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Aerodynamic Performance of the 17-M-Diameter Darrieus Wind Turbine in the Three-Bladed Configuration: An Addendum

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AERODYNAMIC PERFORMANCE OF THE 17-M-DIAMETER DARRIEUS WIND TURBINE IN THE THREE-BLADED CONFIGURATION: AN ADDENDUM

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ABSTRACT

The U.S. Department of Energy (DOE)/Sandia 17-m wind turbine has been tested in the three-bladed configuration at five rotational speeds. These data are presented along with some fundamental comparisons to the earlier two-bladed results. Also included is the theoretical output of the three-bladed 17-m wind turbine at two selected rotational speeds.

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ILLUSTRATIONS

TABLES

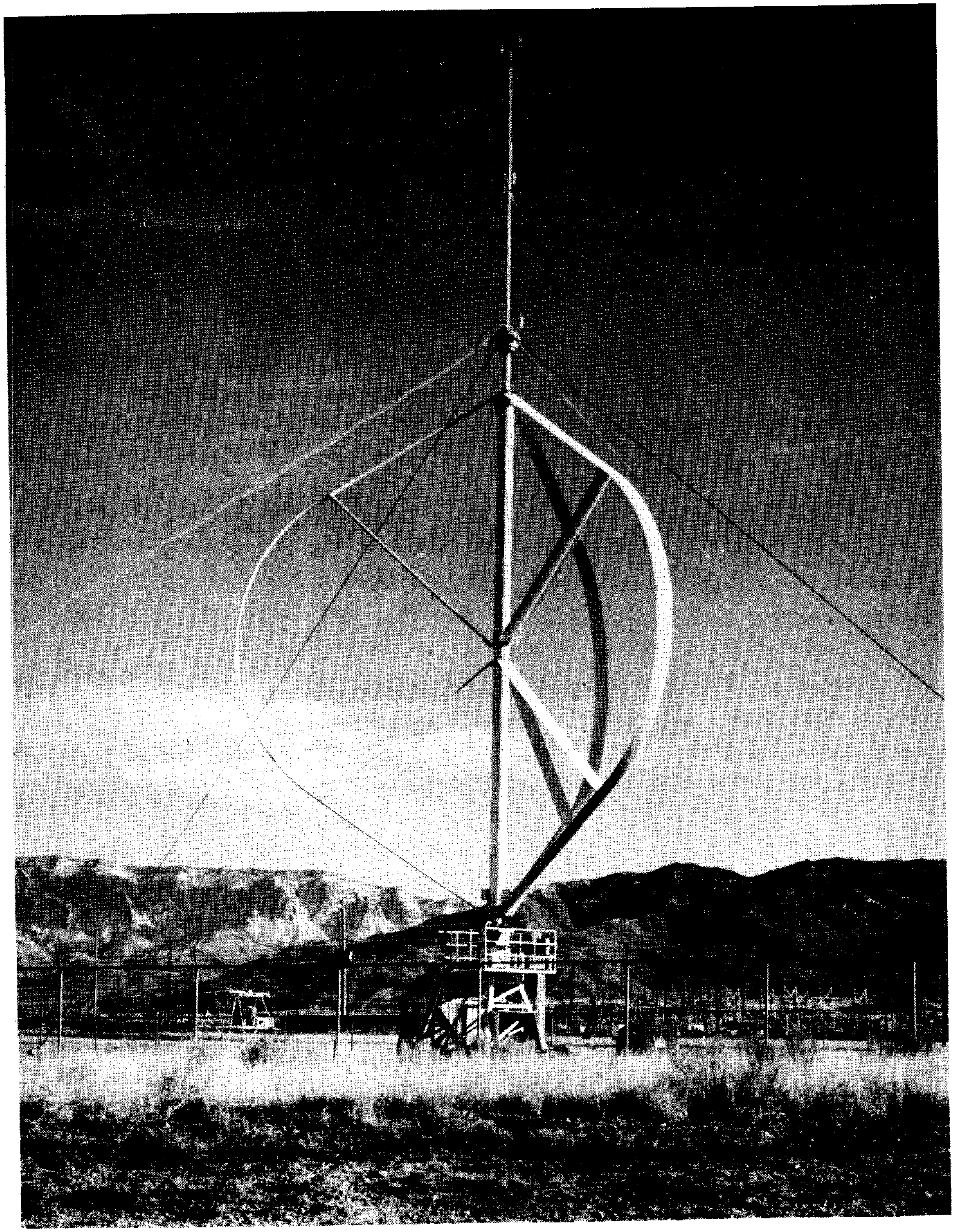

Figure 1. DOE/Sandia 17-m Wind Turbine

AERODYNAMIC PERFORMANCE OF THE 17-M-DIAMETER DARRIEUS WIND TURBINE IN THE THREE-BLADED CONFIGURATION: AN ADDENDUM

Introduction

This report is an addendum to an earlier published report.[1] The first report covered the performance of the DOE/Sandia 17-m turbine in the strutted two-bladed mode. This machine incorporates the flexibility of testing with either two or three blades. The effect of adding a third blade was to increase rotor solidity -- in this case, from $\sigma = 0.14$ to $\sigma = 0.21$. The third blade is identical to the other two.

Testing in the three-bladed mode began in January 1978 and continued ~ 1 year, of which 6 months were lost for repair of the low-speed torque sensor. Aerodynamic performance data were accumulated for five rotational speeds. The nature of data assimilation and reduction is identical to that described in Reference 1. The descriptions, notations, equations, and references in Reference 1 are directly applicable to this report.

This report presents aerodynamic performance test data for the three-bladed 17-m turbine and makes some comparisons with the earlier two-bladed test data[1] in order to identify the trends and characteristics of increasing the rotor solidity. In aerodynamic terms, there is a difference in changing solidity through the addition of more blades or by increasing the chord of the original number of blades, although the calculated value of solidity may be the same in either case. For example, Re_c will change. The test results and data comparisons of this report are attributable only to the former case. Reference 2 presents wind tunnel test results of a 2-m turbine in both two- and three-bladed modes with varying blade chords.

Test Results

Appendix A presents aerodynamic performance data of the 17-m turbine in the strutted three-bladed mode. Rotor speeds tested were 37, 42, 45.5, 48.4, and 52.5 rpm. As in Reference 1, the printed data, wind frequency, C_p, power, and K_p curves are presented for each rotational speed. Table 1 presents a summary of these test data. The K_{pmax} and P_{max} figures stated in Table 1 are 95% of the observed highest test data numbers.

In general, the C_p, power, and K_p curves of the test data exhibited smooth contours, which is quite encouraging for field test data. C_{pmax} ranged from a high of 0.368 @ X = 5 for 37 rpm to a low of 0.323 @ X = 4.45 at 42 rpm. The windspeed at which the turbine rotor would begin producing power increases steadily from 9.5 mph at 37 rpm to 13.5 mph for 52.5 rpm. The highest aerodynamic power output achieved

Table 1
Three-Bladed Test Data Summary

RPM	Breakeven V_∞ (mph)	$C_{P_{max}}$ @ X	$K_{P_{max}}$ @ J	P_{max} @ V_∞ (kW) (mph)
37.0	9.5	.368 @ 5.00	.00775 @ .324	24.69 @ 23.5
42.0	9.5	.323 @ 4.45	.00852 @ .346	39.70 @ 28.5
45.5	10.5	.340 @ 4.57	.00925 @ .353	54.77 @ 31.5
48.4	11.5	.352 @ 4.41	.00866 @ .332	61.75 @ 31.5
52.5	13.5	.346 @ 4.38	.00895 @ .335*	81.44 @ 34.5*

V_∞ is at 44 foot reference height.

*Higher ambient windspeeds needed.

by the 17-m turbine was 81.4 kW at 34.5 mph and 52.5 rpm. This figure might have been higher if ambient winds greater than 35 mph had been available.

The inherent characteristic of the constant-speed Darrieus turbine to level off in power output for increasing wind velocity ($X < 3$) is particularly evident in the power curve for 37 rpm. This is also seen at the other rotational speeds. Maximum turbine output power increased for higher rotational speeds, occurring at progressively higher ambient wind velocities.

One bothersome area of the field-test data was the C_p curve for 42 rpm. Unlike the other C_p curves, this one appears quite rough with no clearly defined maximum. (Note that the power curve for 42 rpm is indeed smooth, with a clearly defined maximum that does not depend upon a V^3 calculation as does C_p.) The range in question is $4 < X < 10$ (20 mph to 8 mph). A review of the individual test records of 42 rpm showed that seven records were in this particular range, with the majority of sample points confined to three records. Each of the seven records was examined; no clear-cut errors were apparent. One noteworthy fact was that all seven records were taken in the last three days of testing before retrofit work began on the 17-m turbine.*

Because there were no anomalies present in the data taken before the last three days of testing, it is suspected that some aberration, such as unusual wind conditions and/or instrument error, occurred during these last three days. Due to lack of further data, the combined performance record for 42 rpm is presented in its entirely with the wind range in question to be noted.

Data Trends and Comparison With Two-Bladed Results

It is the intent here to provide both the trends of the three-bladed data and to make a fundamental comparison with the earlier two-bladed data presented in Reference 1. The figures presented here combine both two- and three-bladed data at two selected rotational speeds of the turbine rotor.

Figure 2 plots the results of field testing of the DOE/Sandia 17-m turbine in both the two- and three-bladed modes at 37 and 52.5 rpm. The first impression of Fig. 2 is that the C_p curves for the three-bladed mode are shifted towards lower tipspeed ratios (higher V_∞) relative to those of the two-bladed configuration. This indicates that the 17-m turbine with three blades can produce more power in higher

*This was the changeover to unstrutted aluminum-extruded blades with other modifications.

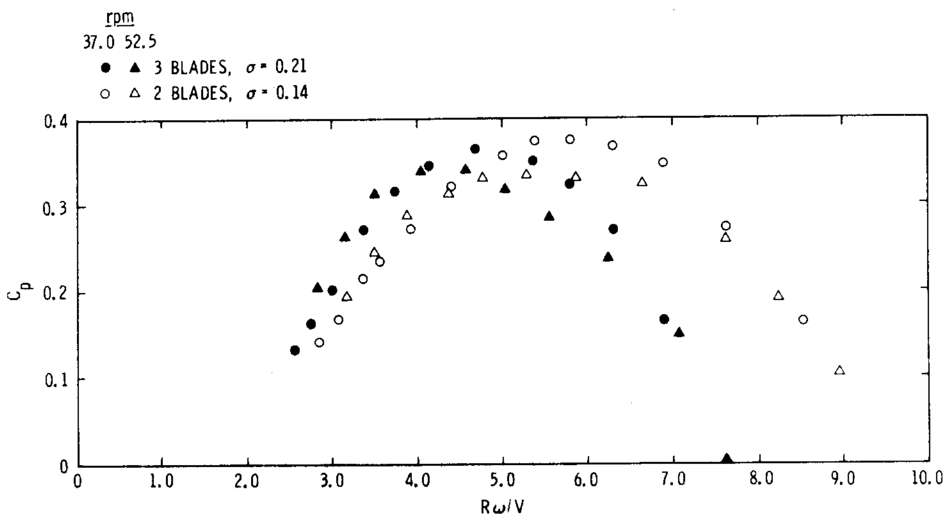

Figure 2. C_p as a Function of Tipspeed Ratio

ambient winds than with two blades at the same rpm, but less at lower V_∞. C_{pmax} of both two and three blades was higher at 37 rpm than at 52.5 rpm. The similarity of the relationship between the C_p curves is also particularly striking.

Figure 3 plots C_{pmax} for both the two- and three-bladed configurations over the

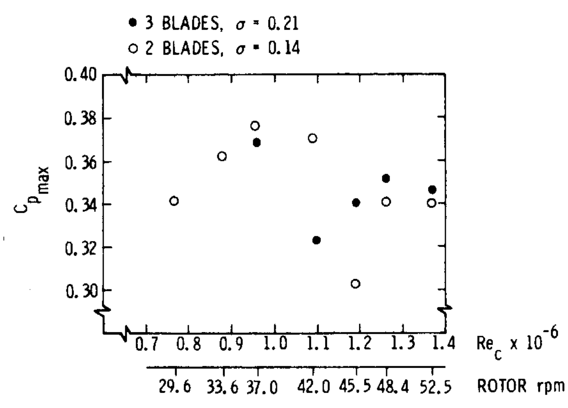

Figure 3. $C_{p_{max}}$ as a Function of Reynolds Number

range of rotational speeds tested. Although two data points of this figure are in question (45.5 rpm, σ = 0.14 as described in Reference 1, and 42 rpm, σ = 0.21 as described earlier), this figure is still presented as a matter of consistency. With these points excluded, no definite conclusions can be drawn other than that C_{pmax} for both solidities is roughly the same, and the highest C_{pmax} for both solidities occurred at 37 rpm.

Figure 4 shows a plot of K_p as a function of advance ratio for both solidities

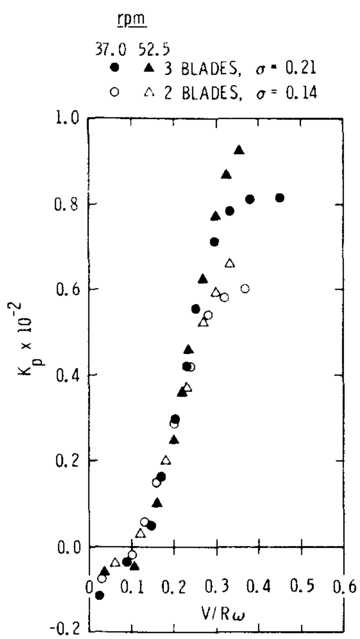

Figure 4. K_p as a Function of Advance Ratio

at 37 and 52.5 rpm. What is clearly evident in this figure is that for $V/R\omega > 0.26$, K_p is decidedly higher for $\sigma = 0.21$ than for $\sigma = 0.14$, with K_p favoring the higher rotational speeds for both solidities. At lower advance ratios, K_p slightly favors $\sigma = 0.14$ at 37 rpm. Not clearly evident in Fig. 4 is that K_p for the higher solidity mode is slightly shifted towards higher values of advance ratios relative to the lower solidity.

In conjunction with Fig. 4, Fig. 5 presents K_{pmax} as a function of Reynolds number, correlated to turbine rotational speed. Two distinct trends are apparent in Fig. 5. One is that K_{pmax} increases for increasing rpm for both solidities. Second, K_{pmax} for the higher solidity configuration is greater than for the lower solidity over the entire test range of turbine rotational speeds. Note that at 52.5 rpm, higher ambient winds than those encountered during testing are necessary to establish actual K_{pmax}; the points shown are the highest for the available winds.

