May 2003 NREL/EL-500-34021

Wind Turbine Generator System

Acoustic Noise Test Report

for the

AOC 15/50 Wind Turbine

at the
National Wind Technology Center
Golden, Colorado

by

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

July 1, 1999

Approval By: Arlinda Huskey 7 July 99
Arlinda Huskey, NREL Certification Test Engineer Date

Approval By: Harold F. Link 7 July 99
Harold F Link, NREL Certification Senior Test Engineer Date

Approval By: C P Butterfield 7/26/99
Charles P Butterfield, NREL Certification QA Manager Date

1.0 Table of Contents

2.0 Table of Tables

3.0 Table of Figures

4.0 Disclaimer

This report was prepared as an account of work sponsored by an agency of the United States government. The test results documented in this report define the characteristics of the test article as configured and under the conditions tested.

The United States government nor any agency thereof, nor any of their employees, makes any warranty, express or implied, or assumes any legal liability or responsibility for the usefulness of any information, apparatus, product, or process disclosed, or represents that its use would not infringe privately owned rights. Nor do they assume legal liability or responsibility for the performance of the test article or any similarly named article when tested under other conditions or using different test procedures.

Neither Midwest Research Institute nor the U. S. Government shall be liable for special, consequential or incidental damages. Reference herein to any specific commercial product, process, or service by trade name, trademark, manufacturer, or otherwise does not necessarily constitute or imply its endorsement, recommendation, or favoring by the United States government or any agency thereof. The views and opinions of the authors expressed herein do not necessarily state or reflect those of the United States government or any agency thereof.

NREL is a National Laboratory of the U. S. Department of Energy, and as an adjunct of the U. S. Government, cannot certify wind turbines. The information in this report is limited to NREL's knowledge and understanding as of this date.

5.0 Results

Turbine and background data was collected on March 30, 1999. The following sections show the results of the analysis of the data.

5.1 A-Weighted Sound Power Level

The apparent sound power level was determined using pairs of turbine plus background and pairs of background data between the wind speeds of 6 to 10 m/s. Table 1 gives the calculated apparent sound power level for the four microphone positions. Figure 1 through Figure 4 show the data pairs for microphone positions 1, 2, 3, and 4, respectively.

Table 1. Apparent Sound Power Levels

Microphone Position	Unit	1	2	3	4
Apparent Sound Power Level	dB	101.1	100.3	98.5	100.0
Uncertainty*	dB	0.6	0.6	0.6	0.6
Number of Turbine plus Background Data Points		58	41	12	50
Number of Background Data Points		14	15	9	8

* - The uncertainty reported is the worst case.

5.2 Wind Speed Sensitivity

In determining the wind speed dependence, 74 pairs of turbine plus background and 31 pairs of background data was used. The results are shown in Table 2 and Figure 5. The wind speed range for the turbine data pairs was 4.14 to 9.46 m/s and background data pairs was 4.14 to 9.41 m/s.

Table 2. Wind Speed Dependence

Bin m/s	Wind Speed Average m/s	Position 1 dBA	Uncertainty* dBA
4	4.26	59.6	1.9
5	5.15	59.6	1.4
6	5.99	62.8	1.5
7	7.20	63.5	1.1
8	8.03	**63.7	1.2
9	9.00	64.7	1.0

* The uncertainty reported is the worst case.
**2 data points in background bin, estimate.

5.3 Directivity

In calculating the directivity, the measurements from the four microphone positions were measured simultaneously. The directivity was calculated for positions 2, 3, and 4 in reference to position 1 at a wind speed of 8 m/s. The results are shown in Table 3.

Table 3. Directivity

Position	Units	2	3	4
Directivity	dB	-0.6	-2.6	-0.9
Uncertainty*	dB	0.8	0.8	0.8

* The uncertainty reported is the worst case.

5.4 Octave Spectra

At the reference position, third octave data was also collected. The octave band results for microphone position 1 is shown in Table 4 and Figure 6

Table 4. Third Octave Bands for Microphone Position 1

Center Frequency	20 Hz	25 Hz	31.5 Hz	40 Hz	50 Hz	63 Hz	80 Hz	100 Hz	125 Hz	160 Hz	200 Hz
Units	dB	dB	dB	dB	dB	dB	dB	dB	dB	dB	dB
Position 1	69.0	67.0	65.0	57.0	58.0	59.9	56.7	54.3	53.8	54.1	54.1
Uncertainty	4.1	3.8	3.3	7.2	4.6	2.7	1.8	3.6	1.7	1.6	1.5

Center Frequency	250 Hz	315 Hz	400 Hz	500 Hz	630 Hz	800 Hz	1000 Hz	1250 Hz	1600 Hz	2000 Hz	2500 Hz
Units	dB	dB	dB	dB	dB	dB	dB	dB	dB	dB	dB
Position 1	52.6	54.1	51.7	53.7	56.8	62.4	52.0	52.0	53.1	47.4	48.8
Uncertainty	1.4	1.7	1.5	1.7	2.4	2.3	1.5	2.1	2.7	1.1	1.4

Center Frequency	3150 Hz	4000 Hz	5000 Hz
Units	dB	dB	dB
Position 1	45.5	41.0	37.7
Uncertainty	1.3	1.4	1.8

5.5 Tonal Analysis

A tonal analysis was completed for frequencies from 20 to 5000 Hz for 5 integer wind speed bins at the reference microphone position. The sets of unweighted spectra were obtained using the settings shown in Table 5.

Table 5. Data Files Created During the Tonal Analysis

Bin	Bandwidth	Frequency Resolution	Setup File Turbine On	Setup File Background	Number of Spectra
5	20 - 3200	6	5TAOCNLW	5BAOCNLO	280
5	2500 - 5000	6	5TAOCNHI	5BAOCNHI	280
6	20 - 3200	6	6TAOCNLW	6BAOCNLO	280
6	2500 - 5000	6	6TAOCNHI	6BAOCNHI	280
7	20 - 3200	6	7TAOCNLW	7BAOCNLO	280
7	2500 - 5000	6	7TAOCNHI	7BAOCNHI	280
8	20 - 3200	6	8TAOCNLW	8BAOCNLO	280
8	2500 - 5000	6	8TAOCNHI	8BAOCNHI	280
9	20 - 3200	6	9TAOCNLW	9BAOCNLO	280
9	2500 - 5000	6	9TAOCNHI	9BAOCNHI	280

5.5.1 Reference Wind Speed

The tonal analysis for the frequency range 20 to 5000 Hz was done with an effective bandwidth of 6 Hz. Figure 10 shows the unweighted spectrum for turbine plus background and background noise. Two critical bands were analyzed. Table 6 shows the results from the critical band analysis.

Table 6. Tonal Analysis at the Reference Wind Speed

Frequency of Tone Hz	Critical Band Hz	$\Delta L_{tn,max}$, Difference between the maximum level of tone and masking level dB	$\Delta L_{tn,avg}$, Difference between the average level of the tone and masking dB	U_C Combined Uncertainty dB
488, 492, 496, 500	432 – 548	7.1	1.8	1.5
1000	916 - 1076	-2.1	-7.8	1.4

5.5.2 Wind Speed Dependence on Tonality

An additional tonal analysis was done for integer wind speed bins from 4 to 9 m/s. Figures 7 through 11 show the spectrums for wind speed bins 5 through 9, respectively. The following tables show the results for the critical band analysis for each wind speed bin.

Table 7. Tonal Analysis for 5 m/s Wind Speed Bin

Critical Band Hz	$\Delta L_{tn,avg}$, Difference between the average level of the tone and masking dB	$\Delta L_{a,max}$, Tonal Audibility dB	$\Delta L_{tn,max}$, Difference between the maximum level of tone and masking dB	U_C Combined Uncertainty dB
432 – 548	0.2	9.7	7.4	2.7

Table 8. Tonal Analysis for 6 m/s Wind Speed Bin

Critical Band Hz	$\Delta L_{tn,avg}$, Difference between the average level of the tone and masking dB	$\Delta L_{a,max}$, Tonal Audibility dB	$\Delta L_{tn,max}$, Difference between the maximum level of tone and masking	U_C Combined Uncertainty dB
432 – 548	2.3	11.9	9.6	2.1

Table 9. Tonal Analysis for 7 m/s Wind Speed Bin

Critical Band Hz	$\Delta L_{tn,avg}$, Difference between the average level of the tone and masking dB	$\Delta L_{a,max}$, Tonal Audibility dB	$\Delta L_{tn,max}$, Difference between the maximum level of tone and masking	U_C Combined Uncertainty dB
432 – 548	4.5	12.4	10.1	1.8
916 - 1076	-4.1	4.3	1.5	1.8

Table 10. Tonal Analysis for 8 m/s Wind Speed Bin

Critical Band Hz	$\Delta L_{tn,avg}$, Difference between the average level of the tone and masking dB	$\Delta L_{a,max}$, Tonal Audibility dB	$\Delta L_{tn,max}$, Difference between the maximum level of tone and masking	U_C Combined Uncertainty dB
432 – 548	1.8	9.5	7.1	1.5
916 - 1076	-7.8	0.8	-2.1	1.4

Table 11. Tonal Analysis for 9 m/s Wind Speed Bin

Critical Band Hz	$\Delta L_{tn,avg}$, Difference between the average level of the tone and masking dB	$\Delta L_{a,max}$, Tonal Audibility dB	$\Delta L_{tn,max}$, Difference between the maximum level of tone and masking	U_C Combined Uncertainty dB
328 – 436	-2.6	3.2	1.0	7.8
432 – 548	5.4	13.4	11.1	2.0
916 - 1076	1.3	10.3	7.4	2.1

