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A USER'S MANUAL FOR THE COMPUTER CODE PAREP

Timothy M. Leonard

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Abstract

This report discusses PAREP (PArametric REPresentation), a computer code that uses numerical and empirical data to estimate the aerodynamic performance of Darrieus-type vertical axis wind turbines. Both program theory and usage are described for the code. Sample runs and program listings are provided.

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Nomenclature

Symbol		Formula	
A_s	=	$\frac{8}{3} R^2 \frac{H}{D}$	Projected blade area
C			Blade chord length
C_p	=	$Q\omega/\frac{1}{2}\rho_\infty V_\infty^3 A_s$	Power coefficient
	=	$\frac{P_t}{A_s}/\frac{1}{2}\rho_\infty (R\omega)^3$	
D			Turbine equatorial diameter
H			Turbine height
K_p	=	$\frac{C_p}{X^3}$	Performance Coefficient for Constant rpm Operations
	=	$Q\omega/\frac{1}{2}\rho_\infty (R\omega)^3 A_s$	
L			Length along blade axis
μ_∞			Freestream kinetic viscosity
N			Number of blades
ω			Angular turbine speed
P_t	=	$Q\omega$	Turbine power output
Q			Turbine shaft torque
R	=	$D/2.$	Turbine radius
Re_c	=	$\rho_\infty R\omega c/\mu_\infty$	Blade chord Reynolds number
ρ_∞			Freestream air density
σ	=	$N_c L/A_s$	Turbine solidity
V_∞			Freestream windspeed
X	=	$R\omega/V_\infty$	Tip speed ratio

A USER'S MANUAL FOR THE COMPUTER CODE PAREP

Introduction

The computer code PAREP[1] (PArametric REPresentation) has been developed as a design tool to aid in estimating aerodynamic performance of Darrieus-type vertical axis wind turbine (VAWT) generators. Some key parameters are adjusted by wind tunnel data rather than by total reliance on numerical predictions.

The program has two phases corresponding roughly to (1) definition of classical dimensionless aerodynamic performance curves, and (2) the implementation of these curves to predict system behavior for constant-rotor rpm applications.

PAREP is a combination of two previous programs, CPPARM[2] and TVSV.[3] This modification was substantiated by the acceleration of data input, increased data output, and the addition of relevant screen graphics.

Program Theory

The primary function of PAREP is to estimate the aerodynamic performance of Darrieus-type VAWTs for a range of five turbine parameters -- two maximized power coefficients $C_{p_{max}}$ and $K_{p_{max}}$ with their corresponding tip speed ratios X_m and X_k, and runaway tip speed ratio X_R. These parameters vary with turbine solidity (σ), Reynolds number (Re_c), and height-to-diameter (H/D) ratio, factors that are needed to construct a smooth power coefficient curve. The first four parameters may be reasonably predicted by a multiple streamtube aerodynamic model,[4] but the runaway tip speed ratio may more accurately be derived from 2-m VAWT wind tunnel data. The definition and significance of these parameters are discussed in detail in the VAWT economic analysis report.[5]

Essentially, the five parameters, $C_{p_{max}}$, $K_{p_{max}}$, X_m, X_k, and X_R, for particular solidities (σ) and H/D ratios are proportional to the natural log of the Reynolds number (Re_c) such that

$$P_i = A_{p_i} + B_{p_i} \ln (Re_c)$$

where P_i is one of the above parameters.

The A's and B's for the parameters have been numerically produced for a series of σ's and H/D's forming a 3x3 matrix from which intermediate values are derived by two-dimensional linear interpolation.

Program Usage

In constant rpm operations, the tip speed ratio (X) is varied by changing the windspeed (V_∞) and the aerodynamic turbine output computed from the previously defined power coefficient curve. PAREP also estimates transmission and generator losses[5] to determine transmission and electrical output.

The necessary program input involves the turbine operating environment.

Question No.	Description	Symbol	Units
1	Turbine Diameter	(D)	Ft.
2	H/D Ratio	(H/D)	None
3	Number of Blades	(N)	None
4	Blade Chord Length	(c)	In.
5	Blade Ground Clearance		Ft.
6	Turbine Speed	(ω)	rpm
7	Rated System Power		kW
8	Air Density	(ρ_∞)	lbm/ft^3

After performing Phase I, PAREP outputs the quantities ρ_∞, μ_∞, Re_c, σ, and the five parameters $C_{p_{max}}$, $K_{p_{max}}$, X_m, X_k, and X_R.

Phase II produces the following output quantities:

Output Quantity	Description	Symbol	Units	Table Heading
*1	Reference Velocity @ 30 ft.	(V_∞)	mph	VREF
*2	Wind Velocity @ Rotor ℄		mph	VTUR
*3	Tip Speed Ratio	(X)	None	TSR
4	Advance Ratio	(1/X)	None	ADVR
*5	Power Out (Turbine)		kW	PTUR
*6	Power Out (Transmission)		kW	PTRAN
*7	Power Out (Generator)		kW	PGEN
*8	Power Coefficient (Turbine)	(C_p)	None	CP
9	Power Coefficient (Transmission)		None	CPT
10	Power Coefficient (Generator)		None	CPG
*11	Performance Coefficient (Turbine)	(K_p)	None	KP

*Those quantities are tabulated initially. If the user wishes to see the remainder, an appropriate question is asked after the initial tabulation is complete.

Output Quantity	Description	Symbol	Units	Table Heading
*12	Performance Coefficient (Transmission)		None	KTP
*13	Performance Coefficient (Generator)		None	KPG
14	Torque (Turbine)**	(Q)	ft-lbs	QTUR
15	Torque (Transmission)**		ft-lbs	QTRAN
16	Torque (Generator)*		ft-lbs	QGEN

The following is a discussion of the sample run listed in Appendix A. It assumes that the code PAREP has been compiled and executed and that input and output are by means of an appropriate timesharing terminal.

All data input is made in one group of eight questions as defined above. Question numbers are used to change quantities for subsequent runs; these are discussed later. Because of internal coding, all quantities must be input in units noted. After each question is asked, a question mark (?) will be printed at the beginning of the next line indicating that the program is waiting for a number. Only one quantity is requested per line. Input questions and answers for this sample run appear in Appendix A, page A-1.

As Phase I is completed, PAREP prints out the information concerning the power coefficient curve as shown on page A-2. Then in Phase II, PAREP begins to tabulate the performance data. Tabulation begins when the power from the turbine shaft (PTUR) exceeds zero, and concludes when either the windspeed (VREF) exceeds 60 mph or the tip speed ratio (TSR) drops below 1.5, as shown on pages A-3 to A-5.

Upon completion of Phase II, the user is prompted for instructions to continue, to which the user should respond with the item number of the desired option (see page A-6).

-2	Terminate program.
-1	Tabulate remaining quantities.
0	Ask all input questions again.
n	(n = 1 - 8) Ask question "n" again.
9	Rerun PAREP with new input.

When single changes are made (n = 1 - 8), the prompt question will be reasked until user enters "9" to rerun the program, or "-2" to quit (page A-6).

*Those quantities are tabulated initially. If the user wishes to see the remainder, an appropriate question is asked after the initial tabulation is complete.

**Torque values are reflected to the low speed output shaft of the rotor.

Screen Graphics

For users having graphics capabilities on their timesharing terminals, PAREP continues with a Phase III that creates X-Y plots of the output quantities as requested.

Any of the 16 output quantities defined in the section on Program Usage can be plotted. One quantity is chosen as a base variable, and up to four other quantities may be plotted against that base variable provided their scales (units) are compatible -- e.g., it is often convenient to plot all three power curves or torque curves against the windspeed.

Because of the wide range of possibilities, the user must also provide the limits of the X- and Y-axis scales and the tick-mark increment. After 10 tick marks are labeled on one axis, the numbers generally become illegible.

Referring to Appendix B, the user will find it quite simple to order any desired plot.

For the continuation prompt at the end of the section on Program Usage, the graphics user has one additional option to choose from -- namely (Item 10) graphics. If he selects this option, the user is asked a few more questions as shown on page B-1. The first additional question requires the item number of the desired base variable, the second wants the number of curves to be plotted, and the third wants the <u>list</u> of item numbers of the dependent variable that corresponds to those curves. The fourth and fifth questions request the bounds and increments of the vertical (Y) and horizontal (X) scales.

PAREP then displays the graph as defined (page B-2) and gives the standard continuation prompt to check for more input and/or graphics (page B-3).

Notes

<u>Phases I and II</u>

After a full page of output ($\simeq$ 35 lines), PAREP stops to allow for copying, perusal, etc., by printing a question mark(?) at the bottom left corner of the screen. Entering zero (0) will clear the screen and continue output. At the end of tabulation (which may or may not be the bottom of the page) a similar response is necessary to allow the continuation prompt to be printed.

Phase III, Graphics

When the plot is complete, a faint set of crosshairs appears on the screen. They will not show up on a screen hard copy but must be cleared for the user to continue with the program. This may be done by pressing any key (A-Z) and pushing "RETURN."

