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Wind Turbine Generator System Acoustic Noise Test Report for the ARE 442 Wind Turbine

A. Huskey and J. van Dam

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Technical Report
NREL/TP-5000-49179
November 2010

Contract No. DE-AC36-08GO28308

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Prepared under Task No(s). WER94501

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Wind Turbine Generator System

Acoustic Noise Test Report

for the

ARE442 Wind Turbine

Conducted for

National Renewable Energy Laboratory
1617 Cole Boulevard
Golden, Colorado 80401

Conducted by

National Wind Technology Center
National Renewable Energy Laboratory
1617 Cole Boulevard
Golden, Colorado 80401

Arlinda Huskey, Jeroen van Dam

August 3, 2010

Notice

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Approval By: _____

Jeroen van Dam, NREL Test Engineer Date

Review By: _____

Sarah Taubitz, NREL Test Engineer Date

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Background

This 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. In total, five turbines are being tested at the National Wind Technology Center (NWTC) as a part of this project. Acoustic noise testing is one of up to five tests that may be performed on the turbines, including duration, safety and function, power performance, and power quality tests.

The acoustic noise test was conducted to the IEC 61400-11 Edition 2.1.

Test Turbine Configuration

The test turbine (Figure 2) is a variable speed, free yawing, three-bladed, upwind, furling turbine with a rated power of 10kW. Table 1 lists the basic turbine configuration and operational data. Both sides of each blade tip had trip strips bonded to them. However, it was found that the trip strips on the high pressure sides of all three blades had come off when the turbine was uninstalled in December 2009. Figure 2 shows the electrical diagram for the test turbine installation. Table 2 gives the rotor speed at integer wind speeds.

Table 1. Test turbine configuration

Manufacturer	Abundant Renewable Energy
Model number	ARE 442
Serial number	Y08-001C
Vertical or horizontal axis	Horizontal axis
Upwind or downwind rotor	Up wind
Rotor center height	30.9 m
Horizontal distance from rotor center to tower axis	0.82 m
Diameter of rotor	7.2 m
Stall or pitch-controlled turbine	Stall, with furling
Fixed or variable pitch	Fixed
Rotational speed at reference wind speed (8 m/s)	120 rpm
Rotational speed at rated power	140 rpm
Pitch angle	0° blade root flat on alternator surface
Rated power output	10 kW
Tower type (lattice or tube)	Lattice
Tower height	30.5 m
Rotor control devices	Furling, dynamic brake
Blade type	Aero Energy
Number of blades	3
Drivetrain	Direct drive
Constant/variable speed	Variable speed
Control software version	Not available
Generator details	Permanent magnet

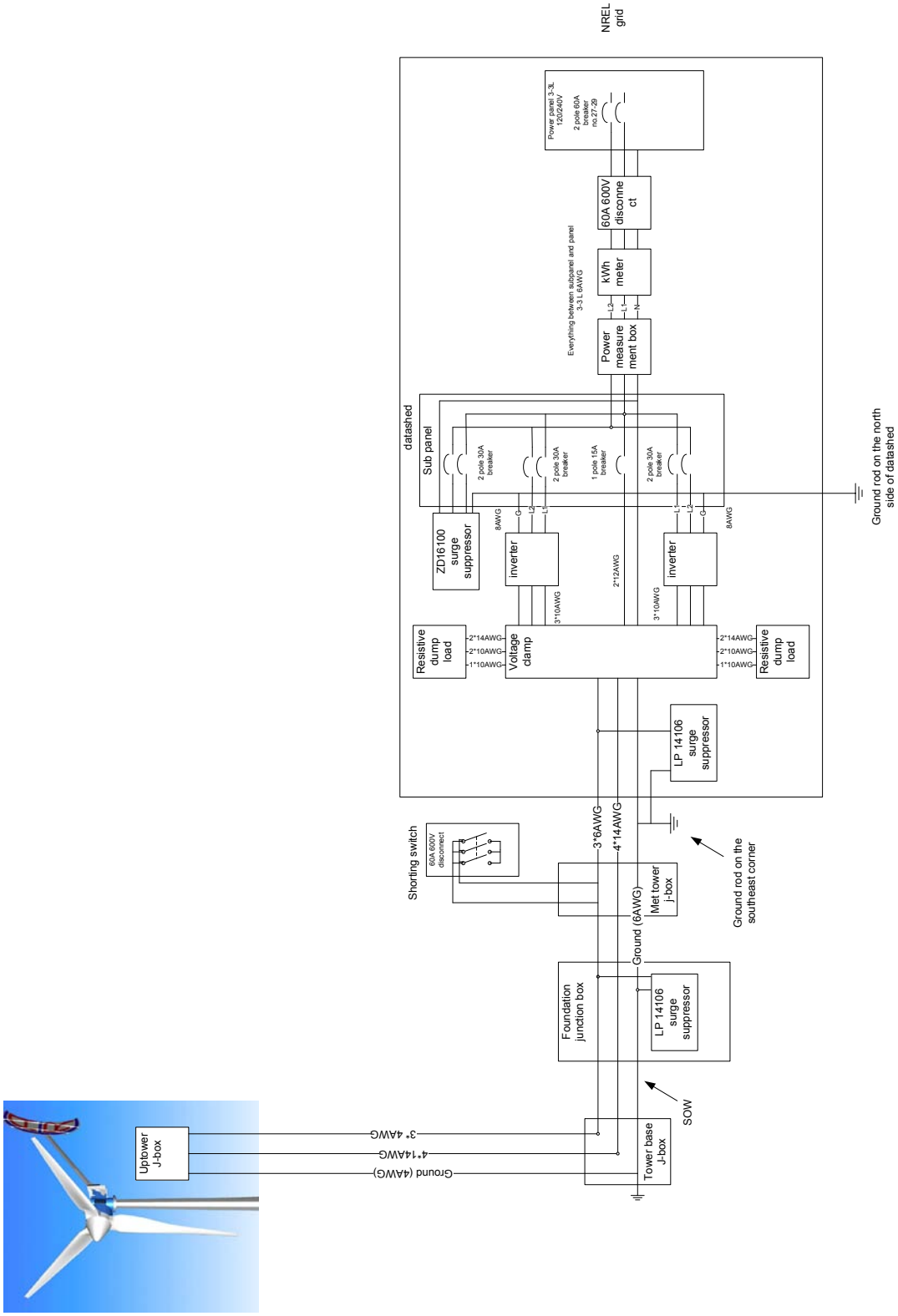

Figure 1. Electrical diagram of the ARE 442 installation

Figure 2. ARE 442 test turbine at the NWTC. PIX #17819

Table 2. Rotor speed at integer standardized wind speeds

Wind speed [m/s]	6	7	8	9	10
Rotor speed [rpm]	107	114	121	130	137

Test Site

The test turbine is located at site 3.3a at the National Wind Technology Center, located 8 miles south of Boulder, Colorado, in mostly flat terrain with short vegetation; the roughness length is estimated as 0.05m. The test site has prevailing winds bearing 292 degrees relative to true north. For measurements where it is important to accurately measure wind speed, NREL used data obtained when wind direction was between 214° and 74° degrees true. In this measurement sector, established in accordance with IEC 61400-12-1, the influence of terrain and obstructions on the anemometer and turbine are small. Figure 4 shows the turbine and meteorological tower locations. This figure also shows nearby obstructions and topographical features of the site. A circle indicating 20 rotor diameters is drawn in the map.

Table 3 provides the neighboring turbines and their operating status during the noise test. The Controls Advanced Research Turbine CART was running through part of the measurements. Measurements taken when the CART was running were not used for third octave or tonality analysis. They were used for

determination of sound power level, after it was verified that the CART did not have an effect and that data blended in with the other data sets.

Pictures of the sound board location, test turbine, and met tower can be found in Appendix A. No picture was taken of the microphone on the soundboard.

Table 3. Nearby noise sources

Source	Location	Shutdown during noise test
NW100b	3.4	Yes
Gaia 11kW	3.3b	Yes
Southwest Windpower Skystream (2*)	3.2	Yes
Endurance	3.1	Yes
CART	4.2	No and Yes
Bergey Excel	1.4	No

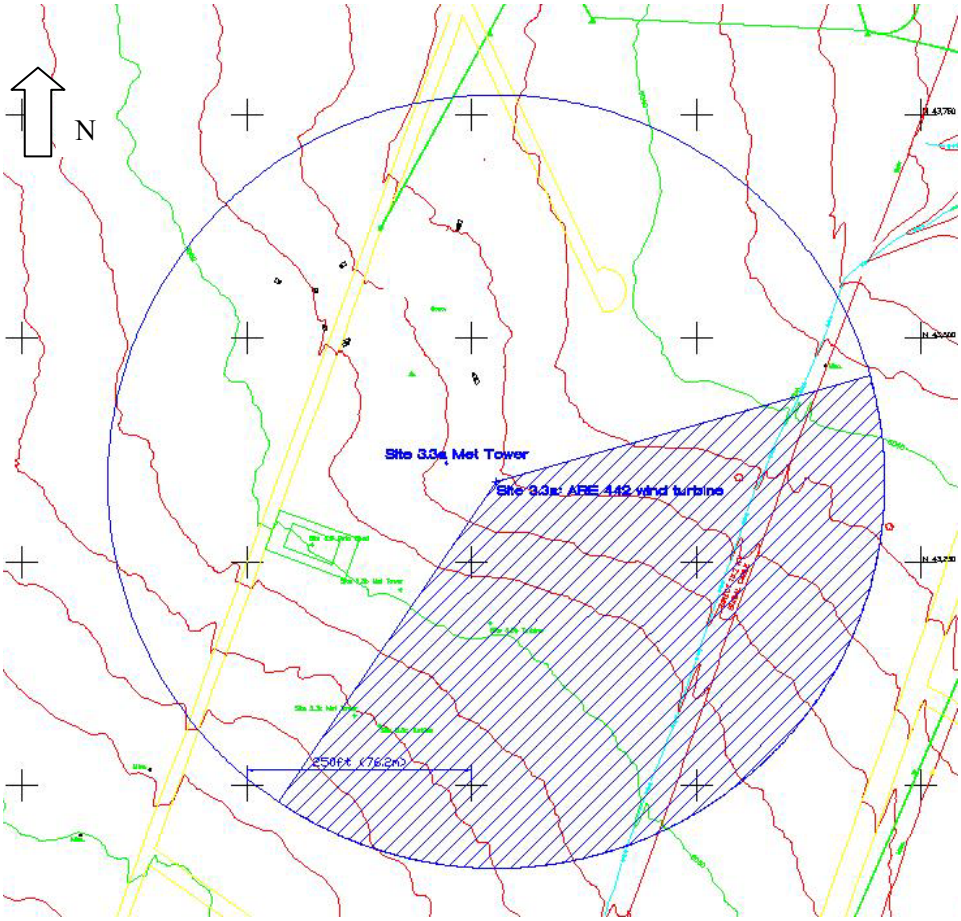

Figure 3. Map of the test site

Description of test equipment

All test equipment was calibrated; calibration sheets are included in Appendix B. Table 4 shows the equipment used and calibration due dates. The anemometer was located at 31.2m height.

