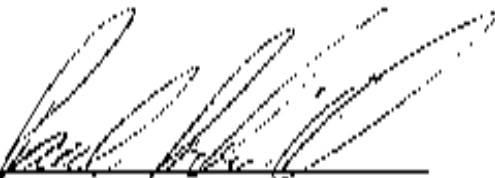


# WHALEPOWER TUBERCLE BLADE POWER PERFORMANCE TEST REPORT

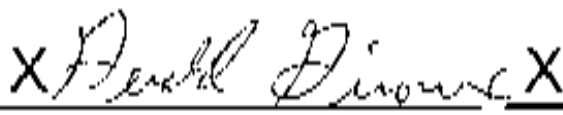


Every effort has been made to ensure that the results contained within this document accurately represent the performance of the product being tested. This report, as well as the testing apparatus and procedure used have been designed to meet the guidelines set by IEC standards for power performance measurements of electricity producing wind turbines (IEC 61400-12-1), unless otherwise stated.

Internal Review:

X   
Paul Duckell  
Director of Technology

X December 11, 2008  
Date

X   
Gerald Groux  
Measurement Engineer

X December 11/08  
Date



---

## Wind Energy Institute of Canada

---

### WhalePower Tubercle Blade Power Performance Test Report

---

Prepared by:

**Wind Energy Institute of Canada**  
21741 Route 12  
North Cape, PE C0B 2B0

Prepared for:

**WhalePower Corporation**  
27 Tyrrel Avenue  
Toronto, ON M6G 2G1

## Table of Contents

<b>1</b>	<b>DISCLAIMER</b> .....	<b>8</b>
<b>2</b>	<b>BACKGROUND</b> .....	<b>9</b>
<b>3</b>	<b>TEST OBJECTIVE</b> .....	<b>9</b>
<b>4</b>	<b>WIND TURBINE CONFIGURATION</b> .....	<b>10</b>
4.1	TURBINE INFORMATION.....	10
4.2	ROTOR INFORMATION.....	11
4.3	POWER RATING .....	11
4.4	BLADE INFORMATION.....	12
4.5	TOWER INFORMATION .....	13
4.6	CONTROL SYSTEMS.....	13
4.7	GRID CONNECTIONS .....	14
<b>5</b>	<b>TEST SITE</b> .....	<b>14</b>
5.1	PHOTOGRAPHS OF SITE.....	15
5.2	SITE LAYOUT .....	16
5.3	SITE ASSESSMENT.....	17
5.4	SITE CALIBRATION .....	18
<b>6</b>	<b>TEST EQUIPMENT</b> .....	<b>19</b>
6.1	SENSORS AND DATA ACQUISITION SYSTEM.....	19
6.2	DESCRIPTION OF CUP ANEMOMETERS .....	20
6.3	DIAGRAM OF METEOROLOGICAL MAST .....	21
6.4	CALIBRATION CONTINUITY .....	22
<b>7</b>	<b>MEASUREMENT PROCEDURE</b> .....	<b>22</b>
7.1	MEASUREMENT PERIOD .....	22
7.2	LOG BOOK .....	23
7.3	DATA REJECTION.....	23
<b>8</b>	<b>MEASURED DATA</b> .....	<b>24</b>
8.1	SCATTER PLOT OF POWER OUTPUT AS A FUNCTION OF WIND SPEED .....	24
8.2	SCATTER PLOT OF WIND SPEED AS A FUNCTION OF VALID WIND DIRECTION.....	24
8.3	SCATTER PLOT OF TURBULENCE INTENSITY AS A FUNCTION OF WIND SPEED .....	25
<b>9</b>	<b>POWER CURVES</b> .....	<b>26</b>
9.1	POWER CURVE NORMALIZED TO STANDARD AIR DENSITY .....	26
9.2	POWER CURVE NORMALIZED TO SITE AVERAGE AIR DENSITY.....	28
<b>10</b>	<b>POWER COEFFICIENT</b> .....	<b>30</b>
<b>11</b>	<b>ANNUAL ENERGY PRODUCTION</b> .....	<b>31</b>
11.1	ANNUAL ENERGY PRODUCTION (STANDARD AIR DENSITY).....	31
11.2	ANNUAL ENERGY PRODUCTION (SITE AVERAGE AIR DENSITY) .....	31
<b>12</b>	<b>UNCERTAINTY OF MEASUREMENT</b> .....	<b>32</b>



---

<b>13</b>	<b>DEVIATIONS FROM IEC-61400-12-1PROCEDURE .....</b>	<b>33</b>
	<b>APPENDIX A: WEATHER PRAMETERS AT NORTH CAPE .....</b>	<b>35</b>
	<b>APPENDIX B: REJECTION ANGLE CALCULATIONS .....</b>	<b>36</b>
	<b>APPENDIX C: WENVOR LOG BOOK FOR THE YEAR 2008 .....</b>	<b>37</b>



---

## List of Tables

TABLE 4-1 - WENVOR NAME PLATE .....	11
TABLE 9-1 - MEASURED POWER CURVE NORMALIZED TO STANDARD AIR DENSITY .....	26
TABLE 9-2 - MEASURED POWER CURVE NORMALIZED TO SITE AVERAGE AIR DENSITY.....	28
TABLE 11-1: ANNUAL ENERGY PRODUCTION NORMALIZED TO STANDARD AIR DENSITY.....	31
TABLE 11-2: ANNUAL ENERGY PRODUCTION NORMALIZED TO SITE AVERAGE AIR DENSITY .....	31
TABLE 12-1: TYPE B UNCERTAINTIES .....	32

## List of Figures

FIGURE 4-1 - WENVOR TEST TURBINE FITTED WITH WHALEPOWER BLADES.....	10
FIGURE 4-2: WHALEPOWER CORPORATION TEST BLADE .....	12
FIGURE 4-3 – WHALEPOWER POWER TRANSDUCER CONNECTIONS .....	14
FIGURE 5-1 – PICTURES OF SITE TAKEN FROM BASE OF WHALEPOWER .....	15
FIGURE 5-2 - WEICAN SITE TOPOGRAPHY .....	16
FIGURE 5-3 - VALID WIND DIRECTIONS .....	17
FIGURE 5-4: SITE CALIBRATION REGIONS .....	18
FIGURE 6-1 - ANEMOMETER CONFIGURATION .....	20
FIGURE 6-2 - DIAGRAM OF METEOROLOGICAL MAST .....	21
FIGURE 6-3: SENSOR ORIENTATION AND WIND ROSE AT 50M .....	22
FIGURE 8-1 - SCATTER PLOT OF POWER OUTPUT AS A FUNCTION OF WIND SPEED .....	24
FIGURE 8-2 - SCATTER PLOT OF WIND SPEED AND TURBULENCE AS A FUNCTION OF WIND DIRECTION .....	25
FIGURE 8-3 - SCATTER PLOT OF TURBULENCE INTENSITY AS A FUNCTION OF WIND SPEED.....	25
FIGURE 9-1 - MEASURED POWER CURVE NORMALIZED TO STANDARD AIR DENSITY.....	27
FIGURE 9-2 - MEASURED POWER CURVE NORMALIZED TO SITE AVERAGE AIR DENSITY .....	29
FIGURE 10-1 - POWER COEFFICIENT (Cp) .....	30

---

## 1 DISCLAIMER

This report was prepared as an account of work sponsored by Natural Resources Canada. The test results documented in this report define the characteristics of the test article as configured under the conditions tested.

Neither the Wind Energy Institute of Canada (WEICan), nor any of their employees, makes any warranty, express or implied, or assumes any legal liability or responsibility for the usefulness of any information, apparatus, product, or process disclosed, or represents that its use would not infringe privately owned rights. Nor do they assume legal liability or responsibility for the performance of the test article or any similarly named article when tested under other conditions or using different test procedures.