Appendix A

Sample Run (ANSI FORTRAN Version)

```
ENTER TURBINE DIAMETER(FT.)
? 55
ENT: HEIGHT-TO-DIAMETER RATIO
? 1.5
ENT: NUMBER OF BLADES
? 2
ENT: CHORD LENGTH (IN)
? 24
ENT: TURBINE GROUND CLEARANCE (FT)
? 15
ENT: TURBINE RPM
? 51.5
ENT: SYSTEM RATED POWER (KW)
? 120
ENT: AIR DENSITY (LBM/FT-3)
? .076
```

```
ENTER TURBINE DIAMETER(FT.)
? 55
ENT: HEIGHT-TO-DIAMETER RATIO
? 1.5
ENT: NUMBER OF BLADES
? 2
ENT: CHORD LENGTH (IN)
? 24
ENT: TURBINE GROUND CLEARANCE (FT)
? 15
ENT: TURBINE RPM
? 51.5
ENT: SYSTEM RATED POWER (KW)
? 120
ENT: AIR DENSITY (LBM/FT-3)
? .076

RHO=   .0760
MEU=  .12050E-04
REYNOLD'S NO. = .18708E+07
SOLIDITY =        .1359
CPK    =    .00799
CPMAX  =    .38645
K      =   3.01
M      =   5.72
R      =  11.46
```

```
ENTER TURBINE DIAMETER(FT.)
? 55
ENT: HEIGHT-TO-DIAMETER RATIO
? 1.5
ENT: NUMBER OF BLADES
? 2
ENT: CHORD LENGTH (IN)
? 24
ENT: TURBINE GROUND CLEARANCE (FT)
? 15
ENT: TURBINE RPM
? 51.5
ENT: SYSTEM RATED POWER (KW)
? 120
ENT: AIR DENSITY (LBM/FT-3)
? .076

RHO=  .0760
MEU= .12050E-04
REYNOLD'S NO. = .18708E+07
SOLIDITY =        .1359
CPK    =   .00799
CPMAX =   .38645
K      =  3.01
M      =  5.72
R      = 11.46
```

VREF	VTUR	PTUR	PMECH	PSYS	TSR	CP	CPK	CPM	CPS
8.0	8.9	.1	-5.3	-10.5	11.4	.0130	.0000	-.0003	-.0007
9.0	10.0	2.5	-3.0	-8.1	10.1	.1614	.0002	-.0002	-.0005
10.0	11.1	5.3	-.1	-5.2	9.1	.2532	.0003	-.0000	-.0003
11.0	12.2	8.7	3.3	-1.9	8.3	.3105	.0006	.0002	-.0001
12.0	13.4	12.6	7.2	2.0	7.6	.3460	.0008	.0005	.0001

?

VREF	VTUR	PTUR	PMECH	PSYS	TSR	CP	CPK	CPM	CPS
13.0	14.5	17.0	11.6	6.4	7.0	.3674	.0011	.0007	.0004
14.0	15.6	21.9	16.5	11.3	6.5	.3794	.0014	.0010	.0007
15.0	16.7	27.3	21.9	16.7	6.1	.3851	.0017	.0014	.0011
16.0	17.8	33.3	27.9	22.6	5.7	.3864	.0021	.0018	.0014
17.0	18.9	39.6	34.2	28.8	5.3	.3833	.0025	.0022	.0018
18.0	20.0	46.2	40.7	35.2	5.0	.3762	.0029	.0026	.0022
19.0	21.1	52.9	47.4	41.7	4.8	.3664	.0033	.0030	.0026
20.0	22.3	59.7	54.3	48.3	4.5	.3548	.0038	.0034	.0031
21.0	23.4	66.6	61.2	55.0	4.3	.3420	.0042	.0039	.0035
22.0	24.5	73.6	68.2	61.7	4.1	.3285	.0047	.0043	.0039
23.0	25.6	80.6	75.1	68.3	4.0	.3146	.0051	.0048	.0043
24.0	26.7	87.4	82.0	74.9	3.8	.3006	.0055	.0052	.0047
25.0	27.8	94.2	88.8	81.3	3.6	.2866	.0060	.0056	.0051
26.0	28.9	100.9	95.4	87.6	3.5	.2728	.0064	.0060	.0055
27.0	30.0	107.3	101.9	93.6	3.4	.2591	.0068	.0065	.0059
28.0	31.2	113.5	108.1	99.4	3.2	.2458	.0072	.0068	.0063
29.0	32.3	119.4	114.0	104.9	3.1	.2327	.0076	.0072	.0066
30.0	33.4	125.0	119.6	110.1	3.0	.2200	.0079	.0076	.0070
31.0	34.5	124.5	119.1	109.7	2.9	.1986	.0079	.0075	.0069
32.0	35.6	122.5	117.1	107.8	2.8	.1777	.0078	.0074	.0068
33.0	36.7	120.7	115.2	106.1	2.8	.1596	.0076	.0073	.0067
34.0	37.8	118.9	113.5	104.4	2.7	.1438	.0075	.0072	.0066
35.0	38.9	117.2	111.7	102.8	2.6	.1299	.0074	.0071	.0065
36.0	40.1	115.5	110.1	101.3	2.5	.1177	.0073	.0070	.0064
37.0	41.2	114.0	108.5	99.8	2.5	.1069	.0072	.0069	.0063
38.0	42.3	112.5	107.0	98.4	2.4	.0974	.0071	.0068	.0062
39.0	43.4	111.0	105.6	97.1	2.3	.0889	.0070	.0067	.0061
40.0	44.5	109.6	104.2	95.8	2.3	.0814	.0069	.0066	.0061
41.0	45.6	108.3	102.8	94.5	2.2	.0747	.0069	.0065	.0060
42.0	46.7	107.0	101.5	93.3	2.2	.0686	.0068	.0064	.0059
43.0	47.8	105.7	100.3	92.1	2.1	.0632	.0067	.0064	.0058

?

VREF	VTUR	PTUR	PMECH	PSYS	TSR	CP	CPK	CPM	CPS
44.0	49.0	104.5	99.1	91.0	2.1	.0583	.0066	.0063	.0058
45.0	50.1	103.3	97.9	89.9	2.0	.0539	.0065	.0062	.0057
46.0	51.2	102.2	96.8	88.8	2.0	.0499	.0065	.0061	.0056
47.0	52.3	101.1	95.7	87.8	1.9	.0463	.0064	.0061	.0056
48.0	53.4	100.1	94.6	86.8	1.9	.0430	.0063	.0060	.0055
49.0	54.5	99.0	93.6	85.8	1.9	.0400	.0063	.0059	.0054
50.0	55.6	98.0	92.6	84.9	1.8	.0373	.0062	.0059	.0054
51.0	56.8	97.1	91.6	84.0	1.8	.0348	.0061	.0058	.0053
52.0	57.9	96.1	90.7	83.1	1.7	.0325	.0061	.0057	.0053
53.0	59.0	95.2	89.8	82.2	1.7	.0304	.0060	.0057	.0052
54.0	60.1	94.3	88.9	81.4	1.7	.0285	.0060	.0056	.0052
55.0	61.2	93.5	88.0	80.6	1.7	.0267	.0059	.0056	.0051
56.0	62.3	92.6	87.2	79.8	1.6	.0251	.0059	.0055	.0051
57.0	63.4	91.8	86.4	79.0	1.6	.0236	.0058	.0055	.0050
58.0	64.5	91.0	85.6	78.3	1.6	.0222	.0058	.0054	.0050
59.0	65.7	90.3	84.8	77.5	1.5	.0209	.0057	.0054	.0049
60.0	66.8	89.5	84.1	76.8	1.5	.0197	.0057	.0053	.0049

?

VREF	VTUR	PTUR	PMECH	PSYS	TSR	CP	CPK	CPM	CPS
44.0	49.0	104.5	99.1	91.0	2.1	.0583	.0066	.0063	.0058
45.0	50.1	103.3	97.9	89.9	2.0	.0539	.0065	.0062	.0057
46.0	51.2	102.2	96.8	88.8	2.0	.0499	.0065	.0061	.0056
47.0	52.3	101.1	95.7	87.8	1.9	.0463	.0064	.0061	.0056
48.0	53.4	100.1	94.6	86.8	1.9	.0430	.0063	.0060	.0055
49.0	54.5	99.0	93.6	85.8	1.9	.0400	.0063	.0059	.0054
50.0	55.6	98.0	92.6	84.9	1.8	.0373	.0062	.0059	.0054
51.0	56.8	97.1	91.6	84.0	1.8	.0348	.0061	.0058	.0053
52.0	57.9	96.1	90.7	83.1	1.7	.0325	.0061	.0057	.0053
53.0	59.0	95.2	89.8	82.2	1.7	.0304	.0060	.0057	.0052
54.0	60.1	94.3	88.9	81.4	1.7	.0285	.0060	.0056	.0052
55.0	61.2	93.5	88.0	80.6	1.7	.0267	.0059	.0056	.0051
56.0	62.3	92.6	87.2	79.8	1.6	.0251	.0059	.0055	.0051
57.0	63.4	91.8	86.4	79.0	1.6	.0236	.0058	.0055	.0050
58.0	64.5	91.0	85.6	78.3	1.6	.0222	.0058	.0054	.0050
59.0	65.7	90.3	84.8	77.5	1.5	.0209	.0057	.0054	.0049
60.0	66.8	89.5	84.1	76.8	1.5	.0197	.0057	.0053	.0049

```
?
ENT: CONTINUATION MODE
? -1
```