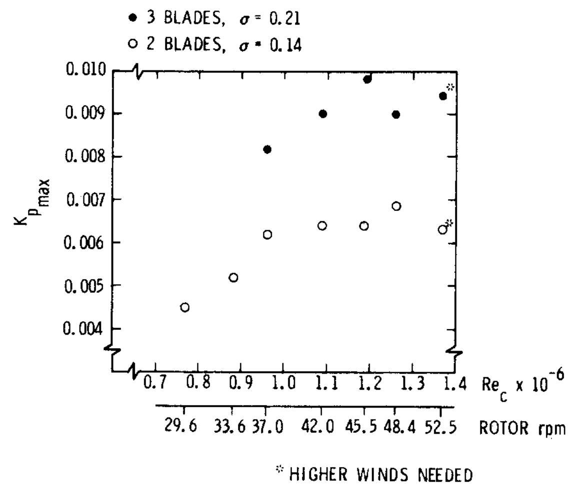

Figure 5. K_{pmax} as a Function of Reynolds Number

Figure 6 shows the power output of the DOE/Sandia 17-m turbine as a function of

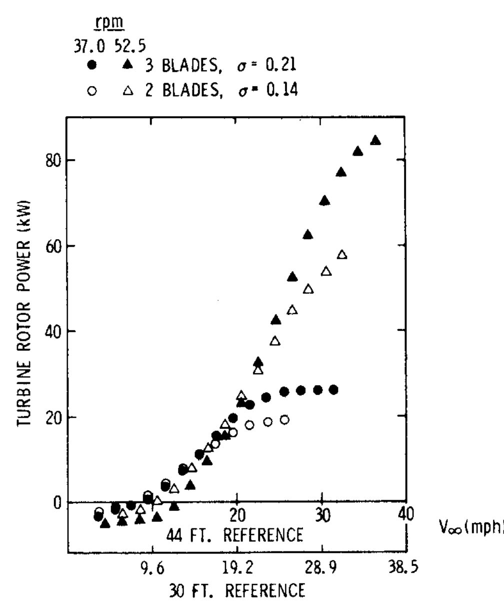

Figure 6. Power Output as a Function of Ambient Wind Velocity

wind velocity. This is essentially analogous to Fig. 4, which was expressed in dimensionless parameters. This clearly shows the effect of shifting the C_p curves of Fig. 2 towards a lower tipspeed ratio for the higher solidity configuration. At higher V_∞ (lower X) C_p for $\sigma = 0.21$ is greater than for $\sigma = 0.14$, which manifests itself as increased rotor power output. The converse is also true; at lower V_∞, C_p for $\sigma = 0.14$ is greater. This can also be seen in Fig. 6, although not as distinctly.

Conclusions

Field-test results of the DOE/Sandia 17-m wind turbine appeared to be quite acceptable and exhibited basic trends and characteristics seen in the earlier two-bladed data of Reference 1. Comparing the two- and three-bladed data revealed several interesting (though predictable) trends. For the same rpm:

1. The peak turbine power output was higher for three blades than two.
2. C_{pmax} was roughly the same for both two and three blades.
3. The C_p curves for three blades were shifted towards lower X relative to two blades. This manifests itself as increased turbine power output at high winds and less output in low winds when compared to two blades.

Again, the results presented in this report are based upon a rotor solidity increase through the addition of a third blade, not by increasing the chord of the two-bladed rotor.

The predicted and experimental power output of the three-bladed DOE/Sandia wind turbine is presented in Figs. 7 and 8 for 37 and 52.5 rpm, respectively. The theoretical prediction is based upon the aerodynamic computer model PAREP, described in References 3 and 4. Very good agreement was obtained for 37 rpm, with the theoretical model tending to overpredict at 52.5 rpm.

As stated earlier, the DOE/Sandia 17-m turbine was refitted with unstrutted extruded aluminum blades. These blades are of a NACA 0015 airfoil section with a 24-in. chord. The geometry of the rotor is the same as that described in Reference 1 except for the struts. Current testing is in the two-bladed mode. Test results obtained to date indicate a significant improvement in performance over the original strutted NACA 0012 21-in. chord blades.

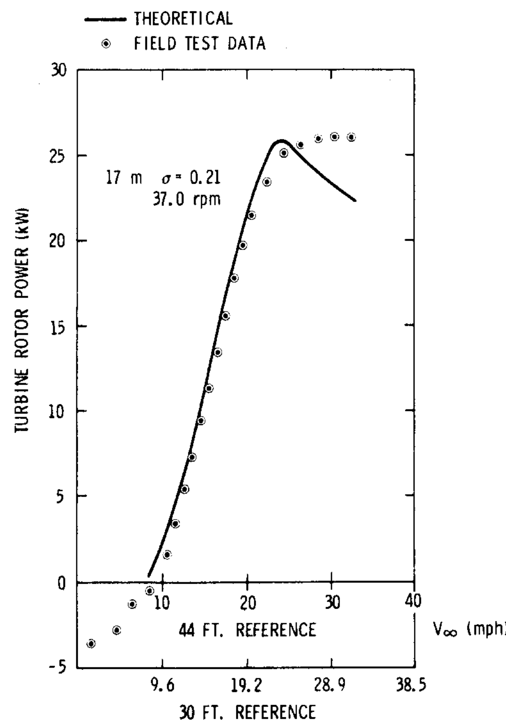

Figure 7. Comparison of Predicted and Experimental Power Output at 37 rpm

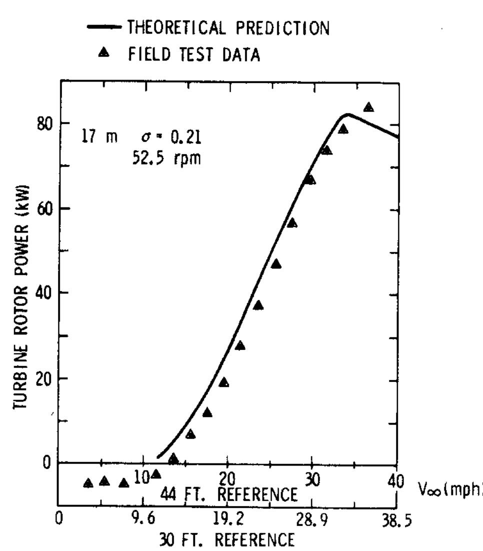

Figure 8. Comparison of Predicted and Experimental Power Output at 52.5 rpm

References

1. M. H. Worstell, Aerodynamic Performance of the 17-Metre-Diameter Darrieus Wind Turbine, SAND78-1737, Sandia Laboratories, Albuquerque, NM, January 1979.

2. B. F. Blackwell, R. E. Sheldahl, and L. V. Feltz, Wind Tunnel Performance Data for the Darrieus Wind Turbine with NACA 0012 Blades, SAND76-0130, Sandia Laboratories, Albuquerque, NM, March 1977.

3. P. C. Klimas and R. E. Sheldahl, Four Aerodynamic Prediction Schemes for Vertical-Axis Wind Turbines: A Compendium, SAND78-0014, Sandia Laboratories, Albuquerque, NM, June 1978.

4. T. M. Leonard, A User's Manual for the Computer Code PAREP, SAND79-0431, Sandia Laboratories, Albuquerque, NM, April 1979.

