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Wind Turbine Generator System

Acoustic Noise Test Report

for the

Whisper H40 Wind Turbine

By

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4.0 Disclaimer

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5.0 Background

This test is being conducted as part of DOE's Small Wind Turbine Field Verification Program. The primary purpose of this program is to provide consumers, manufacturers, and host site organizations with an independent assessment of the performance, reliability, safety, and acoustics of small U.S. wind turbines.

World Power Technologies developed the Whisper H40 wind turbine, which is now manufactured by Southwest Wind Power. The test turbine is located at the National Wind Technology Center's (NWTC's) Site 1.3. NREL is testing three wind turbines as part of DOE's Small Wind Turbine Field Verification Program. As part of these tests, each turbine is subjected to a series of tests, including acoustic noise. After the testing is complete, a summary report will be created that mimics the popular Consumer Reports magazine. This summary report will include a summary of the noise test results.

6.0 Test Objective

The objective of the test is to characterize the noise emissions of the Whisper H40 wind turbine. To meet this objective, the measurements were collected and analyzed in accordance with the IEC 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.

7.0 Results

Turbine and background data were collected on January 4, 2001; January 25, 2001; and February 5, 2001. The following sections show the results of the analysis using the measured wind speed. The measured wind speed was obtained from an anemometer located 292° from the turbine at hub height (9.1 meters) then standardized to the reference height of 10 m. Noise measurements were averaged over 10 seconds, instead of 1 minute as the Standard specifies, to better characterize the noise at higher wind speeds—specifically when the turbine employs overspeed control.

Another analysis was also completed using wind speed derived from the power measurements. However, these derived wind speeds did not correlate well with the noise measurements (discussed in Section 12.2).

Figures 1 through 4 show the data used for analysis for microphone positions 1 through 4, respectively.

7.1 A-Weighted Sound Power Level

The apparent sound power level for all microphone positions was determined using turbine and background data between the wind speeds of 6 to 10 m/s. Table 1 gives the calculated apparent sound power level for four microphone positions around the turbine. As shown in Figure 9, reference microphone position 1 is downwind, microphone position 3 is upwind, and microphone positions 2 and 4 are on each side of the turbine. The Standard states that if the difference between the turbine and background noise is between 3 and 6 dBA, turbine noise can be corrected for background noise but cannot be used to determine the sound power level or directivity. Therefore, the apparent sound power level is reported only for reference microphone position 1.

Table 1. Apparent Sound Power Levels for the Acoustic Reference Wind Speed

Microphone Position	Unit	1	2	3	4
Apparent sound power level at 8 m/s	dBA	84.9	*	*	*
Uncertainty ¥	dBA	3.5	--	--	--
Turbine sound pressure level at 8 m/s	dBA	58.2	58.4	56.1	55.7
Background sound pressure level at 8 m/s	dBA	51.5	52.6	51.6	50.5
Difference between background and turbine	dBA	6.8	5.8	4.5	5.2
Number of turbine points	--	99	44	99	76
Number of background points	--	149	86	149	124

¥ - The uncertainty reported is the worst case.

* - The difference between the turbine and background noise was between 3 and 6 dBA, so the apparent sound power level cannot be determined.

7.2 Wind Speed Dependence

All standardized wind speeds above 4 m/s from reference microphone position 1 were used in this analysis. Higher wind speeds were included to characterize the noise when the Whisper employs overspeed control; in this case, furling. However, for the higher wind speed bins, the difference between the turbine and background noise was less than 3 dBA, and the Standard requires it be reported that the turbine noise was less than the background noise. For bins in which the difference between turbine and background noise is between 3 and 6 dBA, a standard background correction of 1.3 dBA was applied and noted. The results are shown in Table 2 and Figure 5 for all bins with at least 3 data points.

Table 2. Wind Speed Dependence for Measured Wind Speed

Bin m/s	Wind Speed Average m/s	Position 1 Corrected Sound Pressure Level dBA		Uncertainty[¥] dBA
4	4.31	54.9		2.52
5	4.97	56.2		1.13
6	5.97	55.2		1.41
7	7.05	55.8	*	3.09
8	8.04	57.6		3.05
9	9.04	59.6	*	4.11
10	10.01	63.2	*	4.63
11	10.96	64.4	*	4.44
12	11.96	--	**	--
13	13.1	68.6	*	3.53
14	13.97	--	**	--
15	15.02	--	**	--
16	16.01	--	**	--
17	16.87	--	**	--
18	18.12	--	**	--
19	19.03	--	**	--

[¥] The uncertainty reported is the worst case.

* The difference between the turbine and background noise was greater than 3 dB and less than 6 dB, so a standard background correction of 1.3 dB was applied.

** The difference between the turbine and background noise was less than 3 dB, so the turbine noise was less than the background noise.

7.3 Directivity

Directivity is determined from sound power levels for each microphone position. Because the sound power level could not be calculated for microphones 2, 3, and 4, the directivity could not be determined.

7.4 Tonal Analysis

A tone inspection was completed for frequencies from 20 to 5000 Hz for the reference microphone position 1. The sets of unweighted spectra were obtained using the settings shown in Table 3.

Table 3. Data Created for Tone Inspection

Microphone Position	Bandwidth	Frequency Resolution	Number of Spectra
1	0 - 3200	6	480
1	3000 - 6200	6	480

An inspection for tones was completed for the frequency range 20 to 5000 Hz with an effective bandwidth of 6 Hz using a Hanning window. Figure 6 shows an averaged 2-minute unweighted spectrum for turbine noise for reference microphone position 1. No tones were identified for the spectrum.

8.0 Test Turbine

Figure 7 shows the Whisper H40 wind turbine as it was installed at Site 1.3 at the NWTC. The Whisper H40 is a three-bladed, upwind, variable-speed turbine that uses furling for power regulation and overspeed control. The turbine is mounted on a 10-cm (4-in) tube tower at a hub height of 9.1 m (30 ft.). The tower is supported by four guy wires and can be easily lowered to ground level for turbine inspection and maintenance.

The turbine uses a direct-drive, permanent magnet, brushless alternator to produce three-phase, variable-frequency, variable-voltage, AC power. This “wild AC” power is directed through slip rings in the nacelle to the turbine’s EZ Wire controller.

The EZ Wire is a proprietary, SCR-based rectifier that features turbine control and a dump load. In this test, it was configured to produce 24 volts DC. DC voltage is stabilized with four batteries. A Trace sine-wave inverter (model number SW4024) converts the DC power to 120 volts AC and feeds it to the NWTC electrical grid. In case of a utility outage or inverter failure, the resistive dump load dissipates energy from the turbine. A manual switch provides braking for the turbine by disconnecting it from the load and shorting two of the generator leads together.

Table 4 lists configuration and operational data for the Whisper H40.