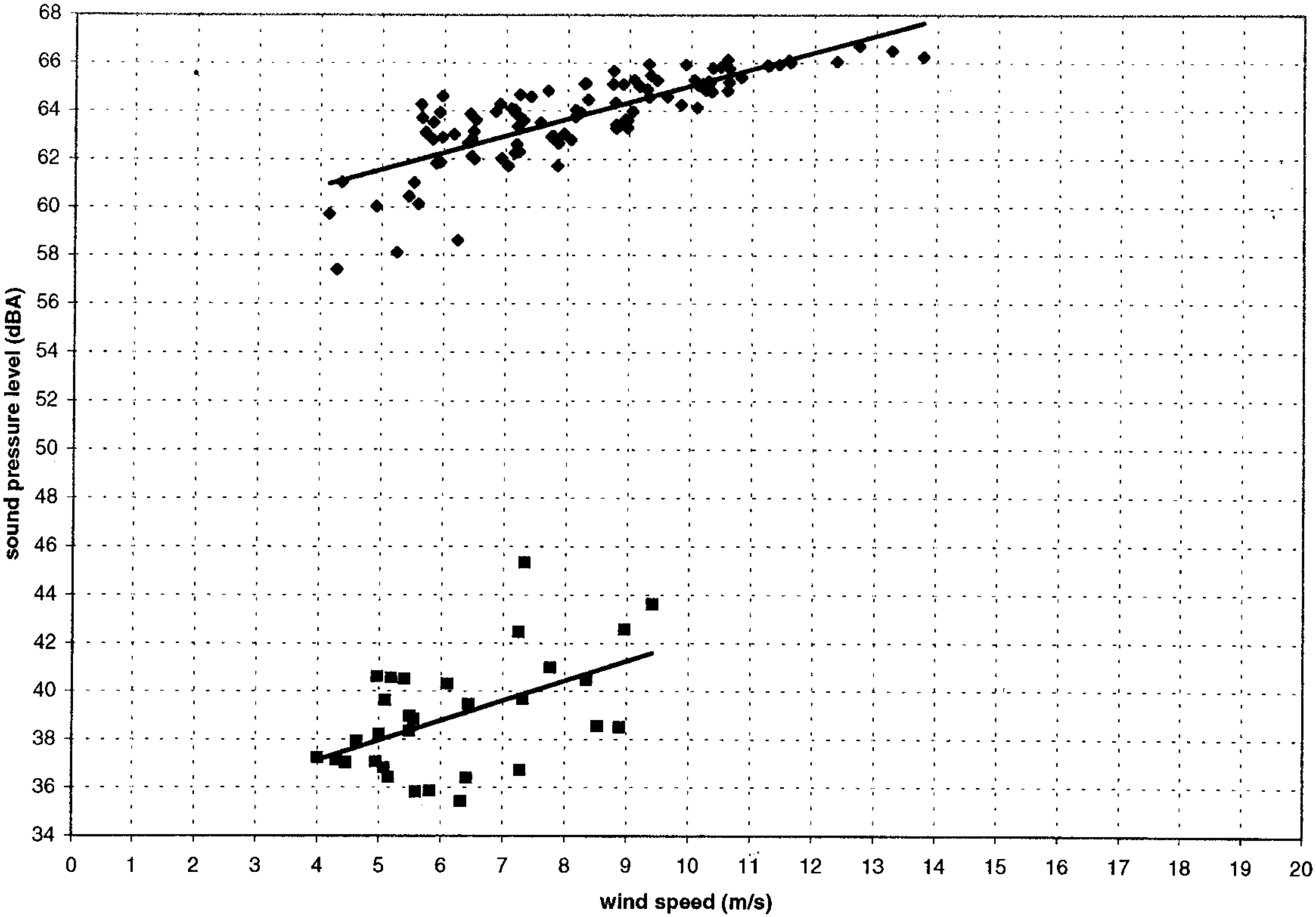


Figure 1. Turbine Plus Background and Background Data For Microphone Position 1

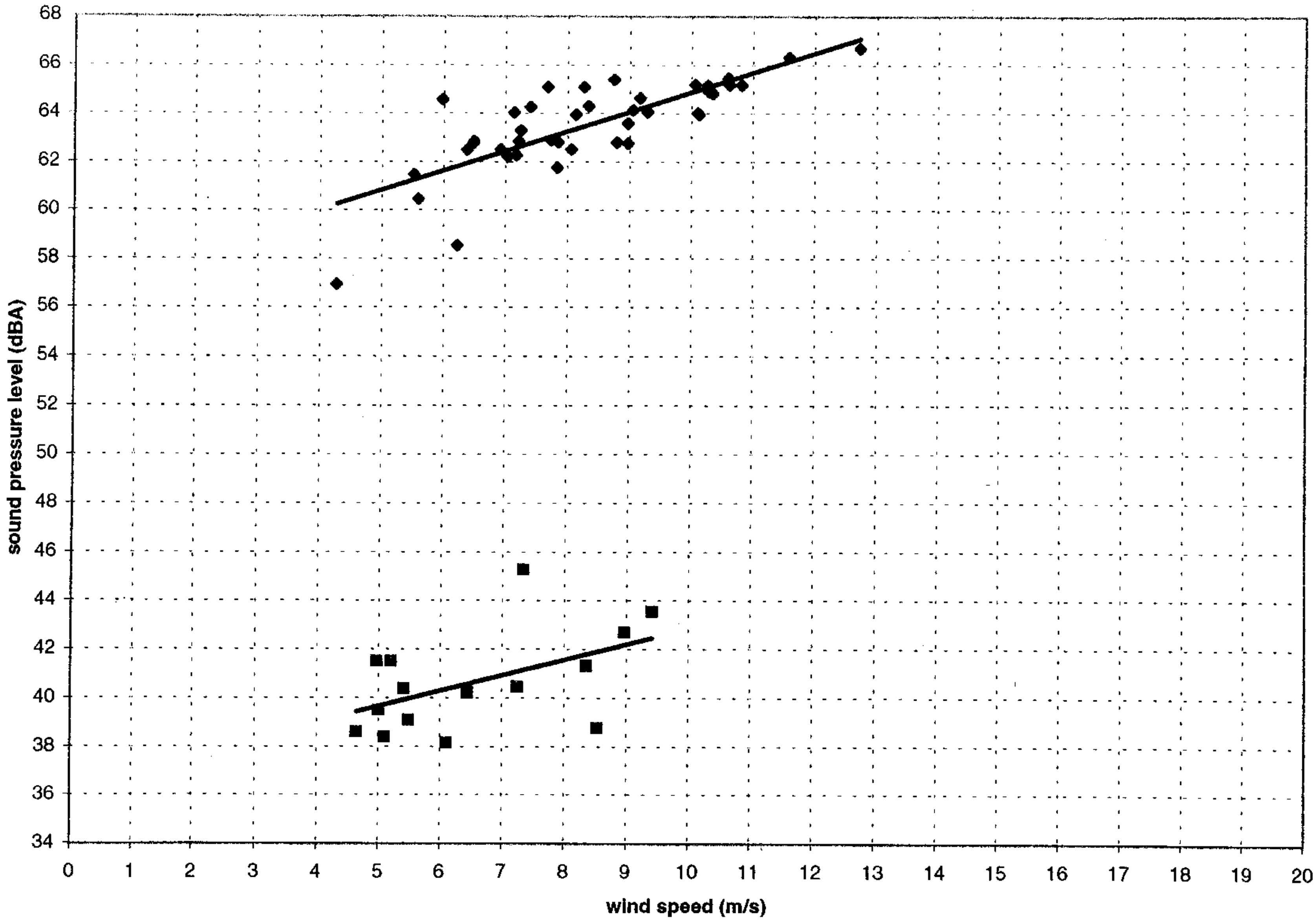


Figure 2. Turbine Plus Background and Background Data For Microphone Position 2

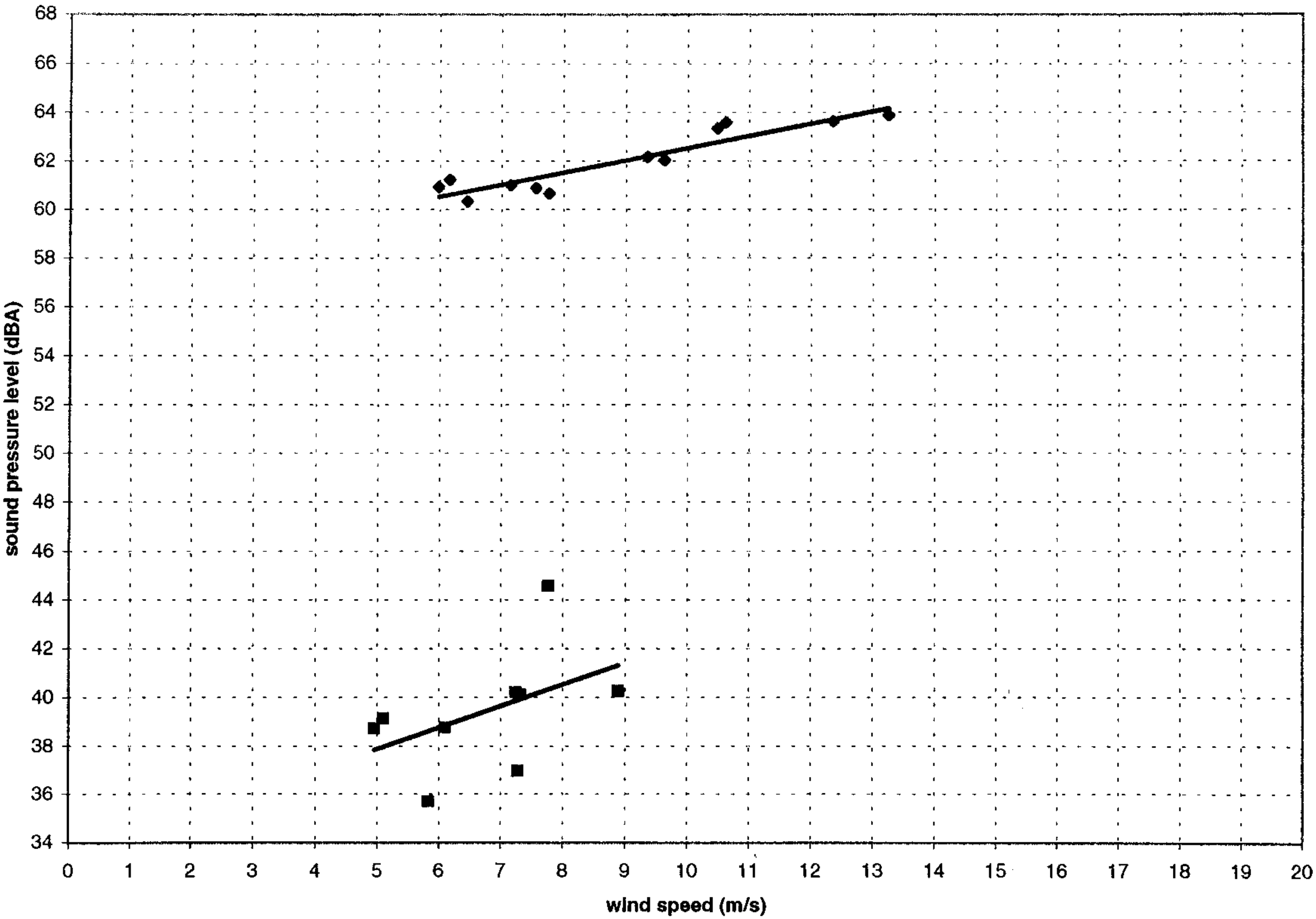


Figure 3. Turbine Plus Background and Background Data For Microphone Position 3

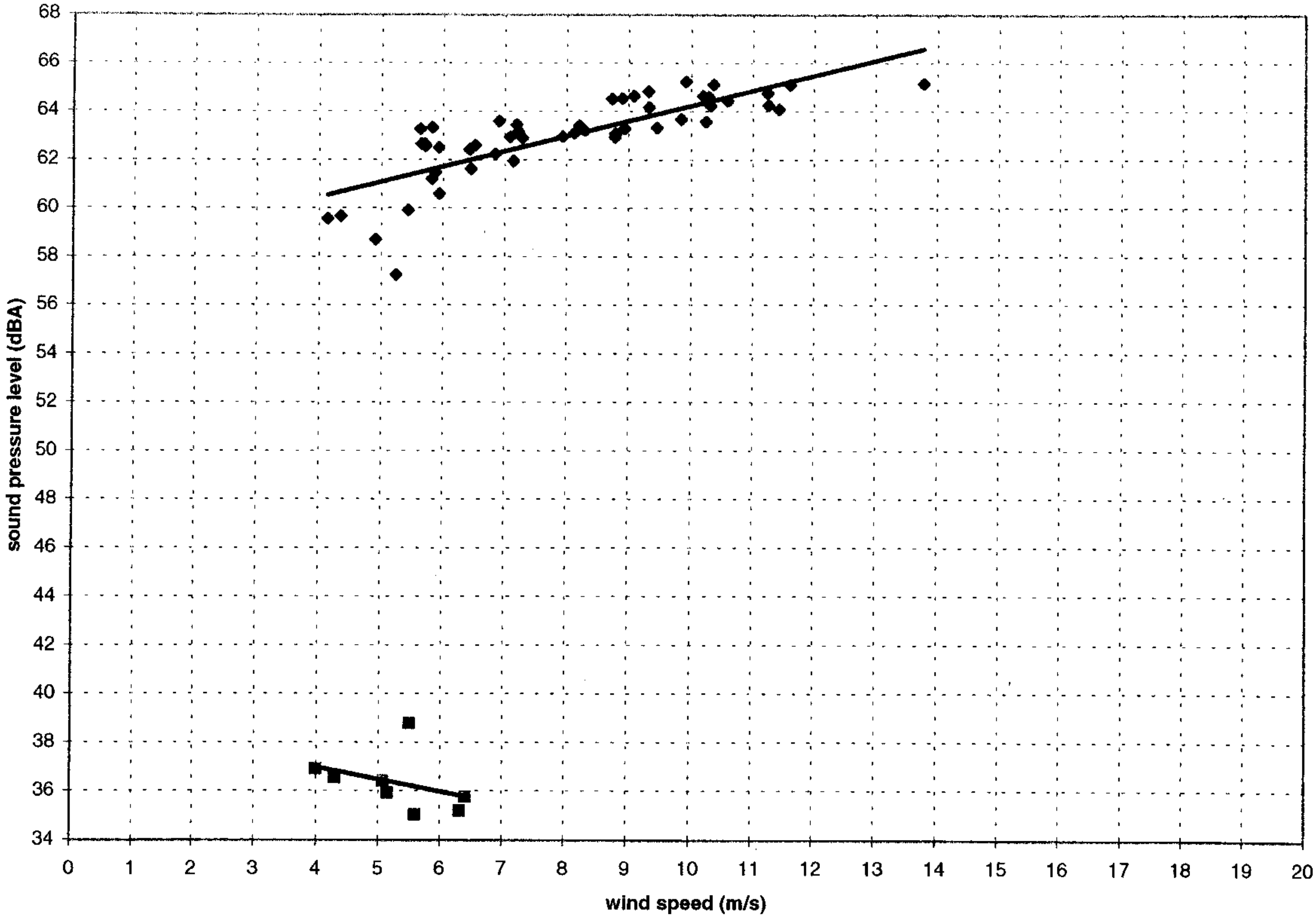


Figure 4. Turbine Plus Background and Background Data For Microphone Position 4

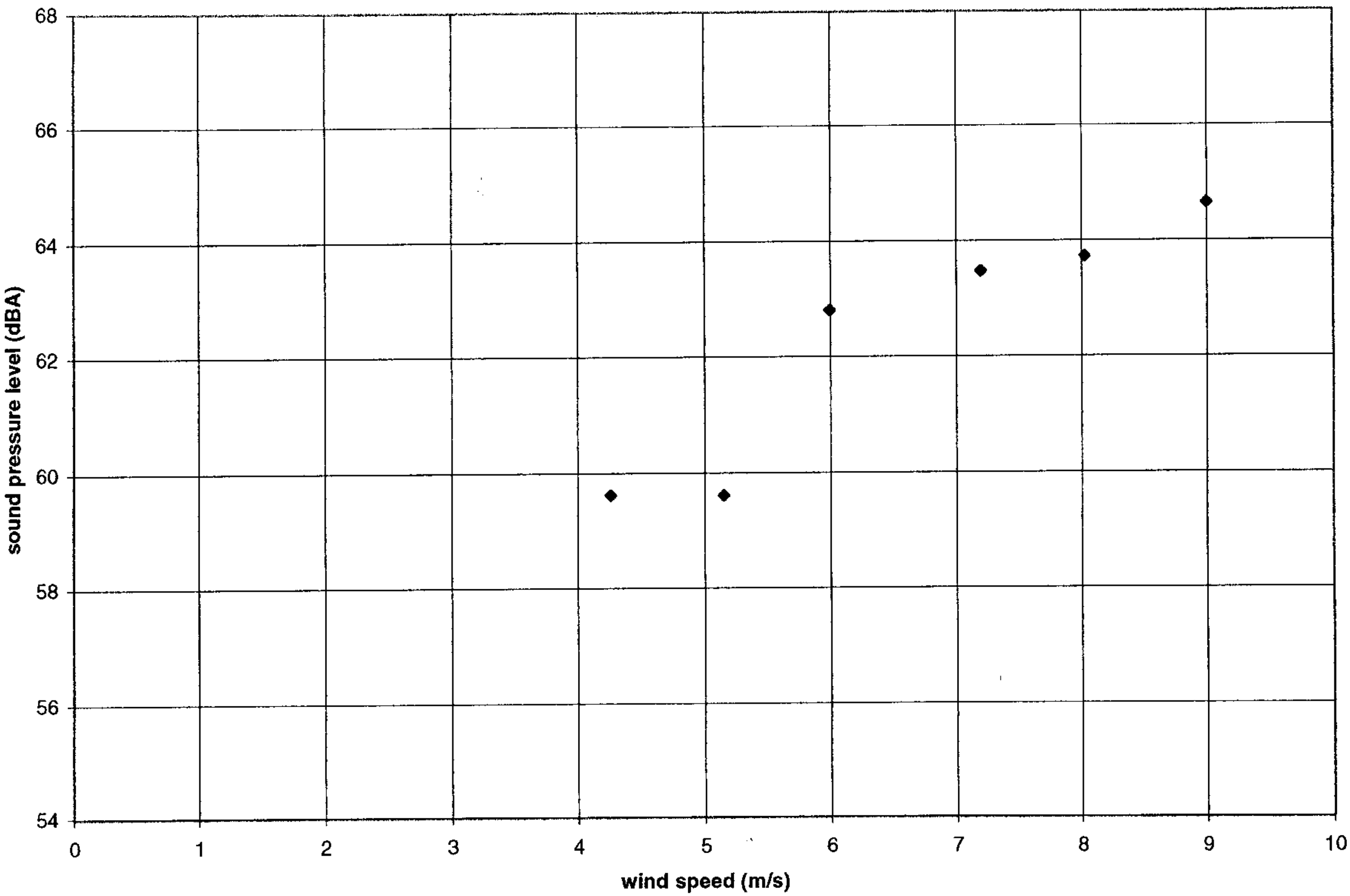


Figure 5. Wind Speed Dependence at Microphone Position 1

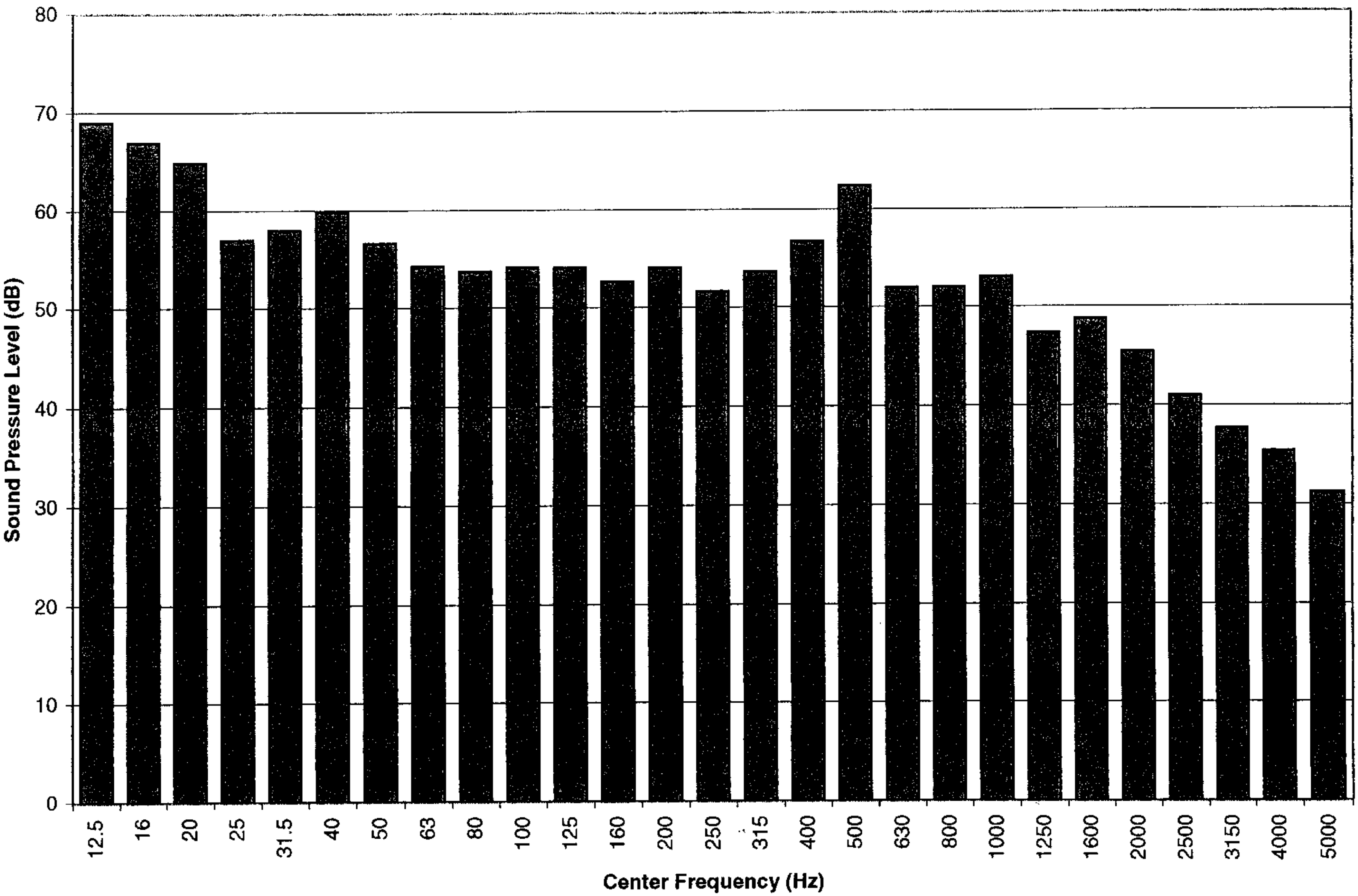


Figure 6. Third Octave Bands for Microphone Position 1

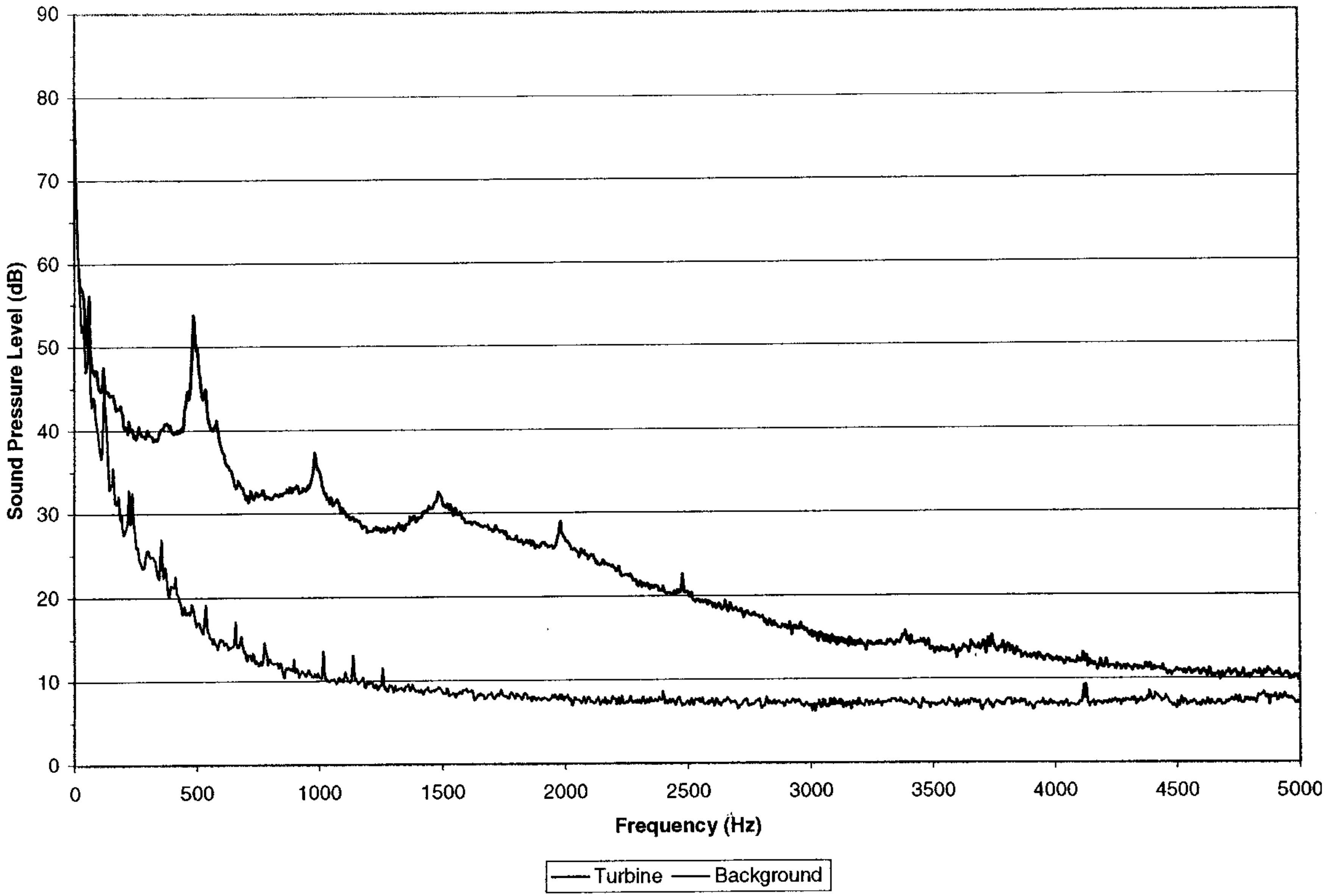


Figure 7. Turbine Plus Background and Background Spectrum for 5 m/s Wind Speed Bin

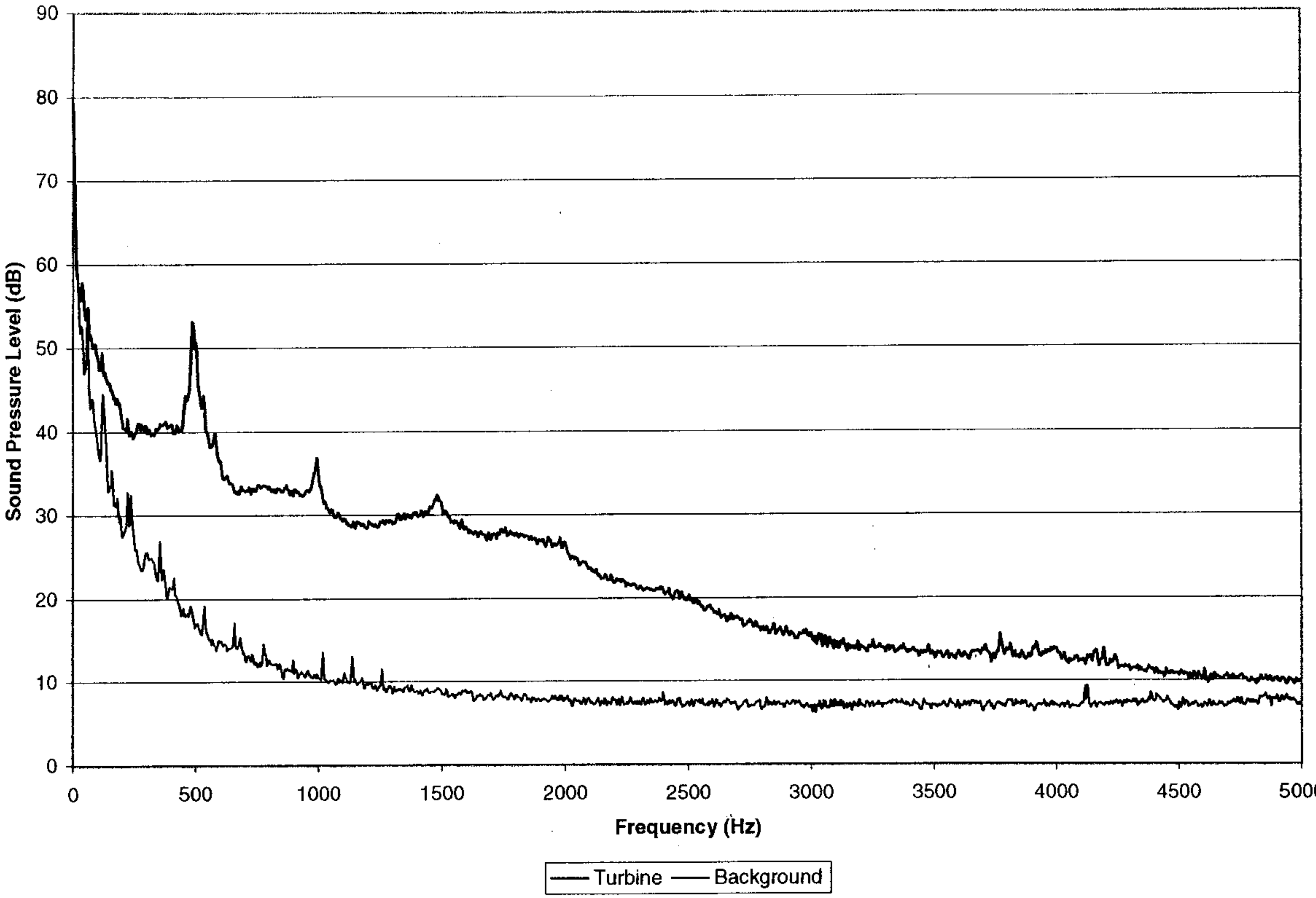


Figure 8. Turbine Plus Background and Background Spectrum for 6 m/s Wind Speed Bin

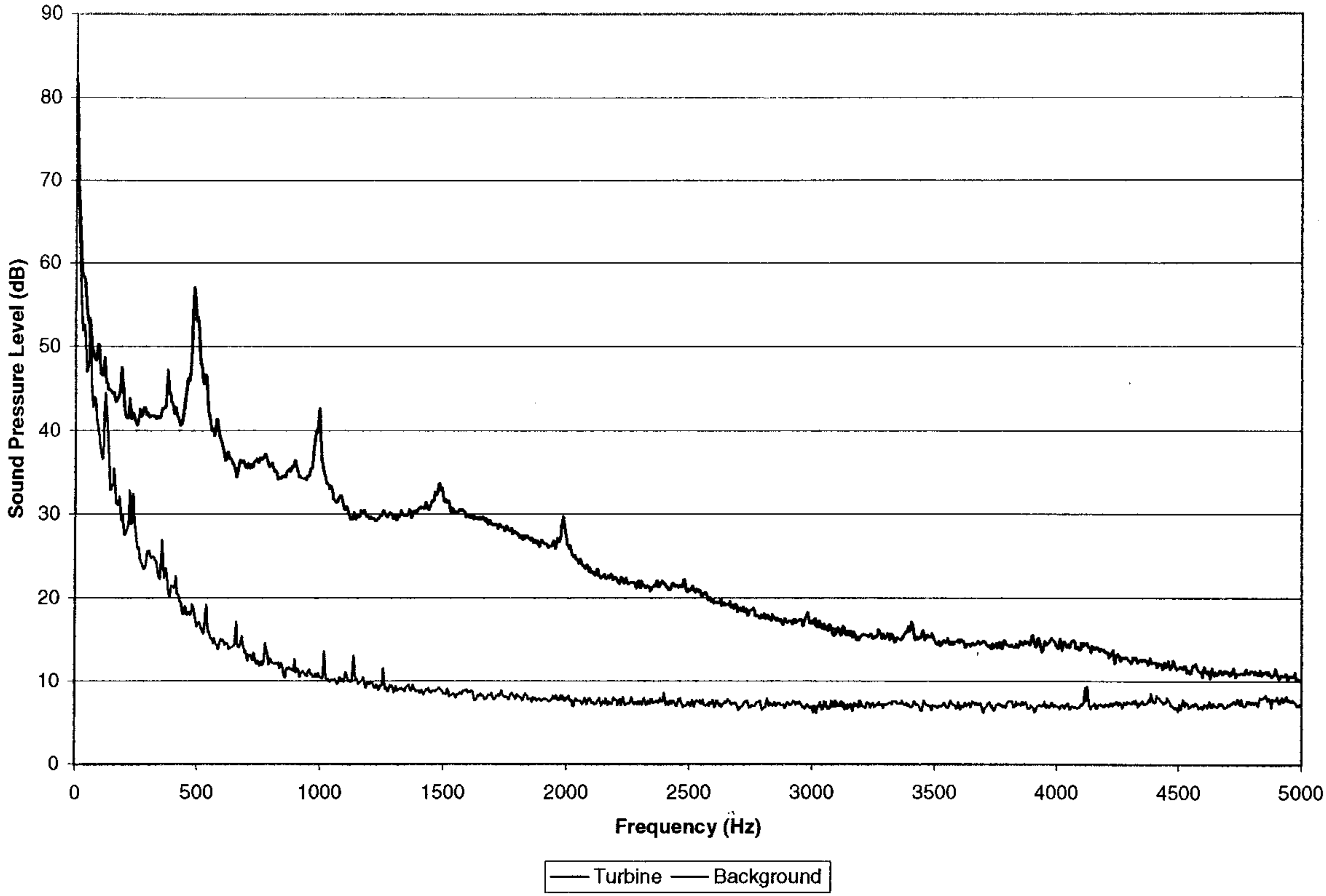


Figure 9. Turbine Plus Background and Background Spectrum for 7 m/s Wind Speed Bin