APPENDIX A

Performance Data

37 rpm

3 Blades, $\sigma = 0.21$

Wind Range 2.5 to 31.5 mph

AIR DENSITY= .0625 LBS PER CU FT
17. M TURBINE, COMBINED DATA, RPM=37.0
NUMBER SAMPLES IN ACCUMULATION = 123392.
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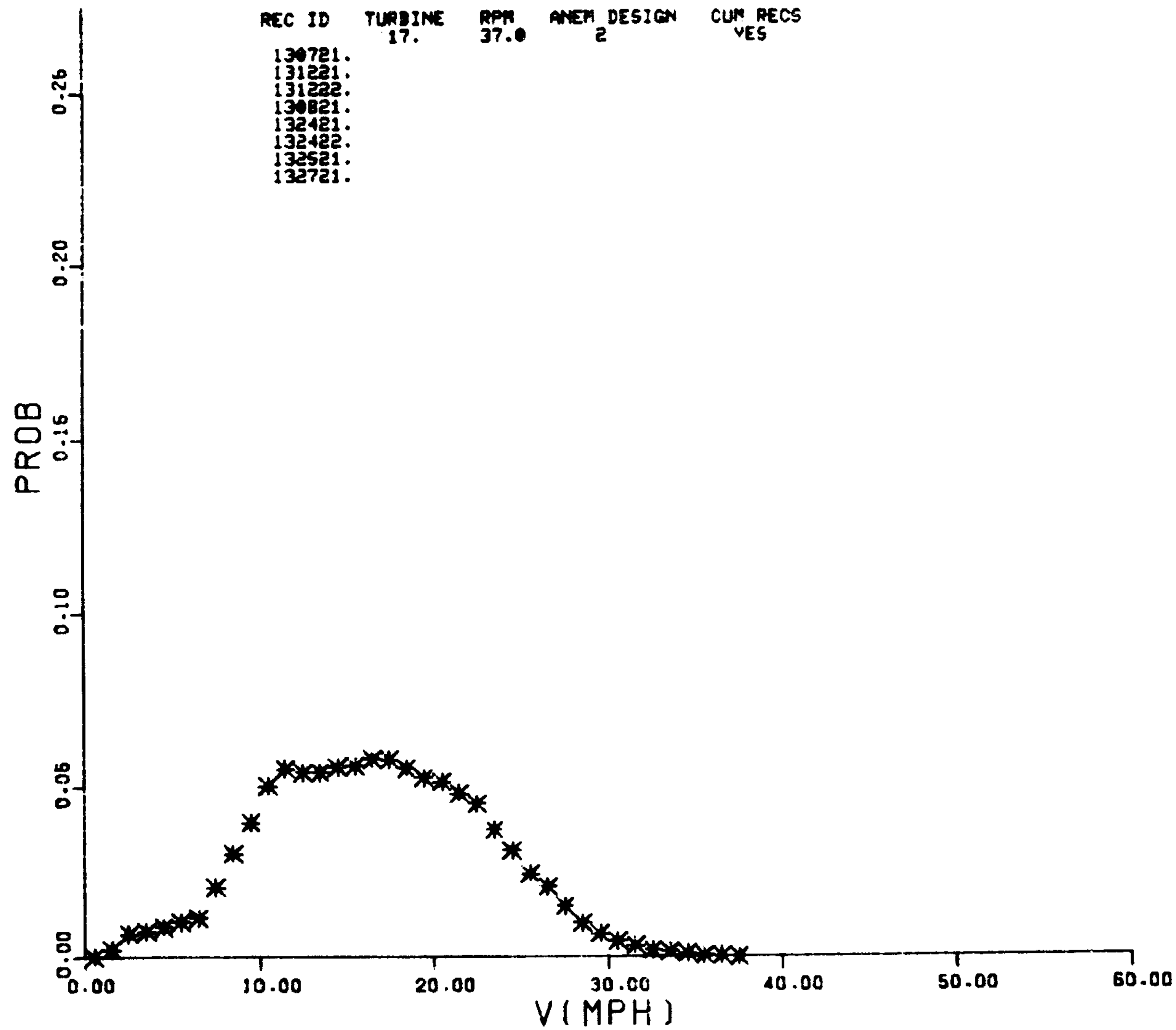
.5	11.	.000	-3.2360	144.97	-3094.99	.007	-.00102	
1.5	284.	.002	-3.6655	48.32	-129.843	.021	-.00115	
2.5	845.	.007	-3.6290	28.99	-27.766	.034	-.00114	
3.5	937.	.008	-3.5439	20.71	-9.882	.048	-.00111	
4.5	1092.	.009	-2.7829	16.11	-3.651	.062	-.00087	
5.5	1296.	.011	-1.9132	13.18	-1.375	.076	-.00060	
6.5	1438.	.012	-1.1491	11.15	-.500	.090	-.00036	
7.5	2541.	.021	-.8472	9.66	-.240	.103	-.00027	
8.5	3739.	.031	-.5504	8.53	-.107	.117	-.00017	
9.5	4919.	.040	.3949	7.63	.055	.131	.00012	
10.5	6241.	.051	1.6297	6.90	.168	.145	.00051	
11.5	6873.	.056	3.4454	6.30	.271	.159	.00108	
12.5	6761.	.055	5.3185	5.80	.326	.172	.00167	
13.5	6758.	.055	7.2459	5.37	.352	.186	.00227	
14.5	6943.	.056	9.3934	5.00	.368	.200	.00295	
15.5	6993.	.057	11.3256	4.68	.364	.214	.00356	
16.5	7236.	.059	13.3869	4.39	.356	.228	.00420	
17.5	7205.	.058	15.5982	4.14	.348	.241	.00490	
18.5	6891.	.056	17.7742	3.92	.336	.255	.00558	
19.5	6563.	.053	19.7190	3.72	.318	.269	.00619	
20.5	6391.	.052	21.4113	3.54	.297	.283	.00672	
21.5	5972.	.048	22.8772	3.37	.275	.297	.00718	
22.5	5622.	.046	23.8147	3.22	.250	.310	.00748	
23.5	4654.	.038	24.6904	3.08	.227	.324	.00775	
24.5	3914.	.032	25.0321	2.96	.203	.338	.00786	
25.5	3032.	.025	25.4961	2.84	.184	.352	.00800	
26.5	2573.	.021	25.6689	2.74	.165	.366	.00806	
27.5	1860.	.015	25.8815	2.64	.149	.379	.00813	
28.5	1237.	.010	25.9340	2.54	.134	.393	.00814	
29.5	841.	.007	25.8499	2.46	.120	.407	.00812	
30.5	583.	.005	26.0964	2.38	.110	.421	.00819	
31.5	416.	.003	25.9521	2.30	.099	.435	.00815	
32.5	257.	.002	25.9584	2.23	.090	.448	.00815	
33.5	208.	.002	25.3236	2.16	.081	.462	.00795	
34.5	124.	.001	25.2867	2.10	.074	.476	.00794	
35.5	51.	.000	26.5539	2.04	.071	.490	.00834	
36.5	29.	.000	23.3194	1.99	.057	.504	.00732	
37.5	7.	.000	27.7382	1.93	.063	.517	.00871	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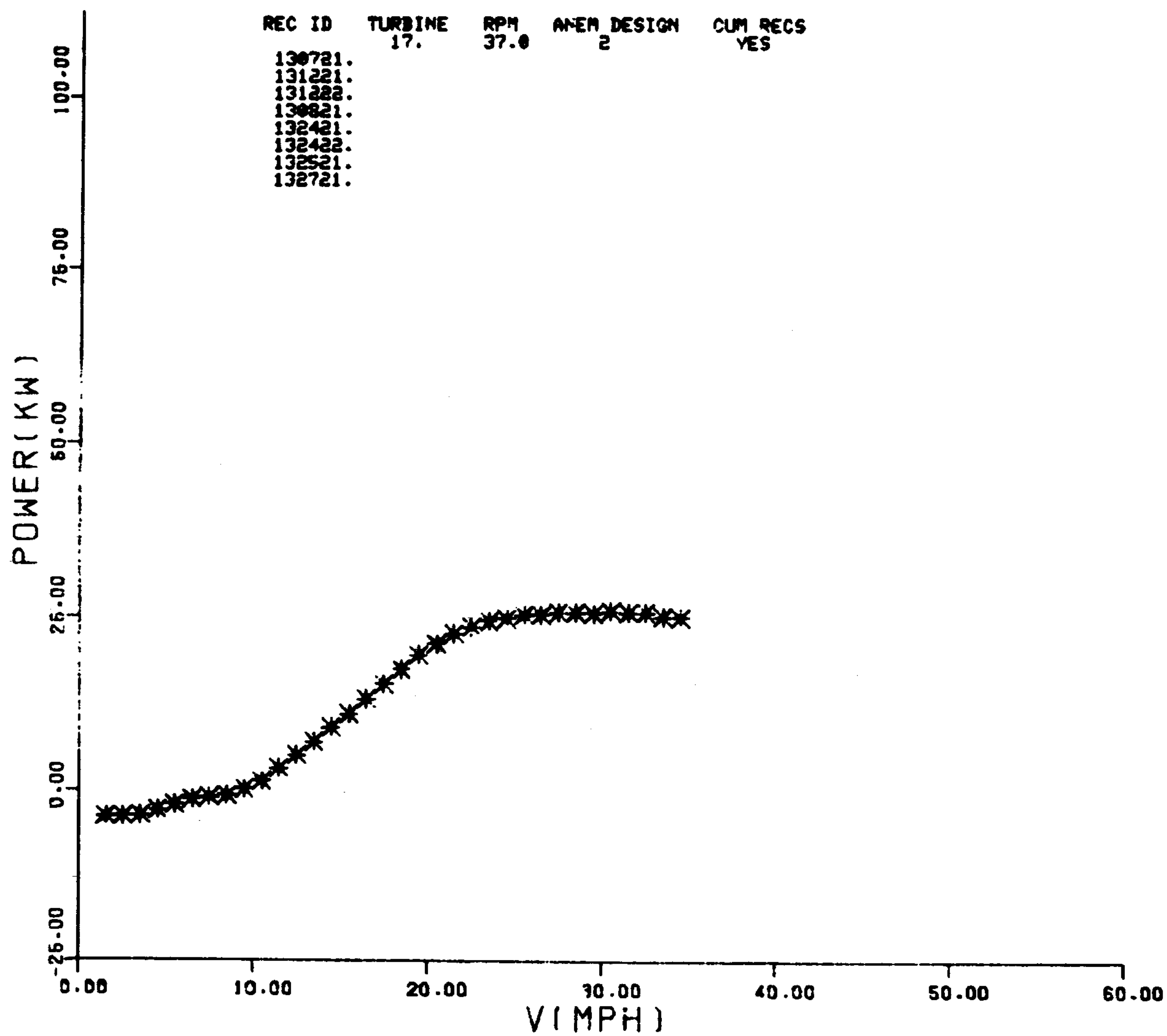
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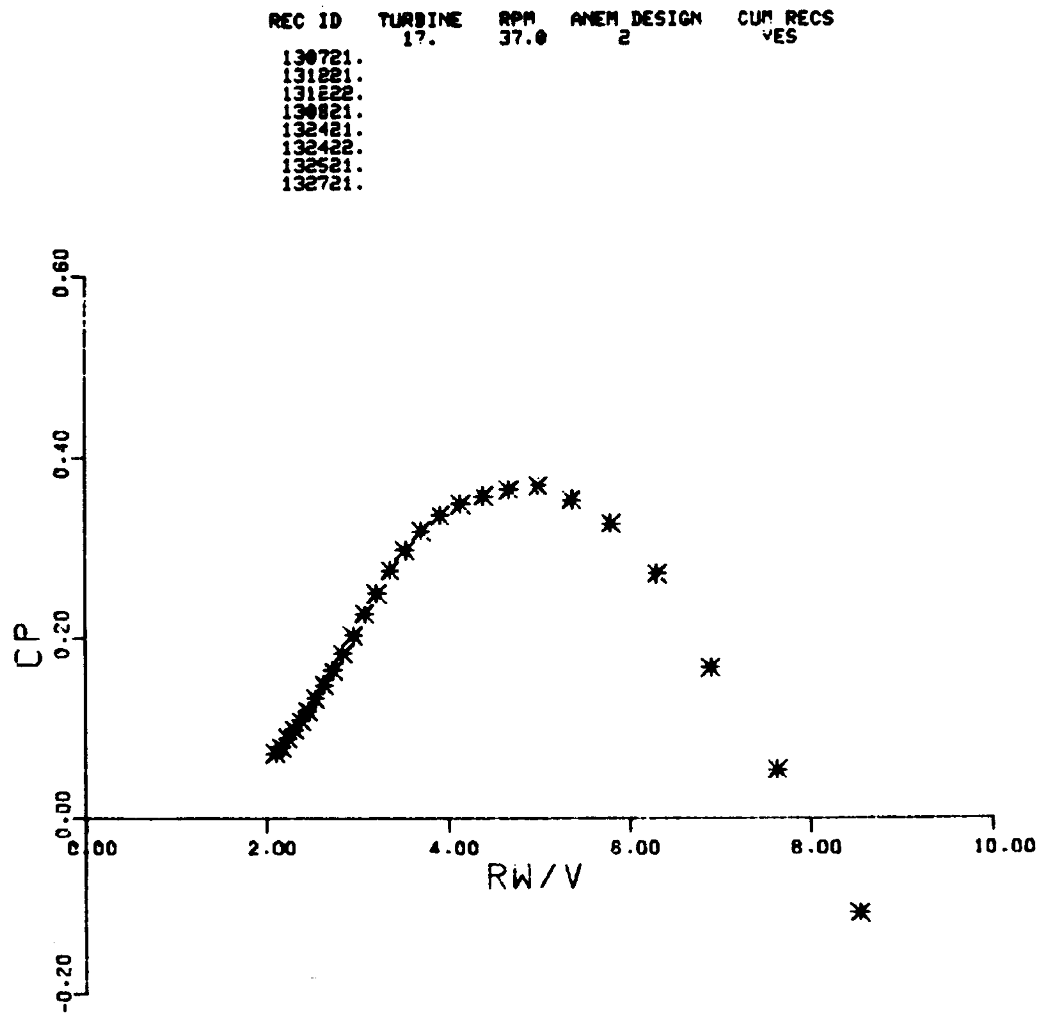
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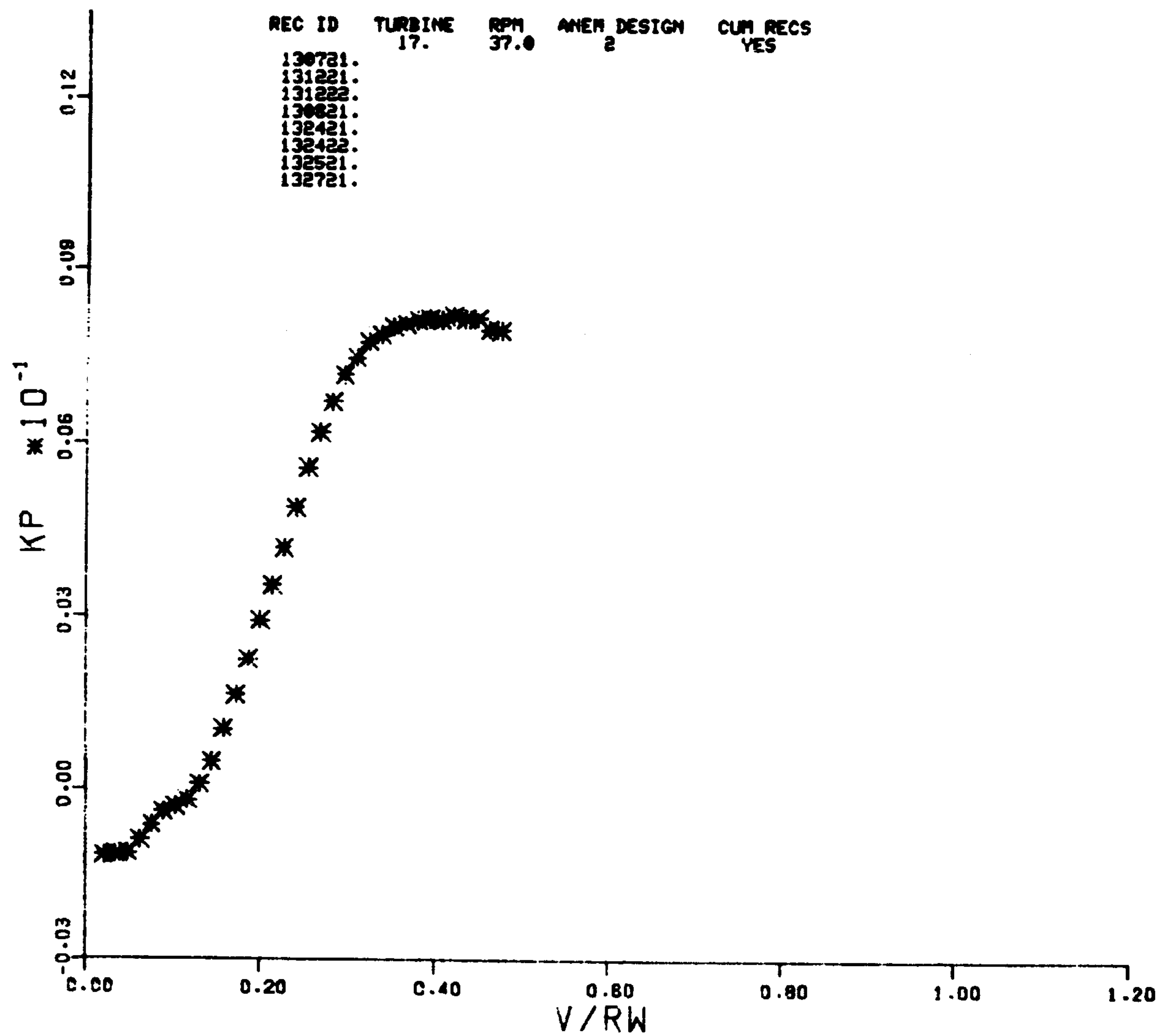
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1.20

42 rpm

3 Blades, $\sigma = 0.21$

Wind Range 4.5 to 37.5 mph

AIR DENSITY= .0625 LBS PER CU FT
17. M TURBINE, COMBINED DATA, RPM=42.0
NUMBER SAMPLES IN ACCUMULATION = 105366.
DATA RECORD NAME(S)= 140821. 141421. 141422. 254921. 255921. 252021. 254021. 255021. 256021. 255121.

