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Power Performance Test Report for the SWIFT Wind Turbine

I. Mendoza and J. Hur
National Renewable Energy Laboratory

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Technical Report
NREL/TP-5000-56499
December 2012

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Power Performance Test Report
for the
SWIFT Wind Turbine

in

Boulder, Colorado

Conducted by
National Wind Technology Center
National Renewable Energy Laboratory
15013 Denver West Parkway
Golden, Colorado 80401

For

Wind Energy Program

DOE/NREL

Ismael Mendoza and Jerry Hur

7 September 2012

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Review By: Jeroen van Dam — Jeroen van Dam, NREL Test engineer — 6 November 2012 — Date

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1. Background

This SWIFT power performance test was conducted as part of the U.S. Department of Energy's (DOE's) Independent Testing project. This project was established to help reduce the barriers of wind energy expansion by providing independent testing results for small turbines. Three turbines were tested at the National Renewable Energy Laboratory (NREL) National Wind Technology Center (NWTC) as a part of round two of the Small Wind Turbine Independent Testing project. Power performance testing was one of up to five tests that were performed on the turbines. Other tests include duration, safety and function, noise, and power quality. Cascade Engineering, of Grand Rapids, Michigan, distributor of the Renewable Devices' SWIFT turbine in North America, was the recipient of the DOE grant and provided the turbine for testing.

2. Test Summary

Figure 1 is a summary of the results of the power performance test that NREL conducted on the SWIFT small wind turbine (shown in Figure 2). In this test, the SWIFT turbine was installed at the NWTC near Boulder, Colorado. This test was conducted in accordance with the International Electrotechnical Commission (IEC) standard, Wind Turbine Generator Systems Part 12: Power Performance Measurements of Electricity Producing Wind Turbines, IEC 61400-12-1 Ed.1.0, 2005-12. Because the SWIFT is a small turbine according to the IEC definition, NREL also followed Annex H, which applies to small wind turbines. This test report refers to these procedures as the "Standard."

In these summary results, power was normalized to sea-level air density. This test began on 7 April 2011 and ended on 30 June 2011. During that period, NREL collected 812 hours of valid data. The highest bin filled was the 24 meters per second (m/s) bin. The amount of test data is sufficient to meet the requirements of the Standard.

NATIONAL RENEWABLE ENERGY LABORATORY

Power Performance Test
SWIFT

Sea-Level Density Power Curve

Turbine Specifications:

Serial Number:	N000780-N	
Rated Power:	1	kW
Cut-in Wind Speed:	3.40	m/s
Cut-out Wind Speed:	-	m/s
Rated Wind Speed:	11	m/s
Rotor Diameter:	2.134	m
Control Type:	Stall	
Pitch Setting:	Fixed	

Site Conditions:

Location:	NWTC, Boulder, CO	
Average Air Density:	0.986	kg/m^3
Measurement Sectors:	178-311	degrees true

Test Statistics:

Start Date:	7-Apr-2011	
End Date:	30-Jun-2011	
Amount of Data Collected:	812.05	hours
Highest Bin Filled:	24.00	m/s
Test Completed?	Yes	

Ismael Mendoza - NREL Test Engineer — Date: Aug 08 2012

Bin Wind Speed (m/s)	Bin Power (kW)	Number Data Points	Cp
0.54	-0.01	1,121	-21.65
1.02	-0.01	1,923	-3.19
1.52	-0.01	2,851	-0.96
2.00	-0.01	3,823	-0.42
2.50	-0.01	3,866	-0.22
3.00	-0.01	3,807	-0.13
3.50	-0.01	3,471	-0.08
4.00	-0.01	3,203	-0.05
4.49	-0.01	2,850	-0.03
4.99	0.00	2,422	0.01
5.50	0.02	2,182	0.07
5.99	0.05	1,950	0.11
6.50	0.08	1,604	0.14
6.99	0.13	1,430	0.17
7.50	0.18	1,269	0.20
8.00	0.25	1,146	0.22
8.51	0.33	1,095	0.25
9.00	0.43	1,042	0.27
9.50	0.53	932	0.28
10.00	0.65	930	0.30
10.49	0.77	782	0.31
10.99	0.90	685	0.31
11.50	1.02	644	0.31
11.99	1.14	584	0.30
12.50	1.25	507	0.29
12.99	1.33	425	0.28
13.49	1.39	339	0.26
14.00	1.43	265	0.24
14.50	1.41	235	0.21
14.98	1.34	230	0.18
15.50	1.21	187	0.15
16.00	1.09	150	0.12
16.48	0.97	122	0.10
16.99	0.76	131	0.07
17.49	0.65	99	0.06
17.97	0.54	70	0.04
18.48	0.47	77	0.03
18.97	0.40	48	0.03
19.49	0.40	38	0.02
19.99	0.35	38	0.02
20.50	0.37	35	0.02
20.95	0.32	19	0.02
21.44	0.37	14	0.02
21.99	0.36	22	0.02
22.48	0.38	14	0.02
23.02	0.37	17	0.01
23.51	0.40	17	0.01
23.99	0.40	12	0.01

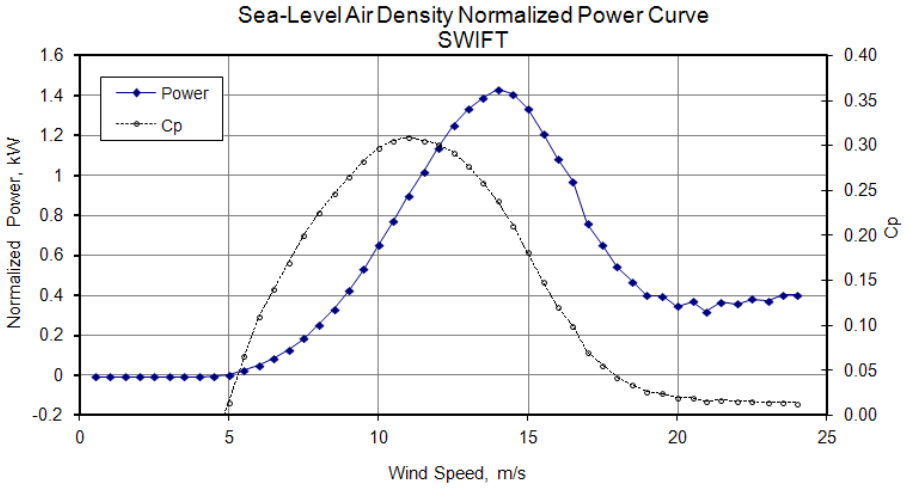


Figure 1. Power curve summary

Figure 2. SWIFT test turbine at the NWTC
Source: NREL PIX 22083

3. Test Turbine Configuration

Table 1 lists the configuration of the SWIFT turbine that was tested at the NWTC.

Table 1. Test Turbine Configuration and Operational Data

Turbine manufacturer and address	Renewable Devices Ltd. AeroMarine House, Turnhouse Aerodrome Turnhouse Road, Edinburgh EH12 9DN Scotland, UK
Turbine distributor and address	Cascade Engineering 4855 Thirty-Seven St. SE Grand Rapids, MI 49512
Model	SWIFT
Serial number	N000780-N
Rotor diameter (m)	2.1 with outer ring*
Hub height (m)	14.2*
Tower type	13.7 m (45 feet) freestanding monopole
Rated electrical power (kW)	1
Rated wind speed (m/s)	11
Rotor speed range (rpm)	0-450
Fixed or variable pitch	Fixed
Number of blades	5
Blade pitch angle (deg)	6˚ at the tip
Blade make, type, serial number	Injection molded nano-fiber reinforced polymer, F000648
Description of control system (device and software version)	Kaco Blueplanet 1502x, Software V2.05

*Measurements verified the rotor diameter and hub height.

4. Test Site Description

The SWIFT wind turbine was located at test site 3.1 of the NWTC, approximately 8 kilometers (km) south of Boulder, Colorado. The site consisted of mostly flat terrain with short vegetation (see Appendix A for photos) and had prevailing winds bearing 292 degrees relative to true north. Figure 3 shows the turbine and meteorological (met) tower locations. This figure also shows nearby obstructions. NREL limited assessments of power and energy production to data obtained when winds were within a 178° to 311° measurement sector. In this measurement sector, the influence of terrain and obstructions on the anemometer was small and met the requirements in the Standard without conducting a site calibration test.

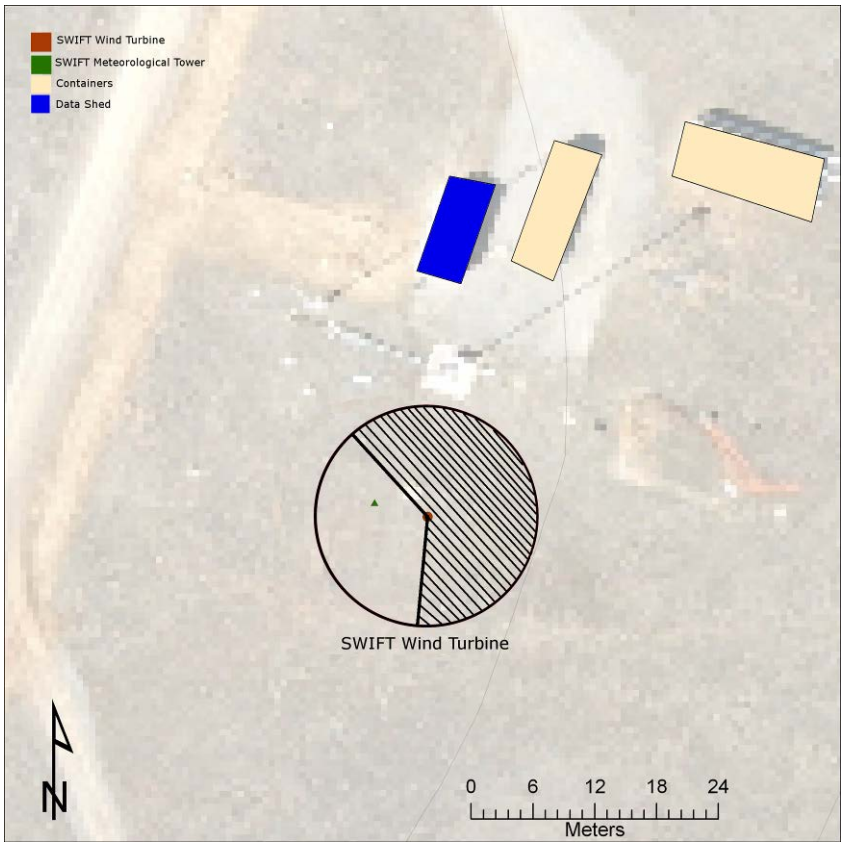


Figure 3. Map of the test site
Source: NREL 2011

Table 2 shows obstructions that affected the wind at the location of the SWIFT wind turbine or its met tower according to the Standard's obstacles assessment criteria in Annex A. The azimuth and distance data were relative to the SWIFT wind turbine. Several of these obstructions do not appear on the map in Figure 3.

Table 2. Structures Close to Test Turbine

Designation	Azimuth [deg true]	Distance [m]	Height [m]	Diam/width [m]
Main building	45	385	15	50
Shipping containers (x2) @ 3-1	49	46	3	15
GE/DOE	77	531	80	77
CART-3	129	365	37	43
CART-2	147	431	37	40
Siemens	153	624	80	101
IUF	330	279	15	50
Quonset hut	335	198	7	20
DTF	352	246	15	20
Data shed	360	26	3.5	7

NREL completed a site assessment to determine if the site fails the requirements of Annex A and B of the Standard and would therefore require a site calibration. Table 3 shows the results from the site assessment, which confirms that a site calibration was not required.

Table 3. Site Assessment Results

Description	Distance	Sector (deg)	Test Site Condition	Pass/Fail
Maximum slope of best fit plane < 3%	<2L	360	1.70%	Pass
Maximum variation from best fit plane < 0.04 (H + D)	<2L	360	0	Pass
Maximum slope of best fit plane < 5%	2 to 4L	In	1.80%	Pass
Maximum variation from best fit plane < 0.08 (H + D)	2 to 4L	In	0	Pass
Steepest slope maximum < 10%	2 to 4L	Out	2.10%	Pass
Maximum slope of best fit plane < 10%	4 to 8L	In	1.70%	Pass
Maximum variation from best fit plane < 0.13 (H + D)	4 to 8L	In	0.1	Pass
No neighboring and operating turbines	<2Dn	360	0	Pass
No obstacles	<2De	360	0	Pass

In = Inside preliminary measurement sector
Out = Outside preliminary measurement sector

The SWIFT turbine was connected to the electrical grid at a nominal voltage of 240 volts alternating current (VAC) at a frequency of 60 hertz (Hz). The grid tolerances were 5% for voltage amplitude and 1% for frequency.

5. Description of Test Equipment

All test equipment was calibrated; Appendix B contains the calibration sheets. Table 4 shows the equipment used and calibration due dates. Figure 4 depicts the placement of the meteorological instruments on the tower. Note that the primary anemometer was within the allowable 2.5% of hub height. The primary anemometer was sent out for recalibration after the test period. The difference between the pre-test and post-test calibrations was less than 0.05 m/s for the range of 6 to 12 m/s and within the tolerances allowed by the Standard (0.1 m/s). The post-test calibration sheets are also included in Appendix B.