The Wind Energy Institute of Canada shall not be liable for special, consequential or incidental damages. Reference herein to any specific commercial product, process, or service by trade name, trademark, manufacturer or otherwise does not necessarily constitute or imply its endorsement, recommendation, or favouring by WEICan. The views and opinions of the authors expressed herein do not necessarily state or reflect those of the WEICan.

The Wind Energy Institute of Canada is a non-profit research institution. It is partially funded by: Natural Resources Canada, the Atlantic Canada Opportunity Agency of the Government of Canada, and the Prince Edward Island Energy Corporation of the Prince Edward Island Government.

This report may only be reproduced with written permission from either WEICan or WhalePower Corporation.



## 2 BACKGROUND

This test is designed to determine the performance characteristics of the WhalePower Corporation's turbine blades, which are modeled after humpback whale flippers. These blades contain tubercles along most of the leading edge of the blade, much in the same way that humpback whales have tubercles on their flippers. The blades have been fitted to a Wenvor 25kW turbine. Both Wenvor and WhalePower Corporation are based in Ontario, Canada.

This turbine has been installed at WEICan's test site located at North Cape, Prince Edward Island, Canada. WEICan has been the leading institute for wind energy research and development in Canada since 1981. WEICan conducts power performance testing on a variety of turbines.

## 3 TEST OBJECTIVE

The objective of this test is to characterize the power performance of the Wenvor 25kW wind turbine with WhalePower Corporation's blades. To meet this objective, measurements were collected and analyzed in accordance with International Electrotechnical Commission (IEC) standards for power performance measurements of electricity producing wind turbines (IEC 61400-12-1), unless otherwise stated. This report is formatted according to section 9 of IEC 61400-12-1.

---

## 4 WIND TURBINE CONFIGURATION

### 4.1 Turbine Information



Figure 4-1 - Wenvor Test Turbine Fitted with WhalePower Blades

Make: Wenvor

Rating: 25kW

Serial number: 5-35575

Production year: 2000

Orientation: Upwind

Rotation Axis: Horizontal

The information below is taken from the generator and gearbox name plates.

WENVOR DATA SHEET			
GENERATOR		GEARBOX	
HP	25kW	MAX AMB.	40C
RPM	1824	DESIGN	B
PHASE	3	CONN.	YY
VOLTS	575	Rating Cont	Empty
AMPS	33.5	Frame#	286TCZ
INSLN	F	MODEL	HKH520
HZ	60	D.E.BRG.NO.	6311ZZ
S.F.	1.15	SER#	5-35575
EEF	Empty	DATE CODE	1/28/2000
Code	G	PF	86%
		GECALSTHOM	
		VENTPAK-HE	

Table 4-1 - Wenvor Name Plate

#### 4.2 Rotor Information

Swept Area: 81.67m<sup>2</sup>

Rotor diameter: 10.2 meters

Rotor speed: 123 RPM

Tilt Angle (deg): NA

Direction of Rotation: CW

Overspeed Control/Protection: Reverse pitch using inertial counterweights.

#### 4.3 Power Rating

Rated power: 25kW

Rated wind speed: 12m/s

---

## Power Regulation: Passive

### 4.4 Blade Information

The blades are retrofitted with leading edges designed by Dr. Laurens Howle of Duke University and fabricated by Soverin Composite Systems of Belœil, Quebec working on contract with WhalePower Corporation. The Tubercle Technology leading edge is patent protected.



Figure 4-2: WhalePower Corporation Test Blade

Make: WhalePower prototype wind turbine blades

Type: Tubercle lined, 10.2 m diameter. This is the first set of blades developed for testing

Serial numbers: RP 001

Number of blades: 2 blades

Fixed or variable pitch: Variable pitch mechanism – inertial counterweights vary pitch during startup and overspeed conditions only.

Pitch angle/range:  $19.9^{\circ}$  to  $-25.4^{\circ}$

#### 4.5 Tower Information

**Hub Height:** The height of the centre of the turbine hub is 27.5m from ground level.

**Tower type:** The tower is of metal tube design and was supplied by Wenvor. It is held vertically by a guyed support system of cables. The tower is designed to tilt up and down using a pole and pulley.

#### 4.6 Control Systems

The WhalePower controller is a WEICan custom-built controller based on a Microchip PIC18C452 microcontroller chip. The signals monitored by the controller are:

- Turbine on line
- Generator voltage
- Generator current
- Generator frequency

The turbine on line signal is read by the data acquisition system as a status signal.

When the generator frequency is between 60 and 68 Hz the generator is connected to the electrical grid. The controller monitors the generator voltage and current and calculates the PF (Power factor). When the PF goes negative for 10 seconds the turbine is taken off line and freewheels.

On line: 60 Hz <RPM <68 Hz

Off Line: PF < 0 (for 10 sec)

During high wind situations, the turbine is manually disconnected from the electrical grid and the brake is manually applied.

## 4.7 Grid Connections

Grid Voltage: 3 ph 600V<sub>AC</sub>

Tolerance:  $\pm 5\%$

Grid Frequency: 60Hz

Tolerance:  $\pm 0.00083\%$

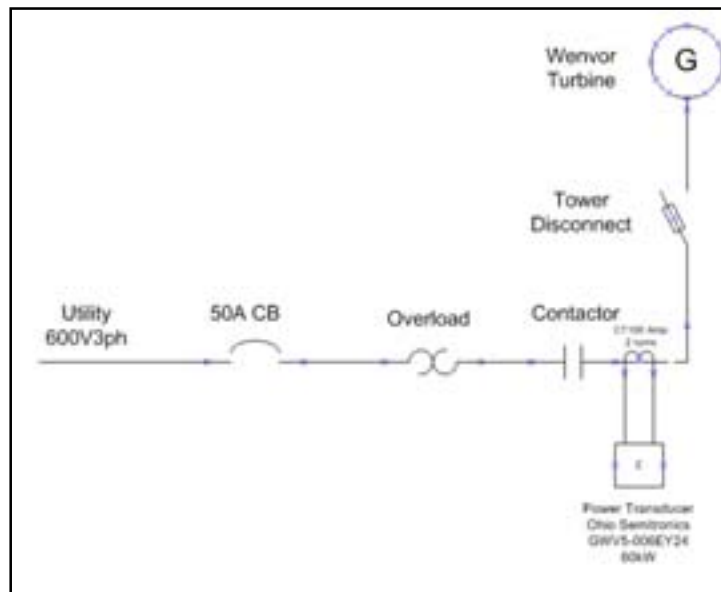


Figure 4-3 – WhalePower power transducer connections

## 5 TEST SITE

The WEICan Site is located on the northern tip of Prince Edward Island, at 47.055°N, 63.997°W. Situated on the coast of the Northumberland Strait, it has a 300 degree exposure to the ocean winds. WEICan Site is approximately 6 - 12 meters above sea level. Figure 5-2 shows a plot plan of the test site.

## 5.1 Photographs of Site

Figure 5-1 shows pictures taken from ground level of all directions, from the WhalePower turbine. To the north is the WEICan office, and the Vergnet and EWS turbines. To the east is a Vestas-47 wind turbine, along with the Lagerway turbine. To the South there are several Vestas-47 wind turbines mixed with a low forest region. To the north-west there is a field which ends at a 7-10 m high cliff. To the south-west there are several small turbines. Figure 5-3 shows the wind directions which are valid for data analysis, and will be explained further.



Figure 5-1 – Pictures of Site Taken from Base of WhalePower

## 5.2 Site Layout

The WEICan test site has little to no grade change in the vicinity of the Wenvor turbine.



Figure 5-2 - WEICan Site Topography



### 5.3 Site Assessment

Figure 5-3 shows valid wind directions that are not disturbed by other turbines or obstacles. There were ten objects on site that were classified as significant according to IEC-61400-12-1: the Lagerway turbine located to the east of the Whalepower, four Vestas-47 turbines located east to south-west of the WhalePower, the Vergnet and EWS turbines located to the north, the Wenvor UNB to the north-east, the ARE turbine to the south-west, and the Windmatic to the south of the WhalePower. The valid measurement sector that is available ranges from 266.1 to 6.8 degrees, shown as the area with green vertical shading below. Please see Appendix B for further information on angle selection process.