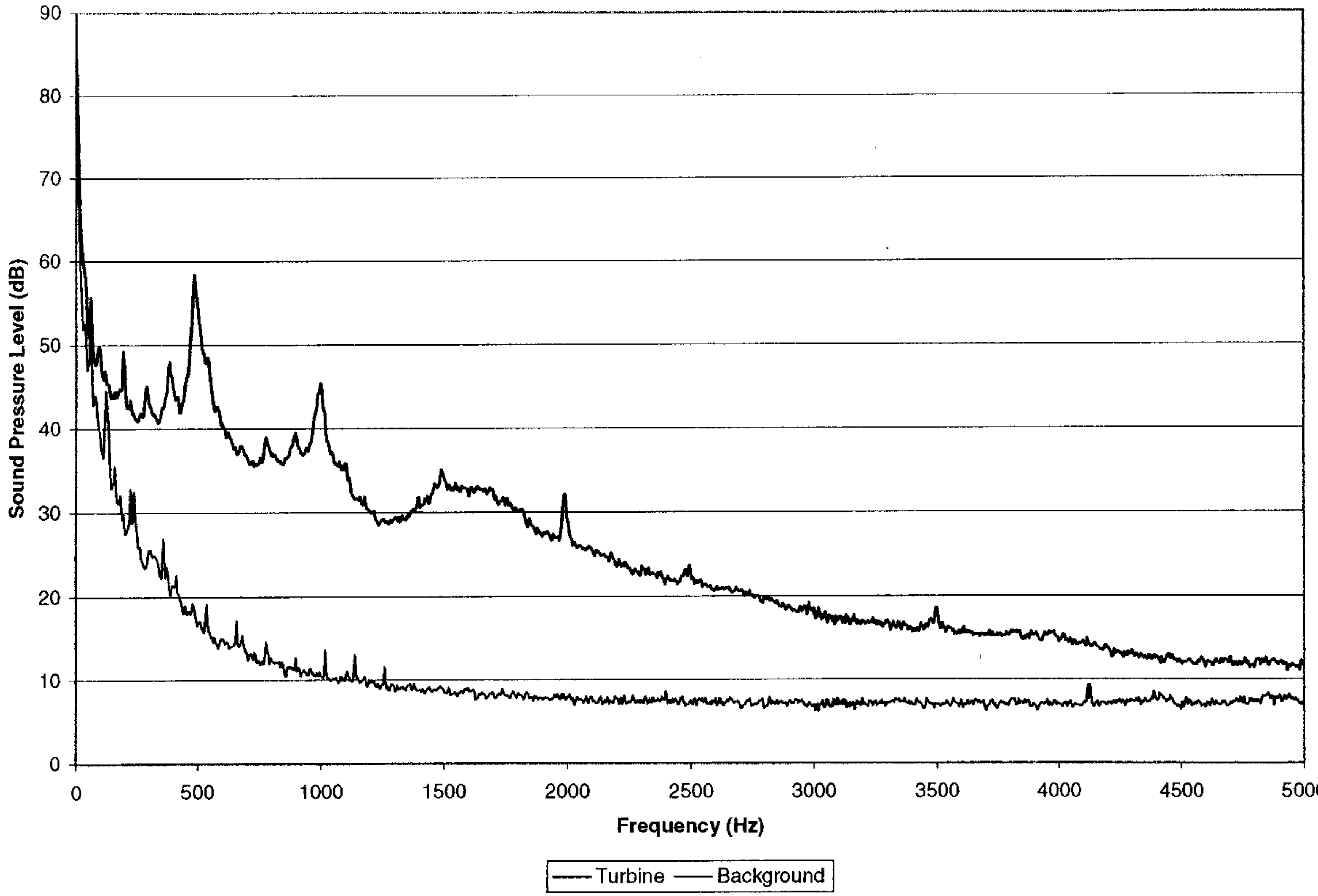


Figure 10. Turbine Plus Background and Background Spectrum for 8 m/s Wind Speed Bin

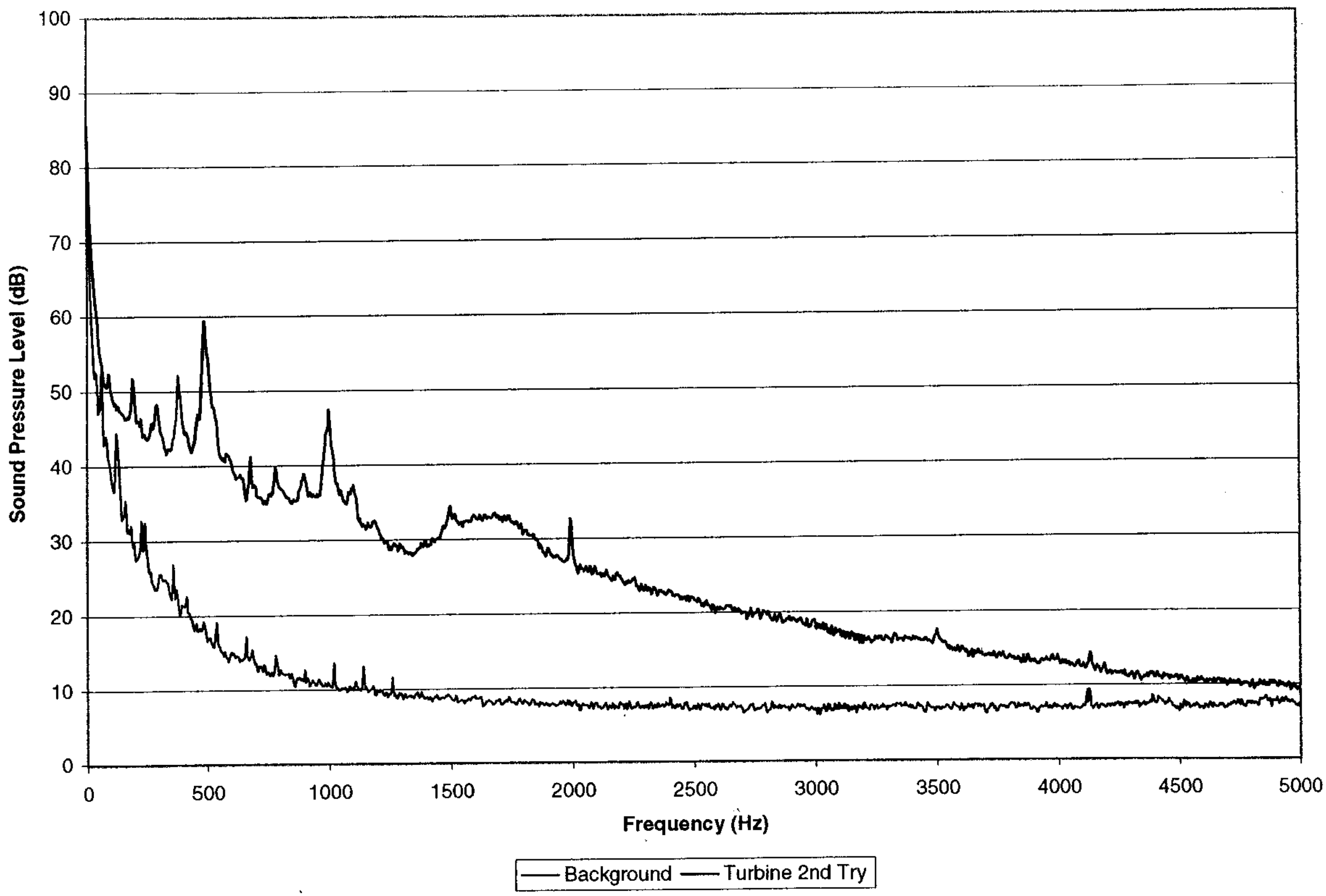


Figure 11. Turbine Plus Background and Background Spectrum for 9 m/s Wind Speed Bin

6.0 Uncertainty

The combined uncertainty is reported for the apparent sound power level, directivity, wind speed dependence, and tonality. The combined standard uncertainty is the combination of Type A and Type B uncertainties. Type A uncertainty components are evaluated by using statistical methods to a series of repeated measurements. Type B uncertainty components are evaluated through estimations or calibrations. The methods used to evaluate the uncertainty components for the apparent sound power level, directivity, wind speed dependence and tonality will be explained in this section.

6.1 Apparent Sound Pressure Level

The Type A uncertainty for the apparent sound pressure level is the standard error of the estimated L_{Aeq} at the acoustic reference wind speed. This is found from the linear regression analysis.

$$U_A = \sqrt{\frac{\Sigma(y - y_{est})^2}{N - 2}} \qquad \textbf{Equation 10}$$

Table 12. Type A Apparent Sound Power Level Uncertainty Components

Parameter	Description	Microphone				Units
		1	2	3	4	
U_A	Type A uncertainty for apparent sound pressure level,	1.1	1.1	0.7	1.2	dB
y	measured sound pressure level,	-	-	-	-	dB
y_{est}	estimated sound pressure level using linear regression,	63.8	63.3	61.5	63.0	dB
N	Number of measurements used in the linear regression.	58	41	12	50	-

The Type B uncertainty components include:

$$U_B = \sqrt{U_{B1}^2 + U_{B2}^2 + U_{B3}^2 + U_{B4}^2 + U_{B5}^2 + U_{B6}^2 + U_{B7}^2 + U_{B8}^2 + U_{B9}^2}$$ **Equation 11**

Table 13. Type B Apparent Sound Power Level Uncertainty Components

Parameter	Description	Microphone Position				Unit	Source
		1	2	3	4		
U_B	Type B uncertainty for apparent sound pressure level	0.6	0.6	0.6	0.6	dB	Equation 11
U_{B1}	uncertainty for calibration of the instruments,	0.0	0.0	0.1	0.1	dB	calibrator calibration and the standard error from field calibrating microphones
U_{B2}	uncertainty for tolerances on the chain of acoustic measurement instruments,	0.2	0.2	0.2	0.2	dB	signal analyzer, microphone, microphone adapter, and preamplifier
U_{B3}	uncertainty for acoustic conditions for microphone mounting board,	0.3	0.3	0.3	0.3	dB	estimate
U_{B4}	uncertainty on the distance from microphone to hub,	0.1	0.1	0.1	0.1	dB	estimate
U_{B5}	uncertainty on the acoustic impedance of air,	0.1	0.1	0.1	0.1	dB	estimate
U_{B6}	uncertainty on the acoustic emission of the turbine due to changing weather conditions,	0.3	0.3	0.3	0.3	dB	estimate
U_{B7}	uncertainty on the measured wind speed	0.1	0.1	0.1	0.1	dB	anemometer calibration and estimate of the site effects
U_{B8}	uncertainty on the wind direction measurement,	0.3	0.3	0.3	0.3	dB	Estimate
U_{B9}	uncertainty for the background correction.	0.0	0.0	0.0	0.0	dB	Applied background correction

These uncertainties are combined into one standard uncertainty by Equation 12.

$$U_C = \sqrt{U_A^2 + U_B^2}$$ **Equation 12**

Table 14. Overall Uncertainty Components

Parameter	Description	Microphone Positions				Units
		1	2	3	4	
U_C	Overall standard uncertainty for apparent sound pressure level,	0.6	0.6	0.6	0.6	dB
U_A	Type A uncertainty for apparent sound pressure level,	1.1	1.1	0.7	1.2	dB
U_B	Type B uncertainty for apparent sound pressure level	0.6	0.6	0.6	0.6	dB

6.2 Wind Speed Sensitivity

Type A uncertainty for wind speed dependence is found from the from a linear regression analysis. The uncertainty, U_A is calculated for integer wind speeds as the root sum of the squared standard error of the estimated value at the actual wind speed. The squared standard error is given in Equation 13.

$$s_i = \sqrt{\frac{\sum (L_{Aeq} - L_{Aeq,j})^2}{(N-1)^2}}$$ **Equation 13**

Table 15. Type A Wind Dependence Uncertainty Components

Parameter	Description	Units
s_i	Type A standard uncertainty for bin i	dB
L_{Aeq}	Average of the sound pressure levels in the bin i	dB
$L_{Aeq,i}$	sound pressure level in the bin	dB
N	number of measurement results in the bin	

The Type B uncertainty for each bin is found using Equation 11.

Table 16. Type B Wind Dependence Uncertainty Components

Parameter	Description	Value	Unit	Source
U_B	Type B uncertainty for bin i	varies by bin	dB	
U_{B1}	uncertainty for calibration of the instruments,	0.1	dB	calibrator calibration and the standard error from field calibrating microphones
U_{B2}	uncertainty for tolerances on the chain of acoustic measurement instruments,	0.2	dB	signal analyzer, microphone, microphone adapter, and preamplifier
U_{B3}	uncertainty for acoustic conditions for microphone mounting board,	0.3	dB	estimate
U_{B4}	uncertainty on the distance from microphone to hub,	0.1	dB	estimate
U_{B5}	uncertainty on the acoustic impedance of air,	0.1	dB	estimate
U_{B6}	uncertainty on the acoustic emission of the turbine due to changing weather conditions,	0.3	dB	estimate
U_{B7}	uncertainty on the measured wind speed	0.1	dB	anemometer calibration and estimate of the site effects
U_{B8}	uncertainty on the wind direction measurement,	0.3	dB	Estimate
U_{B9}	uncertainty for the background correction.	varies by bin	dB	Applied background correction

6.3 Directivity

An estimate of the standard uncertainty on the directivity is shown in Equation 14.

$$U_D = \sqrt{2}\, U_C$$ **Equation 14**

Table 17. Variables for Estimating Directivity Uncertainty

Parameter	Description	Microphone Position			Unit
		2	3	4	
U_D	Standard uncertainty for directivity,	1.6	1.0	1.7	dB
U_C	Overall standard uncertainty for apparent sound pressure level.	1.1	0.7	1.2	dB

6.4 Third Octave Spectra

For the third octave band, U_A for each band is the standard error on the averaged band level. U_A is calculated for each band.

$$U_A = \sqrt{\frac{\sum (y - y_{est})^2}{N - 1}}$$

Equation 15

Table 18. Type A Octave Band Uncertainty Components

Parameter	Description	Units
U_A	Type A standard uncertainty for band	dB
y	Sound pressure level of the band	dB
y_{est}	Average sound pressure level of the band	dB
N	number of measured spectra	

The Type B uncertainty components are estimated to be the same except for U_{B3}. It will be considered much larger than for L_{WA}, estimated value is 1.2 dB as shown in Table 19.

Table 19. Type B Octave Band Uncertainty Components

Parameter	Description	Value	Unit	Source
U_B	Type B uncertainty for octave bands	varies by band	dB	
U_{B1}	uncertainty for calibration of the instruments,	0.1	dB	DAT recorder and calibrator calibration, and the standard error from field calibrating microphones
U_{B2}	uncertainty for tolerances on the chain of acoustic measurement instruments,	0.2	dB	signal analyzer, microphone, microphone adapter, and preamplifier
U_{B3}	uncertainty for acoustic conditions for microphone mounting board,	0.3	dB	estimate
U_{B4}	uncertainty on the distance from microphone to hub,	0.1	dB	estimate
U_{B5}	uncertainty on the acoustic impedance of air,	0.1	dB	estimate
U_{B6}	uncertainty on the acoustic emission of the turbine due to changing weather conditions,	0.3	dB	estimate
U_{B7}	uncertainty on the measured wind speed	varies by band	dB	anemometer calibration and estimate of the site effects
U_{B8}	uncertainty on the wind direction measurement,	0.3	dB	Estimate
U_{B9}	uncertainty for the background correction.	varies by band	dB	Applied background correction

6.5 Tonal Analysis

For the third octave band, U_A for each band is the standard error on the averaged band level. U_A is calculated for each band.

$$U_A = \sqrt{\frac{\sum (y - y_{est})^2}{N - 1}}$$ **Equation 15**

Table 20. Type A Tonality Uncertainty Components

Parameter	Description	Units
U_A	Type A standard uncertainty for tone	dB
y	Maximum sound pressure level of the tone	dB
y_{est}	Average sound pressure level of the band	dB
N	number of spectra used	

The Type B uncertainty components are estimated to be the same as shown in Table 19.

Table 21. Type B Octave Band Uncertainty Components

Parameter	Description	Value	Unit	Source
U_B	Type B uncertainty for octave bands	varies by band	dB	
U_{B1}	uncertainty for calibration of the instruments,	0.0	dB	DAT recorder and calibrator calibration, and the standard error from field calibrating microphones
U_{B2}	uncertainty for tolerances on the chain of acoustic measurement instruments,	0.2	dB	signal analyzer, DAT recorder
U_{B3}	uncertainty for acoustic conditions for microphone mounting board,	0.3	dB	estimate
U_{B4}	uncertainty on the distance from microphone to hub,	0.1	dB	estimate
U_{B5}	uncertainty on the acoustic impedance of air,	0.1	dB	estimate
U_{B6}	uncertainty on the acoustic emission of the turbine due to changing weather conditions,	0.3	dB	estimate
U_{B7}	uncertainty on the measured wind speed	0.1	dB	anemometer calibration and estimate of the site effects
U_{B8}	uncertainty on the wind direction measurement,	0.3	dB	Estimate

7.0 Exceptions

7.1 Exceptions to Standard

1. There were no exceptions to the Standard.

7.2 Exceptions to NWTC-CT Quality Assurance System

There were no exceptions to the NWTC-CT Quality Assurance System.

Appendix A Pictures of Test Site

Figure 12. Picture Taken From the Reference Microphone Position (manlift was not present during test)

Figure 13. Picture Taken From the Meteorological Tower (manlift was not present during test)

Appendix B Data Sheets

TURBINE MEASUREMENTS

Data File	Time stamp dd/mm/yy	Time stamp hh:mm:ss	Wind Spd m/s	Pnorm kW	Pressure Pa	Temp K	Mic 1 dBA	Mic 2 dBA	Mic 3 dBA	Mic 4 dBA
AOC_C_A2	03.30.99	14:20:51	10.13	53.12	80200	295.5	63.84	63.97	62.55	65.07
AOC_C_A2	03.30.99	14:21:56	8.80	37.50	80200	295.5	62.61	62.82	61.36	63.45
AOC_C_A2	03.30.99	14:23:01	8.98	33.16	80200	295.5	62.41	62.77	61.50	63.31
AOC_C_A2	03.30.99	14:24:06	9.29	52.80	80200	295.5	64.19	64.07	63.04	64.91
AOC_C_A2	03.30.99	14:25:11	10.29	60.01	80200	295.5	64.42	64.88	63.35	65.06
AOC_C_A2	03.30.99	14:26:16	10.27	56.62	80200	295.5	64.12	65.18	63.43	65.08
AOC_C_A2	03.30.99	14:27:21	7.84	25.99	80200	295.5	61.73	63.02	61.78	63.12
AOC_C_A2	03.29.99	14:28:26	8.21	33.87	80200	295.5	63.16	63.93	63.51	63.40
AOC_C_A2	03.30.99	14:29:31	5.25	-1.91	80200	295.5	57.77	58.12	57.99	57.25
AOC_C_A2	03.30.99	14:30:36	6.23	0.56	80200	295.5	58.64	59.55	58.54	59.14
AOC_C_A2	03.30.99	14:31:42	5.60	3.18	80200	295.5	60.15	61.53	60.47	61.27
AOC_C_A2	03.30.99	14:32:47	5.52	10.28	80200	295.5	61.04	62.72	61.49	62.55
AOC_C_A2	03.30.99	14:33:52	7.04	19.32	80200	295.5	61.73	63.00	62.22	63.00
AOC_C_A2	03.30.99	14:34:57	10.25	44.38	80200	295.5	64.43	64.86	64.46	63.57
AOC_C_A2	03.30.99	14:36:02	11.62	69.56	80200	295.5	65.79	66.02	65.77	65.08
AOC_C_A2	03.30.99	14:37:08	8.98	41.14	80200	295.5	63.60	64.36	63.59	64.47
AOC_C_A2	03.30.99	14:38:13	7.18	32.09	80200	295.5	62.61	63.61	62.30	63.84
AOC_C_A2	03.30.99	14:39:18	10.20	52.64	80200	295.5	64.55	65.14	64.79	64.64
AOC_C_A2	03.30.99	14:40:23	11.44	63.78	80200	295.5	65.16	65.94	65.16	64.09
AOC_C_A2	03.30.99	14:41:28	11.26	59.97	80200	295.5	65.51	65.87	65.38	64.25
AOC_C_A2	03.30.99	14:42:33	13.78	73.57	80200	295.5	66.26	66.27	66.09	65.14
AOC_C_A2	03.30.99	14:43:39	9.06	41.54	80200	295.5	63.99	64.32	64.16	63.82
AOC_C_A2	03.30.99	14:44:44	10.32	52.87	80200	295.5	65.11	65.17	65.10	64.22
AOC_C_A2	03.30.99	14:45:49	9.46	50.68	80200	295.5	64.87	65.28	64.75	63.32
AOC_C_A2	03.30.99	14:46:54	10.60	59.57	80200	295.5	64.43	65.48	64.84	64.07
AOC_C_A2	03.30.99	14:47:59	9.85	48.06	80200	295.5	63.68	65.11	64.27	63.35
AOC_C_A2	03.30.99	14:49:04	7.14	15.71	80200	295.5	61.94	63.09	62.26	61.67
AOC_C_A2	03.30.99	14:50:09	8.80	31.25	80200	295.5	63.08	64.05	63.29	62.41
AOC_C_A2	03.30.99	14:51:14	8.94	38.37	80200	295.5	63.29	64.18	63.66	62.73
AOC_C_A2	03.30.99	14:52:19	7.29	19.74	80200	295.5	62.69	63.60	63.00	62.89
AOC_C_A2	03.30.99	14:53:24	8.78	37.53	80200	295.5	63.80	64.36	63.91	62.93
AOC_C_A2	03.30.99	14:54:29	8.13	26.13	80200	295.5	63.09	63.75	63.35	63.09
AOC_C_A2	03.30.99	14:55:36	6.49	15.95	80200	295.5	62.03	63.27	62.86	63.58
AOC_C_A2	03.30.99	14:56:41	7.86	26.70	80200	295.5	62.67	63.55	62.83	63.56
AOC_C_A2	03.30.99	14:57:46	10.62	46.37	80200	295.5	65.20	65.16	65.18	64.96
AOC_C_A2	03.30.99	14:58:51	10.29	54.91	80200	295.5	65.03	65.23	65.21	64.59
AOC_C_A2	03.30.99	14:59:57	10.82	61.61	80200	295.5	65.40	65.65	65.17	65.43
AOC_C_A2	03.30.99	15:01:02	10.60	62.78	80200	295.5	66.15	65.95	65.46	66.07
AOC_C_A2	03.30.99	15:02:07	10.35	50.85	80200	295.5	64.81	65.24	64.82	65.35
AOC_C_A2	03.30.99	15:03:13	10.11	42.43	80200	295.5	64.15	64.77	64.04	64.76
AOC_C_A2	03.30.99	15:04:18	10.06	59.55	80200	295.5	65.31	65.80	65.19	65.56
AOC_C_A2	03.30.99	15:05:23	11.25	66.95	80200	295.5	65.98	65.92	65.87	64.73
AOC_C_A2	03.30.99	15:06:28	7.20	22.48	80200	295.5	62.51	63.36	62.96	63.44
AOC_C_A2	03.30.99	15:07:34	6.93	14.29	80200	295.5	62.04	63.23	62.53	63.23
AOC_C_A2	03.30.99	15:08:39	5.44	4.59	80200	295.5	59.91	60.46	60.53	59.93
AOC_C_A2	03.30.99	15:09:44	4.28	-4.04	80200	295.5	57.43	57.54	56.95	57.59
AOC_C_A2	03.30.99	15:10:49	6.38	17.45	80200	295.5	62.69	63.37	62.51	63.65
AOC_C_A2	03.30.99	15:11:55	8.06	25.62	80200	295.5	62.80	63.54	62.54	63.94
AOC_C_A2	03.30.99	15:13:00	7.25	28.16	80200	295.5	62.84	63.31	62.26	63.69
AOC_C_A2	03.30.99	15:14:05	7.74	25.08	80200	295.5	62.93	63.96	62.90	64.16
AOC_C_A2	03.30.99	15:15:10	9.17	43.48	80200	295.5	64.00	64.65	63.25	65.04
AOC_C_A2	03.30.99	15:16:15	7.40	34.22	80200	295.5	63.43	64.28	62.49	64.59
AOC_C_A2	03.30.99	15:17:20	6.46	4.82	80200	295.5	61.65	62.13	61.55	61.61
AOC_C_A2	03.30.99	15:18:25	5.88	5.89	80200	295.5	61.37	61.84	61.85	61.48
AOC_C_A2	03.30.99	15:19:31	7.22	11.00	80200	295.5	62.31	63.02	62.87	62.68