Table 4. Test Turbine Configuration and Operational Data

General Configuration:	
Make, Model, Serial Number	World Power Technologies, Whisper H40, S/N: 09092256
Rotation Axis	Horizontal
Orientation	Upwind
Number of Blades	3
Rotor Hub Type	Rigid
Rotor Diameter (m)	2.1
Hub Height (m)	9.1
Performance:	
Rated Electrical Power (kW)	0.9
Rated Wind Speed (m/s)	12.5
Cut-In Wind Speed (m/s)	3.4
Rotor:	
Swept Area (m2)	3.6
Cut-In Rotational Speed (rpm)	300
Maximum Rotational Speed (rpm)	1200
Tilt Angle (deg)	7
Blade Pitch Angle (deg)	0 (non-linear 13^{o} at root to 1^{o} at tip)
Direction of Rotation	CCW
Overspeed Control	Furling
Braking System:	
Electrical Brake: Make, Type, Location	Electrical single pole
Yaw System:	
Wind Direction Sensor	Tail vane
Tower:	
Type	Guyed tube tilt-down
Height (m)	9.1
Control/Electrical System:	
Controller: Make, Type	EZ Wire system 120 SW4024
Power Converter: Make, Type	Trace
Electrical Output: Voltage, Frequency, Number of Phases	480 VAC, 60 Hz, 1-phase

Figure 7. Test turbine.

9.0 Test Site

The Whisper H40 wind turbine under test is located at Site 1.3 of the NWTC (hereafter referred to as the test site), approximately 8 km south of Boulder, Colorado. The site is located in somewhat complex terrain at an approximate elevation of 1850 m above sea level. Figure 8 shows the location of the test site relative to Boulder and the front range of the Rocky Mountains, as well as a plot plan of the test site, including all obstructions for 20 rotor diameters (with topography lines listed in feet above sea level). During the acoustic noise test, there was little vegetation, and neighboring turbines were shut off during testing. However, there was a concrete plant approximately 900 meters from the test turbine.

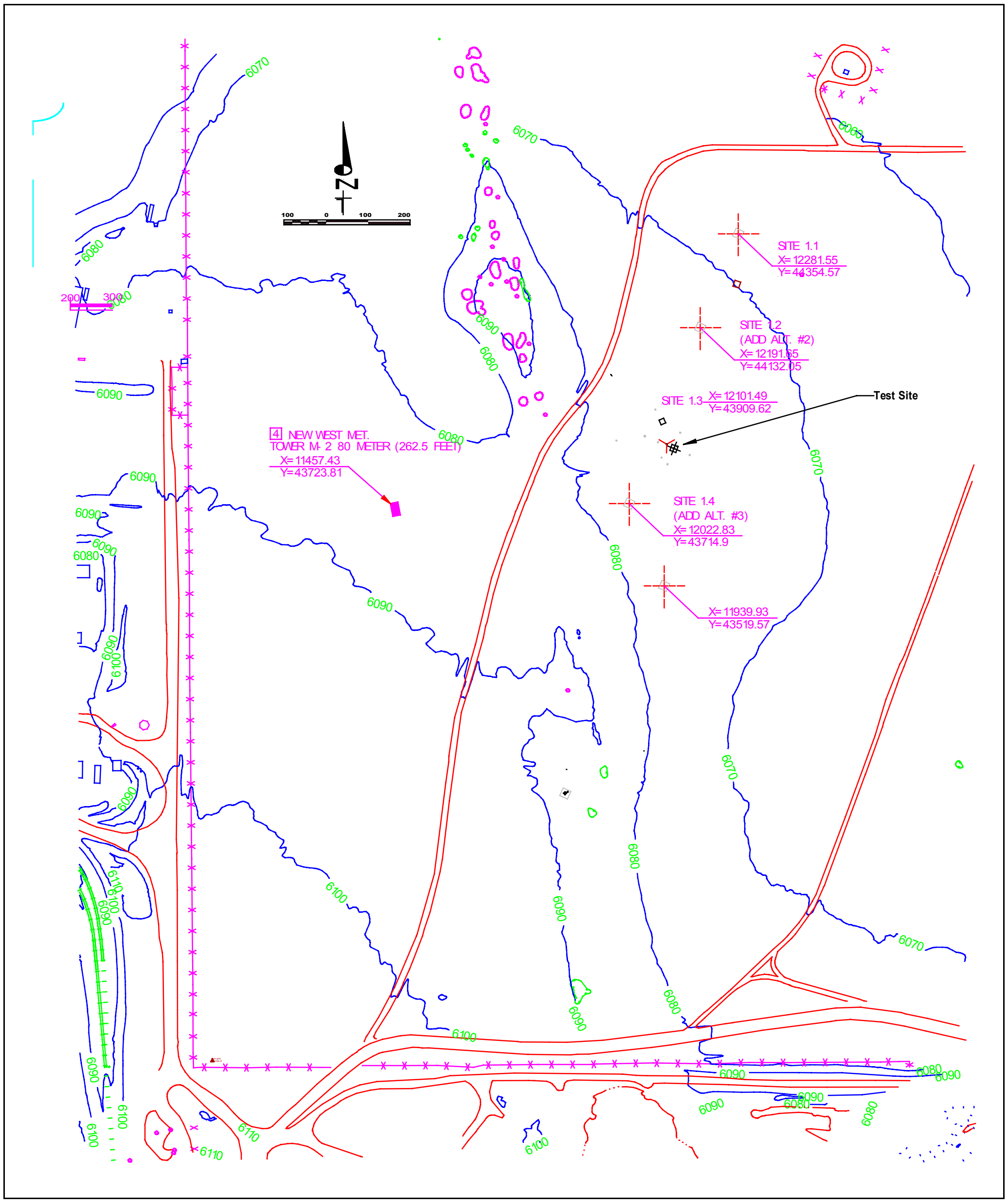


Figure 8. Test turbine location.

10.0 Test Equipment

10.1 Equipment Description

Table 5 shows the list of equipment used for the test.

Table 5. Equipment List for Acoustic Test

Instrument	Manufacturer	Model Number	Serial Number
Signal Analyzer	Hewlett Packard	35670A	3431A01613
Microphone	ACO Japan	7012	17508
Microphone	ACO Japan	7012	17509
Microphone	ACO Japan	7012	17510
Microphone	ACO Japan	7012	19037
Preamplifier	ACO Pacific	4012	9903
Preamplifier	ACO Pacific	4012	960032
Preamplifier	ACO Pacific	4012	96050
Preamplifier	ACO Pacific	4012	9900503
Calibrator	Bruel & Kjaer	4230	830235
Digital Recorder	Sony	PC208AX	U3538
Anemometer	Met One	010C	W1237
Wind Vane	Met One	020C	P3143
Pressure Sensor	Omega	HHP-102F	046/21
Temperature Sensor	Omega	869	T-171111
Data Logger	Campbell Scientific	23X	3099

The power and meteorological measurements (wind speed, wind direction, pressure, and temperature) were averaged and recorded by the Campbell data logger. The digital audio tape recorder recorded the acoustic measurements. Acoustic measurements were synchronized with power and meteorological measurements in post-processing.

10.2 Meteorological Tower Location

The meteorological tower was located 6.7 meters from the test turbine at a bearing of 292° true. This distance is 3.2 rotor diameters from the test turbine and within the range between 2 and 4 rotor diameters specified in the Standard.

10.3 Instrumentation Locations

Figure 9 shows the layout of the microphones. The radius, R_o is determined by Equation 1.

