.NE.1.0) GO TO 4
  E = 0.031/(UO**1.285)
4  IF (AM.GT.1.0) E = 0.0
  SUM2 = SUM2+((UO*UO*AMM)/(1.+UO*UO)-E)*(AI/AIO)
  AM = AM+1.
  AK = ((2.*AM-1.)*AK)/(2.*AM)
5  AMM = AK/(2.*AM+1.)
  G = (U*U)/(1.+U*U)-(8./(PI*PI))*SUM
  CIRC = G-(2./PI)*SUM2
  F = ((1.+U*U)/(U*U))*CIRC
  RETURN
END

```

```

C      PROGRAM POWERCV(INPUT,OUTPUT,PTEFF1,TAPE65,TAPE10,TAPE66,RPMFIL,
C      + TAPE11,TAPE4=PTEFF1,TAPE67=RPMFIL,TAPE8=INPUT,TAPE9=OUTPUT)

```

```

*****
*
*      PROGRAM POWERCV
*      =====
*

```

```

*      Based on the performance data (power coefficient vs.
*      tip-speed ratio ) from PROP code, this program calculates
*      a SWECS rotor or system power curve (power output as a
*      function of windspeed) for three rotor designs:

```

- ```

* 1. A constant rpm rotor
* 2. A constant tip-speed ratio rotor
* 3. A rotor with specified rpm vs. windspeed schedule
* The SWECS must be a horizontal-axis, fixed blade pitch
* machine. Under the constant tip-speed ratio design, an
* automatic blade pitch control is assumed so that a
* required maximum power can be achieved and maintained
* in high winds above the rated windspeed. When the
* power-train efficiencies are included in the calculation,
* the power curve then reflects the system output.

```

```

* Developed by: Peter Tu

```

```

* Written by: Peter Tu
* Veronica Kertesz

```

```

*
* INPUT VARIABLES
*

```

```

* NTESTC - Number of data points
* VV - Free stream wind speed [mph]
* XX - Rotor blade tip speed to wind speed ratio
* TP - Rotor power [KW]
* CPAV - Average rotor power coefficient
* OMEGA - Rotor shaft speed [rpm]
* R - Rotor radius [ft]

```

```

*
* DATA FILES
*

```

```

* SYSDAT - Input file from PROP containing VV,XX,TP,CPAV
* PWRDAT - Input file from PROP containing R,OMEGA,
* XMIN,DELX,XMAX,OMEGA,THETP,GO,XETA,BLD(defined
* in PROP)
* TUDEE - 3-D Efficiency data
* PTEFF1 - 2-D Efficiency data
* RPMFIL - User supplied rpm vs.windspeed data
* TUOUT - Permanent output file
* ENGDAT - Output file used as input for WINDMAT
* PLTDAT1- Input file for the plotting routine,SYSPLIT
* OUTPUT - Output onto CRT

```

```

*
* SUBROUTINES
*

```

```

* READATA - Reads SYSDAT,PWRDAT, calculates constants
* CSTRPM - Does calculations for constant rpm option
* calls INVERT, PWRLIM
* VARIRPM - Does calculations for constant tip speed
* ratio rotor option, calls WINDLIM, PWRLIM
* RPMCURV - Does calculations for special rpm, wind-
* speed option, calls CHANGE, function FNTSR
* SYSEFF - Calculates power-train efficiency into the
* the system, calls CHANGE,INTERPT,INTP2D
* WRITOUT - Prints the final output onto the CRT, TUOUT
* and ENGDAT
* INVERT - Inverts the rotor performance table into a
* table that goes from cut-in to cut-out wind-
* speeds.
* PWRLIM - Uses a max. power to limit the power curve,
* calculates the new values in the power table
* called from CSTRPM or VARIRPM
* WINDLIM - Uses the rated windspeed to limit the power
* curve, called from VARIRPM
* INTERPT - Interpolates a 2-D table, called from SYSEFF
* INTP2D - Interpolates a 3-D table, called from SYSEFF
* CHANGE - Accepts the new points on a table that is
* being changed, called from RPMCURV,SYSEFF

```

```

*

```

```

 DIMENSION VV(26),XX(26),TP(26),CPAV(26),WSPD(26),RPMT(26),
+ AVV(26),AXX(26),ATP(26),ACPAV(26),RPM(26),TX(26),TCP(26),
+ EFF(26),POWERAT(26),XC(26),YC(26),PDRAT(18),SPD(13),EFFGEN(13,18)
 INTEGER YN
 COMMON /FUNCT/TX,TCP,KTOT
 COMMON/INT1D/XC,YC,IPOINT
 COMMON/INTPT/X,Y,Z
 COMMON/INT2D/NXPNT,NYPNT,EFFGEN,PDRAT,SPD
 COMMON/PLIM/TP,XX,CPAV,VV,RPM,NTESTC,VMIN,VMAX,OPTION
 COMMON/CONST/RAREA,POWK,CTSR,TSR,RD,PI,CPMAX
 COMMON/INVRT/OMEGA,NDOA,NDOB
 COMMON/WRIT/ENT
 COMMON/FLAG/MFLAG

```

```

*
* OPENING ALL THE FILES
*

```

```

 OPEN 2,"TUDEF"
 OPEN 4,"PTEFF1"
 OPEN 5,"PTEFF2"
 OPEN 36,"OWNEFF"
 OPEN 9,"OUTPUT"
 OPEN 17,"RPMFIL"
 OPEN 18,"RPMFIL2"
 OPEN 20,"TUOUT"
 OPEN 21,"ENGDAT"
 OPEN 31,"PLTDAT1",ATT="A"
 OPEN 54,"PWRDAT"
 OPEN 55,"SYSDAT"

```

```

C
C READ IN THE DATA AND CHOOSE THE ROTOR OPTION

```

```

 CALL READATA
 TYPE "PLEASE SELECT YOUR OPTIONS:"
 TYPE "1 FOR CONSTANT RPM ROTORS"

```

```

 TYPE "2 FOR CONSTANT TIP SPEED RATIO ROTORS"
 TYPE "3 FOR ROTORS WITH A SPECIAL RPM VS WIND SPEED FUNCTION"
 ACCEPT OPTION
 IF(OPTION-2.0) 37,36,35
37 CONTINUE
C
C CONSTANT RPM ROTOR OPTION
C
 CALL CSTRPM
 GO TO 40
36 CONTINUE
C
C CONSTANT TIP-SPEED RATIO ROTOR OPTION
C
 CALL VARIRPM
 GO TO 40
35 CONTINUE
C
C SPECIAL RPM VS. WINDSPEED OPTION
C
 CALL RPMCURV
40 CONTINUE
C
C PRINTING OUT THE INVERTED FINAL ROTOR PERFORMANCE TABLE
C
 ENT=0.0
 CALL WRITOUT
C
C SYSTEM EFFICIENCY OPTION
C
 TYPE "DO YOU WISH TO OBTAIN SWECS PERFORMANCE BY"
 TYPE "ADDING POWER-TRAN EFFICIENCY TO THE SYSTEM?(Y/N) "
 IF(YN(IDUM).NE.1)GO TO 166
 CALL SYSEFF
161 REWIND 10
 ENT=1.0
C
C PRINTING OUT THE NEW SYSTEM PERFORMANCE TABLE
C
 CALL WRITOUT
166 CONTINUE
 CLOSE 2
 CLOSE 4
 CLOSE 5
 CLOSE 36
 CLOSE 9
 CLOSE 17
 CLOSE 18
 CLOSE 20
 CLOSE 21
 CLOSE 31
 CLOSE 54
 CLOSE 55
 END

```

# SUBROUTINE READATA

## READATA

This subroutine reads in the two data files SYSDAT and PWRDAT, except for the last line of PWRDAT which is for output only (see WRITOUT). READATA also calculates various constants used throughout the program.

### SUBROUTINE VARIABLES

RD - Rotor diameter [ft]  
 NDOA - Maximum number of data points  
 CTSR - Coefficient in calculating tip-speed ratio  
 POWK - Power coefficient  
 RAREA - Rotor area [sq ft]  
 NDOB - A counter that cuts off the bad point that sometimes comes out of PROP

### DOUBLE PRECISION FILE

DIMENSION VV(26),XX(26),TP(26),CPAV(26),RPM(26)  
 COMMON/PLIM/TP,XX,CPAV,VV,RPM,NTESTC,VMIN,VMAX,OPTION  
 COMMON/CONST/RAREA,POWK,CTSR,TSR,RD,PI,CPMAX  
 COMMON/INVRT/OMEGA,NDOA,NDOB  
 PI=3.1415926536  
 NDOA=25

READING IN THE ROTOR PERFORMANCE TABLE FROM PROP  
 DATA FILE SYSDAT

DO 20 I=1,NDOA  
 READ(55,10) VV(I),XX(I),TP(I),CPAV(I)  
 10 FORMAT(4(10X,F10.3))  
 IF(VV(I) .LE. 0.0) GO TO 30

20 CONTINUE  
 30 CONTINUE

READING IN R, OMEGA, RHO FROM PROP  
 DATA FILE PWRDAT

READ(54,50) R,OMEGA,RHO  
 50 FORMAT(1X,F10.3,5X,F10.3,5X,F13.10)

CALCULATING CONSTANTS

RD=R+R  
 CTSR=(3600.0/5280.0)\*(PI\*RD/60.0)  
 POWK=(1.0/2.0)\*((5280.0/3600.0)\*\*3)\*(1./737.6)\*RHO  
 RAREA=(PI)\*(R\*\*2)  
 NDOB=I-1

PRINTING THE TIP-SPEED RATIO VS. CP TABLE ONTO  
 THE CRT AND TUOUT

TYPE "ENTER THE DATAFILE NAME FOR PROP "  
 READ(10,55)FILE  
 55 FORMAT(S20)