Table 4. Equipment Used in the Power Performance Test

Instrument	Make, Model	Serial Number	Calibration Due Date
Power transducer	Secondwind Phaser 5FM-4A20	04607	21 October 2011
Primary anemometer	Thies, First Class	0609006	7 April 2012
Reference anemometer	Met One, 010	W2390	In situ
Wind vane	Met One, 020C with aluminum vane	U1478	13 October 2011
Pressure sensor	Vaisala, PTB101B	C1020014	10 August 2011
Temperature sensor	Met One, T-200	0673553	13 October 2011
Precipitation sensor	Campbell Scientific, 237	None	In situ
Data acquisition system	Compact DAQ w/LabView-based data acquisition cDAQ-9172 NI 9229 NI 9217 NI 9205	 13AB4F9 14A34EE 1494F69 1496266	 22 March 2012 22 March 2012 22 March 2012

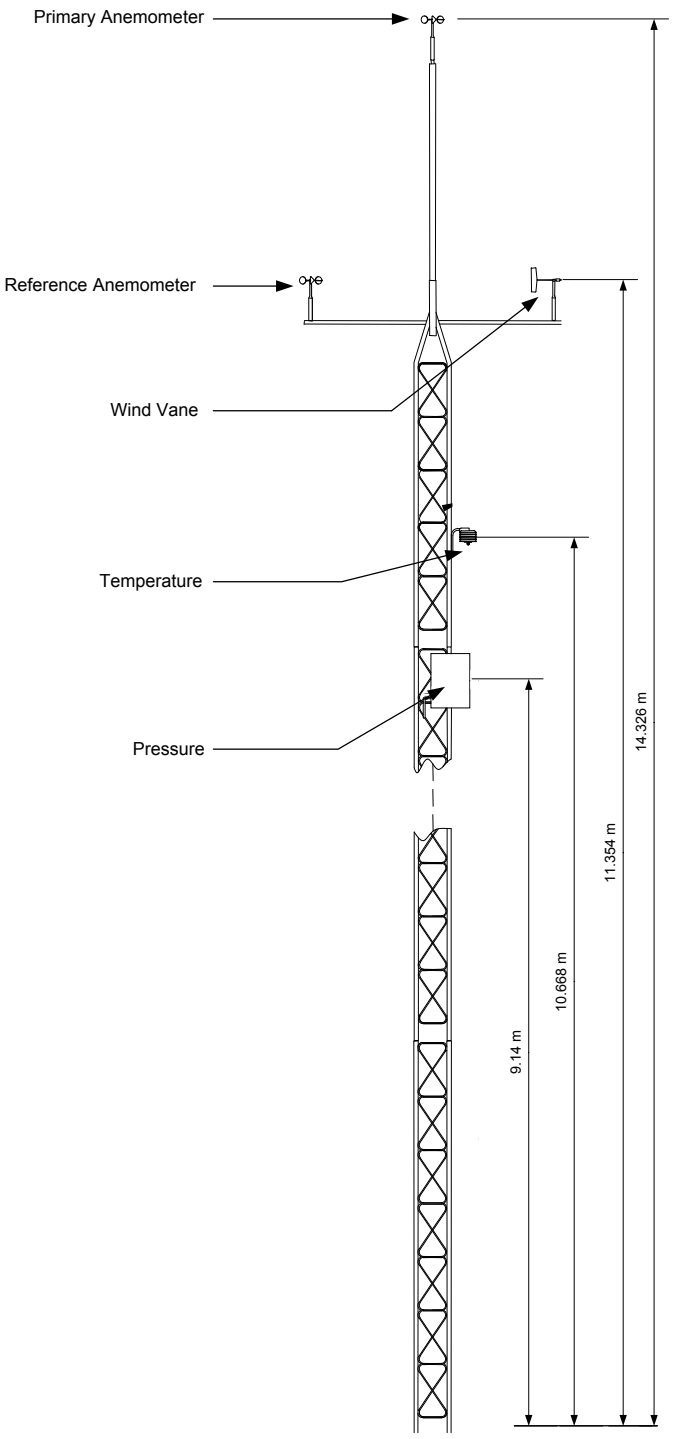


Figure 4. Meteorological tower and instruments (not to scale)
Source: NREL 2011

To ensure that only data obtained during normal operation of the turbine were used in the analysis, and to ensure that data were not corrupted, NREL excluded data sets from the database under the following circumstances:

- External conditions other than wind speed were out of the normal range for turbine operation
- The turbine could not operate because of a turbine fault condition
- The turbine was manually shut down or in a test or maintenance operating mode
- Failure or maintenance of the institute's data acquisition system.

Two methods were used to track when any of these conditions occurred during the test. In the first method, the logbook was checked for such events. For the second, the turbine controller provided a status signal that indicated when the turbine was available or braked. In the second method, the status signal was checked in the data file during analysis. No maintenance was performed during the test period.

6. Description of Test Procedure

NREL conducted the test according to the procedures in the Standard. The sampling rate was 10 kHz, decimated to 40 Hz. The averaging time was 1 minute for the mean values. NREL also collected standard deviation, minimum, and maximum values for each averaging period.

The turbine status signal for the SWIFT was obtained by checking the release of the up-tower brake relay by monitoring its voltage supply. The status signal indicated if the turbine was available or braked.

Only database A is reported because the SWIFT turbine does not have a cut-out wind speed.

Table 5 gives the uncertainty sources and values used in the analysis.

Table 5. Uncertainty Values Used in the Analysis

Component	Uncertainty	Source
Power (Inverter)		
Power transducer	0.00231 kW	IEC
Data acquisition	.01803 kW +0.075%	Specs
Resistor	0.006%	Specs
Wind Speed		
Calibration	0.0179 m/s	Calibration sheet
Operational characteristics	0.052m/s +0.52%	IEC eq. (I.2)
Mounting effects	1%	Assumptions
Terrain effects	2.00%	IEC
Data acquisition	0.002 m/s	Calculations based on sampling frequency
Temperature		
Temperature sensor	0.015˚C	Calibration sheet
Radiation shielding	0.2˚C	Assumptions
Mounting effects	0.069˚C	IEC method
Data acquisition	0.2˚C	Specs
Air Pressure		
Pressure sensor	0.1 kPa	Calibration sheet
Mounting effects	0.005 kPa	IEC method
Data acquisition	0.032 kPa	Specs

7. Test Results

7.1 Tabular Results of Power Performance Test

Table 6 through Table 9 provide the power performance test results in tabular format.

Table 6. Performance at Sea-Level Air Density; 1.225 kg/m^3

Measured Power Curve (Database A)							
Reference air density:	1.225	kg/m^3					
Bin number	**Normalized wind speed (m/s)**	**Power output (kW)**	**Cp**	**Number of 1-minute data sets**	**Category A standard uncertainty** (kW)	**Category B standard uncertainty (kW)**	**Combined standard uncertainty** (kW)
1	0.54	-0.01	-21.65	1121	0.00	0.02	0.02
2	1.02	-0.01	-3.19	1923	0.00	0.02	0.02
3	1.52	-0.01	-0.96	2851	0.00	0.02	0.02
4	2.00	-0.01	-0.42	3823	0.00	0.02	0.02
5	2.50	-0.01	-0.22	3866	0.00	0.02	0.02
6	3.00	-0.01	-0.13	3807	0.00	0.02	0.02
7	3.50	-0.01	-0.08	3471	0.00	0.02	0.02
8	4.00	-0.01	-0.05	3203	0.00	0.02	0.02
9	4.49	-0.01	-0.03	2850	0.00	0.02	0.02
10	4.99	0.00	0.01	2422	0.00	0.02	0.02
11	5.50	0.02	0.07	2182	0.00	0.02	0.02
12	5.99	0.05	0.11	1950	0.00	0.02	0.02
13	6.50	0.08	0.14	1604	0.00	0.02	0.02
14	6.99	0.13	0.17	1430	0.00	0.02	0.02
15	7.50	0.18	0.20	1269	0.00	0.03	0.03
16	8.00	0.25	0.22	1146	0.00	0.03	0.03
17	8.51	0.33	0.25	1095	0.00	0.04	0.04
18	9.00	0.43	0.27	1042	0.00	0.04	0.04
19	9.50	0.53	0.28	932	0.00	0.05	0.05
20	10.00	0.65	0.30	930	0.00	0.06	0.06
21	10.49	0.77	0.31	782	0.00	0.06	0.06
22	10.99	0.90	0.31	685	0.00	0.07	0.07
23	11.50	1.02	0.31	644	0.00	0.07	0.07
24	11.99	1.14	0.30	584	0.00	0.07	0.07
25	12.50	1.25	0.29	507	0.00	0.07	0.07
26	12.99	1.33	0.28	425	0.01	0.05	0.05
27	13.49	1.39	0.26	339	0.01	0.04	0.04
28	14.00	1.43	0.24	265	0.01	0.03	0.04
29	14.50	1.41	0.21	235	0.02	0.02	0.03
30	14.98	1.34	0.18	230	0.02	0.05	0.06
31	15.50	1.21	0.15	187	0.02	0.09	0.09
32	16.00	1.09	0.12	150	0.02	0.10	0.10
33	16.48	0.97	0.10	122	0.02	0.09	0.09
34	16.99	0.76	0.07	131	0.02	0.17	0.17
35	17.49	0.65	0.06	99	0.02	0.09	0.09
36	17.97	0.54	0.04	70	0.02	0.09	0.10
37	18.48	0.47	0.03	77	0.02	0.07	0.07
38	18.97	0.40	0.03	48	0.02	0.06	0.06
39	19.49	0.40	0.02	38	0.02	0.02	0.03
40	19.99	0.35	0.02	38	0.01	0.05	0.05
41	20.50	0.37	0.02	35	0.02	0.03	0.04
42	20.95	0.32	0.02	19	0.01	0.06	0.06
43	21.44	0.37	0.02	14	0.02	0.05	0.06
44	21.99	0.36	0.02	22	0.01	0.02	0.02
45	22.48	0.38	0.02	14	0.01	0.03	0.03
46	23.02	0.37	0.01	17	0.01	0.02	0.02
47	23.51	0.40	0.01	17	0.01	0.04	0.04
48	23.99	0.40	0.01	12	0.01	0.02	0.02

Table 7. Performance at Site Average Density; 0.99 kg/m^3

Measured Power Curve (Database A)							
Reference air density:		0.99	kg/m^3				
Bin number	**Normalized wind speed (m/s)**	**Power output (kW)**	**Cp**	**Number of 1-minute data sets**	**Category A standard uncertainty** (kW)	**Category B standard uncertainty (kW)**	**Combined standard uncertainty** (kW)
1	0.54	-0.01	-21.65	1121	0.00	0.02	0.02
2	1.02	-0.01	-3.19	1923	0.00	0.02	0.02
3	1.52	-0.01	-0.96	2851	0.00	0.02	0.02
4	2.00	-0.01	-0.42	3823	0.00	0.02	0.02
5	2.50	-0.01	-0.22	3866	0.00	0.02	0.02
6	3.00	-0.01	-0.13	3807	0.00	0.02	0.02
7	3.50	-0.01	-0.08	3471	0.00	0.02	0.02
8	4.00	-0.01	-0.05	3203	0.00	0.02	0.02
9	4.49	0.00	-0.03	2850	0.00	0.02	0.02
10	4.99	0.00	0.01	2422	0.00	0.02	0.02
11	5.50	0.02	0.07	2182	0.00	0.02	0.02
12	5.99	0.04	0.11	1950	0.00	0.02	0.02
13	6.50	0.07	0.14	1604	0.00	0.02	0.02
14	6.99	0.10	0.17	1430	0.00	0.02	0.02
15	7.50	0.15	0.20	1269	0.00	0.02	0.02
16	8.00	0.21	0.22	1146	0.00	0.03	0.03
17	8.51	0.27	0.25	1095	0.00	0.03	0.03
18	9.00	0.35	0.27	1042	0.00	0.04	0.04
19	9.50	0.43	0.28	932	0.00	0.04	0.04
20	10.00	0.53	0.30	930	0.00	0.05	0.05
21	10.49	0.63	0.31	782	0.00	0.05	0.05
22	10.99	0.73	0.31	685	0.00	0.06	0.06
23	11.50	0.83	0.31	644	0.00	0.05	0.05
24	11.99	0.93	0.30	584	0.00	0.06	0.06
25	12.50	1.02	0.29	507	0.00	0.06	0.06
26	12.99	1.09	0.28	425	0.01	0.04	0.05
27	13.49	1.13	0.26	339	0.01	0.03	0.04
28	14.00	1.17	0.24	265	0.01	0.03	0.03
29	14.50	1.15	0.21	235	0.01	0.02	0.03
30	14.98	1.09	0.18	230	0.01	0.04	0.05
31	15.50	0.99	0.15	187	0.01	0.07	0.07
32	16.00	0.89	0.12	150	0.02	0.08	0.08
33	16.48	0.79	0.10	122	0.02	0.08	0.08
34	16.99	0.62	0.07	131	0.01	0.14	0.14
35	17.49	0.53	0.06	99	0.02	0.07	0.08
36	17.97	0.44	0.04	70	0.02	0.08	0.08
37	18.48	0.38	0.03	77	0.01	0.06	0.06
38	18.97	0.33	0.03	48	0.01	0.05	0.05
39	19.49	0.32	0.02	38	0.01	0.02	0.02
40	19.99	0.28	0.02	38	0.01	0.04	0.04
41	20.50	0.30	0.02	35	0.02	0.03	0.03
42	20.95	0.26	0.02	19	0.01	0.05	0.05
43	21.44	0.30	0.02	14	0.02	0.05	0.05
44	21.99	0.29	0.02	22	0.01	0.02	0.02
45	22.48	0.31	0.02	14	0.01	0.03	0.03
46	23.02	0.31	0.01	17	0.01	0.02	0.02
47	23.51	0.33	0.01	17	0.01	0.03	0.03
48	23.99	0.33	0.01	12	0.01	0.02	0.02

Table 8. Annual Energy Production (AEP) at Sea-Level Density; 1.225 kg/m^3

Estimated Annual Energy Production, Database A (All Valid Data)					
	Reference air density:	1.225	kg/m^3		
	Cut-out wind speed:	-	m/s		
Hub height annual average wind speed (Rayleigh)	**AEP-measured**	**Standard uncertainty in AEP-measured**		**AEP-extrapolated**	**Complete if AEP measured is at least 95% of AEP extrapolated**
m/s	**kWh**	**kWh**	**%**	**kWh**	
4	301	178	62%	301	Complete
5	900	210	24%	900	Complete
6	1,745	251	15%	1,745	Complete
7	2,665	292	11%	2,666	Complete
8	3,495	331	10%	3,496	Complete
9	4,144	362	9%	4,149	Complete
10	4,592	385	8%	4,604	Complete
11	4,857	398	8%	4,880	Complete
AEP measured assumes zero power between highest bin and cut-out.					
AEP extrapolated assumes power in last bin between last bin and cut-out.					