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

Table 6. Variables for Determining the Distance between the Turbine Base and Microphones

Parameter	Description	Value	Units
R_o	Reference distance	10.2	m
H	Vertical distance from the ground to the rotor center	9.1	m
D	Diameter of the rotor	2.1	m

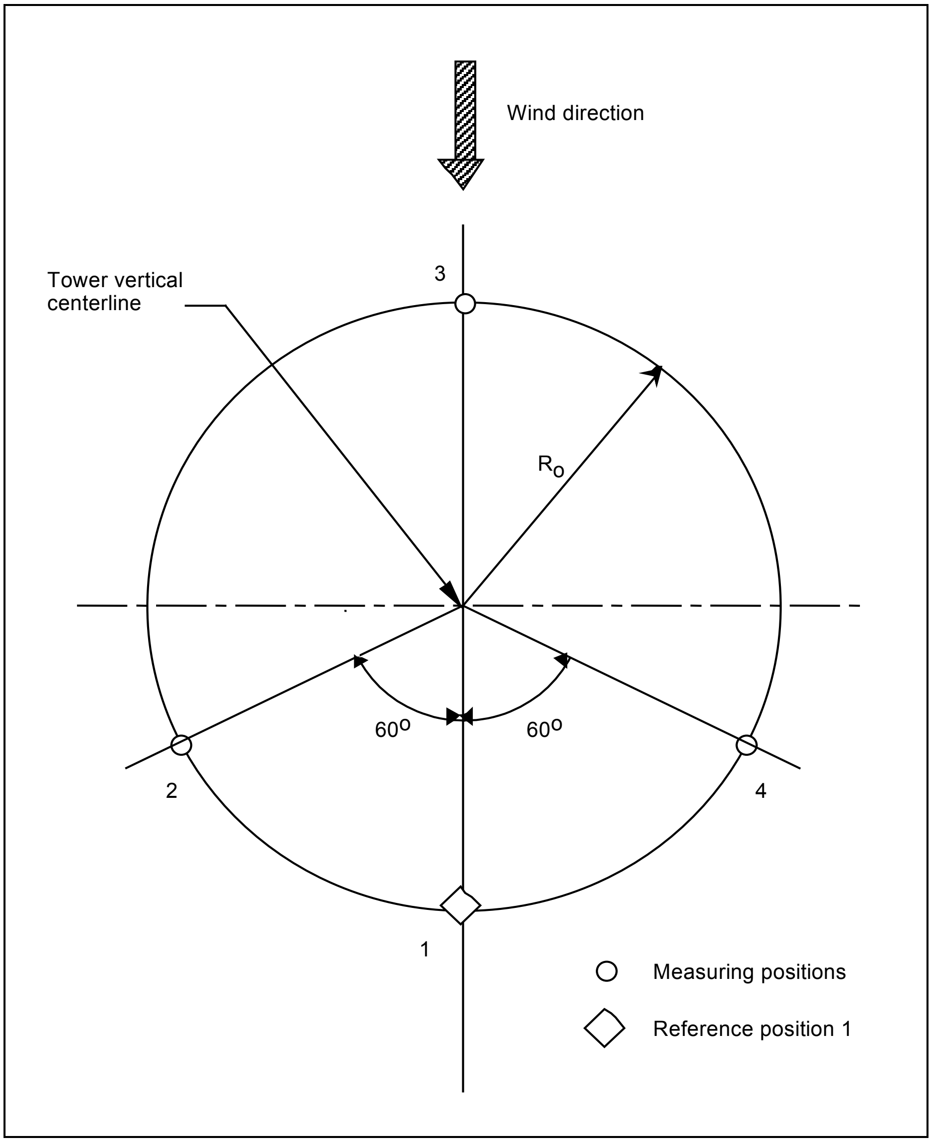


Figure 9. Microphone positions.

Microphones were located 10.2 m from the center of the tower with relative positions as shown in Figure 9. Small adjustments from the nominal microphone positions may be required to avoid reflecting surfaces or to obtain allowable grazing angles.

The anemometer will be located on a permanent meteorological tower at 9.1 m height at a bearing of 292^o true. The meteorological tower will be located upwind from reference microphone position 1 during testing.

11.0 Measurement Procedures

11.1 Test Conduct

The acoustic noise test consists of two types of noise measurements: turbine and background. Turbine noise measurements are taken when the turbine is operating, and background noise measurements are taken when the turbine is stopped.

The operator begins a measurement session by starting the digital tape recording to record noise from the four microphones. Simultaneously, the data logger acquires wind speed, wind direction, and turbine power. The data logger averages each of these readings over 10-second periods. Noise data are processed into 10-second averages and synchronized with the data logger averages in post-processing.

Because the Whisper H40 uses furling for overspeed control, 10-second averages were used instead of 1-minute averages as the Standard recommends so that the noise from turbine response to changes in wind speed could be better characterized.

11.2 Test Completion

The test is complete when all requirements listed in Table 7 are fulfilled for turbine and background measurements.

Table 7. Data Requirements

Measurement Type	Requirements
A-weighted sound pressure level: (turbine and background measurements)	At least ten measurements taken during a wind speed not differing more than 2 m/s from the acoustic reference wind speed (8 m/s)
	At least 25% of the measurements below the acoustic reference wind speed
	At least 25% of the measurements above the acoustic reference wind speed
	Data at or above the point at which the turbine employs overspeed control
Narrowband measurements	Twelve 10-second measurements close to the acoustic reference wind speed (8 m/s)

12.0 Analysis Methods

12.1 Data Selection

All data were collected in three measurement series (conditions listed in Table 8).

Table 8. Measurement Conditions

Date	**Measurement Time** **HH:MM**	**Reference Microphone Position** **degrees**	**Wind Direction Range** **degrees**	**Pressure** **kPa**	**Temperature** **K**
January 4, 2001	09:25 to 15:40	309 °	254.4° to 7.7 °	81.2	271.3
January 25, 2001	16:30 to 18:00	309 °	256.0 ° to 324.9 °	81.2	275.7
February 5, 2001	12:00 to 14:30	309 °	234.6 ° to 0.6 °	81.1	278.1

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 below cut-in
- Turbine failure
- Adverse weather conditions.