The data acquisition modules were out of calibration during the test period. They were sent out for post-test calibration and found to be within specification. Thus, no additional uncertainly was added to the results. The post-test calibration sheets are included in Appendix B as well.

Table 4 shows the list of instrumentation that was used for the test. Figure 4 shows the location of the instrumentation on the meteorological tower. The meteorological tower was located 2.5 rotor diameters upwind of the turbine in the predominant wind direction.

Table 4. Equipment list

Instrument	Make, Model	Serial Number	Calibration Due Date
Power transducer	Secondwind Phaser 5FM-4A20	02663	28 Apr 2009
Current transducers	OSI 12974	001235408 001235411	Calibrated with power transducer
Primary anemometer	Thies, First Class	0707888	2 Feb 2010
Reference anemometer	NRG, Max 40	179500049022	In situ
Wind vane	Met One, 020C with aluminum vane	G4706	28 Feb 2009
Pressure sensor	Vaisala, PTB101B	T4730007	26 Aug 2009
Temperature sensor	Met One, T-200	0789020	10 Oct 2009
Data acquisition system	Compact DAQ w/LabView-based data acquisition cDAQ-9172 NI 9229 NI 9217 NI 9205	 12EAE14 12A2037 12C73B4 12ECB77	 31 May 2008 3 Aug 2008 9 Oct 2008
Digital Recorder and Signal Analyzer	Delta Acoustics NoiseLab	1258E43	24 Nov 2010
Microphone	Bruel & Kjaer, 4189-A-021	2395206	21 Nov 2010
Preamplifier	Bruel & Kjaer, 4012	2373719	21 Nov 2010
Calibrator	Bruel & Kjaer, 4230	2326144	11 Nov 2009

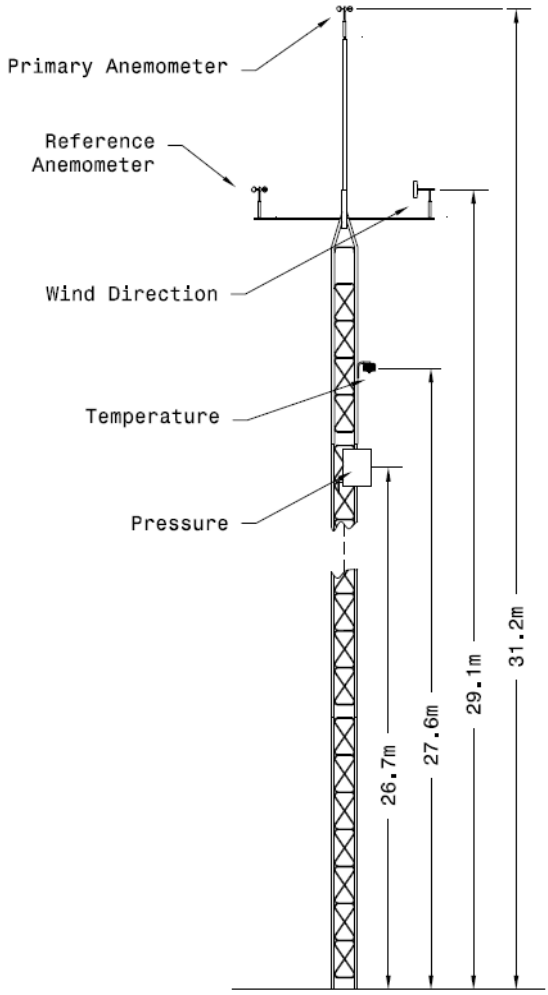

Figure 4. Location of the data acquisition sensors

Results

Turbine and background data was collected on 26 February 2009, 11:20 - 16:50. Winds were coming out of the WNW direction. The sound board location was directly downwind of the turbine for winds out of the 291 direction at a distance of 34.5 m. Data was used only if the wind direction was within 15 degrees of the 291 direction.

Wind speed was measured and not derived from power. NREL research has shown that this method gives a better correlation with noise data for small wind turbines.

Plots of wind speed, wind direction, air temperature, and air pressure during the measurement period are given in Figure 5 through 7.

A total of 346 ten second data points of turbine data and 156 ten second data points of background data were used in the analysis.

