

Table 1. Summary of All Tests: Relationship between Real Wind Speed, Blade Pitch, and Power Output, and Computed Values for Induced and Resulting Wind Speeds and Angle of Attack

Test Conditions	Set Values		Measured Values			Computed Values											
	Real Wind Speed (m/s) (mph)	Blade Pitch at Midpoint (degrees)	RPM	Electrical Output (mV)	Blade Midpoint		Blade Angle (degrees)	Angle of Attack (degrees)	Blade Tip		Blade Angle (degrees)	Angle of Attack (degrees)					
					Induced Wind Speed (m/s) (mph)	Resulting Wind Speed (m/s) (mph)			Induced Wind Speed (m/s) (mph)	Resulting Wind Speed (m/s) (mph)							
Fixed Pitch in Wind Tunnel	7.2	16.0	60.0	140.0	30.5	2.6	5.8	7.6	17.0	60.0	10.0	5.3	11.9	8.9	19.9	52.7	0.7
	8.9	20.0	60.0	180.0	38.4	3.4	7.5	9.5	21.4	60.0	9.5	6.8	15.3	11.2	25.2	52.7	0.0
	10.7	24.0	60.0	0.0	0.0	0.0	0.0	10.7	24.0	60.0	30.0	0.0	0.0	10.7	24.0	52.7	37.3
	12.5	28.0	60.0	0.0	0.0	0.0	0.0	12.5	28.0	60.0	30.0	0.0	0.0	12.5	28.0	52.7	37.3
	14.3	32.0	60.0	0.0	0.0	0.0	0.0	14.3	32.0	60.0	30.0	0.0	0.0	14.3	32.0	52.7	37.3
	7.2	16.0	45.0	240.0	55.6	4.5	10.0	8.4	18.9	45.0	13.0	9.1	20.3	11.6	25.9	37.7	0.5
	8.9	20.0	45.0	320.0	69.7	6.0	13.3	10.7	24.0	45.0	11.3	12.1	27.1	15.1	33.7	37.7	-1.3
	10.7	24.0	45.0	400.0	85.9	7.4	16.7	13.1	29.2	45.0	10.2	15.2	33.9	18.6	41.5	37.7	-2.4
	12.5	28.0	45.0	460.0	100.0	8.6	19.2	15.2	33.9	45.0	10.6	17.4	39.0	21.5	48.0	37.7	-2.0
	14.3	32.0	45.0	540.0	116.9	10.1	22.5	17.5	39.1	45.0	9.9	20.5	45.8	25.0	55.9	37.7	-2.7
	7.2	16.0	33.9	<i>408.0</i>	88.7	7.6	17.0	10.4	23.3	33.9	9.4	15.5	34.6	17.0	38.1	26.6	-1.7
	8.9	20.0	33.9	<i>512.9</i>	111.5	9.5	21.4	13.1	29.3	33.9	9.2	19.4	43.5	21.4	47.9	26.6	-1.9
	10.7	24.0	33.9	<i>610.4</i>	132.7	11.4	25.4	15.6	35.0	33.9	9.5	23.1	51.8	25.5	57.0	26.6	-1.7
	12.5	28.0	33.9	<i>771.0</i>	167.6	14.4	32.1	19.0	42.6	33.9	7.2	29.2	65.4	31.8	71.1	26.6	-3.4
	14.3	32.0	33.9	<i>837.2</i>	182.0	15.6	34.9	21.2	47.3	33.9	8.7	31.7	71.0	34.8	77.9	26.6	-2.3
7.2	16.0	15.0	0.0	0.0	0.0	0.0	7.2	16.0	15.0	75.0	0.0	0.0	7.2	16.0	7.7	82.3	
8.9	20.0	15.0	1360.0	285.0	25.3	56.6	26.9	60.1	15.0	4.4	51.5	115.3	52.3	117.0	7.7	2.1	
Fixed Pitch at Home	4.5	10.0	60.0	<i>78.2</i>	17.0	1.5	3.3	4.7	10.5	60.0	12.0	3.0	6.6	5.4	12.0	52.7	3.8
	5.4	12.0	60.0	<i>101.2</i>	22.0	1.9	4.2	5.7	12.7	60.0	10.6	3.8	8.6	6.6	14.8	52.7	1.7
	6.3	14.0	60.0	<i>124.2</i>	27.0	2.3	5.2	6.7	14.9	60.0	9.7	4.7	10.5	7.8	17.5	52.7	0.4
	7.2	16.0	60.0	<i>133.4</i>	29.0	2.5	5.6	7.6	16.9	60.0	10.9	5.1	11.3	8.8	19.6	52.7	2.0
	4.5	10.0	45.0	<i>110.4</i>	24.0	2.1	4.6	4.9	11.0	45.0	20.3	4.2	9.4	6.1	13.7	37.7	9.2
	5.4	12.0	45.0	<i>161.0</i>	35.0	3.0	6.7	6.1	13.7	45.0	15.8	6.1	13.7	8.1	18.2	37.7	3.6
	6.3	14.0	45.0	<i>174.8</i>	38.0	3.3	7.3	7.1	15.8	45.0	17.5	6.6	14.8	9.1	20.4	37.7	5.7
	7.2	16.0	45.0	<i>179.4</i>	39.0	3.3	7.5	7.9	17.7	45.0	20.0	6.8	15.2	9.9	22.1	37.7	8.7
	4.5	10.0	33.0	<i>0.0</i>	0.0	0.0	0.0	4.5	10.0	33.0	57.0	0.0	0.0	4.5	10.0	25.7	64.3
	5.4	12.0	33.0	<i>0.0</i>	0.0	0.0	0.0	5.4	12.0	33.0	57.0	0.0	0.0	5.4	12.0	25.7	64.3
	6.3	14.0	33.0	<i>239.2</i>	52.0	4.5	10.0	7.7	17.2	33.0	21.6	9.1	20.3	11.0	24.6	25.7	8.9
	7.2	16.0	33.0	<i>239.2</i>	52.0	4.5	10.0	8.4	18.8	33.0	25.1	9.1	20.3	11.5	25.8	25.7	12.6