VREF	VTUR	ADVR	CP	CPM	CPS	QTUR	QMECH	QSYS
8.0	8.9	.0880	.0130	-.4908	-.9714	12.	-439.	-868.
9.0	10.0	.0990	.1614	-.1925	-.5290	205.	-245.	-673.
10.0	11.1	.1100	.2532	-.0048	-.2495	442.	-8.	-435.
11.0	12.2	.1211	.3105	.1167	-.0668	721.	271.	-155.
12.0	13.4	.1321	.3460	.1967	.0554	1044.	593.	167.
13.0	14.5	.1431	.3674	.2500	.1385	1409.	959.	531.
14.0	15.6	.1541	.3794	.2854	.1956	1817.	1367.	937.
15.0	16.7	.1651	.3851	.3086	.2349	2269.	1818.	1384.
16.0	17.8	.1761	.3864	.3234	.2617	2763.	2313.	1871.
17.0	18.9	.1871	.3833	.3308	.2782	3287.	2837.	2386.
18.0	20.0	.1981	.3762	.3319	.2865	3830.	3379.	2917.
19.0	21.1	.2091	.3664	.3288	.2889	4387.	3936.	3459.
20.0	22.3	.2201	.3548	.3225	.2871	4954.	4504.	4009.
21.0	23.4	.2311	.3420	.3141	.2822	5529.	5079.	4563.
22.0	24.5	.2421	.3285	.3043	.2753	6106.	5656.	5117.
23.0	25.6	.2531	.3146	.2934	.2669	6683.	6233.	5668.
24.0	26.7	.2641	.3006	.2820	.2574	7255.	6804.	6212.
25.0	27.8	.2751	.2866	.2701	.2473	7818.	7368.	6746.
26.0	28.9	.2861	.2728	.2581	.2368	8369.	7918.	7265.
27.0	30.0	.2971	.2591	.2460	.2261	8903.	8453.	7767.
28.0	31.2	.3081	.2458	.2340	.2153	9418.	8968.	8249.
29.0	32.3	.3191	.2327	.2222	.2045	9908.	9458.	8706.
30.0	33.4	.3301	.2200	.2105	.1938	10371.	9921.	9136.
31.0	34.5	.3411	.1986	.1900	.1749	10329.	9879.	9097.
32.0	35.6	.3521	.1777	.1699	.1564	10167.	9716.	8946.
33.0	36.7	.3632	.1596	.1524	.1403	10012.	9561.	8802.
34.0	37.8	.3742	.1438	.1372	.1263	9863.	9413.	8664.
35.0	38.9	.3852	.1299	.1239	.1140	9721.	9271.	8532.
36.0	40.1	.3962	.1177	.1122	.1032	9585.	9135.	8405.
37.0	41.2	.4072	.1069	.1018	.0937	9455.	9005.	8283.
38.0	42.3	.4182	.0974	.0927	.0853	9330.	8879.	8166.

?

VREF	VTUR	ADVR	CP	CPM	CPS	QTUR	QMECH	QSYS
39.0	43.4	.4292	.0889	.0846	.0778	9209.	8759.	8054.
40.0	44.5	.4402	.0814	.0774	.0711	9093.	8643.	7945.
41.0	45.6	.4512	.0747	.0709	.0652	8982.	8532.	7841.
42.0	46.7	.4622	.0686	.0651	.0598	8874.	8424.	7740.
43.0	47.8	.4732	.0632	.0599	.0551	8771.	8320.	7643.
44.0	49.0	.4842	.0583	.0553	.0508	8670.	8220.	7549.
45.0	50.1	.4952	.0539	.0511	.0469	8573.	8123.	7458.
46.0	51.2	.5062	.0499	.0473	.0434	8480.	8029.	7370.
47.0	52.3	.5172	.0463	.0438	.0402	8389.	7939.	7284.
48.0	53.4	.5282	.0430	.0407	.0373	8301.	7851.	7202.
49.0	54.5	.5392	.0400	.0378	.0347	8216.	7766.	7121.
50.0	55.6	.5502	.0373	.0352	.0323	8133.	7683.	7044.
51.0	56.8	.5612	.0348	.0328	.0301	8053.	7603.	6968.
52.0	57.9	.5722	.0325	.0307	.0281	7975.	7525.	6894.
53.0	59.0	.5832	.0304	.0287	.0263	7900.	7450.	6823.
54.0	60.1	.5942	.0285	.0268	.0246	7826.	7376.	6754.
55.0	61.2	.6053	.0267	.0252	.0230	7755.	7305.	6686.
56.0	62.3	.6163	.0251	.0236	.0216	7685.	7235.	6620.
57.0	63.4	.6273	.0236	.0222	.0203	7618.	7167.	6556.
58.0	64.5	.6383	.0222	.0208	.0191	7552.	7101.	6494.
59.0	65.7	.6493	.0209	.0196	.0179	7487.	7037.	6433.
60.0	66.8	.6603	.0197	.0185	.0169	7425.	6974.	6374.

?

VREF	VTUR	ADVR	CP	CPM	CPS	QTUR	QMECH	QSYS
39.0	43.4	.4292	.0889	.0846	.0778	9209.	8759.	8054.
40.0	44.5	.4402	.0814	.0774	.0711	9093.	8643.	7945.
41.0	45.6	.4512	.0747	.0709	.0652	8982.	8532.	7841.
42.0	46.7	.4622	.0686	.0651	.0598	8874.	8424.	7740.
43.0	47.8	.4732	.0632	.0599	.0551	8771.	8320.	7643.
44.0	49.0	.4842	.0583	.0553	.0508	8670.	8220.	7549.
45.0	50.1	.4952	.0539	.0511	.0469	8573.	8123.	7458.
46.0	51.2	.5062	.0499	.0473	.0434	8480.	8029.	7370.
47.0	52.3	.5172	.0463	.0438	.0402	8389.	7939.	7284.
48.0	53.4	.5282	.0430	.0407	.0373	8301.	7851.	7202.
49.0	54.5	.5392	.0400	.0378	.0347	8216.	7766.	7121.
50.0	55.6	.5502	.0373	.0352	.0323	8133.	7683.	7044.
51.0	56.8	.5612	.0348	.0328	.0301	8053.	7603.	6968.
52.0	57.9	.5722	.0325	.0307	.0281	7975.	7525.	6894.
53.0	59.0	.5832	.0304	.0287	.0263	7900.	7450.	6823.
54.0	60.1	.5942	.0285	.0268	.0246	7826.	7376.	6754.
55.0	61.2	.6053	.0267	.0252	.0230	7755.	7305.	6686.
56.0	62.3	.6163	.0251	.0236	.0216	7685.	7235.	6620.
57.0	63.4	.6273	.0236	.0222	.0203	7618.	7167.	6556.
58.0	64.5	.6383	.0222	.0208	.0191	7552.	7101.	6494.
59.0	65.7	.6493	.0209	.0196	.0179	7487.	7037.	6433.
60.0	66.8	.6603	.0197	.0185	.0169	7425.	6974.	6374.

```
?
ENT: CONTINUATION MODE
? 5
ENT: TURBINE GROUND CLEARANCE (FT)
? 10
ENT: CONTINUATION MODE
? 9
```

RHO= .0760
MEU= 12050E-04
REYNOLD'S NO. = .18708E+07
SOLIDITY = .1359
CPK = .00799
CPMAX = .38645
K = 3.01
M = 5.72
R = 11.46

VREF	VTUR	PTUR	PMECH	PSYS	TSR	CP	CPK	CPM	CPS
9.0	9.9	2.1	-3.3	-8.5	10.3	.1445	.0001	-.0002	-.0005
10.0	11.0	4.8	-.6	-5.7	9.2	.2415	.0003	-.0000	-.0004
11.0	12.0	8.1	2.6	-2.5	8.4	.3024	.0005	.0002	-.0002
12.0	13.1	11.8	6.4	1.2	7.7	.3406	.0007	.0004	.0001
13.0	14.2	16.0	10.6	5.5	7.1	.3639	.0010	.0007	.0003
14.0	15.3	20.8	15.4	10.2	6.6	.3774	.0013	.0010	.0006
15.0	16.4	26.0	20.6	15.4	6.2	.3842	.0016	.0013	.0010
16.0	17.5	31.8	26.3	21.0	5.8	.3864	.0020	.0017	.0013
17.0	18.6	37.9	32.5	27.1	5.4	.3846	.0024	.0021	.0017
18.0	19.7	44.3	38.9	33.3	5.1	.3785	.0028	.0025	.0021
19.0	20.8	50.9	45.4	39.7	4.9	.3695	.0032	.0029	.0025
20.0	21.9	57.6	52.1	46.2	4.6	.3586	.0036	.0033	.0029
21.0	23.0	64.4	58.9	52.8	4.4	.3463	.0041	.0037	.0033
22.0	24.1	71.2	65.8	59.4	4.2	.3332	.0045	.0042	.0038
23.0	25.2	78.0	72.6	65.9	4.0	.3197	.0049	.0046	.0042
24.0	26.3	84.9	79.4	72.4	3.8	.3059	.0054	.0050	.0046
25.0	27.4	91.6	86.2	78.8	3.7	.2921	.0058	.0055	.0050
26.0	28.5	98.2	92.8	85.0	3.6	.2784	.0062	.0059	.0054
27.0	29.6	104.6	99.2	91.1	3.4	.2649	.0066	.0063	.0058
28.0	30.7	110.8	105.4	96.9	3.3	.2516	.0070	.0067	.0061
29.0	31.8	116.8	111.4	102.5	3.2	.2386	.0074	.0071	.0065
30.0	32.9	122.4	117.0	107.7	3.1	.2260	.0078	.0074	.0068

?