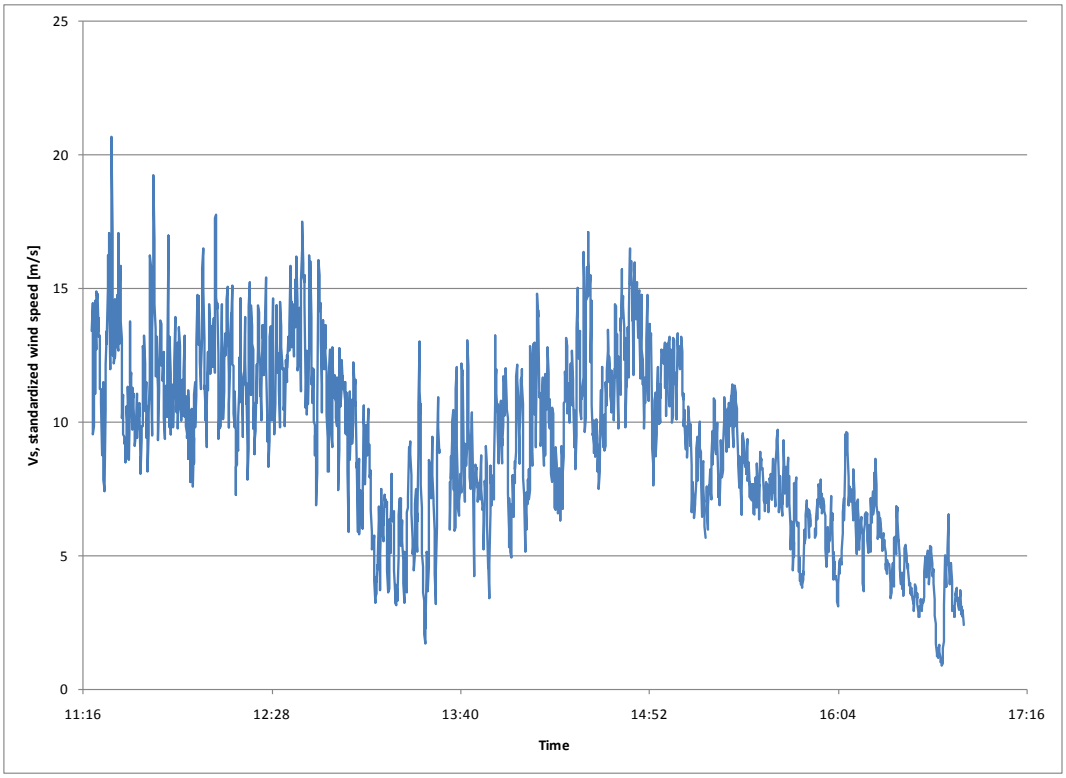

Figure 5. Standardized wind speed during the measurement period

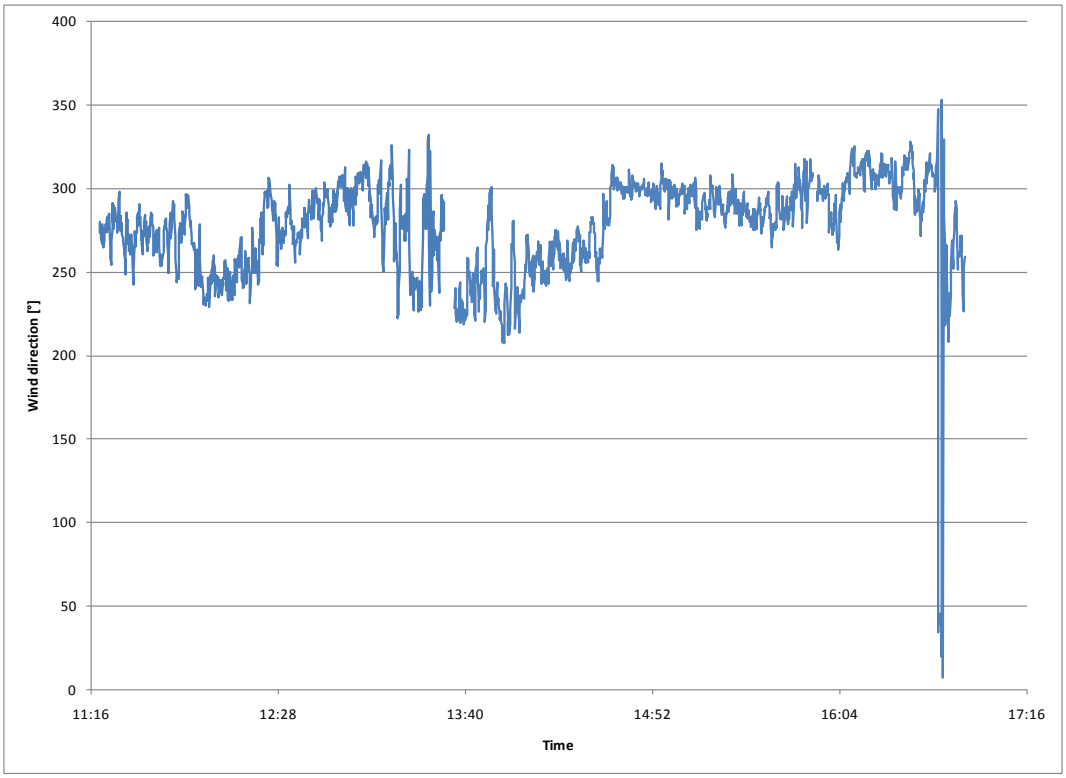

Figure 6. Wind direction during the measurement period

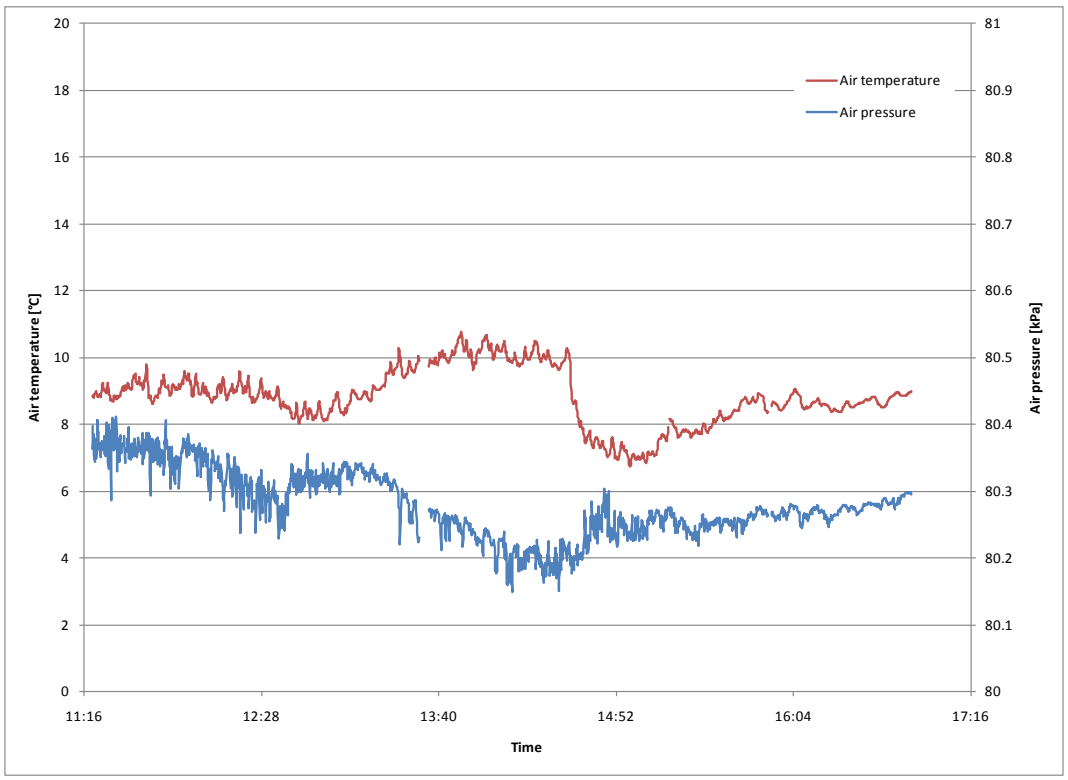

Figure 7. Measure air temperature and air pressure during the measurement period

Figure 8 shows the measured data pairs. The method of bins was used to calculate the bin average turbine and background sound pressure level. The sound pressure levels at the integer wind speeds were interpolated between bins. The background correction was then applied to the bin averaged values at the integer wind speeds. Figure 9 and Table 5 give the calculated apparent sound power levels, with the combined uncertainty for each integer wind speed.

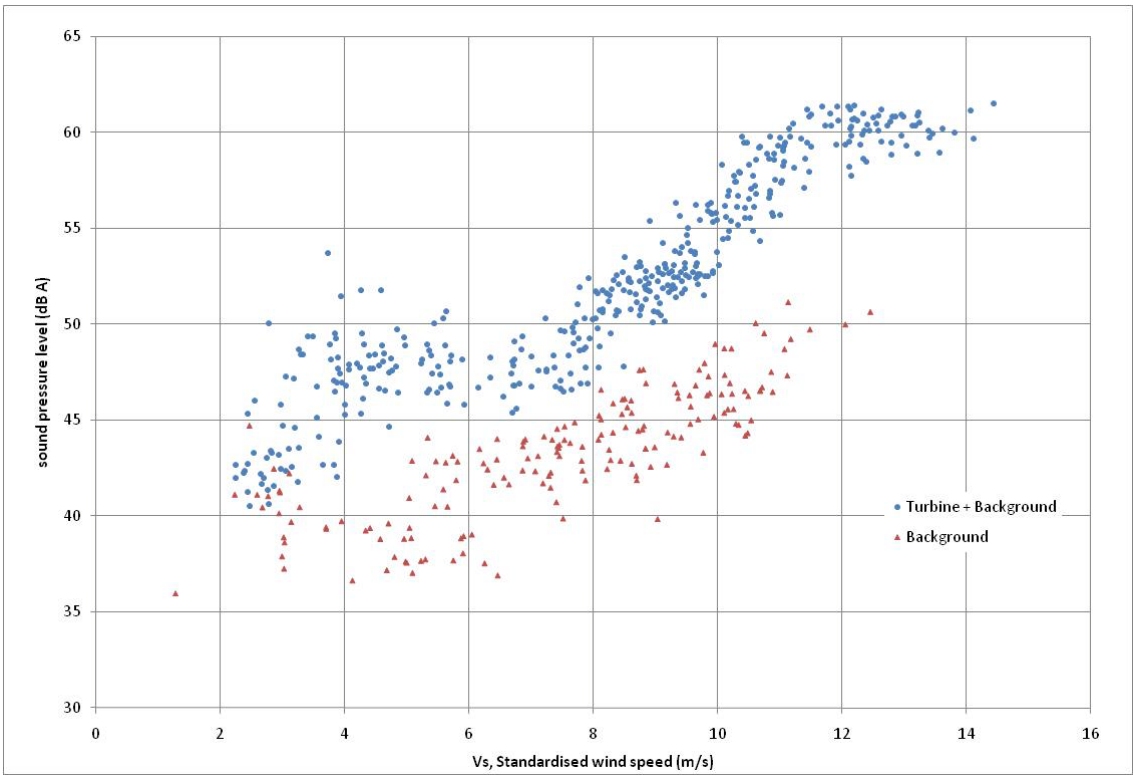

Figure 8. Measured 10 second averaged sound pressure levels as a function of standardized wind speed

Table 5. Sound power levels for integer wind speeds 4 m/s through 12 m/s

Wind Speed Bin [m/s]	Sound Power Level [dB (A)]	Combined Uncertainty [dB (A)]	Type A uncertainty [dB(A)]	Type B uncertainty [dB(A)]
4	85.8	2.6	2.5	0.8
5	85.9	1.7	1.5	0.8
6	85.2	1.7	1.5	0.9
7	84.9*	2.0	1.3	1.6
8	87.6	2.3	1.8	1.4
9	89.9	2.3	1.2	1.9
10	93.7	2.9	2.2	1.9
11	96.5	2.3	1.7	1.6
12	98.2	1.3	1.0	0.8

* Background noise was within 3-6 dB(A) of overall noise

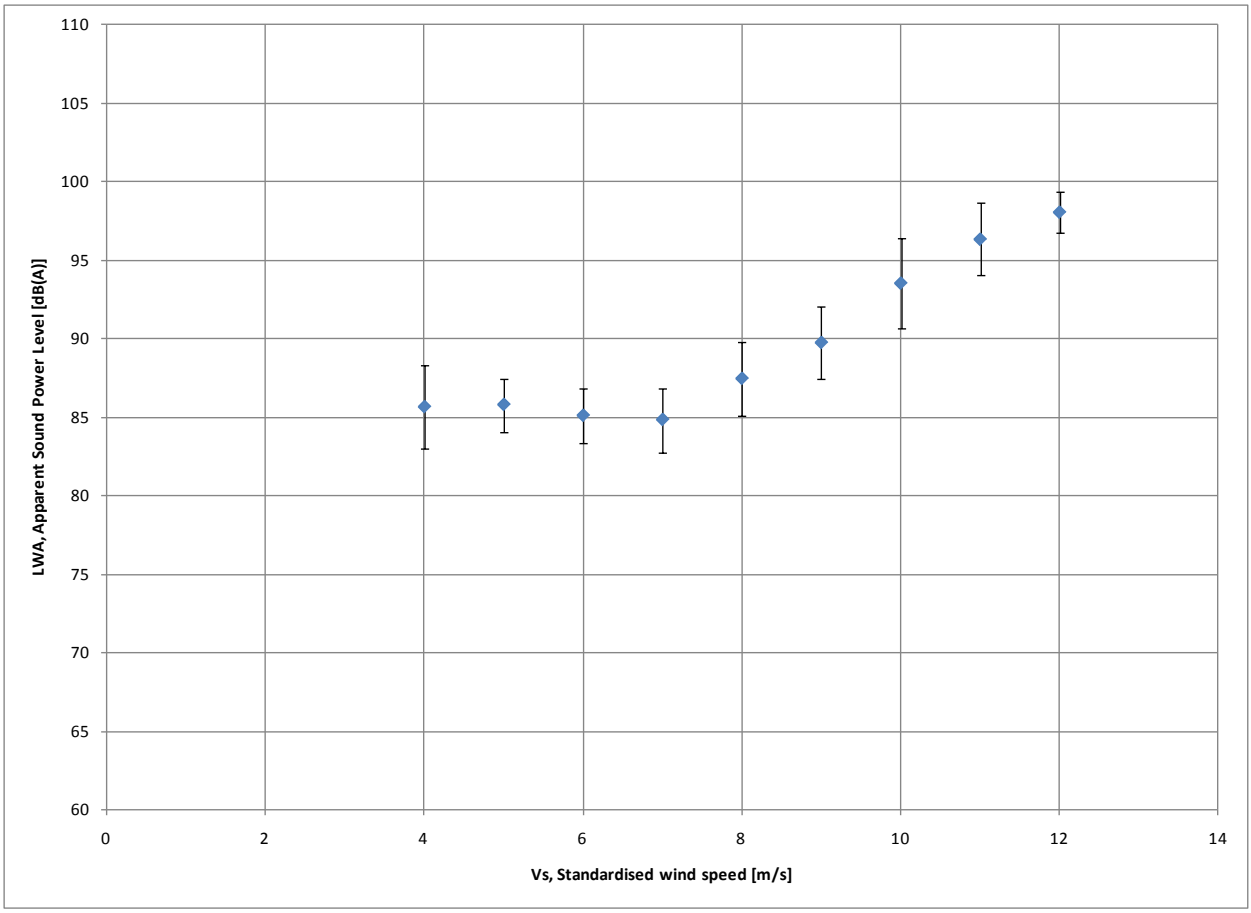

Figure 9. Apparent sound power level as a function of standardized wind speed.