Table 9. AEP at Site Average Density; 0.99 kg/m^3

Estimated Annual Energy Production, Database A (All Valid Data)					
	Reference air density:	0.99	kg/m^3		
	Cut-out wind speed:	-	m/s		
Hub height annual average wind speed (Rayleigh)	**AEP-measured**	**Standard uncertainty in AEP-measured**		**AEP-extrapolated**	**Complete if AEP measured is at least 95% of AEP extrapolated**
m/s	**KWh**	**kWh**	**%**	**KWh**	
4	246	173	73%	246	Complete
5	734	197	27%	734	Complete
6	1,425	228	16%	1,425	Complete
7	2,176	260	12%	2,176	Complete
8	2,853	289	10%	2,854	Complete
9	3,383	314	9%	3,387	Complete
10	3,749	331	9%	3,759	Complete
11	3,965	341	9%	3,984	Complete
AEP measured assumes zero power between highest bin and cut-out.					
AEP extrapolated assumes power in last bin between last bin and cut-out.					

7.2 Graphical Results Power Performance Test

Figure 5 through Figure 11 show the results of the power performance test. Figure 5 shows a plot of the binned power curve normalized to sea-level air density.

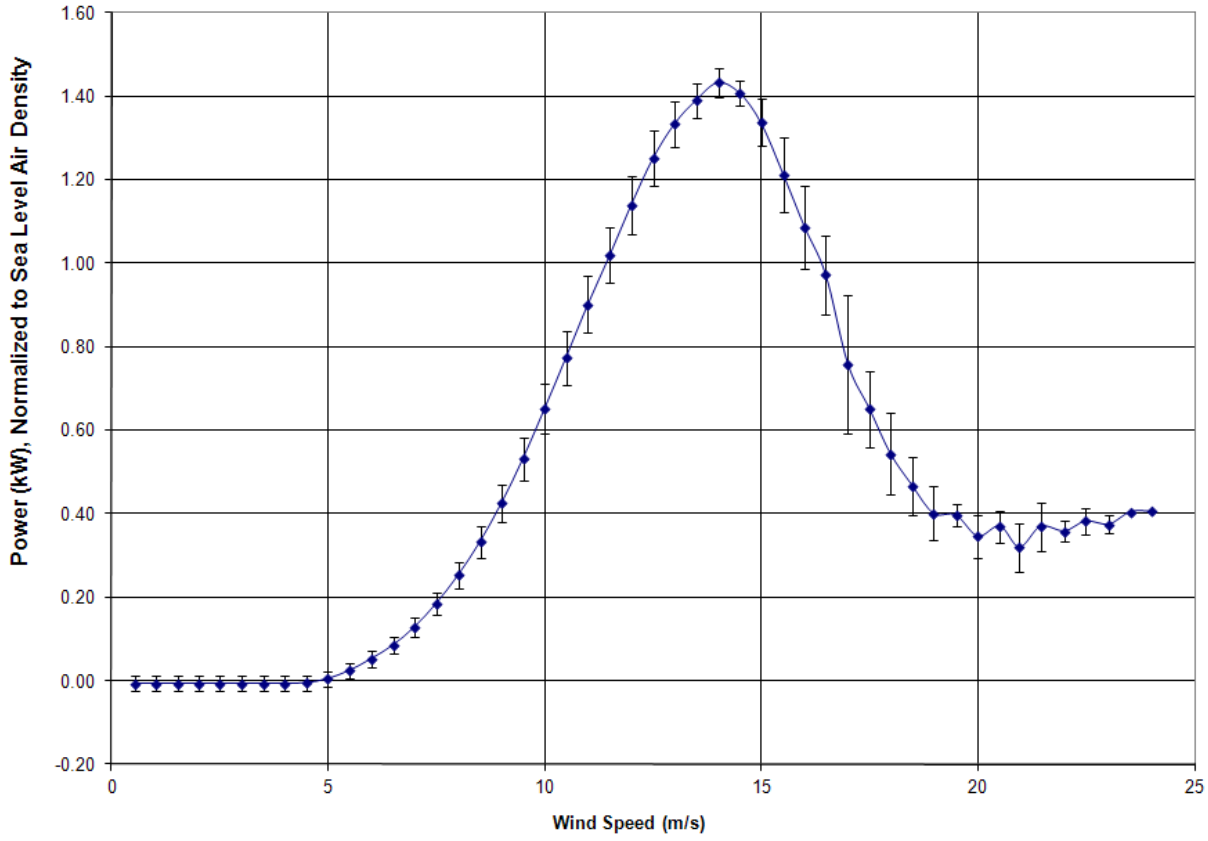


Figure 5. Power curve at sea-level density, 1.225 kg/m^3

Figure 6 shows a plot of the binned power curve at the site average air density during the test period.

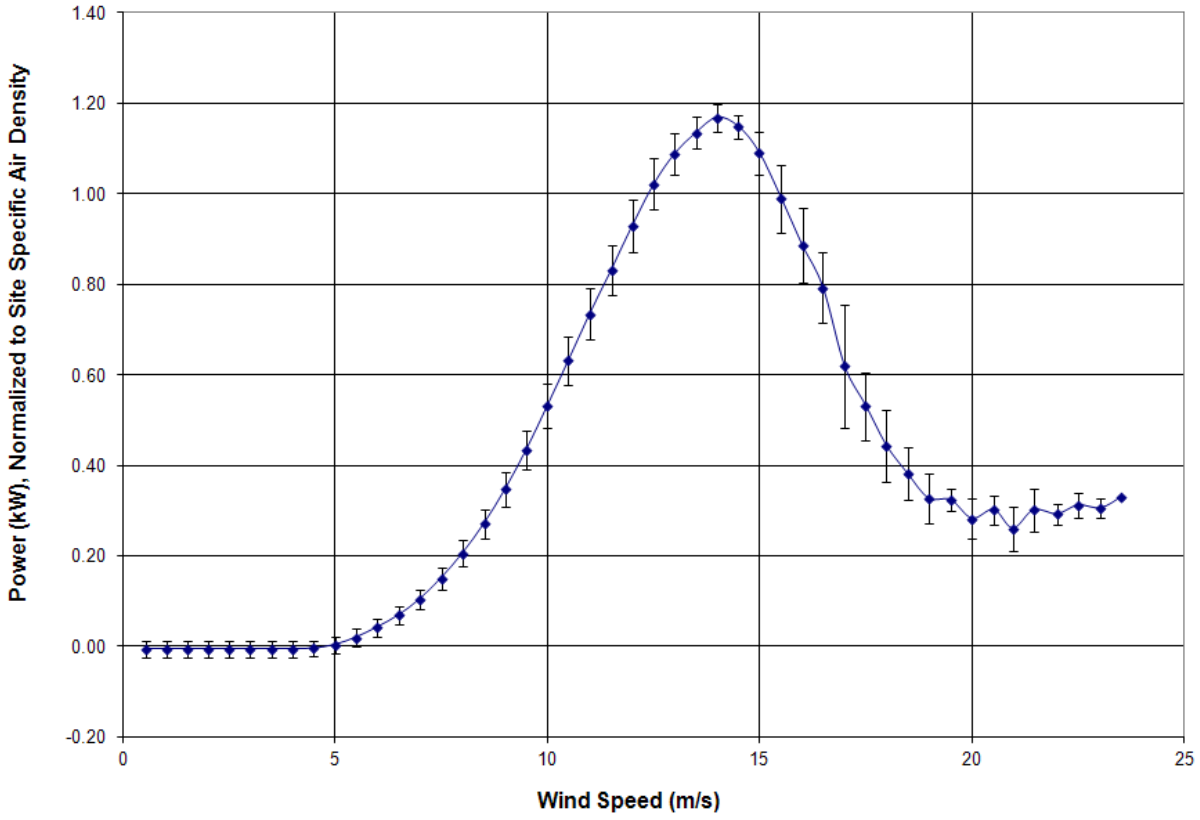


Figure 6. Power curve at site average density, 0.99 kg/m^3

Figure 7 shows a scatter plot of statistics for power for the turbine.

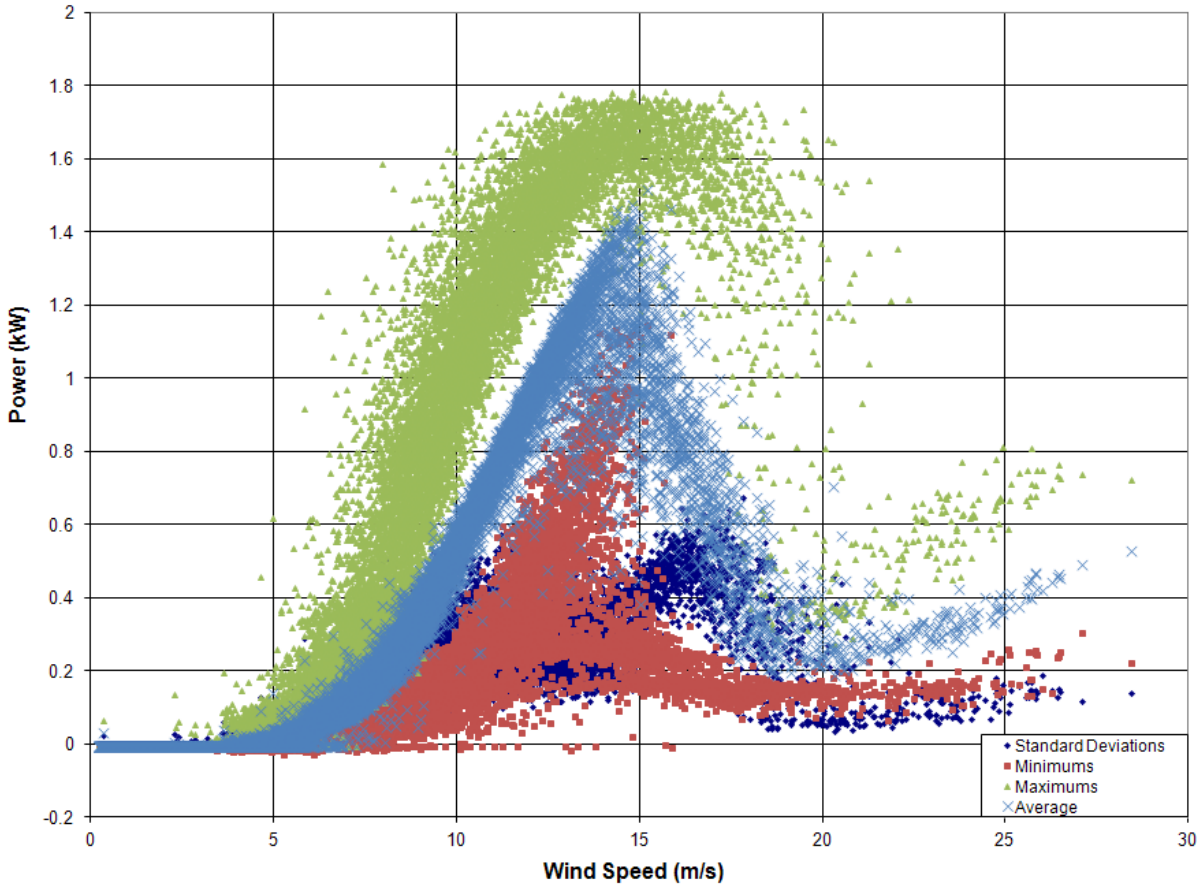


Figure 7. Scatter plot of mean and standard deviation power data as measured

Figure 8 shows a plot of the binned coefficient of performance as a function of wind speed at sea-level normalized air density.