VREF	VTUR	PTUR	PMECH	PSYS	TSR	CP	CPK	CPM	CPS
31.0	34.0	125.5	120.1	110.6	3.0	.2099	.0079	.0076	.0070
32.0	35.0	123.5	118.1	108.7	2.9	.1879	.0078	.0075	.0069
33.0	36.1	121.6	116.2	107.0	2.8	.1687	.0077	.0074	.0068
34.0	37.2	119.8	114.4	105.3	2.7	.1519	.0076	.0072	.0067
35.0	38.3	118.1	112.7	103.7	2.6	.1373	.0075	.0071	.0066
36.0	39.4	116.5	111.0	102.2	2.6	.1244	.0074	.0070	.0065
37.0	40.5	114.9	109.4	100.7	2.5	.1130	.0073	.0069	.0064
38.0	41.6	113.4	107.9	99.3	2.4	.1029	.0072	.0068	.0063
39.0	42.7	111.9	106.5	97.9	2.4	.0940	.0071	.0067	.0062
40.0	43.8	110.5	105.1	96.6	2.3	.0860	.0070	.0067	.0061
41.0	44.9	109.1	103.7	95.3	2.3	.0789	.0069	.0066	.0060
42.0	46.0	107.8	102.4	94.1	2.2	.0725	.0068	.0065	.0060
43.0	47.1	106.6	101.1	92.9	2.1	.0668	.0067	.0064	.0059
44.0	48.2	105.3	99.9	91.8	2.1	.0616	.0067	.0063	.0058
45.0	49.3	104.2	98.7	90.7	2.1	.0570	.0066	.0063	.0057
46.0	50.4	103.0	97.6	89.6	2.0	.0527	.0065	.0062	.0057
47.0	51.5	101.9	96.5	88.6	2.0	.0489	.0065	.0061	.0056
48.0	52.6	100.9	95.4	87.6	1.9	.0454	.0064	.0060	.0055
49.0	53.7	99.8	94.4	86.6	1.9	.0423	.0063	.0060	.0055
50.0	54.8	98.8	93.4	85.6	1.8	.0394	.0063	.0059	.0054
51.0	55.9	97.8	92.4	84.7	1.8	.0368	.0062	.0059	.0054
52.0	57.0	96.9	91.5	83.8	1.8	.0343	.0061	.0058	.0053
53.0	58.1	96.0	90.6	83.0	1.7	.0321	.0061	.0057	.0053
54.0	59.1	95.1	89.7	82.1	1.7	.0301	.0060	.0057	.0052
55.0	60.2	94.2	88.8	81.3	1.7	.0282	.0060	.0056	.0051
56.0	61.3	93.4	87.9	80.5	1.6	.0265	.0059	.0056	.0051
57.0	62.4	92.6	87.1	79.7	1.6	.0249	.0059	.0055	.0050
58.0	63.5	91.7	86.3	79.0	1.6	.0234	.0058	.0055	.0050
59.0	64.6	91.0	85.5	78.2	1.6	.0221	.0058	.0054	.0050
60.0	65.7	90.2	84.8	77.5	1.5	.0208	.0057	.0054	.0049

?

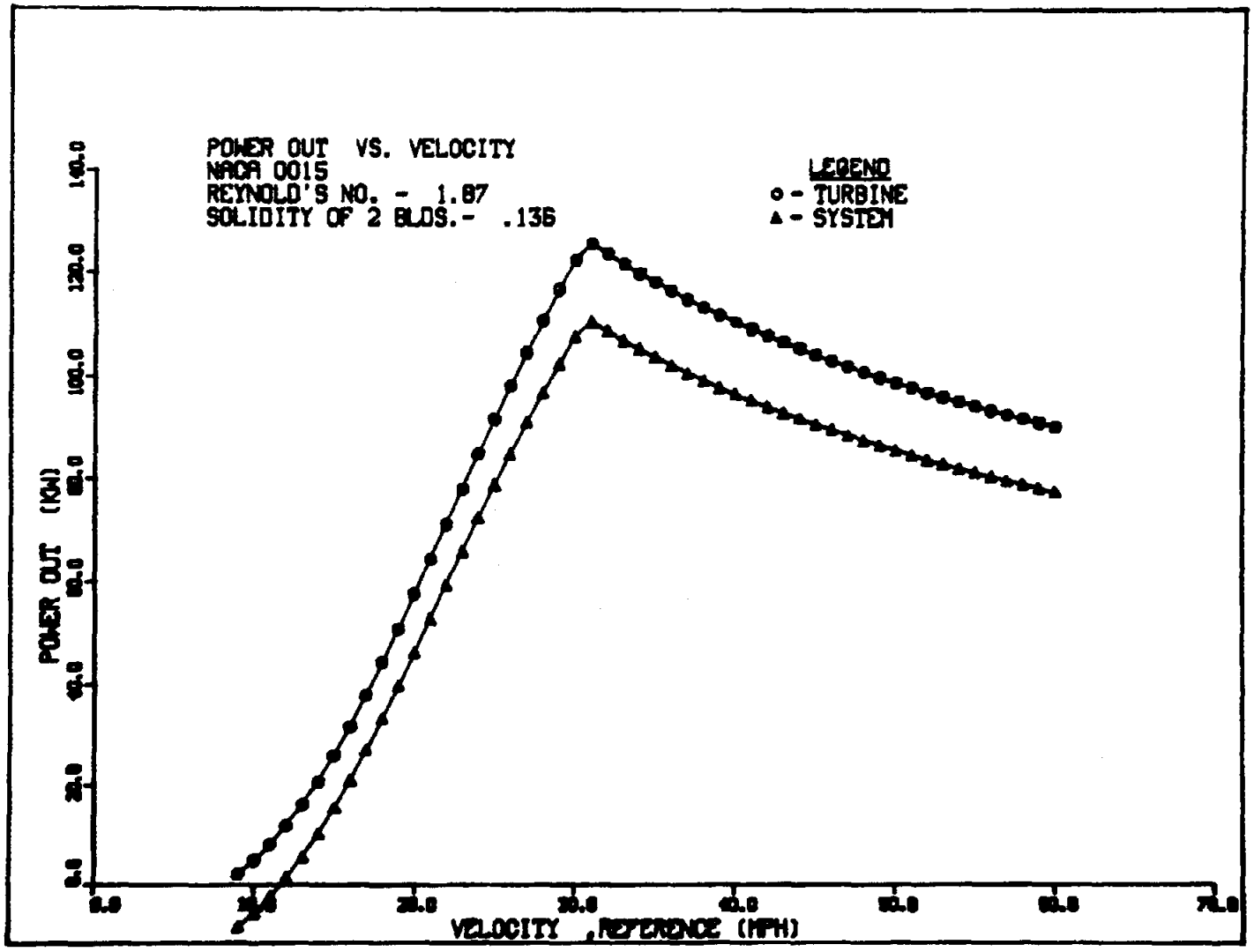
VREF	VTUR	PTUR	PMECH	PSYS	TSR	CP	CPK	CPM	CPS
31.0	34.0	125.5	120.1	110.6	3.0	.2099	.0079	.0076	.0070
32.0	35.0	123.5	118.1	108.7	2.9	.1879	.0078	.0075	.0069
33.0	36.1	121.6	116.2	107.0	2.8	.1687	.0077	.0074	.0068
34.0	37.2	119.8	114.4	105.3	2.7	.1519	.0076	.0072	.0067
35.0	38.3	118.1	112.7	103.7	2.6	.1373	.0075	.0071	.0066
36.0	39.4	116.5	111.0	102.2	2.6	.1244	.0074	.0070	.0065
37.0	40.5	114.9	109.4	100.7	2.5	.1130	.0073	.0069	.0064
38.0	41.6	113.4	107.9	99.3	2.4	.1029	.0072	.0068	.0063
39.0	42.7	111.9	106.5	97.9	2.4	.0940	.0071	.0067	.0062
40.0	43.8	110.5	105.1	96.6	2.3	.0860	.0070	.0067	.0061
41.0	44.9	109.1	103.7	95.3	2.3	.0789	.0069	.0066	.0060
42.0	46.0	107.8	102.4	94.1	2.2	.0725	.0068	.0065	.0060
43.0	47.1	106.6	101.1	92.9	2.1	.0668	.0067	.0064	.0059
44.0	48.2	105.3	99.9	91.8	2.1	.0616	.0067	.0063	.0058
45.0	49.3	104.2	98.7	90.7	2.1	.0570	.0066	.0063	.0057
46.0	50.4	103.0	97.6	89.6	2.0	.0527	.0065	.0062	.0057
47.0	51.5	101.9	96.5	88.6	2.0	.0489	.0065	.0061	.0056
48.0	52.6	100.9	95.4	87.6	1.9	.0454	.0064	.0060	.0055
49.0	53.7	99.8	94.4	86.6	1.9	.0423	.0063	.0060	.0055
50.0	54.8	98.8	93.4	85.6	1.8	.0394	.0063	.0059	.0054
51.0	55.9	97.8	92.4	84.7	1.8	.0368	.0062	.0059	.0054
52.0	57.0	96.9	91.5	83.8	1.8	.0343	.0061	.0058	.0053
53.0	58.1	96.0	90.6	83.0	1.7	.0321	.0061	.0057	.0053
54.0	59.1	95.1	89.7	82.1	1.7	.0301	.0060	.0057	.0052
55.0	60.2	94.2	88.8	81.3	1.7	.0282	.0060	.0056	.0051
56.0	61.3	93.4	87.9	80.5	1.6	.0265	.0059	.0056	.0051
57.0	62.4	92.6	87.1	79.7	1.6	.0249	.0059	.0055	.0050
58.0	63.5	91.7	86.3	79.0	1.6	.0234	.0058	.0055	.0050
59.0	64.6	91.0	85.5	78.2	1.6	.0221	.0058	.0054	.0050
60.0	65.7	90.2	84.8	77.5	1.5	.0208	.0057	.0054	.0049

```
?
ENT: CONTINUATION MODE
? -2
```