The A-weighted third octave spectra were calculated for each bin. Table 6 and Figure 10 give the results. For several wind speeds, at the high and low frequencies, the separation between turbine and background was insufficient to report a value. Only spectra for bins, in which at least 10 data points were recorded for both turbine and background, are reported. For bands that have no value listed, the background noise was within 3dB(A) of the overall noise.

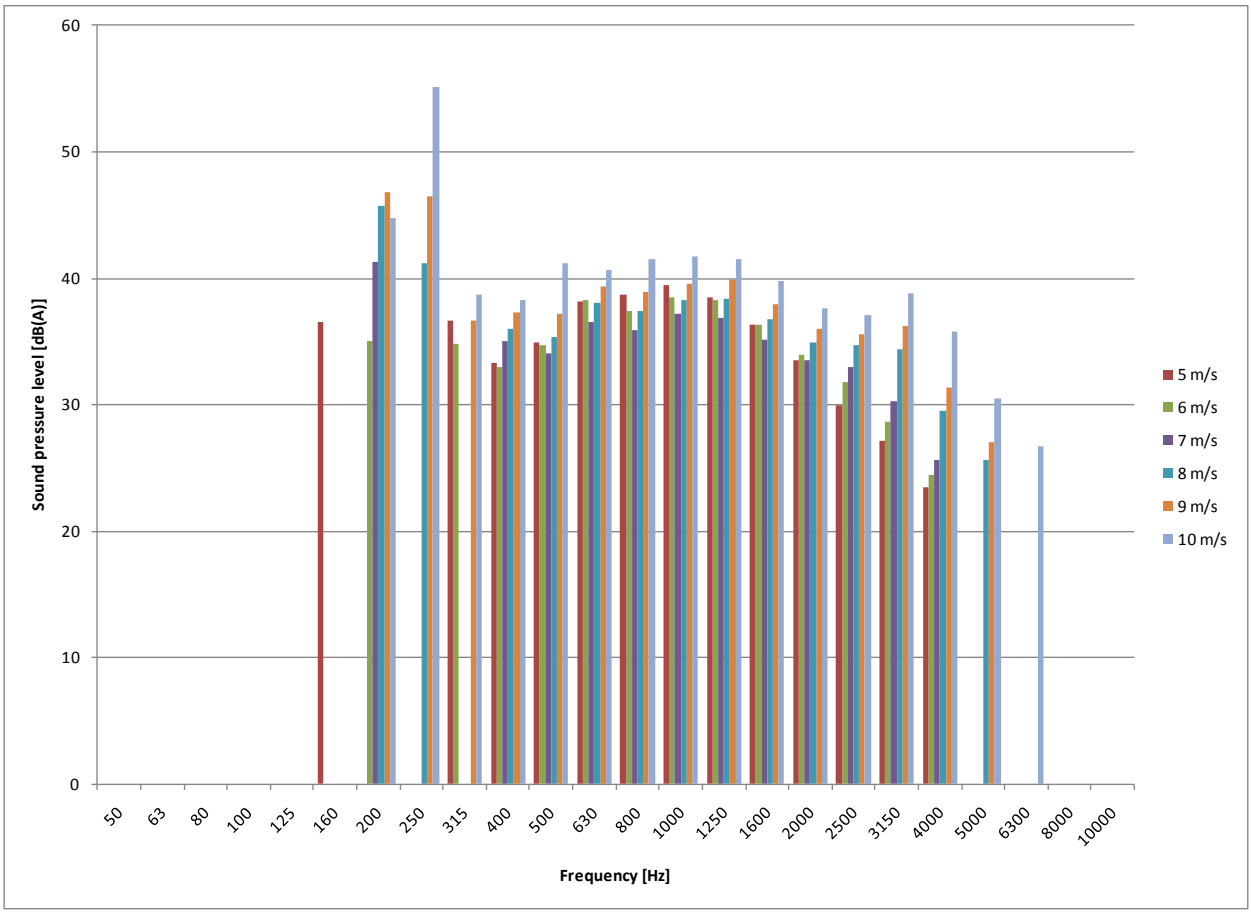

Figure 10. Third octave spectra for several integer wind speeds.

Table 6. Background corrected Third octave spectra for several wind speeds

	5 [m/s]		6 [m/s]		7 [m/s]		8 [m/s]		9 [m/s]		10 [m/s]	
Freq [Hz]	Ls [dB(A)]	U_C [dB(A)]	Ls [dB(A)]	U_C [dB(A)]	Ls [dB(A)]	U_C [dB(A)]	Ls [dB(A)]	U_C [dB(A)]	Ls [dB(A)]	U_C [dB(A)]	Ls [dB(A)]	U_C [dB(A)]
50												
63												
80												
100												
125												
160	36.6	2.3										
200			35*	4.1	41.2	3.2	45.7	2.1	46.8	2.1	44.8	1.9
250							41.1	3.4	46.5	4.6	55.1	2.3
315	36.7	2.2	34.8*	2.7					36.6*	2.5	38.7*	2.4
400	33.3	2.4	33*	2.4	35*	2.3	36*	2.3	37.3*	2.3	38.3*	2.3
500	34.9	2.0	34.8	2.1	34.1*	2.3	35.3*	2.5	37.2*	2.8	41.1	2.2
630	38.2	2.0	38.3	2.5	36.5	2.3	38.0	2.2	39.3	2.2	40.7	2.2
800	38.7	1.9	37.4	2.1	35.9*	2.3	37.4	2.2	39.0	2.3	41.5	2.1
1000	39.4	1.9	38.5	2.1	37.1	2.1	38.2	2.2	39.6	2.3	41.7	2.0
1250	38.5	1.9	38.2	2.0	36.9	2.1	38.4	2.1	39.9	2.1	41.5	2.0
1600	36.3	1.9	36.3	2.0	35.1	2.1	36.7	2.1	38.0	2.2	39.8	2.1
2000	33.5	1.9	34.0	1.9	33.5	2.1	34.9	2.1	36.0	2.2	37.6	2.1
2500	29.9	2.1	31.8	2.0	33.0	2.1	34.7	1.9	35.6	2.0	37.1	2.0
3150	27.2	2.2	28.7	2.1	30.2	2.8	34.4	2.1	36.3	2.2	38.8	2.0
4000	23.5	2.3	24.5*	2.2	25.7*	2.8	29.6	2.2	31.4	2.8	35.8	2.2
5000							25.6*	2.4	27*	2.7	30.4	2.3
6300											26.7*	2.4
8000												
10000												

* Background noise was within 3-6 dB(A) of overall noise

The tonality analysis resulted in one reportable tone for 8, 9, and 10 m/s. The tonality analysis results, including the standard uncertainties, are given in Table 7. Figure 11, Figure 12, and Figure 13 show an example of a 10 second spectrum, with line classification for 8, 9, and 10 m/s.

Table 7. Tonality results

k (m/s):	8	9	10
Freq [Hz]:	240	240	243
$\Delta L_{tn1,k}$	-13.6	7.3	5.1
$\Delta L_{tn2,k}$	-13.6	-13.6	-13.6
$\Delta L_{tn3,k}$	-13.6	-13.6	5.9
$\Delta L_{tn4,k}$	-13.6	-13.6	4.2
$\Delta L_{tn5,k}$	-13.6	-13.6	-13.6
$\Delta L_{tn6,k}$	-13.6	-13.6	8.3
$\Delta L_{tn7,k}$	-13.6	-13.6	-13.6
$\Delta L_{tn8,k}$	-13.6	-13.6	9.8
$\Delta L_{tn9,k}$	-13.6	11.1	-13.6
$\Delta L_{tn10,k}$	8.7	-13.6	-13.6
$\Delta L_{tn11,k}$	9.4	-13.6	-13.6
$\Delta L_{tn12,k}$	-13.6	4.9	10.7
ΔL_k dB(A)	1.4	2.6	5.0
$\Delta L_{a,k}$ dB(A)	3.5	4.6	7.1
U_A dB(A)	6.7	10.6	4.4
U_B dB(A)	2.2	2.1	2.0
U_C dB(A)	7.1	10.8	4.9

