HAYES MCKENZIE

PARTNERSHIP

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Gaia Wind Turbine Noise Performance Test

Report HM: 2064/R1

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GAIA-WIND TURBINE NOISE PERFORMANCE TEST

Report HM: 2064/R1

Version: 1.1

Date of Issue: 19th February 2009

Site: White Lodge Farm, Melton Mowbray, Leicestershire, UK

Dates of Measurements: 21st November 2008 (Sylvia Broneske Dipl.-Ing. and Joel J Braham BSc)
16th January 2009 (Andrew A Roberts BSc, BEng.)

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1. Introduction

1.1 A turbine noise performance test has been carried out on a Gaia-Wind GW11 turbine at White Lodge Farm located to the south east of Frisby on the Wreake and approximately 4 miles south west of Melton Mowbray, Leicestershire, United Kingdom.

1.2 The turbine has a hub height of 18.3 m and a downwind rotor with a diameter of 13 m. The Gaia-Wind turbine is passive stall regulated and has a rated power of 11 kW, which is achieved at a wind speed of approximately 9.5 m/s at hub height.

1.3 The objective of this test was to measure the noise performance characteristics of The wind turbine. The test consisted of measurement of the sound power level and tonal characteristics.

1.4 This noise test was conducted in accordance with the BWEA Small Wind Turbine Performance and Safety Standard (February 2008) which is based on BS EN 61400-11 (2003) with exceptions to allow for the differing performance of small wind turbines.

1.5 The test took place on two days: 21st November 2008 with wind speeds from ranging from 6 to 11 m/s at rotor centre height and 16th January 2009 with wind speeds ranging from 4 to 8 m/s at rotor centre height.

2. Turbine Specification

2.1 The wind turbine is a two-bladed, passive stall downwind turbine. A summary of the turbine's specification, as supplied by the manufacturer, is shown in Table 1 below.

Table 1: Turbine Specifications

Parameter	Value/Feature
Manufacturer	Gaia-Wind Ltd.
Model Number	GW11
Type (upwind/downwind)	Downwind
Hub Height	18.3 m (tower height 18 m)
Rotor Diameter	13 m
Rated Power	11 kW (at 9.5 m/s at rotor centre)

Parameter	Value/Feature
Tower Type	Lattice
Turbine Control (stall/pitch)	Passive stall
Rotational Speed	Constant, 56 rpm nominal
Number of Blades	2
Cut-in Wind Speed	3.5 m/s
Cut-out Wind Speed	> 25 m/s

3. Measurement

Site Layout and Measurement Position

3.1 The site layout is shown at Appendix A. The site consists of open farmland bordered by hedgerows, which occasionally include trees. The GW11 is the only wind turbine on the site. At the time of the first measurement in November 2008, sheep were kept on the adjacent field, where the microphone was positioned downwind of the wind turbine. The sheep kept well away from the microphone so that no interference from the animals with the measurement equipment was caused.

3.2 The BWEA Small Wind Turbine Performance and Safety Standard dated February 2008 [1] states that acoustic noise emissions shall be measured in general accordance with BS EN 61400-11 (2003) [2] with exceptions to allow for the differing performance of small wind turbines.

3.3 [1] and [2] specify that the microphone used for the noise tests is to be mounted on a 1 m diameter ground-mounted board, facing in the direction of the wind turbine under test, at a distance corresponding to the tip height of the turbine (+/- 20%) directly downwind of the turbine. According to [1], measured noise data is valid as long as the board is substantially within the downwind sector (i.e. +/- 60° of the directly downwind direction) to allow for frequent yawing of small wind turbines. Photos of the noise monitoring equipment set up are shown in Appendix B.

3.4 The microphone was fitted inside a primary open cell foam wind shield of 90 mm in diameter which had been cut in half to allow it to lie flat on the board. The primary wind shield was surrounded by a secondary wind shield, consisting of a 450 mm diameter hemisphere of 50 mm thickness foam.

3.5 [1] requires an anemometer to measure wind speed, to be placed at a distance of 2 to 4 D, directly upwind of the turbine rotor, where D is the rotor diameter of the wind turbine (here D = 13 m). Wind speed values are valid as long as the anemometer position is within the upwind sector (i.e. +/- 90° of the directly upwind direction).

3.6 Synchronised wind speed and wind direction measurements were made using a Second Wind C3 anemometer and an NRG #200P wind vane mounted at 10 m height connected to a Nomad 2 GSM data logger.

3.7 The microphone and the met mast position were in its acceptable range throughout the whole measurement period.

3.8 Table 2 details the measurement positions. $R_{0,i}$ is the reference distance on each measurement day and R_i is the slant distance from the measurement position to the centre of the hub where it meets the nacelle. All distances were measured using a laser distance finder with an accuracy of ±0 .3m.