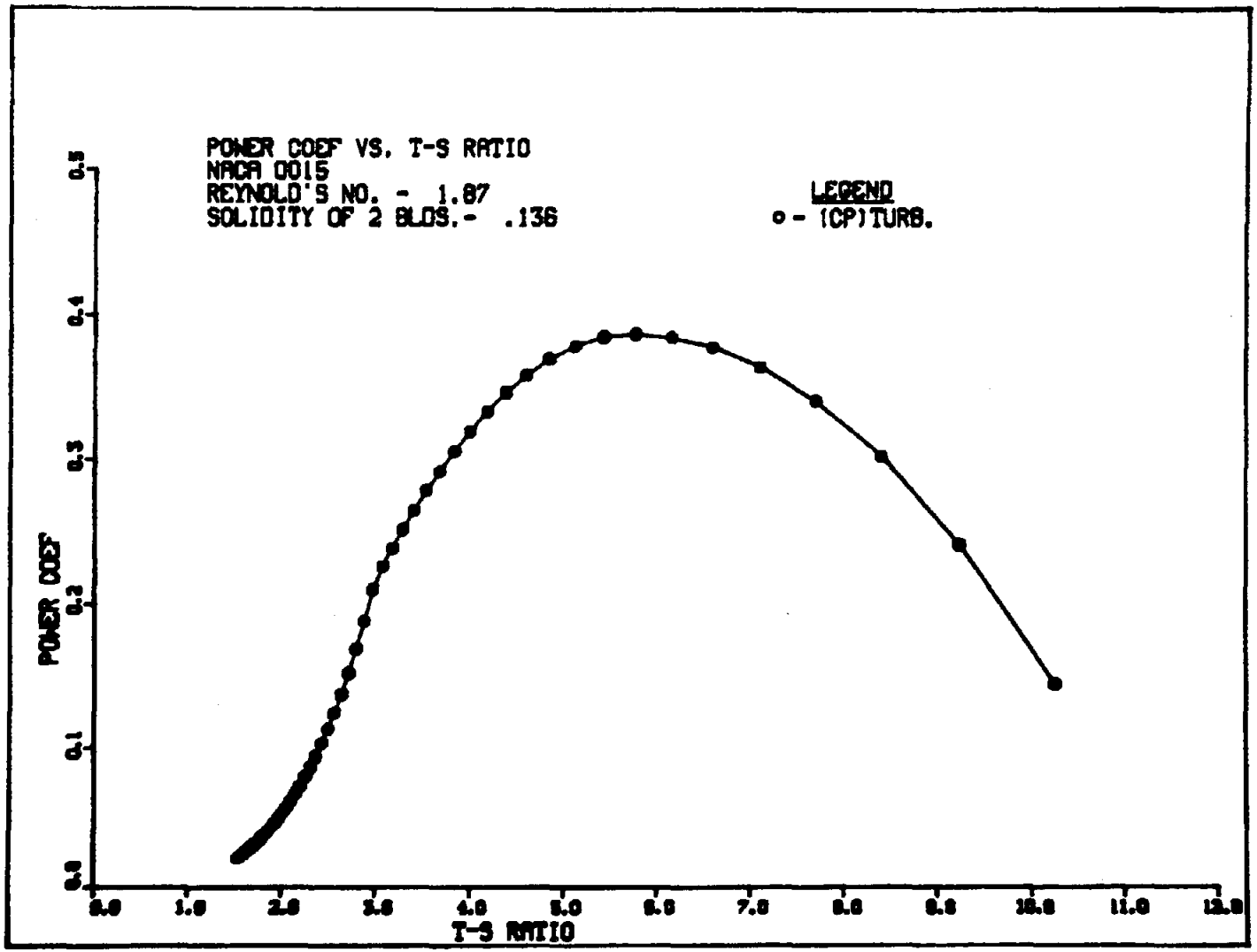
Appendix B

Sample Run (Graphics Option)

```
ENT: CONTINUATION MODE
? 10

ENT: X AXIS VBL. CODE
? 1
ENT: NO. OF CURVES
? 2
ENT: LIST OF Y AXIS VBL. CODES
? 5,7

ENT: MIN,MAX,INCR OF X VALUES
? 0,70,10
MIN,MAX,INCR OF Y VALUES
? 0,140,20
```

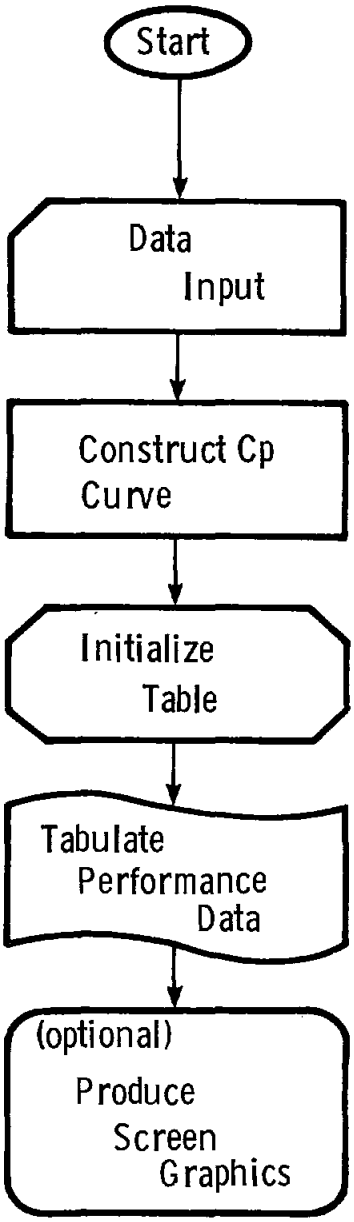

POWER OUT VS. VELOCITY
NACA 0015
REYNOLD'S NO. - 1.87
SOLIDITY OF 2 BLDS.- .136
LEGEND
o - TURBINE
▲ - SYSTEM
POWER OUT (KW)
VELOCITY ,REFERENCE (MPH)

```
ENT: CONTINUATION MODE
? 10

ENT: X AXIS VBL. CODE
? 3
ENT: NO. OF CURVES
? 1
ENT: LIST OF Y AXIS VBL. CODES
? 8

ENT: MIN,MAX,INCR OF X VALUES
? 0,12,1
MIN,MAX,INCR OF Y VALUES
? 0,.5,.1
```


POWER COEF VS. T-S RATIO
NACA 0015
REYNOLD'S NO. - 1.87
SOLIDITY OF 2 BLDS.- .136
LEGEND
o - (CP)TURB.
POWER COEF
0.0
0.1
0.2
0.3
0.4
0.5
0.0
1.0
2.0
3.0
4.0
5.0
6.0
7.0
8.0
9.0
10.0
11.0
12.0
T-S RATIO