TURBINE MEASUREMENTS

Data File	Time stamp dd/mm/yy	Time stamp hh:mm:ss	wind spd m/s	Pnorm kW	Pressure Pa	Temp K	Mic 1 dBA	Mic 2 dBA	Mic 3 dBA	Mic 4 dBA
AOC_C_A2	03.30.99	15:20:36	7.94	17.97	80200	295.5	62.18	63.06	62.68	62.96
AOC_C_A2	03.30.99	15:27:25	7.77	29.26	80200	295.5	62.96	63.65	60.68	63.72
AOC_C_A2	03.30.99	15:28:30	8.34	29.77	80200	295.5	63.10	64.32	61.63	64.48
AOC_C_A2	03.30.99	15:29:35	12.73	67.68	80200	295.5	65.99	66.69	64.60	66.71
AOC_C_A2	03.30.99	15:30:40	11.59	60.96	80200	295.5	65.56	66.32	63.29	66.12
AOC_C_A3	03.30.99	15:38:37	9.62	42.69	80100	294.7	64.60	65.22	62.05	65.01
AOC_C_A3	03.30.99	15:39:42	12.36	61.48	80100	294.7	66.06	66.14	63.63	65.75
AOC_C_A3	03.30.99	15:40:47	13.26	68.24	80100	294.7	66.51	66.62	63.88	66.26
AOC_C_A3	03.30.99	15:41:52	10.37	63.54	80100	294.7	66.00	65.80	63.10	65.11
AOC_C_A3	03.30.99	15:42:57	9.92	61.08	80100	294.7	65.86	65.94	63.64	65.24
AOC_C_A3	03.30.99	15:44:02	9.32	61.02	80100	294.7	65.86	65.95	63.29	64.82
AOC_C_A3	03.30.99	15:45:07	8.90	46.24	80100	294.7	64.83	65.12	61.93	64.54
AOC_C_A3	03.30.99	15:46:13	9.35	54.85	80100	294.7	65.48	65.54	62.19	65.13
AOC_C_A3	03.30.99	15:48:24	10.49	65.06	80100	294.7	65.83	66.03	63.35	65.59
AOC_C_A3	03.30.99	15:50:11	7.68	41.01	80100	294.7	63.79	65.09	61.74	64.85
AOC_C_A3	03.30.99	15:51:16	6.49	21.75	80100	294.7	62.63	62.80	61.46	63.16
AOC_C_A3	03.30.99	15:52:21	8.13	31.60	80100	294.7	63.22	63.97	61.87	64.04
AOC_C_A3	03.30.99	15:53:26	8.75	51.29	80100	294.7	64.75	65.40	62.92	65.67
AOC_C_A3	03.30.99	15:54:31	8.27	45.27	80100	294.7	64.04	65.10	62.35	65.14
AOC_C_A3	03.30.99	15:55:36	7.14	30.32	80100	294.7	62.73	64.05	61.33	64.04
AOC_C_A3	03.30.99	15:56:41	5.98	37.62	80100	294.7	63.44	64.59	61.78	64.61
AOC_C_A3	03.30.99	15:57:46	6.16	31.13	80100	294.7	63.04	64.24	61.24	64.23
AOC_C_A3	03.30.99	15:58:51	6.45	26.87	80100	294.7	62.85	63.95	60.35	64.21
AOC_C_A3	03.30.99	15:59:56	7.56	31.28	80100	294.7	63.53	64.64	60.89	64.67
AOC_C_A3	03.30.99	16:01:02	10.62	56.38	80100	294.7	65.77	65.71	63.60	64.90
AOC_C_A3	03.30.99	16:02:07	8.74	49.97	80100	294.7	65.15	65.11	62.47	64.52
AOC_C_A3	03.30.99	16:03:12	9.33	32.24	80100	294.7	63.75	64.57	61.27	64.16
AOC_C_A3	03.30.99	16:04:17	9.08	49.16	80100	294.7	64.91	65.31	61.89	64.65
AOC_C_A3	03.30.99	16:05:23	7.14	36.00	80100	294.7	63.94	64.53	61.03	64.20
AOC_C_A3	03.30.99	16:07:33	5.98	14.22	80100	294.7	62.91	63.69	60.93	62.99
AOC_C_A3	03.30.99	16:10:50	5.64	7.17	80100	294.7	63.61	64.27	61.82	63.27
AOC_C_A3	03.30.99	16:11:55	5.83	9.86	80100	294.7	62.87	63.53	61.04	63.32
AOC_C_A3	03.30.99	16:13:00	6.52	23.04	80100	294.7	63.08	63.64	61.15	62.58
AOC_C_A3	03.30.99	16:14:05	5.65	11.08	80100	294.7	62.93	63.71	61.27	62.64
AOC_C_A3	03.30.99	16:15:10	5.94	11.00	80100	294.7	63.19	63.94	61.49	62.50
AOC_C_A3	03.30.99	16:16:15	8.30	38.49	80100	294.7	64.68	65.16	63.02	63.21
AOC_C_A3	03.30.99	16:18:25	7.23	34.77	80100	294.7	64.56	64.68	62.28	63.16
AOC_C_A3	03.30.99	16:19:30	4.36	3.09	80100	294.7	60.74	61.05	58.73	59.67
AOC_C_A3	03.30.99	16:20:35	4.91	1.09	80100	294.7	59.21	60.03	57.48	58.71
AOC_C_A3	03.30.99	16:21:40	6.43	21.32	80100	294.7	63.36	63.88	61.26	62.42
AOC_C_A3	03.30.99	16:22:45	6.84	28.84	80100	294.7	63.63	63.99	61.62	62.25
AOC_C_A3	03.30.99	16:23:50	7.09	26.99	80100	294.7	63.87	64.09	61.95	62.94
AOC_C_A3	03.30.99	16:24:55	5.83	10.54	80100	294.7	61.70	62.82	60.45	61.20
AOC_C_A3	03.30.99	16:26:00	5.95	5.69	80100	294.7	61.31	61.87	59.51	60.59
AOC_C_A3	03.30.99	16:27:05	6.91	32.16	80100	294.7	63.80	64.29	61.95	63.60
AOC_C_A3	03.30.99	16:28:10	5.72	12.97	80100	294.7	62.29	63.07	60.91	62.57
AOC_C_A3	03.30.99	16:30:20	5.71	13.04	80100	294.7	62.42	63.11	60.69	62.64
AOC_C_A3	03.30.99	16:31:25	4.14	0.46	80100	294.7	59.13	59.74	58.01	59.58

BACKGROUND MEASUREMENTS

Data File	Time stamp dd/mm/yy	Time stamp hh:mm:ss	Wind Spd m/s	Pnorm kW	Pressure Pa	Temp K	Mic 1 dBA	Mic 2 dBA	Mic 3 dBA	Mic 4 dBA
AOC_C_A2	03.30.99	11:10:59	7.25	-1.94	80500	291.5	42.50	41.77	40.49	40.22
AOC_C_A2	03.30.99	11:12:04	6.11	-1.99	80500	291.5	40.32	40.16	38.18	38.78
AOC_C_A2	03.30.99	11:13:09	5.57	-1.93	80500	291.5	39.10	38.86	37.57	38.03
AOC_C_A2	03.30.99	11:14:14	4.47	-1.94	80500	291.5	37.62	37.06	36.38	37.65
AOC_C_A2	03.30.99	11:15:20	5.10	-1.94	80500	291.5	39.65	39.52	38.42	39.17
AOC_C_A2	03.30.99	12:31:03	8.97	-1.81	80400	294.5	42.59	42.32	42.73	44.96
AOC_C_A2	03.30.99	12:32:08	7.34	-1.80	80400	294.5	45.37	44.92	45.29	48.88
AOC_C_A2	03.30.99	12:33:13	9.41	-1.84	80400	294.5	43.66	43.60	43.59	48.92
AOC_C_A2	03.30.99	12:42:58	8.90	-1.82	80400	294.5	39.66	38.54	38.99	40.29
AOC_C_A2	03.30.99	12:44:04	7.29	-1.79	80400	294.5	37.13	36.74	37.01	36.99
AOC_C_A2	03.30.99	12:45:09	6.42	-1.81	80400	294.5	35.79	36.06	36.42	36.55
AOC_C_A2	03.30.99	12:46:14	6.33	-1.75	80400	294.5	35.22	35.04	35.45	34.52
AOC_C_A2	03.30.99	12:47:19	5.09	-1.69	80400	294.5	36.45	36.45	36.84	36.71
AOC_C_A2	03.30.99	12:48:24	4.96	-1.68	80400	294.5	37.93	37.09	37.52	38.74
AOC_C_A2	03.30.99	12:49:29	5.83	-1.74	80400	294.5	36.58	35.89	36.53	35.71
AOC_C_A2	03.30.99	12:50:34	5.16	-1.67	80400	294.5	35.95	36.26	36.45	35.93
AOC_C_A2	03.30.99	12:51:39	4.01	-1.67	80400	294.5	36.93	36.73	37.27	36.79
AOC_C_A2	03.30.99	12:52:44	5.60	-1.67	80400	294.5	35.04	35.21	35.83	34.72
AOC_C_A2	03.30.99	12:53:49	4.32	-1.68	80400	294.5	36.57	36.73	37.16	36.37
AOC_C_A2	03.30.99	12:59:16	7.77	-1.71	80400	294.5	42.29	41.01	41.60	44.61
AOC_C_A2	03.30.99	13:00:21	7.33	-1.66	80400	294.5	40.49	39.71	40.30	40.13
AOC_C_A2	03.30.99	13:22:37	8.54	-1.21	80400	294.5	38.63	38.57	38.41	38.79
AOC_C_A2	03.30.99	13:24:48	5.20	-1.46	80400	294.5	41.06	40.58	41.14	41.53
AOC_C_A2	03.30.99	13:25:53	6.45	-1.55	80400	294.5	39.48	39.73	40.24	40.86
AOC_C_A2	03.30.99	13:29:34	5.41	-1.56	80400	294.5	40.53	40.25	40.40	41.68
AOC_C_A2	03.30.99	13:31:45	8.36	-1.49	80400	294.5	40.93	40.50	40.94	41.35
AOC_C_A2	03.30.99	13:32:50	4.97	-1.43	80400	294.5	40.79	40.65	41.17	41.53
AOC_C_A2	03.30.99	13:35:00	4.65	-1.23	80400	294.5	38.10	37.95	38.32	38.63
AOC_C_A2	03.30.99	13:36:05	5.50	-1.18	80400	294.5	38.81	38.68	39.00	39.79
AOC_C_A2	03.30.99	13:37:11	5.01	-1.19	80400	294.5	38.72	38.25	39.45	39.53
AOC_C_A2	03.30.99	13:39:21	5.49	-1.21	80400	294.5	38.37	38.47	39.13	39.60

Appendix C Log Sheets

NREL

Acoustics Test Log

Turbine	AOC 15/50
Filename	AOC-C-A2
Comp time	9:37
DAT time	10:29

Date mm/dd/yy	Time hh:mm:ss	DAT ID	Range mVpk	Sensitivity mVoruV/EU	Action
3/30/99					MIC 1 175° Looking from
					2 205° mic pos
					3 235° to turbine
					4 355°
					Winds out of south
	9:40				Pressure = 80500
		84			Temp 18.4°C
					Reset DAT Time (hr & min)
					to match Comp. Sec. still off
	9:50:15	84	79.5271	17.9355	Cal Mic 1
	9:51:35		79.5271	18.9849	Cal Mic 2
	9:53:00		79.5271	17.4224	Cal Mic 3
	9:54:15		79.5271	16.4059	Cal Mic 4
					Start Meas 1 (Turbine but
	10:04:22				" " 2 Turbine Off)
2nd	10:05:29				" " 3
3rd	10:06:27				" " 4
					stopped
	10:14:45				Switched to background
	10:15:47				Start Meas 1
	10:16:47				2
	10:17:49				3
	10:18:56				4
	10:22:30				Rick left - stopped
					Start Meas 1
	10:23:36				2
	10:24:35				3
	10:25:39				4
	10:26:44				
	10:56:03				Stopped, started
	~~10:59~~ 11:00:04				Meas 2
	11:01:00				Meas 3
	11:03:25				Stopped Grant Arrived & Left

NREL

Date mm/dd/yy	Time hh:mm:ss	DAT ID	Range mVpk	Sensitivity mV or uV/EU	Action
03/30/99	11:10:02	84			Start Meas #1
					2
	11:12:27				3
	11:13:38				4
	11:14:43				5
	11:25:14				stopped

205°

Mikes 1 255°
2 285°
3 315°
4(a) 105°
4(b) 345
4(c) ~~225°~~

Acoustics Test Log

Turbine	AOC-C-A3 AOC 15/50
Filename	
Comp time	
DAT time	

Date mm/dd/yy	Time hh:mm:ss	DAT ID	Range mVpk	Sensitivity mVoruV/EU	Action
				17.8929 mV	Cal 1
			79.5271	18.6791 mV	2
				17.2366 mV	3
				16.2531 mV	4
3/30/99	11:52:00	84			BACKGROUND
					Start Meas. (1st data pt. bad)
					Meas 1
~~12:00:09~~	12:00:09	85	6		Meas 2
~~12:01:12~~	12:01:12				Meas 3
	12:02:17				Meas 4
	12:03:22				Ran out of DAT → Moved Mic po:
	~13:00				Meas 1 to 345°
	13:17:46	86			Meas 2
	13:18:51				Meas 3
	13:19:56				Stopped for passing truck
	13:24:35				Started Meas
	13:25:55				Stopped to shift boards
	13:55:00				
				18.4503	Cal Mic 1 (previous 2)
	14:10:02			16.9736	Cal Mic 2 (previous 3)
	14:11:32			16.1397	Cal Mic 3 (previous 4)
	14:12:37				~~Cal Mic 4~~ (previous 1)
				16.1976	Redo Mic 3
	14:16:40			17.6943	Mic 4
	14:17:36				
					Pressure 80200
	14:19				Temp 295.5
	14:19				TURBINE MEAS Mic 1 24
					Meas 1
	14:20:20				Meas 2 Mic 2 27
	14:21:35				Meas 3 Mic 3 30
	14:22:30				Meas 4 Mic 4 21
	14:23:35				Moved board 3 to 60°
	15:22				Start Meas 1
	15:26:54				Meas 2
	15:27:59				
	15:38:07		79.5271		Meas 1 Upped Ran[ge]
	15:39:12				Meas 2
	15:49:40		100.1187		Upped range Start Meas 1
	15:49:45				Meas 2
					Moved Board 3 to 180°
	16:10:19				Started Meas 1
	16:11:22				Started Meas 2

16:31:56 Ran out of tape

Appendix D Test Plan

Wind Turbine Generator System

Acoustic Emission Test Plan

for the

AOC 15/50 Wind Turbine

at the
National Wind Technology Center
Golden, Colorado

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

A. Huskey, H. Link

March 1, 1999

Approved:

Arlinda A. Huskey, NREL Certification Test Engineer — Date: 4 Mar 99

Harold F. Link, NREL Certification Senior Test Engineer — Date: 4 Mar 99

1.0 Table of Contents

2.0 Table of Tables

3.0 Table of Figures

4.0 Disclaimer

This report was prepared as an account of work sponsored by an agency of the United States government. The test results documented in this report define the characteristics of the test article as configured and under the conditions tested.

The United States government nor any agency thereof, nor any of their employees, makes any warranty, express or implied, or assumes any legal liability or responsibility for the usefulness of any information, apparatus, product, or process disclosed, or represents that its use would not infringe privately owned rights. Nor do they assume legal liability or responsibility for the performance of the test article or any similarly named article when tested under other conditions or using different test procedures.

Neither Midwest Research Institute nor the U. S. Government shall be liable for special, consequential or incidental damages. Reference herein to any specific commercial product, process, or service by trade name, trademark, manufacturer, or otherwise does not necessarily constitute or imply its endorsement, recommendation, or favoring by the United States government or any agency thereof. The views and opinions of the authors expressed herein do not necessarily state or reflect those of the United States government or any agency thereof.

NREL is a National Laboratory of the U. S. Department of Energy, and as an adjunct of the U. S. Government, cannot certify wind turbines. The information in this report is limited to NREL's knowledge and understanding as of this date.

5.0 Test Objective

The objective of the test is to characterize the noise emissions of the AOC 15/50 wind turbine in a manner suitable for certification. To meet this objective, the test was conducted in accordance with the IEC draft standard for acoustic noise measurement techniques, IEC 61400-11 (Ref. 1). This report documents the measurement techniques, test equipment, analysis procedures, results, and uncertainty for the following quantities:

- apparent sound power level,
- dependence on wind speed,
- directivity,
- octave band levels,
- tonality.

6.0 Test Turbine

The test turbine was a model AOC 15/50 wind turbine manufactured by Atlantic Orient Corporation and installed at the National Wind Technology Center just south of Boulder, Colorado. The turbine has no serial number but was the third turbine of this type to be manufactured by Atlantic Orient Corporation.

The AOC 15/50 wind turbine is shown in Figure 1 and its configuration is detailed in Table 1. The turbine is a horizontal-axis, downwind, free-yaw, fixed-pitch machine. Hub height is 25 m (82 ft). Rotational energy is converted to electrical power in the nacelle, which contains a gearbox and a generator. Operation of the turbine is controlled from a programmable logic controller (PLC) located in a control shed on the ground. Wind speed data, required for operation of the wind turbine, is gathered from instrumentation located on the turbine tower.

The blades are lofted from NREL S825/S809/S810 thick-airfoil sections, and are made of wood-epoxy laminates, reinforced with carbon fiber. The rotor is a three-bladed, fixed-pitch, stall-regulated design. It has a diameter of 15 m (49.2 ft) and has a nominal speed of 65 rpm. For the present performance test, the blade pitch is set to 0.09°, where the pitch is measured at the blade tip, and positive pitch angles are towards feather. The rotor is connected directly to the gearbox main shaft, and the gearbox increases the main shaft speed to 1800 rpm, driving a three-phase, 60 Hz, 480 volt, induction generator.

The tower is a 24.4 m (80 ft) high free-standing, steel lattice, three-legged structure. The machine is controlled by a PLC that is located in a control house adjacent to the tower. This PLC communicates with the PLC in the nacelle and provides performance and maintenance diagnostic information. Connection to the grid is made at the switchboard enclosure in the control house.