Table 2: Distances and Reference Values

Parameter		Value
Hub Height	H	18.3 m
Rotor Diameter	D	13 m
Reference Distance	$R_{0,calc}$	24.8 m
Reference Distance day 1	$R_{0,1}$	25 m
Reference Distance day 2	$R_{0,2}$	24 m
Slant Distance day 1	R_1	29.3 m
Slant Distance day 2	R_2	28.5 m
Reference Roughness Length	z_{0ref}	0.05 m
Anemometer Height	z	10 m
Reference Height	h_{ref}	18.3 m

3.9 During the noise tests the wind turbine was shut down for certain periods to allow for background noise measurements to be included as part of the test procedure in order to establish the level of contribution from other noise sources.

4. Instrumentation

4.1 Noise measurements were carried out using the following equipment:

General

Bruel & Kjær Type 4231 calibrator (Serial No. 2218188) on 21/11/2008

Larson Davis Calibrator CAL200 (S/N 3599) on 16/01/2009

Reference Position

Larson Davis Sound Level Meter LD820 (Serial No. 1142)

GRAS 1/2" Microphone model 40AE (S/N 49531)

Larson Davis Model 828 Pre-Amplifier (S/N 1587)

Zoom Handy Recorder H4 for audio files

4.2 The microphone was connected via 5 m of microphone cable to the sound level meter, which was programmed to record the 1 minute values of equivalent continuous sound pressure levels (L_{Aeq}). A WAV audio recording of the turbine noise was collected continuously from the A/C output of the sound level meter. The time clock of the sound level meter was set to GMT at the start of the measurements.

4.3 The equipment was calibrated prior to measurements being performed and checked at the end. The maximum calibration drift recorded for measurements was 0.2 dB.

4.4 Wind speed and wind direction were measured in 1 minute periods at 10 m height with an anemometer and a wind vane. The data logger was set to GMT at the start of the measurements.

5. Calculation of Wind Speed

5.1 According to [1] the wind speed shall be measured and not derived from a turbine power curve. Minimum measurement height is 5 m.

5.2 Wind speed was measured at 10 m height. The reference height for small wind turbines is the rotor centre height. The reference wind speed was calculated by using following equation:

$$v_{ref} = v_{10m} \cdot \frac{\ln \frac{h_{ref}}{z_0}}{\ln \frac{10\text{m}}{z_0}}$$

where:

v_{ref}	is the wind speed at reference height (here at 18.3 m)
v_{10m}	is the wind speed at 10 m height
h_{ref}	is the reference height = hub height
z_0	roughness length (0.05 m for farmland with some vegetation)

6. Results

Measured Noise Levels

6.1 1-minute average measured L_{Aeq} Noise data was plotted against the reference height wind speed for operational noise periods and separately for background noise periods. All noise data has been filtered such that any 1-minute period that was affected by specific extraneous noises such as aircraft, vehicles, rainfall, and any other anomalies have been removed from the assessment.

6.2 Appendix C shows the measured total noise and measured background noise at the microphone position, plotted against the wind speed at rotor centre height for both days. After the removal of data as described above, the data base of the first survey consists of 100 and for the second survey of 191 wind speed – noise data pairs for total measured noise.

6.3 As required by [1], a linear regression line was plotted through the measured L_{Aeq} turbine data and through the measured background data at the reference position, as shown in Appendix C.

6.4 The equation obtained for the regression lines of the data of both measurement days was used to determine the turbine and background noise levels at each integer wind speed. The measured total noise levels were corrected for the influence of background noise as described below.

Calculation of Sound Power Level

6.5 The methodology prescribed by [1] was used to calculate the sound power level of the turbine under test. A summary table detailing the steps is shown below in Table 3.

Table 3: Calculation of Sound Power Level for all measured data (R_l= 28.9 m)

Reference height wind speed (m/s)	4	5	6	7	8	9	10
Total Noise Level (dB L_{Aeq})	48.1	49.2	50.3	51.4	52.5	53.6	54.7
Background Noise Level (dB L_{Aeq})	39.1	40.7	42.3	43.9	45.5	47.1	48.7
Difference Between Total and Background Noise (dB)	9.0	8.5	8.0	7.5	7.0	6.5	6.0
Background Corrected Sound Pressure Level, $L_{Aeq,c,k}$ (dB L_{Aeq})	47.5	48.5	49.6	50.6	51.6	52.5	53.5
Apparent Sound Power Level, $L_{WA,k}$ (dB L_{WA})	**81.7**	**82.7**	**83.8**	**84.8**	**85.8**	**86.7**	**87.7**

1/3 Octave Band Data

6.6 The four 1-minute average periods closest to the reference wind speed of 8 m/s for each measurement day have been used to calculate the energy average 1/3 octave band spectra between 20 and 10 kHz as measured at the Reference Position. The linear, A-weighted and C-weighted results are shown in Appendix D. The data has been corrected for the influence of background noise as described in [2].

Tonality

6.7 The tonality assessment was carried out with the method according to ISO 1996-2: 2007 [3] Annex D, as suggested in [1].