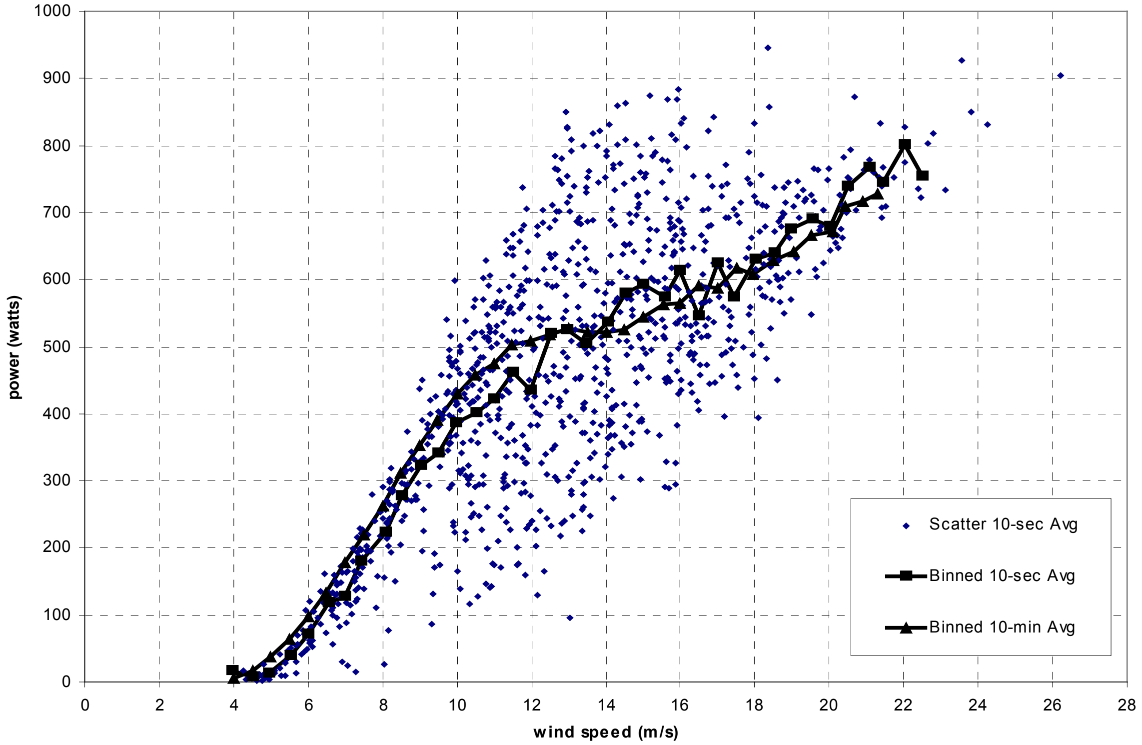


Figure 10. Measured power curve 10-second and 10-minute averages.

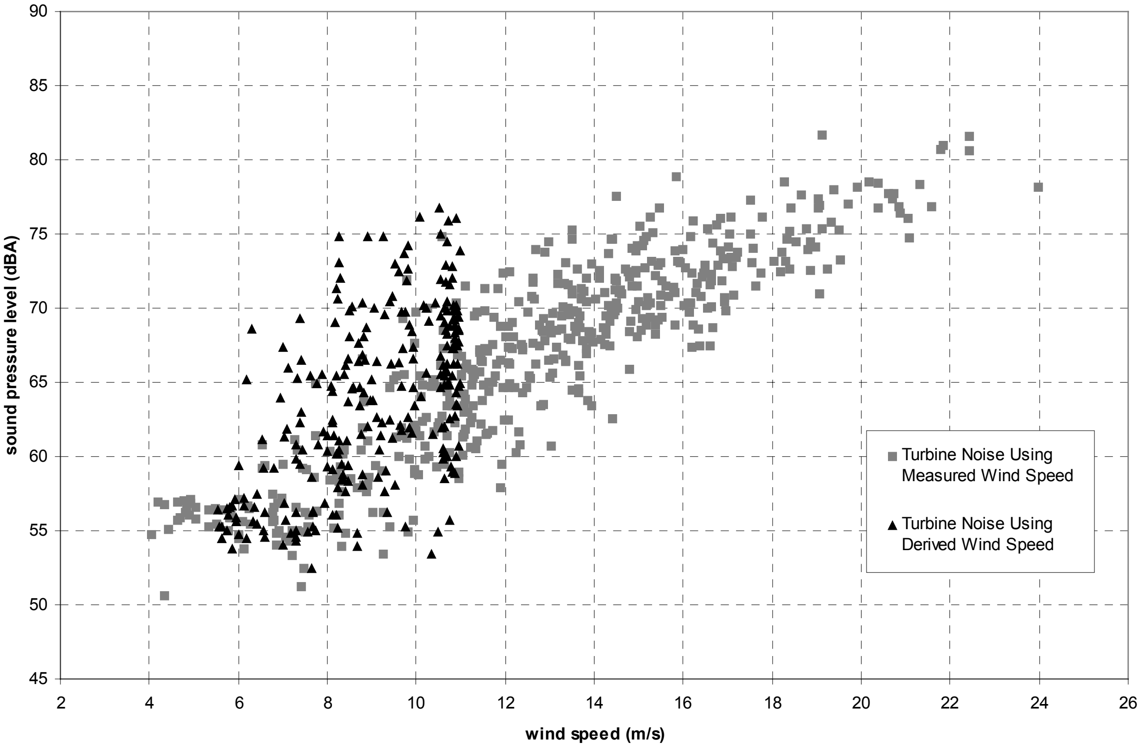


Figure 11. Reference microphone position 1 data using measured and derived wind speed.

12.2 Determination of Wind Speed

The Standard's preferred method of determining the wind speed is using the measured power output and deriving the wind speed through the power curve. The power curve relates the power to the wind speed averaged over the rotor-swept area. The turbine is used as a large anemometer and usually gives a better determination of wind speed at the rotor than using a cup anemometer located on a meteorological tower a distance from the turbine.

For most wind turbines, the output power correlates well to wind speed up to the point of maximum power. However, this is not true for the Whisper H40. Figure 10 displays the large scatter in the power-versus-wind-speed relationship using the same 10-second data that were used for acoustic noise measurements. These 10-second averaged power measurements were used to derive the wind speed from the 10-minute averaged power curve. Figure 10 also shows that there was little difference between the 10-minute averaged and 10-second power curve.

Figure 11 shows the results obtained when this method was applied to the acoustic noise data. It shows that there is a large scatter of data and poor correlation of noise level to wind speed derived from power measurements. Therefore, the results obtained through this method were not reported.

NREL personnel have not determined why this method did not show a better correlation than the method that uses the anemometer on the meteorological tower. It is suspected the scatter originates from the changes in rotor speed. In increasing winds, output power is reduced by the energy needed to accelerate the rotor. In decreasing winds, output power is higher.

Therefore, the second method was used by measuring the wind speed by an anemometer and adjusting it to reference conditions, as described in Section 12.3.

12.3 Wind Speed Correction

Wind speed is 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 9. 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	0.05	m
z_o	Roughness length	0.05	m
H	Rotor center height	9.1	m
z_{ref}	Reference height	10.0	m
z	Anemometer height	9.1	m

12.4 A-Weighted Sound Power Level

A linear regression analysis is done with at least ten pairs of equivalent continuous sound pressure levels from the microphone at the reference position and the corrected wind speed. These pairs are selected to cover 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 difference between the turbine and background noise is greater than 6 dB, Equation 3 is used to correct the turbine noise level for background noise and provides the corrected sound pressure level at the reference position, $L_{Aeq,c}$. If the difference is less than 6 dB and greater than 3 dB, then the turbine noise level is corrected by subtracting 1.3 dB from the turbine noise. However, these corrected sound pressure levels may not be used in any other calculations, including sound power level. If the difference is less than 3 dB, then it must be reported that the turbine noise was less than the background noise and cannot be used in any calculations.

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

Table 10. 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	dB
L_n	sound pressure level of the background	dB

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

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

Table 11. Variables in Calculating the Apparent Sound Power Level

Parameter	Description	Value	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	13.6	m
S_o	reference area	1.0	m^2

12.5 Wind Speed Sensitivity

The 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 is corrected for that bin's background noise as described above.

12.6 Directivity

Directivity, Δ_i, is the difference in A-weighted sound power levels at Positions 2, 3, and 4 compared to the A-weighted sound power levels at the reference position. The sound power levels at all microphone positions are determined using the methods described in Section 12.3. In addition, corrections are 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 12. 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

13.0 Uncertainty

The combined uncertainty is reported for the apparent sound power level and wind speed dependence. 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 and wind speed dependence will be explained in this section.