```

 WRITE(9,57)FILE
 WRITE(20,57)FILE
57 FORMAT("THE AIRFOIL DATAFILE USED IS ",S20//)
 WRITE(9,60)
 WRITE(20,60)
60 FORMAT("THE FOLLOWING IS PROP'S ROTOR TIP SPEED RATIO V.S. CP TABLE:")
 WRITE(9,70)
 WRITE(20,70)
70 FORMAT(5X,"TIP SPEED RATIO",5X,"POWER COEF.,CP")
 DO 90 I=1,ND0B
 WRITE(9,80) XX(I), CPAV(I)
 WRITE(20,80) XX(I), CPAV(I)
80 FORMAT(8X,F10.3,9X,F10.3)
90 CONTINUE
 RETURN
 END

```



# SUBROUTINE CSTRPM

## CSTRPM

This subroutine is used by the constant rpm rotor option. It allows the changing of the rpm and does the necessary calculations to correct the other variables. It takes the cut-out windspeed and cuts out all windspeeds above the limit, it then inverts the rotor performance table into increasing windspeed. An option for limiting the power curve by a power is provided. Called by POWERCV.

Subroutines called - INVERT  
- PWRLIM

```
DIMENSION VV(26),XX(26),TP(26),CPAV(26),AVV(26),AXX(26),
+ ATP(26),ACPAV(26),RPM(26)
INTEGER YN
COMMON /PLIM/TP,XX,CPAV,VV,RPM,NTESTC,VMIN,VMAX,OPTION
COMMON/CONST/RAREA,POWK,CTSR,TSR,RD,PI,CPMAX
COMMON/INVRT/OMEGA,NDOA,NDOB
COMMON/FLAG/MFLAG
```

OPTION FOR CHANGING THE RPM (THE RPM REMAINS CONSTANT AS SPECIFIED)

```
TYPE "DO YOU WISH TO CHANGE PROP'S ROTOR RPM ?"
IF(YN(IDUM).NE.1) GO TO 20
TYPE "ENTER ROTOR RPM"
ACCEPT OMEGA
```

ALL CALCULATIONS FOR THE OTHER VARIABLES

```
DO 10 K=1,NDOB
VV(K)=CTSR*OMEGA/XX(K)
TP(K)=POWK*RAREA*CPAV(K)*(VV(K)**3)
RPM(K)=OMEGA
10 CONTINUE
GO TO 40
20 CONTINUE
DO 30 K=1,NDOB
RPM(K)=OMEGA
30 CONTINUE
40 CONTINUE
```

PRINTING THE RAW TABLE ONTO THE SCREEN

```
WRITE(9,11)
11 FORMAT("//"ROTOR PERFORMANCE DATA GIVEN BY PROP CODE ARE:")
WRITE(9,12)
12 FORMAT(/9X,"WIND SPEEDS",2X,"POWER",2X,"TIP SPEED",2X,"POWER COEF",
+ 2X,"ROTOR"/12X,"MPH",3X,"KW",6X,"RATIOS",6X,"CP",8X,"RPM"/)
WRITE(9,13) (VV(J),TP(J),XX(J),CPAV(J),RPM(J), J=1,NDOB)
13 FORMAT(9X,F8.3,3X,F8.3,2X,F7.3,3X,F6.3,4X,F8.3)
WRITE(20,11)
WRITE(20,12)
WRITE(20,13) (VV(J),TP(J),XX(J),CPAV(J),RPM(J), J=1,NDOB)
```

```

* ENTERING THE CUT-OUT WINDSPEED
*
 TYPE "ENTER MAXIMUM POWER CUT-OFF WIND SPEED IN MPH"
 ACCEPT VMAX
*
* CALLING THE INVERTING SUBROUTINE, INVERT
*
 CALL INVERT
*
* POWER LIMITING OPTION, SUBOUTINE PWRLIM
*
 TYPE "DO YOU WANT A MAX. POWER OUTPUT LIMIT?"
 IF(YN(IDUM).NE.1)GO TO 100
 CALL PWRLIM
100 CONTINUE
 RETURN
 END

```

SUBROUTINE VARIRPM

VARIRPM

This subroutine is used by the constant tip-speed ratio rotor option. The optimum tip-speed ratio and power coefficient are entered in by the user. The cut-in and cut-out windspeeds are also entered and used as the limits on the inverted table. Two options for limiting the power curve are provided one using an entered power, another uses an entered rated windspeed.

Subroutines called - WINDLIM
- PWRLIM

SUBROUTINE VARIABLES

VMIN - Entered cut-in windspeed [mph]
VMAX - Entered cut-out windspeed [mph]
TSR - Entered tip-speed ratio
CPMAX - Entered power coefficient

DIMENSION TP(26),XX(26),RPM(26),CPAV(26),VV(26)
INTEGER YN
COMMON /PLIM/TP,XX,CPAV,VV,RPM,NTESTC,VMIN,VMAX,OPTION
COMMON/CONST/RAREA,POWK,CTSR,TSR,RD,PI,CPMAX

ACCEPT USER INPUT VARIABLES

TYPE "ENTER CUT-IN AND CUT-OUT WIND SPEEDS IN MPH"
ACCEPT VMIN,VMAX
TYPE "ENTER TIP SPEED RATIO AND POWER COEFFICIENT,CP "
ACCEPT TSR,CPMAX
TYPE "ENTER YOUR CHOICE OF USING POWER (TYPE IN 1) OR"
TYPE "RATED WIND SPEED (TYPE IN 2) TO LIMIT MAX. POWER"
ACCEPT AMAXP
IF(AMAXP .EQ. 1.0) GO TO 50

RATED WINDSPEED LIMITING OPTION, SUBROUTINE WINDLIM

CALL WINDLIM
GO TO 100
50 CONTINUE

POWER LIMITING OPTION, SUBROUTINE PWRLIM

CALL PWRLIM
CONTINUE
RETURN
END

SUBROUTINE RPMCURV

RPMCURV

This subroutine is used by the special rpm vs. windspeed option. The rpm varies with windspeed in a specified manner, so it requires the user to input a special RPM vs. V table. This file, RPMFIL, must be created before execution. Rotor tip-speed ratio will be calculated from this table. In addition PROP's CP vs TSR table is modified so that all neg. CP's are interpolated to zero.

Subroutines called - INVERT

SUBROUTINE VARIABLES

NTESTC - The no. of points in RPMFIL
WSPD - The windspeed from RPMFIL
RPMT - The RPM from RPMFIL
KTOT - The no. of points in the CP/TSR table

```

DIMENSION VV(26),XX(26),TP(26),CPAV(26),WSPD(26),RPMT(26)
+ ,RPM(26),TX(26),TCP(26)
INTEGER YN
COMMON/INVRT/OMEGA,NDOA,NDOB
COMMON /FUNCT/TX,TCP,KTOT
COMMON/PLIM/TP,XX,CPAV,VV,RPM,NTESTC,VMIN,VMAX,OPTION
COMMON/CONST/RAREA,POWK,CTSR,TSR,RD,PI,CPMAX
COMMON/CHNG/NLINE

```

READ IN THE RPM VS. WINDSPEED TABLE
PRINTING THE TABLE ONTO THE CRT

```

55 READ FREE(17) NTESTC,WSPD(1),RPMT(1)
 FORMAT(I5,5X,F10.3,F10.3)
 DO 56 I=2,NTESTC
 READ FREE(17) WSPD(I),RPMT(I)
57 FORMAT(10X,F10.3,F10.3)
56 CONTINUE
 WRITE(9,52)
52 FORMAT("THE FOLLOWING RPM TABLE HAS BEEN STORED IN THE FILE:")
 WRITE(9,58)
58 FORMAT(/4X,"TOTAL NO.OF POINTS",2X,"WIND SPEEDS",4X,"RPM"/)
 WRITE(9,59) NTESTC,WSPD(1),RPMT(1)
59 FORMAT(10X,I4,8X,F10.3,2X,F10.3)
 DO 60 I=2,NTESTC
 WRITE(9,61) WSPD(I),RPMT(I)
61 FORMAT(22X,F10.3,2X,F10.3)
60 CONTINUE

```

OPTION FOR CHANGING THE TABLE