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4.5	440.	.004	-2.5184	18.28	-3.304	.055	-.00054	
5.5	974.	.009	-1.8677	14.96	-1.342	.067	-.00040	
6.5	2227.	.021	-1.2365	12.66	-.538	.079	-.00027	
7.5	4036.	.038	-.8473	10.97	-.240	.091	-.00018	
8.5	5647.	.054	-.0960	9.68	-.019	.103	-.00002	
9.5	6032.	.057	1.0218	8.66	.142	.115	.00022	
10.5	6367.	.060	2.1905	7.84	.226	.128	.00047	
11.5	6881.	.065	3.0479	7.15	.240	.140	.00065	
12.5	6583.	.062	4.0837	6.58	.250	.152	.00088	
13.5	6157.	.058	5.8532	6.09	.284	.164	.00126	
14.5	5640.	.054	7.9494	5.67	.312	.176	.00171	
15.5	5149.	.049	9.6303	5.31	.309	.188	.00207	
16.5	4212.	.040	11.3066	4.99	.301	.201	.00243	
17.5	3556.	.034	13.6810	4.70	.305	.213	.00294	
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24.5	2679.	.025	32.8887	3.36	.267	.298	.00706	
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32.5	1672.	.016	41.9097	2.53	.146	.395	.00900	
33.5	1533.	.015	41.6077	2.46	.132	.407	.00893	
34.5	1362.	.013	42.0988	2.38	.123	.419	.00904	
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36.5	655.	.006	42.1079	2.25	.104	.444	.00904	
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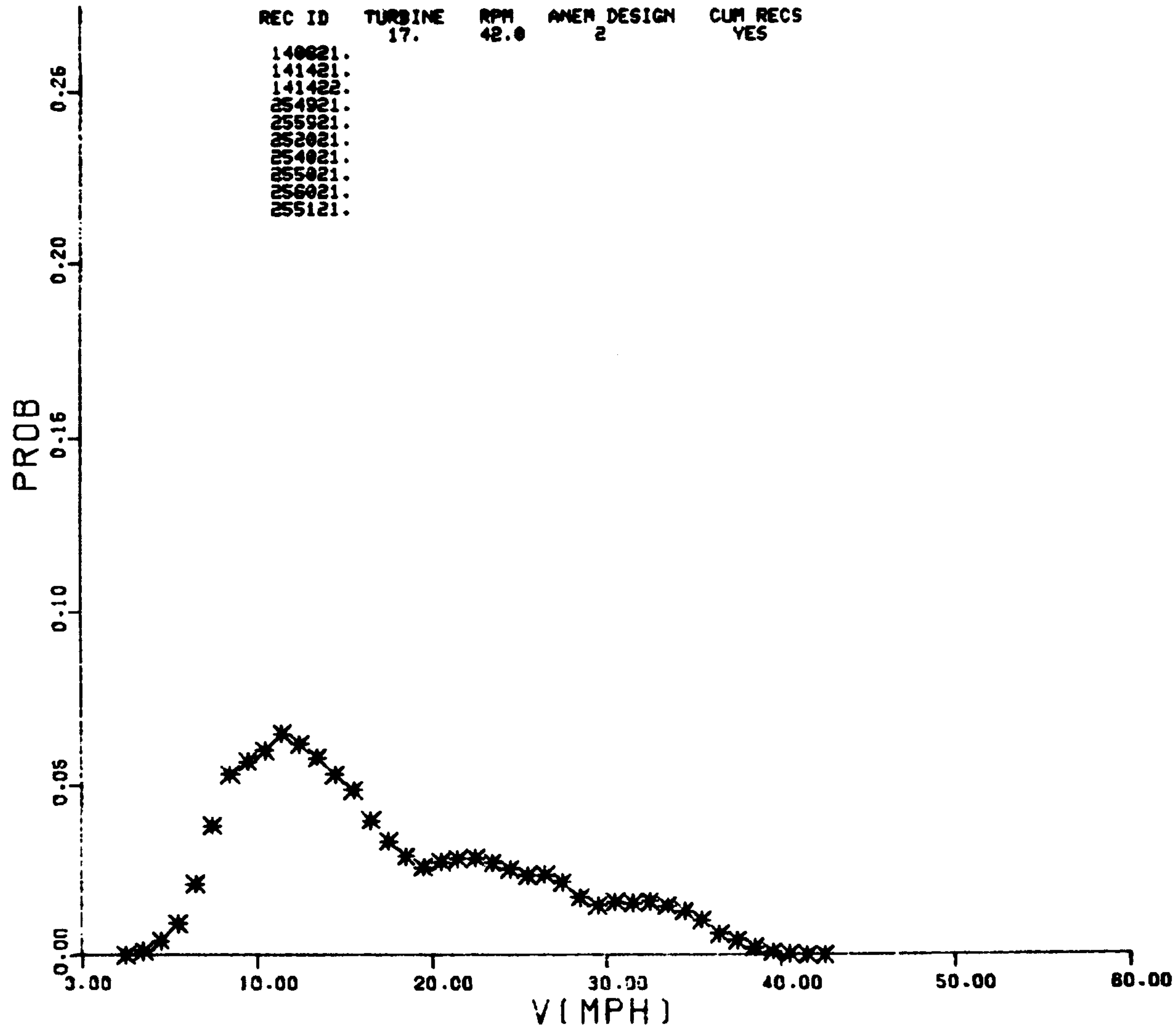
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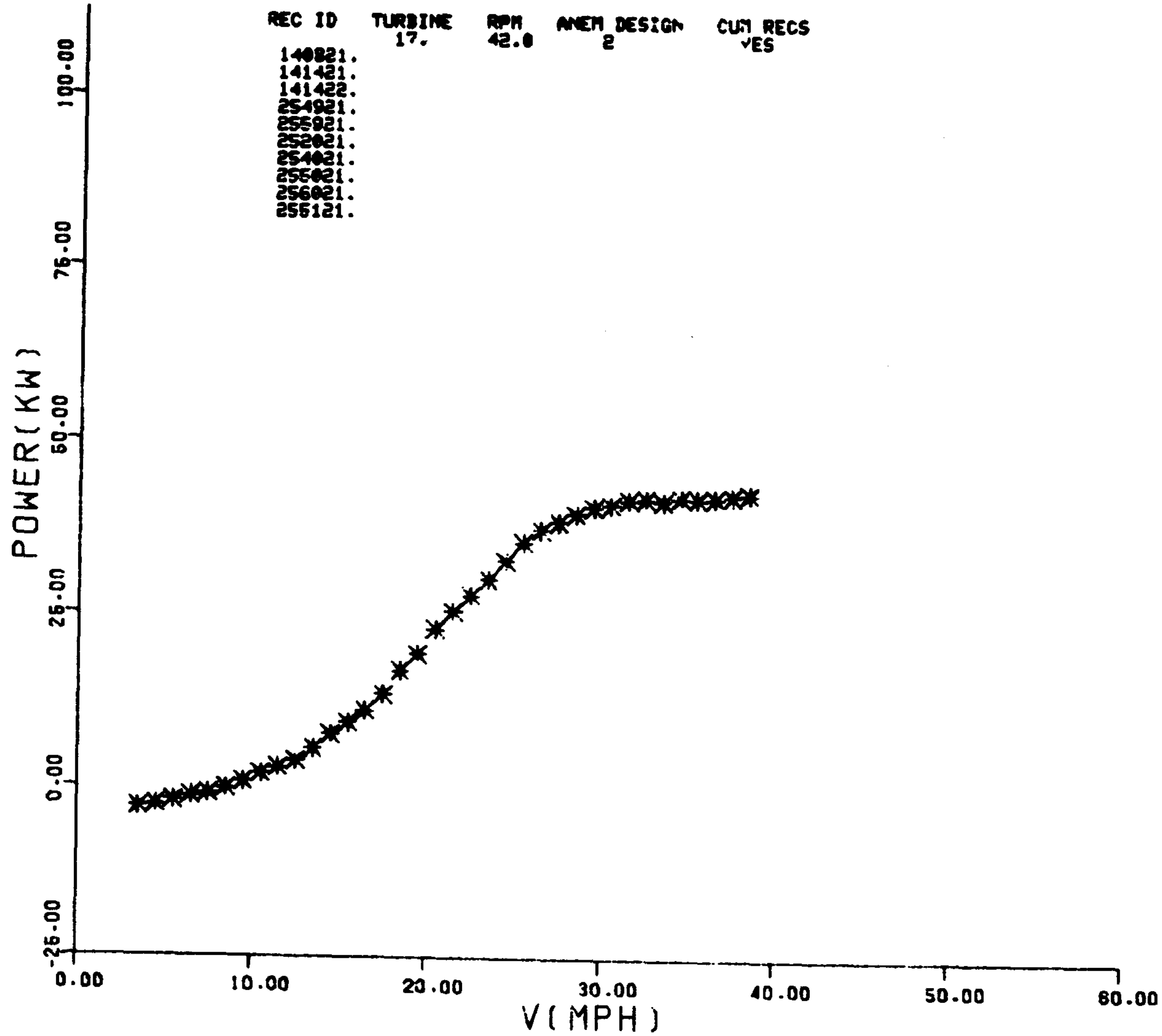
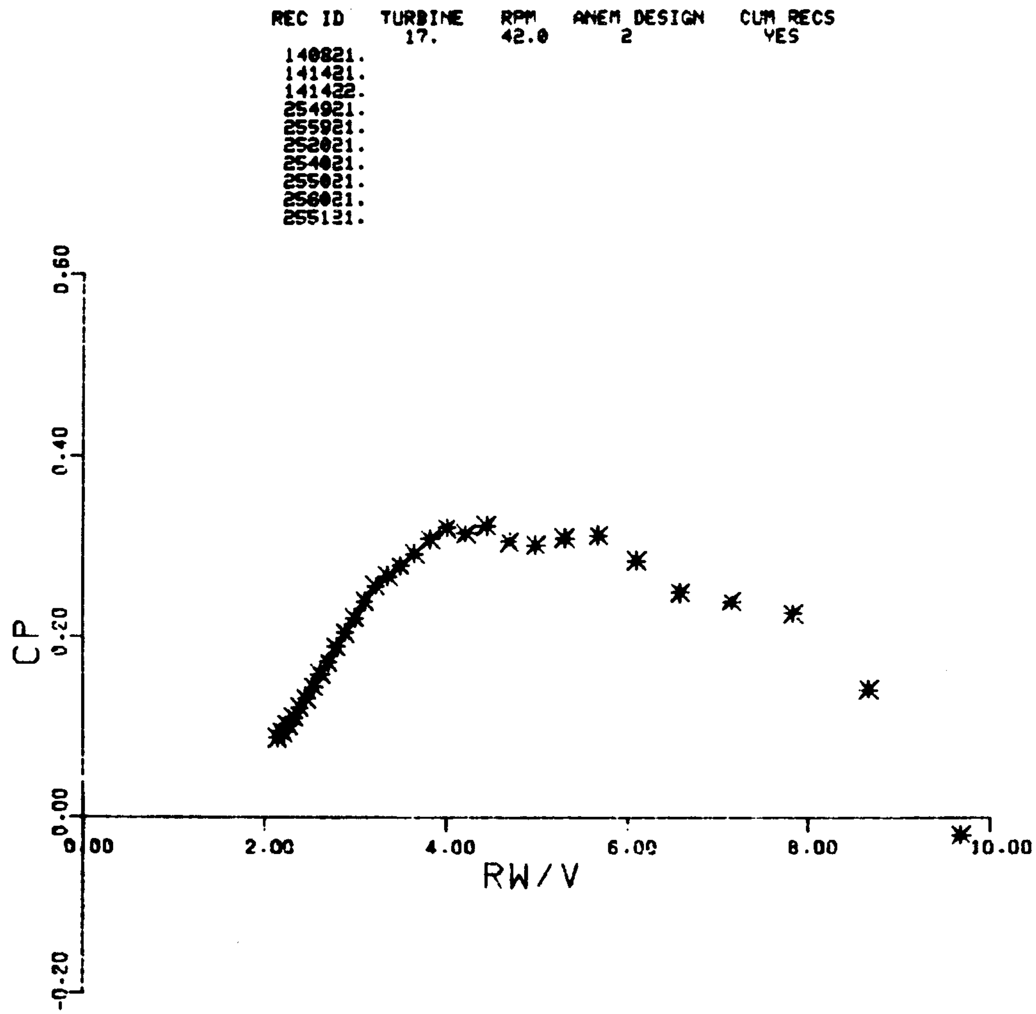
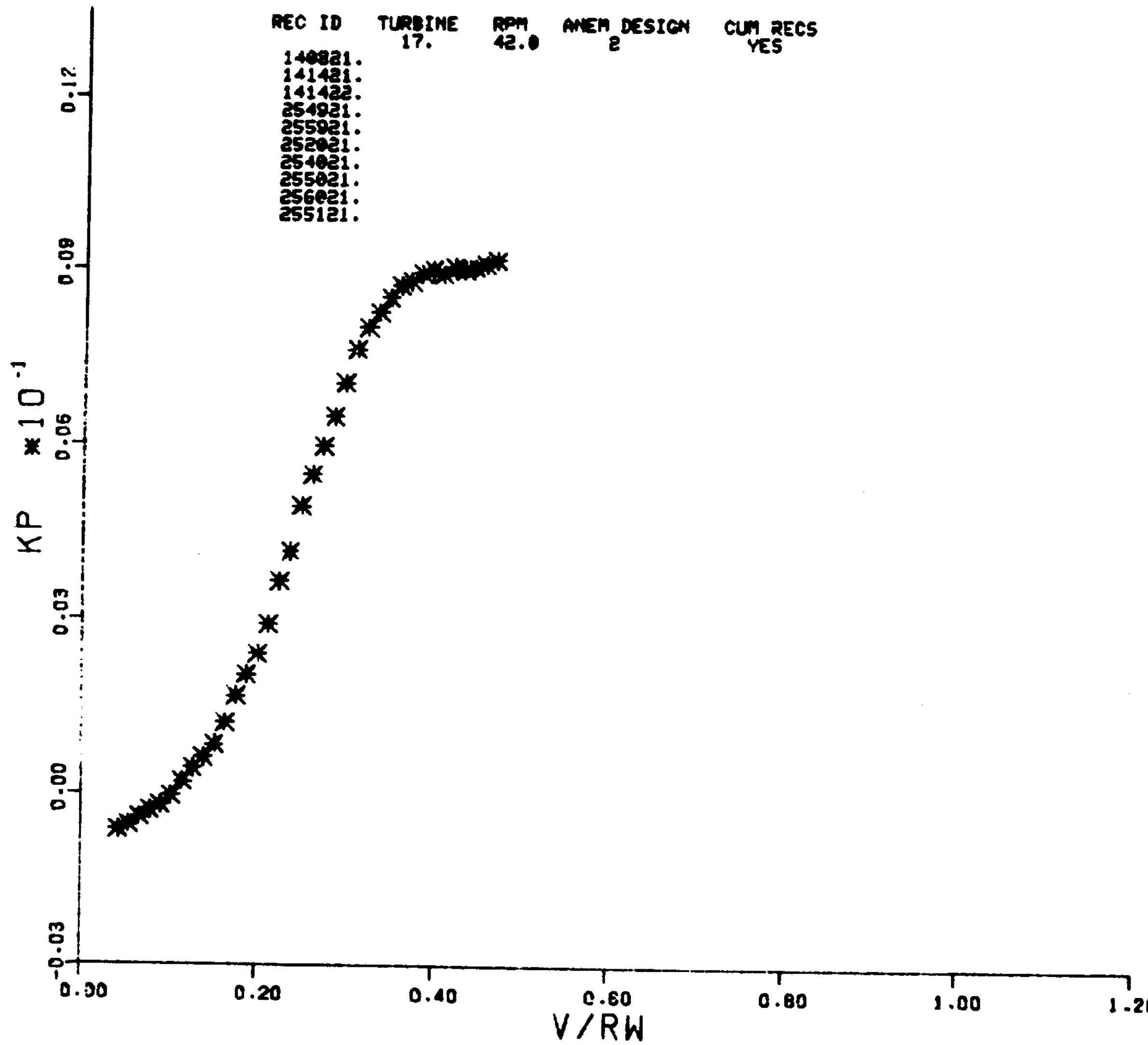
60.00
V(MPH)



REC ID
TURBINE
17.
RPM
42.0
ANEM DESIGN
2
CUM RECS
YES
140821.
141421.
141422.
254921.
255921.
252021.
254021.
255021.
256021.
255121.
POWER(KW)
100.00
75.00
50.00
25.00
0.00
-25.00
0.00
10.00
20.00
30.00
40.00
50.00
60.00
V(MPH)


REC ID TURBINE RPM ANEM DESIGN CUM RECS
17. 42.0 2 YES
140821.
141421.
141422.
254921.
255921.
252021.
254021.
255021.
256021.
255121.
CP
0.60
0.40
0.20
0.00
-0.20
0.00
2.00
4.00
6.00
8.00
10.00
RW/V


REC ID TURBINE RPM ANEM DESIGN CUM RECS
17. 42.0 2 YES
140821.
141421.
141422.
254921.
255921.
252021.
254021.
255021.
256021.
255121.
KP *10⁻¹
0.12
0.09
0.06
0.03
0.00
-0.03
0.00 0.20 0.40 0.60 0.80 1.00 1.20
V/RW