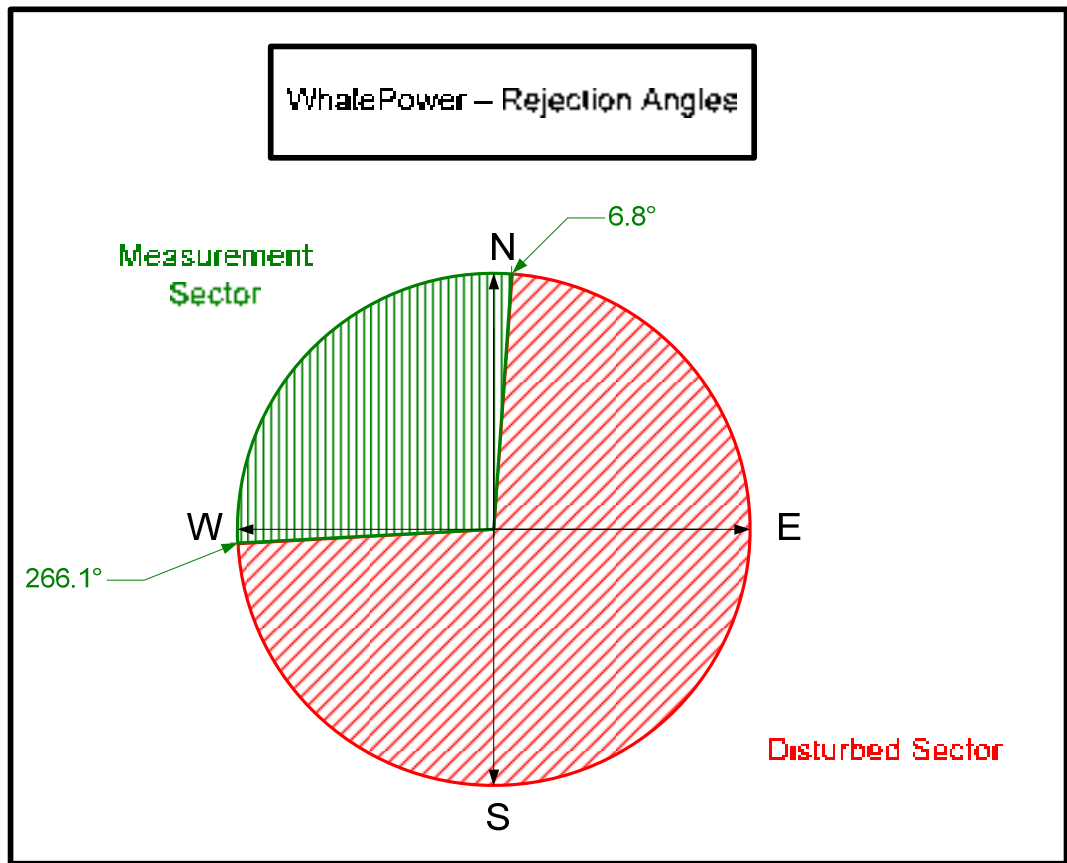


Figure 5-3 - Valid Wind Directions

## 5.4 Site Calibration

As shown in Figure 5-4, the cliff west of the site is within the region assessed for site calibration. This area has a radius that is eight times the distance between the WhalePower turbine, and its MET tower. The distance between the turbine and the MET tower (shown as  $L$  in Figure 5-4) is 38m. The largest radius ( $8L$ ) is equal to 304m. As shown below, this area contains a steep drop located to the west of the WhalePower turbine. Therefore, according to IEC 61400-12-1, a site calibration should be undertaken. However, a site calibration was not undertaken for the purposes of this report.



Figure 5-4: Site Calibration Regions

---

## 6 TEST EQUIPMENT

All test equipment meets IEC 61400-12-1 standards and was mounted accordingly, with the exception of the power transducer not meeting IEC 60688.

### 6.1 Sensors and Data Acquisition System

Data Acquisition System:	Campbell Scientific CR21XL Ser#4202 with a SM16 Storage Module
Anemometers	Riso Model P2546A Ser#3470 & Ser#3471, replaced with Ser#4382 & Ser#4386
Temperature	Campbell Scientific Model 107 Ser# 41303
Barometric Pressure	RMYoung #61205V Ser#BP04834
Direction vane	Met1 020C Ser#G2561
Power transducer	Ohio Semitronics Model GWV5-006EY24 Ser#02090217

See Appendix D for calibration sheets.

## 6.2 Description of Cup Anemometers

There are 4 anemometers located on the meteorological tower. The two anemometers used for the test are RISOE. The top one was mounted on a round vertical tube. The second one is mounted 320° relative to true north. These anemometers were replaced with ones of the same model after they experienced breakage due to icing. There are two NRG anemometers located below the test anemometers. The data collected by these anemometers is not analyzed. They are installed for comparison purposes only.

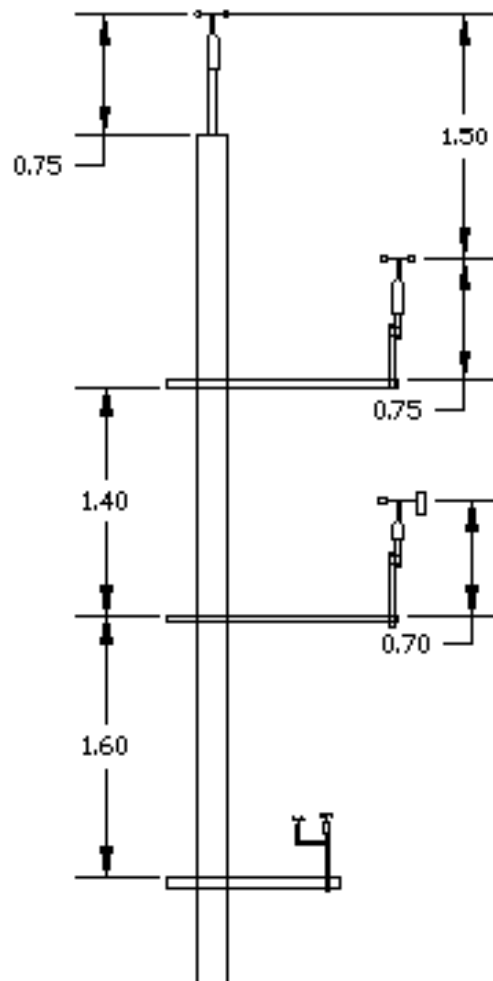


Figure 6-1 - Anemometer Configuration

### 6.3 Diagram of Meteorological Mast

Below is a diagram showing dimensions and orientation of sensors. The tower contains, from top to bottom: anemometer, anemometer, direction vane, two anemometers, temperature sensor and a barometric pressure sensor. The meteorological tower is located 38 meters from the test turbine. This equates to 3.7 times the diameter of the turbine blades. This falls in the allowable range of 2 to 4 times the diameter.