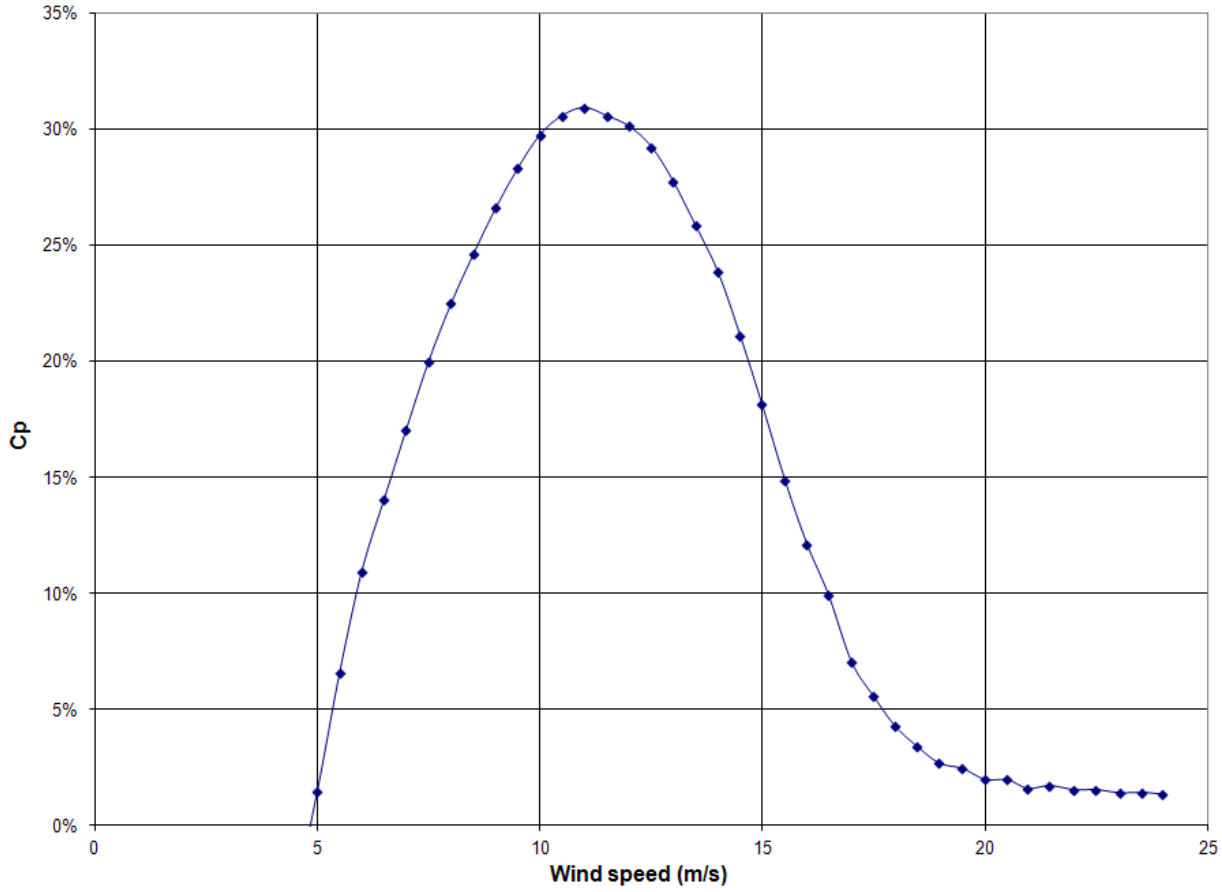


Figure 8. Coefficient of performance at sea-level average density, 1.225 kg/m^3

Figure 9 shows a scatter plot of wind speed and turbulence intensity as a function of wind direction.

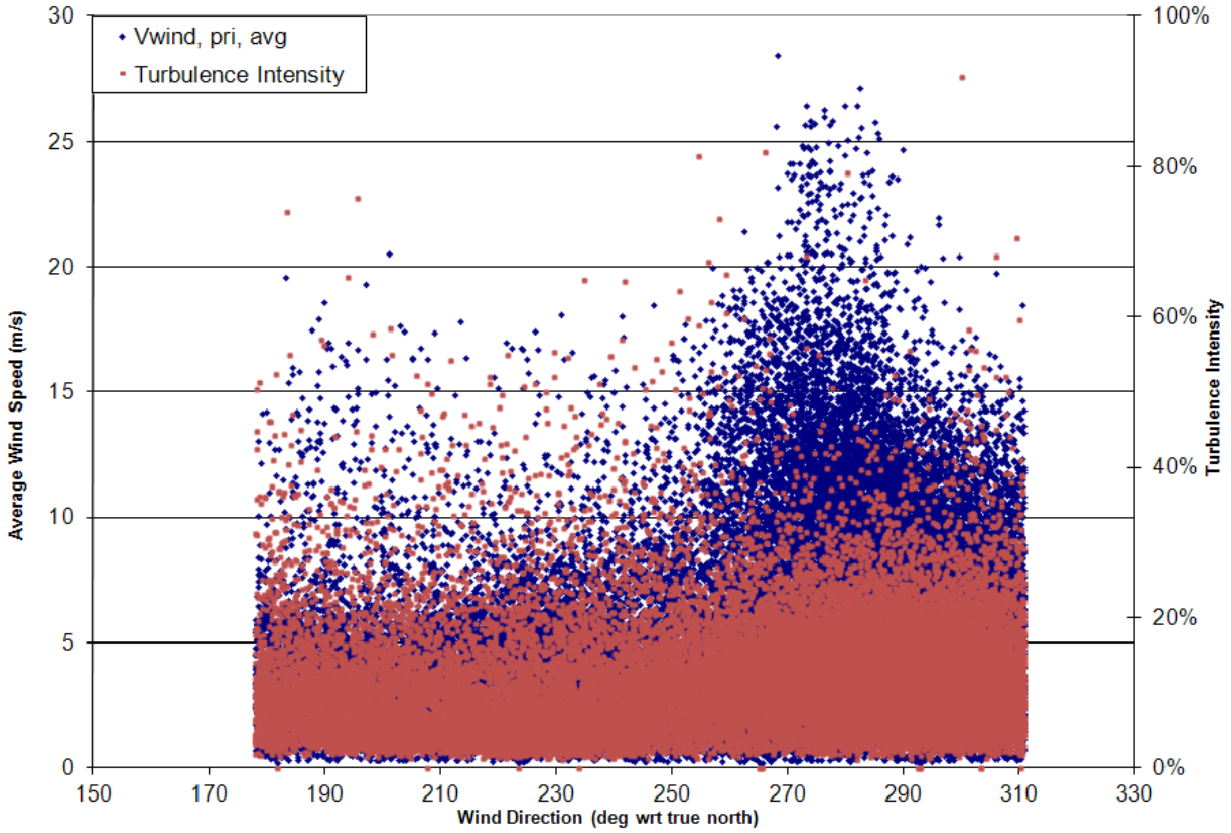


Figure 9. Wind speed and turbulence intensity as a function of wind direction

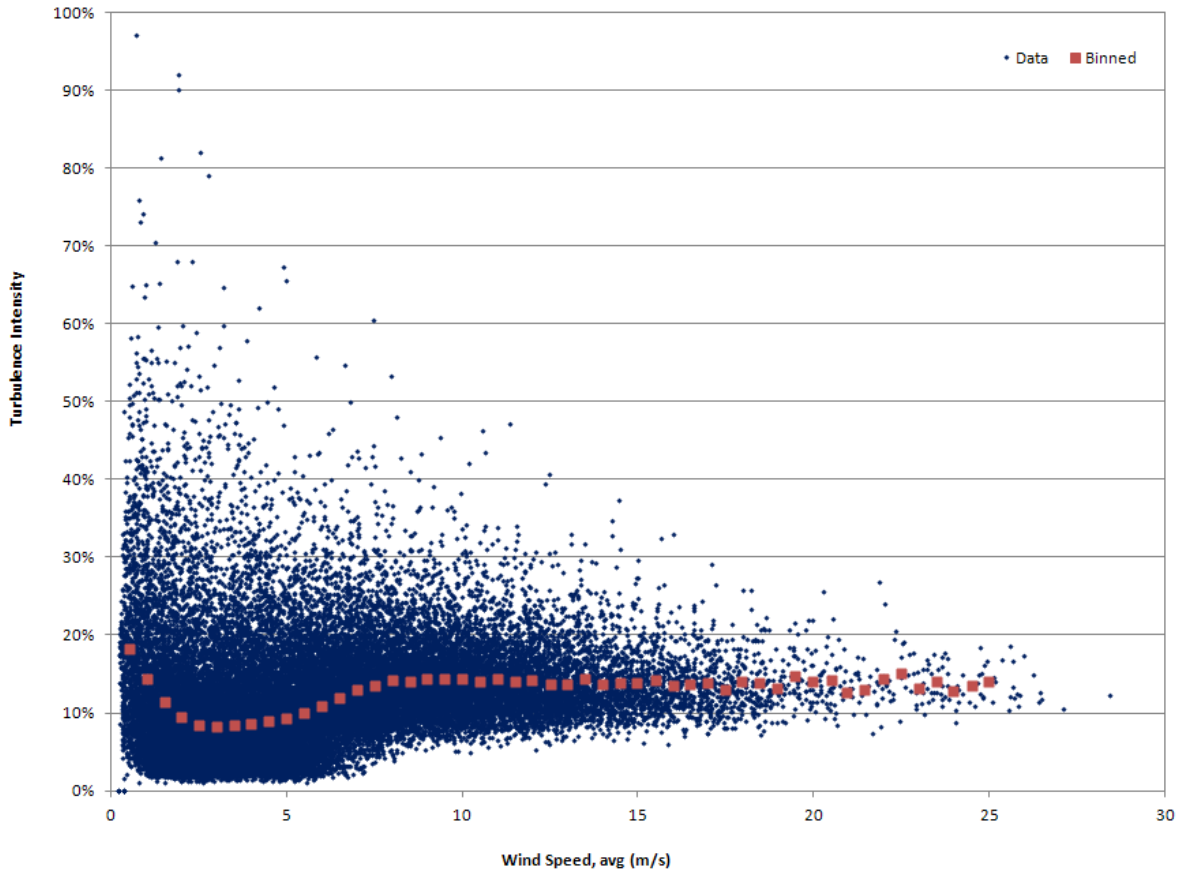


Figure 10. Wind turbulence at the test site

Figure 11 shows a scatter plot and binned values of rotor speed as a function of wind speed.

Table 10. Binned Rotor Speed from 0.5 up to 30 m/s

Wind Speed	(m/s)	0.5	1	1.5	2	2.5	3	3.5	4	4.5	5	5.5	6	6.5	7	7.5
Rotor Speed	(rpm)	0	1	4	5	15	17	43	75	130	152	170	194	215	231	257
Wind Speed	(m/s)	8	8.5	9	9.5	10	10.5	11	11.5	12	12.5	13	13.5	14	14.5	15
Rotor Speed	(rpm)	274	296	316	331	347	360	368	377	382	393	395	398	397	390	384
Wind Speed	(m/s)	15.5	16	16.5	17	17.5	18	18.5	19	19.5	20	20.5	21	21.5	22	22.5
Rotor Speed	(rpm)	367	350	335	316	300	285	280	268	261	261	258	257	261	263	254
Wind Speed	(m/s)	23	23.5	24	24.5	25	25.5	26	26.5	27	27.5	28	28.5	29	29.5	30
Rotor Speed	(rpm)	257	262	270	267	276	279	277	277	289	284	301	286	-	319	307

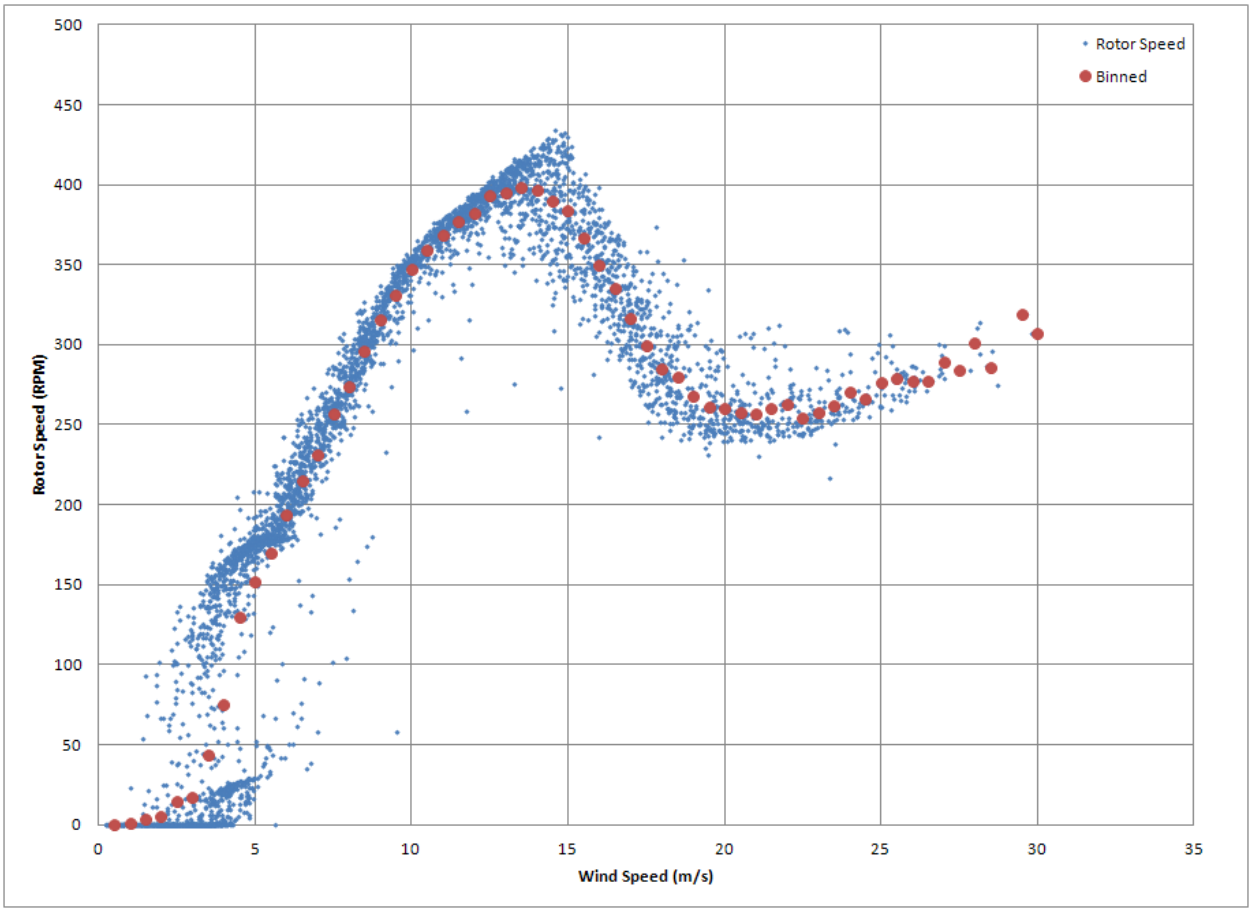


Figure 11. Rotor speed as a function of wind speed (1-minute average) and binned values

8. Deviations and Exceptions

8.1 Deviations from the Standard

The reference anemometer was mounted 2.97 m below the primary. This exceeded the Standard's allowable maximum of 2.5 m below the primary as shown in Annex G.5. This should have no effect on results or uncertainty because the primary anemometer was post-test calibrated and the reference anemometer was not used for an in situ calibration.