```

TYPE "DO YOU WISH TO CHANGE THIS TABLE(Y/N)? "
IF(YN(IDUM).NE. 1) GO TO 70
CALL CHANGE(1,WSPD,RPMT)

```

```

 WRITE(9,68)
68 FORMAT("RPM CURVE USED IN SUBSEQUENT CALCULATION IS :")
 WRITE(9,58)
 WRITE(18,55) NTESTC,WSPD(1),RPMT(1)
 WRITE(9,59) NTESTC,WSPD(1),RPMT(1)
 DO 69 I=2,NTESTC
 WRITE(18,57) WSPD(I),RPMT(I)
 WRITE(9,61) WSPD(I),RPMT(I)
69 CONTINUE
70 CONTINUE
*
* CREATING A USEFUL CP VS. TIP-SPEED RATIO TABLE
* FROM THE PROP CODE TABLE AND
* PRINT OUT THE FINAL TABLE
*
 CALL CPCORR(KTOT)
*
* CALCULATING THE POWER CURVE BASED ON THE RPM VS. V TABLE
* AND THE CP VS. TSR TABLE
*
 DO 100 I=1,NTESTC
 TSR=(RPMT(I)/WSPD(I))*CTSR
 VV(I)=WSPD(I)
 CPAV(I)=FNTPSR(TSR)
 TP(I)=PDWK*RAREA*CPAV(I)*(VV(I)**3)
 XX(I)=TSR
 RPM(I)=RPMT(I)
100 CONTINUE
 RETURN
 END

```

SUBROUTINE SYSEFF

SYSEFF

This subroutine adds the power-train efficiency to the rotor performance table to create the system performance table. A one dimensional table of efficiency verses the normalized power ratios or a two dimensional table of efficiency verses rotor rpm and load. The user can also enter, or change, a 1-D table. For the 1-D case a rated power is entered and for every power in the rotor performance table a power ratio is calculated, an efficiency is interpolated and the power and cp are adjusted accordingly. For the 2-D case a rated power and rpm are entered and the rpm and power ratios are calculated, the efficiency is interpolated and the rotor performance table is adjusted accordingly. Called by POWERCV.

Subroutines called - CHANGE
- INTERPT
- INTP2D

SUBROUTINE VARIABLES

EFF - 1-D efficiency read in from PTEFF1
POWERAT - 1-D power ratio read from PTEFF1
GENKW - Entered generator's rated power [KWH]
GENRPM - Entered generator's rated rpm

DIMENSION TP(26),XX(26),RPM(26),CPAV(26),VV(26),EFF(26)
DIMENSION POWERAT(26),EFFGEN(13,18),XC(26),YC(26),SPD(13)
DIMENSION PDRAT(18)
INTEGER YN
COMMON /PLIM/TP,XX,CPAV,VV,RPM,NTESTC,VMIN,VMAX,OPTION
COMMON/INT1D/XC,YC,IPOINT
COMMON/INTPT/X,Y,Z
COMMON/INT2D/NXPNT,NYPNT,EFFGEN,PDRAT,SPD
COMMON/CHNG/NLINE

SELECTING THE TYPE OF POWER-TRAIN TABLE

ACCEPT "ENTER 2 FOR A 2-D TABLE OR 3 FOR A 3-D TABLE ",TABL
IF(TABL.EQ.3.0)GO TO 170
TYPE ""
TYPE "ENTER YOUR PREFERENCE OF CONSTRUCTING THE POWER-TRAIN EFFICIENCY
TYPE "1 FOR USING THE EXISTING TABLE"
TYPE "2 FOR ENTERING A NEW TABLE"
TYPE "3 FOR USER SUPPLIED TABLE (FILE OWNEFF)"
ACCEPT SELECT
IF(SELECT.EQ.2.0)GO TO 85

THE 1-D OPTION

READ 1-D EFFICIENCY TABLE- FILE PTEFF1

```

 IFILE=4
 IF(SELECT.EQ.3.0)IFILE=36
 DO 20 I=1,100
 READ FREE(IFILE) EFF(I),POWERAT(I)
10 FORMAT(F5.1,F8.4)
 IF(EFF(I).EQ.0.0)GO TO 30
20 CONTINUE
30 IF(I.EQ.1)GO TO 20
40 CONTINUE
 IPOINT=I-1
 WRITE(9,50)
50 FORMAT("THIS IS YOUR EXISTING POWER TRAN EFF. TABLE:"/,
+5X,"BASED ON LOAD POWER RATIOS:"/,
+ "ITEM NO.",5X,"EFFICIENCIES",5X,"POWER RATIO")
60 CONTINUE
 DO 80 I=1,IPOINT
 WRITE(9,70)I,EFF(I),POWERAT(I)
70 FORMAT(I3,11X,F5.1,11X,F8.4)
80 CONTINUE
*
* OPTION TO CHANGE, OR CREATE, THE 1-D TABLE
*
 WRITE(9,82)
82 FORMAT("DO YOU WISH TO MAKE CHANGES TO THE ABOVE TABLE?(Y/N) ")
 IF(YN(IDUM).NE.1)GO TO 90
85 CONTINUE
 CALL CHANGE(2,EFF,POWERAT)
 DO 86 I=1,NLINE
 WRITE(5,10)EFF(I),POWERAT(I)
86 CONTINUE
 IPOINT=NLINE
 WRITE(9,88)
88 FORMAT("THIS IS YOUR FINAL POWER TRAN EFF TABLE:"/
+ "ITEM NO.",5X,"EFFICIENCIES",5X,"POWER RATIO")
 GO TO 60
90 CONTINUE
 WRITE(9,100)
100 FORMAT("THIS IS THE POWER TRAN EFF. TABLE"/,
+ "BASED ON INPUT POWER RATIOS:"/,
+ "ITEM NO.",5X,"EFFICIENCIES",5X,"POWER RATIOS"/)
*
* CHANGES THE POWER RATIOS FROM INPUT TO OUTPUT POWER
* OVER THE RATED GENERATOR POWER
*
 DO 140 I=1,IPOINT
 IF(POWERAT(I).EQ.0.0)GO TO 130
 POWERAT(I)=POWERAT(I)/EFF(I)*100.0
130 WRITE(9,70) I,EFF(I),POWERAT(I)
140 CONTINUE
150 CONTINUE
*
* ACCEPTING THE RATED POWER
* AND CHANGING THE VARIABLE NAMES FOR THE INTERPOLATION
*
 ACCEPT "ENTER THE GENERATOR'S RATED POWER ", GENKW
 DO 154 I=1,IPOINT
 XC(I)=POWERAT(I)
 YC(I)=EFF(I)/100.
154 CONTINUE

```

* CALLING THE INTERPOLATION ROUTINE - INTERPT

* CALCULATING THE NEW SYSTEM VALUES

*

```
 DO 160 I=1,NTESTC
 X=TP(I)/GENKW
 CALL INTERPT
 TP(I)=Y*TP(I)
 CPAV(I)=CPAV(I)*Y
```

```
160 CONTINUE
 GO TO 900
```

*

* THE 2-D OPTION

* READING THE DATA FILE - TUDEE

*

```
170 READ FREE(2)XPNT,YPNT
180 FORMAT(2F10.5)
 NXPNT=XPNT
 NYPNT=YPNT
 READ FREE(2)(PDRAT(J),J=1,NXPNT)
190 FORMAT(8X,9F6.2,/8X,9F6.2)
 DO 220 I=1,NYPNT
 READ(2,200)SPD(I),(EFFGEN(I,J),J=1,NXPNT)
200 FORMAT(F6.1,9F6.1/6X,9F6.1)
220 CONTINUE
```

*

* ACCEPTING THE RATED POWER AND RPM

*

```
 ACCEPT "ENTER THE RATED POWER AND RPM OF THE GENERATOR ",GENKW,GENRP
 WRITE(9,222)
```

```
222 FORMAT(/,6X,"POWER",11X,"RPM",11X,"POWER-TRAIN")
 WRITE(9,224)
```

```
224 FORMAT(6X,"RATIO",11X,"RATIO",9X,"EFFICIENCY")
```

*

* CALLING THE 2-D INTERPOLATION ROUTINE - INPT2D

* AND PRINTING THE INTERPOLATION TABLE

* AND CALCULATING THE NEW VALUES

*

```
 DO 230 I=1,NTESTC
 X=TP(I)/GENKW
 Y=RPM(I)/GENRPM
 CALL INTP2D
 TYPE X,Y,Z
 TP(I)=Z*TP(I)/100.0
 CPAV(I)=Z*CPAV(I)/100.0
```

```
230 CONTINUE
900 RETURN
 END
```


SUBROUTINE WRITOUT

WRITOUT

This subroutine prints out the final tables and other useful information onto TUOUT, ENG DAT and the CRT. By using ENT it decides whether to use the rotor (ENT=0) or the system (ENT=1) performance printing statements. Called from POWERCV.