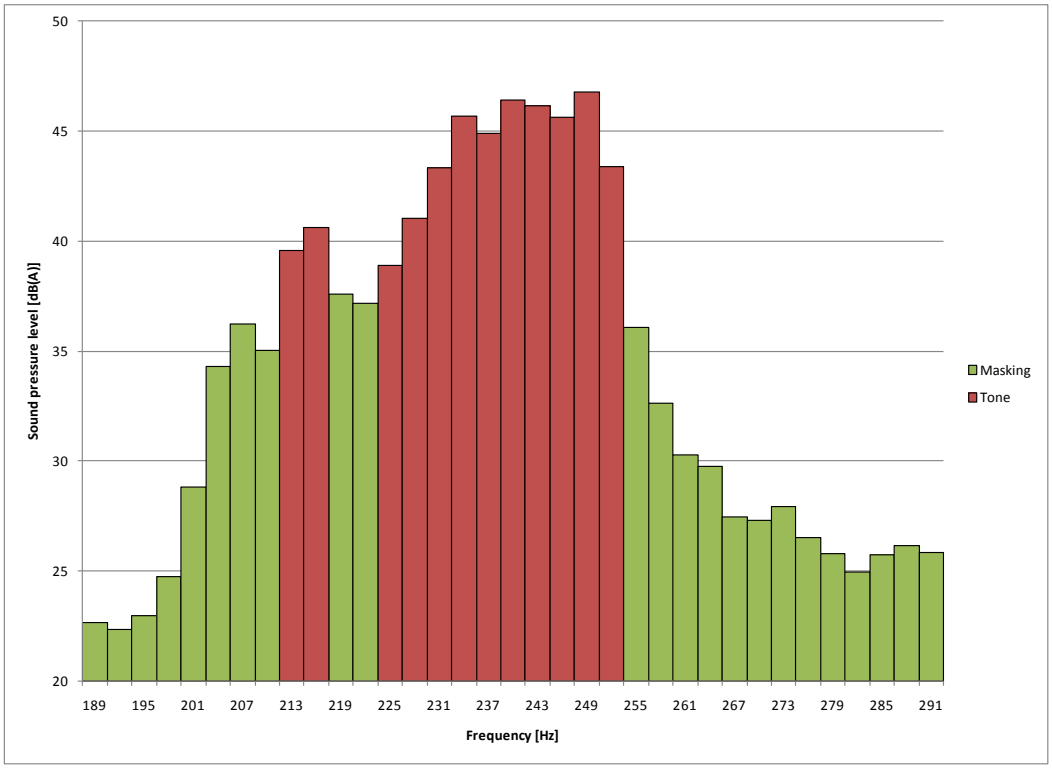

Figure 11. Example of critical band and classification of lines for 8 m/s

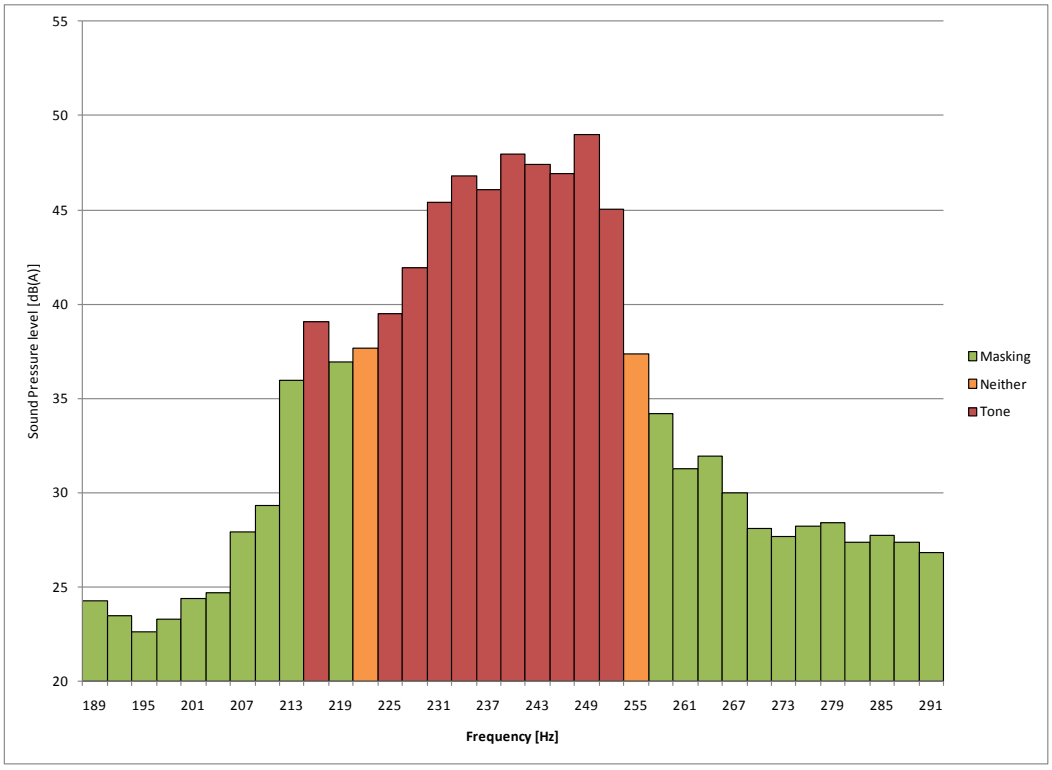

Figure 12. Example of critical band and classification of lines for 9 m/s

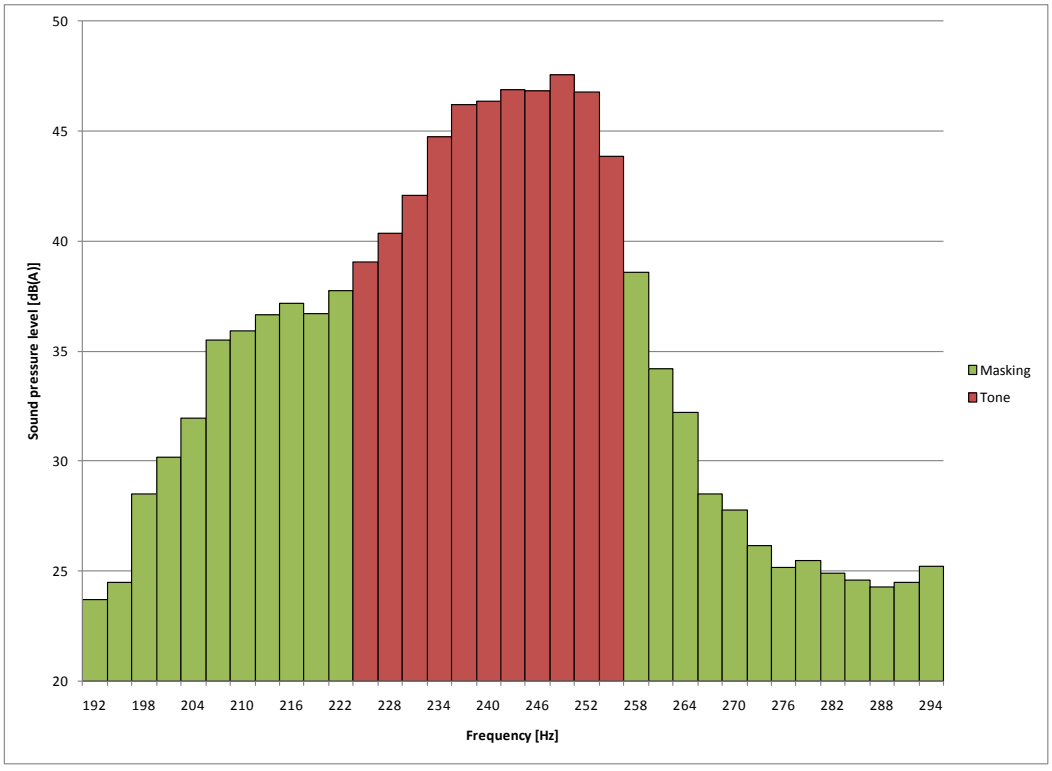

Figure 13. Example of critical band and classification of lines for 10 m/s

Uncertainty

The Type A uncertainty for the apparent sound pressure level is the standard error of the estimated L_{Aeq} and is calculated per the Annex D of the standard for each bin. For the Type B uncertainty, the typical values from the standard are used except for U_{B7} and U_{B9}.

For U_{B7}, an uncertainty of 0.5 m/s is assumed. This value is multiplied by the wind speed dependence (dB(A)/(m/s)) of the sound power level in each bin.

For U_{B9}, the actual background correction in each wind speed bin is used.

Table 8. Type B Uncertainty Components for Apparent Sound Power Level

Componen	Description	Value	Uni	Source
U_{B1}	Calibration	0.2	dB	Estimate
U_{B2}	Instrument	0.2	dB	Estimate
U_{B3}	Board	0.3	dB	Estimate
U_{B4}	Distance	0.1	dB	Estimate
U_{B5}	Impedance	0.1	dB	Estimate
U_{B6}	Turbulence	0.4	dB	Estimate
U_{B7}	Measured wind	Bin	dB	Assume 0.5 m/s uncertainty
U_{B8}	Direction	0.3	dB	Estimate
U_{B9}	Background	Bin	dB	Applied background

For the uncertainty on the third octave bands, the typical values from the standards were used except for U_{B7} and U_{B9}. For U_{B7} a wind speed uncertainty of 0.5m/s was used in combination with the wind speed dependence of the band level. For U_{B9}, the actual background correction in the band was used. Table 9 lists the values used.

Table 9. Type B Uncertainty Components for third octave spectra

Componen	Description	Value	Uni	Source
U_{B1}	Calibration	0.2	dB	Estimate
U_{B2}	Instrument	0.2	dB	Estimate
U_{B3}	Board	1.7	dB	Estimate
U_{B4}	Distance	0.1	dB	Estimate
U_{B5}	Impedance	0.1	dB	Estimate
U_{B6}	Turbulence	0.4	dB	Estimate
U_{B7}	Measured wind	Bin	dB	Assume 0.5 m/s uncertainty
U_{B8}	Direction	0.3	dB	Estimate
U_{B9}	Background	Bin	dB	Applied background

For tonality, for the Type B uncertainty, the recommendations from the standard were used. Table 10 shows the values used.

Table 10. Type B Uncertainty Components for Tonality

Componen	Description	Value	Uni	Source
U_{B1}	Calibration	0.1	dB	Estimate
U_{B2}	Instrument	0.2	dB	Estimate
U_{B3}	Board	1.7	dB	Estimate
U_{B4}	Distance	0.05	dB	Estimate
U_{B5}	Impedance	0.1	dB	Estimate
U_{B6}	Turbulence	0.2	dB	Estimate
U_{B7}	Measured wind	0.9	dB	Assume 0.5 m/s uncertainty
U_{B8}	Direction	0.3	dB	Estimate
U_{B9}	Background	Bin dependent	dB	Average of difference of $L_{pn,ave}$ and background level at tone frequency

U_{B9} at 8m/s: 0.88, 9m/s: 0.77, and 10m/s: 0.5dB

Exceptions

Exceptions to Standard
The control software version was not available. A table with measured rotor speeds is provided in Table 2. The turbine did not use pitch control.

The averaging period used was ten seconds, instead of one minute. Research by NREL has shown this provides a better correlation of sound with wind speed.

The sound power level at 7 m/s was reported even though the background noise was within 3-6dB of total noise. If anything, the reported value is conservatively high.

No picture is available of the microphone and wind screen on the soundboard.

Exceptions to NWTC Quality Assurance System
DAS modules were out of calibration. The modules were post-test calibrated and found within specification. Thus, additional uncertainty was not necessary.

Deviations from the Test Plan
There were no exceptions to the test plan.