	4.5	10.0	15.0	<i>0.0</i>	0.0	0.0	0.0	4.5	10.0	15.0	75.0	0.0	0.0	4.5	10.0	7.7	82.3
	5.4	12.0	15.0	<i>0.0</i>	0.0	0.0	0.0	5.4	12.0	15.0	75.0	0.0	0.0	5.4	12.0	7.7	82.3
	6.3	14.0	15.0	<i>0.0</i>	0.0	0.0	0.0	6.3	14.0	15.0	75.0	0.0	0.0	6.3	14.0	7.7	82.3
7.2	16.0	15.0	<i>0.0</i>	0.0	0.0	0.0	7.2	16.0	15.0	75.0	0.0	0.0	7.2	16.0	7.7	82.3	
Starting Pitch at Home	4.5	10.0	42.0	<i>96.6</i>	21.0	1.8	4.0	4.8	10.8	42.0	26.1	3.7	8.2	5.8	12.9	34.7	16.0
	5.4	12.0	37.0	<i>170.2</i>	37.0	3.2	7.1	6.2	13.9	37.0	22.4	6.5	14.4	8.4	18.8	29.7	10.0
	6.3	14.0	29.0	<i>289.8</i>	63.0	5.4	12.1	8.3	18.5	29.0	20.2	11.0	24.6	12.6	28.3	21.7	8.0
	7.2	16.0	26.0	<i>312.8</i>	68.0	5.8	13.0	9.2	20.6	26.0	24.8	11.9	26.5	13.8	31.0	18.7	12.4
Last Pitch before Stalling at Home	3.6	8.0	18.0	<i>248.4</i>	54.0	4.6	10.3	5.8	13.1	18.0	19.7	9.4	21.1	10.1	22.5	10.7	10.1
	4.5	10.0	2.0	<i>598.0</i>	130.0	11.1	24.9	12.0	26.8	2.0	19.9	22.7	50.7	23.1	51.7	-5.3	16.5
	5.4	12.0	3.0	<i>874.0</i>	190.0	16.3	36.4	17.1	38.3	3.0	15.2	33.1	74.1	33.6	75.1	-4.3	13.5
Starting Pitch at Home (fan never moved)	6.3	14.0	29.0	<i>289.8</i>	63.0	5.4	12.1	8.3	18.5	29.0	20.2	11.0	24.6	12.6	28.3	21.7	8.0
	6.3	14.0	29.0	<i>289.8</i>	63.0	5.4	12.1	8.3	18.5	29.0	20.2	11.0	24.6	12.6	28.3	21.7	8.0
	6.3	14.0	29.0	<i>317.4</i>	69.0	5.9	13.2	8.6	19.3	29.0	17.6	12.0	26.9	13.6	30.3	21.7	5.8
	6.3	14.0	29.0	<i>299.0</i>	65.0	5.6	12.5	8.4	18.7	29.0	19.3	11.3	25.4	12.9	29.0	21.7	7.2
	6.3	14.0	29.0	<i>303.6</i>	66.0	5.7	12.6	8.4	18.9	29.0	18.9	11.5	25.7	13.1	29.3	21.7	6.8
	6.3	14.0	29.0	<i>308.2</i>	67.0	5.7	12.8	8.5	19.0	29.0	18.5	11.7	26.1	13.3	29.6	21.7	6.5
Stalling Pitch at Home (fan never moved)	6.3	14.0	3.0	<i>920.0</i>	200.0	17.1	38.3	18.2	40.8	3.0	17.1	34.9	78.0	35.4	79.3	-4.3	14.5
	6.3	14.0	2.0	<i>851.0</i>	185.0	15.8	35.4	17.0	38.1	2.0	19.6	32.3	72.2	32.9	73.5	-5.3	16.3
	6.3	14.0	3.0	<i>924.6</i>	201.0	17.2	38.5	18.3	41.0	3.0	17.0	35.0	78.4	35.6	79.6	-4.3	14.4
	6.3	14.0	3.0	<i>952.2</i>	207.0	17.7	39.7	18.8	42.1	3.0	16.4	36.1	80.7	36.6	81.9	-4.3	14.1
6.3	14.0	2.0	<i>869.4</i>	189.0	16.2	36.2	17.4	38.8	2.0	19.1	33.0	73.7	33.5	75.0	-5.3	16.1	
Program to Find Best Pitch in Wind Tunnel Using RPMs	7.2	16.0	9.4	<i>625.6</i>	136.0	11.6	26.1	13.7	30.6	9.4	22.1	23.7	53.0	24.8	55.4	2.1	14.7
	8.0	18.0	9.0	<i>990.0</i>	216.0	18.4	41.2	20.1	45.0	9.0	14.6	37.5	83.9	38.4	85.8	1.7	10.4
	8.9	20.0	9.0	<i>1140.0</i>	255.0	21.2	47.5	23.0	51.5	9.0	13.8	43.2	96.7	44.1	98.7	1.7	10.0
	9.8	22.0	8.5	<i>1320.0</i>	277.0	24.6	55.0	26.5	59.2	8.5	13.3	50.0	111.9	51.0	114.1	1.2	10.0
	10.7	24.0	8.0	<i>1500.0</i>	335.0	27.9	62.5	29.9	66.9	8.0	13.0	56.9	127.2	57.9	129.4	0.7	10.0
	11.6	26.0	8.3	<i>1710.0</i>	385.0	31.8	71.2	33.9	75.8	8.3	11.8	64.8	145.0	65.8	147.3	1.0	9.2
	12.5	28.0	7.4	<i>870.0</i>	186.9	16.2	36.2	20.5	45.8	7.4	30.3	33.0	73.8	35.3	78.9	0.1	20.7
Program to Find Best Pitch at Home Using RPMs	4.5	10.0	32.7	150.0	34.0	2.8	6.2	5.3	11.8	32.7	25.3	5.7	12.7	7.2	16.2	25.4	12.7
	5.4	12.0	17.8	360.0	74.0	6.7	15.0	8.6	19.2	17.8	20.9	13.6	30.5	14.7	32.8	10.5	11.0
	6.3	14.0	10.1	840.0	186.0	15.6	35.0	16.8	37.7	10.1	11.7	31.8	71.2	32.4	72.6	2.8	8.3
	7.2	16.0	8.1	870.0	193.0	16.2	36.2	17.7	39.6	8.1	15.7	33.0	73.8	33.7	75.5	0.8	11.4