```

DIMENSION VV(26),XX(26),TP(26),CPAV(26),RPM(26)
COMMON/PLIM/TP,XX,CPAV,VV,RPM,NTESTC,VMIN,VMAX,OPTION
COMMON/WRIT/ENT
COMMON/FLAG/MFLAG
IF(ENT.EQ.1.0)GO TO 120

```

READING AND PRINTING OF PROP INPUT VARIABLES (SEE PROP)

```

 READ(54,20)XMIN,XMAX,DELX,OMEGA,THETP,GO,XETA,BLD
20 FORMAT(8F8.3)
 WRITE(20,40)
40 FORMAT(// "XMIN",5X,"XMAX",7X,"DELX",5X,"OMEGA",5X,"THETP",
+ 6X,"GO",7X,"XETA",7X,"BLD")
 WRITE(20,60)XMIN,XMAX,DELX,OMEGA,THETP,GO,XETA,BLD
60 FORMAT(F5.2,7F10.3//)
```

PRINTING OF THE TYPE OF OPTION USED

```

 IF(OPTION.EQ.1.0)WRITE(20,45)
45 FORMAT(5X,"CONSTANT RPM ROTOR OPTION "//)
 IF(OPTION.EQ.2.0)WRITE(20,50)
50 FORMAT(5X,"CONSTANT TIP SPEED RATIO ROTOR OPTION"//)
 IF(OPTION.EQ.3.0)WRITE(20,55)
55 FORMAT(5X,"SPECIAL RPM FUNCTION OPTION "//)
```

PRINTING THE ROTOR PERFORMANCE HEADINGS

```

 WRITE(9,80)
 WRITE(20,80)
80 FORMAT("FINAL ROTOR PERFORMANCE DATA ARE AS FOLLOWS:")
 WRITE(9,100)
 WRITE(20,100)
100 FORMAT(//1X,"NO. OF",2X,"WIND SPEEDS",2X,"POWER",2X,"TIP SPEED",
+ 2X,"POWER COEF",2X,"ROTOR"/1X,"POINTS",5X,"MPH",8X,"KW",6X,"RATIOS",
+ 6X,"CP",8X,"RPM"/)
 GO TO 180
120 CONTINUE
```

PRINTING THE SYSTEM PERFORMANCE HEADINGS

```

 WRITE(9,140)
 WRITE(20,140)
140 FORMAT(// "FINAL SWECS PERFORMANCE DATA ARE AS FOLLOWS:")
 WRITE(9,160)
 WRITE(20,160)
160 FORMAT(//1X,"NO. OF",2X,"WIND SPEEDS",2X,"SYSTEM",2X,
+ "TIP SPEED",2X,"SYSTEM ",2X,"ROTOR"/1X,"POINTS",5X,
+ "MPH",7X,"POWER",4X,"RATIOS",2X,"POWER COEF",4X,"RPM"/,
```

```

 + 23X,"KW",18X,"CP"/)
*
* REWINDING THE WINDMAT INPUT TAPE SO THE SYSTEM PERFORMANCE
* DATA IS USED, IF THAT OPTION IS TAKEN
*
 REWIND 21
180 CONTINUE
*
* PRINTING OUT THE ACTUAL VALUES
*
 WRITEFREE(31) NTESTC
 DO 190 I=1,NTESTC
 WRITEFREE(31) VV(I),TP(I),XX(I),CPAV(I),RPM(I)
190 CONTINUE
 WRITE(9,200) NTESTC,VV(1),TP(1),XX(1),CPAV(1),RPM(1)
 WRITE(20,200) NTESTC,VV(1),TP(1),XX(1),CPAV(1),RPM(1)
 WRITE(21,200) NTESTC,VV(1),TP(1),XX(1),CPAV(1),RPM(1)
 WRITE(9,220) (VV(I),TP(I),XX(I),CPAV(I),RPM(I),I=2,NTESTC)
 WRITE(20,220) (VV(I),TP(I),XX(I),CPAV(I),RPM(I),I=2,NTESTC)
 WRITE(21,220) (VV(I),TP(I),XX(I),CPAV(I),RPM(I),I=2,NTESTC)
200 FORMAT(1X,I4,4X,F8.3,3X,F8.3,2X,F7.3,3X,F6.3,4X,F8.3)
220 FORMAT(9X,F8.3,3X,F8.3,2X,F7.3,3X,F6.3,4X,F8.3)
 IF(MFLAG.EQ.0)RETURN
 WRITE(9,230)
 WRITE(20,230)
230 FORMAT(/"NOTE: THE GIVEN CUT-OUT WINDSPEED EXCEEDED THE MAX POSITIVE
$ 6X,"CP VALUE. THE CUT-OUT WINDSPEED IS ASSUMED TO BE THE"/
$ 6X,"MAX WINDSPEED ON THE TABLE"/)
 MFLAG=0
 RETURN
 END

```

SUBROUTINE INVERT

INVERT

This subroutine takes PROP's rotor performance table and limits it to the cut-in to cut-out windspeeds and inverts the original table thus creating a table that goes from cut-in to cut-out windspeeds. In addition any neg. CP's are interpolated to zero.

Called from - CSTRPM
Subroutines called - CPCORR

SUBROUTINE VARIABLES

VMAX - From CSTRPM the cut-out windspeed
NDOB - The no. of points in the table
NTESTC - ditto
A__ - The alternate array used for inverting
INDEX - A counter for the number of points
MFLAG - =1 when VMAX is greater than the table

```
DIMENSION VV(26),XX(26),TP(26),CPAV(26),AVV(26),AXX(26),
+ ATP(26),ACPAV(26),RPM(26)
INTEGER YN
COMMON /PLIM/TP,XX,CPAV,VV,RPM,NTESTC,VMIN,VMAX,OPTION
COMMON/CONST/RAREA,POWK,CTSR,TSR,RD,PI,CPMAX
COMMON/INVRT/OMEGA,NDOA,NDOB
COMMON/FLAG/MFLAG
MFLAG=0
```

CALL TO CUT OFF THE TRAILING NEG.CP'S
INTERPOLATE ANY INTERMEDIATE NEG CP'S TO ZERO
AND PRINT OUT A NEW CP VS TSR TABLE

CALL CPCORR(IND)
NDOB=IND

INVERT THE TABLE

```
DO 10 I=1,NDOB
 AVV(I)=VV(I)
 AXX(I)=XX(I)
 ATP(I)=TP(I)
 ACPAV(I)=CPAV(I)
10 CONTINUE
DO 30 I=1,NDOB
 J=I-1
 VV(I)=AVV(NDOB-J)
 XX(I)=AXX(NDOB-J)
 TP(I)=ATP(NDOB-J)
 CPAV(I)=ACPAV(NDOB-J)
30 CONTINUE
```

LIMIT THE TABLE TO THE CUT-OUT WINDSPEED
IF IT IS GREATER THAN THE MAX.TABLE VALUE

★

```
DO 50 I=1,NDOB
 INDEX=I
 IF(VV(I).EQ.VMAX)GO TO 60
 IF(VV(I).LT.VMAX)GO TO 50
 DELTA=(VMAX-VV(I))/(VV(I-1)-VV(I))
 VV(I)=VMAX
 XX(I)=DELTA*(XX(I-1)-XX(I))+XX(I)
 TP(I)=DELTA*(TP(I-1)-TP(I))+TP(I)
 CPAV(I)=DELTA*(CPAV(I-1)-CPAV(I))+CPAV(I)
 GO TO 60
50 CONTINUE
 MFLAG=1
60 CONTINUE
 NDOB=INDEX
 NTESTC=INDEX
 DO 70 K=1,NTESTC
 RPM(K)=OMEGA
70 CONTINUE
 RETURN
END
```

SUBROUTINE PWRLIM

PWRLIM

This subroutine uses either a specified power or the maximum power to limit the power curve. It is called from two different subroutines and does a different calculation for each subroutine.

Called from - CSTRPM
- VARIRPM

SUBROUTINE VARIABLES

TPMAX - Maximum power in the Rotor Performance table [KWH]
LIM - The index of the max. power
PLIM - User supplied limiting power
KRPM - Control variable for RPM values
RPMC - Control variable for RPM values

```
DIMENSION TP(26),XX(26),RPM(26),CPAV(26),VV(26)
INTEGER YN
COMMON /PLIM/TP,XX,CPAV,VV,RPM,NTESTC,VMIN,VMAX,OPTION
COMMON/CONST/RAREA,POWK,CTSR,TSR,RD,PI,CPMAX
WRITE(20,10)
10 FORMAT(/"POWER LIMITING OPTION")
IF(OPTION.EQ.2)GO TO 550
```

SUBROUTINE CSTRPM CALCULATIONS

TYPE "DO YOU WISH TO SPECIFY THE LIMITING POWER"
IF(YN(IDUM).EQ.1)GO TO 400

USING THE MAX. POWER TO LIMIT THE POWER CURVE