13.1 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.

$$U_A = \sqrt{\frac{\Sigma(y - y_{est})^2}{N-2}} \qquad \textbf{Equation 6}$$

Table 13 lists the Type A uncertainty for the apparent sound power levels using the measured wind speed. Table 13 lists the Type A uncertainty for the apparent sound power levels using the wind speed derived from the measured power.

Table 13. Type A Apparent Sound Power Level Uncertainty Components

Parameter	**Description**	**Microphone**				**Unit**
		1	**2**	**3**	**4**	
U_A	Type A uncertainty for apparent sound pressure level	3.5	4.5	3.5	4.6	dB
y	Measured sound pressure level	-	-	-	-	dB
y_{est}	Estimated sound pressure level using linear regression	58.2	58.4	56.1	55.7	dB
N	Number of measurements used in the linear regression	99	44	99	76	-

The Type B uncertainty components include:

$$U_B = \sqrt{U_{B1}^2 + U_{B2}^2 + U_{B3}^2 + U_{B4}^2 + U_{B5}^2 + U_{B6}^2 + U_{B7}^2 + U_{B8}^2 + U_{B9}^2} \qquad \textbf{Equation 7}$$

Table 14. Type B Apparent Sound Power Level Uncertainty Components

Parameter	Description	Microphone				Unit	Source
		1	2	3	4		
U_B	Type B uncertainty for apparent sound pressure level	1.2	1.2	1.4	1.2	dB	Equation 7
U_{B1}	Uncertainty for calibration of the instruments	0.6	0.3	0.2	0.2	dB	calibrator calibration and the standard error from field calibrating
U_{B2}	Uncertainty for tolerances on the chain of acoustic measurement instruments	0.1	0.2	0.1	0.1	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	0.4	0.4	0.4	0.4	dB	estimate
U_{B7}	Uncertainty on the measured wind speed	0.6	0.6	0.6	0.6	dB	anemometer calibration and estimate of the site effects
U_{B8}	Uncertainty on the wind direction measurement	0.2	0.2	0.2	0.2	dB	wind vane calibration
U_{B9}	Uncertainty for the background correction	0.6	0.8	1.1	0.9	dB	applied background correction

These uncertainties are combined into one standard uncertainty by Equation 8.

$$U_C = \sqrt{U_A^2 + U_B^2} \qquad \textbf{Equation 8}$$

Table 15. Overall Uncertainty Components

Parameter	Description	Microphone				Units
		1	2	3	4	
U_C	Overall standard uncertainty for apparent sound power level	3.5	--	--	--	dB
U_A	Type A uncertainty for apparent sound pressure level	3.3	4.4	3.2	4.4	dB
U_B	Type B uncertainty for apparent sound pressure level	1.2	1.2	1.4	1.2	dB

13.2 Wind Speed Sensitivity

Type A uncertainty for wind speed dependence is found 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 9.

$$s_i = \sqrt{\frac{\sum (L_{Aeq} - L_{Aeq,j})^2}{(N-1)^2}} \qquad \textbf{Equation 9}$$

Table 16. Type A Wind Dependence Uncertainty Components

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

The Type B uncertainty for each bin is found using Equation 7.

Table 17. Type B Wind Dependence Uncertainty Components

Parameter	Description	Value	Unit	Source
U_B	Type B uncertainty for bin i	varies by bin	dB	Equation 7
U_{B1}	Uncertainty for calibration of the instruments	0.4	dB	calibrator calibration and the standard error from field calibrating microphones
U_{B2}	Uncertainty for tolerances on the chain of acoustic measurement instruments	0.1	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	0.4	dB	estimate
U_{B7}	Uncertainty on the wind speed derived from measured power	0.6	dB	estimated uncertainty from the power curve and estimate of the site effects
U_{B8}	Uncertainty on the wind direction measurement	0.3	dB	wind calibration
U_{B9}	Uncertainty for the background correction	varies by bin	dB	applied background correction

14.0 Exceptions

1. Measurement averaging period was reduced to 10 seconds to better characterize noise when the turbine responds to changes in the wind speed.

2. One-third octave analysis was not completed because some band levels could not be reported due to the small difference between turbine and background noise levels.

3. Instrument calibrations are not reported because some acoustic instruments were used beyond calibration due dates. All acoustic instruments will be checked and post-calibrated.

Appendix A: Pictures of Test Site

Figure 12. Picture taken from the reference microphone position.

(Picture not taken during test.)

Figure 13. Picture taken from the meteorological tower.

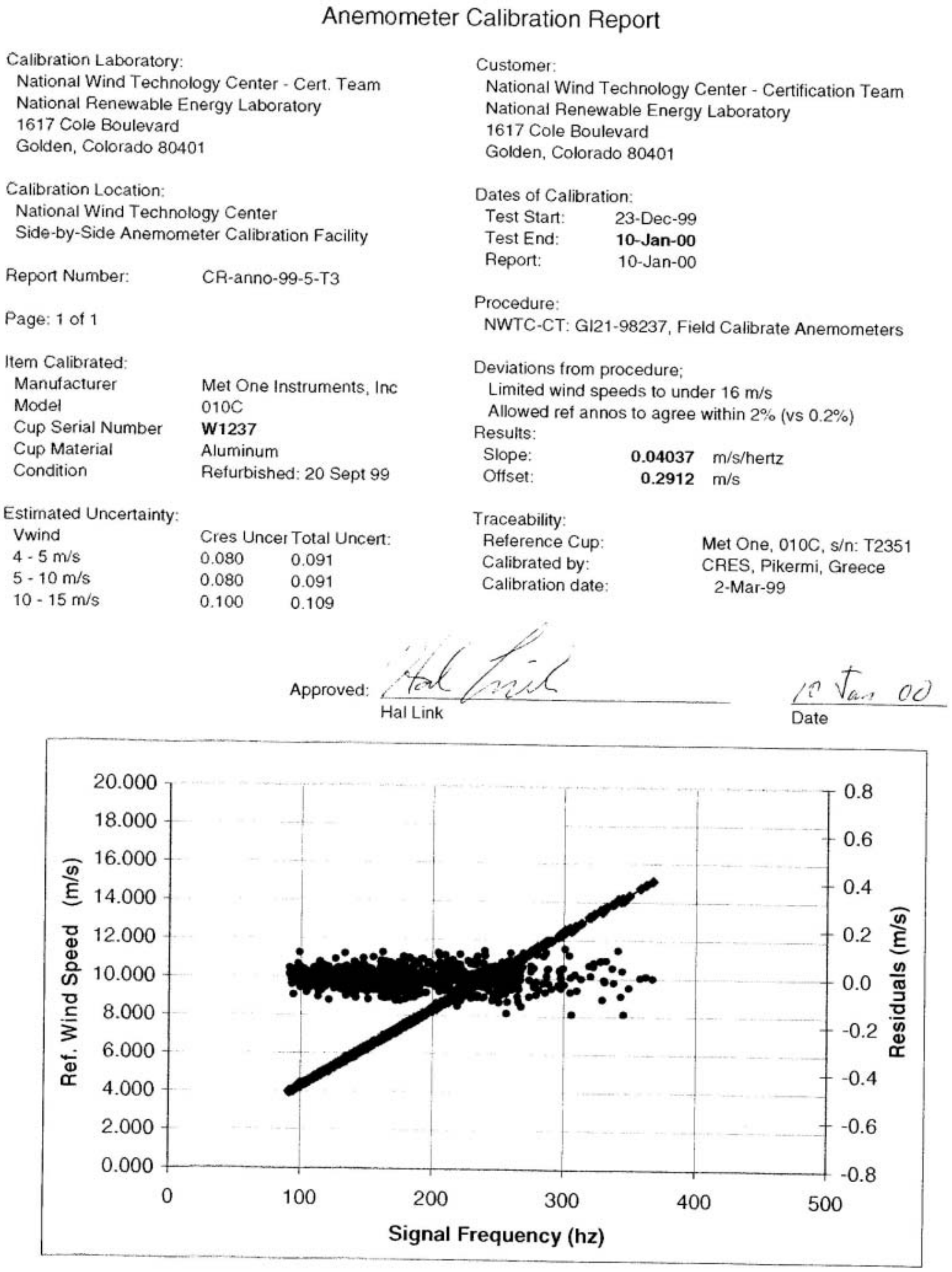
(Picture not taken during test. Meteorological tower in background was not there during test.)