*Numbers in italics were computed, not measured (see Discussion).

Figure 2: Annual Average Wind Power in the United States

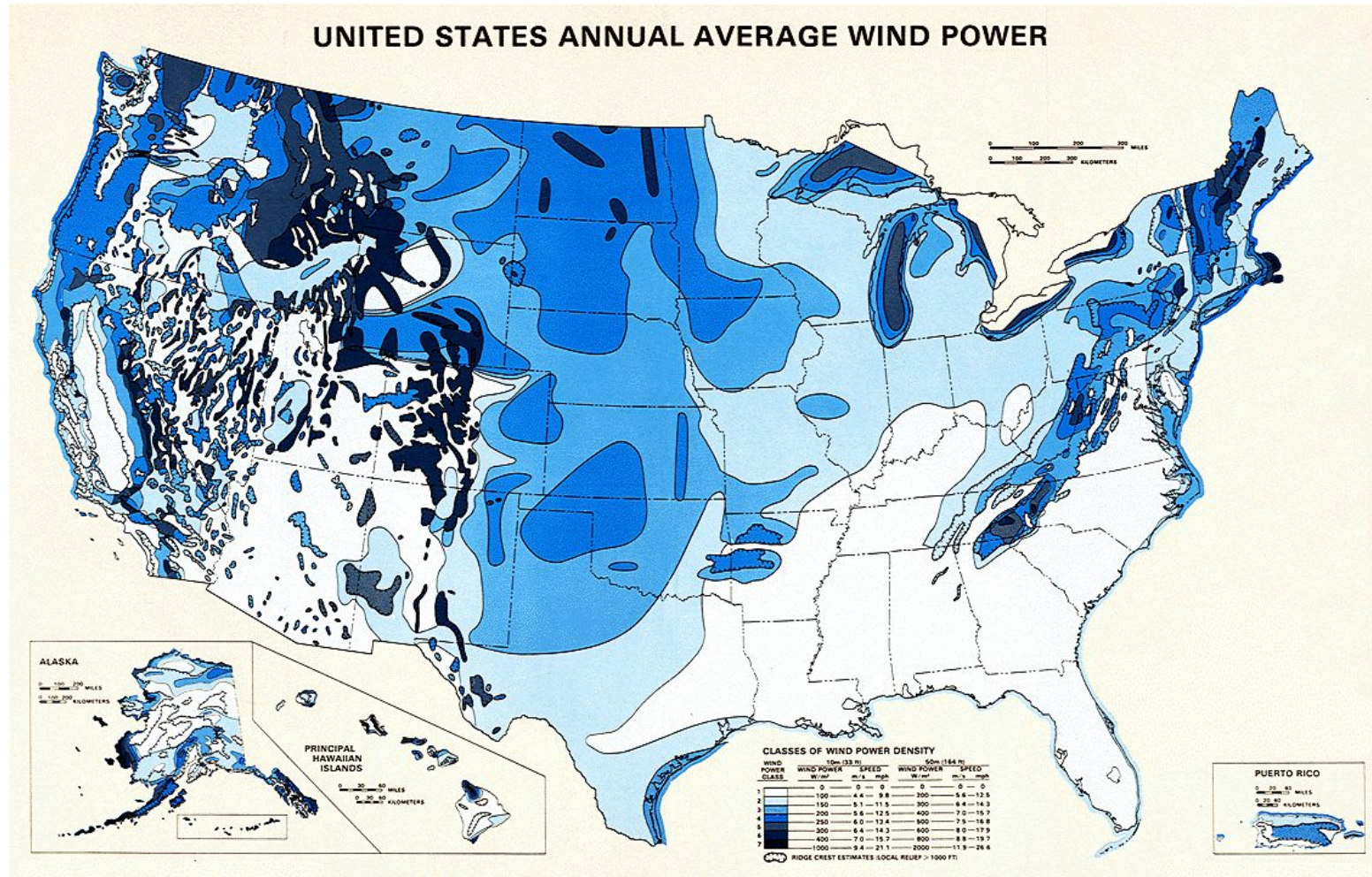