A complete description of the AOC 15/50 control system is available in the AOC 15/50 Operations and Maintenance Manual (Ref. 2).

Figure 1. AOC 15/50 Test Turbine

Table 1. Test Turbine Configuration

	Test Turbine
General Configuration:	
Make and Model	Atlantic Orient Corporation, AOC 15/50
Rotation Axis (H / V)	Horizontal
Orientation (upwind / downwind)	Downwind
Number of Blades	3
Rotor Hub Type	Rigid
Rotor Diameter (m)	15.0
Hub Height (m)	25
Performance:	
Rated Electrical Power (kW)	50
Rated Wind Speed (m/s)	12
Cut-in Wind Speed (m/s)	4.9
Cut-out Wind Speed (m/s)	22.4
Extreme Wind Speed (m/s)	59.5
Rotor:	
Swept Area (m^2)	177
Rotational Speed (rpm)	65
Rotational Speed at reference wind speed (rpm)	65
Rotational Speed at rated power (rpm)	65
Coning Angle (deg)	6
Tilt Angle (deg)	0
Blade Pitch Angle (deg)	0.09
Power Regulation	Stall
Overspeed Control	Failsafe redundant aerodynamic tips and high-speed shaft brake
Drive Train:	
Gearbox Make, Type, Ratio	AOC Custom-made, Planetary, 28.25:1
Generator: Make, Type, Speed, Voltage, Frequency	Magnetek, 3-Phase Induction, 1800 rpm, 480 V, 60 Hz
Yaw System:	
Wind Direction Sensor	None
Yaw Control Method	Free
Tower:	
Type	Lattice
Height	24.4
Control / Electrical System:	
Controller: Make, Type	Koyo Direct Logic 205, PLC
Power Converter: Make, Type	None
Logic System	PLC Ladder
Monitoring System	None
Electrical Output: Voltage, Frequency, Number of Phases	480 V, 60 Hz, 3-phase

7.0 Test Site

The test turbine is located at NREL's National Wind Technology Center, located off Colorado State Highway 128, approximately 8.1 km (5 miles) south of Boulder, Colorado. The turbine site, as shown in Figure 2, is at an approximate elevation of 1849 m (6065 ft).

Power connection is made to the wind site 13.8 kV main collector line via a cable from the site control house to a pad-mounted transformer (D68215) and breaker panel. The main collector line connects to the Public Service of Colorado's 69 kV distributor line, which represents an infinite load to the wind turbine.

The test site terrain is flat, farm land with an estimated roughness of 0.5 m. Table 2 lists the structures close to the test turbine. The turbine shed is located upwind of the microphone positions and its wake does not influence wind speed measurements or microphone measurements. The Bergey 850 W wind turbine noise does not influence microphone measurements.

Table 2. Structures Close to AOC 15/50 Test Turbine

Description	Bearing From Turbine (deg. T)	Distance From Test (m)	Tower Or Structure Height (m)	Rotor Diameter Or Structure Width (m)	Operating Status
Turbine shed	340	23.7	3.0	2.5	-
Whisper 3000	190	71.3	32.0	4.5	Operating

The existing meteorological tower is located 35.7 meters from the test turbine at a bearing of 292^{o} true. This distance is 2.38 rotor diameters from the test turbine and within the range between 2 and 4 rotor diameters specified in the IEC standard.

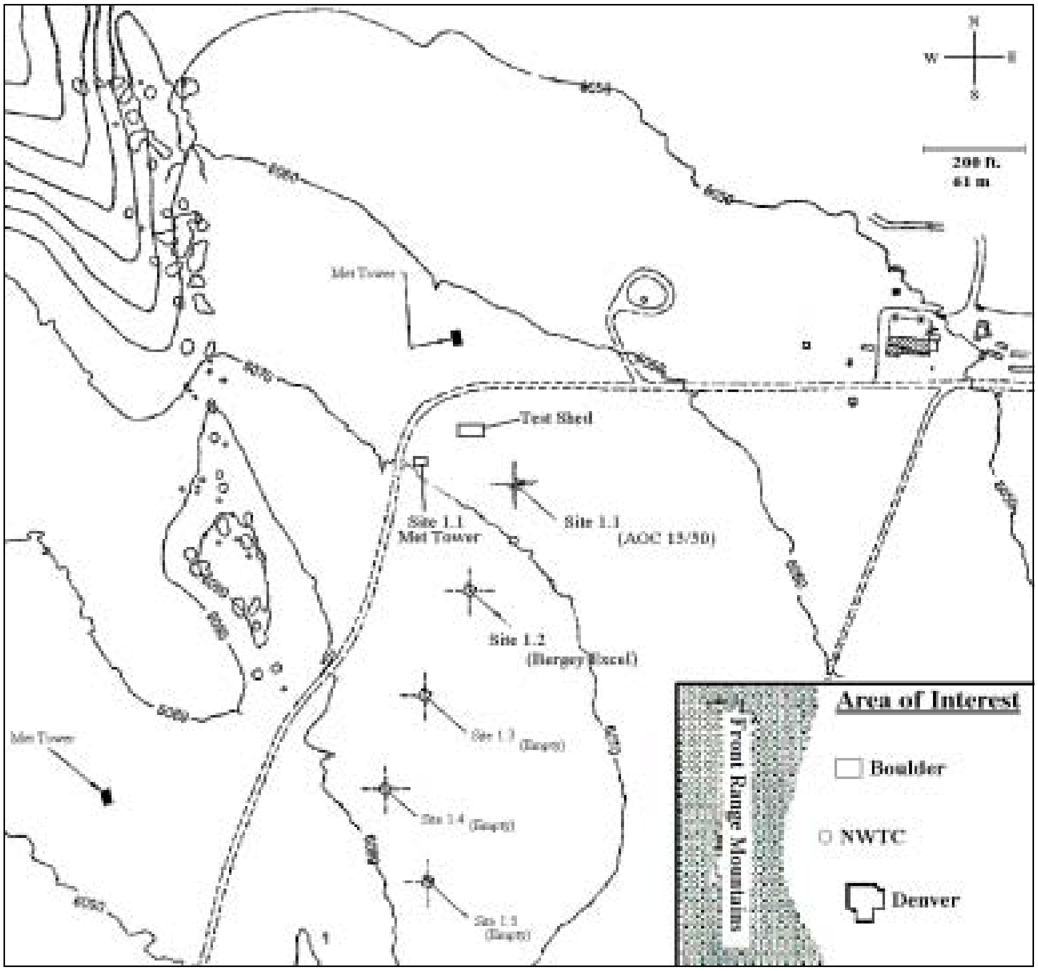


Figure 2. Location of AOC 15/50 Test Turbine

8.0 Test Equipment

8.1 Equipment Description

Table 3 shows the list of equipment used for the test. All instruments met the requirements defined by the Standard.

Table 3. Equipment List for Acoustic Test

Instrument	Manufacturer	Model Number	Serial Number	Calibration Due
Signal Analyzer	Hewlett Packard	35670A	3431A01613	8/14/00
Microphone 1	ACO Japan	7012	19037	1/29/00
Microphone 2	ACO Japan	7012	19014	1/29/00
Microphone 3	ACO Japan	7012	19017	1/29/00
Microphone 4	ACO Japan	7012	19035	1/29/00
Preamplifier 1	ACO Pacific	4012	79900503	1/29/00
Preamplifier 2	ACO Pacific	4012	96049	1/29/00
Preamplifier 3	ACO Pacific	4012	79900502	1/29/00
Preamplifier 4	ACO Pacific	4012	79900504	1/29/00
Acoustic Calibrator	Bruel & Kjaer	4230	861619	4/22/99
Digital Recorder	Sony	PC208AX	U3538	8/25/00
Anemometer	Met One	010C	T2346	10/29/99
Wind Vane	Met One	020C	U1475	12/18/99
Pressure Sensor	Omega	HHP-102	046/21	9/14/99
Temperature Sensor	Omega	869	T171111	9/14/99
GPIB Card	National Instruments	PCMCIA-GPIB	A2B275	n/a
DAQ Card	National Instruments	AI-16XE-50	A4CBCC	n/a
Laptop Computer	Panasonic	CF-25	7DkSA01050	n/a
Campbell Datalogger	Campbell Scientific	CR23X	1214	10/16/00

The data acquisition system synchronizes the acoustic measurements with the meteorological measurements. This system is run from a laptop computer. From the laptop, two PCMCIA (Personal Computer Memory Card International Association) cards are used. One card, a GPIB (General Purpose Interface Bus) card, controls and downloads one-minute acoustic data from the signal analyzer. The other card, a DAQ (Data Acquisition) card, records samples of wind speed, wind direction, and power data. The wind speed signal is shared with the power performance datalogger, pre-scaled to 1 Volt equals 360^o and 1 Volt approximately equals 120 kW These signals are sent to the National Instruments DAQ card from the power performance datalogger continuous analog out ports. All meteorological signals are updated once a second. A Microsoft Visual Basic program AcoustDAQ Version 1.2 averages the meteorological data and synchronizes with the acoustic averages. The program also records, graphs, and updates the user on all incoming data.

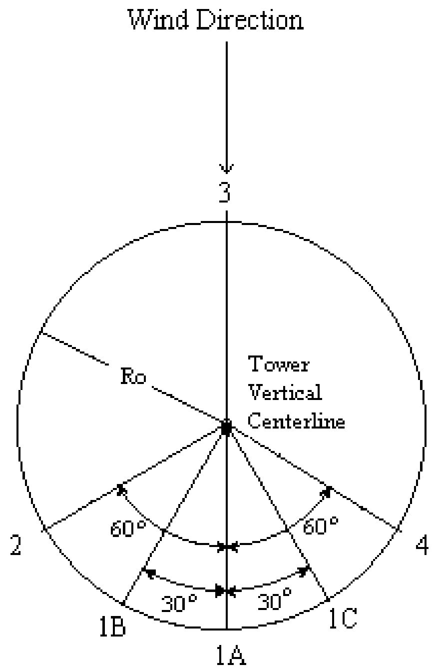


Figure 3. Microphone Positions

8.2 Instrumentation Locations

Figure 3 shows the layout of the microphones. The radius, R_o is determined by Equation 1.

$$R_o = H + \frac{D}{2}$$ **Equation 1**

Table 4. Variables for Determining the Distance Between the Turbine and Microphones

Parameter	Description	Value	Units
R_o	reference distance,	32.5	m
H	vertical distance from the ground to the rotor center,	25	m
D	diameter of the rotor.	15	m

Microphones were located 32.5 m from the center of the tower with positions as shown in Figure 3. Measurements from three microphones will be placed at microphone positions 1A, 1B, and 1C will meet the requirements for the reference microphone position shown in Table 5. One additional microphone will be moved between microphone positions 2, 3, and 4 to meet the requirements for these positions as shown in Table 5. No adjustments from the nominal microphone positions were required to avoid reflecting surfaces or to obtain allowable grazing angles.

The microphones were placed on a reflecting surface. The reflecting boards were 1 m diameter circular plywood boards with a thickness of approximately 13 mm. In addition, microphone primary windscreens were used. The primary windscreen was one half of an open cell foam sphere with a diameter of approximately 90 mm.

The anemometer was located on a meteorological tower at the turbine's hub height. The meteorological tower was located 35.7 m (2.38 rotor diameters) from the turbine at a bearing of 292^{o} true.

To meet the requirements of the Standard, the NWTC-CT quality assurance document, AI05, is used to define allowable wind directions. With an anemometer height equal to turbine hub height and anemometer position 2.38 rotor diameters from the turbine, the tolerance on wind direction due to anemometer placement is 57^{o}.

9.0 Measurement Procedures

9.1 Test Conduct

During the test, the temperature and pressure was read from the Campbell Scientific data logger and manually entered into laptop computer. Temperature and pressure were updated at least every 2 hours. Also, the microphone calibrations were documented on the log sheet, included in Appendix B. Changes to analyzer settings were also documented on the log sheet.

After the data acquisition and related equipment was checked out, the data acquisition program, AcoustDAQ, was initiated. AcoustDAQ requires the operator to start a new project file and enter general test information, such as turbine information and site characteristics. The operator enters some data, such as air pressure and temperature and the reference microphone position, at the beginning of each measurement session. A session is started when the turbine is stopped for background measurements, when it is started for operating measurements, and when microphone positions are changed.

The four microphones were calibrated through a procedure in AcoustDAQ. During the calibration process, the sensitivity factors to calibrate the microphone transducers were entered on the test log sheet (Appendix B). The microphones were also recalibrated at the start and end of each measurement session.

After the microphones were calibrated, a measurement session was started. AcoustDAQ initiated and triggered the signal analyzer that acquired and averaged four channels of microphone data. The program also acquired and averaged one-minute of wind speed and wind direction data. Wind speed averages were corrected to a reference height of 10 m using Equation 2. The data were accepted if the wind speed and wind direction were in the acceptable range. If the data were acceptable, the wind speed and wind direction averages were synchronized with the microphone averages and recorded in a data file along with pressure and temperature readings. One-minute octave averages were also downloaded from the analyzer, synchronized with the corrected wind speed, and stored in a separate data file.

AcoustDAQ also tracked how much data was collected. Different counts were kept of acceptable data sets according to wind speed. The number of data sets overall, with wind speed between 4 and 8 m/s, with wind speed between 8 and rated wind speed, and with wind speed between 6 and 10 m/s was tracked. The counts were kept for both turbine and background data sets.

9.2 Test Completion

The test was complete when all requirements listed in Table 5 are fulfilled.

Table 5. Data Requirements for Turbine and Background Measurements

Measurement Type	Microphone Position	Requirements
Overall measurements	1*	At least 30 one-minute averages.
Overall measurements	2, 3, and 4	At least 10 one-minute averages taken during a wind speed not differing more than 2 m/s from the acoustic reference wind speed.
For A-weighted sound pressure level:	1*	At least 10 measurements taken during a wind speed not differing more than 2 m/s from the acoustic reference wind speed (8 m/s).
		At least 8 of the measurements below the acoustic reference wind speed.
		At least 8 of the measurements above the acoustic reference wind speed.
For octave or third octave band measurements:	1*	At least 5 one-minute averaged spectra measured with wind speeds differing less than 2 m/s from the acoustic reference wind speed.
Narrow band measurements	1*	At least 2 minutes of measurements taken each for 4 integer wind speeds including the acoustic reference wind speed (8 m/s)

* - This position includes microphone positions 1A, 1B, and 1C.

10.0 Analysis Methods

10.1 Data Selection

The first step in the data analysis procedure is to reject all data obtained during the following circumstances:

- Interrupting noise sources such as a passing vehicle or airplane
- Failure of test equipment
- Wind direction is outside of allowable range
- Wind speed is outside of allowable range
- Turbine failure
- Adverse weather conditions

10.2 Wind Speed Correction

Wind speed was corrected to the reference condition of an anemometer height of 10 meters using Equation 2.

$$V_s = V_z \left[\frac{\ln \frac{z_{ref}}{z_{oref}} \ln \frac{H}{z_o}}{\ln \frac{H}{z_{oref}} \ln \frac{z}{z_o}} \right]$$

Equation 2

Table 6. Variables for Standardizing Wind Speed

Parameter	Description	Value	Units
V_s	corrected wind speed	-	m/s
V_z	wind speed measured at anemometer height z	-	m/s
z_{oref}	reference roughness length of 0.05 m	0.05	m
z_o	roughness length	0.05	m
H	rotor center height	25	m
z_{ref}	reference height 10 m	10	m
z	anemometer height	25	m

10.3 A-Weighted Sound Power Level

A linear regression analysis will be done with at least 10 pairs of equivalent continuous sound pressure levels from the microphone at the reference positions and the corrected wind speed. These pairs were selected to cover wind speeds that differ less than 2 m/s from the acoustic reference wind speed of 8 m/s or wind speeds between 6 and 10 m/s. The reference position sound pressure level, L_{Aeq}, is the value of the regression line at the acoustic reference wind speed. A similar analysis yields the background noise level at the acoustic reference wind speed. If the sound pressure level is less than 6 dB but more than 3 dB higher than the background sound pressure level, the turbine sound pressure level is corrected for background by subtracting 1.3 dB and marked by an asterisk, "*". These corrected sound pressure levels would not be used in calculating the apparent sound power level or directivity. If the difference was less than 3 dB, no data will be reported and it will be reported the turbine noise was less than the background noise. If the turbine sound pressure level was more than 6 dB above the background sound pressure levels, Equation 3 corrects the measured turbine noise level for background noise and provides the corrected sound pressure level at the reference position, $L_{Aeq,c}$.

$$L_{Aeq,c} = 10 * \log\left[10^{(0.1L_{s+n})} - 10^{(0.1L_n)}\right]$$ **Equation 3**

Table 7. Variables for Determining Equivalent Sound Pressure Level

Parameter	Description	Units
$L_{Aeq,c}$	sound pressure level of the turbine operating alone	dB
L_{s+n}	sound pressure level of the turbine plus background	dB
L_n	sound pressure level of the background	dB

Finally, we calculated the apparent sound power level, L_{WA}, from the corrected sound pressure level using Equation 4.

$$L_{WA} = L_{Aeq,c} - 6 + 10 * \log\left(\frac{4\pi R_1^2}{S_o}\right)$$ **Equation 4**

Table 8. Variables in Calculating the Apparent Sound Power Level

Parameter	Description	Units
$L_{Aeq,c}$	background-corrected, A-weighted, sound pressure level at the acoustic reference wind speed under reference conditions,	dB
R_1	slant distance from the rotor center to the microphone	m
S_o	reference area $S_o = 1\ m^2$	m^2

10.4 Wind Speed Sensitivity

In addition to the scatter plot obtained from the procedure in Section 8.4.3, the IEC Standard requires that wind speed sensitivity be defined by binning the reference microphone data into integer values of corrected wind speed. For each bin, the reference position sound pressure level was corrected for that bin's background noise as described above.

10.5 Directivity

Directivity, Δ_i, is the difference in A-weighted sound pressure levels at Positions 2, 3, and 4 compared to the A-weighted sound pressure levels at the reference position. The sound pressure levels at the reference wind speed of 8 m/s were corrected for background noise using the methods described in Section 8.4.3. In addition, corrections were made for differences in slant distances. (Slant distance is the distance from the microphone to the center of the turbine's rotor.) The directivity at each position is calculated by Equation 5.

$$\Delta_i = L_{Aeq,i} - L_{Aeq,1} + 20 * \log\left(\frac{R_i}{R_1}\right). \qquad \textbf{Equation 5}$$

Table 9. Variables in Determining the Directivity

Parameter	Description	Units
$L_{Aeq,i}$	A-weighted sound pressure level at positions 2, 3, or 4, corrected for background noise in the same position,	dB
$L_{Aeq,1}$	A-weighted sound pressure level at the reference position, measured simultaneously with $L_{Aeq,I}$ and also corrected for background noise,	dB
R_i	slant distance between the rotor center and positions 2, 3, or 4	m
R_1	slant distance between the rotor center and the reference position.	m

10.6 Octave Spectra

Spectral content of the noise signal at the reference microphone is obtained using the spectrum analyzer's octave analysis setting.

10.7 Tonal Analysis

10.7.1 Tonality at the Acoustic Reference Wind Speed (8 m/s)

Quantification of the tonal characteristics is the final analysis activity. The first step in this analysis is to identify a data set where wind speed is close to 8 m/s for a minimum of 2 minutes. The signal analyzer was set to perform Fast Fourier Transforms (FFTs) using a Hanning window in the time domain and 800 lines resolution. The unweighted noise data from the reference position microphone were played back from the DAT recorder to the signal analyzer.

The frequency resolution accounted for a 50 percent decrease in resolution resulting from use of a Hanning window, calculated by Equation 6. (The frequency resolution used in this analysis is much finer than the 20-57 hertz required by the Standard.) The spectra were RMS-averaged and saved as files listed in the table above. The files are imported into an Excel^{tm} spreadsheet for plotting. The plots allow the analyst to identify suspected tones.

$$\text{Effective NoiseBandwidth} = \frac{\text{Band}}{\text{Number of lines}} * \text{Window Factor} \qquad \textbf{Equation 6}$$

Next, each suspected tone was compared to the masking level of its neighboring frequencies. The range of neighboring frequencies that was considered was called the "critical band" and was defined as follows:

1. If the suspected tone is between 20 and 500 hertz, the critical band spans 100 hertz.
2. If the suspected tone is above 500 hertz, the critical band spans 20% of the tone frequency.

If a suspected tone is single peak, the critical band is located to center the peak. If the suspected tone consists of multiple peaks closely spaced, the critical band is located to include the largest possible number of the most prominent peaks. If the suspected tone is between 20 and 70 hertz, the critical band is 20 to 120 hertz.

Each line in the critical band was then classified according to the following criteria:

1. A peak is classed as a tone if its RMS-averaged level is:
   - more than 6 dB above the average masking level. The average masking level is the logarithmic average of the sound pressure levels of the rest of the lines in the critical band but excluding one line each side of the peak.
2. Lines adjacent to a tone are also classified as a tones if their RMS-averaged levels are:
   - within 10dB of the peak and
   - more than 6 dB above the average masking level.
3. Lines adjacent to a tone are classified as neither tones nor masking if their RMS-averaged levels are:
   - more than 10dB below the peak level and
   - more than 6 dB above the average masking level.
4. Lines are classified as masking if their RMS-averaged levels are less than 6 dB above the average masking level.

Because classifying a line as a tone means it can no longer be counted as masking, an iterative procedure is required for the proper identification of tones and masking. A spreadsheet analysis method is used for this iteration. For more information, refer to the NWTC-CT quality assurance document, AI09.

This process was repeated for every suspected tone in the spectrum. The result was that within each critical band every spectral line was classified as tone energy, masking energy or neither. The frequency of each tone was also determined during this part of the analysis.