APPENDIX C

Program Flow Diagram



Program PAREP - Interactive Data Input

Subroutine CPPARM

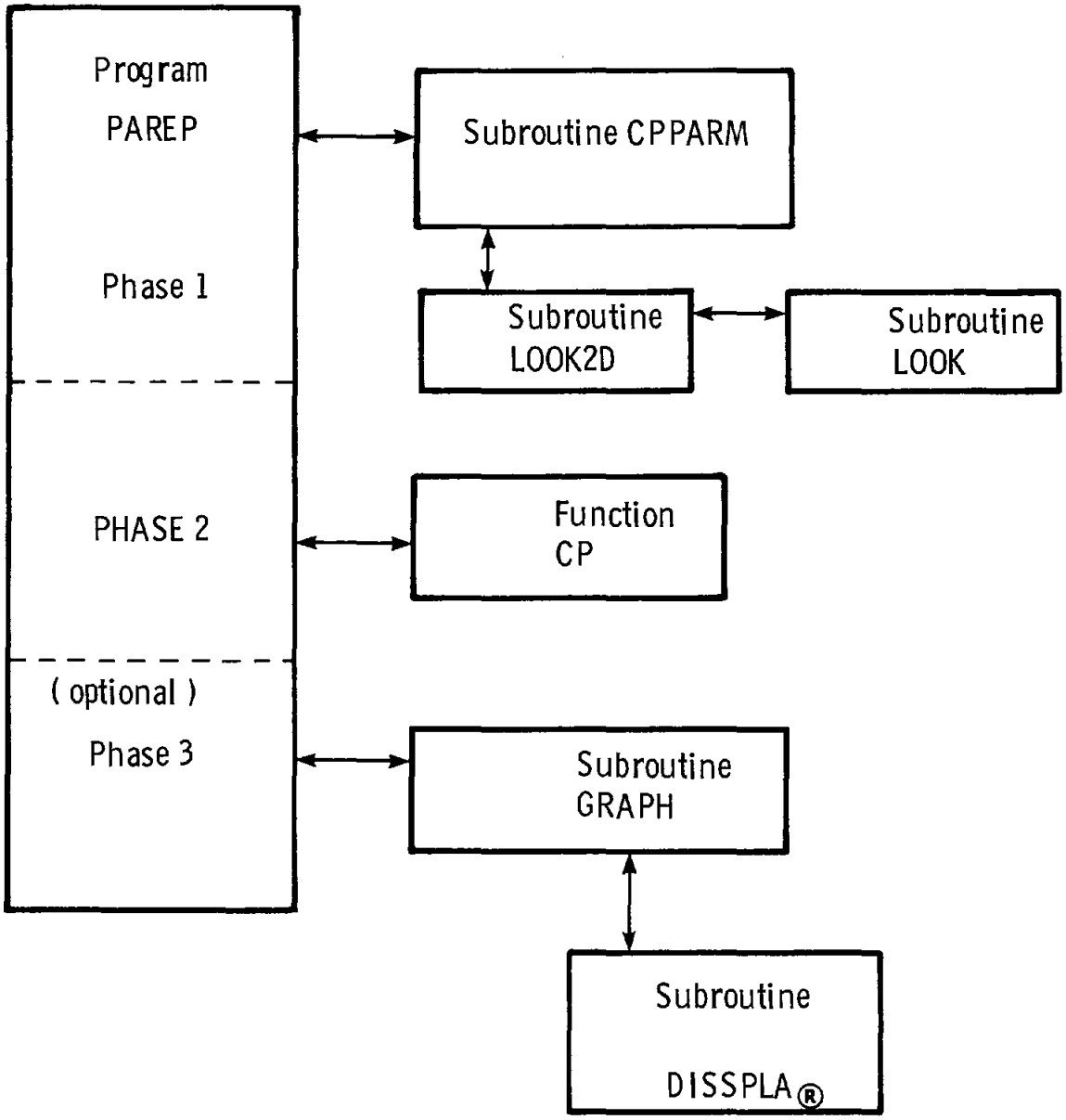
Program PAREP (TVSV)

Subroutine GRAPH Using

DISSPLA®

APPENDIX D

Program Module Diagram



Appendix E

Module Descriptions

Program PAREP

PAREP functions as the main calling program. It contains all input and output sections as well as the aerodynamic performance computation section.

Primary calls are to subroutine CPPARM to construct the C_p curve, function CP to read the C_p curve, and optionally, subroutine GRAPH to produce screen graphics.

Subroutine CPPARM

CPPARM establishes the 3x3 matrix and calls LOOK2D to calculate the A and B values by 2-D interpolation.

Subroutine LOOK2D

Sandia math library routine LOOK2D performs linear interpolation on a two-dimensional matrix and incorporates subroutine LOOK for 1-D interpolation computations.

Function CP

CP, according to the tip speed ratio (X), computes a value of C_p based on the curve parameters provided by CPPARM.

Subroutine GRAPH

GRAPH sets up plot labeling, makes a run and "remembers" data to be plotted. Actual screen graphics are produced by calls to the proprietary graphics package DISSPLA®.[6]

Function POT

Calculates high speed shaft power output from transmission as a function of mechanical input from low speed shaft.

Function POG

Calculates generator electrical power output as a function of mechanical input power.