8.2 Exceptions to NREL Quality Assurance System

The reference anemometer was mounted 2.97 m below the primary. This exceeded the Standard's allowable maximum of 2.5 m below the primary as shown in Annex G.5.

9. Reference

Wind Turbines, Part 12-1: Power performance measurements of electricity producing wind turbines, IEC 61400-12-1, Edition 1, 2005-12, International Electrotechnical Commission, Geneva, Switzerland, 2005.

Appendix A: Photographs of the Test Site from the Turbine Base

Direction pictures are facing:

A1. North

A2. Northeast

A3. East

A4. Southeast

A5. South

A6. Southwest

A7. West

A8. Northwest

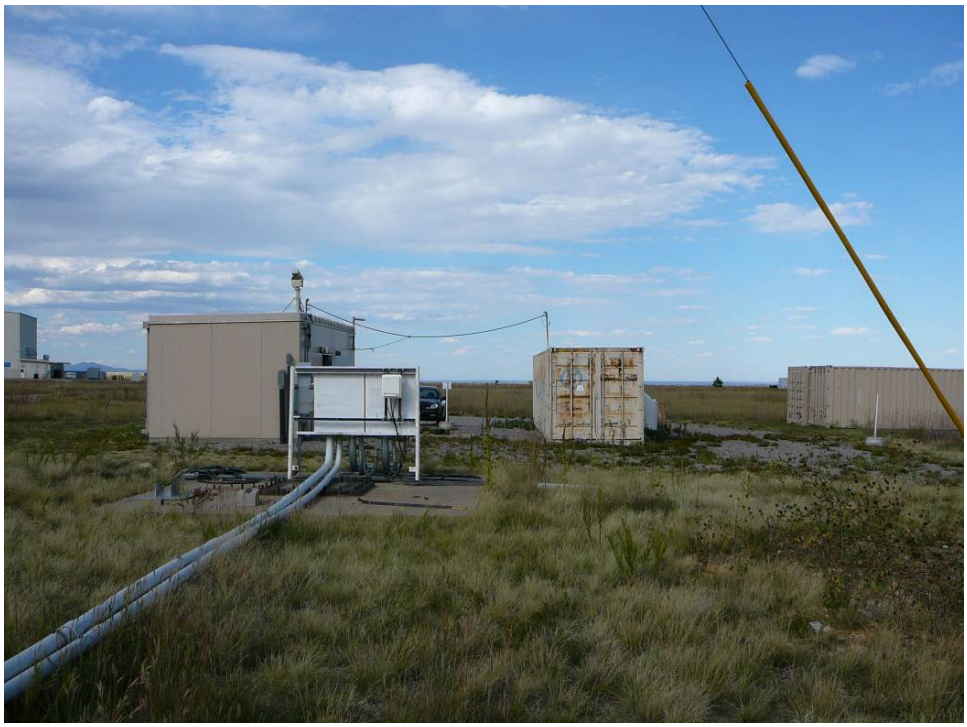


Figure A1. Facing north
Source: NREL 2011

Figure A2. Facing northeast
Source: NREL 2011

Figure A3. Facing east
Source: NREL 2011

Figure A4. Facing southeast
Source: NREL 2011

Figure A5. Facing south
Source: NREL 2011

Figure A6. Facing southwest
Source: NREL 2011

Figure A7. Facing west
Source: NREL 2011

Figure A8. Facing northwest
Source: NREL 2011

Appendix B: Equipment Calibration Sheets

Figure B1. Power transducer calibration sheet I

Figure B2. Power transducer calibration sheet II

Figure B3. Power transducer calibration sheet III

Figure B4. Primary anemometer calibration sheet I

Figure B5. Primary anemometer calibration sheet II

Figure B6. Primary anemometer post-test calibration sheet I

Figure B7. Primary anemometer post-test calibration sheet II

Figure B8. Primary anemometer pre- and post-test calibration comparison; the difference is less than 0.1m/s for the range of 6 to 12m/s

Figure B9. Wind vane calibration sheet

Figure B10. Pressure transducer calibration sheet

Figure B11. RTD-Probe calibration sheet

Figure B12. NI 9229 data acquisition module calibration sheet I

Figure B13. NI 9217 data acquisition module calibration sheet I

Figure B14. NI 9205 data acquisition module calibration sheet I

Figure B15. NI 9229 data acquisition module calibration sheet II

Figure B16. NI 9217 data acquisition module calibration sheet II

Figure B17. NI 9205 data acquisition module calibration sheet II

Power

Branch #: 5000

NREL METROLOGY LABORATORY

Test Report

Test Instrument: Phaser Power Transducer DOE #: 03503C

Model # : Phaser-5-485-4A 20 S/N : 04607

Calibration Date: 10/20/2010 Due Date: 10/20/2012

A. Set-Up for Power Calibration:
A.1. Voltage is applied to phases A&B = 120 V @ 60 Hz.
A.2. Current is applied to phases A&B.
A.3. Analog Output-1 is measured across precision resistor = 250 Ω.

Calibrator Output		Transducer Input/Output		
Current (AAC)	Power 2*V*I (W)	Input Current (AAC)	Input Power 2*n*V*I (W)	Analog Output-1 (VDC)
-9	-2160	N/A	N/A	.997
-8	-1920	"	"	1.078
-6	-1440	"	"	1.557
-4	-960	"	"	2.037
-2	-480	"	"	2.516
-1	-240	"	"	2.754
0	0	"	"	2.994
1	240	"	"	3.234
2	480	"	"	3.473
4	960	"	"	3.953
6	1440	"	"	4.432
8	1920	"	"	4.911
9	2160	"	"	4.991

Page 1 of 3

Figure B1. Power transducer calibration sheet I, installed 20 October 2010 to 24 October 2011

B. Set-Up for Power Factor Calibration:
B.1. Voltage @120VAC and Current @ 4A @ 60Hz
B.2. Analog Output-2 is measured across precision resistor = 250 Ω.

Calibrator Output		Analog Output-2 (VDC)
Current (AAC)	Power Factor	
4	1	4.994
4	0.75	3.990
4	0.5	2.990
4	0.25	1.990
4	0.0	1.010

C. Set-Up for Total Harmonic Distortion (THD) Calibration:
C.1. Voltage & Current are applied as A.1 & A.2.
C.2. Analog Output-3 is set for Current THD
C.3. Analog Output-3 is measured across precision resistor = 250 Ω.

Current THD (%)	Analog Output-3 (VDC)
0	.999
10	1.395
20	1.796
30	2.191

D. Set-Up for A to B Voltage Measurement:
D.1. Voltage is applied as listed below @ 60Hz
D.3. Analog Output-4 is measured across precision resistor = 250 Ω.

Calibrator Output	Analog Output-4 (VDC)
0V	2.996
80V	3.611
160V	4.226
240V	4.680

Page 2 of 3

Figure B2. Power transducer calibration sheet II installed 20 October 2010 to 24 October 2011

Notes:
- Calibration was performed using instruments that are traceable to NIST, DOE# 126410 and 01886C.
- Calibration was performed at temperature = 24 °C, ± 1 °C, and relative humidity =45%, ± 10%.
- Uncertainty of nominal values is ± 0.15% of reading.

Calibrated By: P. Morse

Date: 10/20/2010

Approved By : Reda

Date: 10/20/2010

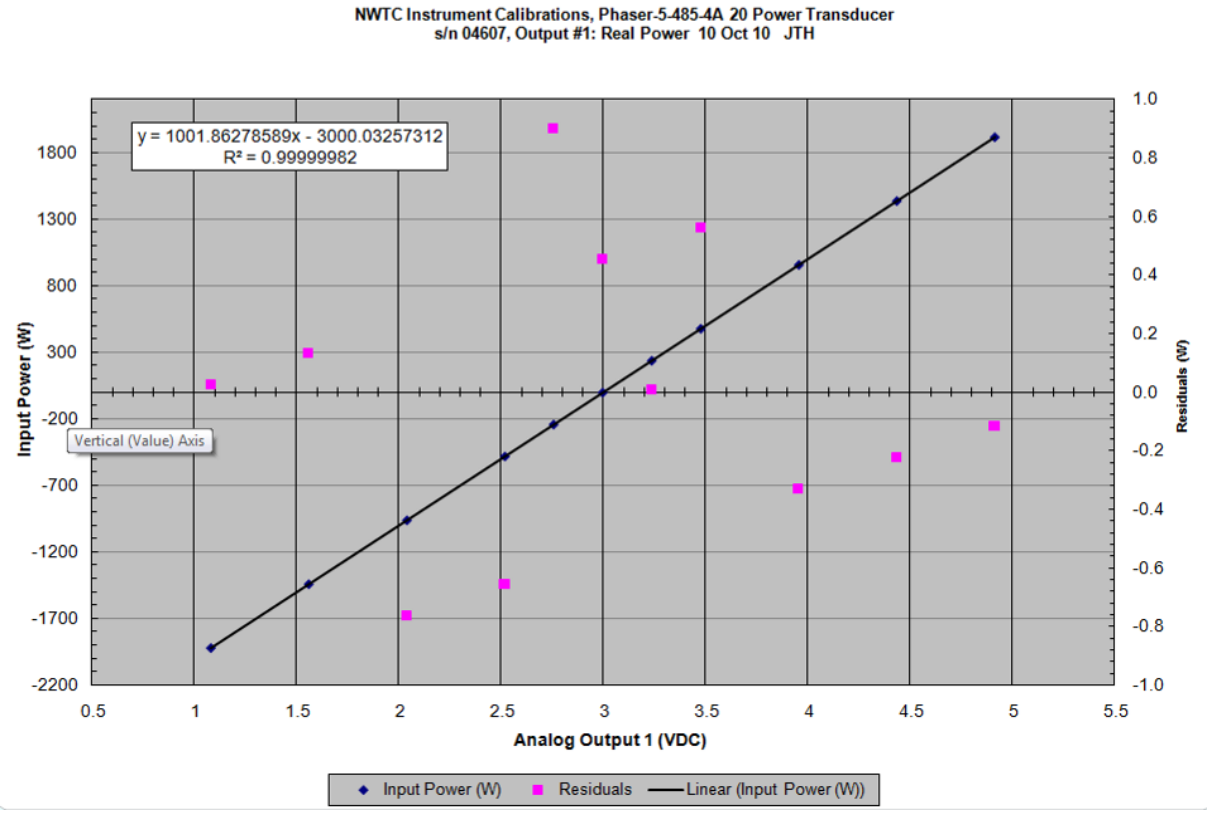
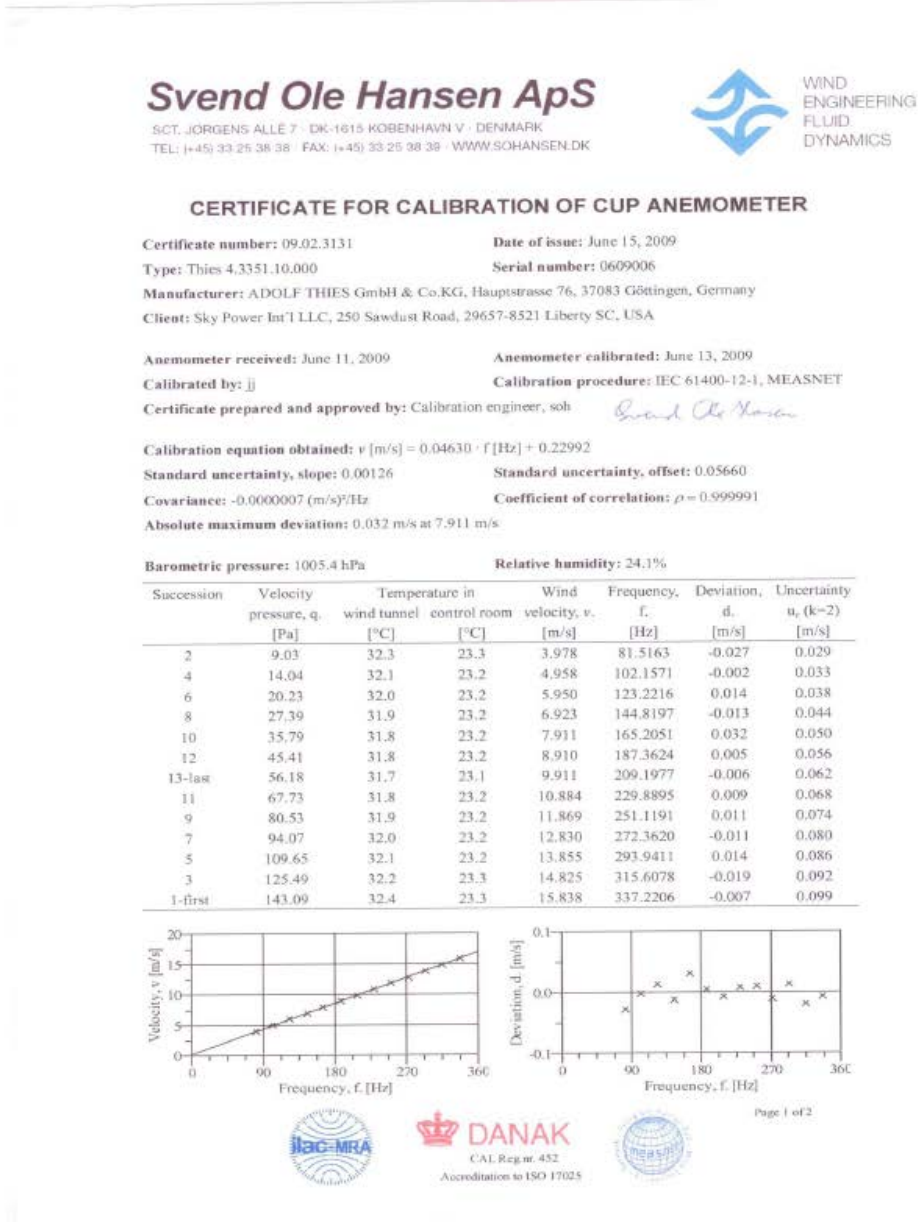