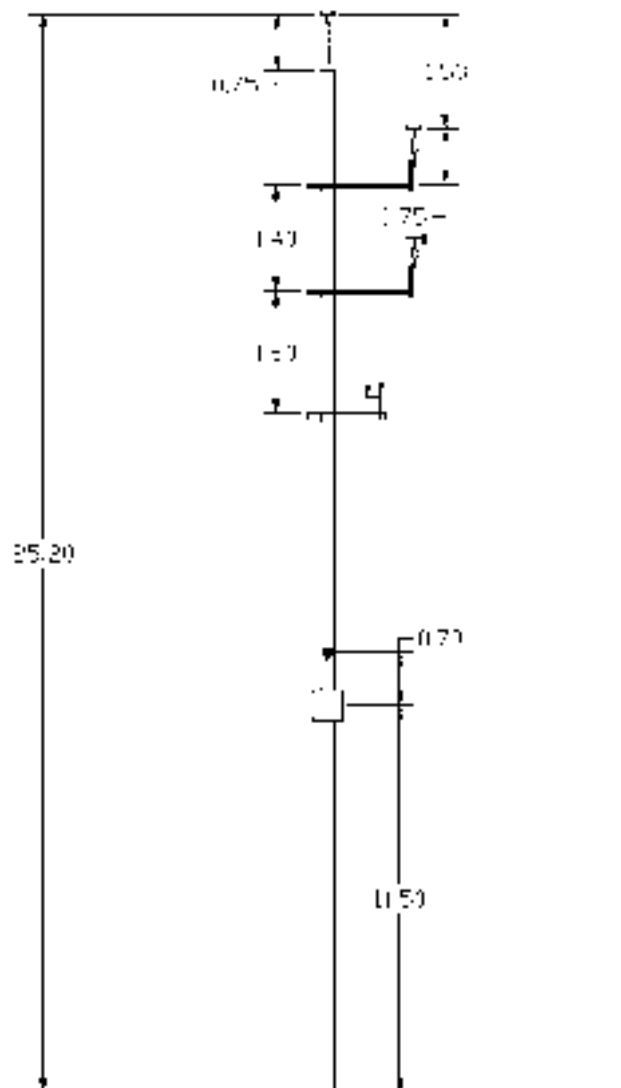


Figure 6-2 - Diagram of Meteorological Mast

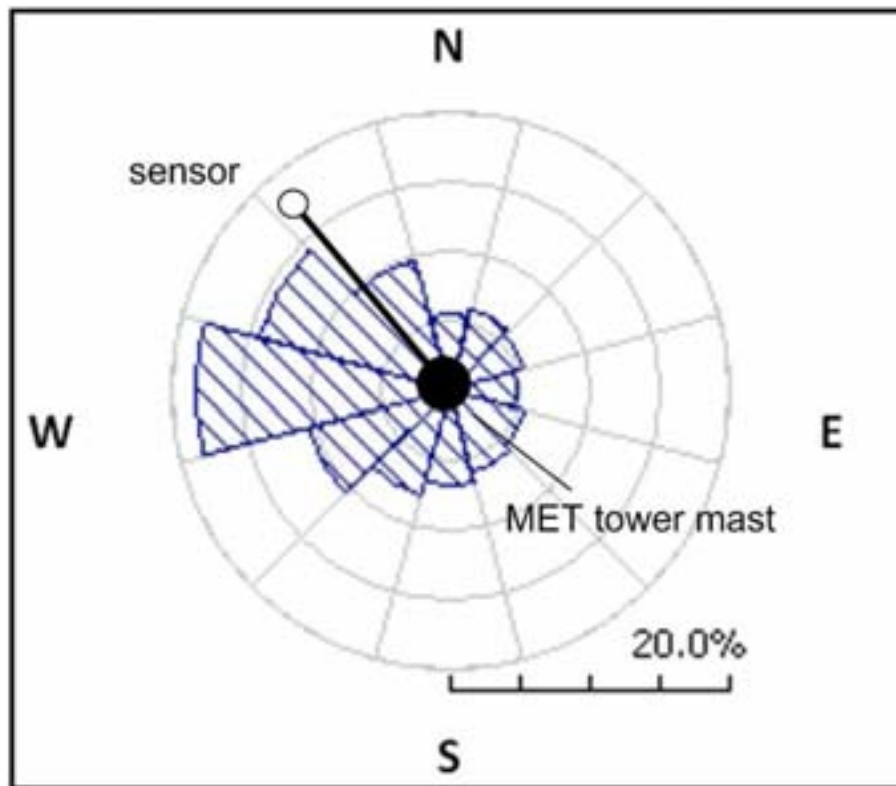


Figure 6-3: Sensor Orientation and Wind Rose at 50m

## 6.4 Calibration Continuity

Instruments will be sent for calibration verification.

# 7 MEASUREMENT PROCEDURE

## 7.1 Measurement Period

The measurement of data started on January 4, 2008 and continued through until June 2, 2008. There were a few points in this range where the turbine was not operational. Weather conditions such as icing and precipitation accounted for much downtime and data rejection, since testing was done during winter months. Please refer to Appendix C to see all down time due to maintenance and other issues.

Readings of wind speed, power output, temperature, barometric pressure and wind direction were collected at a sampling rate of 1Hz (1-second data). From these one second readings, one minute groupings of contiguous data were derived. These one-minute groupings were ensured to be of a complete sixty seconds each. Average, standard deviation, maximum and minimum values were calculated for each one-minute data set.

## 7.2 Log Book

The log book was updated each day significant events occurred. Please see Appendix C for all entries in the log book.

## 7.3 Data Rejection

All data was reviewed and any data falling under the following circumstances were rejected:

- The turbine was offline due to low wind speeds.
- External conditions other than wind speed are out of the operating range of the wind turbine (e.g. due to fog).
- Turbine cannot operate because of a turbine fault condition
- Turbine is manually shut down or in a test of maintenance operating mode
- Failure or degradation of test equipment (e.g. due to icing)
- Wind direction outside the measurement sector(s) as defined in Site Assessment
- Wind directions outside valid (complete) site calibration sectors. This does not apply to the WEICan test site.

Since the turbine is manually shut off at times of high winds, no significant hysteresis effect should be occurring, and therefore a hysteresis analysis was not undertaken.

## 8 MEASURED DATA

The following section includes a presentation of the raw one minute test data as it was collected. No normalization has been undergone to account for site specific atmospheric conditions. Figure 8-3 displays distinct arches in the turbulence pattern, at low wind speeds. This is a normal occurrence, due to the characteristic of the RISOE anemometer, which produces only two pulses per revolution.