```
TPMAX=TP(1)
DO 200 I=2,NTESTC
IF(TP(I).LE.TP(I-1)) GO TO 250
TPMAX=TP(I)
LIM=I
200 CONTINUE
GO TO 900
250 CONTINUE
DO 300 J=LIM,NTESTC
TP(J)=TPMAX
CPAV(J)=TP(J)/(POWK*RAREA*VV(J)**3)
300 CONTINUE
GO TO 900
400 CONTINUE
```

USING A USER SUPPLIED LIMITING POWER

TYPE "WHAT IS THE LIMITING POWER?"
ACCEPT PLIM

```

DO 500 K=1,NTESTC
IF(TP(K) .GE. PLIM) GO TO 530
500 CONTINUE
GO TO 900
530 CONTINUE
VPLIM = VV(K) - (VV(K)-VV(K-1)) * (TP(K)-PLIM) / (TP(K)-TP(K-1))
XX(K) = XX(K) - VV(K)/VPLIM
VV(K) = VPLIM
DO 540 J=K,NTESTC
IF(TP(J) .LT. PLIM) GO TO 540
TP(J)=PLIM
CPAV(J)=TP(J)/(POWK*RAREA*VV(J)**3)
540 CONTINUE
GO TO 900
550 CONTINUE
*
* SUBROUTINE VARIRPM CALCULATIONS
*
ACCEPT "WHAT IS THE LIMITING POWER?",PLIM
DV=(VMAX-VMIN)/19.0
KRPM=0
*
* RECALCULATION OF THE AFFECTED VARIABLES
*
DO 600 K=1,20
DK=K
VV(K)=VMIN+DV*(DK-1.0)
TP(K)=POWK*RAREA*CPMAX*(VV(K)**3)
RPM(K)=VV(K)*(5280.0/3600.0)*TSR*(60.0)/(PI*RD)
XX(K)=TSR
CPAV(K)=CPMAX
IF(TP(K) .GE. PLIM) GO TO 700
600 CONTINUE
GO TO 800
700 CONTINUE
VPLIM = VV(K) * (PLIM/TP(K))**(.333333)
VV(K) = VPLIM
RPM(K) = XX(K) * VV(K)/CTSR
TP(K)=PLIM
DO 800 J=K+1,20
DJ=J
VV(J)=VMIN+DV*(DJ-1.0)
TP(J)=PLIM
RPM(J)=RPM(K)
XX(J) = CTSR * RPM(K)/VV(J)
CPAV(K)=TP(J)/(POWK*RAREA*(VV(K)**3))
800 CONTINUE
NTESTC=20.0
900 CONTINUE
RETURN
END

```

This subroutine uses a specified rated windspeed to limit the power curve. All necessary calculations are done on the other variables.

```

DIMENSION TP(26),XX(26),RPM(26),CPAV(26),VV(26)
INTEGER YN
COMMON/PLIN/TP,XX,CPAV,VV,RPM,NTESTC,VMIN,VMAX,OPTION
COMMON/CONST/RAREA,POWK,CTSR,TSR,RD,PI,CPMAX

```

```
TYPE "WHAT IS THE RATED WIND SPEED?"
ACCEPT VRAT
DV=(VMAX-VMIN)/19.0
DO 10 K=1,20
```

```

DK=K
VV(K)=VMIN+DV*(DK-1.0)
TP(K)=POWK*RAREA*CPMAX*(VV(K)**3)
RPM(K)=VV(K)*(5280./3600.)*TSR*(60.)/(PI*RD)
XX(K)=TSR
CPAV(K)=CPMAX
DIFF = ABS(VRAT-VV(K))
IF(DIFF .LT. .005) GO TO 20
IF(VV(K) .GT. VRAT) GO TO 20
CONTINUE
GO TO 50
CONTINUE
TPLIM = TP(K) * (VRAT/VV(K))**3
RPM(K) = RPM(K) * VRAT/VV(K)
TP(K) = TPLIM
VV(K) = VRAT

```

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SUBROUTINE CPCORR(INDEX)

```

*
* This subroutine takes PROP'S CP vs. tip speed
* ratio table and interpolates any neg. CP to zero
* and finds the corresponding tip speed ratio.
* Then it prints the modified table.
*
* Called from - INVERT
* RPMCURV
*

*
* SUBROUTINE VARIABLES
*
* CP - The max. CP in the table
* TS - The corresponding tip speed ratio to CP
* NDOB - The no. of points on entry
* INDEX - A counter for the current no. of points
* NFLAG - =1 when a neg. CP is interpolated to zero
* TX - Used in RPMCURV as power
* TCP - Used in RPMCURV as CP
*

 DIMENSION VV(26),XX(26),TP(26),CPAV(26),WSPD(26),RPMT(26)
+ ,RPM(26),TX(26),TCP(26)
 COMMON/INVRT/OMEGA,NDOA,NDOB
 COMMON /FUNCT/TX,TCP,KTOT
 COMMON/PLIM/TP,XX,CPAV,VV,RPM,NTESTC,VMIN,VMAX,OPTION
 NFLAG=0
 TS=XX(1)
 CP=CPAV(1)
 DO 80 I=2,NDOB
 IF(CPAV(I).LE.CP)GO TO 80
 CP=CPAV(I)
 TS=XX(I)
80 CONTINUE
 DO 90 I=1,NDOB
*
* FIGURING OUT WHICH SIDE OF THE CURVE PT.IS ON
*
 INDEX=I
 IF(XX(I).GT.TS)GO TO 82
*
* FINDING A NEW TSR IF CP IS NEG.
*
 IF(CPAV(I) .GE. 0.0) GO TO 90
 NFLAG=1
 DCP =CPAV(I+1)-CPAV(I)
 XX(I)=XX(I+1)-(((CPAV(I+1)-0.0)/DCP)*(XX(I+1)-XX(I)))
 VV(I)=VV(I+1)-(((CPAV(I+1)-0.0)/DCP)*(VV(I+1)-VV(I)))
 TP(I)=0.0
 CPAV(I)=0.0
 GO TO 90
82 CONTINUE
*
* AT END INTERPOLATE A TSR AT CP=0 IF CP NEG.
*
 IF(CPAV(I).GE.0.0)GO TO 90
 NFLAG=1

```



```

 DCP=CPAV(I-1)-CPAV(I)
 XX(I)=XX(I)+(((CPAV(I-1)-0.0)/DCP)*(XX(I-1)-XX(I)))
 VV(I)=VV(I)+(((CPAV(I-1)-0.0)/DCP)*(VV(I-1)-VV(I)))
 CPAV(I)=0.0
 TP(I)=0.0
 GO TO 91
90 CONTINUE
91 CONTINUE
*
* PRINT THE MODIFIED CP VS TSR TABLE
*
 WRITE(9,92)
 WRITE(20,92)
92 FORMAT(/"THIS IS YOUR MODIFIED CP CURVE FROM PROP:")
 WRITE(9,93)
 WRITE(20,93)
93 FORMAT(5X,"TIP SPEED RATIO",5X,"POWER COEFF CP"/)
 DO 94 I=1,INDEX
 TX(I)=XX(I)
 TCP(I)=CPAV(I)
 WRITE(9,96) TX(I),TCP(I)
 WRITE(20,96) TX(I),TCP(I)
94 CONTINUE
96 FORMAT(11X,F7.3,13X,F6.3)
*
* PRINT A MESSAGE IF ANY INTERPLOATING DONE
*
 IF(NFLAG.EQ.0)RETURN
 WRITE(9,100)
 WRITE(20,100)
100 FORMAT(/"NOTE: THE NEG. CP'S HAVE BEEN INTERPOLATED TO ZERO"/)
 RETURN
 END

```

```

 FUNCTION FNTSR(X)

 *
 * FNTSR *
 *
 * This function does a linear interpolation of a
 * tip-speed ratio. Called from RPMCURV.
 *
 * *****
 *
 * FUNCTION VARIABLES *
 *
 * TSR - Calculated tip-speed ratio from RPMCURV
 * TX - Tip-speed ratio from CP vs. TSR table
 * KTOT - Total number of tip-speed ratio points
 * DTSR - Difference between old and new interpolated
 * tip-speed ratio
 * FNTSR - Interpolated tip-speed ratio
 * TCP - Power coeff. from CP vs. TSR table
 *
 * *****
 * DIMENSION TX(26),TCP(26)
 * COMMON /FUNCT/TX,TCP,KTOT
 * COMMON/CONST/RAREA,POWK,CSTR,TSR,RD,PI,CPMAX
 *
 * CHECK IF TSR WITHIN TABLE LIMITS
 *
 * IF(TSR .LT. TX(1)) GO TO 115
 * IF(TSR .GT. TX(KTOT)) GO TO 115
 *
 * INTERPOLATING TSR FROM THE TABLE
 *
 * DO 110 J=1,KTOT
 * IF(TSR .GT. TX(J)) GO TO 110
 * IF(TSR .EQ. TX(J)) GO TO 117
 * DTSR=TX(J)-TX(J-1)
 * FNTSR=TCP(J)-(((TX(J)-TSR)/DTSR)*(TCP(J)-TCP(J-1)))
 * GO TO 118
 * 110 CONTINUE
 * GO TO 118
 * 115 CONTINUE
 *
 * If TSR is out of the tables limits, set to zero
 *
 * WRITE(9,116) TSR
 * 116 FORMAT("TIP SPD RATIO ",F7.3," IS OUT OF LIMITS, PLEASE DISCARD")
 * FNTSR=0.0
 * GO TO 118
 * 117 CONTINUE
 *
 * FNTSR set to TCP if TSR equals a table value
 *
 * FNTSR=TCP(J)
 * 118 CONTINUE
 * RETURN
 * END

```

SUBROUTINE INTERPT

INTERPT

This subroutine interpolates a 2 list table.
Given an X a corresponding Y will be found.

SUBROUTINE VARIABLES

XC - A X point from the table
YC - A Y point from the table
X - The X value to be interpolated from
Y - The Y value found from the interpolation
X1,Y1 - The table X,Y value that are slightly
smaller than X
X2,Y2 - The next table entries from X1,Y1
X3,Y3 - The table entries after X2,Y2