The next step in tonal analysis was to determine the maximum sound pressure level of the tone(s). The sound data were again played from the DAT recorder into the signal analyzer. This time the analyzer was programmed to display the spectra as a "waterfall." The analyst used analyzer functions to slice through the waterfall-displayed spectra at single frequency bins (frequency lines). Sound pressure levels of the tone in each spectrum were saved in files whose names correspond with the frequency of the tone. These files were imported into an Excel[tm] spreadsheet and sorted to enable the analyst to identify and arithmetically-average the maximum 25% of the sound pressure levels of each tone. Finally, if multiple tones were present within the critical band, they are energy-summed to determine the overall tone level, L_{pt}.

Next the analyst determined the sound pressure level of the masking noise, L_{pn}, in the critical bands. Masking energy was calculated from the same 2-minute data set as used to determine the tone level. The short-term spectra were RMS-averaged into a single, 2-minute spectrum. The masking level was corrected for the reduction in the number of lines due to the exclusion of tones and for the Hanning window using Equation 7.

$$L_{pn} = L_{pn,avg} + 10 * \log\left(\frac{bandwidth\ of\ critical\ band}{effective\ noise\ bandwidth}\right)$$ **Equation 7**

Table 10. Variables in Determining the Masking Noise Level

Parameter	Description	Units
L_{pn}	Sound pressure level of masking noise within a critical band,	dB
$L_{pn,avg}$	energy averaged measured masking noise determined by averaging the masking noise separate from any tones within the critical band.	dB

The analyst determined if background noise affected the masking noise level by performing an FFT of background noise obtained under similar wind conditions to those used for the turbine operating noise analysis. First, the analyst verified that the background noise does not contain the same tone as the turbine noise. Next, the analyst determined the background noise level for the same critical band as used for each tone. Equation 3 was used to correct the masking noise level of each critical band for background noise. If background noise level was within 6 dB of the masking noise, then the report states that the masking noise was affected by background noise.

The analyst determined the tone level difference, $\Delta L_{tn,max}$, between the maximum tone level and the background-corrected masking noise level using Equation 8.

$$\Delta L_{tn,\max} = L_{pt} - L_{pn}$$ **Equation 8**

Table 11. Variable in Determining the Tone Level Difference

Parameter	Description	Units
$\Delta L_{tn,max}$	Tone level difference,	dB
L_{pt}	maximum tone level within the critical band,	dB
L_{pn}	total masking noise within the critical band.	dB

Tone levels were subjected to a final check for audibility by determining the minimum tone level, $\Delta L_{tm,crit}$, that an average listener would be able to hear using Equation 9.

$$\Delta L_{tn,crit} = -2 - \log\left[1 + \left(\frac{f}{502}\right)^{2.5}\right]$$ **Equation 9**

Table 12. Variables in Determining the Masking Threshold

Parameter	Description	Units
$\Delta L_{tn,crit}$	Masking threshold for tones in noise,	dB
f	frequency at the center of the critical band.	dB

If the tone level difference, $\Delta L_{tn,max}$, is less than $\Delta L_{tm,\ crit}$, the tone is not reported.

For each value of $\Delta L_{tn,max}$ a frequency dependent correction must be applied to compensate for the response of the human ear to tones of different frequency.

The 'tonal audibility', $\Delta L_{a,max}$, is defined as:

$$\Delta L_{a,\max} = \Delta L_{tn,\max} - L_{ac} \qquad \textbf{Equation 10}$$

Where L_a is the frequency dependent audibility criterion, defined as:

$$L_a = -2 - \log_{10}\left[1 + \left(\frac{f}{502}\right)^{2.5}\right] \qquad \textbf{Equation 11}$$

A corresponding value of $\Delta L_{a,max}$ must be calculated for each value of $\Delta L_{tn,max}$. For tonal audibilities meeting the condition:

$$\Delta L_{a,\max} \geq 0 \qquad \textbf{Equation 12}$$

the values of $\Delta L_{a,max}$ must be reported. According to the criterion curve defined above, a 'typical' listener would consider such tones as being 'audible'. For tonal audibilities not meeting this condition, there is no requirement to report the values. According to the criterion curve defined above, a 'typical' listener would consider such tones as being 'inaudible'.

10.7.2 Wind Speed Dependence of Tonality

The wind speed and spectra are averaged over a two-minute period for acoustic/wind speed data pairs and binned into integer wind speed bins. The bins must cover at least a 4 m/s wind speed range including the acoustic reference wind speed (8 m/s). A tonal analysis will be done on measurements in each bin as detailed in the previous section.

11.0 Uncertainty

The combined uncertainty is reported for the apparent sound power level, directivity, wind speed dependence, and tonality. The combined standard uncertainty is the combination of type A and type B uncertainties. Type A uncertainty components are evaluated by using statistical methods to a series of repeated measurements. Type B uncertainty components are evaluated through estimations or calibrations. The methods used to evaluate the uncertainty components for the apparent sound power level, directivity, wind speed dependence and tonality will be explained in this section.

11.1 A-Weighted Sound Power Level

The type A uncertainty for the apparent sound pressure level is the standard error of the estimated L_{Aeq} at the acoustic reference wind speed. This is found from the linear regression analysis.

$$U_A = \sqrt{\frac{\Sigma(y - y_{est})^2}{N - 2}} \qquad \textbf{Equation 13}$$

Table 13. Type A Apparent Sound Power Level Uncertainty Components

Parameter	Description	Units
U_A	Type A uncertainty for apparent sound pressure level,	dB
y	measured sound pressure level,	dB
y_{est}	estimated sound pressure level using linear regression,	dB
N	Number of measurements used in the linear regression.	

The Type B uncertainty is found using Equation 14. It components are listed in Table 14:

$$U_B = \sqrt{U_{B1}^2 + U_{B2}^2 + U_{B3}^2 + U_{B4}^2 + U_{B5}^2 + U_{B6}^2 + U_{B7}^2 + U_{B8}^2 + U_{B9}^2}$$ **Equation 14**

Table 14. Type B Apparent Sound Power Level Uncertainty Components

Parameter	Description	Unit	Source
U_B	Type B uncertainty for apparent sound pressure level	dB	
U_{B1}	uncertainty for calibration of the instruments,	dB	calibrator calibration and the standard error from field calibrating microphones
U_{B2}	uncertainty for tolerances on the chain of acoustic measurement instruments,	dB	signal analyzer, microphone, microphone adapter, and preamplifier
U_{B3}	uncertainty for acoustic conditions for microphone mounting board,	dB	estimate
U_{B4}	uncertainty on the distance from microphone to hub,	dB	estimate
U_{B5}	uncertainty on the acoustic impedance of air,	dB	estimate
U_{B6}	uncertainty on the acoustic emission of the turbine due to changing weather conditions,	dB	estimate
U_{B7}	uncertainty on the measured wind speed	dB	anemometer calibration and estimate of the site effects
U_{B8}	uncertainty on the wind direction measurement,	dB	Estimate
U_{B9}	uncertainty for the background correction.	dB	Applied background correction

These uncertainties are combined into one standard uncertainty using Equation 15.

$$U_C = \sqrt{U_A^2 + U_B^2}$$ **Equation 15**

Table 15. Overall Uncertainty Components

Parameter	Description	Units
U_C	Overall standard uncertainty for apparent sound pressure level,	dB
U_A	Type A uncertainty for apparent sound pressure level,	dB
U_B	Type B uncertainty for apparent sound pressure level	dB

11.2 Wind Speed Sensitivity

Type A uncertainty for wind speed dependence is found from the from a linear regression analysis. The uncertainty, U_A is calculated for integer wind speeds as the root sum of the squared standard error of the estimated value at the actual wind speed. The squared standard error is given by Equation 16.

$$s_i = \sqrt{\frac{\sum (L_{Aeq} - L_{Aeq,j})^2}{(N-1)^2}}$$ **Equation 16**

Table 16. Type A Wind Dependence Uncertainty Components

Parameter	Description	Units
s_i	Type A standard uncertainty for bin i	dB
L_{Aeq}	Average of the sound pressure levels in the bin i	dB
$L_{Aeq,i}$	sound pressure level in the bin	dB
N	number of measurement results in the bin	

The type B uncertainty for each bin is found by combining the components listed in Table 17 and the square root of the some of the squares.

Table 17. Type B Wind Dependence Uncertainty Components

Parameter	Description	Unit	Source
U_B	Type B uncertainty for bin i	dB	
U_{B1}	uncertainty for calibration of the instruments,	dB	calibrator calibration and the standard error from field calibrating microphones
U_{B2}	uncertainty for tolerances on the chain of acoustic measurement instruments,	dB	signal analyzer, microphone, microphone adapter, and preamplifier
U_{B3}	uncertainty for acoustic conditions for microphone mounting board,	dB	estimate
U_{B4}	uncertainty on the distance from microphone to hub,	dB	estimate
U_{B5}	uncertainty on the acoustic impedance of air,	dB	estimate
U_{B6}	uncertainty on the acoustic emission of the turbine due to changing weather conditions,	dB	estimate
U_{B7}	uncertainty on the measured wind speed	dB	anemometer calibration and estimate of the site effects
U_{B8}	uncertainty on the wind direction measurement,	dB	Estimate
U_{B9}	uncertainty for the background correction.	dB	Applied background correction

11.3 Directivity

An estimate of the standard uncertainty on the directivity is shown in Equation 17.

$$U_D = \sqrt{2}\, U_C$$ **Equation 17**

Table 18. Variables for Estimating Directivity Uncertainty

Parameter	Description	Unit
U_D	Standard uncertainty for directivity,	dB
U_C	Overall standard uncertainty for apparent sound pressure level.	dB

11.4 Octave Spectra

For the third octave band, U_A for each band is the standard error on the averaged band level.

$$U_A = \sqrt{\frac{\sum (y - y_{est})^2}{N-1}}$$ **Equation 18**

Table 19. Type A Octave Band Uncertainty Components

Parameter	Description	Units
U_A	Type A standard uncertainty for band	dB
y	Sound pressure level of the band	dB
y_{est}	Average sound pressure level of the band	dB
N	number of measured spectra	

The type B uncertainty components are estimated to be the same except for U_{B3}. It will be considered much larger than for L_{WA}, estimated value is 1.2 dB as shown in Table 20.

Table 20. Type B Octave Band Uncertainty Components

Parameter	Description	Unit	Source
U_B	Type B uncertainty for octave bands	dB	
U_{B1}	uncertainty for calibration of the instruments,	dB	calibrator calibration and the standard error from field calibrating microphones
U_{B2}	uncertainty for tolerances on the chain of acoustic measurement instruments,	dB	signal analyzer, microphone, microphone adapter, and preamplifier
U_{B3}	uncertainty for acoustic conditions for microphone mounting board,	dB	estimate
U_{B4}	uncertainty on the distance from microphone to hub,	dB	estimate
U_{B5}	uncertainty on the acoustic impedance of air,	dB	estimate
U_{B6}	uncertainty on the acoustic emission of the turbine due to changing weather conditions,	dB	estimate
U_{B7}	uncertainty on the measured wind speed	dB	anemometer calibration and estimate of the site effects
U_{B8}	uncertainty on the wind direction measurement,	dB	Estimate
U_{B9}	uncertainty for the background correction.	dB	Applied background correction

12.0 Reporting

After the test has been completed to the above requirements and NREL has analyzed the data, a test report will be generated. This report will consist of two main volumes. The first is the test results, which will consist of the following sections:

- A-weighted sound power level
- Wind speed sensitivity (graphically and tabularly)
- Plots of all data and regression lines
- Directivity
- Octave spectra (graphically and tabularly)
- Tonal analysis including wind speed dependence of tonality

- Uncertainty
- Exceptions to the test plan

The goal of Volume 1 of the test report is that the client will have a small and easily usable summary of the acoustic noise test done on their turbine. Volume 2 of the test report is the Test Plan, where all the details of the turbine and test equipment are listed.

13.0 Roles and Responsibilities

Table 21 lists the test team and identifies roles and responsibilities for each team member.

Table 21. Roles and Responsibilities

Test Team Title	Person (Employer)	Roles and Responsibility
Test Manager	Hal Link - NREL	Overall test management and responsibility. Customer contact person. Authorization for any deviations from planned test procedures. Reviews and approves test plan and test report.
Test Engineer and Analyst	Arlinda Huskey – NREL	Supervision of acoustic test set-up, checkout, and conduct. Periodic review of test data. Review and report test results. Primary point of contact between test technician and the test site manager.
Test Technician	Mark Meadors – NREL	Responsible for installation and maintenance of test equipment. Also assists in execution of test.
Site Technician	Mark Meadors – NREL	Provide on-site assistance to test, responsible for turning on/off surrounding turbines and test turbine. Must be available during regular working hours and off-hours.

14.0 References

1. IEC 61400-11: Wind Turbine Generator Systems, Part 11: Acoustic Noise Measurement Techniques, 88/67/FDIS, International Electrotechnical Commission, Netherlands, 1995 as corrected by TJ Dubois Jan 1998.
2. AOC 15/50 Wind Turbine Operation & Maintenance Manual, Atlantic Orient Corporation, Revision 1.1, 1995.

15.0 Appendix A: Calibration Sheets

Microphone 1 calibration s/n 19037
Microphone 2 calibration s/n 19014
Microphone 3 calibration s/n 19017
Microphone 4 calibration s/n 19035
Preamplifier 1 calibration s/n 79900503
Preamplifier 2 calibration s/n 96049
Preamplifier 3 calibration s/n 79900502
Preamplifier 4 calibration s/n 79900504
Signal Analyzer
Acoustic Calibrator
DAT Recorder
Anemometer
Wind vane
Pressure Sensor
Temperature Sensor
Campbell Datalogger

Microphone 1 Calibration Sheet for s/n 19037

Excalibur Engineering Inc.
3198-C Airport Loop Dr.
Costa Mesa, CA 92626
714-540-0169

CERTIFICATE OF CALIBRATION

Customer Name: INSTRUMENT REPAIR LABS, INC Dept :

INSTRUMENT INFORMATION

Manufacturer	: ACO PACIFIC	Report #	: 15608-1
Model #	: 7012	Cust P.O.#	: 015726
Asset #	: 19033	Date Recvd	: 01/25/99
Serial #	: 19037	Accuracy	: ±.12DB
Description	: MICROPHONE	Maint. Proc	: 1371
Date Cal	: 01/29/99	Temperature	: 21
Date Due	: 01/29/00	Humidity	: 49
Interval	: 12	Employee #	: 17

CONDITION INSTRUMENT RECEIVED

Condition Received : In Tolerance
Remarks : UNIT SENSATIVITY FOUND TO BE -34.5DB RE IV/PA

CONDITION INSTRUMENT RETURNED

Condition Returned : In Tolerance
Remarks : SEE ATTACHED CHART FOR FREQUENCY CURVE.
OTHER STANDARDS USED: 595, 051

STANDARDS USED

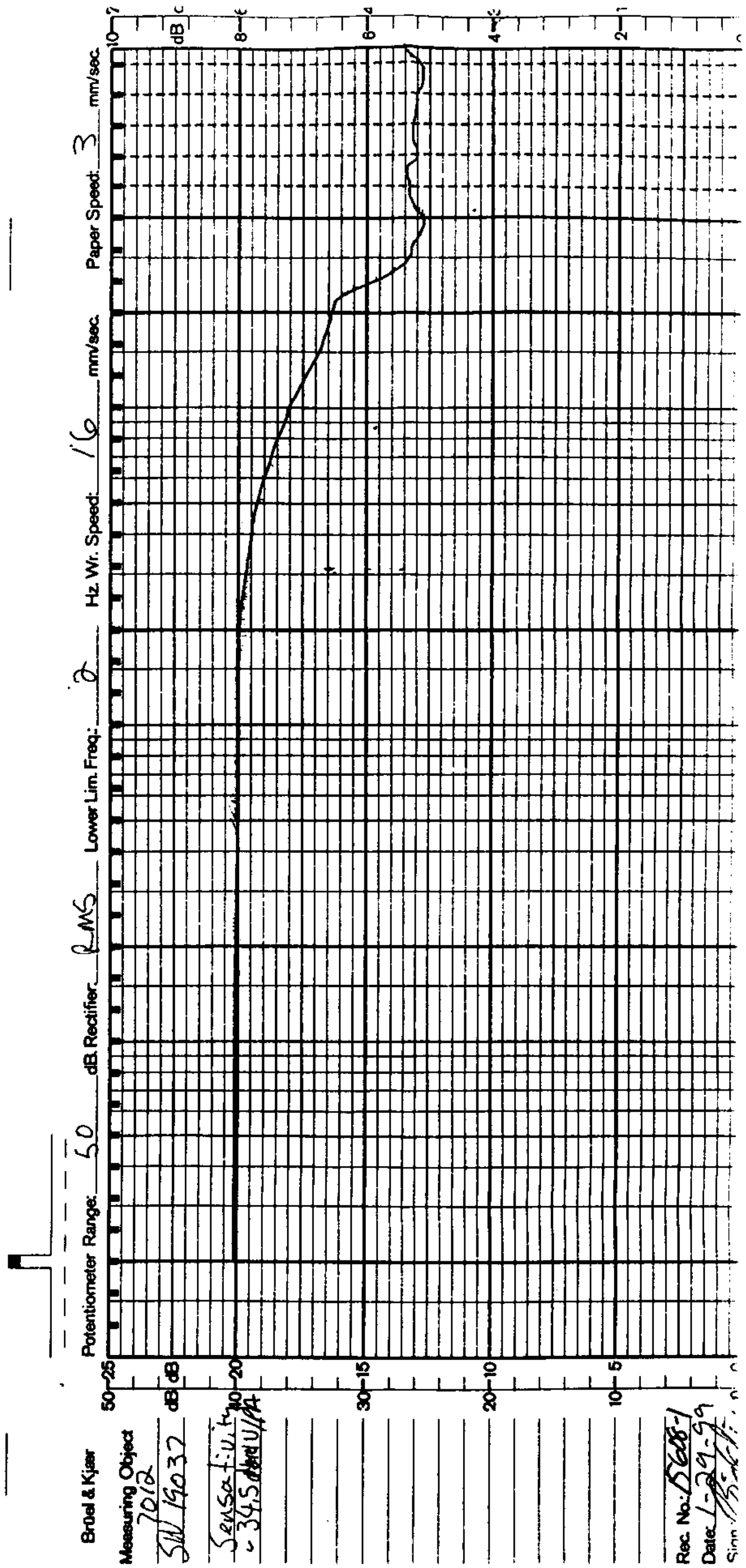
ID #	Manufacturer	Model #	Accuracy	Description	Due Date
631	BRUEL & KJAER	1023	MFR. SPECS.	SINE/RADNOM GENER	12/23/99
632	BRUEL & KJAER	2706	MFR. SPECS.	POWER AMPLIFIER	12/23/99
653	BRUEL & KJEAR	2610	MFR. SPECS.	MEASURING AMPLIFI	04/09/99
654	BRUEL & KJAER	2307	MFR. SPECS.	LEVEL RECORDER	03/30/99
655	BRUEL & KJAER	4142	MFR. SPECS.	MIC CAL APPARATUS	04/10/99
089	BRUEL & KJAER	4228	.09 dB	PISTONPHONE	09/05/99
593	BRUEL & KJAER	4165	±.12 DB	MICROPHONE	06/19/99

Excalibur Engineering Inc. certifies that the instrument specified above meets the manufacturer's specifications and has been calibrated using standards and instruments also listed above whose accuracies are traceable to the National Institute of Standards and Technology (NIST), and the calibration systems and records are in compliance to ISO-10012 and ANSI Z540-1. This document cannot be reproduced without prior approval.