Appendix B: Calibration Sheets

Only meteorological instrument calibration sheets included. Data logger will be post-test calibrated.

Acoustic instruments will be post-test calibrated.

Anemometer



Anemometer 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:	23-Dec-99
Test End:	**10-Jan-00**
Report:	10-Jan-00

Report Number: CR-anno-99-5-T3

Page: 1 of 1

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

Item Calibrated:

Manufacturer	Met One Instruments, Inc
Model	010C
Cup Serial Number	**W1237**
Cup Material	Aluminum
Condition	Refurbished: 20 Sept 99

Deviations from procedure;
Limited wind speeds to under 16 m/s
Allowed ref annos to agree within 2% (vs 0.2%)

Results:

Slope:	**0.04037**	m/s/hertz
Offset:	**0.2912**	m/s

Estimated Uncertainty:

Vwind	Cres Uncer	Total Uncert:
4 - 5 m/s	0.080	0.091
5 - 10 m/s	0.080	0.091
10 - 15 m/s	0.100	0.109

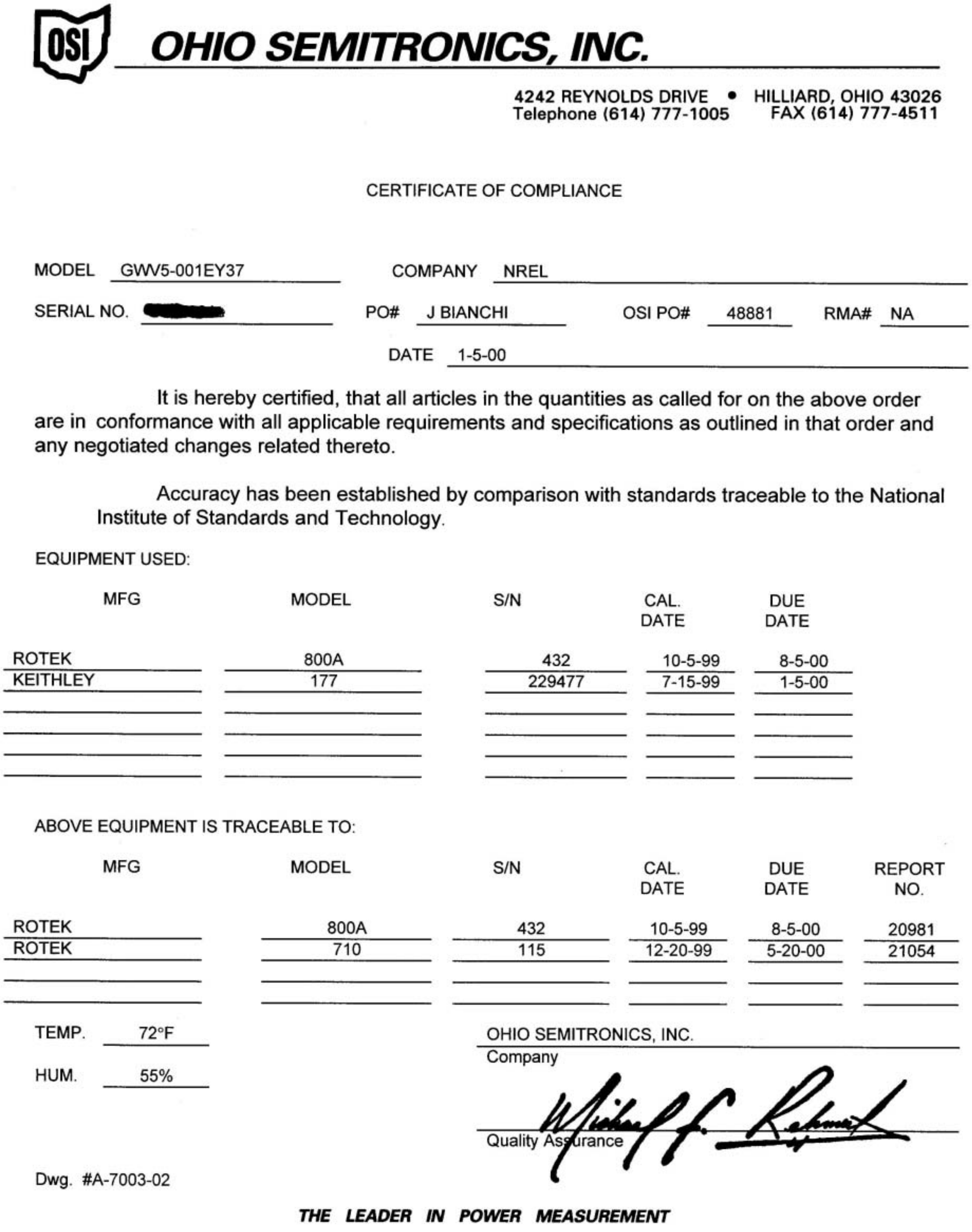
Traceability:

Reference Cup:	Met One, 010C, s/n: T2351
Calibrated by:	CRES, Pikermi, Greece
Calibration date:	2-Mar-99

Approved: Hal Link
Hal Link

10 Jan 00
Date

Power Transducer



OHIO SEMITRONICS, INC.

4242 REYNOLDS DRIVE • HILLIARD, OHIO 43026
Telephone (614) 777-1005 FAX (614) 777-4511

CERTIFICATE OF COMPLIANCE

MODEL GWV5-001EY37
COMPANY NREL
SERIAL NO. [redacted]
PO# J BIANCHI
OSI PO# 48881
RMA# NA
DATE 1-5-00

It is hereby certified, that all articles in the quantities as called for on the above order are in conformance with all applicable requirements and specifications as outlined in that order and any negotiated changes related thereto.

Accuracy has been established by comparison with standards traceable to the National Institute of Standards and Technology.