References

IEC 61400-11 Ed 2.1 2006-11 Wind Turbine Generator Systems – Part 11 Acoustic Noise Measurement Techniques

Appendix A: Pictures of Test Site

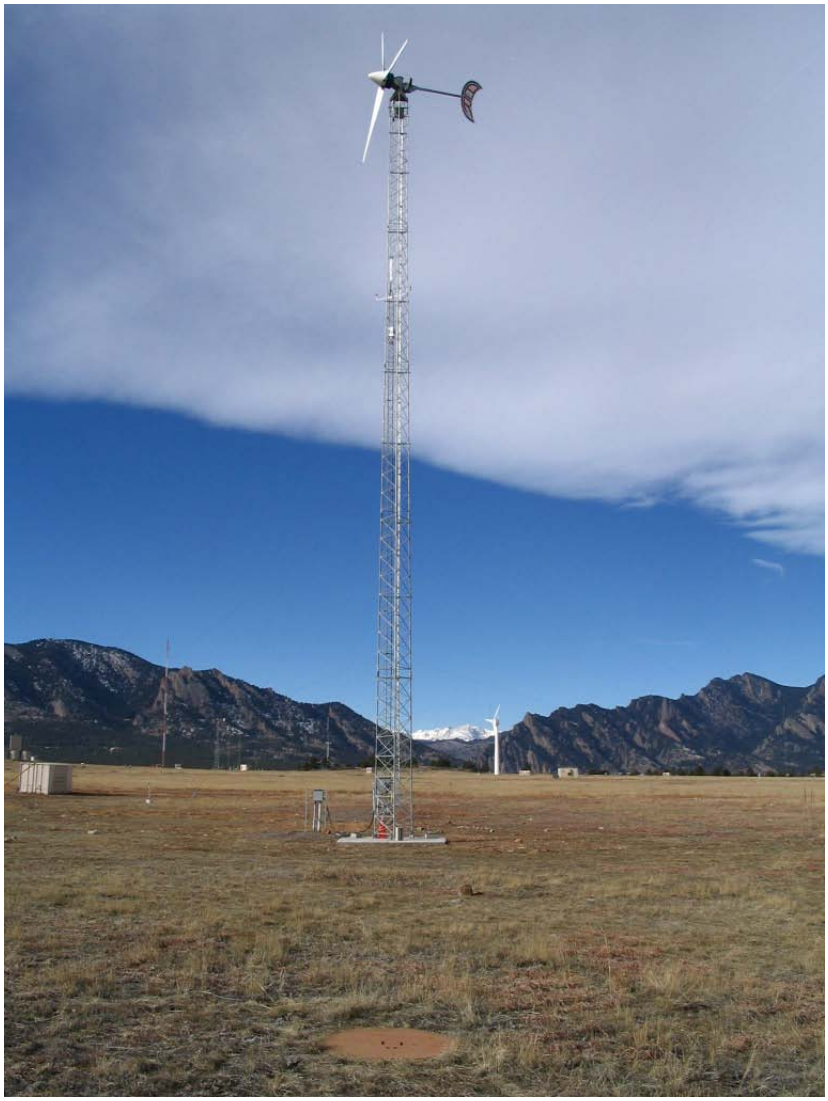

Figure A.1. Picture taken from microphone position towards the turbine. PIX #17919

Figure A.2. Picture taken from the meteorological tower (in the foreground) toward the turbine. PIX #17816

Figure A.3. Close up of soundboard and surroundings without microphone. PIX #17817

Appendix B: Calibration Sheets for Instruments

Scantek, Inc.
CALIBRATION LABORATORY

ISO 17025: 2005, ANSI/NCSL Z540:1994 Part 1 and relevant requirements of ISO 9002:1994 ACCREDITED by NVLAP (an ILAC and APLAC signatory)

NVLAP®
NVLAP Lab Code: 200625-0

Calibration Certificate No.18951

Instrument: **noiseLAB Platform**
Model: **noiseLAB3-NI-9233**
Manufacturer: **Delta**
Serial number: **1258E43_3-0-16**
Composed of: **Laptop s/n 54018537H w/ noiseLAB v. 3.0.16**
NI-9233 acquisition board s/n 1258E43
Type (class): **1**

Date Calibrated: **11/24/2008**

Status:	Received	Sent
In tolerance:	X	X
Out of tolerance:		

See comments:
Contains non-accredited tests: __Yes X No
Calibration service: __ Basic X Standard

Customer: **National Renewable Energy Laboratory, Inc.**
Tel/Fax: **303-382-6987**

Address: **16253 Denver West Parkway**
Golden, CO 80401

Tested in accordance with the following procedures and standards:
Calibration of Sound Level Meters, Scantek Inc., 06/07/2005
Calibration of Analyzers, Scantek, Inc., 06/07/2005

Instrumentation used for calibration: Nor-1504 Norsonic Test System:

Instrument - Manufacturer	Description	S/N	Cal. Date	Traceability evidence Cal. Lab / Accreditation	Cal. Due
483B-Norsonic	SME Cal Unit	31052	Jan 15, 2008	Scantek, Inc.	Jan 15, 2009
DS-360-SRS	Function Generator	33584	Jan 3, 2008	Davis Calibration / AClass	Jan 3, 2009
34401A-Agilent Technologies	Digital Voltmeter	US36120731	Aug 19, 2008	ACR Env. / A2LA	Aug 14, 2009
HM30-Thommen	Meteo Station	1040170/39633	Dec 21, 2007	Transcat / A2LA	Jun 21, 2009
PC Program 1019 Norsonic	Calibration software	v.46	Validated Dec 2006	-	-

Instrumentation and test results are traceable to SI (International System of Units) through standards maintained by NIST (USA) and NPL (UK).

Environmental conditions:

Temperature (°C)	Barometric pressure (kPa)	Relative Humidity (%)
21 °C	99.54 kPa	34.8 %RH

Calibrated by	Javier Albarracin	Checked by	Mariana Buzduga
Signature		Signature	
Date	11/25/2008	Date	11/25/2008

Document stored as: C:\Nor1504\SlmCal\2008\DeltaNoiseLab3-9233_1258E43_3-0-16_M2.doc

Figure B.1. NoiseLAB calibration sheet

Scantek, Inc.
CALIBRATION LABORATORY

ISO 17025: 2005, ANSI/NCSL Z540:1994 Part 1 and relevant requirements of ISO 9002:1994 ACCREDITED by NVLAP (an ILAC and APLAC signatory)

NVLAP®
NVLAP Lab Code: 200625-0

Calibration Certificate No.18947

Instrument:	**Acoustical Calibrator**	*Date Calibrated:*	**11/21/2008**
Model:	**4231**	*Status:*	**Received** / **Sent**
Manufacturer:	**Brüel and Kjær**	*In tolerance:*	X / X
Serial number:	**2326144**	*Out of tolerance:*	
Class (IEC 60942):	**1**	*See comments:*	
Barometer type:		*Contains non-accredited tests:*	__Yes _X_ No
Barometer s/n:			

Customer:	**National Renewable Energy Laboratory**	*Address:*	**16253 Denver West Parkway**
Tel/Fax:	**303-382-6987/ arlinda_huskey@nrel.gov**		**Golden, CO 80401**

Tested in accordance with the following procedures and standards:
Calibration of Acoustical Calibrators, Scantek Inc., 06/06/2005

Instrumentation used for calibration: Nor-1504 Norsonic Test System:

Instrument - Manufacturer	Description	S/N	Cal. Date	Traceability evidence Cal. Lab / Accreditation	Cal. Due
483B-Norsonic	SME Cal Unit	25747	Jan 15, 2008	Scantek, Inc./NVLAP	Jan 15, 2009
DS-360-SRS	Function	61646	Nov 19, 2007	Davis Inotek / AClass	Nov 19, 2009
34401A-Agilent	Digital Voltmeter	MY41022043	Nov 13, 2008	Transcat / NVLAP	Nov 13, 2009
HM30-Thommen	Meteo Station	1040170/39633	Dec 21, 2007	Transcat / A2LA	Jun 21, 2009
8903A-HP	Audio Analyzer	2514A05691	Jan 2, 2008	Transcat/ NVLAP	Jan 2, 2010
HMP233-Vaisala Oyj	Humidity & Temp. Transmitter	V3820001	May 7, 2008	Transcat/ NVLAP	Nov 7, 2009
PC Program 1018 Norsonic	Calibration software	v.44	Validated May 2006	-	
1253-Norsonic	Calibrator	28326	Mar 3, 2008	NPL (UK) / UKAS	Mar 3, 2010
1203-Norsonic	Preamplifier	14059	Jan 4, 2008	Scantek, Inc./ NVLAP	Jan 4, 2010
4180-Bruel&Kjaer	Microphone	2246115	Mar 3, 2008	NPL (UK) / UKAS	Mar 3, 2010

Instrumentation and test results are traceable to SI (International System of Units) through standards maintained by NIST (USA) and NPL (UK)

Calibrated by	Valentin Buzduga	Checked by	Mariana Buzduga
Signature		Signature	
Date	11/21/2008	Date	11/21/2008

Document stored as: C:\Nor1504\CalCal\2008\BNK4231_2326144_M1.doc

Figure B.2. Acoustical Calibrator calibration sheet

Scantek, Inc.
CALIBRATION LABORATORY

ISO 17025: 2005, ANSI/NCSL Z540:1994 Part 1
and relevant requirements of ISO 9002:1994
ACCREDITED by NVLAP (an ILAC and APLAC signatory)

NVLAP®
NVLAP Lab Code: 200625-0

Calibration Certificate No.18945

Instrument:	**Microphone Unit**	*Date Calibrated:*	**11/21/2008**
Model:	**4189-A-021**	*Status:*	**Received** / **Sent**
Manufacturer:	**Brüel & Kjær**	*In tolerance:*	X / X
Serial number:	**2406809**	*Out of tolerance:*	
Formed of:	**Microphone 4189 s/n 2395206** **Preamplifier 2671 s/n 2373719**	*See comments:*	

Contains non-accredited tests: __Yes _X_ No

Customer:	**National Renewable Energy Laboratory**	*Address:*	**16253 Denver West Parkway** **Golden, CO 80401**
Tel/Fax:	**303-382-6987/** **arlinda_huskey@nrel.gov**		