EEQA 8 1FEB99

Approved By

Page 1



Brüel & Kjær
Measuring Object
Potentiometer Range: 50 dB
Rectifier: RMS
Lower Lim. Freq.: 2 Hz
Wr. Speed: 16 mm/sec.
Paper Speed: 3 mm/sec.
Rec. No.
Date
Sign

D-26

Microphone 2 Calibration Sheet for s/n 19014

Excalibur Engineering Inc.
3198-C Airport Loop Dr.
Costa Mesa, CA 92626
714-540-0169

CERTIFICATE OF CALIBRATION

Customer Name: INSTRUMENT REPAIR LABS, INC Dept :

INSTRUMENT INFORMATION

Manufacturer	: ACO PACIFIC	Report #	: 15608-3
Model #	: 7012	Cust P.O.#	: 015726
Asset #	: 19035	Date Recvd	: 01/25/99
Serial #	: 19014	Accuracy	: ±.12DB
Description	: MICROPHONE	Maint. Proc:	1371
Date Cal	: 01/29/99	Temperature:	21
Date Due	: 01/29/00	Humidity	: 49
Interval	: 12	Employee #	: 17

CONDITION INSTRUMENT RECEIVED

Condition Received : In Tolerance
Remarks : UNIT SENSATIVITY FOUND TO BE -33.23DB RE IV/PA

CONDITION INSTRUMENT RETURNED

Condition Returned : In Tolerance
Remarks :
OTHER STANDARDS USED: 595, 051

STANDARDS USED

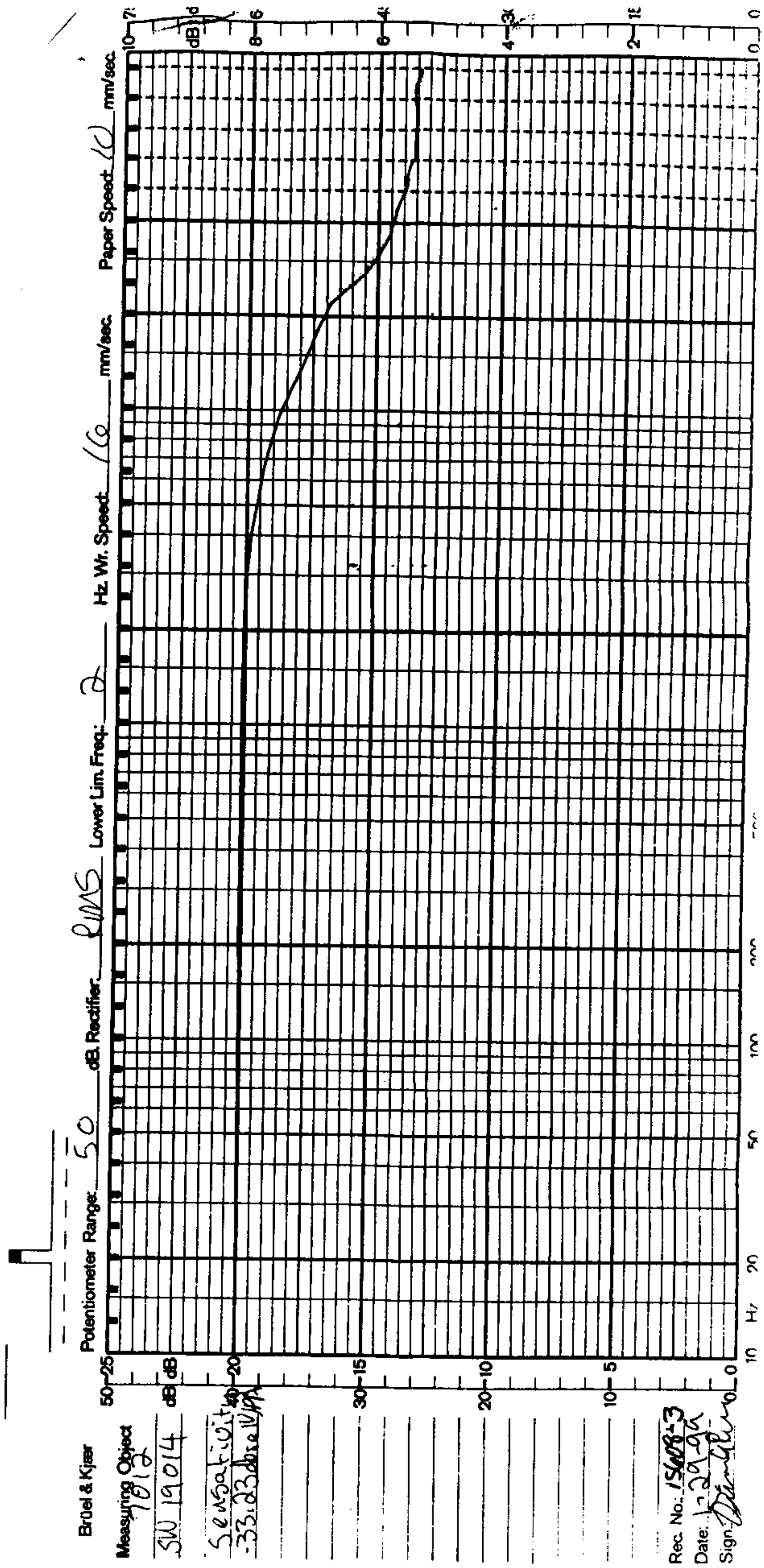
ID #	Manufacturer	Model #	Accuracy	Description	Due Date
631	BRUEL & KJAER	1023	MFR. SPECS.	SINE/RADNOM GENER	12/23/99
632	BRUEL & KJAER	2706	MFR. SPECS.	POWER AMPLIFIER	12/23/99
653	BRUEL & KJEAR	2610	MFR. SPECS.	MEASURING AMPLIFI	04/09/99
654	BRUEL & KJAER	2307	MFR. SPECS.	LEVEL RECORDER	03/30/99
655	BRUEL & KJAER	4142	MFR. SPECS.	MIC CAL APPARATUS	04/10/99
089	BRUEL & KJAER	4228	.09 dB	PISTONPHONE	09/05/99
593	BRUEL & KJAER	4165	±.12 DB	MICROPHONE	06/19/99

Excalibur Engineering Inc. certifies that the instrument specified above meets the manufacturer's specifications and has been calibrated using standards and instruments also listed above whose accuracies are traceable to the National Institute of Standards and Technology (NIST), and the calibration systems and records are in compliance to ISO-10012 and ANSI Z540-1. This document cannot be reproduced without prior approval.

EEQA 8 1FEB99

Approved By

Page 1


Brüel & Kjær
Measuring Object
Potentiometer Range:
dB. Rectifier:
Lower Lim. Freq.:
Hz. Wr. Speed:
mm/sec.
Paper Speed:
mm/sec.
Rec. No.:
Date:
Sign:

D-28

Microphone 3 Calibration Sheet for s/n 19017

Excalibur Engineering Inc.
3198-C Airport Loop Dr.
Costa Mesa, CA 92626
714-540-0169

C E R T I F I C A T E O F C A L I B R A T I O N

Customer Name: INSTRUMENT REPAIR LABS, INC   Dept :

I N S T R U M E N T I N F O R M A T I O N

Manufacturer	ACO PACIFIC	Report #	15608-2
Model #	7012	Cust P.O.#	015726
Asset #	19036	Date Recvd	01/25/99
Serial #	19017	Accuracy	±.12DB
Description	MICROPHONE	Maint. Proc	1371
Date Cal	01/29/99	Temperature	21
Date Due	01/29/00	Humidity	49
Interval	12	Employee #	17

C O N D I T I O N I N S T R U M E N T R E C E I V E D

Condition Received : In Tolerance
Remarks : UNIT SENSATIVITY FOUND TO BE -34.95DB RE IV/PA

C O N D I T I O N I N S T R U M E N T R E T U R N E D

Condition Returned : In Tolerance
Remarks : SEE ATTACHED CHART FOR FREQUENCY CURVE.
OTHER STANDARDS USED: 595, 051

S T A N D A R D S U S E D

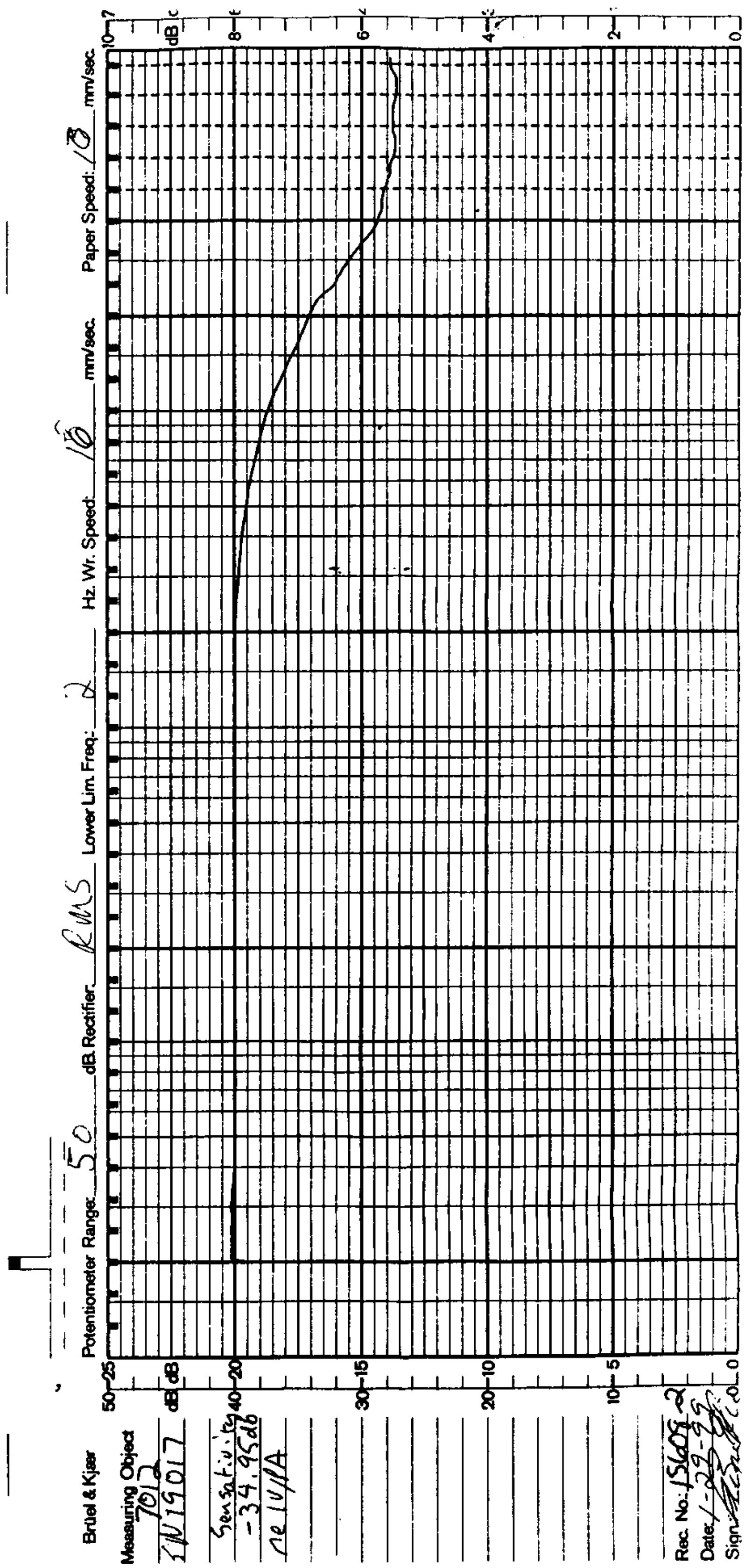
ID #	Manufacturer	Model #	Accuracy	Description	Due Date
631	BRUEL & KJAER	1023	MFR. SPECS.	SINE/RADNOM GENER	12/23/99
632	BRUEL & KJAER	2706	MFR. SPECS.	POWER AMPLIFIER	12/23/99
653	BRUEL & KJEAR	2610	MFR. SPECS.	MEASURING AMPLIFI	04/09/99
654	BRUEL & KJAER	2307	MFR. SPECS.	LEVEL RECORDER	03/30/99
655	BRUEL & KJAER	4142	MFR. SPECS.	MIC CAL APPARATUS	04/10/99
089	BRUEL & KJAER	4228	.09 dB	PISTONPHONE	09/05/99
593	BRUEL & KJAER	4165	±.12 DB	MICROPHONE	06/19/99

Excalibur Engineering Inc. certifies that the instrument specified above meets the manufacturer's specifications and has been calibrated using standards and instruments also listed above whose accuracies are traceable to the National Institute of Standards and Technology (NIST), and the calibration systems and records are in compliance to ISO-10012 and ANSI Z540-1. This document cannot be reproduced without prior approval.

EEQA 8   1FEB99

Approved By

Page 1


Brüel & Kjær
Measuring Object
Potentiometer Range: 50
dB Rectifier: RMS
Lower Lim. Freq.: 2
Hz Wr. Speed: 16 mm/sec.
Paper Speed: 10 mm/sec.
Rec. No.:
Date:
Sign:

D-30

Microphone 4 Calibration Sheet for s/n 19035

Excalibur Engineering Inc.
3198-C Airport Loop Dr.
Costa Mesa, CA 92626
714-540-0169

CERTIFICATE OF CALIBRATION

Customer Name: INSTRUMENT REPAIR LABS, INC Dept :

INSTRUMENT INFORMATION

Manufacturer	: ACO PACIFIC	Report #	: 15608-4
Model #	: 7012	Cust P.O.#	: 015726
Asset #	: 19034	Date Recvd	: 01/25/99
Serial #	: 19035	Accuracy	: ±.12DB
Description	: MICROPHONE	Maint. Proc:	MFIB
Date Cal	: 01/29/99	Temperature:	21
Date Due	: 01/29/00	Humidity	: 49
Interval	: 12	Employee #	: 17

CONDITION INSTRUMENT RECEIVED

Condition Received : In Tolerance
Remarks : UNSIT SENSATIVITY FOUND TO BE -34.23DB

CONDITION INSTRUMENT RETURNED

Condition Returned : In Tolerance
Remarks :
OTHER STANDARDS USED: 595, 051

STANDARDS USED

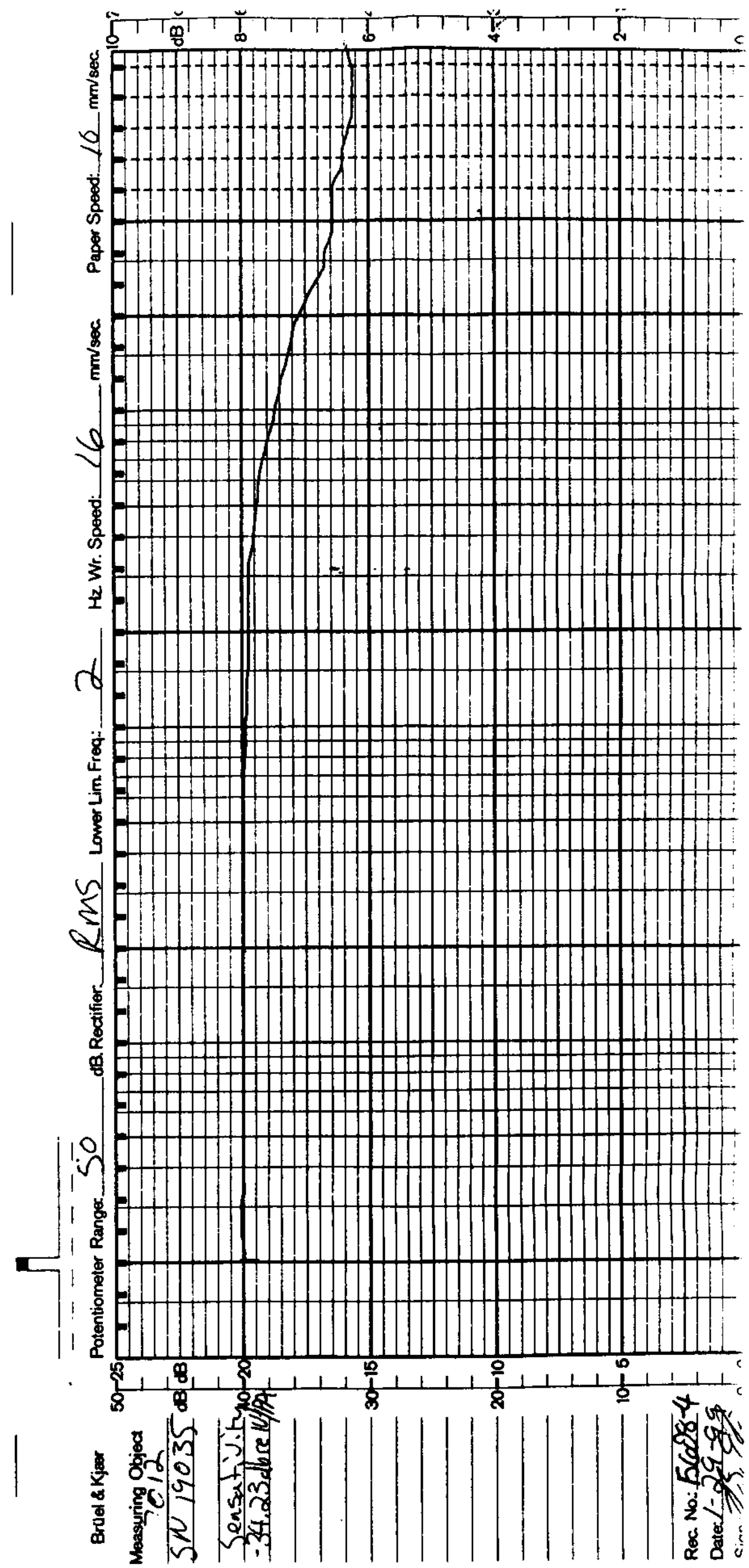
ID #	Manufacturer	Model #	Accuracy	Description	Due Date
631	BRUEL & KJAER	1023	MFR. SPECS.	SINE/RADNOM GENER	12/23/99
632	BRUEL & KJAER	2706	MFR. SPECS.	POWER AMPLIFIER	12/23/99
653	BRUEL & KJEAR	2610	MFR. SPECS.	MEASURING AMPLIFI	04/09/99
654	BRUEL & KJAER	2307	MFR. SPECS.	LEVEL RECORDER	03/30/99
655	BRUEL & KJAER	4142	MFR. SPECS.	MIC CAL APPARATUS	04/10/99
089	BRUEL & KJAER	4228	.09 dB	PISTONPHONE	09/05/99
593	BRUEL & KJAER	4165	±.12 DB	MICROPHONE	06/19/99

Excalibur Engineering Inc. certifies that the instrument specified above meets the manufacturer's specifications and has been calibrated using standards and instruments also listed above whose accuracies are traceable to the National Institute of Standards and Technology (NIST), and the calibration systems and records are in compliance to ISO-10012 and ANSI Z540-1. This document cannot be reproduced without prior approval.

EEQA 8 1FEB99

Approved By

Page 1


Brüel & Kjær
Measuring Object
Potentiometer Range: 50 dB
Rectifier: RMS
Lower Lim. Freq.: 2 Hz
Wr. Speed: 16 mm/sec.
Paper Speed: 16 mm/sec.
Rec. No.: 5608-4
Date:

D-32

Preamplifier 1 Calibration Sheet for s/n 79900503

Excalibur Engineering Inc.
3198-C Airport Loop Dr.
Costa Mesa, CA 92626
714-540-0169

CERTIFICATE OF CALIBRATION

Customer Name: INSTRUMENT REPAIR LABS, INC Dept :

INSTRUMENT INFORMATION

Manufacturer	: ACO PACIFIC	Report #	: 15608-9
Model #	: 4012	Cust P.O.#	: 015726
Asset #	: NAN	Date Recvd	: 01/25/99
Serial #	: L79900503	Accuracy	: MFR. SPECS.
Description	: 1/2" MIKE PREAMP.	Maint. Proc	: MFIB
Date Cal	: 01/29/99	Temperature	: 21
Date Due	: 01/29/00	Humidity	: 49
Interval	: 12	Employee #	: 17

CONDITION INSTRUMENT RECEIVED

Condition Received : In Tolerance
Remarks :

CONDITION INSTRUMENT RETURNED

Condition Returned : In Tolerance
Remarks :

STANDARDS USED

ID #	Manufacturer	Model #	Accuracy	Description	Due Date
595	HEWLETT PACKAR	8903B	MFR SPECS	AUDIO ANALYZER	06/17/99

Excalibur Engineering Inc. certifies that the instrument specified above meets the manufacturer's specifications and has been calibrated using standards and instruments also listed above whose accuracies are traceable to the National Institute of Standards and Technology (NIST), and the calibration systems and records are in compliance to ISO-10012 and ANSI Z540-1. This document cannot be reproduced without prior approval.

EEQA 8, 1FEB99

Approved By

Page 1

Preamplifier 2 Calibration Sheet for s/n 96049

Excalibur Engineering Inc.
3198-C Airport Loop Dr.
Costa Mesa, CA 92626
714-540-0169

CERTIFICATE OF CALIBRATION

Customer Name: INSTRUMENT REPAIR LABS, INC   Dept :

INSTRUMENT INFORMATION

Manufacturer	: ACO PACIFIC	Report #	: 15608-8
Model #	: 4012	Cust P.O.#	: 015726
Asset #	: NAN	Date Recvd	: 01/25/99
Serial #	: XX96049	Accuracy	: MFR. SPECS.
Description	: 1/2" MIKE PREAMP.	Maint. Proc:	MFIB
Date Cal	: 01/29/99	Temperature:	21
Date Due	: 01/29/00	Humidity	: 49
Interval	: 12	Employee #	: 17

CONDITION INSTRUMENT RECEIVED

Condition Received : In Tolerance
Remarks :

CONDITION INSTRUMENT RETURNED

Condition Returned : In Tolerance
Remarks :

STANDARDS USED

ID #	Manufacturer	Model #	Accuracy	Description	Due Date
595	HEWLETT PACKAR	8903B	MFR SPECS	AUDIO ANALYZER	06/17/99

Excalibur Engineering Inc. certifies that the instrument specified above meets the manufacturer's specifications and has been calibrated using standards and instruments also listed above whose accuracies are traceable to the National Institute of Standards and Technology (NIST), and the calibration systems and records are in compliance to ISO-10012 and ANSI Z540-1. This document cannot be reproduced without prior approval.

[signature] EEQA 8 1Feb99

Approved By

Page 1

Preamplifier 3 Calibration Sheet for s/n 79900502

Excalibur Engineering Inc.
3198-C Airport Loop Dr.
Costa Mesa, CA 92626
714-540-0169

CERTIFICATE OF CALIBRATION

Customer Name: INSTRUMENT REPAIR LABS, INC Dept :

INSTRUMENT INFORMATION

Manufacturer	: ACO PACIFIC	Report #	: 15608-6
Model #	: 4012	Cust P.O.#	: 015726
Asset #	: NAN	Date Recvd	: 01/25/99
Serial #	: L79900502	Accuracy	: MFR. SPECS.
Description	: 1/2" MIKE PREAMP.	Maint. Proc:	MFIB
Date Cal	: 01/29/99	Temperature:	21
Date Due	: 01/29/00	Humidity	: 49
Interval	: 12	Employee #	: 17

CONDITION INSTRUMENT RECEIVED

Condition Received : In Tolerance
Remarks :

CONDITION INSTRUMENT RETURNED

Condition Returned : In Tolerance
Remarks :

STANDARDS USED

ID #	Manufacturer	Model #	Accuracy	Description	Due Date
595	HEWLETT PACKAR	8903B	MFR SPECS	AUDIO ANALYZER	06/17/99

Excalibur Engineering Inc. certifies that the instrument specified above meets the manufacturer's specifications and has been calibrated using standards and instruments also listed above whose accuracies are traceable to the National Institute of Standards and Technology (NIST), and the calibration systems and records are in compliance to ISO-10012 and ANSI Z540-1. This document cannot be reproduced without prior approval.