EQUIPMENT USED:

MFG	MODEL	S/N	CAL. DATE	DUE DATE
ROTEK	800A	432	10-5-99	8-5-00
KEITHLEY	177	229477	7-15-99	1-5-00

ABOVE EQUIPMENT IS TRACEABLE TO:

MFG	MODEL	S/N	CAL. DATE	DUE DATE	REPORT NO.
ROTEK	800A	432	10-5-99	8-5-00	20981
ROTEK	710	115	12-20-99	5-20-00	21054

TEMP. 72°F

HUM. 55%

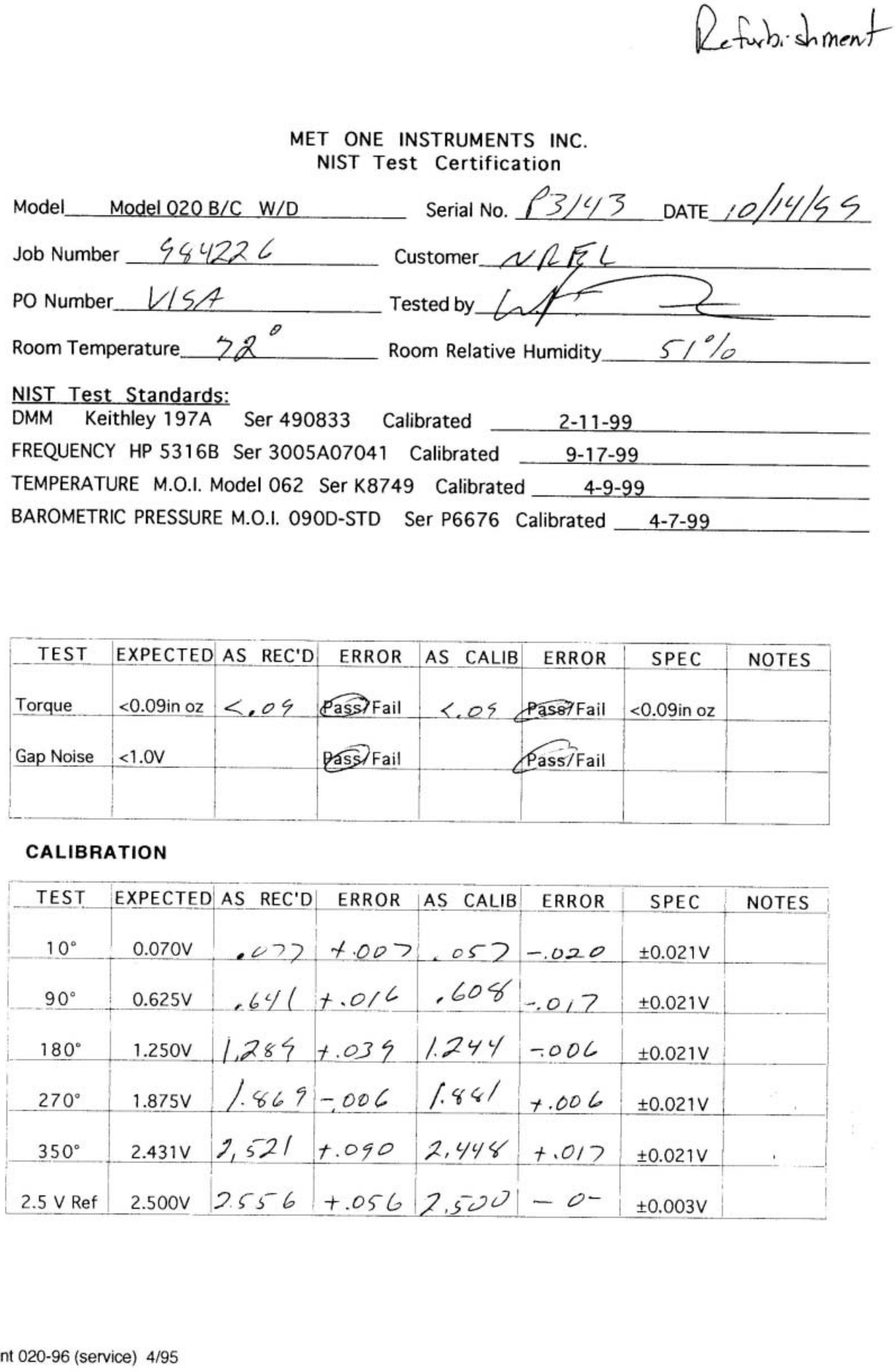
OHIO SEMITRONICS, INC.
Company

Quality Assurance

Dwg. #A-7003-02

THE LEADER IN POWER MEASUREMENT

Wind Vane



Refurbishment

MET ONE INSTRUMENTS INC.
NIST Test Certification

Model Model 020 B/C W/D Serial No. P3143 DATE 10/14/99

Job Number 984226 Customer NREL

PO Number VISA Tested by

Room Temperature 72° Room Relative Humidity 51%

NIST Test Standards:

DMM Keithley 197A Ser 490833 Calibrated 2-11-99

FREQUENCY HP 5316B Ser 3005A07041 Calibrated 9-17-99

TEMPERATURE M.O.I. Model 062 Ser K8749 Calibrated 4-9-99

BAROMETRIC PRESSURE M.O.I. 090D-STD Ser P6676 Calibrated 4-7-99

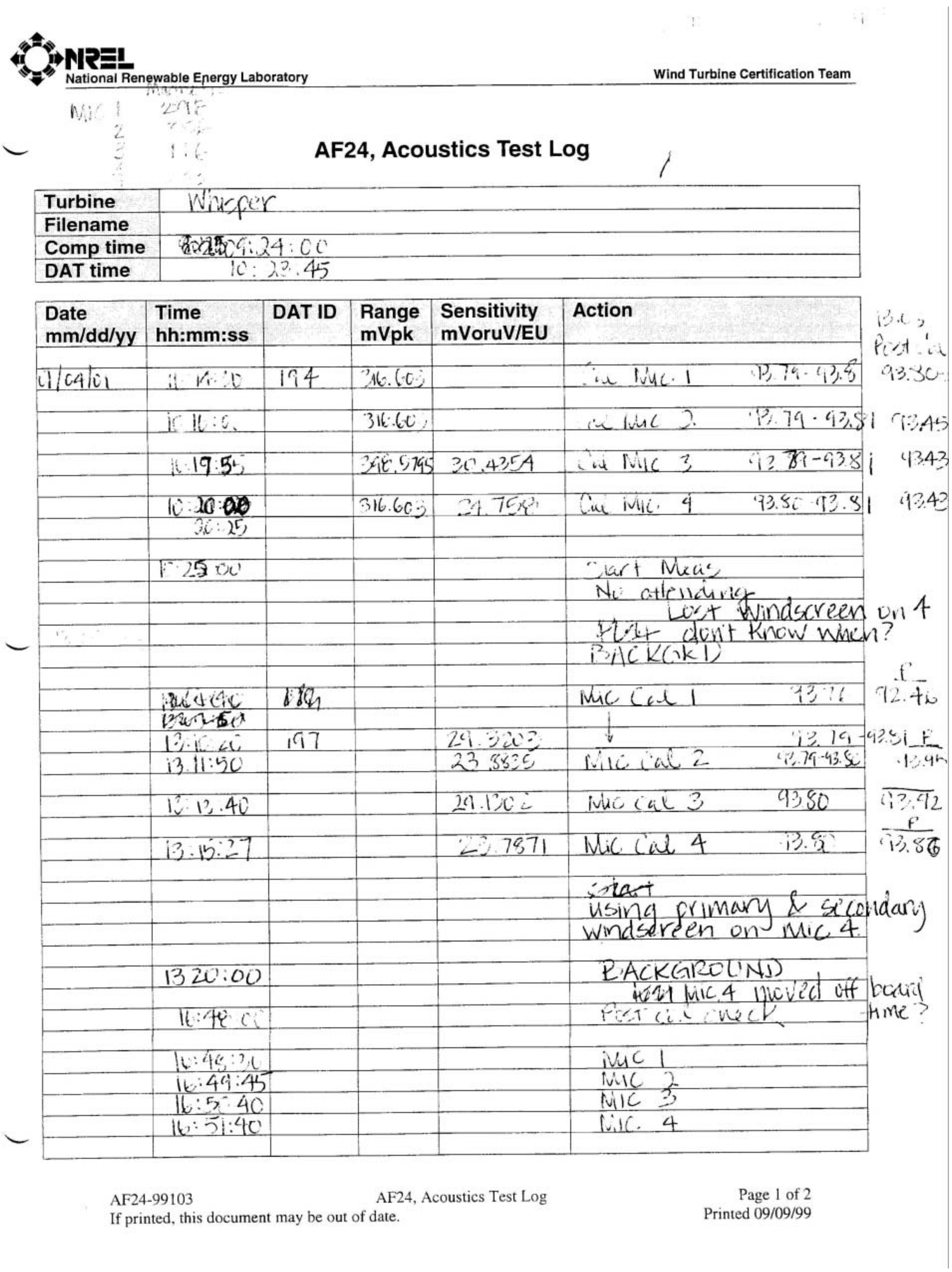
TEST	EXPECTED	AS REC'D	ERROR	AS CALIB	ERROR	SPEC	NOTES
Torque	<0.09in oz	<.09	[✓ Pass]/Fail	<.09	[✓ Pass]/Fail	<0.09in oz	
Gap Noise	<1.0V		[✓ Pass]/Fail		[✓ Pass]/Fail		