### 8.1 Scatter Plot of Power Output as a function of Wind Speed

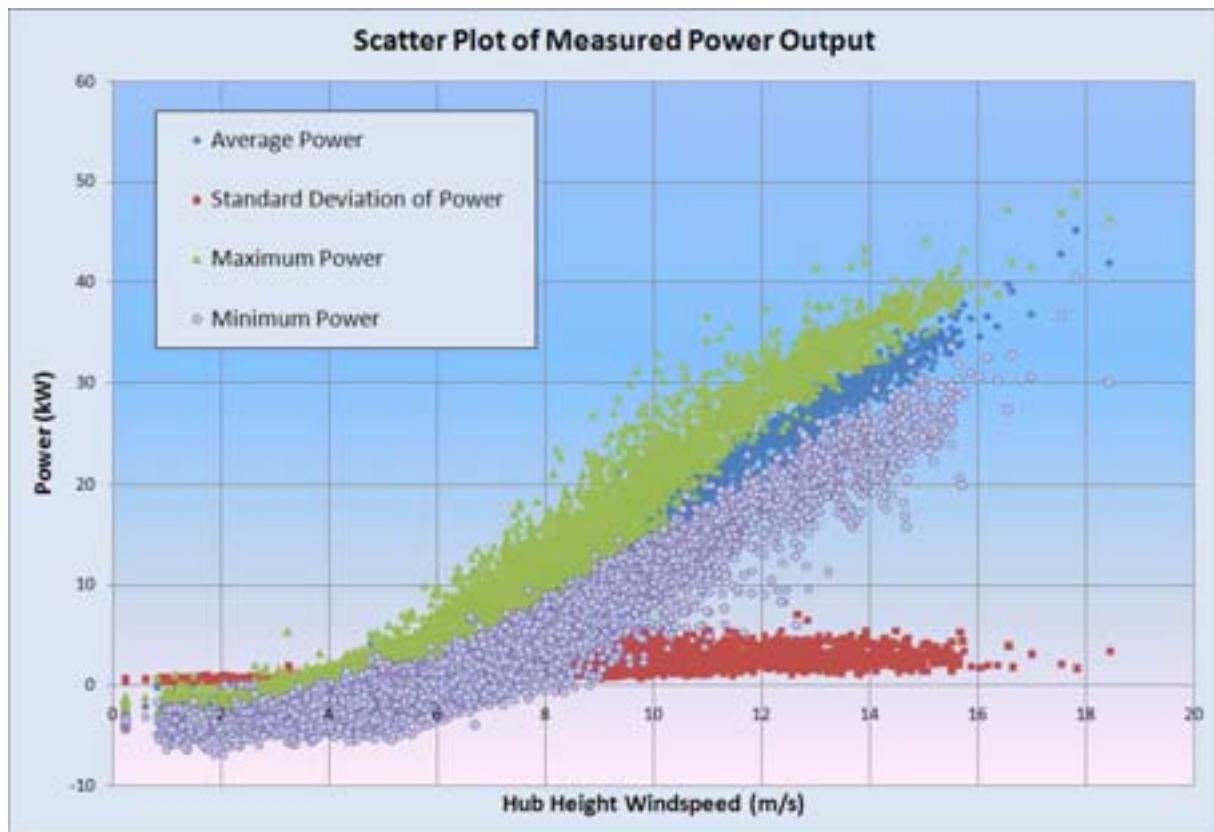


Figure 8-1 - Scatter Plot of Power Output as a Function of Wind Speed

### 8.2 Scatter Plot of Wind Speed as a Function of Valid Wind Direction



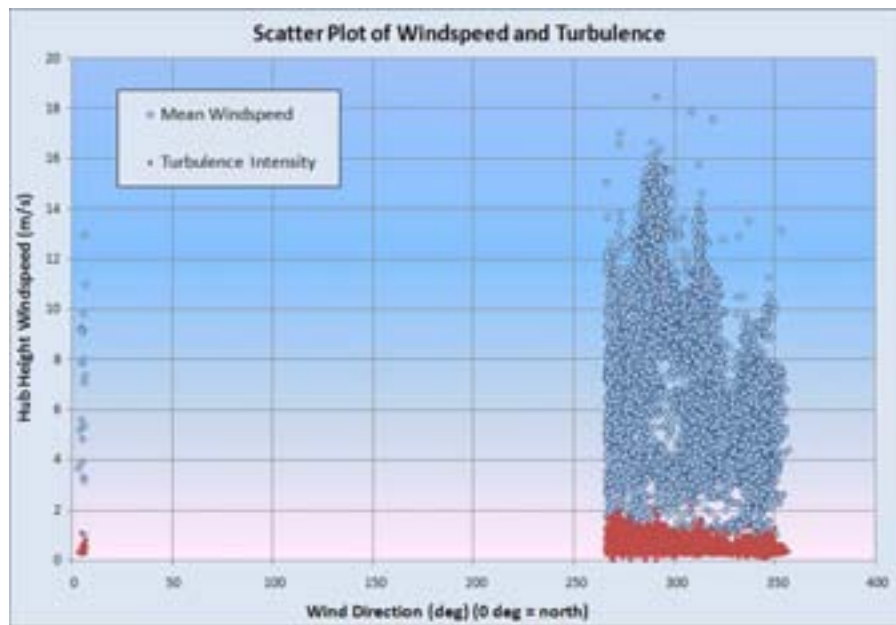


Figure 8-2 - Scatter Plot of Wind Speed and Turbulence as a Function of Wind Direction

### 8.3 Scatter Plot of Turbulence Intensity as a Function of Wind Speed

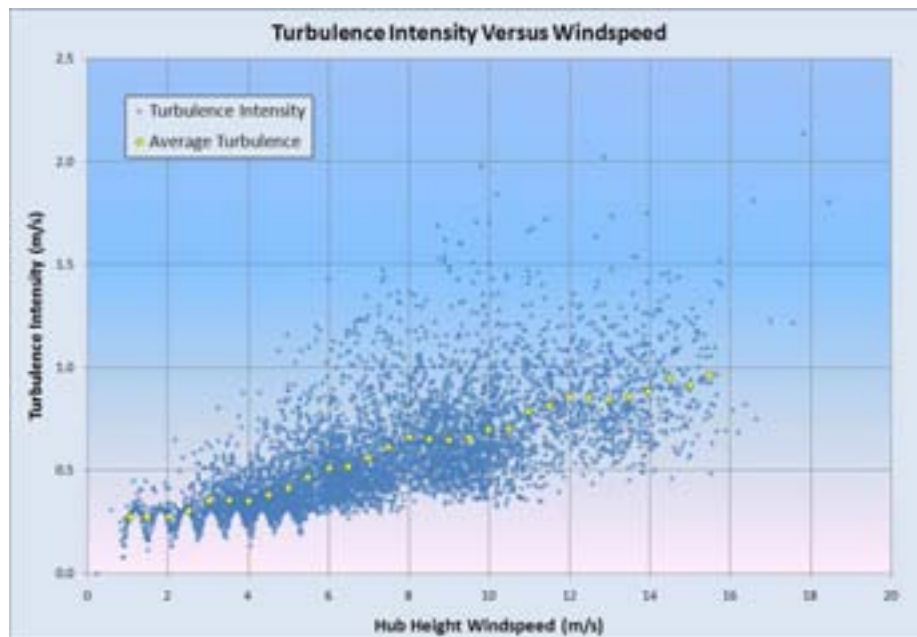


Figure 8-3 - Scatter Plot of Turbulence Intensity as a Function of Wind Speed

## 9 POWER CURVES

### 9.1 Power Curve Normalized to Standard Air Density

Measured Power Curve										
Reference Air Density: ISO Std. at Sea Level 1.225 kg/m <sup>3</sup>					Sets in Bin (1 Minute Avg.)	Category A Std. Uncertainty S <sub>i</sub> (kW)	Category B Std. Uncertainty U <sub>i</sub> (kW)	Combined Std. Uncertainty U <sub>c</sub> (kW)		
Bin #	Bin Center (m/s)	Avg Wind (m/s)	Avg Power (kW)	C <sub>p</sub>						
2	1	1.0693	-2.9861	-48.7960	61	0.1447	0.2468		0.2861	
3	1.5	1.4773	-3.1720	-19.6593	69	0.1403	0.1085		0.1774	
4	2	2.0356	-3.0466	-7.2171	83	0.1245	0.0983		0.1586	
5	2.5	2.5234	-2.0677	-2.5710	130	0.0889	0.2894		0.3027	
6	3	3.0271	-1.9352	-1.3939	161	0.0684	0.1016		0.1224	
7	3.5	3.5206	-1.5806	-0.7237	285	0.0546	0.1474		0.1572	
8	4	4.0077	-1.1299	-0.3507	352	0.0518	0.1831		0.1903	
9	4.5	4.5031	-0.6679	-0.1461	336	0.0667	0.1943		0.2054	
10	5	4.9971	0.0643	0.0103	377	0.0677	0.3045		0.3119	
11	5.5	5.4840	1.0154	0.1230	312	0.0605	0.4181		0.4225	
12	6	6.0177	2.1908	0.2009	372	0.0615	0.5008		0.5046	
13	6.5	6.4922	3.4462	0.2516	383	0.0679	0.6332		0.6369	
14	7	6.9913	4.8515	0.2837	302	0.0865	0.7131		0.7184	
15	7.5	7.4790	6.5839	0.3145	277	0.0894	0.9467		0.9509	
16	8	8.0087	8.0700	0.3139	242	0.0975	0.7932		0.7991	
17	8.5	8.5112	9.7242	0.3151	304	0.0860	0.9774		0.9811	
18	9	8.9977	11.6507	0.3196	360	0.0853	1.2317		1.2347	
19	9.5	9.4983	13.1949	0.3077	295	0.0971	1.0073		1.0120	
20	10	9.9795	15.1682	0.3049	296	0.0975	1.3961		1.3995	
21	10.5	10.4977	17.3052	0.2989	180	0.1181	1.4685		1.4732	
22	11	10.9820	19.0780	0.2878	145	0.1333	1.3582		1.3647	
23	11.5	11.5042	21.4328	0.2813	117	0.1298	1.7434		1.7482	
24	12	12.0043	23.4362	0.2707	92	0.1499	1.6110		1.6179	
25	12.5	12.4873	24.5064	0.2515	99	0.1584	0.9281		0.9415	
26	13	12.9862	26.5551	0.2423	125	0.1554	1.7753		1.7821	
27	13.5	13.4789	28.2140	0.2302	100	0.1199	1.5082		1.5130	
28	14	13.9613	29.2758	0.2150	83	0.1373	1.0223		1.0315	
29	14.5	14.5032	31.0420	0.2033	60	0.1695	1.5634		1.5725	
30	15	15.0028	32.6369	0.1931	42	0.1867	1.5811		1.5921	
31	15.5	15.4916	33.9628	0.1825	25	0.2209	1.3863		1.4038	