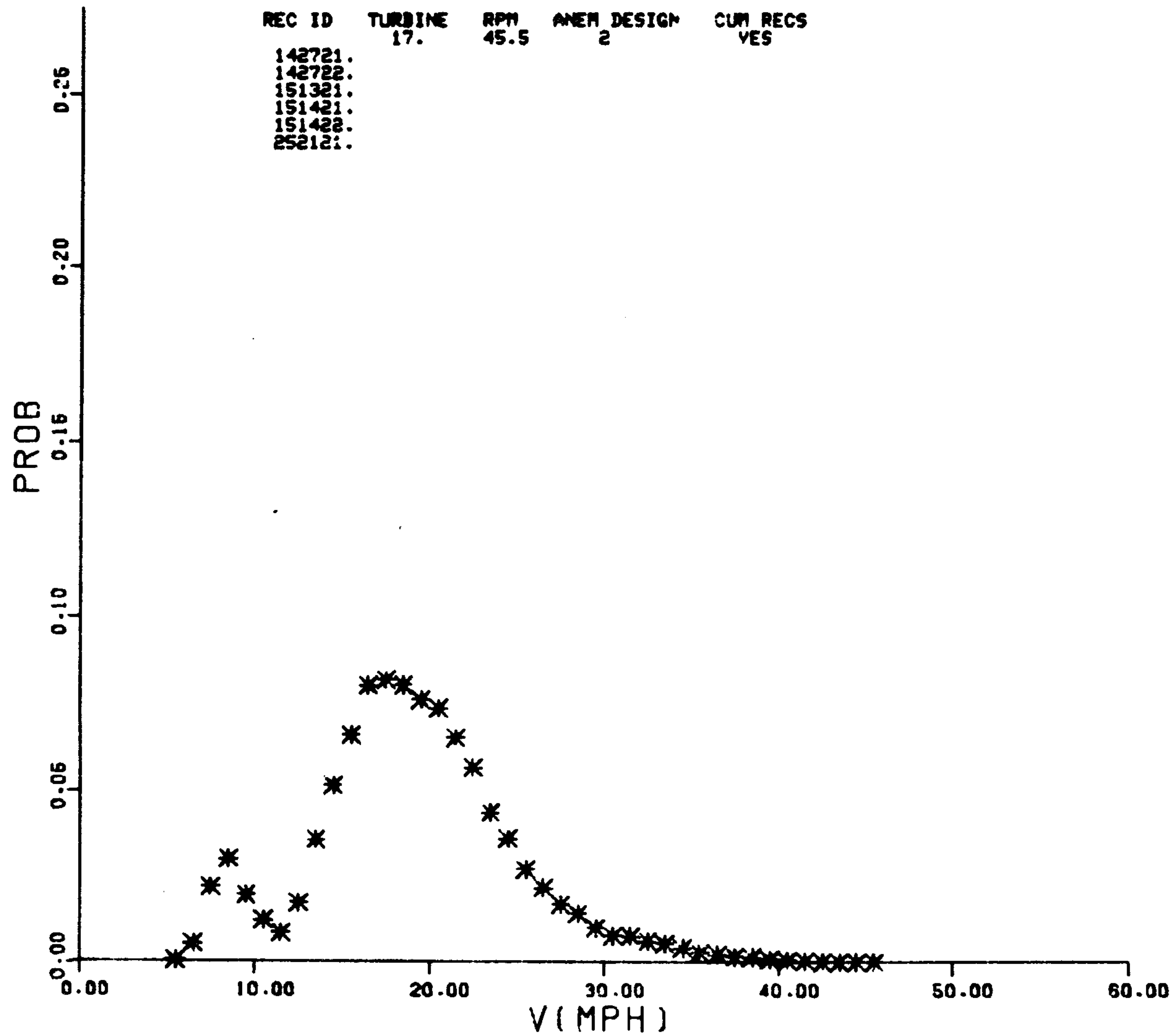
45.5 rpm

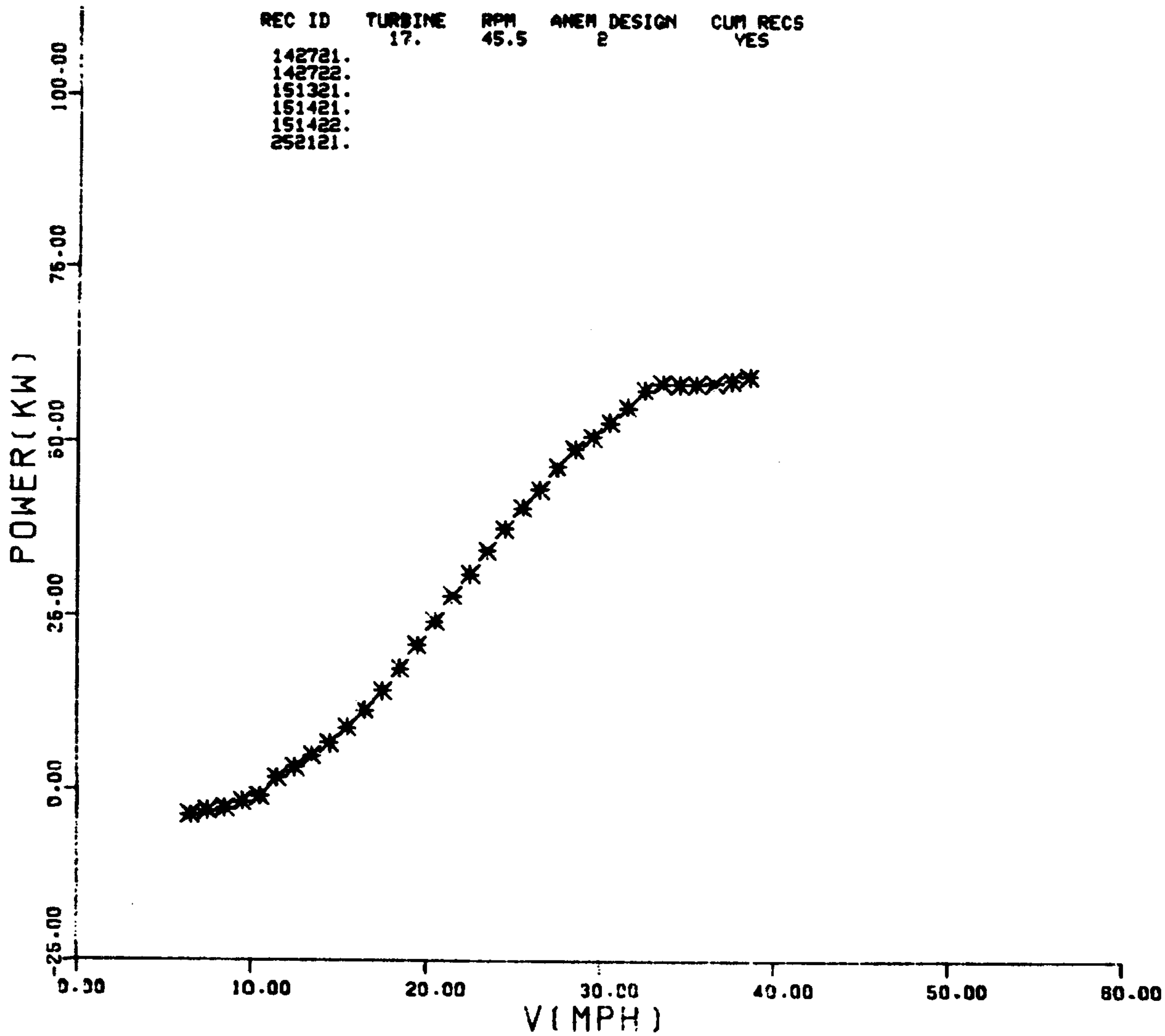
3 Blades, $\sigma = 0.21$

Wind Range 6.5 to 34.5 mph

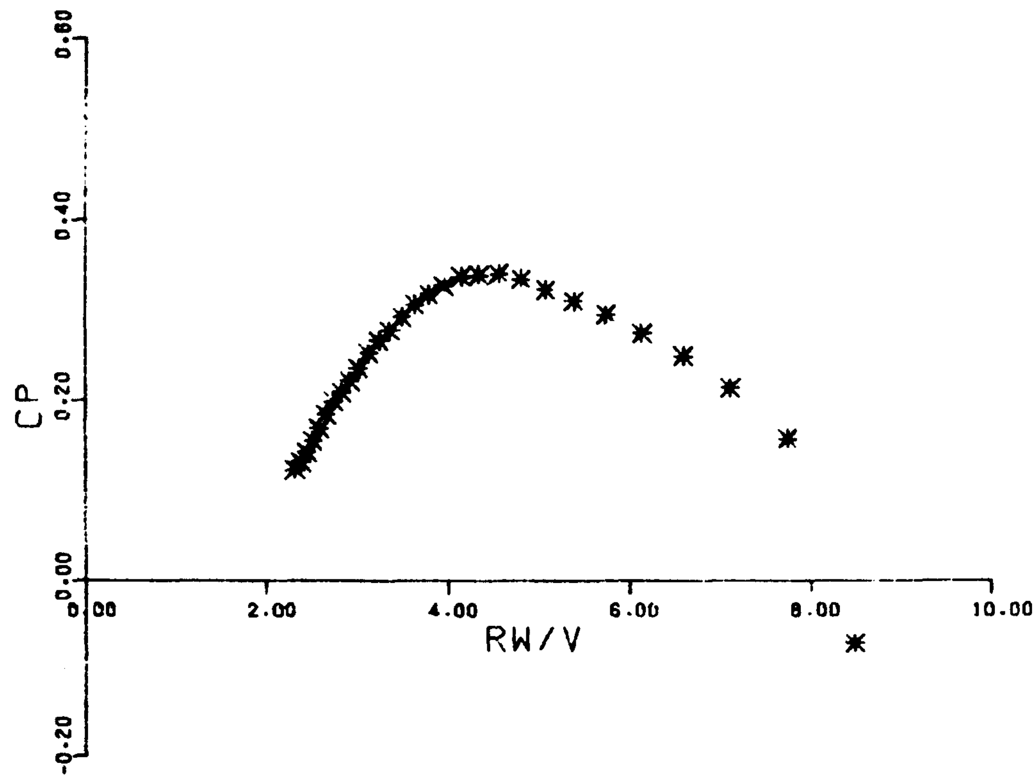
AIR DENSITY= .0626 LBS PER CU FT
17. M TURBINE, COMBINED DATA, RPM=45.5
NUMBER SAMPLES IN ACCUMULATION = 87978.
DATA RECORD NAME(S)= 142721. 142722. 151321. 151421. 151422. 252121.

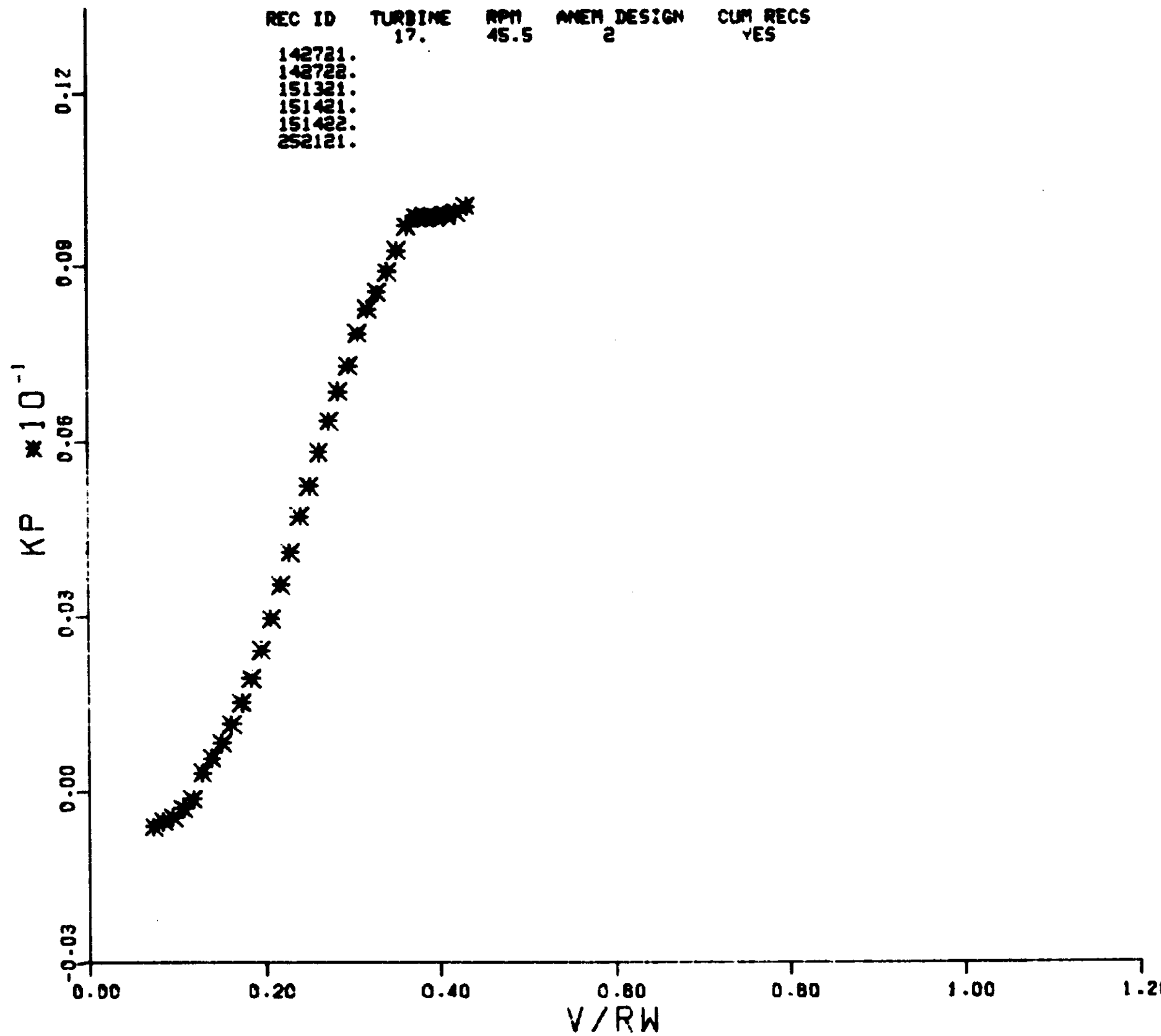
V	N	F	POWER(KW)	RW/V	CP	V/RW	KP	RMS
5.5	38.	.000	-3.9004	16.21	-2.803	.062	-.00066	
6.5	459.	.005	-3.5223	13.71	-1.533	.073	-.00059	
7.5	1930.	.022	-2.9673	11.88	-.841	.084	-.00053	
8.5	2658.	.030	-2.5650	10.49	-.499	.095	-.00043	
9.5	1737.	.020	-1.5961	9.38	-.223	.107	-.00027	
10.5	1069.	.012	-.6810	8.49	-.070	.118	-.00011	
11.5	753.	.009	2.0069	7.75	.158	.129	.00034	
12.5	1526.	.017	3.4983	7.13	.214	.140	.00059	
13.5	3174.	.036	5.1257	6.60	.249	.151	.00037	
14.5	4577.	.052	6.9954	6.15	.274	.163	.00118	
15.5	5856.	.067	9.1922	5.75	.295	.174	.00155	
16.5	7097.	.081	11.6436	5.40	.310	.185	.00137	
17.5	7255.	.082	14.4413	5.09	.322	.196	.00244	
18.5	7106.	.081	17.6451	4.82	.333	.208	.00298	
19.5	6735.	.077	21.0566	4.57	.340	.219	.00355	
20.5	6517.	.074	24.3810	4.35	.338	.230	.00412	
21.5	5797.	.066	27.9986	4.15	.337	.241	.00473	
22.5	5032.	.057	31.0005	3.96	.326	.252	.00525	
23.5	3883.	.044	34.4732	3.79	.318	.264	.00582	
24.5	3209.	.036	37.5928	3.64	.306	.275	.00635	
25.5	2408.	.027	40.5758	3.50	.293	.286	.00685	
26.5	1927.	.022	43.1558	3.36	.277	.297	.00729	
27.5	1490.	.017	46.4126	3.24	.267	.309	.00784	
28.5	1259.	.014	48.8969	3.13	.253	.320	.00825	
29.5	832.	.010	50.6074	3.02	.236	.331	.00854	
30.5	684.	.008	52.6358	2.92	.222	.342	.00889	
31.5	676.	.008	54.7741	2.83	.210	.353	.00925	
32.5	536.	.006	57.3038	2.74	.200	.365	.00967	
33.5	474.	.005	58.2511	2.66	.185	.376	.00983	
34.5	361.	.004	58.1547	2.58	.169	.387	.00982	
35.5	242.	.003	58.1708	2.51	.155	.398	.00982	
36.5	203.	.002	58.3330	2.44	.143	.409	.00985	
37.5	150.	.002	58.6998	2.38	.133	.421	.00991	
38.5	119.	.001	59.2613	2.32	.124	.432	.01000	
39.5	76.	.001	57.6477	2.26	.112	.443	.00973	
40.5	37.	.000	58.2725	2.20	.105	.454	.00984	
41.5	18.	.000	57.7481	2.15	.097	.466	.00975	
42.5	6.	.000	57.3845	2.10	.089	.477	.00969	
43.5	3.	.000	65.8179	2.05	.096	.488	.01111	
44.5	4.	.000	63.7428	2.00	.086	.499	.01076	
45.5	2.	.000	55.2828	1.96	.070	.510	.00933	