```

DIMENSION XC(26),YC(26)
COMMON/INT1D/XC,YC,IPOINT/INTPT/X,Y,Z
NSTOP=IPOINT-2
IF(X.LE.XC(1))GO TO 300
DO 100 I=1,NSTOP
IF(X.GT.XC(I))GO TO 150
GO TO 100
150 IT=I
100 CONTINUE
X1=XC(IT)
X2=XC(IT+1)
X3=XC(IT+2)
Y1=YC(IT)
Y2=YC(IT+1)
Y3=YC(IT+2)
Y=Y1*(X-X2)*(X-X3)/(X1-X2)/(X1-X3)
Y=Y+Y2*(X-X1)*(X-X3)/(X2-X1)/(X2-X3)
Y=Y+Y3*(X-X1)*(X-X2)/(X3-X1)/(X3-X2)
IF(X.GT.XC(IPOINT))Y=0.0
GO TO 400
300 CONTINUE
Y=0.0
400 CONTINUE
RETURN
END

```

SUBROUTINE INTP2D

```

*
* INTP2D
*
* This subroutine interpolates a 2-D table, 1 depend-
* ant varilabe, 2 independant variables. Given an
* X and Y a Z will be found.
*

*
* SUBROUTINE VARIABLES
*
* NXPNT - The number of X points
* NYPNT - The number of Y points
* PDRAT - The power ratio an independant variable,X
* SPD - The rotor rpm, an independant variable,Y
* X - The known power ratio
* Y - The known rotor rpm
* Z - The efficiency, the variable to be interpolated*
* X1,X2 - The two table X's on either side of X
* Y1,Y2 - The two table Y's on either side of Y
* Z1,Z2,Z3,Z4 - The Z's surrounding the value of Z being
* interpolated
*

 DIMENSION PDRAT(18),SPD(13),EFFGEN(13,18)
 COMMON/INT2D/NXPNT,NYPNT,EFFGEN,PDRAT,SPD/INTPT/X,Y,Z
 DO 40 J=1,NXPNT
 IF(X .LT. PDRAT(1)) GO TO 60
 IF(X .GT. PDRAT(NXPNT)) GO TO 60
 IF(X.GE.PDRAT(J))GO TO 30
 GO TO 40
30 JT=J
40 CONTINUE
 DO 50 I=1,NYPNT
 IF(Y .LT. SPD(1)) GO TO 60
 IF(Y .GT. SPD(NYPNT)) GO TO 60
 IF(Y.GE.SPD(I))GO TO 45
 GO TO 50
45 IT=I
50 CONTINUE
 IP=IT+1
 JP=JT+1
C WRITE(9,55) IT,IP,JT,JP
C 55 FORMAT(4I4)
 X1=PDRAT(JT)
 X2=PDRAT(JP)
 Y1=SPD(IT)
 Y2=SPD(IP)
 Z1=EFFGEN(IT,JT)
 Z2=EFFGEN(IT,JP)
 Z3=EFFGEN(IP,JT)
 Z4=EFFGEN(IP,JP)
 ZH=Z1-((X1-X)*(Z1-Z2)/(X1-X2))
 ZL=Z3-((X1-X)*(Z3-Z4)/(X1-X2))
 Z=ZH-((Y1-Y)*(ZH-ZL)/(Y1-Y2))
 GO TO 70
60 CONTINUE
 Z=0.0

```

70 CONTINUE

C WRITE(9,85) Z1,Z2,Z3,Z4,ZH,ZL

C 85 FORMAT(6F10.5)

C PRINT(9,80)X,Y,Z

C 80 FORMAT(3F10.4)

RETURN

END

SUBROUTINE CHANGE(ENTRY,QITEM1,QITEM2)

```

*
* *
* CHANGE *
* *
* This subroutine changes a table entry to one
* inputed by the user. This subroutine also will
* create a new 2 list table. Called from RPMCURV
* and SYSEFF.
*

 DIMENSION QITEM1(26),QITEM2(26)
 COMMON/CHNG/NLINE
 INTEGER ENTRY
 WRITE(9,10)
10 FORMAT("ENTER NUMBER OF LINES YOU WISH TO CHANGE(OR ENTER)")
 ACCEPT NLINE
 IF(ENTRY.EQ.2)GO TO 30
*
* HEADING FOR THE NEW POINTS FOR A RPM CURVE
*
 WRITE(9,20)
20 FORMAT("ENTER I,WSPD(I),RPM(I): ")
 GO TO 50
30 CONTINUE
*
* HEADING FOR THE NEW POINTS FOR 1-D EFF. CURVE
*
 WRITE(9,40)
40 FORMAT("ENTER ITEM NO.,EFFICIENCY,POWER RATIO")
50 CONTINUE
*
* ACCEPTING THE CHANGED POINTS
*
 DO 60 K=1,NLINE
 ACCEPT I,QITEM1(I),QITEM2(I)
60 CONTINUE
 RETURN
 END

```

integer function yn(idum)

*****

*
*
* YN *
*
* This function reads in a character, "y" or "n", *
* and converts it to a number, y=0 and n=1. The *
* calling routine can then use an if statement to *
* evaluate the response. Called from all routines. *
*

*****

1001 read (11,1001) iflag
format(a1)
yn=0
if(.not.((iflag.eq."Y ").or.(iflag.eq."y ")))go to 2300
yn=1
2300 continue
return
end

```

C PROGRAM WINDENG(INPUT,OUTPUT,TAPE7,TAPE10,TAPE12,WINDDI,LOADDI,
C +TAPE16,TAPE6=OUTPUT,TAPE5=INPUT,TAPE3=WINDDI,TAPE15=LOADDI)

```

```

```

WINDMAT

Based on the power curve (power in KW vs. wind-speed) from the POWERCV code, this program calculates the annual energy production under a Weibull wind distribution, requiring the input of the K and C values. If a Rayleigh wind distribution is used, when K=2, the annual energy production will be expressed as a function of annual average wind-speed ranging from 5 to 18 mph.

An option is given for a user's diurnal energy supply/demand match (or mismatch). The local wind characteristics and load profile must be known and provided in the files WINDDI and LOADDI.

Developed by: Peter Tu

Written by: Peter Tu
Veronica Kertesz

```

```

INPUT VARIABLES

NTESTC - Number of data points
VV - Free stream wind speed [mph]
XX - Rotor blade tip speed to wind speed ratio
TP - Rotor power [KW]
CPAV - Average rotor power coefficient
HUB - Entered hub height [ft]
NDIST - Choice of distribution
RK - Weibull K value
NDEC - Choice of output format

```

```

INTERMEDIATE VALUES

WK - Inverse of RK
GK - Wind distribution equation constant
GARMA - ditto
GAR - ditto
VBAR - Average windspeed [mph]
HVBAR - VBAR at hub height
C - HVBAR/GAR

```

```

DATA FILES

WFILE - New WINDDI file if WINDDI changed
OUTPUT - Output onto CRT
ENGDAT - Input file from POWERCV containing
NTESTC,VV,TP,XX,CPAV
WINDDI - Diurnal windspeed distribution file


```

* LOADDI - Local load distribution file
* WINDOUT - Permanent output file
* PLTDAT2 - Input file for the plotting routine
*

```

SUBROUTINES

```

* ENERGI - Calculates the energy yield for a given
* windspeed, Calls INTERPT
* MISMAT - Calculates the energy supply/demand match
* Reads WINDDI, LOADDI, calls INTERPT,
* MATOUT, WCHANGE
* MATOUT - Prints the energy yield table, the wind-
* speed, load distributions and the supply/
* demand match onto WINDOUT and the CRT
* WCHANGE - Option for changing WINDDI (a 2-D array)
* INTERPT - Interpolates a 2-D table called from ENERGI
*

```