EEQA 8 1FEB99

Approved By

Page 1

Preamplifier 4 Calibration Sheet for s/n 79900504

Excalibur Engineering Inc.
3198-C Airport Loop Dr.
Costa Mesa, CA 92626
714-540-0169

CERTIFICATE OF CALIBRATION

Customer Name: INSTRUMENT REPAIR LABS, INC Dept :

INSTRUMENT INFORMATION

Manufacturer	: ACO PACIFIC	Report #	: 15608-10
Model #	: 4012	Cust P.O.#	: 015726
Asset #	: NAN	Date Recvd	: 01/25/99
Serial #	: L79900504	Accuracy	: MFR. SPECS.
Description	: 1/2" MIKE PREAMP.	Maint. Proc	: MFIB
Date Cal	: 01/29/99	Temperature	: 21
Date Due	: 01/29/00	Humidity	: 49
Interval	: 12	Employee #	: 17

CONDITION INSTRUMENT RECEIVED

Condition Received : In Tolerance
Remarks :

CONDITION INSTRUMENT RETURNED

Condition Returned : In Tolerance
Remarks :

STANDARDS USED

ID #	Manufacturer	Model #	Accuracy	Description	Due Date
595	HEWLETT PACKAR	8903B	MFR SPECS	AUDIO ANALYZER	06/17/99

Excalibur Engineering Inc. certifies that the instrument specified above meets the manufacturer's specifications and has been calibrated using standards and instruments also listed above whose accuracies are traceable to the National Institute of Standards and Technology (NIST), and the calibration systems and records are in compliance to ISO-10012 and ANSI Z540-1. This document cannot be reproduced without prior approval.

EEQA 8 1FEB99

Approved By

Page 1

Signal Analyzer Calibration Sheet

ISO 9002

FS 23253

HEWLETT PACKARD

Certificate Of Calibration

Model No: 35670A
Serial No: 3431A01613
Description: DYNAMIC SIGNAL ANALYZER
Customer Name: NATIONAL RENEWABLE ENERGY LABORATORY
Customer P.O. No: VISA/ARLINDA HUSKEY
Agreement No:
Certificate No: 2452K947701
Customer ID No: 123502

At the time of calibration, this certifies that the above product was calibrated in accordance with applicable Hewlett-Packard procedures.

At planned intervals, Hewlett-Packard measurement standards are calibrated by comparison to or measurement against national standards, natural physical constants, consensus standards, or by ratio type measurements using self-calibrating techniques.

National Standards are administered by NIST (National Institute of Standards and Technology) or other recognized national standards laboratories.

Initial testing found your instrument was IN-SPECIFICATION. No adjustment was necessary to ensure performance to published operating specifications where tested.

Supporting documentation relative to traceability is on file and is available for examination upon request.

The calibration interval for this unit is 12 months and the calibration due date based on this interval is 14-Aug-1999.

Temperature: 21.6 °C **Relative Humidity:** 40 %

Remarks or special requirements:

STE 9000 TEST PROGRAM HP35670A/REV.A.00.03.

Calibration Date: 14-Aug-1998

Dave McCarthy, Quality Manager

U.S. Test & Measurement Service Centers • Englewood Branch
24 Inverness Place East • Englewood, CO 80112 ph. (800 403 0801)

1 of 2

ISO 9002

FS 23253

HEWLETT PACKARD

Certificate Of Calibration

Model No: 35670A
Serial No: 3431A01613
Description: DYNAMIC SIGNAL ANALYZER
Customer Name: NATIONAL RENEWABLE ENERGY LABORATORY
Customer P.O. No: VISA/ARLINDA HUSKEY
Agreement No:
Certificate No: 2452K947701
Customer ID No: 123502

Calibration Equipment Used:

Model Number	Model Description	Trace Number	Cal Due Date
FLU5700A	AC DC CALIBRATOR	5700A15016	05-Mar-1999
3325A	SYNTHESIZER/FUNCTION GENERATOR	3325A01121	01-Apr-1999
3325B	SYNTHESIZER/FUNCTION GENERATOR	3325B01972	27-Sep-1998
3458A	SYSTEM MULTIMETER	3458A01113	25-Sep-1998

U.S. Test & Measurement Service Centers • Englewood Branch
24 Inverness Place East • Englewood, CO 80112 ph. (800 403 0801)

2 of 2

Acoustic Calibrator Calibration Sheet

CERTIFICATE OF CONFORMANCE
FOR BRÜEL & KJÆR

Sound Level Calibrator Type 4230

The Sound Pressure Level has been measured by comparison with Standard Reference Pistonphone.

Type: **4220** serial number **1510240**
and
Type: **4220** serial number **1048795**

Calibrated by: **SN** (BRÜEL & KJÆR)
Date of Calibration: **18 AUG 1997**
Re-calibration Due: **18 AUG 1998**

UNCERTAINTY OF MEASUREMENT:

A: Estimated Uncertainty of comparison:+/-0.09dB at 99% Confidence Level
B: Estimated Uncertainty of Ref. 4220: +/-0.10 dB at 99% Confidence Level
C: Total Uncertainty 0.13 dB (calculated as the square root of the summed squares of A and B) at 99% Confidence Level

The calibrator type	**4230**
ID #:	**00787C**
Serial number	**861619**

has been found to be within the **specifications** listed below.

Sound Pressure Level produced in the coupler terminated by a loading volume of 1.333 cm^3:
94.0 ± 0.3 dB

Frequency:	**1000 ± 15 Hz**
Distortion:	**< 1%**
Equivalent Coupler Volume:	V > **140 cm^3**

ENVIRONMENTAL CONDITIONS:

Ambient Pressure	**986.93** hPa
Temperature	**23°** C
Relative Humidity	**38** %
Date of Calibration	**22 APR 1998**
Re-calibration due on	**22 APR 1999**

Calibration procedure: Brüel & Kjær 4230, Rev. 18 Nov.1997

Certificate No.: **6922-7** PO# **Verbal - A. Huskey**
For: **National Renewable Energy Lab, Golden, CO 80403**

PERFORMANCE AS RECEIVED:

Frequency	997.4	Hz
SPL	93.89	dB
Volume Check	-0.04	dB
Distortion	0.55	%
Battery Voltage	8.8	VOLT

Was frequency and SPL adjusted for improvement? **Yes-SPL!**
Was battery replaced with new alkaline type? **Yes!**

FINAL PERFORMANCE:

Frequency	997.4	Hz
SPL	93.98	dB
Volume Check	-0.02	dB
Distortion	0.65	%

Note: This calibrator was **within** Mfg specifications as received.

Performed on a test system which operates in compliance with ANSI/ NCSL Z540-1.
Reference standards 4220 No.; 1510240 and 4228 serial # 1793011 calibrated traceable to NIST with, NIST test no.822/258435-97.

Signed:

Torben Ehlert, Quality Assurance Mgr.

ODIN METROLOGY, Inc.
A BRÜEL & KJÆR, DIV.OF SPECTRIS TECHNOLOGY, INC.,
AUTHORIZED CALIBRATION CENTER.
3533 OLD CONEJO ROAD, SUITE # 125
THOUSAND OAKS, CA 91320
PHONE: (805) 375-0830 FAX: (805) 375-0405

Page 1 of 2

Sony Precision Technology America, Inc.

137 West Bristol Lane, Orange, CA 92865
Telephone: (714) 921-0630
Fax: (714) 921-1162

Certificate of Calibration

Customer Name: National Renewable Energy Laboratory   Date: August 25, 1998

Instrument Information

Model No.	PC208Ax	Report No.	145401-1
Serial No.	U3538	Cust. P.O.	VISA Card
Asset No.	124037	Date Recvd.	08/18/98
Date Cal.	08/24/98	Accuracy:	Mfr. Specs.
Date Due:	08/24/99	Maint. Prco:	1341
Interval:	12	Temperature:	23
Description:	Data Recorder	Humidity:	47

Condition Instrument Received / Returned

Condition Received: In Tolerance
Remarks:

Condition Returned: In Tolerance
Remarks: Calibrated

Standards Used

ID #	Manufacturer	Model No.	Accuracy	Description	Due Date
569	Hewlett Packard	3325A	Mfr. Specs	Sweep Generator	11/14/98
533	Keithley	2000	Mfr. Specs	6 1/2 Digit DMM	03/20/99
616	Fluke	5500A/SC	Mfr. Specs	Multi Calibrator	10/14/98
643	Bruel & Kjaer	2032	Mfr. Specs	FFT Signal Analyzer	02/11/99
595	Hewlett Packard	8903B	Mfr. Specs	Audio Analyzer	06/17/99

Sony Precision Technology America, Inc. certifies that the instrument specified above meets the manufacture's specifications and has been calibrated using standards and instruments also listed above whose accuracy's are traceable to the National Institute of Standards and Technology (N.I.S.T.), and the calibration systems and records are in compliance to ISO-10012 and ANSI Z540-1. This document cannot be reproduced without prior approval.

Approved by: [signature] 8/25/98

SONY

Anemometer Calibration Sheet

Annemometer 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
Side-by-Side Anemometer Calibration Facility

Dates of Calibration:

Test Start:	1-Oct-98
Test End:	**28-Oct-98**
Report:	6-Nov-98

Report Number: CR-anno-98-4-T3

Procedure:
NWTC-CT: GI21-98237, Field Calibrate Anemometers

Page: 1 of 1

Item Calibrated:

Manufacturer	Met One Instruments, Inc
Model	010C
Cup Serial Number	**T2346**
Cup Material	Aluminum
Condition	Refurbished 15 Sep 98

Deviations from procedure;
None

Results:

Slope:	**0.0399**	m/s/hertz
Offset:	**0.3247**	m/s

Estimated Uncertainty:

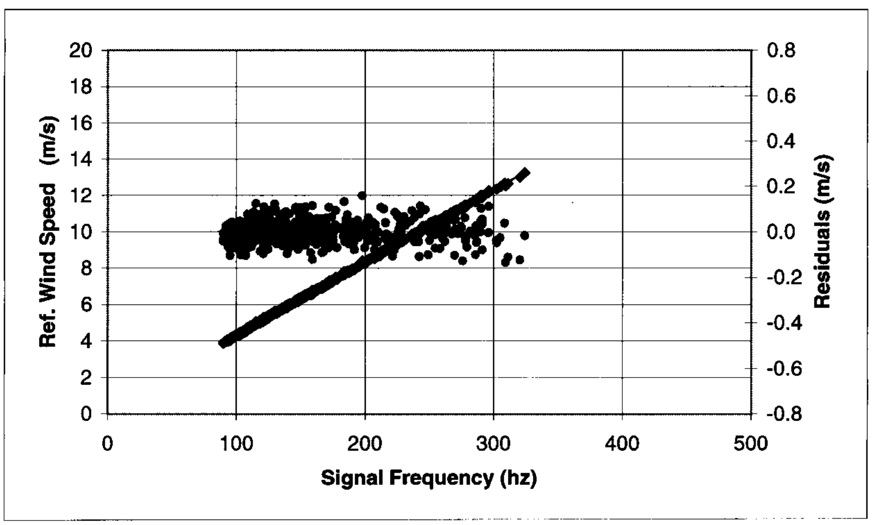
Vwind	Cres Uncei	Total Uncert:
4 - 5 m/s	0.083	0.096
5 - 10 m/s	0.067	0.083
10 - 15 m/s	0.078	0.092

Traceability:

Reference Cup:	Met One, 010C, s/n: U2645
Calibrated by:	CRES, Pikermi, Greece
Calibration date:	11-Mar-98

Approved: Hal Link (signature) Hal Link

6Nov98
Date



Wind Vane Calibration Sheet

INSTRUMENT REPAIR LABS INC.

Certificate of Calibration

COMPANY NAME: National Renewable Energy Lab
CERTIFICATION #: 981023192
CALIBRATION LOCATION: IRL Depot

MANUFACTURER	MODEL NUMBER	P.O. NUMBER
Met One	020C	
SERIAL NUMBER	CALIBRATION ID #	CUSTOMER ID #
U1475	17815	

RECEIVED	☒ Within Tolerance ☐ Out Of Tolerance	☐ Operational Failure ☐ Physical Damage
RETURNED	☒ Within Tolerance ☐ Other	☐ Limited
CALIBRATION	Due 11/03/99	
STANDARD(S)	Used MD1 FL8	
CALIBRATION PROCEDURE USED	MFGR Cal Procedure	

Instrument Repair Labs, Inc. does hereby certify that the above listed instrument meets or exceeds all manufacturer's or agreed upon local specifications. The instrument has been calibrated using standards whose accuracies are traceable to N.I.S.T. within the limitation of their calibration services, or have been derived from accepted values of natural physical constants. Our "Calibration System Requirements" satisfy ANSI/NCSL Z540, MIL-STD-45662A, FDA GMP 820.61 and ISO Guide 25. The calibration environment was 70°F ⁄. 5°F and <70% RH unless otherwise noted. This report is not to be reproduced, except in full, without the written approval of Instrument Repair Labs' Quality Manager.

CERTIFIED BY: Mark Shann
DATE CALIBRATED: 11/03/98
QUALITY MANAGER: BILL HEDRICK

TÜV CERT CERTIFIED TO ISO 9002 INSTRUMENT REPAIR LABS ISO 9002 • CERT NO. 12 100 5851

2100 W. 6th Ave. • Broomfield, CO 80020
(303) 469-5375 or (800) 345-6140 FAX (303) 469-5378

page 1 of 2

Form 07, Rev. 03, 3-26-98

INSTRUMENT REPAIR LABS INC.

Report of Calibration

Customer NREL Manufacturer MET ONE Calibration # 9810Z802

Model # 020C Serial # U1475 / 17815 Tech 18

Date 11-3-98 Due 11-3-99 Ambient ____ °F ____ % RH

☒ As Received ☒ As Returned

READINGS

5VDC OUTPUT	READING	2.5VDC OUTPUT	READING
MARK ALIGNED	2.5069		1.2542
CW 90°	3.7527		1.9012
CW 180°	4.9995		2.5026
CW 270°	1.2539		[illegible].6025
CW 360°	2.5023		1.2515
MARK ALIGNED	2.5005		1.2495
CCW 270°	1.2540		.6072
CCW 180°	5.0039		2.5010
CCW 90°	3.7573		1.8999
CCW 0°	2.5009		1.2495

TOLERANCE = +/- 3°

5V OUTPUT = +/- .042V

2.5V OUTPUT = +/- .021V

2100 W. 6th Ave. • Broomfield, CO 80020
(303) 469-5375 or (800) 345-6140 FAX (303) 469-5378

page 2 of 2

Pressure Sensor Calibration Sheet

INSTRUMENT
REPAIR LABS
INC.

Certificate of Calibration

COMPANY NAME: National Renewable Energy Lab
CERTIFICATION #: 980911237
CALIBRATION LOCATION: IRL Depot

MANUFACTURER	MODEL NUMBER	P.O. NUMBER
Omega	HHP-102F	
SERIAL NUMBER	CALIBRATION ID #	CUSTOMER ID #
046/21	17304	

RECEIVED	☒ Within Tolerance ☐ Out Of Tolerance	☐ Operational Failure ☐ Physical Damage
RETURNED	☒ Within Tolerance ☐ Other	☐ Limited
CALIBRATION	Due 09/14/99	
STANDARD(S)	Used ME3	
CALIBRATION PROCEDURE USED	MFGR Cal Procedure	

Instrument Repair Labs, Inc. does hereby certify that the above listed instrument meets or exceeds all manufacturer's or agreed upon local specifications. The instrument has been calibrated using standards whose accuracies are traceable to N.I.S.T. within the limitation of their calibration services, or have been derived from accepted values of natural physical constants. Our "Calibration System Requirements" satisfy ANSI/NCSL Z540, MIL-STD-45662A, FDA GMP 820.61 and ISO Guide 25. The calibration environment was 70°F ± 5°F and <70% RH unless otherwise noted. This report is not to be reproduced, except in full, without the written approval of Instrument Repair Labs' Quality Manager.

CERTIFIED BY: Ronald Horton

DATE CALIBRATED: 09/14/98

QUALITY MANAGER: BILL HEDRICK

TÜV CERT CERTIFIED TO ISO 9002 INSTRUMENT REPAIR LABS ISO 9002 • CERT NO. 12 100 5851

2100 W. 6th Ave. • Broomfield, CO 80020
(303) 469-5375 or (800) 345-6140 FAX (303) 469-5378

page 1 of 3

Form 07, Rev. 03, 3-26-98

INSTRUMENT REPAIR LABS INC.

Report of Calibration

Customer NREL Manufacturer OMEGA Calibration # 980911237

Model # HHP-102F Serial # 046/21 / 17304 Tech QUL-3

Date 9-14-98 Due 9-14-99 Ambient 70 °F 42 % RH

☑ As Received ☑ As Returned

READINGS

Actual (STD)	Read (UUT)
1.43 PSIA	1.44 PSIA
7.43	7.44
12.15	12.15
20.31	20.3
29.00	29.0

2100 W. 6th Ave. • Broomfield, CO 80020
(303) 469-5375 or (800) 345-6140 FAX (303) 469-5378

page 2 of 3

Temperature Sensor Calibration Sheet

INSTRUMENT REPAIR LABS INC.

Certificate of Calibration

COMPANY NAME: National Renewable Energy Lab
CERTIFICATION #: 980911238
CALIBRATION LOCATION: IRL Depot

MANUFACTURER	MODEL NUMBER	P.O. NUMBER
Omega	869	
SERIAL NUMBER	CALIBRATION ID #	CUSTOMER ID #
T-171111	17305	

RECEIVED	☒ Within Tolerance ☐ Out Of Tolerance	☐ Operational Failure ☐ Physical Damage
RETURNED	☒ Within Tolerance ☐ Other	☐ Limited
CALIBRATION	Due 09/14/99	
STANDARD(S)	Used FL11, HS1	
CALIBRATION PROCEDURE USED	MFGR Cal Procedure	

Instrument Repair Labs, Inc. does hereby certify that the above listed instrument meets or exceeds all manufacturer's or agreed upon local specifications. The instrument has been calibrated using standards whose accuracies are traceable to N.I.S.T. within the limitation of their calibration services, or have been derived from accepted values of natural physical constants. Our "Calibration System Requirements" satisfy ANSI/NCSL Z540, MIL-STD-45662A, FDA GMP 820.61 and ISO Guide 25. The calibration environment was 70°F ± 5°F and <70% RH unless otherwise noted. This report is not to be reproduced, except in full, without the written approval of Instrument Repair Labs' Quality Manager.

CERTIFIED BY: Ronald Horton
DATE CALIBRATED: 09/14/98
QUALITY MANAGER: BILL HEDRICK

TÜV CERT CERTIFIED TO ISO 9002 INSTRUMENT REPAIR LABS ISO 9002 • CERT NO. 12 100 5851

2100 W. 6th Ave. • Broomfield, CO 80020
(303) 469-5375 or (800) 345-6140 FAX (303) 469-5378

Page 1 of 3

Form 07, Rev. 03, 3-26-98

INSTRUMENT REPAIR LABS INC.

Report of Calibration

Customer NREL Manufacturer OMEGA Calibration # 980911238

Model # 869 Serial # T-171111 / 17305 IRL Tech RWH-3

Date 9-14-98 Due 9-14-99 Ambient N/A °F N/A % RH

☑ As Received ☑ As Returned

READINGS

	Actual (STD)	Read (UUT)
Simulated Test	100.00Ω = 0.0°C	0.0°C
	174.00Ω = 195.0°C	195.0°C
	313.59Ω = 600.0°C	600.0°C

	Actual (STD)	Read (UUT)
Probe Comp. Test	25.0°C	25.0°C

2100 W. 6th Ave. • Broomfield, CO 80020
(303) 469-5375 or (800) 345-6140 FAX (303) 469-5378

Page 2 of 3

Campbell Datalogger Calibration Sheet

CSI DATALOGGER
MODEL: CR23X Item #10517
FINAL DATALOGGER TEST REPORT AND CALIBRATION CERTIFICATION

Serial # **1214**
Test Panel Position 12

TEST #	ANALOG INPUTS	PASS/FAIL	INPUT V.	MEASURED mV.	% ERROR	TEST TEMP.
1	Diff. Range 5 (+-0.05% FSR)	P	5	4996.9	.03	-25 C
2				5000.7	.01	+50 C
3	Channel Multiplexing	P				
4	Panel Temperature	P				
5	Battery Voltage	P				
	ANALOG OUTPUTS					
6	Switched (+-0.05% FSR)	P		5002.4	.02	-25 C
7				4999.9	.00	+50 C
8	Continuous (+-0.05% FSR)	P		5001.2	.01	-25 C
9				4999.6	.00	+50 C
10	Excit. Multiplexing	P				
11	CAO Channels	P				
12	PULSE COUNTERS	P				
13	DIGITAL CONTROL OUT	P				
	CPU AND INTERFACE					
14	Memory	P				
15	Serial I/O	P				
16	Clock	P				
	SYSTEM POWER			MEASURED CURRENT		
17	Quiescent (2.2mA typ.)	P		1.910 mA		
18	Measurement (loaded) (70 mA typ., 150 mA loaded typ.)	P		87.9 mA		
	TEMPERATURE RANGE		INPUT V.	MEASURED V.	% ERROR	TEST TEMP.
19	Diff Range 5 Cold (Derated)		5	____	____	____
20	Diff Range 5 Hot (Derated)		5	____	____	____

NOTE: The collective measurement uncertainty of the calibration process exceeds a 4:1 accuracy ratio.

TEST STANDARDS USED:
Test Procedure TST10517C Rev.9
Environmental Chamber:
DC Calibrator S/N A021205 (Traceable to NIST 2396111)
Oscillatek S/N 205345 TCXO (Traceable to NIST 0141/WWVB)

Final Report Validation By

A. PARKINSON

10/16/98