CALIBRATION

TEST	EXPECTED	AS REC'D	ERROR	AS CALIB	ERROR	SPEC	NOTES
10°	0.070V	.077	+.007	.057	-.020	±0.021V	
90°	0.625V	.641	+.016	.608	-.017	±0.021V	
180°	1.250V	1,289	+.039	1.244	-.006	±0.021V	
270°	1.875V	1.869	-.006	1.841	+.006	±0.021V	
350°	2.431V	2,521	+.090	2,448	+.017	±0.021V	
2.5 V Ref	2.500V	2.556	+.056	2.500	-0-	±0.003V	

Document 020-96 (service) 4/95

Appendix C: Log Sheets



National Renewable Energy Laboratory

Wind Turbine Certification Team

MIC 1 295
2
3 116
4

AF24, Acoustics Test Log

Turbine	Whisper
Filename	
Comp time	09:24:00
DAT time	10: 22.45

Date mm/dd/yy	Time hh:mm:ss	DAT ID	Range mVpk	Sensitivity mVoruV/EU	Action	B.C., Post Cal
01/04/01	11 16:30	194	316.603		Cal Mic 1 93.79-93.8	93.80
	10:16:0		316.603		Cal Mic 2 93.79-93.81	93.45
	10:19:55		398.5795	30.4354	Cal Mic 3 93.79-93.81	93.43
	10:20:00 30:25		316.603	24.7583	Cal Mic 4 93.80-93.81	93.43
	1:25:00				Start Meas No attending Lost windscreen on 4 don't know when? BACKGND	
	12:44:40	196			Mic Cal 1 93.76	F 92.46
	13:10:40	197		29.3203	↓ 93.79-93.81	F
	13:11:50			23.8835	Mic Cal 2 93.79-93.80	93.94
	13:13:40			29.1302	Mic Cal 3 93.80	93.92
	13:15:27			23.7871	Mic Cal 4 93.80	F 93.86
					Start using primary & secondary windscreen on Mic 4.	
	13 20:00				BACKGROUND Mic 4 moved off board time?	
	16:48:00				Post cal check	
	16:48:30				Mic 1	
	16:49:45				Mic 2	
	16:50:40				Mic 3	
	16:51:40				Mic 4	

AF24-99103 AF24, Acoustics Test Log Page 1 of 2
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[illegible]

NREL Magnetic
National Renewable Energy Laboratory

Wind Turbine Certification Team

1 298
2 356
3 116
4 233

AF24, Acoustics Test Log

Turbine	Whisper ~~H~~ 900
Filename	mic postns same as last Test
Comp time	Datalogger Time → 15:59:00
DAT time	16:58:42

Date mm/dd/yy	DAT ↓ Time hh:mm:ss	DAT ID	Range mVpk	Sensitivity mVoruV/EU	Action hybrid diesel is on
01/25/01	16:56:XX	199			Mic pwr on
" "	17:23:25	199			Cal tone #1
" "	17:24:54	199			Cal tone #2
" "	17:26:29	199			Cal tone #3
" "	17:28:21	199			Cal tone #4
		200			Turbine on
	~17:40				#4 wind screen (Lg) Blew away
	~17:43				Sm screen only at 4 New screens 1-3
	~17:45				Turbine off
	~18:02				Rick Leaves
	18:10:00				Turbine on
	18:24:20				Turbine off
	~18:40				Hal Arrives (car
	~18:46				Hal Leaves runs)
	18:50				Cal mic 1
					Cal mic 2
					Cal mic 3
	18:55				Cal mic 4

NREL [illegible]
National Renewable Energy Laboratory

Wind Turbine Certification Team [illegible]

1 29[illegible]
2 [illegible]
3 [illegible]
4 [illegible]

Calibrator 1 S/N: 830235
2 S/N: 861619

AF24, Acoustics Test Log

Turbine	Whisper H40
Filename	
Comp time	12:16:30 — NO POSITION 2 —
DAT time	13:16:09 have only 3 Secondary windscr.

Date mm/dd/yy	Time hh:mm:ss	DAT ID	Range mVpk	Sensitivity mV or uV/EU	Action MIC 1 PRE ~~Cali 1~~ ~~Cali 2~~
02/05/01	12:55:19	203	199	30.4537	Cal Mics 93.79-93.88 1st Cali
	12:57:00				2nd Calibrator 93.80-93.81
					1st cali lower than 2nd using
					MIC 3 2nd as calibrator
	12:59.30			31.184	MIC 3: 2nd Cali 9381-93.82
					1st Cali 91.79-91.87
					MIC 4
	13:03:00			31.9954 2nd	~~2nd Cali~~ 93.78-93.80
	13:04:00				1st Cali 91.85-91.88
					1st calibrator slowly
					creeps up. Calibration
					is not steady
					TURBINE ~~OFF~~ ON
	13:11:30				AOC TURNED OFF
					START MEAS
	13:12:45				START MEAS
	13:22:50 -	13:24:00			Plane noise
					TURBINE ~~ON~~ OFF
	14:01:00	14:01.10			
	14:01:10				START MEAS
	14:21:15				MIC CHECK
					MIC 1 91.68-91.7
					87.88 89
					MIC 3 91.66-91.7
					MIC 4 91.72-91.73
	14:27:45				START MEAS

AF24-99103
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AF24, Acoustics Test Log.doc

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MIC 1 9901 17509
MIC 3 9900503 17508
MIC 2/4 PA: 96050 MIC 17510

Date mm/dd/yy	Time hh:mm:ss	DAT ID	Range mVpk	Sensitivity mVoruV/EU	Action
02/05/01	15:30:00	203			Cal tone to mic 1
	15:31:30				" " " " 3
	15:33:00				" " " " 4
	15:34:30			start meas.	Normal data
					TAPE RAN OUT