REC ID TURBINE RPM ANEM DESIGN CUM RECS
17. 45.5 2 YES
142721.
142722.
151321.
151421.
151422.
252121.
PROB
0.25
0.20
0.15
0.10
0.05
0.00
V(MPH)
0.00
10.00
20.00
30.00
40.00
50.00
60.00


REC ID
142721.
142722.
151321.
151421.
151422.
252121.
TURBINE
17.
RPM
45.5
ANEM DESIGN
2
CUM RECS
YES
POWER(KW)
100.00
75.00
50.00
25.00
0.00
-25.00
0.00
10.00
20.00
30.00
40.00
50.00
60.00
V(MPH)

REC ID	TURBINE	RPM	ANEM DESIGN	CUM RECS
	17.	45.5	2	YES
142721.				
142722.				
151321.				
151421.				
151422.				
252121.				




REC ID
142721.
142722.
151321.
151421.
151422.
252121.
TURBINE
17.
RPM
45.5
ANEM DESIGN
2
CUM RECS
YES
KP *10^-1
V/RW
0.00
0.20
0.40
0.60
0.80
1.00
1.20
-0.03
0.00
0.03
0.06
0.09
0.12

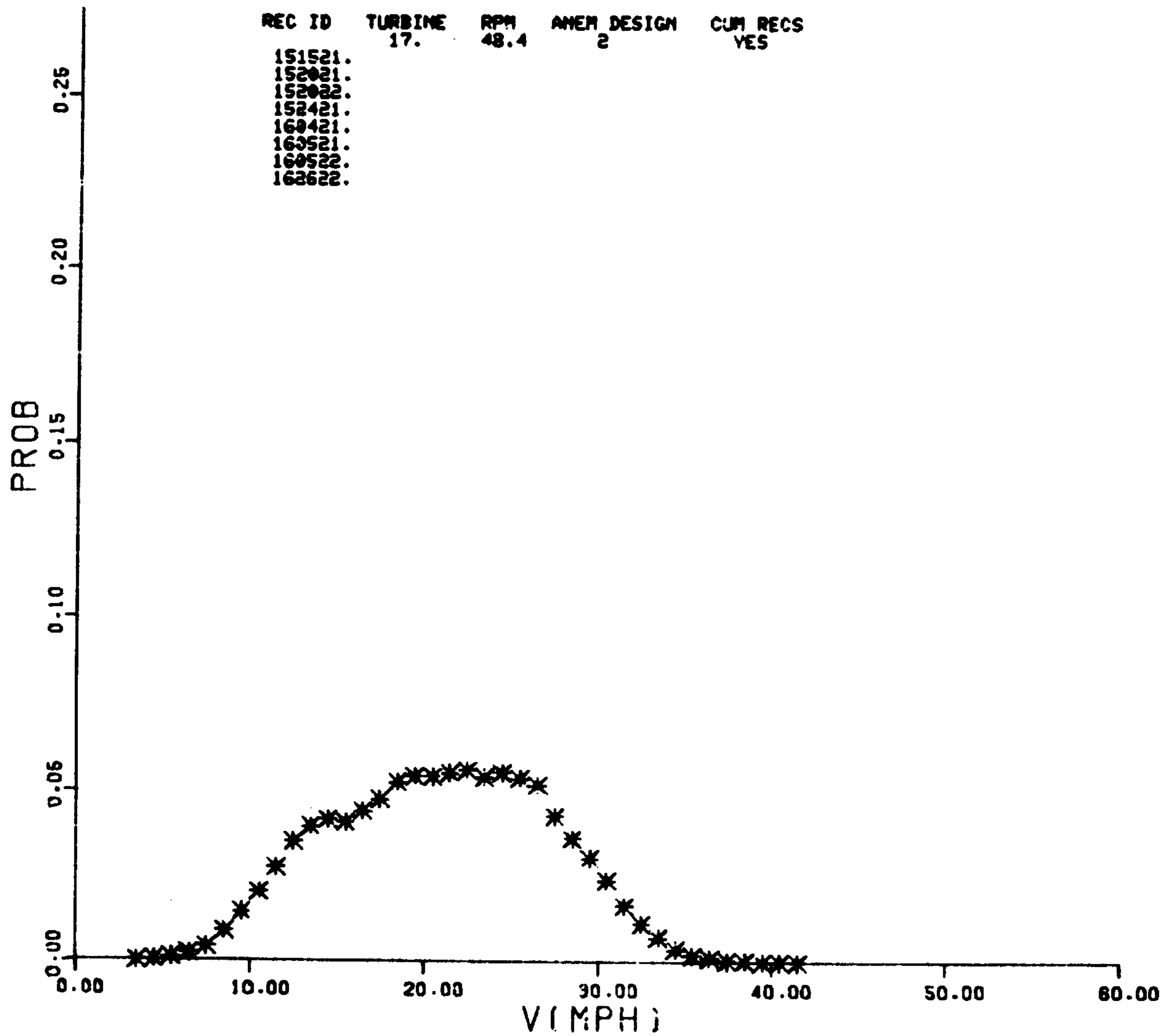
48.4 rpm

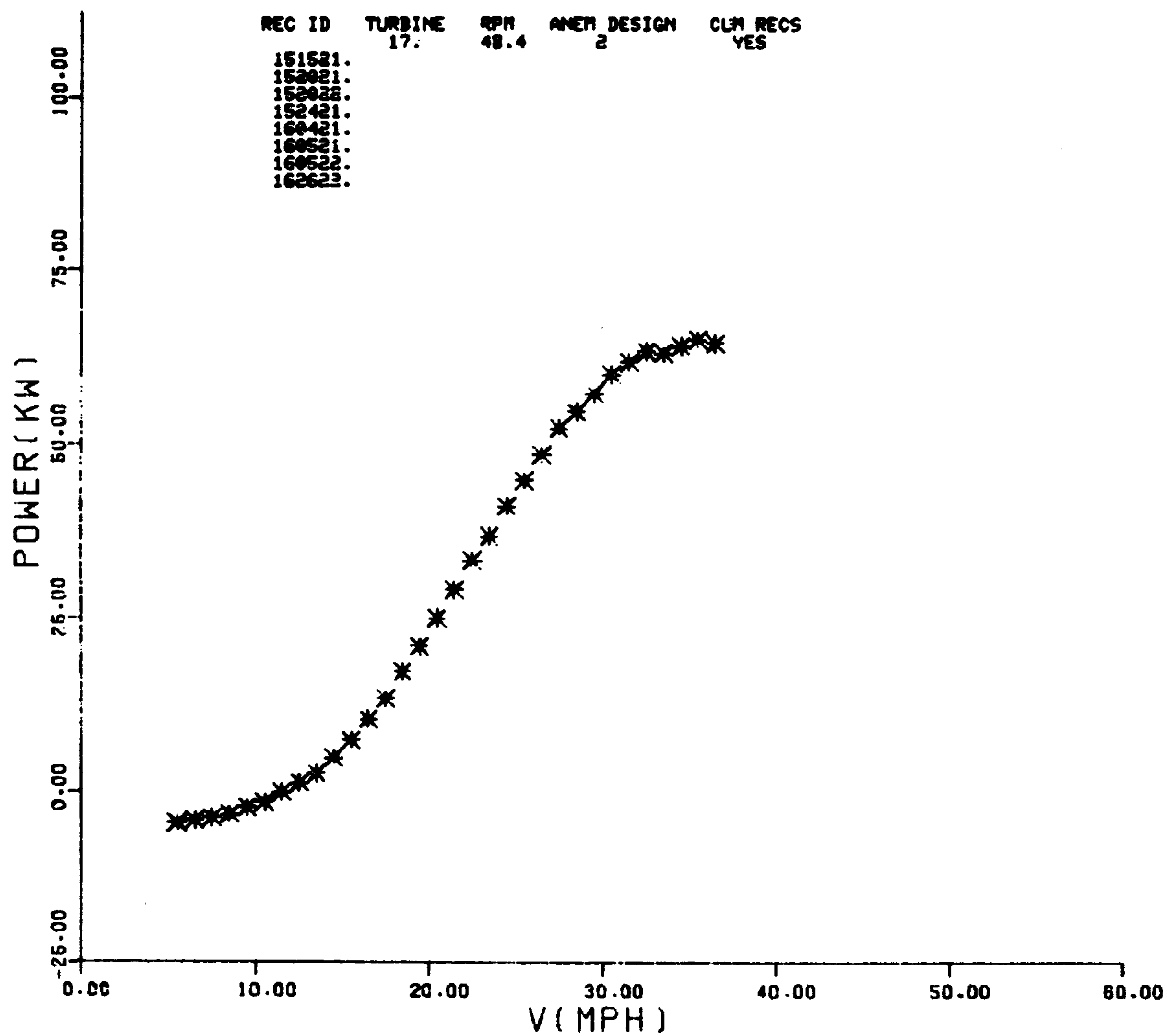
3 Blades, $\sigma = 0.21$

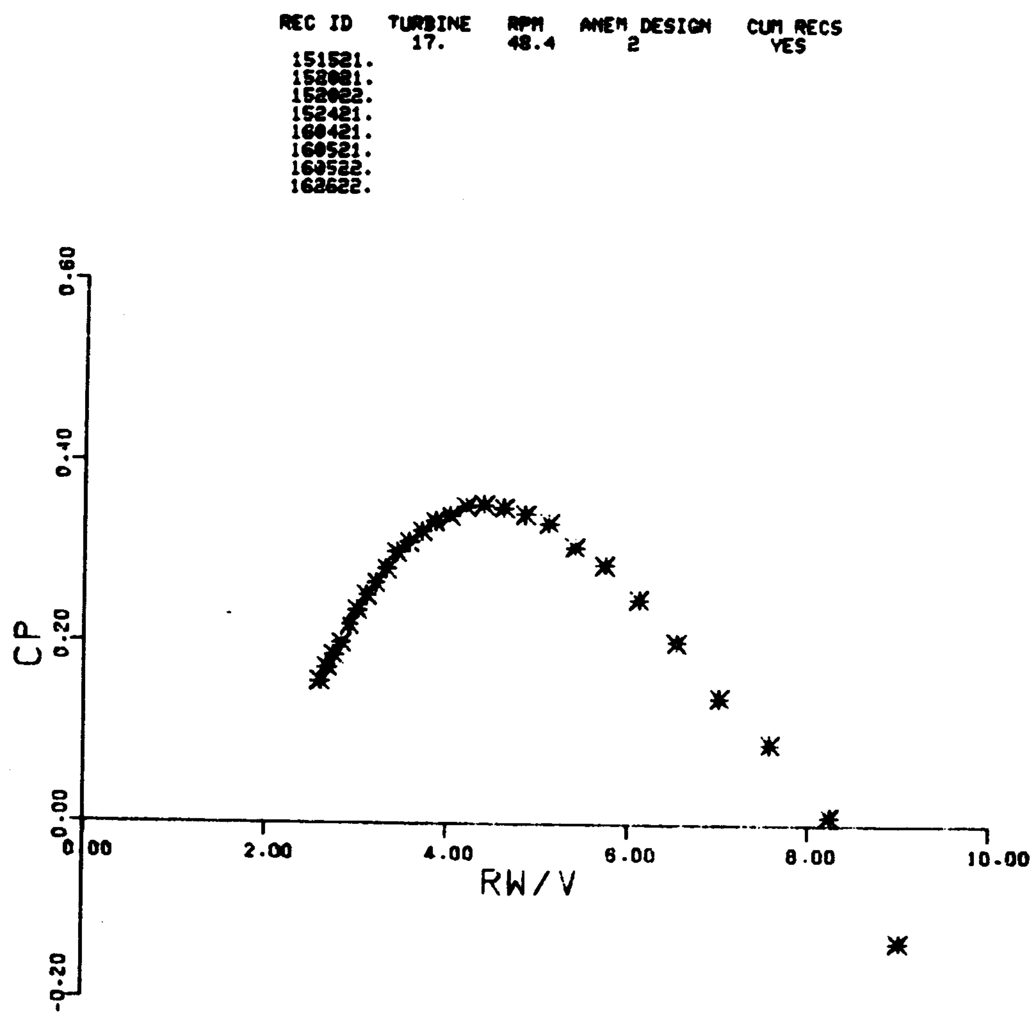
Wind Range 6.5 to 34.5 mph

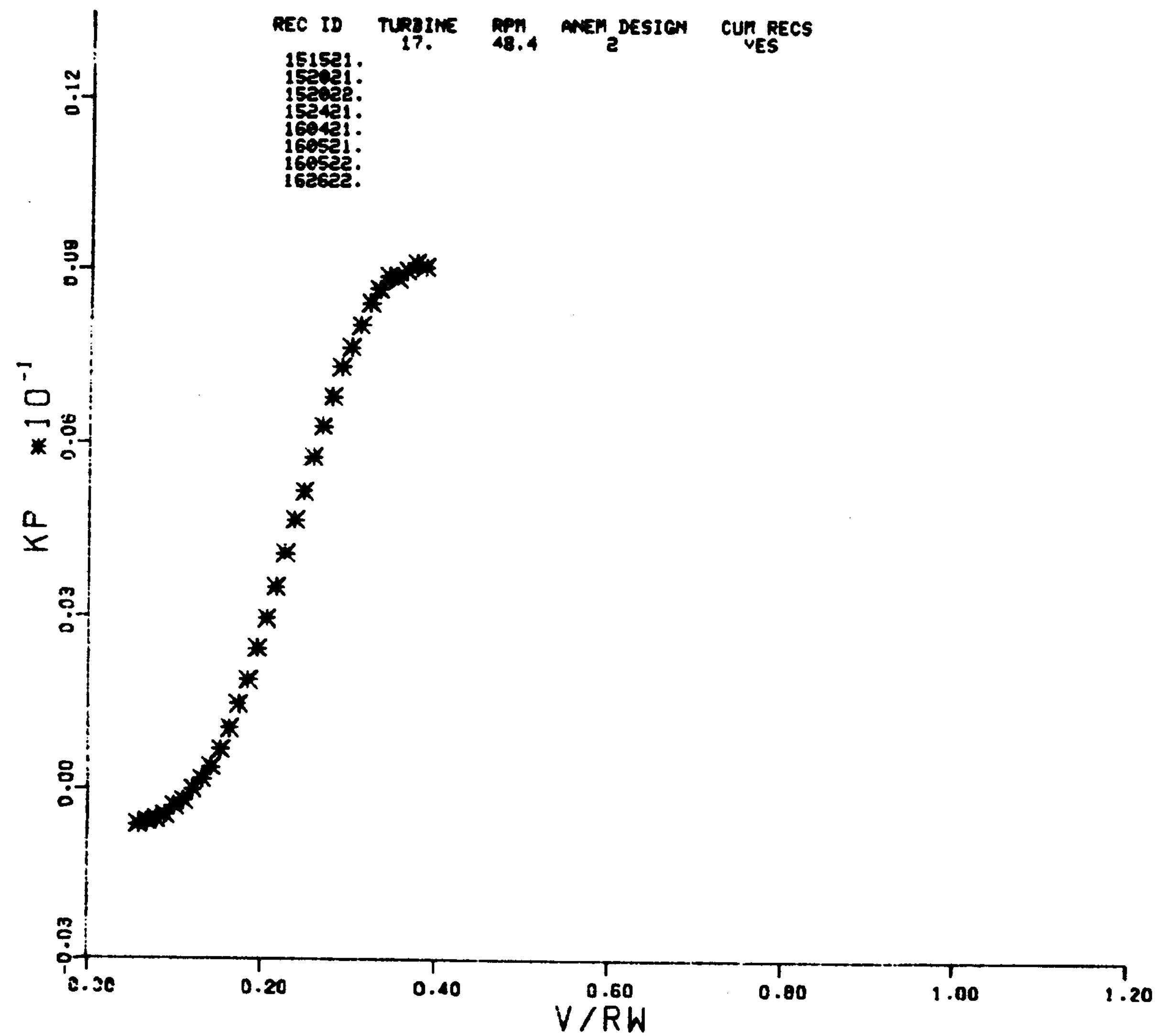
AIR DENSITY= .0625 LBS PER CU FT
17. M TURBINE, COMBINED DATA, RPM=48.4
NUMBER SAMPLES IN ACCUMULATION = 130048.
DATA RECORD NAME(S)= 151521. 152021. 152022. 152421. 160421. 160521. 160522. 162622.

V	N	F	POWER(KW)	RW/V	CP	V/RW	KP	RMS
3.5	10.	.000	-5.0830	27.09	-14.174	.037	-.00071	
4.5	42.	.000	-4.3238	21.07	-5.673	.047	-.00061	
5.5	144.	.001	-4.3474	17.24	-3.124	.058	-.00061	
6.5	312.	.002	-4.0112	14.59	-1.746	.069	-.00056	
7.5	566.	.004	-3.5961	12.64	-1.019	.079	-.00050	
8.5	1162.	.009	-3.1018	11.15	-.604	.090	-.00044	
9.5	1876.	.014	-2.0484	9.98	-.286	.100	-.00029	
10.5	2666.	.021	-1.2859	9.03	-.133	.111	-.00018	
11.5	3607.	.028	.1331	8.24	.010	.121	.00002	
12.5	4626.	.036	1.4780	7.59	.090	.132	.00021	
13.5	5193.	.040	2.9122	7.02	.142	.142	.00041	
14.5	5470.	.042	5.1542	6.54	.202	.153	.00072	
15.5	5374.	.041	7.7416	6.12	.249	.163	.00109	
16.5	5792.	.045	10.7682	5.75	.287	.174	.00151	
17.5	6240.	.048	13.7109	5.42	.306	.185	.00192	