Figure 1: Energy Consumption in the United States in 2001

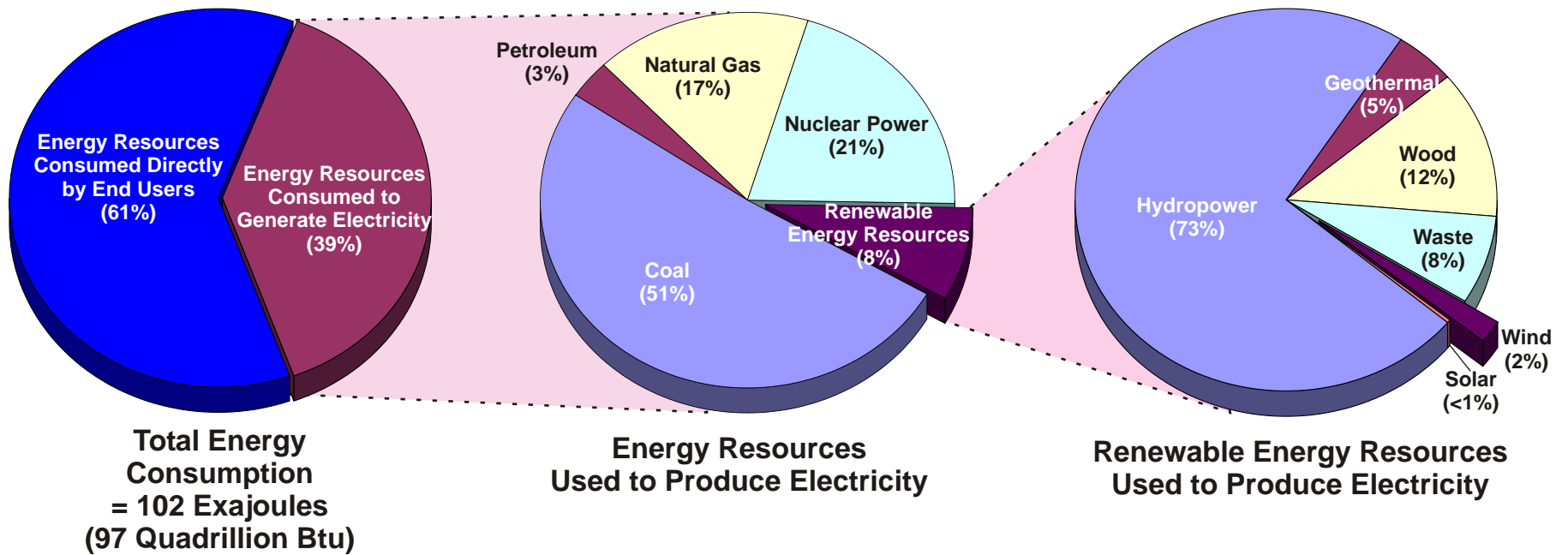


Figure 3: Potential Sources of Wind Energy in Virginia

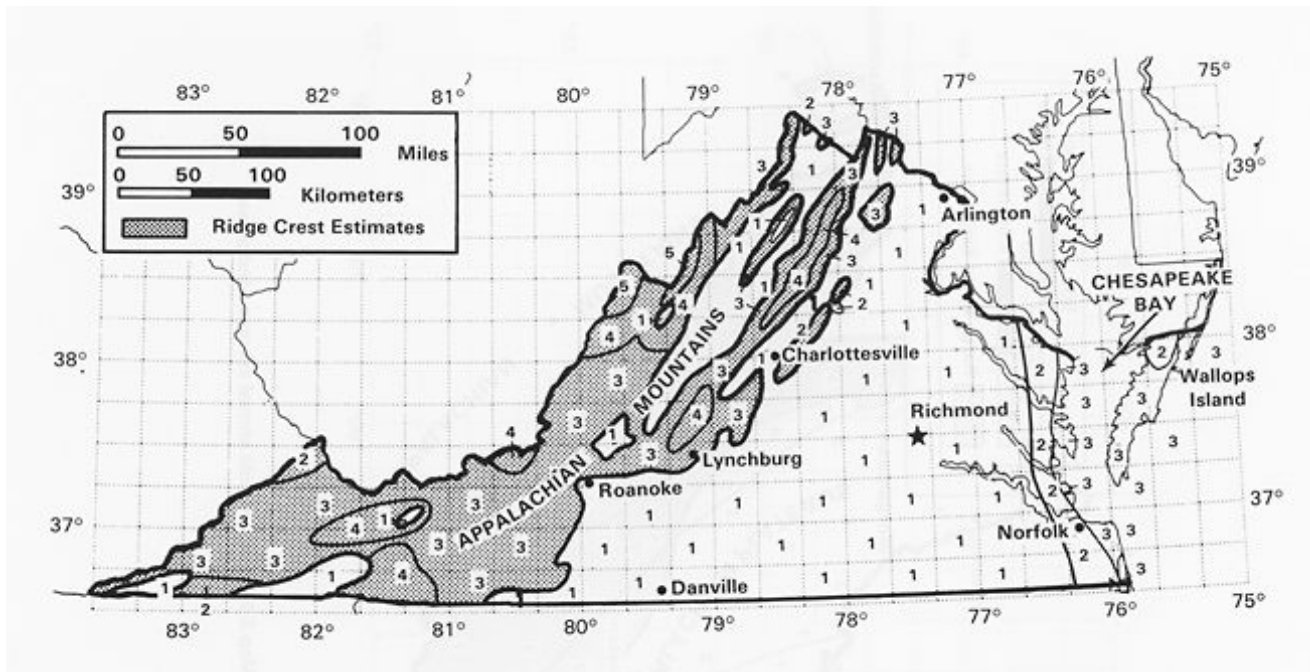