Appendix F

Code Listing (NonANSI Code Noted)

```
      PROGRAM PAREP(INPUT=101B,OUTPUT=101B,TAPE1=INPUT,TAPE66=INPUT,
     *TAPE77=OUTPUT)
      COMMON/ENG/A,PRATED,RW,CON,RLOSSG,RLOSST,S,GR
      COMMON/CPTSR/XLK,CPK,XLM,CPMAX,XN,RLRLM
      COMMON /N/ NACA
C
C      STATEMENTS LISTED AS COMMENTS BEARING  C>> IN THE
C
C      FIRST THREE COLUMNS ARE USED IN GRAPHICS PHASE.
C
C      STATEMENTS WITH  C.. MUST BE INCLUDED IF GRAPHICS
C
C      ARE NOT.
C
C>>   CALL TCS(120)
C>>   KKKK=1HG
C..   KKKK=1HT
  776 IPRT=0
      NACA=15
  777 CONTINUE
      IF(IPRT.NE.0.AND.IPRT.NE.1)GOTO 701
C>>   IF(IPRT.EQ.0.AND.KKKK.EQ.1HG)CALL ERASE
      WRITE(77,7)
    7 FORMAT(25X/*ENTER TURBINE DIAMETER(FT.)*)
      READ(66,*)DIA
      CHORD=CHORD/12.
  701 IF(IPRT.NE.0.AND.IPRT.NE.2)GOTO 702
      WRITE(77,51)
   51 FORMAT(*ENT  HEIGHT-TO-DIAMETER RATIO*)
      READ(66,*)HOD
  702 IF(IPRT.NE.0.AND.IPRT.NE.3)GOTO 703
      WRITE(77,52)
   52 FORMAT(*ENT  NUMBER OF BLADES*)
      READ(66,*)NBLADE
  703 IF(IPRT.NE.0.AND.IPRT.NE.4)GOTO 704
      WRITE(77,53)
   53 FORMAT(*ENT  CHORD LENGTH (IN)*)
      READ(66,*)CHORD
      CHORD=CHORD/12.
  704 CONTINUE
      R=DIA/2.
      A=8.*R*R*HOD/3.
      HREF=30.
      IF(IPRT.NE.0.AND.IPRT.NE.5)GOTO 705
      WRITE(77,97)
   97 FORMAT(*ENT  TURBINE GROUND CLEARANCE (FT)*)
      READ(66,*)HCLR
  705 CONTINUE
       FACT=((HCLR+R*HOD)/HREF)**.17
      IF(IPRT.NE.0.AND.IPRT.NE.6)GOTO 706
      WRITE(77,1)
    1 FORMAT(*ENT  TURBINE RPM*)
      READ(66,*)S
  706 CONTINUE
```

```
      GR=1800./S
      RPCT=.04
      IF(GR.GT.36.)RPCT=.06
      IF(IPRT.NE.0.AND.IPRT.NE.7)GOTO 707
      WRITE(77,61)
   61 FORMAT(*ENT  SYSTEM RATED POWER (KW)*)
      READ(66,*)PRATED
  707 CONTINUE
      RPCG=.05*(1000./PRATED)**.215
      PIR=PRATED/(1.-RPCT-RPCG+RPCG*RPCT)
      PTR=PIR-PIR*RPCT
      RLOSSG=PTR*RPCG
      RLOSST=PIR*RPCT
      PI=4.*ATAN(1.)
      W = S*PI/30.
      RW=R*W
      XMEU=1.205E-5
      IF(IPRT.NE.0.AND.IPRT.NE.8)GOTO 708
      WRITE(77,107)
  107 FORMAT(*ENT  AIR DENSITY (LBM/FT-3)*)
      READ(66,*)RHO
  708 CONTINUE
      LINE=28
      IF(IPRT.EQ.9)LINE=11
      IF(IPRT.GT.0.AND.IPRT.NE.9)GOTO 8003
C>>   IF(IPRT.EQ.9.AND.KKKK.EQ.1HG)CALL ERASE
      IF(IPRT.EQ.9)IPRT=0
      RE=RHO*RW*CHORD/XMEU
      IF(RE.GT.3.E6)RE=3.E6
      EFF=SQRT(4.+HOD**2)
      BL=R*(EFF+0.5*HOD**2*ALOG((2.+EFF)/HOD))
      SOL=NBLADE*BL*CHORD*3./(8.*(R)**2*HOD)
      ARDEN=RHO
      CALL CPPARM(SOL,HOD,RE,CPK,XLK,CPMAX,XLM,XLR)
      IF(IPRT.GE.0)WRITE(77,9996)RHO,XMEU,RE,SOL,CPK,CPMAX,XLK,XLM,XLR
 9996 FORMAT(70X/*RHO= *,F6.4/*MEU= *,E10.5/*REYNOLD↑S NO. = *,E10.5/
     **SOLIDITY =       *,F6.4/*CPK    = *,F8.5/*CPMAX = *,F8.5/
     **K      = *,F5.2/*M      = *,F5.2/*R      = *,F5.2)
      RLRLM=XLR/XLM
      XN=3.5
 8007 VREF=1.0
C>>   IF(IPRT.EQ.-1.AND.KKKK.EQ.1HG)CALL ERASE
      IF(IPRT.EQ.-1)LINE=2
 11   IF(IPRT.EQ.0)WRITE(77,27)
   27 FORMAT(25X/3X,*VREF*,3X,*VTUR*,3X,*PTUR*,3X,*PMECH*,2X,
     1 *PSYS*,3X,*TSR*,4X,*CP      CPK      CPM      CPS*)
      IF(IPRT.EQ.-1)WRITE(77,28)
 28   FORMAT(70X/3X,*VREF*,3X,*VTUR*,3X,*ADVR*,4X,*CP       CPM*,
     :4X,*CPS      QTUR      QMECH      QSYS*)
   10 VO=VREF*FACT*88./60.
      TSR=RW/VO
      TORQ=CP(TSR)*A*ARDEN*(VO**3)/(32.2*2.*W)
      CPKM=CP(TSR)/(TSR**3)
      VO=VO*60./88.
      TCOEF=R*12.*0.7457/0.55/W
      PTUR=TORQ*W*.7457/550.
      PK=PTUR/CPKM
```

```
      TT=PTUR*TCOEF
      PGEN=POT(PTUR)
      CPM=PGEN/PK
      TM=PGEN*TCOEF
      PSYS=POG(PGEN)
      CPS=PSYS/PK
      TS=PSYS*TCOEF
      CP1=PGEN*CP(TSR)/PTUR
      CP2=PSYS*CP1/PGEN
      IF(PTUR.LT.0.)GO TO 74
      LINE=LINE+1
      IF(IPRT.EQ.0)WRITE(77,5)VREF,VO,PTUR,PGEN,PSYS,TSR,CP(TSR),CPKM,
     *CPM,CPS
      OTSR=1./TSR
      IF(IPRT.EQ.-1)WRITE(77,6)VREF,VO,OTSR,CP(TSR),CP1,CP2,TT,TM,TS
C>>   IF(KKKK.EQ.1HG)CALL STUFFY(RE,SOL,NBLADE,
C>>  *VREF,VO,TSR,OTSR,PTUR,PGEN,PSYS,CP(TSR),CP1,CP2,CPKM,CPM,CPS,
C>>  *TT,TM,TS)
    5 FORMAT(6F7.1,4(1X,F6.4))
    6 FORMAT(2F7.1,4(1X,F6.4),3(1X,F9.0))
   74 VREF=VREF+1.
      IF(VREF.GT.60.)GOTO 8888
      IF(TSR.LT.1.5) GOTO 8888
      IF(LINE.LT.33)GOTO 10
C>>   IF(IPRT.GE.-1)READ(66,*)NNNNNN
C>>   IF(EOF(66))8008,8008
 8008 CONTINUE
      LINE=2
C>>   IF(KKKK.EQ.1HG.AND.IPRT.GE.-1)CALL ERASE
      GO TO 11
 8888 IF(KKKK.NE.1HG)GOTO 8003
C>>   IF(IPRT.EQ.-3)GOTO 8877
C>>   IF(IPRT.GE.-1)READ(66,*)N
C..   GOTO 8003
C>>   IF(EOF(66))8003,8003
 8877 CONTINUE
C>>   CALL PLOTIT(RE,SOL,NBLADE)
      GOTO 8003
 8004 IPRT=-3
C>>   CALL GRAPH(VBLIST)
C>>   GOTO 777
 8003 WRITE(77,8886)
 8886 FORMAT(*ENT  CONTINUATION MODE*)
      READ(66,*)IPRT
      IF(IPRT.EQ.-2)STOP
      IF(IPRT.EQ.-1)GOTO 8007
      IF(IPRT.GE.0.AND.IPRT.LE.10)GOTO(777,777,701,702,703,704,705,706,
     ;707,708,8004),(IPRT+1)
      STOP
      END
```

```
      FUNCTION CP(TSR)
      COMMON/CPTSR/XLK,CPK,XLM,CPMAX,XN,RLRLM
      IF(TSR.LE.XLK) GO TO 1
      IF(TSR.GE.XLM)GO TO 2
      A = (TSR-XLM)/(XLK-XLM)
      B = CPK*(XLK**3) - CPMAX
      CP = CPMAX + A*A*B
      RETURN
    2 A = (TSR-XLM)/(XLM*RLRLM - XLM)
      CP = CPMAX - A*A*CPMAX
      RETURN
    1 CP=CPK*XLK**3*(TSR/XLK)**XN
      RETURN
      END
```

```
      FUNCTION POG(PING)
      COMMON/ENG/A,PRATED,RW,CON,RLOSSG,RLOSST,S,GR
CC FUNCTION GIVES OUTPUT GENT POWER AS FUNCTION OF INPUT POWER
C
      AA = PRATED**2/(.5*RLOSSG)
      B = SQRT(1.+4.*(PING-.5*RLOSSG)/AA)
      POG = AA*(B-1.)*.5
      RETURN
      END
```

```
      FUNCTION POT(PINT)
      COMMON/ENG/A,PRATED,RW,CON,RLOSSG,RLOSST,S,GR
      POT = PINT-RLOSST
      RETURN
      END
```

```
      SUBROUTINE CPPARM(SIG,HOD,REC,KPM,XK,CPM,XM,XR)
      REAL KPM,LOGREC
      DIMENSION AKPM(3,3),BKPM(3,3),AXK(3,3),BXK(3,3),ACPM(3,3),BCPM
     1 (3,3),AXM(3,3),BXM(3,3),THOD(3,3),TSIG(3)
      COMMON/LIMITS/ILO(4),IHI(4),IR(4),DEN,IEX,VR
      DIMENSION Z(4),DZ(4)
      DATA (IHI(I),I=1,4)/3,3,3,3/
      DATA (ILO(I),I=1,4)/1,1,1,1/
      DATA (IR(I),I=1,4)/1,1,1,1/
      DATA (THOD(I),I=1,9)/1.0,1.25,1.5,1.0,1.25,1.5,1.0,1.25,1.5/
      DATA (TSIG(I),I=1,3)/0.05,0.132,0.20/
C     NACA 0015
      DATA (AKPM(I),I=1,9)/-2.393,-7.183,-3.378,-5.319,-7.295,-9.057,
     1 -11.649,-22.539,-14.359/
      DATA (BKPM(I),I=1,9)/0.360,0.667,0.443,0.882,1.039,1.166,
     1 1.571,2.285,1.785/
      DATA (AXK(I),I=1,9)/3.631,7.217,3.748,3.480,4.235,4.285,
     1 3.726,4.328,4.497/
      DATA (BXK(I),I=1,9)/-0.030,-0.242,-0.034,-0.034,-0.083,-0.088,
     1 -0.060,-0.101,-0.110/
      DATA (ACPM(I),I=1,9)/0.213,0.099,0.238,0.350,0.334,0.328,
     1 0.345,0.336,0.340/
      DATA (BCPM(I),I=1,9)/0.001,0.012,0.003,0.001,0.003,0.004,
     1 0.003,0.004,0.004/
      DATA (AXM(I),I=1,9)/4.662,6.740,4.871,6.204,7.023,7.695,
     1 4.909,3.935,1.214/
      DATA (BXM(I),I=1,9)/0.281,0.163,0.268,0.013,-0.075,-0.131,
     1 -0.007,0.042,0.211/
      LOGREC=ALOG(REC)
      CALL LOOK2D(4,SIG,TSIG,0,HOD,THOD,AKPM,BKPM,AXK,BXK,Z,DZ,4,3)
      KPM = Z(1) + Z(2)*LOGREC
      KPM=KPM*.001
      XK   = Z(3) + Z(4)*LOGREC
      CALL LOOK2D(4,SIG,TSIG,0,HOD,THOD,ACPM,BCPM,AXM,BXM,Z,DZ,4,3)
 1000 FORMAT(10X,4(2XF7.3))
      CPM = Z(1) + Z(2)*LOGREC
      XM = Z(3) + Z(4)*LOGREC
      XR = 1.04*LOGREC - 3.45*ALOG(SIG) - 10.45
      RETURN
      END
```

```
C
      SUBROUTINE LOOK (II,XL,X,A,B,C,E,Y,D,IDN)
      COMMON/LIMITS/ILO(4),IHI(4),IR(4),DEN,IEX,VR
      DIMENSION X(1), A(1), B(1), C(1), E(1), Y(1), D(1)
      IH=IHI(II)
      IL=ILO(II)
      DO 5 J=1,IDN
      D(J) = 0.0
      Y(J) = 0.0
    5 CONTINUE
      VR = 0.0
      IEX=0
      IF (X(IH)-X(IL)) 10,10,30
10    IEX=1
      IF (XL-X(IH)) 120,130,20
20    IF (XL-X(IL)) 50,150,140
30    IF (XL-X(IH)) 40,130,120
40    IF (XL-X(IL)) 140,150,50
50    I=IR(II)
      I=MIN0(I,IH)
      I=MAX0(I,IL)
      IS=1
      IT=1
      GO TO 70
60    I=I+1
      IS=0
70    IF (IEX) 80,80,90
80    IF (XL-X(I)) 100,160,110
90    IF (XL-X(I)) 110,160,100
100   I=I-1
      IT=0
      IF (IS) 160,160,70
110   IF (IT) 160,160,60
120   IEX=3
130   I=IH-1
      GO TO 160
140   IEX=2
150   I=IL
160   DEN=X(I+1)-X(I)
      IR(II)=I
      VR=XL-X(I)
      IF (IDN) 230,230,170
170   GO TO (210,200,190,180), IDN
180   Y(4)=E(I)
      D(4)=E(I+1)-E(I)
190   Y(3)=C(I)
      D(3)=C(I+1)-C(I)
200   Y(2)=B(I)
      D(2)=B(I+1)-B(I)
210   Y(1)=A(I)
      D(1)=A(I+1)-A(I)
      IF(DEN.EQ.0.0) RETURN
      DO 220 J=1,IDN
      D(J)=D(J)/DEN
220   Y(J)=Y(J)+D(J)*VR
230   VR=VR/DEN
      RETURN
      END
```

```
C
      SUBROUTINE LOOK2D(II,XL,X,IF,YL,Y,A,B,C,E,Z,DZ,NLOOK,ND)
      COMMON/LIMITS/ILO(4),IHI(4),IR(4),DEN,IEX,VR
      DIMENSION          X(1),      Y(ND,1),   A(ND,1),   B(ND,1),   C(ND,1),
     1          E(ND,1),   Z(4),      DZ(4),     ZL(4),     DZL(4),    ZR(4),
     2          DZR(4)
      VRS = 1.0
      J = 0
      DO 10 I=1,NLOOK
      Z(I) = DZ(I) = 0.0
   10 CONTINUE
      IF(IHI(II).EQ.1) GO TO 20
      CALL LOOK(II,XL,X,0,0,0,0,Z,DZ,0)
      VRS = VR
      J = IR(II)
      JJ = IF + J
      CALL LOOK(JJ,YL,Y(1,J),A(1,J),B(1,J),C(1,J),E(1,J),Z,DZ,NLOOK)
      DO 15 I=1,NLOOK
      ZL(I) = Z(I)
      DZL(I) = DZ(I)
   15 CONTINUE
   20 CONTINUE
      J = J + 1
      JJ = IF + J
      CALL LOOK(JJ,YL,Y(1,J),A(1,J),B(1,J),C(1,J),E(1,J),Z,DZ,NLOOK)
      DO 30 I=1,NLOOK
      ZR(I) = Z(I)
      DZR(I) = DZ(I)
   30 CONTINUE
      VRSP = 1. - VRS
      DO 40 I=1,NLOOK
      Z(I) = ZL(I)*VRSP  + ZR(I)*VRS
      DZ(I) = DZL(I)*VRSP + DZR(I)*VRS
   40 CONTINUE
      RETURN
      END
```

```
      SUBROUTINE GRAPH(RE,SOL,NBLADE,V1,V2,V3,V4,
     *V5,V6,V7,V8,V9,V10,V11,V12,V13,V14,V15,V16)
C
C       THIS SUBROUTINE SHOULD NOT BE INCLUDED IF GRAPHICS OPTION
C
C       IS NOT IMPLEMENTED.
C
      DIMENSION VBLIST(16),X(100),Y(100,4)
      DIMENSION IYAXIS(4),LINEN(3),LABEL(3,16)
      DIMENSION IPAK(70),IPK(70),XN(2),YN(2)
      DIMENSION ITITLE(1),IXTITL(3),IYTITL(2)
      COMMON /N/ NACA
      DATA ITITLE/2H  /
      DATA LABEL/
     *10HVELOCITY  ,10H,REFERENCE,10H (MPH)     ,
     *10HVELOCITY  ,10H,TURBINE  ,10H (MPH)     ,
     *10HT-S RATIO ,2H  ,2H  ,
     *10HADV. RATIO,2H  ,2H  ,
     *10HPOWER OUT ,10HTURBINE   ,10H (KW)      ,
     *10HPOWER OUT ,10HMECHANICAL,10H (KW)      ,
     *10HPOWER OUT ,10HSYSTEM    ,10H (KW)      ,
     *10HPOWER COEF,10H(CP)TURB. ,2H  ,
     *10HPOWER COEF,10H(CP1)MECH.,2H  ,
     *10HPOWER COEF,10H(CP2)SYS. ,2H  ,
     *10HPERF.COEF.,10H(CPK)TURB.,2H  ,
     *10HPERF.COEF.,10H(CPM)MECH.,2H  ,
     *10HPERF.COEF.,10H(CPS) SYS.,2H  ,
     *10HTORQUE    ,10HTURBINE   ,10H (FT-LBS) ,
     *10HTORQUE    ,10HMECHANICAL,10H (FT-LBS) ,
     *10HTORQUE    ,10HSYSTEM    ,10H (FT-LBS) /
      I=0
      WRITE(77,999)
  999 FORMAT(70X/*ENT  X AXIS VBL. CODE*)
      READ(66,*)IXAXIS
      WRITE(77,995)
  995 FORMAT(*ENT  NO. OF CURVES*)
      READ(66,*)NYAXIS
      WRITE(77,998)
  998 FORMAT(*ENT  LIST OF Y AXIS VBL. CODES*)
      READ(66,*)(IYAXIS(N),N=1,NYAXIS)
      RETURN
      ENTRY PLOTIT
      ENCODE(30,7399,LINEN(1))LABEL(1,IYAXIS(I)),LABEL(1,IXAXIS)
 7399 FORMAT(A10,* VS. *,A10,*$*)
      CALL LINES(LINEN,IPAK,1)
      ENCODE(30,7394,LINEN(1))NACA
 7394 FORMAT(*NACA 00*,I2,*$*)
      CALL LINES(LINEN,IPAK,2)
      ENCODE(30,7398,LINEN(1))RE
 7398 FORMAT(*REYNOLD*S NO. = *,-6PF5.2,*$*)
      CALL LINES(LINEN,IPAK,3)
      ENCODE(30,7397,LINEN(1))NBLADE,SOL
 7397 FORMAT(*SOLIDITY OF *,I1,* BLDS.= *,F5.3,*$*)
      CALL LINES(LINEN,IPAK,4)
      DO 7300 JJ=1,NYAXIS
      ENCODE(11,7396,LINEN(1))LABEL(2,IYAXIS(JJ))
 7300 CALL LINES(LINEN,IPK,JJ)
```

```
7396 FORMAT(A10,*$*)
     ENCODE(20,7395,IYTITL(1))(LABEL(II,IYAXIS(1)),II=1,3,2)
7395 FORMAT(3A10)
     ENCODE(30,7395,IXTITL(1))(LABEL(II,IXAXIS),II=1,3)
     GOTO 8899
     ENTRY STUFFY
     VBLIST(1)=V1  $ VBLIST(2)=V2  $ VBLIST(3)=V3 $ VBLIST(4)=V4
     VBLIST(5)=V5  $ VBLIST(6)=V6  $ VBLIST(7)=V7 $ VBLIST(8)=V8
     VBLIST(9)=V9  $ VBLIST(10)=V10$ VBLIST(11)=V11
     VBLIST(12)=V12 $ VBLIST(13)=V13
     VBLIST(14)=V14 $ VBLIST(15)=V15 $ VBLIST(16)=V16
     I=I+1
     X(I)=VBLIST(IXAXIS)
     DO 200 J=1,NYAXIS
200  Y(I,J)=VBLIST(IYAXIS(J))
     RETURN
8899 CONTINUE
     WRITE(77,997)
997  FORMAT(70X/*ENT  MIN,MAX,INCR OF X VALUES*)
     READ(66,*)XMIN,XMAX,XINCR
     WRITE(77,996)
996  FORMAT(*MIN,MAX,INCR OF Y VALUES*)
     READ(66,*)YMIN,YMAX,YINCR
     CALL BGNPL(1)
     CALL NOCHEK
     CALL TITLE(ITITLE,-10,IXTITL,30,IYTITL,20,10,6.5)
     CALL GRAF(XMIN,XINCR,XMAX,YMIN,YINCR,YMAX)
     XN(1)=XMIN
     XN(2)=XMAX
     YN(1)=YN(2)=0.
     CALL CURVE(XN,YN,2,0)
     DO 300 J=1,NYAXIS
300  CALL CURVE(X,Y(1,J),I,1)
     CALL LSTORY(IPAK,4,1,6)
     CALL LEGEND(IPK,NYAXIS,6,6)
     CALL ENDPL(0)
     CALL ANMODE
     RETURN
     END
```