18.5	6884.	.053	17.5802	5.13	.332	.195	.00247	
19.5	7124.	.055	21.2265	4.86	.342	.206	.00298	
20.5	7123.	.055	25.1161	4.63	.349	.216	.00352	
21.5	7245.	.056	29.2854	4.41	.352	.227	.00411	
22.5	7353.	.057	33.3923	4.21	.350	.237	.00468	
23.5	7085.	.054	36.9180	4.03	.340	.248	.00518	
24.5	7273.	.056	41.0735	3.87	.334	.258	.00576	
25.5	7038.	.054	44.8481	3.72	.323	.269	.00629	
26.5	6779.	.052	48.4742	3.58	.311	.279	.00680	
27.5	5609.	.043	52.2154	3.45	.300	.290	.00732	
28.5	4774.	.037	54.6191	3.33	.282	.301	.00766	
29.5	3994.	.031	57.2587	3.21	.267	.311	.00803	
30.5	3128.	.024	59.9950	3.11	.253	.322	.00841	
31.5	2154.	.017	61.7543	3.01	.236	.332	.00866	
32.5	1462.	.011	63.2818	2.92	.220	.343	.00888	
33.5	927.	.007	62.9904	2.83	.200	.353	.00883	
34.5	488.	.004	63.9774	2.75	.186	.364	.00897	
35.5	271.	.002	64.9770	2.67	.174	.374	.00911	
36.5	152.	.001	64.4520	2.60	.158	.385	.00904	
37.5	64.	.000	67.5408	2.53	.153	.396	.00947	
38.5	27.	.000	65.5347	2.46	.137	.406	.00919	
39.5	6.	.000	73.9258	2.40	.143	.417	.01037	
40.5	1.	.000	74.8466	2.34	.135	.427	.01050	
41.5	2.	.000	82.8276	2.28	.139	.438	.01162	


REC ID TURBINE RPM ANEM DESIGN CUM RECS
17. 48.4 2 YES
151521.
152021.
152022.
152421.
160421.
160521.
160522.
162622.
PROB
0.00
0.05
0.10
0.15
0.20
0.25
0.00
10.00
20.00
30.00
40.00
50.00
60.00
V(MPH)


REC ID TURBINE RPM ANEM DESIGN CUM RECS
17. 48.4 2 YES
151521.
152021.
152026.
152421.
160421.
160521.
160522.
162623.
POWER(KW)
100.00
75.00
50.00
25.00
0.00
-25.00
0.00
10.00
20.00
30.00
40.00
50.00
60.00
V(MPH)


REC ID TURBINE RPM ANEM DESIGN CUM RECS
17. 48.4 2 YES
151521.
152021.
152022.
152421.
160421.
160521.
160522.
162622.
CP
0.60
0.40
0.20
0.00
-0.20
0.00
2.00
4.00
6.00
8.00
10.00
RW/V


REC ID
TURBINE
17.
RPM
48.4
ANEM DESIGN
2
CUM RECS
YES
151521.
152021.
152022.
152421.
160421.
160521.
160522.
162622.
KP *10^-1
V/RW
0.12
0.09
0.06
0.03
0.00
-0.03
0.00
0.20
0.40
0.60
0.80
1.00
1.20