```

 DIMENSION VV(26),XX(26),TP(26),CPAV(26),DAYHR(26),WNDSP(4,26)
 DIMENSION WTKWH(26),LDKWH(26),NTKWH(26),WTKW(4,26),LDKW(4,26)
 DIMENSION NTKW(4,26),XC(26),YC(26)
 COMMON/ENRGI/C,RK,VBAR,NDIST,NDEC
 COMMON/INT1D/XC,YC,NPOINT
 COMMON/INTPT/X,Y,Z
 COMMON/MISMT/HUB,VV,TP,NTESTC
 INTEGER YN
 REAL LDKWH,LDKW,NTKWH,NTKW,MTRHT
 OPEN 3,"WINDDI"
 OPEN 6,"OUTPUT"
 OPEN 15,"LOADDI"
 OPEN 16,"WFILE"
 OPEN 25,"WINDOUT",ATT="A"
 OPEN 30,"ENGDAT"
 OPEN 32,"PLTDAT2",ATT="A"
 REWIND 30
 READ(30,24) NTESTC,VV(1),TP(1),XX(1),CPAV(1)
24 FORMAT(1X,I4,4X,F8.3,3X,F8.3,2X,F7.3,3X,F6.3)
 READ(30,25) (VV(J),TP(J),XX(J),CPAV(J), J=2,NTESTC)
25 FORMAT(9X,F8.3,3X,F8.3,2X,F7.3,3X,F6.3)
 PI=3.14159
27 CONTINUE
 ACCEPT "ENTER HUB HEIGHT, IN FT. ",HUB
 ACCEPT "ENTER 1 FOR WEIBULL, 2 FOR NASA DISTRIBUTION ",NDIST
 IF(NDIST .EQ. 2) GO TO 35
 ACCEPT "ENTER WEIBULL DISTRIBUTION'S K VALUE ",RK
 GO TO 60
35 CONTINUE
 RK=2.27
60 CONTINUE
 WRITE(6,33)
33 FORMAT("FOR ENERGY OUTPUT ENTER 1 FOR A QUICK SUMMARY,"/
+ 24X,"2 FOR A DETAILED REPORT ")
 ACCEPT NDEC
 WK=1.0/RK
 GK=1.0+(1.0/(12.0*WK))+(1.0/(288.0*(WK**2)))
+ -(139.0/(51840.0*(WK**3)))
 GARMA=(WK**WK)*(EXP(-WK))*((2.0*PI/WK)**0.5)*GK

```

```

 GAR=WK*GARMA
 VBAR=5.0
 WRITE(6,46)
 WRITE(25,46)
46 FORMAT(/"AVERAGE WIND SPEED ENERGY YIELD"/,7X,"MPH",16X,"KWH")
 DO 70 J=1,14
 HVBAR=VBAR*((HUB/30.0)**.143)
 C=HVBAR/GAR
C
C CALL TO ENERGI
C
 CALL ENERGI
 VBAR=VBAR+1.0
70 CONTINUE
 ACCEPT "DO YOU WANT THE ENERGY SUPPLY/DEMAND MISMATCH ESTIMATE(Y/N)
82 FORMAT(A1)
 IF(YN(IDUM).NE.1)GO TO 290
C
C FORMER POSITION OF MISMAT
C
 CALL MISMAT
290 CONTINUE
 CLOSE 3
 CLOSE 6
 CLOSE 15
 CLOSE 16
 CLOSE 25
 CLOSE 30
 CLOSE 32
 RETURN
 END

```

SUBROUTINE ENERGI

ENERGI

This subroutine calculates the annual hours of operation and energy production of a SWECS under the specified Weibull wind distribution and the annual average windspeed. The windspeed used in the calculations increases from the cut-in to the cut-out windspeed at an increment of 0.05 mph. The max. hours, max. rotor power and the max. energy output for the interval of V to V+DV mph are found and the integrated value of these energies is printed out.

Subroutines called - INTERPT
MATOUT

SUBROUTINE VARIABLES

V - Windspeed
DV - Windspeed increment, 0.05
XC,YC - Holding arrays for windspeed vs power table to be transfered to INTERPT
X - INTERPT variable for windspeed
Y - Interpolated value for power output
HOURS - Hours of operation for V to V+DV
DELEN - Energy output for V to V+DV
HMAX - Max. value of HOURS for the interval
VMAX - Max. value of V at HMAX
PMAX - Max. value of power at HMAX
ENERGI - Integrated value of all the differential energies between the cut-in and cut-out windspeeds.

DIMENSION VV(26),TP(26),XC(26),YC(26)
COMMON/ENRGI/C,RK,VBAR,NDIST,NDEC
COMMON/INT1D/XC,YC,NPOINT
COMMON/INTPT/X,Y,Z
COMMON/MISMT/HUB,VV,TP,NTESTC
COMMON/MTOUT/ENERGY,VMAX,PMAX,VMAXE

Setting the constants

CONST=1.0
ENERGY=0.0
EMAX=0.0
HMAX=0.0
V=VV(1)
DV=0.05
CONTINUE

Checking if V is within the windspeed vs power table

IF(V .GT. VV(NTESTC)) GO TO 50

```

* Setting the table into INTERPT's arrays
* Calling INTERPT to interpolate a power
*
 DO 41 I=1,NTESTC
 XC(I)=VV(I)
 YC(I)=TP(I)
41 CONTINUE
 X=V
 NPOINT=NTESTC
 CALL INTERPT
*
* Calculations of power dependant variables
*
 HOURS=8766.0*(EXP(-CONST*(V/C)**RK)-
+ EXP(-CONST*((V+DV)/C)**RK))
 DELEN=Y*HOURS
*
* Searching for the max. energies and hours
*
 IF(DELEN .LT. EMAX) GO TO 42
 EMAX=DELEN
 VMAXE=V
42 CONTINUE
 IF(HOURS .LT. HMAX) GO TO 44
 HMAX=HOURS
 VMAX=V
 PMAX=Y
44 CONTINUE
*
* Integration for ENERGY
*
 ENERGY=ENERGY+DELEN
 V=V+DV
 GO TO 40
50 CONTINUE
*
*Call to MATOUT
*
 CALL MATOUT(1)
 RETURN
 END

```

SUBROUTINE MISMAT

MISMAT

This subroutine calculates the energy supply/demand match(or mismatch). Using a user supplied wind distribution to calculate the SWECS power output and comparing this to a user supplied load distribution, WINDDI and LOADDI respectively, the match between these two is printed out.

Subroutines called - WCHANGE
MATOUT

SUBROUTINE VARIABLES

MTRHT - Anemometer height, from WINDDI
WNDAVE - Average windspeed, from WINDDI
DAYHR - Time of day, 24 hr. clock, WINDDI & LOADDI
WNDSPD - Windspeed for a certain time and season
FACT - Correction factor for the hub height
LDKW - Load for a certain time and season, LOADDI
TOTKWH - Yearly total of energy summation
TOTWT - Yearly total of SWECS power summation
TOTLOAD - Yearly total of load summation
WTKWH - Seasonal total of SWECS energy summation
LDKWH - Seasonal total of load energy summation
NTKWH - Seasonal net energy(SWECS-load) summation
AVEKWH - Annual average energy (net)
AVEWT - Annual average SWECS power
AVELOAD - Annual average load power

```
DIMENSION VV(26),XX(26),TP(26),CPAV(26),DAYHR(26),WNDSP(4,26)
DIMENSION WTKWH(26),LDKWH(26),NTKWH(26),WTKW(4,26),LDKW(4,26)
DIMENSION NTKW(4,26),XC(26),YC(26)
INTEGER YN
REAL LDKWH,LDKW,NTKWH,NTKW,MTRHT
COMMON/INT1D/XC,YC,NPOINT
COMMON/INTPT/X,Y,Z
COMMON/MISMT/HUB,VV,TP,NTESTC
COMMON/MSOUT/AVEWT,TOTWT,AVELOAD,TOTLOAD,AVEKWH,TOTKWH
COMMON/MOUT/WTKWH,LDKWH,NTKWH
NFLAG=0
WRITE(6,83)
```

Selecting the type of table desired

```
83 FORMAT(// "SELECT THE FOLLOWING OPTIONS FOR" /
+ "DETERMINING THE WIND SPEED DISTRIBUTION " //
+ "1- FOR ENTERING A NEW DISTRIBUTION BY THE USER" /
+ "2- FOR USING THE EXISTING DISTRIBUTION" /)
+ "3- FOR USING A STANDARDIZED DISTRIBUTION" /)
ACCEPT SELECTW
IF(SELECTW-2.0)145,90,200
```

* Option for using the existing distribution

* i.e. WINDDI

* Reading in WINDDI