Figure 4: Wind Turbine Design

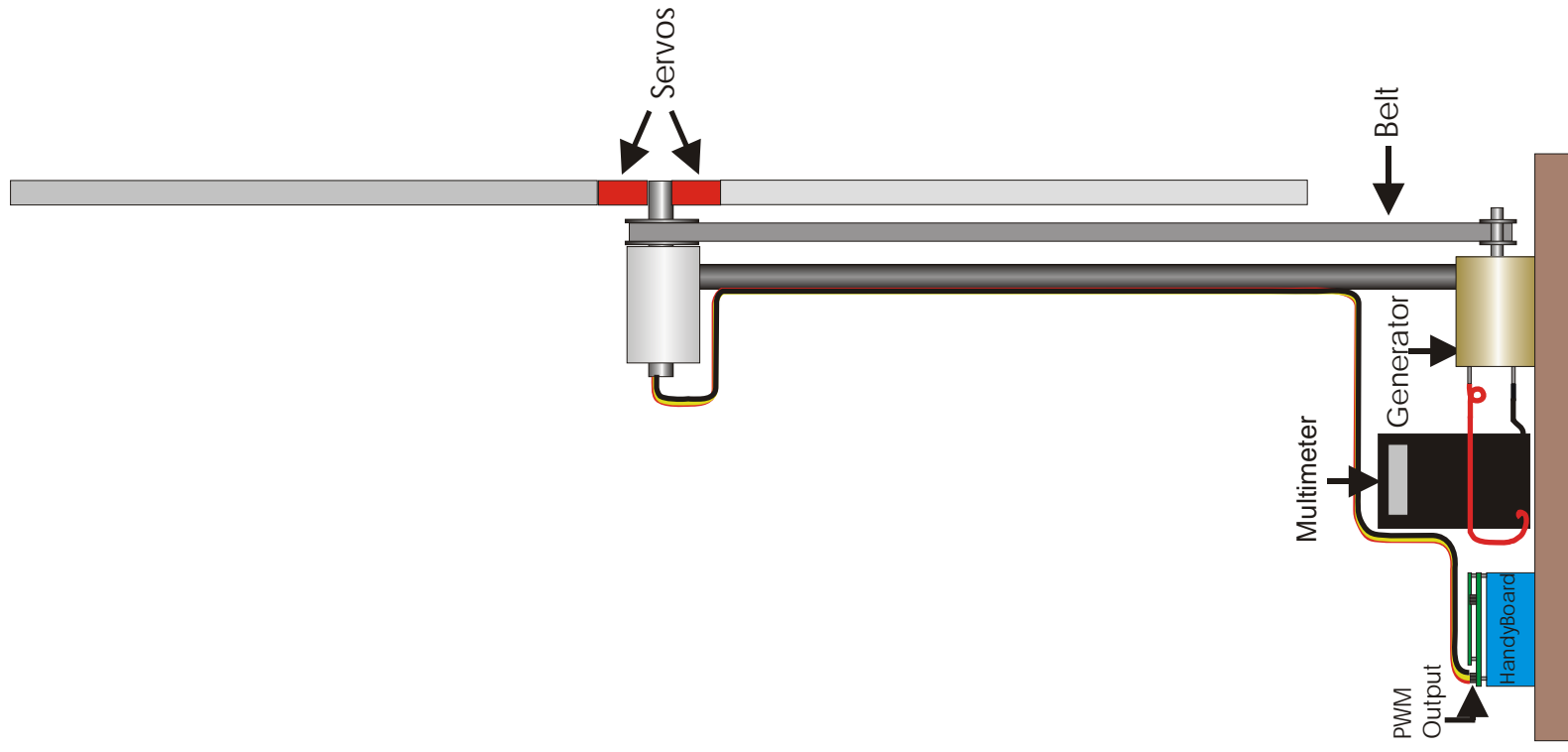


Figure 5: Effect of Wind Speed on Optimum Pitch

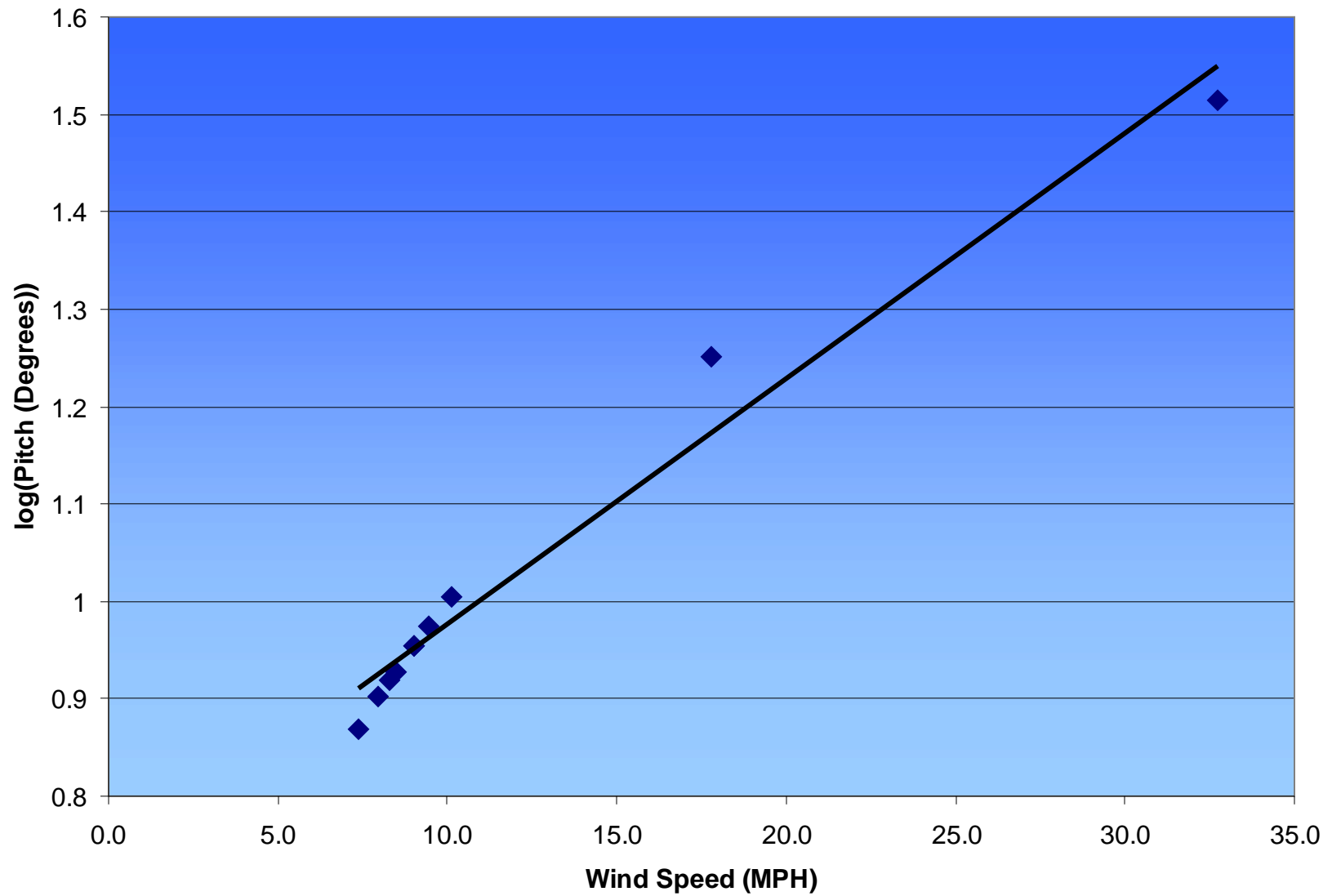