Figure B3. Power transducer calibration sheet III installed 20 October 2010 to 24 October 2011

Wind Speed



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TEL: (+45) 33 25 38 38 · FAX: (+45) 33 25 38 39 · WWW.SOHANSEN.DK

WIND ENGINEERING FLUID DYNAMICS

CERTIFICATE FOR CALIBRATION OF CUP ANEMOMETER

Certificate number: 09.02.3131 **Date of issue:** June 15, 2009
Type: Thies 4.3351.10.000 **Serial number:** 0609006
Manufacturer: ADOLF THIES GmbH & Co.KG, Hauptstrasse 76, 37083 Göttingen, Germany
Client: Sky Power Int'l LLC, 250 Sawdust Road, 29657-8521 Liberty SC, USA

Anemometer received: June 11, 2009 **Anemometer calibrated:** June 13, 2009
Calibrated by: jj **Calibration procedure:** IEC 61400-12-1, MEASNET
Certificate prepared and approved by: Calibration engineer, soh

Calibration equation obtained: v [m/s] = 0.04630 · f [Hz] + 0.22992
Standard uncertainty, slope: 0.00126 **Standard uncertainty, offset:** 0.05660
Covariance: -0.0000007 (m/s)²/Hz **Coefficient of correlation:** ρ = 0.999991
Absolute maximum deviation: 0.032 m/s at 7.911 m/s

Barometric pressure: 1005.4 hPa **Relative humidity:** 24.1%

Succession	Velocity pressure, q. [Pa]	Temperature in wind tunnel [°C]	Temperature in control room [°C]	Wind velocity, v. [m/s]	Frequency, f. [Hz]	Deviation, d. [m/s]	Uncertainty u, (k=2) [m/s]
2	9.03	32.3	23.3	3.978	81.5163	-0.027	0.029
4	14.04	32.1	23.2	4.958	102.1571	-0.002	0.033
6	20.23	32.0	23.2	5.950	123.2216	0.014	0.038
8	27.39	31.9	23.2	6.923	144.8197	-0.013	0.044
10	35.79	31.8	23.2	7.911	165.2051	0.032	0.050
12	45.41	31.8	23.2	8.910	187.3624	0.005	0.056
13-last	56.18	31.7	23.1	9.911	209.1977	-0.006	0.062
11	67.73	31.8	23.2	10.884	229.8895	0.009	0.068
9	80.53	31.9	23.2	11.869	251.1191	0.011	0.074
7	94.07	32.0	23.2	12.830	272.3620	-0.011	0.080
5	109.65	32.1	23.2	13.855	293.9411	0.014	0.086
3	125.49	32.2	23.3	14.825	315.6078	-0.019	0.092
1-first	143.09	32.4	23.3	15.838	337.2206	-0.007	0.099

Page 1 of 2

ilac-MRA DANAK CAL Reg.nr. 452 Accreditation to ISO 17025 measnet

Figure B4. Primary anemometer calibration sheet I

EQUIPMENT USED

Serial number	Description
-	Boundary layer wind tunnel.
1255	Control cup anemometer.
-	Mounting tube, D = 35 mm
t3	PT100 temperature sensor, wind tunnel.
t4	PT100 temperature sensor, control room.
950610	PPC500 Furness pressure manometer
Z0420014	HMW71U Humidity transmitter
U4220037	PTB100AVaisala analogue barometer.
PI1	Pitot tube
001551	Computer Board. 16 bit A/D data acquisition board.
-	PC dedicated to data acquisition.

Traceable calibrations of the equipment are carried out by external accredited institutions: Furness (PPC500) and Saab Metech. A real-time analysis module within the data acquisition software detects pulse frequency.

Photo of a cup anemometer in the wind tunnel. The shown anemometer is of the same type as the calibrated one.

UNCERTAINTIES

The documented uncertainty is the total combined uncertainty at 95% confidence level (k=2) in accordance with EA-4/02. The uncertainty at 10 m/s comply with the requirements in the MEASNET procedure that prescribes an absolute uncertainty less than 0.1 m/s at a mean wind velocity of 10 m/s, that is 1%. See Document 97.00.004 "MEASNET-Test report on the calibration campaign" for further details.

Certificate number: 09.02.3131

Figure B5. Primary anemometer calibration sheet II

DOE # 043900

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WIND ENGINEERING FLUID DYNAMICS

CERTIFICATE FOR CALIBRATION OF CUP ANEMOMETER

Certificate number: 12.02.6727 **Date of issue:** August 24, 2012

Type: Thies 4.3351.10.000 **Serial number:** 0609006

Manufacturer: ADOLF THIES GmbH & Co.KG, Hauptstrasse 76, 37083 Göttingen, Germany

Client: National Renewable Energy Lab, 1617 Cole Boulevard, Golden, Colorado 80401-3393, USA

Anemometer received: August 13, 2012 **Anemometer calibrated:** August 23, 2012

Calibrated by: asj **Calibration procedure:** IEC 61400-12-1, MEASNET

Certificate prepared by: ea **Approved by:** Calibration engineer, ml

Calibration equation obtained: $v\,[m/s] = 0.04654 \cdot f\,[Hz] + 0.15404$

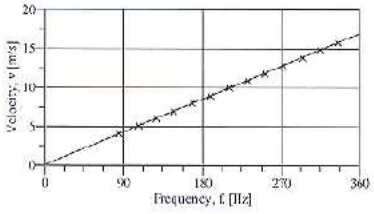
Standard uncertainty, slope: 0.00114 **Standard uncertainty, offset:** 0.07713

Covariance: -0.0000006 $(m/s)^2/Hz$ **Coefficient of correlation:** $\rho = 0.999993$

Absolute maximum deviation: -0.036 m/s at 13.844 m/s

Barometric pressure: 1009.3 hPa **Relative humidity:** 27.6%

Succession	Velocity pressure, q. [Pa]	Temperature in wind tunnel [°C]	Temperature in control room [°C]	Wind velocity, v. [m/s]	Frequency, f. [Hz]	Deviation, d. [m/s]	Uncertainty u_c (k=2) [m/s]
2	9.65	33.4	25.5	4.112	85.1908	-0.007	0.021
4	14.95	33.3	25.5	5.119	106.6331	0.002	0.025
6	21.07	33.1	25.4	6.075	127.4800	-0.012	0.029
8	28.26	33.1	25.4	7.035	147.5747	0.012	0.033
10	36.34	33.0	25.4	7.977	168.1495	-0.003	0.037
12	45.88	33.0	25.4	8.962	189.1365	0.005	0.042
13-last	56.70	32.9	25.4	9.963	210.5526	0.009	0.046
11	68.46	33.0	25.4	10.948	231.7626	0.007	0.051
9	80.56	33.1	25.4	11.878	251.6408	0.012	0.055
7	94.56	33.1	25.4	12.870	273.2038	0.000	0.059
5	109.38	33.2	25.4	13.844	294.9135	-0.036	0.064
3	125.53	33.4	25.5	14.833	315.5930	-0.009	0.068
1-first	141.94	33.6	25.5	15.780	335.3141	0.020	0.073



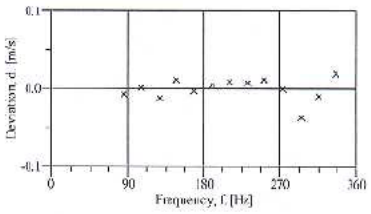


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Figure B6. Primary anemometer post-test calibration sheet I

EQUIPMENT USED

Serial number	Description
-	Boundary layer wind tunnel.
1256	Control cup anemometer.
-	Mounting tube, D = 35 mm
t1	PT100 temperature sensor, wind tunnel.
t2	PT100 temperature sensor, control room.
9904031	PPC500 Furness pressure manometer
X4650038	HMW71U Humidity transmitter
X4350042	PTB100AVaisala analogue barometer.
P11	Pitot tube
HB2835279	Computer Board. 16 bit A/D data acquisition board.
-	PC dedicated to data acquisition.

Traceable calibrations of the equipment are carried out by external accredited institutions: Furness (PPC500) and Saab Metech. A real-time analysis module within the data acquisition software detects pulse frequency.

Photo of the wind tunnel setup (hxb = 0.85x1.75 m). The shown anemometer is of the same type as the calibrated one.

UNCERTAINTIES

The documented uncertainty is the total combined uncertainty at 95% confidence level (k=2) in accordance with EA-4/02. The uncertainty at 10 m/s comply with the requirements in the MEASNET procedure that prescribes an absolute uncertainty less than 0.1 m/s at a mean wind velocity of 10 m/s, that is 1%. See Document 97.00.004 "MEASNET - Test report on the calibration campaign" for further details.

Certificate number: 12.02.6727

Figure B7. Primary anemometer post-test calibration sheet II

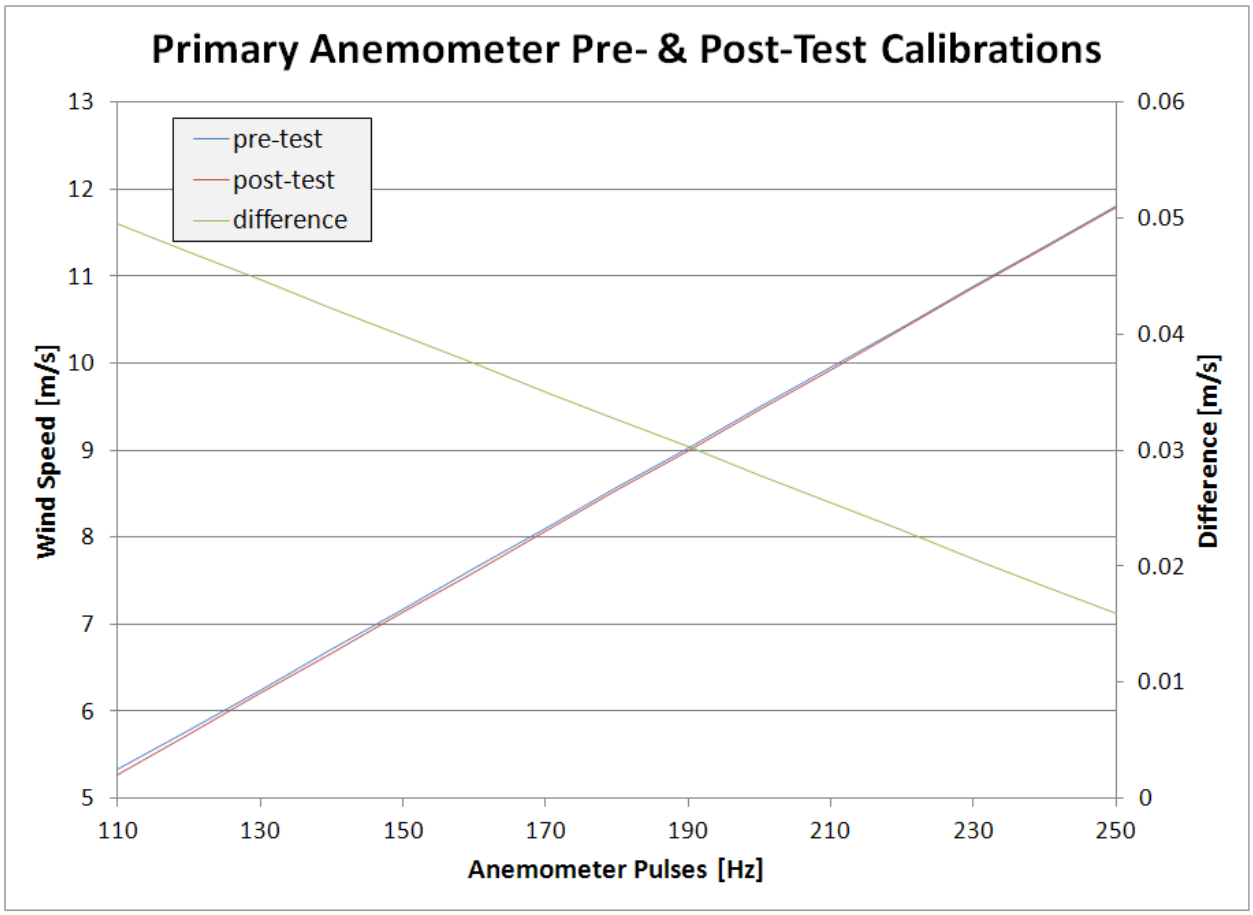


Figure B8. Primary anemometer pre- and post-test calibration comparison; the difference is less than 0.1 m/s for the range of 6 to 12 m/s