5

Appendix G

Sandia Implementation

The following control cards may be used to execute PAREP at Sandia Laboratories, Albuquerque, on the NOS timeshare system.

```
GET, PAREP/UN = EGKADLE.
FTN, I = PAREP.
ATLIB, TKLIB, DISSPLA.
LGO.
```

Priot to compilation, the file PAREP should be edited to either include or exclude graphics. After entering XEDIT, the command;

c/c>>/ÞÞÞ/* will enable graphics

or

c/c../ÞÞÞ/* will exclude them.

<u>One or the other must be performed</u>.

References

1. The computer code PAREP was written by T. M. Leonard, Division 4715, Sandia Laboratories, under contract from UNM's Civil Engineering Research Facility, Albuquerque, NM.
2. The computer code CPPARM was written by B. F. Blackwell, formerly of Sandia Laboratories, Albuquerque, NM.
3. The computer code TVSV was written by W. N. Sullivan, Division 4715, Sandia Laboratories, Albuquerque, NM.
4. The computer code DARTER, adapted from the code DART. For a discussion of DART, see J. H. Strickland, The Darrieus Turbine: A Performance Prediction Model Using Multiple Streamtubes, SAND75-0431, Sandia Laboratories, Albuquerque, NM, October 1975.
5. W. N. Sullivan, Economic Analysis of Darrieus Vertical Axis Wind Turbine Systems for the Generation of Utility Grid Electrical Power, V. II, SAND78-0962, Sandia Laboratories, Albuquerque, NM, to be published.
6. The graphics proprietary code, DISSPLA®, distributed by Integrated Software Systems Corporation, P.O. Box 9906, San Diego, CA, 92109. All rights reserved.

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