Figure 6: The Effect of Wind Speed on Starting Pitch

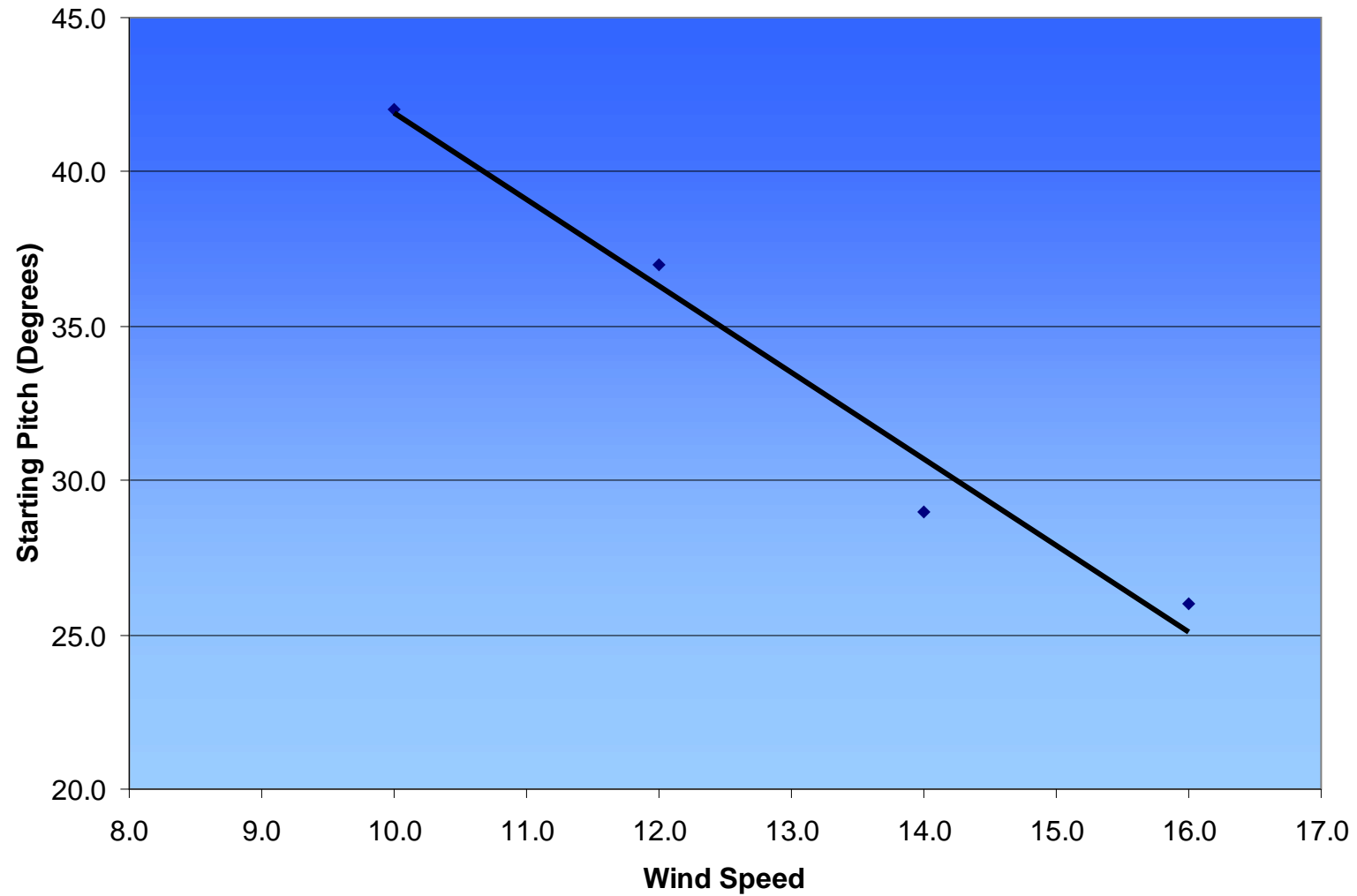


Figure 7: Effect of Wind Speed on Power Output Using Blades with Different Fixed Pitches