Wind Direction

NWTC Testing Group

Wind Vane Calibration Report

Calibration Laboratory:
National Wind Technology Center - Cert. Team
National Renewable Energy Laboratory
1617 Cole Boulevard
Golden, Colorado 80401

Customer:
National Wind Technology Center - Certification Team
National Renewable Energy Laboratory
1617 Cole Boulevard
Golden, Colorado 80401

Calibration Location:
National Wind Technology Center
Room 101, NWTC Bldg 256

Calibration Date: 6-Oct-10

Report Number: U1478-101006

Page: 1 of 1

Procedure:
NWTC-CT: CI04 Calibrate Wind Vane_091209.pdf

Deviations from procedure: Calibrated on 5V Range
Calibrated in Volts (not mV)

Item Calibrated:

Manufacturer	Met One Instruments, Inc
Model	020C
Serial Number	U1478
Vane Material	Aluminum
Condition	Refurbished

Results:

Slope:	**71.3248**	**deg/V**
Offset to boom:	**97.8**	**deg**
Max error:	0.5	deg

Estimated Uncertainty:

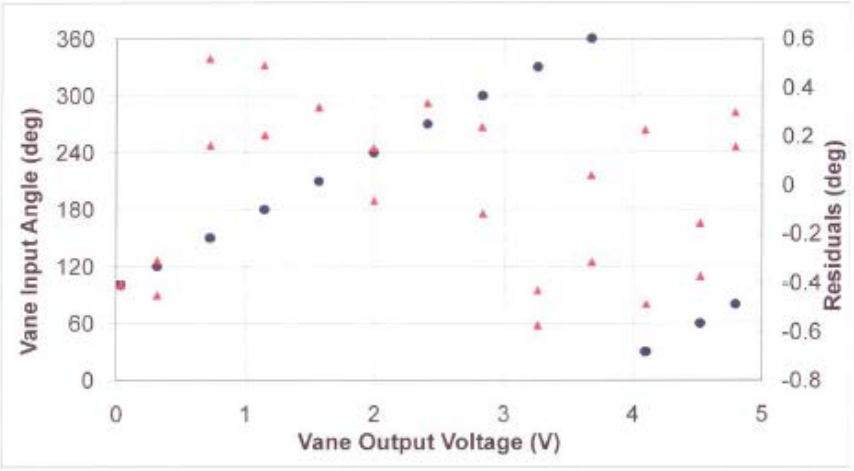
Inclinometer Uncertainty (deg)	Total Uncertainty (deg)
0.10	0.36

Traceability:

	Mfg & Mode	Serial Number	Cal Date
Inclinometer:	SPI-Tronic	31-038-3	2-Sep-11
Voltmeter:	HP 3458A	2823A05145	3-May-11

Calibration by: Jerry Hur

Date: 6 Oct 10



Vane Cal U1478 101006.xlsx — If printed, this document may be out of date — Page 1 of 1

Figure B9. Wind vane calibration sheet

Pressure

Branch #: 5000 sheet: 1 of: 1

NREL METROLOGY LABORATORY

Test Report

Test Instrument: Pressure Transmitter DOE #: 03509C

Model # : PTB101B S/N : C1020014

Calibration Date: 08/10/2010 Due Date: 08/10/2011

No	Function Tested	Nominal Value (kPa)	Measured Output Voltage (VDC)		( )Mfr. Specs. OR (X)Data only (mb)
			As Found	As Left	
*	Absolute Pressure				
		65	0.274		
		70	0.546		
		75	0.818		
		80	1.089		
		85	1.361		
		90	1.633		
		95	1.904		
		100	2.176		
	Notes: 1. Expanded Uncertainty of the nominal value is ± 0.2 kPa, with k = 2. 2. Calibration was performed at 23°C and 40% RH. 3. Calibration was performed using standards that are traceable to NIST. DOE numbers: 108685, 128120, and 02301C.				

Calibrated By: P. Morse
Date: 08/10/2010

QA By: Bev
Date: 08/10/2010

Figure B10. Pressure transducer calibration sheet

Temperature

Branch #: 5000 sheet: 1 of: 1

NREL METROLOGY LABORATORY

Test Report

Test Instrument: RTD Probe DOE #: 03506C

Model # : 78N01N00N04 S/N : 0673553

Calibration Date: 10/31/2008 Due Date: 10/31/2009

No	Nominal Values		Measured Values		
	Nominal Resistance	Equivalent Temperature	Measured Resistance	Equivalent Temperature	Temperature Error
1	96.09 Ω	-10 °C	96.080 Ω	-10.03 °C	0.03 °C
2	100.00 Ω	0 °C	99.99 Ω	-0.03 °C	0.03 °C
3	103.90 Ω	10 °C	103.89 Ω	9.97 °C	0.03 °C
4	107.79 Ω	20 °C	107.78 Ω	19.97 °C	0.03 °C
5	111.67 Ω	30 °C	111.67 Ω	30.00 °C	0.00 °C
6	115.54 Ω	40 °C	115.53 Ω	39.97 °C	0.03 °C

Notes:

1. Total Uncertainty of Nominal Values = ±0.02 °C
2. Calibration was performed at 23 °C and 38% RH
3. Resistance is measured using 4-wire technique

Calibrated by: Reda QA by: Bev

Date : 10/31/2008 Date : 10/31/2008

Figure B11. RTD-Probe calibration sheet

Data Acquisition System

Certificate of Calibration

Certificate Number:	1593423	**Date:**	01-JUN-2012
Serial Number:	14A34EE	**Part Number:**	198858A-01L
Description:	MODULE ASSY,NI 9229,PRECISION +/- 60V ISOLATION AMPLIFIER WITH ANTI-ALIAS FILTER		
Calibration Date:	29-JAN-2010	**Recommended Calibration Due*:**	29-JAN-2011
Temperature:	24.12 °C	**Humidity:**	38% RH

Standards Used

Manufacturer	Model	Tracking Number	Calibration Date	Calibration Due
NATIONAL INSTRUMENTS	PXI 4461	1739	29-OCT-09	29-OCT-10
VAISALA	HMP35E	5014	25-FEB-09	25-FEB-10
NATIONAL INSTRUMENTS	PXI-6653	6228	30-OCT-09	30-OCT-10
NATIONAL INSTRUMENTS	PXI-4070	6625	26-JUN-08	26-JUN-10
NATIONAL INSTRUMENTS	PXI-6120	6815	20-MAR-09	20-MAR-10
NATIONAL INSTRUMENTS	PXI-4110	6995	18-JAN-10	18-JAN-11

The standards used in this calibration are traceable to NIST and/or other National Measurement Institutes (NMI's) that are signatories of the International Committee of Weights and Measures (CIPM) mutual recognition agreement (MRA).

National Instruments certifies that at the time of test, the above product was calibrated in accordance with applicable National Instrument procedures. These procedures are designed to assure that the product listed above meets or exceeds National Instruments specifications.

We further certify that the environment in which this product was calibrated is maintained within the operating specifications of the instrument and standards. The measurement standards and instruments used during the calibration of this product are traceable to NIST and/or other International Measurement Institutes (NMI's) that are signatories of the International Committee of Weights and Measure (CIPM) Mutual Recognition Agreement (MRA).

The information shown on this certificate applies only to the instrument identified above and this certificate may not be reproduced, except in full, without the prior written consent of National Instruments.

For questions or comments, please contact National Instruments Technical Support.

** Recommended calibration due date is based on a combination of calibration interval and, when applicable, calibration shelf life. This date may vary depending on your application requirements.*

Andrew Krupp
Vice President, Quality and Continuous Improvement

National Instruments Corporation
11500 N. Mopac Expressway
Austin, TX 78759-3504
USA
Tel: (800) 531-5066

Figure B12. NI 9229 data acquisition module calibration sheet I

Certificate of Calibration

Certificate Number:	1570587	**Date:**	01-JUN-2012
Serial Number:	1494F69	**Part Number:**	192547E-01L
Description:	CCA,NI 9217,4-CHANNEL CRIO MODULE FOR RTD INPUTS		
Calibration Date:	29-DEC-2009	**Recommended Calibration Due*:**	29-DEC-2010
Temperature:	24.2 °C	**Humidity:**	39.61% RH

Standards Used

Manufacturer	Model	Tracking Number	Calibration Date	Calibration Due
VAISALA	HMP35E	5014	25-FEB-09	25-FEB-10
NATIONAL INSTRUMENTS	PXI-4110	6803	08-JUN-09	08-JUN-10
NATIONAL INSTRUMENTS	PXI-4461	6835	09-JUN-09	09-JUN-10
NATIONAL INSTRUMENTS	PXI-5122	7184	28-OCT-09	28-OCT-11
NATIONAL INSTRUMENTS	PXI-4070	7221	13-MAY-09	13-MAY-11

The standards used in this calibration are traceable to NIST and/or other National Measurement Institutes (NMI's) that are signatories of the International Committee of Weights and Measures (CIPM) mutual recognition agreement (MRA).

National Instruments certifies that at the time of test, the above product was calibrated in accordance with applicable National Instrument procedures. These procedures are designed to assure that the product listed above meets or exceeds National Instruments specifications.

We further certify that the environment in which this product was calibrated is maintained within the operating specifications of the instrument and standards. The measurement standards and instruments used during the calibration of this product are traceable to NIST and/or other International Measurement Institutes (NMI's) that are signatories of the International Committee of Weights and Measure (CIPM) Mutual Recognition Agreement (MRA).

The information shown on this certificate applies only to the instrument identified above and this certificate may not be reproduced, except in full, without the prior written consent of National Instruments.

For questions or comments, please contact National Instruments Technical Support.

** Recommended calibration due date is based on a combination of calibration interval and, when applicable, calibration shelf life. This date may vary depending on your application requirements.*

Andrew Krupp
Vice President, Quality and Continuous Improvement

National Instruments Corporation
11500 N. Mopac Expressway
Austin, TX 78759-3504
USA
Tel: (800) 531-5066

Figure B13. NI 9217 data acquisition module calibration sheet I

Certificate of Calibration

Certificate Number:	1566735	**Date:**	01-JUN-2012
Serial Number:	1496266	**Part Number:**	193299F-01
Description:	CCA,9205,16 BIT 32 CH VOLTAGE ANALOG INPUT MODULE (MIO CLASS)		
Calibration Date:	22-DEC-2009	**Recommended Calibration Due*:**	22-DEC-2011
Temperature:	24.7 °C	**Humidity:**	39.77% RH

Standards Used

Manufacturer	Model	Tracking Number	Calibration Date	Calibration Due
VAISALA	HMP35E	5014	25-FEB-09	25-FEB-10
NATIONAL INSTRUMENTS	PXI-4070	6625	26-JUN-08	26-JUN-10
NATIONAL INSTRUMENTS	PXI-5122	6692	15-JAN-08	15-JAN-10
NATIONAL INSTRUMENTS	PXI-4110	6793	19-JAN-09	19-JAN-10
NATIONAL INSTRUMENTS	PXI-6120	6815	20-MAR-09	20-MAR-10
NATIONAL INSTRUMENTS	PXI-5422	6851	14-JAN-08	14-JAN-10

The standards used in this calibration are traceable to NIST and/or other National Measurement Institutes (NMI's) that are signatories of the International Committee of Weights and Measures (CIPM) mutual recognition agreement (MRA).

National Instruments certifies that at the time of test, the above product was calibrated in accordance with applicable National Instrument procedures. These procedures are designed to assure that the product listed above meets or exceeds National Instruments specifications.

We further certify that the environment in which this product was calibrated is maintained within the operating specifications of the instrument and standards. The measurement standards and instruments used during the calibration of this product are traceable to NIST and/or other International Measurement Institutes (NMI's) that are signatories of the International Committee of Weights and Measure (CIPM) Mutual Recognition Agreement (MRA).

The information shown on this certificate applies only to the instrument identified above and this certificate may not be reproduced, except in full, without the prior written consent of National Instruments.

For questions or comments, please contact National Instruments Technical Support.