Tested in accordance with the following procedures and standards:
Procedure for Calibration of Measurement Microphones, Scantek Inc., 06/15/2005

Instrumentation used for calibration: N-1504 Norsonic Test System:

Instrument - Manufacturer	Description	S/N	Cal. Date	Traceability evidence Cal. Lab / Accreditation	Cal. Due
483B-Norsonic	SME Cal Unit	25747	Jan 15, 2008	Scantek, Inc./NVLAP	Jan 15, 2009
DS-360-SRS	Function Generator	61646	Nov 19, 2007	Davis Inotek / AClass	Nov 19, 2009
34401A-Agilent	Digital Voltmeter	MY41022043	Nov 13, 2008	Transcat / NVLAP	Nov 13, 2009
HM30-Thommen	Meteo Station	1040170/39633	Dec 21, 2007	Transcat / A2LA	Jun 21, 2009
HMP233-Vaisala Oyj	Humidity & Temp. Transmitter	V3820001	May 7, 2008	Vaisala / A2LA	Nov 7, 2009
PC Program 1017 Norsonic	Calibration software	v.46	Validated Feb 2006	-	-
1253-Norsonic	Calibrator	28326	Mar 3, 2008	NPL (UK) / UKAS	Mar 3, 2010
1203-Norsonic	Preamplifier	14059	Jan 4, 2008	Scantek, Inc./ NVLAP	Jan 4, 2009
4180-Bruel&Kjaer	Microphone	2246115	Mar 3, 2008	NPL (UK) / UKAS	Mar 3, 2010

Instrumentation and test results are traceable to SI - BIPM through standards maintained by NPL (UK) and NIST (USA)

Calibrated by	Valentin Buzduga	Checked by	Mariana Buzduga
Signature		Signature	
Date	11/21/2008	Date	11/26/2008

Figure B.3. Microphone and preamplifier calibration sheet

Branch #: 5000

NREL METROLOGY LABORATORY

Test Report

Test Instrument: Phaser Power Transducer & 2-CTs DOE #: 02824C

Model # : Phaser-5-F-5A S/N : 02663

Calibration Date: 01/28/2008 Due Date: 01/28/2010

A. Set-Up for Total Real Power Calibration:
A.1. Voltage is applied to phases A&B = 120 V @ 60 Hz.
A.2. Current is applied to n = 5-TURNS through two current transformers that are connected to phases A&B.
A.3. Analog Output-1 is measured across precision resistor = 250 Ω.
A.4. Phaser Full Scale setting = -7.2KW to 7.2KW.

Input Current (AAC)	Input Power (KW)	Analog Output-1 (VDC)
28	6.72	4.790
21	5.04	4.341
14	3.36	3.892
7	1.68	3.444
0	0	2.995
-7	-1.68	2.547
-14	-3.36	2.099
-21	-5.04	1.651
-28	-6.72	1.203

B. Set-Up for Power Factor Calibration:
B.1. Voltage & Current are applied as A.1 & A.2.
B.2. Analog Output-2 is measured across precision resistor = 250 Ω.

Power (KW)	Power Factor	Analog Output-2 (VDC)
6.72	1.0	4.989
"	0.8	4.179
"	0.6	3.377
"	0.4	2.577
"	0.2	1.778

Page 1 of 2

Figure B.4. Power transducer calibration sheet

DEUTSCHER KALIBRIERDIENST DKD

Kalibrierlaboratorium für Strömungsgeschwindigkeit von Luft
Calibration laboratory for velocity of air flow
Akkreditiert durch die / *accredited by the*
Akkreditierungsstelle des DKD bei der
PHYSIKALISCH-TECHNISCHEN BUNDESANSTALT (PTB)

Deutsche WindGuard
Wind Tunnel Services GmbH
Varel

Deutscher Akkreditierungs Rat
DAR
DKD-K- 36801

Kalibrierschein
Calibration Certificate

Kalibrierzeichen
Calibration label

DKD-K-
36801
07_2406

Gegenstand *Object*	Cup Anemometer
Hersteller *Manufacturer*	Thies Clima D-37083 Göttingen
Typ *Type*	4.3350.00.000
Fabrikat/Serien-Nr. *Serial number*	Body: 0707888 Cup: 0707888
Auftraggeber *Customer*	Thies Clima D-37083 Göttingen
Auftragsnummer *Order No.*	VT07255
Anzahl der Seiten des Kalibrierscheines *Number of pages of the certificate*	3
Datum der Kalibrierung *Date of calibration*	24.07.2007

Dieser Kalibrierschein dokumentiert die Rückführung auf nationale Normale zur Darstellung der Einheiten in Übereinstimmung mit dem Internationalen Einheitensystem (SI).
Der DKD ist Unterzeichner der multi- lateralen Übereinkommen der European co-operation for Accreditation (EA) und der International Laboratory Accreditation Cooperation (ILAC) zur gegenseitigen Anerkennung der Kalibrierscheine.
Für die Einhaltung einer angemessenen Frist zur Wiederholung der Kalibrierung ist der Benutzer verantwortlich.
This calibration certificate documents the traceability to national standards, which realize the units of measurement according to the International System of Units (SI).
The DKD is signatory to the multilateral agreements of the European co-operation for Accreditation (EA) and of the International Laboratory Accreditation Cooperation (ILAC) for the mutual recognition of calibration certificates.
The user is obliged to have the object recalibrated at appropriate intervals.

Stempel *Seal*	Datum *Date*	Leiter des Kalibrierlaboratoriums *Head of the calibration laboratory*	Bearbeiter *Person in charge*
Deutscher Kalibrierdienst DKD-K- 36801	24.07.2007	Dipl. Phys. D. Westermann	Tech. Ass. Inf. H. Westermann

Deutsche WindGuard Wind Tunnel Services GmbH
Oldenburger Str. 65
26316 Varel ; Tel. ++49 (0)4451 9515 0

Deutsche WindGuard
Wind Tunnel Services GmbH

Figure B.5. Anemometer calibration report

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, Building 256

Calibration Date: **13-Sep-07**

Report Number: G4706-070913

Page: 1 of 1

Procedure:
NWTC-CT: GI24-000613, Wind Vane Calibration

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

Item Calibrated:

Manufacturer	Met One Instruments, Inc
Model	020C
Serial Number	**G4706**
Vane Material	Aluminum
Condition	Refurbished

Results:

Slope:	**72.17**	**deg/V**
Offset to boom:	**94.81**	**deg**
Max error:	0.99	deg

Estimated Uncertainty:

Inclinometer Uncertainty (deg)	Total Uncertainty (deg)
0.10	0.57

Traceability:

	Mfg & Model	Serial Number	Cal Date
Inclinometer:	Spi-Tronic	31-038-3	22-Mar-07
Voltmeter:	Fluke743B	6965608	10-May-07

Calibration by: Mark Meadors — 13-Sep-07 Date

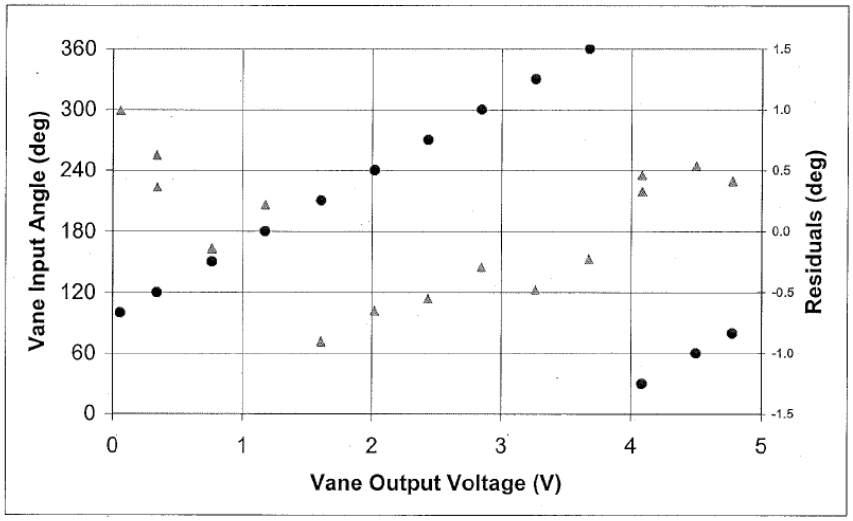

Figure B.6. Wind vane calibration report

Branch #: 5000 sheet: 1 of: 1

NREL METROLOGY LABORATORY

Test Report

Test Instrument: RTD-Probe DOE #: 03722C

Model # : 78N01N00N S/N : 0789020

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

No	Function Tested	Nominal Value (°C)	Measured Values (Ω)		( )Mfr. Specs. OR (X)Data only
			AS Found	AS Left	
*	Temperature:	0	99.96	Same	
		25	109.68	"	
		50	119.32	"	
	Notes: - Calibration was performed using instruments that are traceable to NIST. DOE#s 124272, 108603, and 108604. - Calibration was performed at temperature = 23 °C and relative humidity = 38. - Uncertainty of Nominal Values = ± 0.03 °C, k = 2.				

Tested By: Reda

Date : 10/10/2008

Figure B.7. RTD calibration report

Branch #: 5000 sheet: 1 of: 1

NREL METROLOGY LABORATORY

Test Report

Test Instrument: Pressure Transmitter DOE #: 02795C

Model # : PTB101B S/N : T4730007

Calibration Date: 08/26/2008 Due Date: 08/26/2009

No	Function Tested	Nominal Value (kPa)	Measured Output Voltage (VDC)		( )Mfr. Specs. OR (X)Data only (mb)
			As Found	As Left	
*	Absolute Pressure				
		65	0.287	Same	
		70	0.560	"	
		75	0.832	"	
		80	1.105	"	
		85	1.377	"	
		90	1.648	"	
		95	1.921	"	
		100	2.194	"	
		105	2.467	"	
	Notes: 1. Uncertainty of the nominal value is ± 0.2 kPa, k = 2. 2. Calibration was performed at 23°C and 37% RH. 3. Calibration was performed using standards that are traceable to NIST. DOE numbers: 02625C, 02727C, and 02301C.				