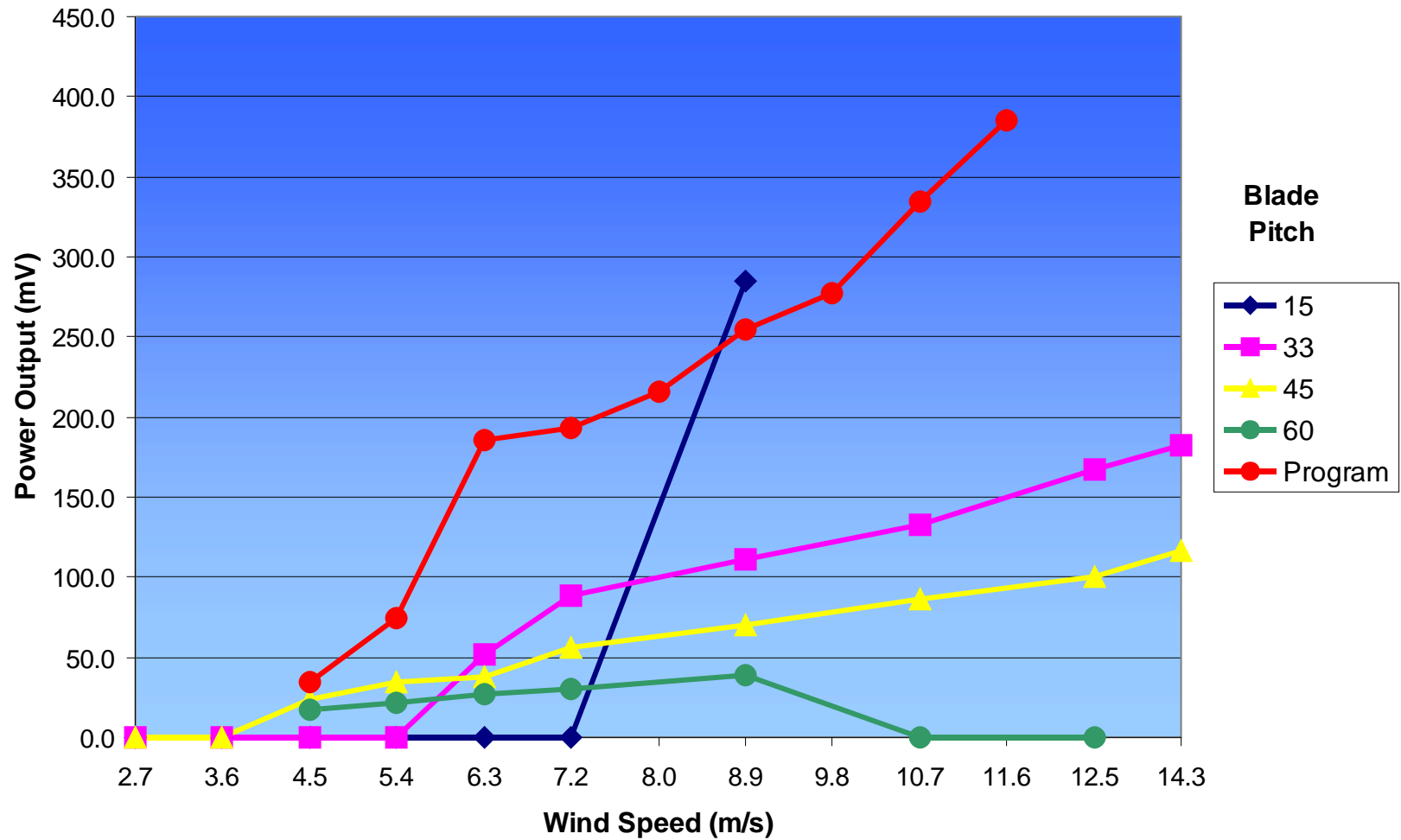
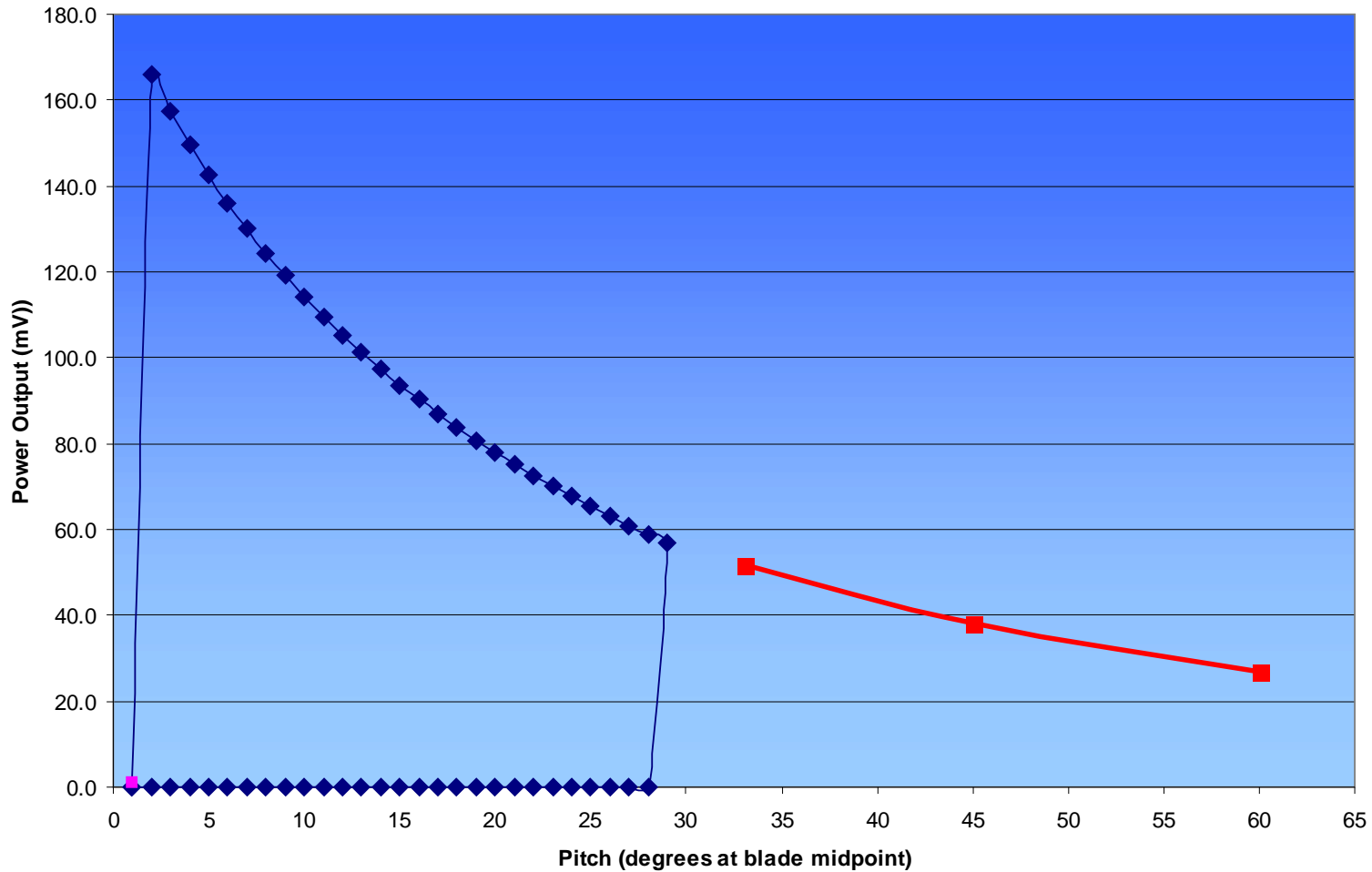


Figure 8: Effect of Varying Blade Pitch on Power Output When Wind Speed is Constant (6.3 m/s)



The blue line shows variable-pitch blades. Along the bottom, the pitch is increased from 0 degrees to 27 degrees where the blade starts turning. From that point on, the pitch is decreased and blue line moves back towards 0 degrees with the blade turning, and the power output increases as pitch decreases. The red line shows static-pitch blades at 33, 45, and 60 degrees.

**Photo 1: Wind Turbine set up for testing
in wind tunnel**