Table 9-1 - Measured Power Curve Normalized to Standard Air Density

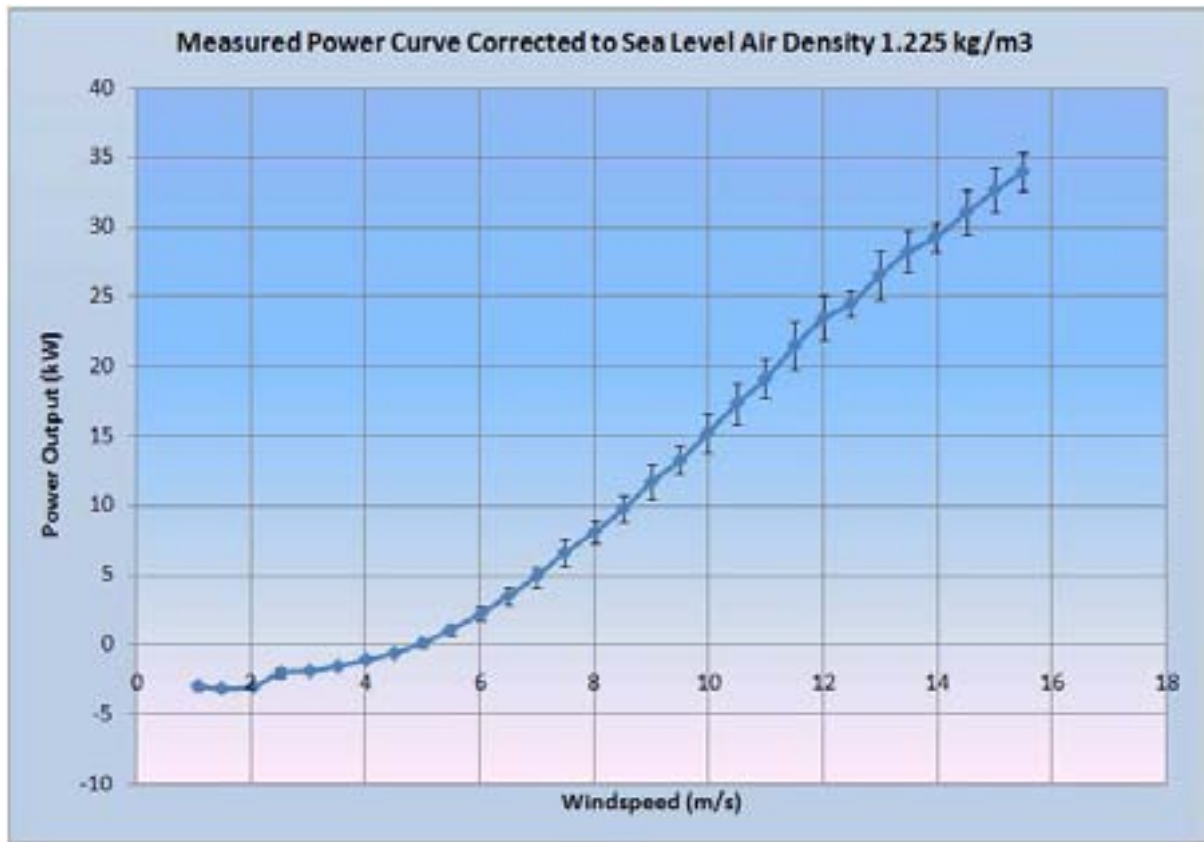


Figure 9-1 - Measured Power Curve Normalized to Standard Air Density

## 9.2 Power Curve Normalized to Site Average Air Density

Note that Site average air density was calculated during times of valid data collection

Measured Power Curve										
Reference Air Density: Average Site Air Density During Valid Test Periods 1.239kg/m <sup>3</sup>					Sets in Bin (1 Minute Avg.)	Category A Std. Uncertainty SI (kW)	Category B Std. Uncertainty UI (kW)	Combined Uncertainty Uci (kW)		
Bin #	Bin Center (m/s)	Avg Wind (m/s)	Avg Power (kW)	Cp						
2	1	1.0693	-3.0205	-48.7960	61	0.1464	0.2493	0.2891		
3	1.5	1.4773	-3.2085	-19.6593	69	0.1420	0.1088	0.1789		
4	2	2.0356	-3.0818	-7.2171	83	0.1259	0.0984	0.1598		
5	2.5	2.5234	-2.0915	-2.5710	130	0.0899	0.2924	0.3059		
6	3	3.0271	-1.9575	-1.3939	161	0.0692	0.1017	0.1230		
7	3.5	3.5206	-1.5988	-0.7237	285	0.0552	0.1484	0.1584		
8	4	4.0077	-1.1430	-0.3507	352	0.0524	0.1846	0.1919		
9	4.5	4.5031	-0.6756	-0.1461	336	0.0675	0.1960	0.2073		
10	5	4.9971	0.0651	0.0103	377	0.0685	0.3077	0.3152		
11	5.5	5.4840	1.0271	0.1230	312	0.0612	0.4227	0.4271		
12	6	6.0177	2.2161	0.2009	372	0.0622	0.5064	0.5102		
13	6.5	6.4922	3.4860	0.2516	383	0.0687	0.6404	0.6441		
14	7	6.9913	4.9074	0.2837	302	0.0875	0.7212	0.7265		
15	7.5	7.4790	6.6599	0.3145	277	0.0904	0.9575	0.9618		
16	8	8.0087	8.1631	0.3139	242	0.0987	0.8022	0.8082		
17	8.5	8.5112	9.8363	0.3151	304	0.0870	0.9885	0.9924		
18	9	8.9977	11.7850	0.3196	360	0.0863	1.2458	1.2488		
19	9.5	9.4983	13.3471	0.3077	295	0.0982	1.0188	1.0236		
20	10	9.9795	15.3431	0.3049	296	0.0986	1.4121	1.4156		
21	10.5	10.4977	17.5047	0.2989	180	0.1195	1.4853	1.4901		
22	11	10.9820	19.2980	0.2878	145	0.1349	1.3738	1.3804		
23	11.5	11.5042	21.6799	0.2813	117	0.1313	1.7634	1.7683		
24	12	12.0043	23.7064	0.2707	92	0.1516	1.6295	1.6365		
25	12.5	12.4873	24.7890	0.2515	99	0.1602	0.9387	0.9523		
26	13	12.9862	26.8613	0.2423	125	0.1571	1.7958	1.8026		
27	13.5	13.4789	28.5394	0.2302	100	0.1213	1.5255	1.5303		
28	14	13.9613	29.6134	0.2150	83	0.1389	1.0340	1.0433		
29	14.5	14.5032	31.3999	0.2033	60	0.1714	1.5813	1.5906		
30	15	15.0028	33.0132	0.1931	42	0.1888	1.5993	1.6104		
31	15.5	15.4916	34.3544	0.1825	25	0.2235	1.4022	1.4199		