Calibrated By: Reda
Date: 08/26/2008

QA By: Bev
Date: 08/26/2008

Figure B.8. Pressure transmitter calibration sheet

NATIONAL INSTRUMENTS

Certificate of Calibration

Board Information:
Serial Number: 12C73B4
NI Part Number: 192547D-01
Description: NI 9217

Certificate Information:
Certificate Number: 786529
Date Printed: 05-JAN-09

Calibration Date: 03-AUG-07
Recommended Calibration Due Date: 03-AUG-08*

Ambient Temperature: 23 °C
Relative Humidity: 46 %

National Instruments certifies that at the time of manufacture, the above product was calibrated in accordance with applicable National Instruments procedures. These procedures are in compliance with relevant clauses of ISO 9001 and are designed to assure that the product listed above meets or exceeds National Instruments specifications.

National Instruments further certifies that the measurements standards and instruments used during the calibration of this product are traceable to National and/or International Standards administered by NIST or Euromet members or are derived from accepted values of natural physical constants.

The environment in which this product was calibrated is maintained within the operating specifications of the instrument and the standards.

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

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

NI Hungary Software és
Hardware Gyártó Kft.
4031 Debrecen, Határ út
1/A.
HUNGARY

Signed,

Andrew Krupp
Quality Director

* 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.

Figure B.9. NI 9217 data acquisition module calibration sheet I

NATIONAL INSTRUMENTS

Certificate of Calibration

Board Information:
Serial Number: 12A2037
NI Part Number: 192580D-02
Description: NI 9229

Certificate Information:
Certificate Number: 733748
Date Printed: 05-JAN-09

Calibration Date: 31-MAY-07
Recommended Calibration Due Date: 31-MAY-08*

Ambient Temperature: 22 °C
Relative Humidity: 50 %

National Instruments certifies that at the time of manufacture, the above product was calibrated in accordance with applicable National Instruments procedures. These procedures are in compliance with relevant clauses of ISO 9001 and are designed to assure that the product listed above meets or exceeds National Instruments specifications.

National Instruments further certifies that the measurements standards and instruments used during the calibration of this product are traceable to National and/or International Standards administered by NIST or Euromet members or are derived from accepted values of natural physical constants.

The environment in which this product was calibrated is maintained within the operating specifications of the instrument and the standards.

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

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

NI Hungary Software és
Hardware Gyártó Kft.
4031 Debrecen, Határ út
1/A.
HUNGARY

Signed,

Andrew Krupp
Quality Director

* 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.

Figure B.10. NI 9229 data acquisition module calibration sheet I

NATIONAL INSTRUMENTS

Certificate of Calibration

Board Information:
Serial Number: 12ECB77
NI Part Number: 193299F-01
Description: NI-9205

Certificate Information:
Certificate Number: 837236
Date Printed: 05-JAN-09

Calibration Date: 09-OCT-07
Recommended Calibration Due Date: 09-OCT-08*

Ambient Temperature: 23 °C
Relative Humidity: 37 %

National Instruments certifies that at the time of manufacture, the above product was calibrated in accordance with applicable National Instruments procedures. These procedures are in compliance with relevant clauses of ISO 9001 and are designed to assure that the product listed above meets or exceeds National Instruments specifications.

National Instruments further certifies that the measurements standards and instruments used during the calibration of this product are traceable to National and/or International Standards administered by NIST or Euromet members or are derived from accepted values of natural physical constants.

The environment in which this product was calibrated is maintained within the operating specifications of the instrument and the standards.

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

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

NI Hungary Software és
Hardware Gyártó Kft.
4031 Debrecen, Határ út
1/A.
HUNGARY

Signed,

Andrew Krupp
Quality Director

* 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.

Figure B.11. NI 9205 data acquisition module calibration sheet I

Davis Calibration

ACCREDITED CALIBRATION

Certificate of Calibration

3214191

Instrument Identification

Company ID: 229037
NATIONAL INSTRUMENTS

PO Number: 337683

11500 N. MOPAC EXPWY
ATTN. RMA DEPT.
AUSTIN, TX 78759

Instrument ID: **12A2037**
Model Number: NI 9229
Manufacturer: NATIONAL INSTRUMENTS
Serial Number: 12A2037
Description: 4-CHANNEL, ±60 V, 24-BIT SIMULTANEOUS ANALOG INPUT

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 REV 3.3.1

Remarks: *Reference attached Data.*

Technician: WAYNE GETCHELL
Cal Date 06May2009
Cal Due Date: 06May2010
Interval: 12 MONTHS
Temperature: 23.0 C
Humidity: 44.0 %

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.

Davis Calibration Laboratory is certified to ISO 9001:2000 by Eagle Registrations (certificate # 3046). Lab Operations meet the requirements of ANSI/NCSL Z540-1-1994, ISO 10012:2003, 10CFR50 AppxB, and 10CFR21.

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

Approved By: VICTOR PENA
Service Representative

Calibration Standards

NIST Traceable#	Inst. ID#	Description	Model	Cal Date	Date Due
3143038	15-0271	MULTIFUNCTION CALIBRATOR	5700A	15Apr2009	14Jul2009

Figure B.12. NI 9229 data acquisition module calibration sheet II

Davis Calibration

ACCREDITED CALIBRATION

Certificate of Calibration

3214178

Instrument Identification

Company ID: 229037
NATIONAL INSTRUMENTS

PO Number: 337683

11500 N. MOPAC EXPWY
ATTN. RMA DEPT.
AUSTIN, TX 78759

Instrument ID: **12C73B4**
Manufacturer: NATIONAL INSTRUMENTS
Description: 4-CH 100 OHM 24-BIT RTD ANALOG INPUT

Model Number: NI 9217
Serial Number: 12C73B4

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: CAL EXEC 3.3.1 CAL EXEC 3.3.1

Remarks: *Reference attached data.*

Technician: WAYNE GETCHELL
Cal Date 06May2009
Cal Due Date: 06May2010
Interval: 12 MONTHS
Temperature: 23.0 C
Humidity: 46.0 %

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.

Davis Calibration Laboratory is certified to ISO 9001:2000 by Eagle Registrations (certificate # 3046). Lab Operations meet the requirements of ANSI/NCSL Z540-1-1994, ISO 10012:2003, 10CFR50 AppxB, and 10CFR21.

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

Approved By: VICTOR PENA
Service Representative

Calibration Standards

NIST Traceable#	Inst. ID#	Description	Model	Cal Date	Date Due
3078982	15-0011	DECADE RESISTOR	DB52	24Mar2009	24Mar2010
3004176	15-0060	DIGITAL MULTIMETER (GOLDEN CAL)	3458A OPT 002	17Feb2009	17May2009

Figure B.13. NI 9217 data acquisition module calibration sheet II

Davis Calibration

ACCREDITED CALIBRATION

Certificate of Calibration

3214150

Certificate Page 1 of 1

Instrument Identification

Company ID: 229037
NATIONAL INSTRUMENTS

PO Number: 337683

11500 N. MOPAC EXPWY
ATTN. RMA DEPT.
AUSTIN, TX 78759

Instrument ID: **12ECB77**
Model Number: NI 9205
Manufacturer: NATIONAL INSTRUMENTS
Serial Number: 12ECB77
Description: 32-CH ±200 MV TO ±10 V, 16-BIT, 250 KS/S ANALOG INPUT MODULE

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 REV 3.3.1
Remarks: *Reference attached Data.*

Technician: WAYNE GETCHELL
Cal Date 06May2009
Cal Due Date: 06May2010
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.

Davis Calibration Laboratory is certified to ISO 9001:2000 by Eagle Registrations (certificate # 3046). Lab Operations meet the requirements of ANSI/NCSL Z540-1-1994, ISO 10012:2003, 10CFR50 AppxB, and 10CFR21.

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

Approved By: VICTOR PENA
Service Representative

Calibration Standards

NIST Traceable#	Inst. ID#	Description	Model	Cal Date	Date Due
3143038	15-0271	MULTIFUNCTION CALIBRATOR	5700A	15Apr2009	14Jul2009

Davis Calibration • 2324 Ridgepoint Drive, Suite D • Austin, TX 78754 • Phone: 800-365-0147 • Fax: 512-926-8450

Figure B.14. NI 9205 data acquisition module calibration sheet II

REPORT DOCUMENTATION PAGE

Form Approved
OMB No. 0704-0188

PLEASE DO NOT RETURN YOUR FORM TO THE ABOVE ORGANIZATION.

1. REPORT DATE *(DD-MM-YYYY)*	2. REPORT TYPE	3. DATES COVERED *(From - To)*
November 2010	Technical Report	

4. TITLE AND SUBTITLE
Wind Turbine Generator System Acoustic Noise Test Report for the ARE442 Wind Turbine

5a. CONTRACT NUMBER
DE-AC36-08GO28308

5b. GRANT NUMBER

5c. PROGRAM ELEMENT NUMBER

6. AUTHOR(S)
A. Huskey and J. van Dam

5d. PROJECT NUMBER
NREL/TP-5000-49179

5e. TASK NUMBER
WER9 4501

5f. WORK UNIT NUMBER

7. PERFORMING ORGANIZATION NAME(S) AND ADDRESS(ES)
National Renewable Energy Laboratory
1617 Cole Blvd.
Golden, CO 80401-3393

8. PERFORMING ORGANIZATION REPORT NUMBER
NREL/TP-5000-49179

9. SPONSORING/MONITORING AGENCY NAME(S) AND ADDRESS(ES)

10. SPONSOR/MONITOR'S ACRONYM(S)
NREL

11. SPONSORING/MONITORING AGENCY REPORT NUMBER

12. DISTRIBUTION AVAILABILITY STATEMENT
National Technical Information Service
U.S. Department of Commerce
5285 Port Royal Road
Springfield, VA 22161

13. SUPPLEMENTARY NOTES

14. ABSTRACT *(Maximum 200 Words)*

This test was conducted on the ARE 442 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. In total, five turbines are being tested at the National Wind Technology Center (NWTC) as a part of this project. Acoustic noise testing is one of up to five tests that may be performed on the turbines, including duration, safety and function, power performance, and power quality tests. The acoustic noise test was conducted to the IEC 61400-11 Edition 2.1.

15. SUBJECT TERMS
Independent Testing project; small wind turbine; ARE 442; acoustic noise testing

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