** Recommended calibration due date is based on a combination of calibration interval and, when applicable, calibration shelf life. This date may vary depending on your application requirements.*

Andrew Krupp
Vice President, Quality and Continuous Improvement

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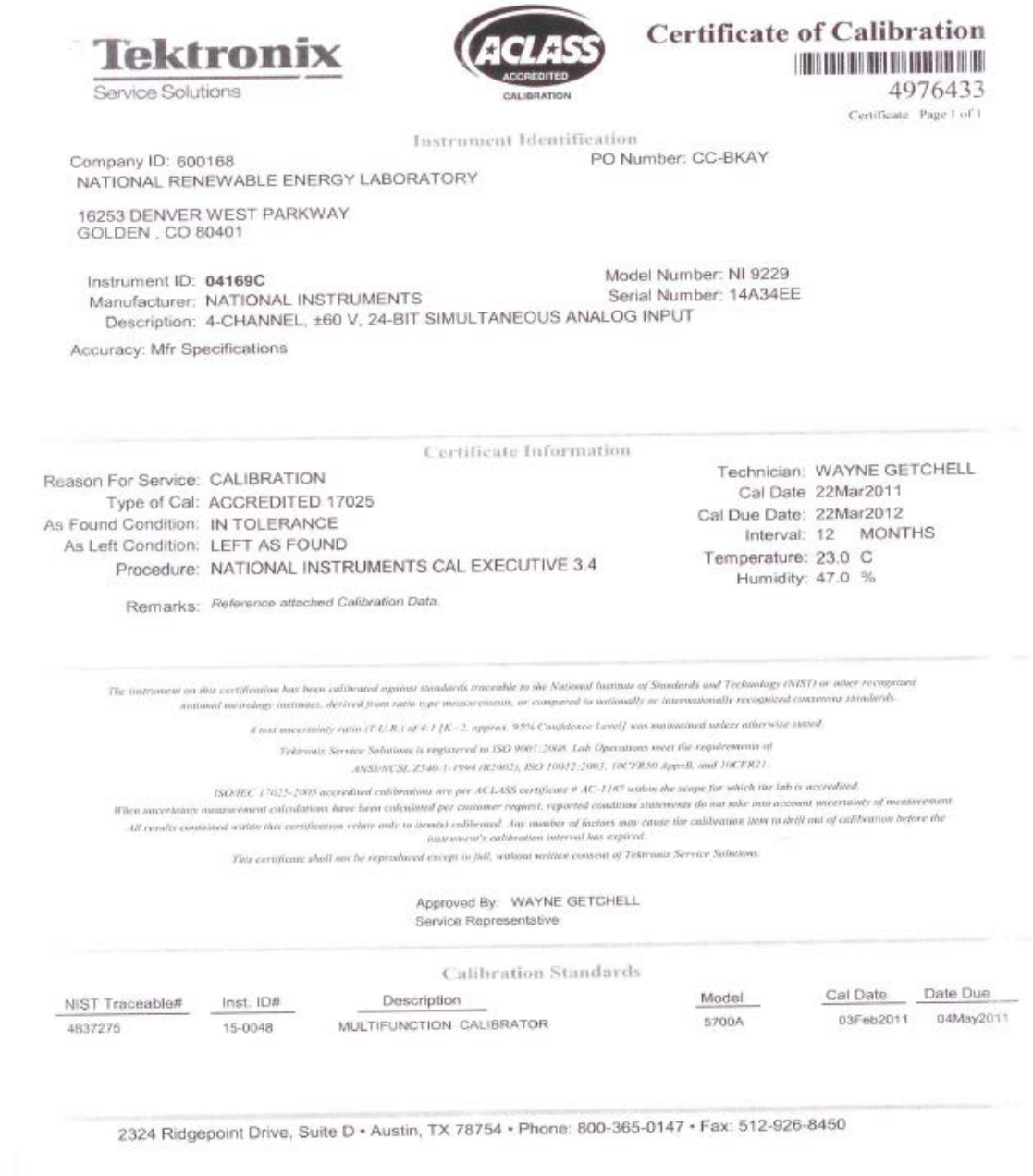
USA
Tel: (800) 531-5066

Figure B14. NI 9205 data acquisition module calibration sheet I



Tektronix
Service Solutions

ACCREDITED CALIBRATION

Certificate of Calibration

4976433

Certificate Page 1 of 1

Instrument Identification

Company ID: 600168
NATIONAL RENEWABLE ENERGY LABORATORY

16253 DENVER WEST PARKWAY
GOLDEN , CO 80401

PO Number: CC-BKAY

Instrument ID: **04169C**
Manufacturer: NATIONAL INSTRUMENTS
Description: 4-CHANNEL, ±60 V, 24-BIT SIMULTANEOUS ANALOG INPUT

Model Number: NI 9229
Serial Number: 14A34EE

Accuracy: Mfr Specifications

Certificate Information

Reason For Service: CALIBRATION
Type of Cal: ACCREDITED 17025
As Found Condition: IN TOLERANCE
As Left Condition: LEFT AS FOUND
Procedure: NATIONAL INSTRUMENTS CAL EXECUTIVE 3.4

Remarks: *Reference attached Calibration Data.*

Technician: WAYNE GETCHELL
Cal Date 22Mar2011
Cal Due Date: 22Mar2012
Interval: 12 MONTHS
Temperature: 23.0 C
Humidity: 47.0 %

The instrument on this certification has been calibrated against standards traceable to the National Institute of Standards and Technology (NIST) or other recognized national metrology institutes, derived from ratio type measurements, or compared to nationally or internationally recognized consensus standards.

A test uncertainty ratio (T.U.R.) of 4:1 [K = 2, approx. 95% Confidence Level] was maintained unless otherwise stated.

Tektronix Service Solutions is registered to ISO 9001:2008. Lab Operations meet the requirements of ANSI/NCSL Z540-1-1994 (R2002), ISO 10012:2003, 10CFR50 AppB, and 10CFR21.

ISO/IEC 17025-2005 accredited calibrations are per ACLASS certificate # AC-1187 within the scope for which the lab is accredited.

When uncertainty measurement calculations have been calculated per customer request, reported condition statements do not take into account uncertainty of measurement.

All results contained within this certification relate only to item(s) calibrated. Any number of factors may cause the calibration item to drift out of calibration before the instrument's calibration interval has expired.

This certificate shall not be reproduced except in full, without written consent of Tektronix Service Solutions.

Approved By: WAYNE GETCHELL
Service Representative

Calibration Standards

NIST Traceable#	Inst. ID#	Description	Model	Cal Date	Date Due
4837275	15-0048	MULTIFUNCTION CALIBRATOR	5700A	03Feb2011	04May2011

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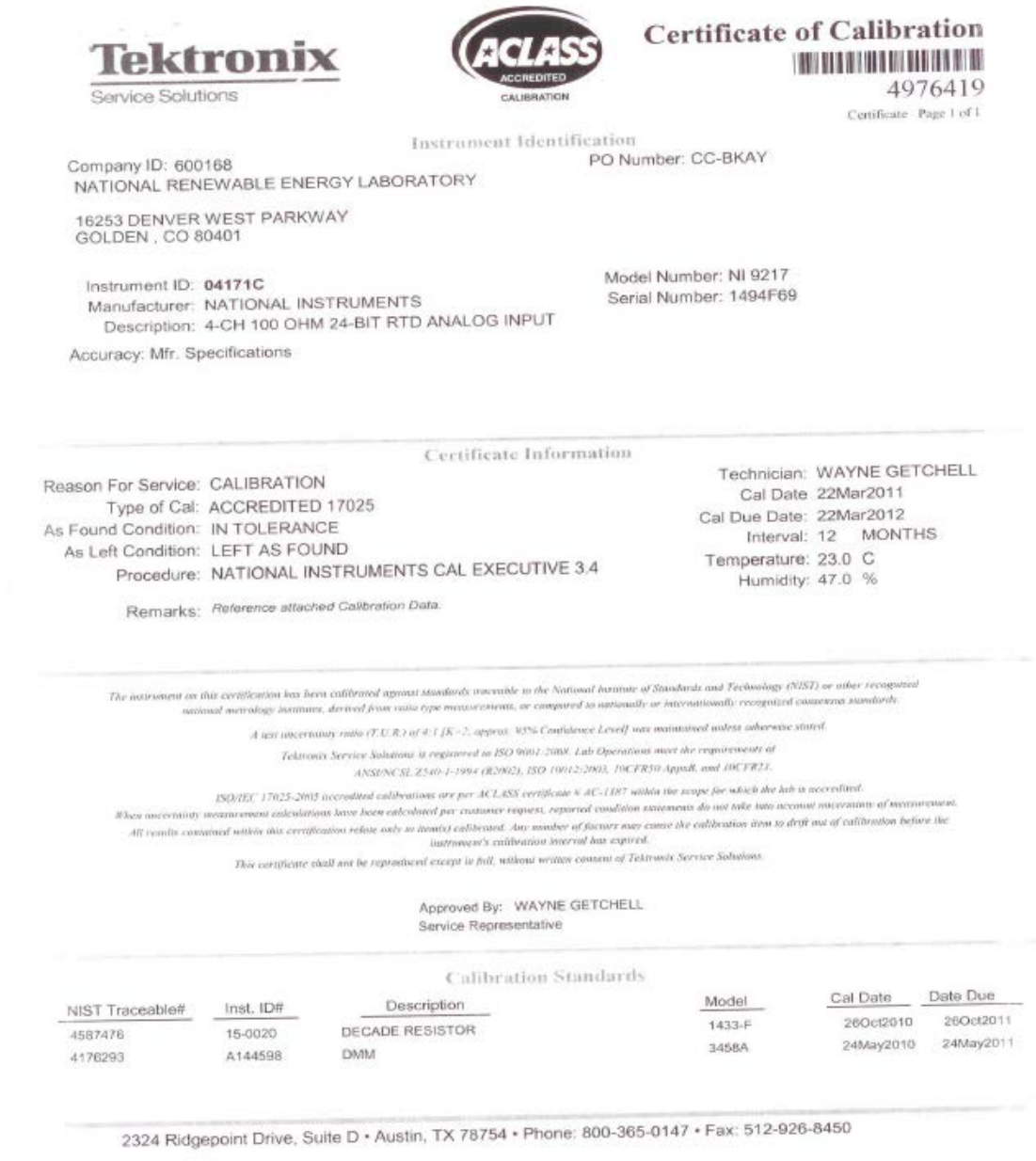
Figure B15. NI 9229 data acquisition module calibration sheet II



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Service Solutions

ACCREDITED CALIBRATION

Certificate of Calibration

4976419

Certificate Page 1 of 1

Instrument Identification

Company ID: 600168
NATIONAL RENEWABLE ENERGY LABORATORY

16253 DENVER WEST PARKWAY
GOLDEN , CO 80401

PO Number: CC-BKAY

Instrument ID: **04171C**
Manufacturer: NATIONAL INSTRUMENTS
Description: 4-CH 100 OHM 24-BIT RTD ANALOG INPUT

Model Number: NI 9217
Serial Number: 1494F69

Accuracy: Mfr. Specifications

Certificate Information

Reason For Service: CALIBRATION
Type of Cal: ACCREDITED 17025
As Found Condition: IN TOLERANCE
As Left Condition: LEFT AS FOUND
Procedure: NATIONAL INSTRUMENTS CAL EXECUTIVE 3.4

Remarks: *Reference attached Calibration Data.*

Technician: WAYNE GETCHELL
Cal Date 22Mar2011
Cal Due Date: 22Mar2012
Interval: 12 MONTHS
Temperature: 23.0 C
Humidity: 47.0 %

The instrument on this certification has been calibrated against standards traceable to the National Institute of Standards and Technology (NIST) or other recognized national metrology institutes, derived from ratio type measurements, or compared to nationally or internationally recognized consensus standards.

A test uncertainty ratio (T.U.R.) of 4:1 [K = 2, approx. 95% Confidence Level] was maintained unless otherwise stated.

Tektronix Service Solutions is registered to ISO 9001:2008. Lab Operations meet the requirements of ANSI/NCSL Z540-1-1994 (R2002), ISO 10012:2003, 10CFR50 Appx.B, and 10CFR21.

ISO/IEC 17025-2005 accredited calibrations are per ACLASS certificate # AC-1187 within the scope for which the lab is accredited.

When uncertainty measurement calculations have been calculated per customer request, reported condition statements do not take into account uncertainty of measurement.

All results contained within this certification relate only to item(s) calibrated. Any number of factors may cause the calibration item to drift out of calibration before the instrument's calibration interval has expired.

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Approved By: WAYNE GETCHELL
Service Representative

Calibration Standards

NIST Traceable#	Inst. ID#	Description	Model	Cal Date	Date Due
4587476	15-0020	DECADE RESISTOR	1433-F	26Oct2010	26Oct2011
4176293	A144598	DMM	3458A	24May2010	24May2011

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Figure B16. NI 9217 data acquisition module calibration sheet II

Tektronix
Service Solutions

ACCREDITED
CALIBRATION

Certificate of Calibration

4976401

Certificate Page 1 of 1

Instrument Identification

Company ID: 600168
NATIONAL RENEWABLE ENERGY LABORATORY

16253 DENVER WEST PARKWAY
GOLDEN , CO 80401

PO Number: CC-BKAY

Instrument ID: **04170C**
Manufacturer: NATIONAL INSTRUMENTS
Description: 32-CH ±200 MV TO ±10 V, 16-BIT, 250 KS/S ANALOG INPUT MODULE

Model Number: NI 9205
Serial Number: 1496266

Accuracy: Mfr Specifications

Certificate Information

Reason For Service: CALIBRATION
Type of Cal: ACCREDITED 17025
As Found Condition: IN TOLERANCE
As Left Condition: LEFT AS FOUND
Procedure: NATIONAL INSTRUMENTS CAL EXECUTIVE 3.4

Remarks: *Reference attached Calibration Data.*

Technician: WAYNE GETCHELL
Cal Date 22Mar2011
Cal Due Date: 22Mar2012
Interval: 12 MONTHS
Temperature: 23.0 C
Humidity: 47.0 %

The instrument on this certification has been calibrated against standards traceable to the National Institute of Standards and Technology (NIST) or other recognized national metrology institutes, derived from ratio type measurements, or compared to nationally or internationally recognized consensus standards.

A test uncertainty ratio (T.U.R.) of 4:1 [K=2, approx. 95% Confidence Level] was maintained unless otherwise stated.

Tektronix Service Solutions is registered to ISO 9001:2008. Lab Operations meet the requirements of ANSI/NCSL Z540-1-1994 (R2002), ISO 10012:2003, 10CFR50 Appx B, and 10CFR21.

ISO/IEC 17025:2005 accredited calibrations are per ACLASS certificate # AC-1187 within the scope for which the lab is accredited.

When uncertainty measurement calculations have been calculated per customer request, reported condition statements do not take into account uncertainty of measurement.

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Approved By: WAYNE GETCHELL
Service Representative

Calibration Standards

NIST Traceable#	Inst. ID#	Description	Model	Cal Date	Date Due
4837275	15-0048	MULTIFUNCTION CALIBRATOR	5700A	03Feb2011	04May2011

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Figure B17. NI 9205 data acquisition module calibration sheet II