Table 9-2 - Measured Power Curve Normalized to Site Average Air Density

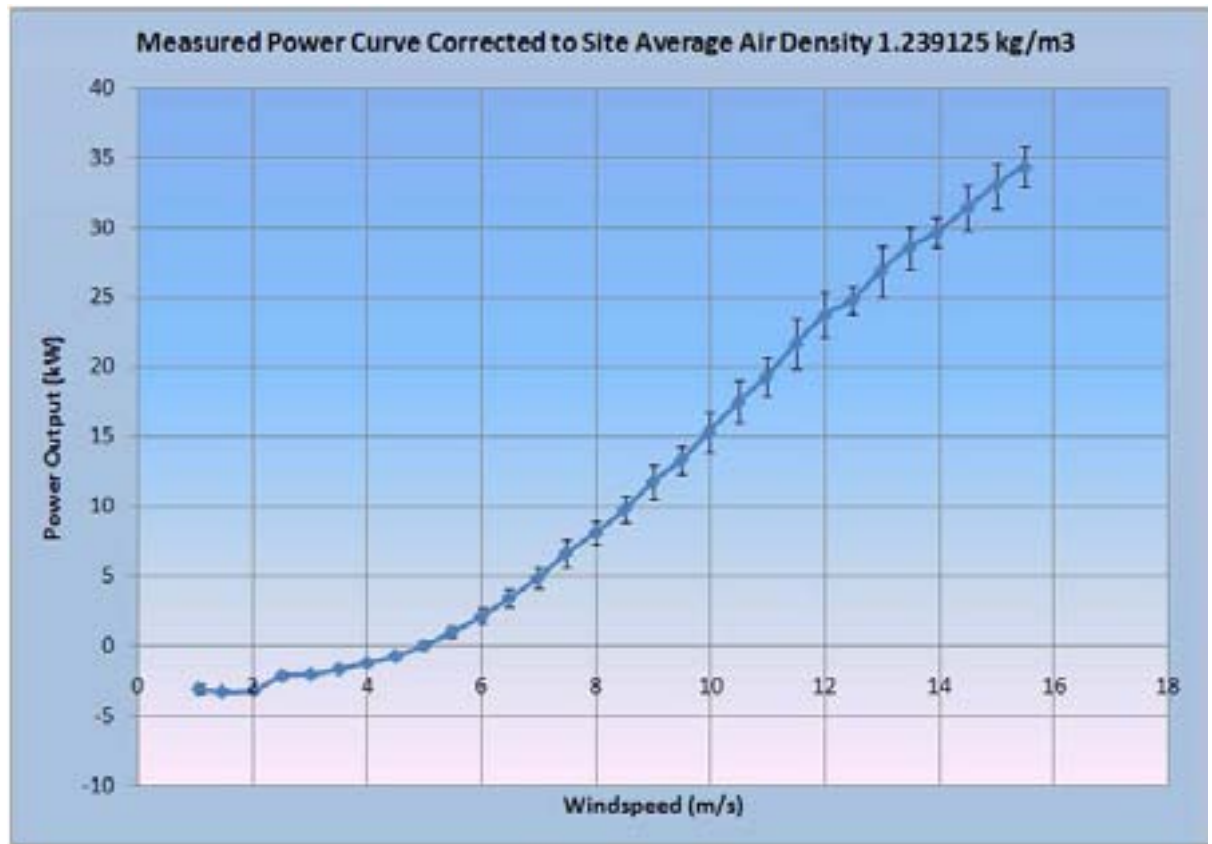


Figure 9-2 - Measured Power Curve Normalized to Site Average Air Density

## 10 POWER COEFFICIENT

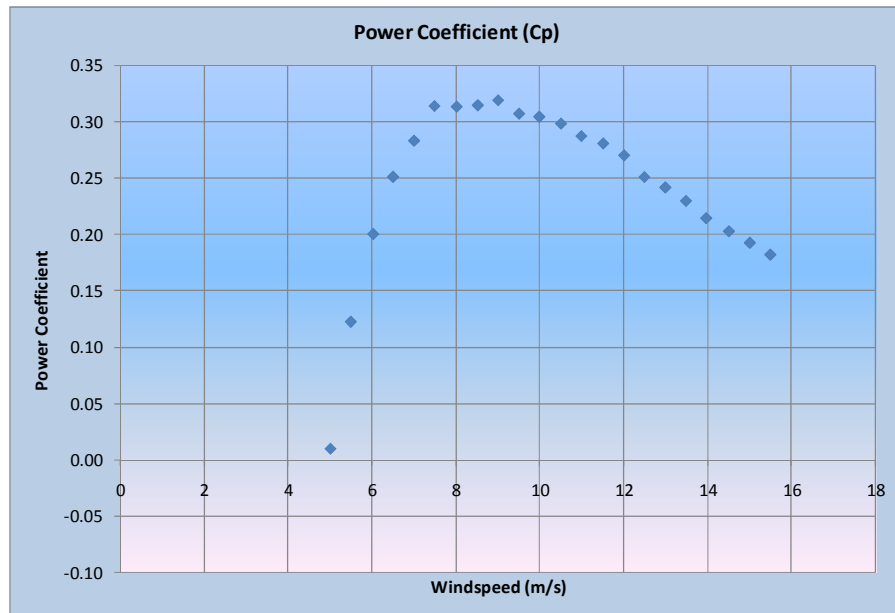


Figure 10-1 - Power Coefficient (Cp)



## 11 ANNUAL ENERGY PRODUCTION

### 11.1 Annual Energy Production (Standard Air Density)

Estimated Annual Energy Production						
Reference air density: 1.225 kg/m <sup>3</sup> (ISO standard at sea level)						
Cut-out windspeed 25 m/s						
(extrapolation by constant power from last bin)						
Hub height annual average wind speed (Rayleigh) (m/s)	AEP-Measured (measured power curve) (MWh)	Standard uncertainty in AEP		AEP-Extrapolated (extrapolated power curve) (MWh)	AEP Incomplete	
		(MWh)	(%)			
4	-0.170	3.542	2088.56%	-0.168	Incomplete	
5	17.574	2.419	13.77%	17.701		
6	38.068	1.400	3.68%	39.418		
7	57.402	0.953	1.66%	63.022	Incomplete	
8	72.482	1.208	1.67%	86.596	Incomplete	
9	82.275	1.563	1.90%	108.527	Incomplete	
10	87.271	1.803	2.07%	127.583	Incomplete	
11	88.571	1.923	2.17%	142.991	Incomplete	

Table 11-1: Annual Energy Production Normalized to Standard Air Density

### 11.2 Annual Energy Production (Site Average Air Density)

Estimated Annual Energy Production						
Reference air density: 1.239125 kg/m <sup>3</sup> (site average during valid test periods)						
Cut-out windspeed 25 m/s						
(extrapolation by constant power from last bin)						
Hub height annual average wind speed (Rayleigh) (m/s)	AEP-Measured (measured power curve) (MWh)	Standard uncertainty in AEP		AEP-Extrapolated (extrapolated power curve) (MWh)	AEP Incomplete	
		(MWh)	(%)			
4	-0.172	3.587	2090.90%	-0.170	Incomplete	
5	17.777	2.450	13.78%	17.905		
6	38.507	1.419	3.68%	39.872		
7	58.064	0.964	1.66%	63.748	Incomplete	
8	73.318	1.220	1.66%	87.594	Incomplete	
9	83.223	1.580	1.90%	109.778	Incomplete	
10	88.277	1.822	2.06%	129.054	Incomplete	
11	89.593	1.945	2.17%	144.639	Incomplete	

Table 11-2: Annual Energy Production Normalized to Site Average Air Density

## 12 UNCERTAINTY OF MEASUREMENT

The results for the power curve and the AEP contain a level of uncertainty which is calculated using the procedure described in Annex E of IEC-61400-12-1. Uncertainty of measurement is expressed in terms of a “standard uncertainty”, which corresponds to a coverage factor of 1 and a level of confidence of approximately 68%. Standard uncertainty is the root-sum-squared of Type A and Type B uncertainties. Type A uncertainty is determined by statistical means, and is proportional to the standard deviation in the data. Type B uncertainty is calculated as a sum of the uncertainties in the sensors, data acquisition system, terrain, as well as other components. The Type B uncertainties are summarized in Table 12-1 below.