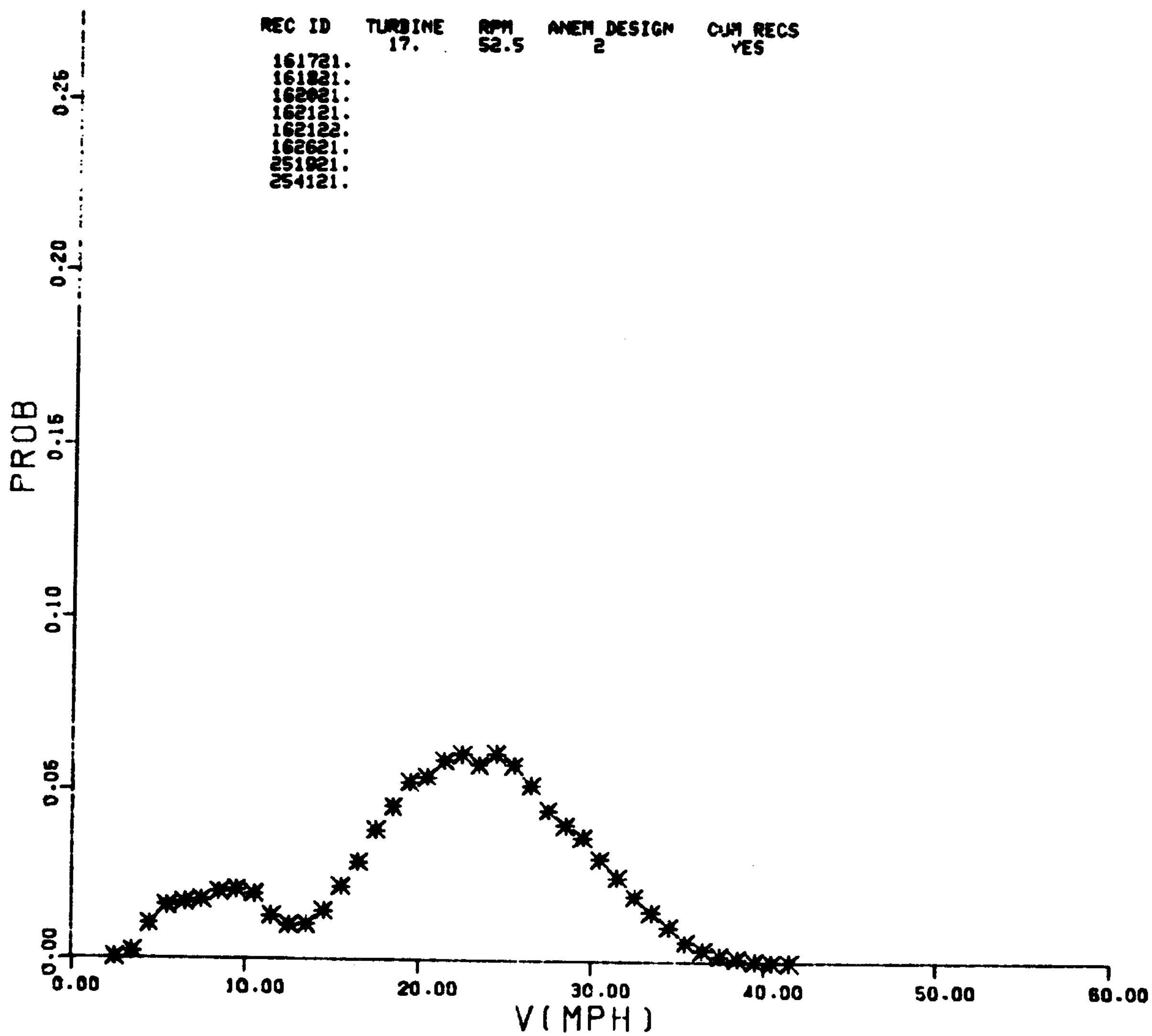
52.5 rpm

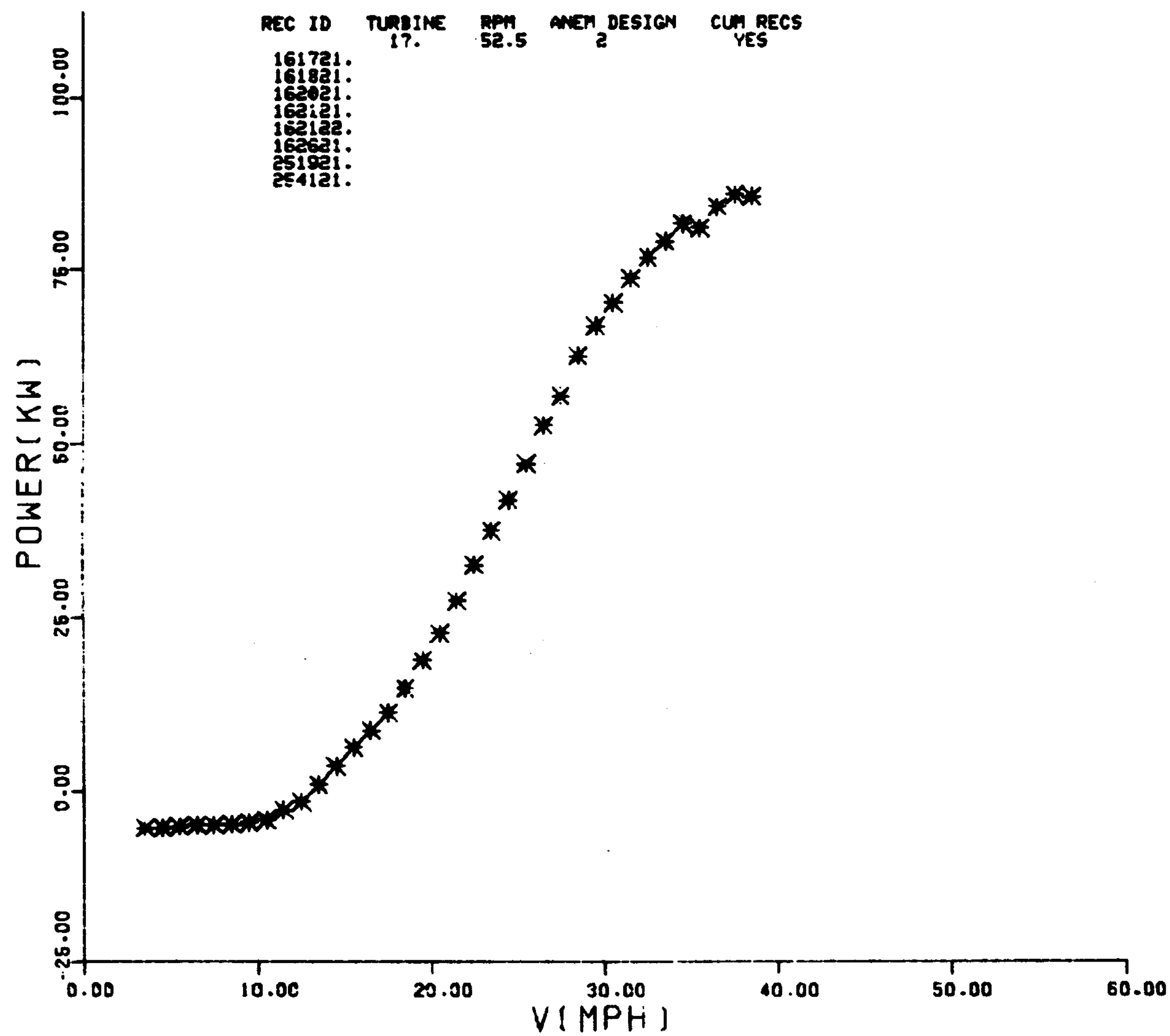
3 Blades, $\sigma = 0.21$

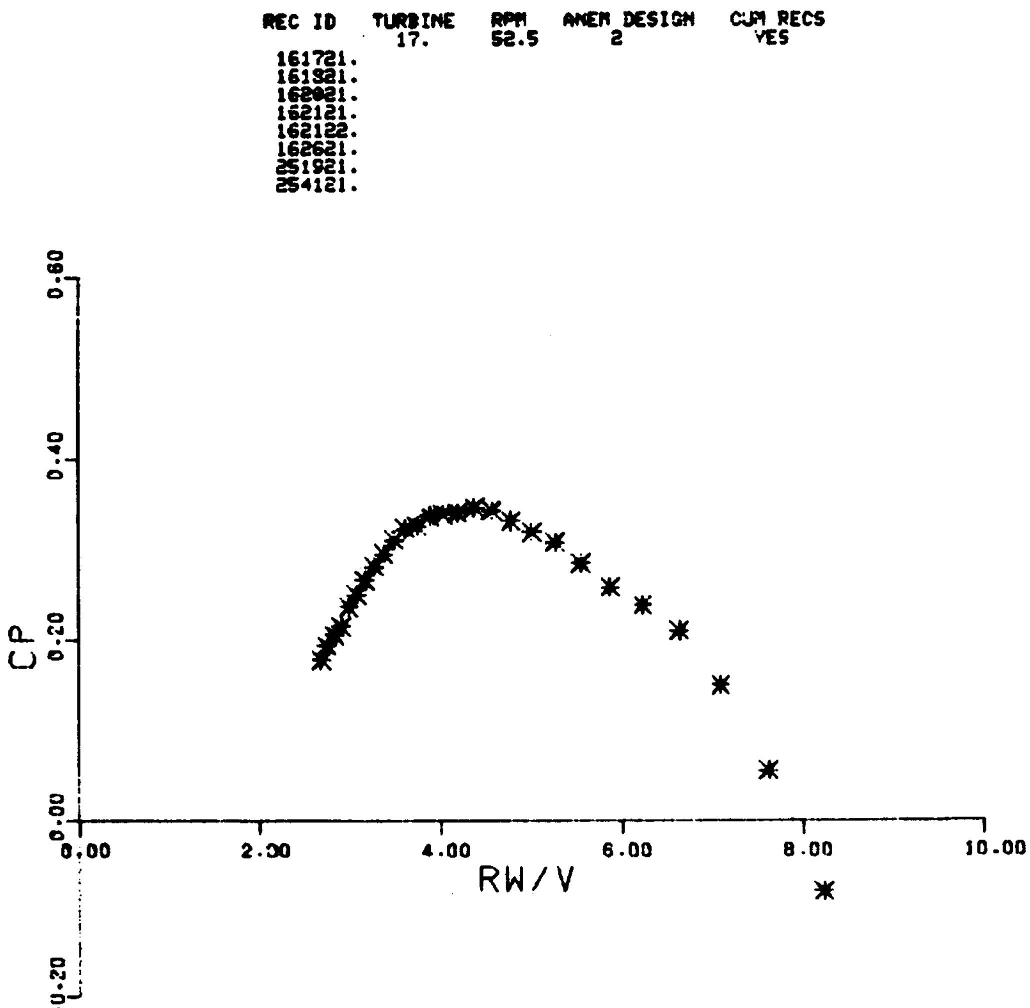
Wind Range 4.5 to 36.5 mph

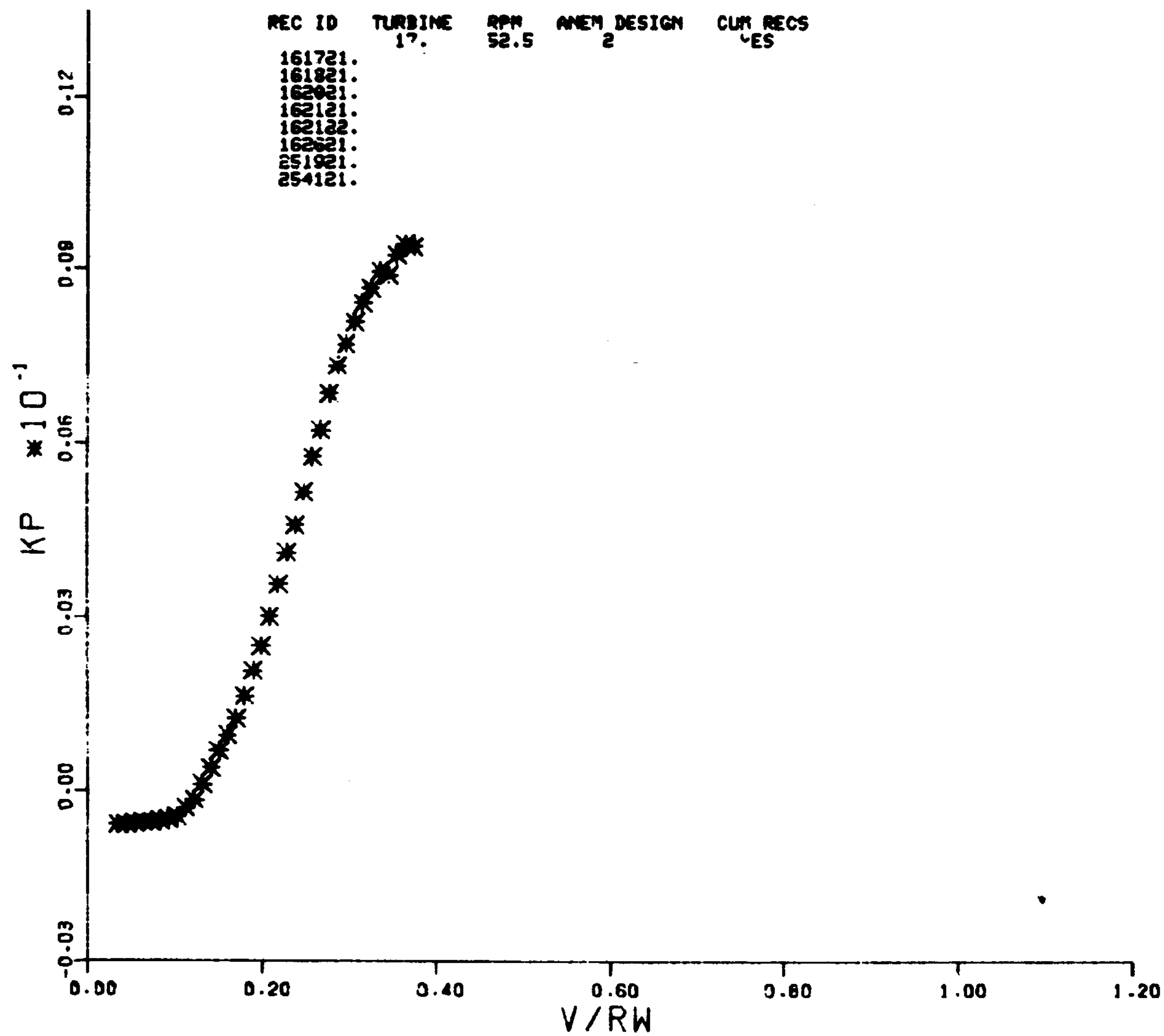
AIR DENSITY= .0625 LBS PER CU FT
17. M TURBINE, COMBINED DATA, RPM=52.5
NUMBER SAMPLES IN ACCUMULATION = 108573.
DATA RECORD NAME(S)= 161721. 161821. 162021. 162121. 162122. 162621. 251921. 254121.

V	N	F	POWER(KW)	RW/V	CP	V/RW	KP	RMS
2.5	23.	.000	-5.5790	41.14	-42.687	.024	-.00061	
3.5	231.	.002	-5.2073	29.38	-14.520	.034	-.00057	
4.5	1130.	.010	-5.2052	22.85	-6.829	.044	-.00057	
5.5	1720.	.016	-5.0393	18.70	-3.621	.053	-.00055	
6.5	1832.	.017	-4.7425	15.82	-2.065	.063	-.00052	
7.5	1912.	.018	-4.7327	13.71	-1.358	.073	-.00053	
8.5	2172.	.020	-4.6984	12.10	-.915	.083	-.00052	
9.5	2254.	.021	-4.3820	10.83	-.611	.092	-.00048	
10.5	2118.	.020	-3.9812	9.79	-.411	.102	-.00044	
11.5	1399.	.013	-2.5675	8.94	-.202	.112	-.00028	
12.5	1115.	.010	-1.2964	8.23	-.079	.122	-.00014	
13.5	1144.	.011	1.1672	7.62	.057	.131	.00013	
14.5	1577.	.015	3.8476	7.09	.151	.141	.00042	
15.5	2379.	.022	6.5548	6.64	.210	.151	.00072	
16.5	3158.	.029	8.9677	6.23	.239	.160	.00093	
17.5	4208.	.039	11.5618	5.83	.258	.170	.00127	
18.5	4986.	.046	15.0552	5.56	.285	.180	.00166	
19.5	5746.	.053	19.0673	5.27	.307	.190	.00210	
20.5	5916.	.054	22.9605	5.02	.319	.199	.00252	
21.5	6442.	.059	27.5599	4.78	.332	.209	.00303	
22.5	6647.	.061	32.6173	4.57	.342	.219	.00358	
23.5	6323.	.058	37.5570	4.38	.346	.228	.00413	
24.5	6673.	.061	41.8511	4.20	.340	.238	.00460	
25.5	6323.	.058	47.0248	4.03	.339	.248	.00517	
26.5	5661.	.052	52.5313	3.88	.337	.258	.00577	
27.5	4878.	.045	56.6792	3.74	.326	.267	.00623	
28.5	4386.	.040	62.4663	3.61	.323	.277	.00686	
29.5	3990.	.037	66.7213	3.49	.311	.287	.00733	
30.5	3307.	.030	70.0817	3.37	.295	.297	.00770	
31.5	2702.	.025	73.5160	3.26	.281	.306	.00808	
32.5	2098.	.019	76.4454	3.16	.266	.316	.00840	
33.5	1600.	.015	78.8251	3.07	.251	.326	.00866	
34.5	1126.	.010	81.4417	2.98	.237	.335	.00895	
35.5	637.	.006	80.8280	2.90	.216	.345	.00828	
36.5	390.	.004	83.9049	2.82	.206	.355	.00922	
37.5	203.	.002	85.6257	2.74	.194	.365	.00941	
38.5	107.	.001	85.3150	2.67	.179	.374	.00938	
39.5	36.	.000	84.2483	2.60	.163	.384	.00926	
40.5	18.	.000	83.6891	2.54	.151	.394	.00920	
41.5	6.	.000	93.9541	2.48	.157	.404	.01033	


REC ID
161721.
161821.
162021.
162121.
162122.
162621.
251921.
254121.
TURBINE
17.
RPM
52.5
ANEM DESIGN
2
CUM RECS
YES
PROB
0.00
0.05
0.10
0.15
0.20
0.25
0.00
10.00
20.00
30.00
40.00
50.00
60.00
V(MPH)


REC ID
TURBINE
RPM
ANEM DESIGN
CUM RECS
17.
52.5
2
YES
161721.
161821.
162021.
162121.
162122.
162621.
251921.
254121.
POWER(KW)
V(MPH)
100.00
75.00
50.00
25.00
0.00
-25.00
0.00
10.00
20.00
30.00
40.00
50.00
60.00


REC ID TURBINE RPM ANEM DESIGN CUM RECS
17. 52.5 2 YES
161721.
161921.
162021.
162121.
162122.
162621.
251921.
254121.
CP
0.60
0.40
0.20
0.00
-0.20
RW/V
0.00
2.00
4.00
6.00
8.00
10.00


REC ID TURBINE RPM ANEM DESIGN CUM RECS
17. 52.5 2
161721.
161821.
162021.
162121.
162122.
162621.
251921.
254121.
KP *10^-1
0.12
0.09
0.06
0.03
0.00
-0.03
0.00
0.20
0.40
0.60
0.80
1.00
1.20
V/RW

DISTRIBUTION:

TID-4500-R66 UC-60 (283)

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Wichita State University
Wichita, KS 67208
Attn: M. Snyder
W. Wentz

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