```
*
90 READ(3,95) MTRHT,WNDAVE
95 FORMAT(16X,F6.1,23X,F6.1)
DO 100 J=1,25
 READ FREE(3)DAYHR(J),WNDSP(1,J),WNDSP(2,J),WNDSP(3,J),WNDSP(4,J)
110 FORMAT(5F10.2)
100 CONTINUE
 FACT=(HUB/MTRHT)**(1.0/7.0)
 DO 117 I=1,4
 DO 115 J=1,25
 WNDSP(I,J)=WNDSP(I,J)*(20.0/9.0)*FACT
115 CONTINUE
117 CONTINUE
 WRITE(6,120)
120 FORMAT(/"THE FOLLOWING IS THE 4 SEASONS" DIURNAL WIND SPEED"1X,
+ "DISTRIBUTION TABLE"//5X"DAYHR",6X"WINDSPEED IN MPH"/15X"SPRING"
+ 4X"SUMMER"4X"FALL"4X"WINTER"/)
 DO 130 J=1,25
 WRITE(6,140)DAYHR(J),WNDSP(1,J),WNDSP(2,J),WNDSP(3,J),WNDSP(4,J)
130 CONTINUE
140 FORMAT(5(F10.3))
```

*
* Option to change WINDDI, WCHANGE
* or to input a wind distribution from the CRT
*

```
 WRITE(6,150)
150 FORMAT(/"DO YOU WISH TO CHANGE THE TABLE?")
 IF(YN(IDUM).NE.0)GO TO 145
 NFLAG=1
 GO TO 205
145 CONTINUE
 CALL WCHANGE(WNDSP)
200 WRITE(6,210)
205 WRITE(25,120)
210 FORMAT("THIS IS THE FINAL DIURNAL WINDSPEED DISTRIBUTION"//
+ 8X"DAYHR"9X"WINDSPEED IN MPH"/21X"SPRING SUMMER FALL WINTER"/)
 DO 220 J=1,25
 IF(NFLAG.EQ.1)GO TO 215
 WRITE(6,140)DAYHR(J),WNDSP(1,J),WNDSP(2,J),WNDSP(3,J),WNDSP(4,J)
215 WRITE(25,140)DAYHR(J),WNDSP(1,J),WNDSP(2,J),WNDSP(3,J),WNDSP(4,J)
 WRITE(16,110)DAYHR(J),WNDSP(1,J),WNDSP(2,J),WNDSP(3,J),WNDSP(4,J)
220 CONTINUE
```

*
* Reading in and printing out the load distribution, LOADDI
*

```
 WRITE(6,300)
 WRITE(25,300)
300 FORMAT(/5X,"THE LOAD DISTRIBUTION TABLE"//2X,"DAYHOUR"5X,"SPRING",
+ 5X,"SUMMER",5X,"FALL",5X,"WINTER"/)
 DO 330 J=1,25
 READ(15,310) DAYHR(J),LDKW(1,J),LDKW(2,J),LDKW(3,J),LDKW(4,J)
310 FORMAT(5F10.2)
 WRITE(6,310) DAYHR(J),LDKW(1,J),LDKW(2,J),LDKW(3,J),LDKW(4,J)
 WRITE(25,310) DAYHR(J),LDKW(1,J),LDKW(2,J),LDKW(3,J),LDKW(4,J)
330 CONTINUE
```

*
* Intializing the match variables

```

*
 TOTKWH=0.
 TOTWT=0.
 TOTLOAD=0.
 DO 240 I=1,4
 WTKWH(I)=0.
 LDKWH(I)=0.
 NTKWH(I)=0.
*
* Interpolating a power for each windspeed
*
 DO 230 J=1,25
 X=WNDSP(I,J)
 DO 225 K=1,NTESTC
 XC(K)=VV(K)
 YC(K)=TP(K)
225 CONTINUE
 CALL INTERPT
*
* Calculate the match variables
*
 WTKW(I,J)=Y
 WTKWH(I)=WTKWH(I)+WTKW(I,J)
 LDKWH(I)=LDKWH(I)+LDKW(I,J)
 NTKW(I,J)=WTKW(I,J)-LDKW(I,J)
 NTKWH(I)=NTKWH(I)+NTKW(I,J)
230 CONTINUE
 TOTKWH=TOTKWH+NTKWH(I)
 TOTWT=TOTWT+WTKWH(I)
 TOTLOAD=TOTLOAD+LDKWH(I)
240 CONTINUE
 AVEKWH=TOTKWH/4.
 AVEWT=TOTWT/4.
 AVELOAD=TOTLOAD/4.
*
* Printing of the match table
*
 CALL MATOUT(2)
 RETURN
 END

```

SUBROUTINE WCHANGE(QITEM)

```

*
* WCHANGE *
*
* This subroutine accepts the points for the wind
* distribution table, either as a whole new table
* or as corrections to the old table. Called from
* MISMAT.
*

 DIMENSION QITEM(4,26)
 WRITE(6,170)
170 FORMAT("HOW MANY POINTS DO YOU WISH TO CHANGE(OR ENTER)? ")
 ACCEPT NCHANGE
 DO 180 K=1,NCHANGE
 WRITE(6,190)
190 FORMAT("ENTER SEASON-1=SPR,2=SUMMER,ETC.: ,HOUR,WINDSPEED")
 ACCEPT I,J,QITEM(I,J+1)
180 CONTINUE
 RETURN
 END

```


SUBROUTINE MATOUT(IENTRY)

MATOUT

This subroutine prints out the final output data
onto the CRT and the file WINDOUT.

```

 DIMENSION WTKWH(26),LDKWH(26),NTKWH(26)
 COMMON/ENRGI/C,RK,VBAR,NDIST,NDEC
 COMMON/MTOJT/ENERGY,VMAX,PMAX,VMAXE
 COMMON/MSOUT/AVEWT,TOTWT,AVELOAD,TOTLOAD,AVEKWH,TOTKWH
 COMMON/MOUT/WTKWH,LDKWH,NTKWH
 REAL LDKWH,NTKWH
 IF(IENTRY.EQ.2)GO TO 80
 IF(NDEC .EQ. 2) GO TO 48

```

Print out the quick summary of the energy table

```

 WRITEFREE(32) VBAR,ENERGY
 WRITE(6,47) VBAR,ENERGY
 WRITE(25,47) VBAR,ENERGY
47 FORMAT(5X,F5.2,9X,F10.0)
 GO TO 500
48 CONTINUE

```

Print out the Weibull distribution parameters

```

 IF(NDIST .EQ. 2) GO TO 52
 WRITE(6,51) RK, C, VBAR
 WRITE(25,51) RK, C, VBAR
 GO TO 55
52 CONTINUE

```

Print out of the detailed report of the energy table

```

 WRITE(6,53) VBAR
 WRITE(25,53) VBAR
55 CONTINUE
 WRITE(6,56) ENERGY
 WRITE(25,56) ENERGY
 WRITEFREE(32) VBAR,ENERGY
 PBAR=ENERGY/8766.0
 WRITE(6,57) PBAR
 WRITE(25,57) PBAR
 WRITE(6,58) VMAX,PMAX,VMAXE
 WRITE(25,58) VMAX,PMAX,VMAXE
51 FORMAT(//"WEIBULL DISTRIBUTION PARAMETERS: K ="F4.2," C = "F4.1/5X,
+ "ANNUAL AVERAGE WIND SPEED = "F5.2)
53 FORMAT(//"NASA VELOCITY DISTRIBUTION"/5X,"MEAN SPEED = "
+ F5.2)
56 FORMAT(/8X,"ANNUAL ENERGY YIELD = "F10.0," KWH")
57 FORMAT(8X,"ANNUAL AVERAGE POWER OUTPUT = "F10.2," KW")
58 FORMAT(/5X,"MOST PROBABLE WIND SPEED = "F5.1,
+ /5X,"MOST PROBABLE POWER OUTPUT = "F6.2,
+ /5X,"WIND SPEED FOR MAXIMUM ENERGY DENSITY = "F5.1)
59 FORMAT(F10.2)
 GO TO 500

```

80 CONTINUE

*
* Print out the supply/demand results
*

```
 WRITE(6,250)
 WRITE(25,250)
250 FORMAT(// "DAILY ENERGY SUPPLY AND DEMAND SUMMARY ARE:"//
+ "ENERGY TYPE SPRING"4X "SUMMER"5X "FALL"5X "WINTER"5X
+ "TOTAL",5X,"AVERAGE"/)
 WRITE(6,260)(WTKWH(I),I=1,4),TOTWT,AVEWT
 WRITE(25,260)(WTKWH(I),I=1,4),TOTWT,AVEWT
260 FORMAT("SWEGS KWH",6F10.2)
 WRITE(6,270)(LDKWH(I),I=1,4),TOTLOAD,AVELOAD
 WRITE(25,270)(LDKWH(I),I=1,4),TOTLOAD,AVELOAD
270 FORMAT("LOAD KWH ",6F10.2)
 WRITE(6,280)(NTKWH(I),I=1,4),TOTKWH,AVEKWH
 WRITE(25,280)(NTKWH(I),I=1,4),TOTKWH,AVEKWH
280 FORMAT("NET KWH ",6F10.2)
500 CONTINUE
 RETURN
 END
```

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