Measurement	Component	Uncertainty	Unit	Source
Power	power transducer	0.07	kW	manufacturer
	current transformer	0.2%		manufacturer
	voltage transformer	0.0%		N/A
	data acquisition	0.06	kW	manual
Wind Speed*	anemometer	0.10	m/s	specifications
	mounting effects	1.0%		assumption
	terrain effects	3.0%		assumption
	data acquisition	0.00	m/s	manual
Air Temperature	temperature sensor	0.23	K	calibration documents
	radiation shielding	0.00	K	N/A
	mounting effects	0.04	K	calculated
	data acquisition	0.09	K	manual
Air Pressure**	pressure sensor	0.18	hPa	calibration documents
	data acquisition	0.50	hPa	manual

\*uncertainty due to operational characteristics of the anemometer is calculated according to IEC-61400-12-1, formula I.2, and is dependent on the bin wind speed

\*\*uncertainty due to mounting of the pressure sensor is 10% of the pressure correction, and varies with temperature.

Table 12-1: Type B Uncertainties

Type A uncertainty is calculated for each wind speed bin as the standard deviation of the one-minute mean power values divided by the square root of the number of data sets in each bin. Type B uncertainty is determined from the uncertainty components listed in Table 12-1. Because all



components are assumed to be uncorrelated, they are combined using the root-sum-squared method. In order to express all uncertainties in terms of power (i.e.: kW), sensitivity factors are used. The sensitivity factor for wind speed is the local slope of the power versus wind speed curve. The sensitivity factor for air pressure at sea-level air density is equal to the bin average power divided by sea-level barometric pressure (101.3 kPa). The sensitivity factor for air temperature is equal to the bin average power divided by 288.15 K. Both power curve and AEP uncertainties are composed of Type A and Type B uncertainties. The difference between the two is the way in which Type A and Type B uncertainties are combined. Power curve uncertainty is the root sum of the squares of Type A and Type B uncertainties. AEP uncertainty is combined in the same way, except that the for each wind speed, the probability of the wind speed in each bin is added into the calculation.

Uncertainty due to site calibration was not calculated.

### **13 DEVIATIONS FROM IEC-61400-12-1PROCEDURE**

- Site calibration was not undertaken, and uncertainty was calculated assuming that site calibration was not necessary.
- Only two current transformers are used for the data acquisition system. Despite this, uncertainty calculations were done as if three transformers were in use.
- The power transducer was not tested for compliance with IEC 60688
- The current transformers were not tested for compliance with IEC 60044
- The height of the main anemometer is not within 2.5% of hub height.



## APPENDIX A: WEATHER PRAMETERS AT NORTH CAPE

Average annual wind speed at 50m: 8.2 m/s

Predominant wind direction: WNW – WSW

Environment Canada meteorological site data: <http://tinyurl.com/2wmxz>

## APPENDIX B: REJECTION ANGLE CALCULATIONS

WHALEPOWER	Item:	WHALEPOWER	MET	n	0.14								
	Height:	27.00	25.00	Z <sub>0</sub>	0.3								
	Dia:	10.20		k	0.4	Effect on Turbine			Effect on MET Tower				
Object	Height	Width/ Dia.	U <sub>h</sub> (m/s)	Distance To Turbine	Distance To MET	Rejected Angle Turbine	Rejected angle range (Turbine)		Rejected Angle MET	Rejected angle range (MET)			
WEICan Office	10.00	39.00	5.56	261.39	275.75								
Accomadation	10.00	16.00	5.56	237.31	244.86								
UNB Building	6.00	16.00	5.00	182.58	205.07								
Electric Building	6.00	15.00	5.00	178.55	197.96								
Diesel Building	6.00	12.00	5.00	167.10	187.09								
Vestas Building	10.00	21.00	5.56	238.82	262.98								
Old Shop	6.00	16.00	5.00	136.19	155.75								
Vergnet	25.00	15.00	6.35	160.04	167.24	37.33	6.97	44.30	36.67	20.45	57.12		
Vergnet 60 shed	3.50	3.00	4.40	110.42	128.18								
Vergnet 60 MET(ews)	24.00	0.25	6.35	165.26	161.28								
EWS	24.00	15.00	6.35	93.06	107.90	47.62	10.02	57.64	44.39	31.83	76.22		
EWS shed	3.50	3.00	4.40	98.25	112.43								
EWS MET (ver 60)	26.70	0.25	6.35	95.45	96.12								
WhalePower	27.00	10.20	6.35	0.00	38.14	-----			61.09	80.87	141.96		
Wenvor shed	3.50	3.00	4.40	20.13	40.82								
Wenvor MET	25.00	0.25	6.35	38.14	0.00				-----				
Lagerwey	26.70	18.00	6.35	69.00	107.01	60.35	75.17	135.52	48.62	83.20	131.81		
Lagerwey shed	3.50	3.00	4.40	66.19	104.02								
Lagerwey MET(wvrUNB)	26.70	0.25	6.35	107.87	141.50								
Bornay	20.00	3.60	6.15	80.92	61.91				31.39	201.19	232.59		
ARE	20.00	3.60	6.15	64.01	43.22	31.07	234.87	265.93	35.62	197.20	232.82		
Skystream	10.10	3.72	6.15	108.35	87.58								
SWTB shed	3.50	3.00	4.40	65.44	54.51								
SWTB MET	20.00	0.25	6.15	77.33	52.66								
Windmatic	26.70	10.00	6.35	102.88	121.62	37.89	161.92	199.81	35.44	146.07	181.51		
Windmatic shed	4.00	4.00	4.80	92.99	108.64								
Windmaticc MET	26.70	0.25	6.35	104.90	109.27								
Wenvor UNB	25.00	15.00	6.35	128.73	160.11	40.96	51.72	92.68	37.32	62.20	99.52		
Wenvo rUNB MET	26.70	0.25	6.35	107.87	141.50								
ETS3	62.00	0.50	7.70	58.01	54.82								
N1 - V47	50.00	47.00	7.60	276.32	312.85	48.88	69.20	118.08	46.04	72.75	118.79		
N2 - V47	50.00	47.00	7.60	175.01	209.07	61.22	110.24	171.46	56.09	107.67	163.75		
N3 - V47	50.00	47.00	7.60	226.86	232.15	53.86	171.27	225.13	53.25	162.13	215.38		
N4 - V47	50.00	47.00	7.60	403.20	398.85	40.96	190.18	231.14	41.16	184.67	225.83		

All objects/turbines that are highlighted red, cause disturbances.

---

## APPENDIX C: WENVOR LOG BOOK FOR THE YEAR 2008

- Day 47 to 51 (*February 16<sup>th</sup>-20<sup>th</sup>*):
  - Broken anemometer
- Day 51 (*February 20<sup>th</sup>*):
  - Replaced anemometer
- Day 52 (*February 21<sup>st</sup>*):
  - Changed Programming
  - UNB students arrived
- Day 54 (*February 23<sup>rd</sup>*):
  - UNB students caused power outage on site
- Day 57, 58 (*February 26<sup>th</sup>, 27<sup>th</sup>*):
  - Icing on site
- Day 69 (*March 9<sup>th</sup>*):
  - Replaced UPS
- Day 94 (*April 3<sup>rd</sup>*):
  - Breaker tripped, offline
- Day 105-119 (*April 14<sup>th</sup> – 28<sup>th</sup>*):
  - Defective (intermittent) anemometer cable
- Day 129-141 (*May 8<sup>th</sup> – 20<sup>th</sup>*):
  - Turbine taken down due to site construction