6.8 The turbine is declared tonal if any 1/3 octave band is higher than its adjacent bands by:

- 15 dB in the low frequency bands (50 to 125 Hz)
- 8 dB in the mid-frequency bands (160 to 400 Hz)
- 5 dB in the high frequency bands (500 to 10000 Hz).

6.9 For the assessment four 1/3 octave band spectra from the first measurement day and four 1/3 octave band spectra from the second measurement day, closest to the wind speed of 8 m/s at rotor centre height, were used.

6.10 The tonal analysis was carried out for the linear, A-weighted and C-weighted 1/3 octave band spectra of the total noise measured at the microphone reference point as shown in Appendix E.

6.11 Based on the 4 spectra being closest to the reference wind speed of 8 m/s at rotor centre height from the measurement on 21/11/08 and 16/01/2009 respectively, the Gaia-Wind turbine is not found to be tonal.

6.12 This assessment is valid for the reference point, where the noise measurement took place and describes the noise character for the proximity of the wind turbine only.

7. Uncertainty

7.1 An assessment of measurement uncertainty has been carried out, based on the procedure outlined in Annex D of [2], as follows: Type A uncertainties are evaluated from the extent to which the measured values vary around the derived mean based on the regression analysis; Type B uncertainties are a measure of the assumed accuracy of various factors in the measurements procedure and have been taken from the Annex D except where indicated. The total uncertainty U_C is evaluated from the square root of the sum of the squares of each individual component.

7.2 The standard uncertainty of the apparent sound power is calculated in Table 4 using Equation D.1 in Annex D of [2]. The total uncertainty of the measured L_{WA} calculated from all uncertainties, as given in Table 5, is ± 1.4 dB for the Reference Position.

Table 4: Calculation of L_{WA} Uncertainty U_A

Number of Elements	291
sum((y-y(est))^2)	172.1
Standard Error U_A	0.772

Table 5: Calculation of Uncertainty U_C

Type A Uncertainty	
Standard Error of L_{WA} Estimate from Regression Analysis	0.772
Type B Uncertainty	
Calibration	0.2
Instrument	0.2
Board & Mounting	0.3
Distance	0.1
Impedance	0.1
Turbulence	0.4
Wind Speed Derived	0.9
Background	0.5
Total	1.4

8. Tables of Results

8.1 According to [1] the declared apparent emission sound power level $L_{Wd,\,8m/s}$ is calculated using the approach of [4] for a 95% confidence level:

$$L_{Wd\,8m/s} = L_{W,8m/s} + 1.645 \cdot \sigma$$

where

$L_{Wd,\,8m/s}$ is the declared apparent sound power level at the reference wind speed 8 m/s

$L_{W,\,8m/s}$ is the apparent sound power level at the reference wind speed 8 m/s

σ is here equivalent to the measurement uncertainty UC.

Table 6: Noise Levels of a Gaia-Wind GW11 Wind Turbine for a reference wind speed of 8 m/s

Parameter	Value
Apparent Sound Power Level $L_{W,\,8m/s}$	85.8 dB(A)
Measurement Uncertainty U_C	1.4 dB
Declared Apparent Emission Sound Power Level $L_{Wd,\,8m/s}$	88.1 dB(A)
Noise Slope S_{dB}	1.015 dB/m/s
Noise Penalty P	none

Table 7: Immission Sound Pressure Levels at given Distance for a reference wind speed of 8 m/s

Parameter	Value
Immission Sound Pressure Level at 60 m $L_{p,60m}$	44.6 dB(A)
Immission Sound Pressure Level at 25 m $L_{p,25m}$	52.1 dB(A)
Slant Distance required for 45 dB(A)	56.9 m
Slant Distance required for 40 dB(A)	101.2 m

8.2 The Noise Label according to [1] is attached in Appendix F.

9. Conclusions

9.1 A noise test has been carried out, according to BWEA Small Wind Turbine Performance and Safety Standard on a Gaia-Wind turbine installed at White Lodge Farm, Melton Mowbray to measure the sound power level and tonal characteristics.

9.2 The turbine was calculated to have an apparent sound power level of 85.8 dB(A) ± 1.4 dB at a wind speed of 8 m/s at rotor centre height, as measured at the Reference Position directly down wind of the turbine. The declared apparent emission sound power level for 8 m/s at rotor centre height was calculated to be 88.1 dB(A).

9.3 The tonal output from the Gaia-Wind turbine has been assessed using the methodology prescribed by [1]. Based on the methodology described in [3], Annex D, no tonal characteristics were found.

Reference List

[1] Small Wind Turbine Performance and Safety Standard
British Wind Energy Association, February 2008

[2] BS EN 61400-11 Wind turbine generator systems – Part 11: Acoustic noise measurement techniques (identical with IEC 61400-11:2002)
Standards Policy and Strategy Committee, August 2003

[3] ISO 1996-2 Acoustics – Description, measurement and assessment of environmental noise, Part 2: Determination of environmental noise levels
International Organization for Standardization, 2007

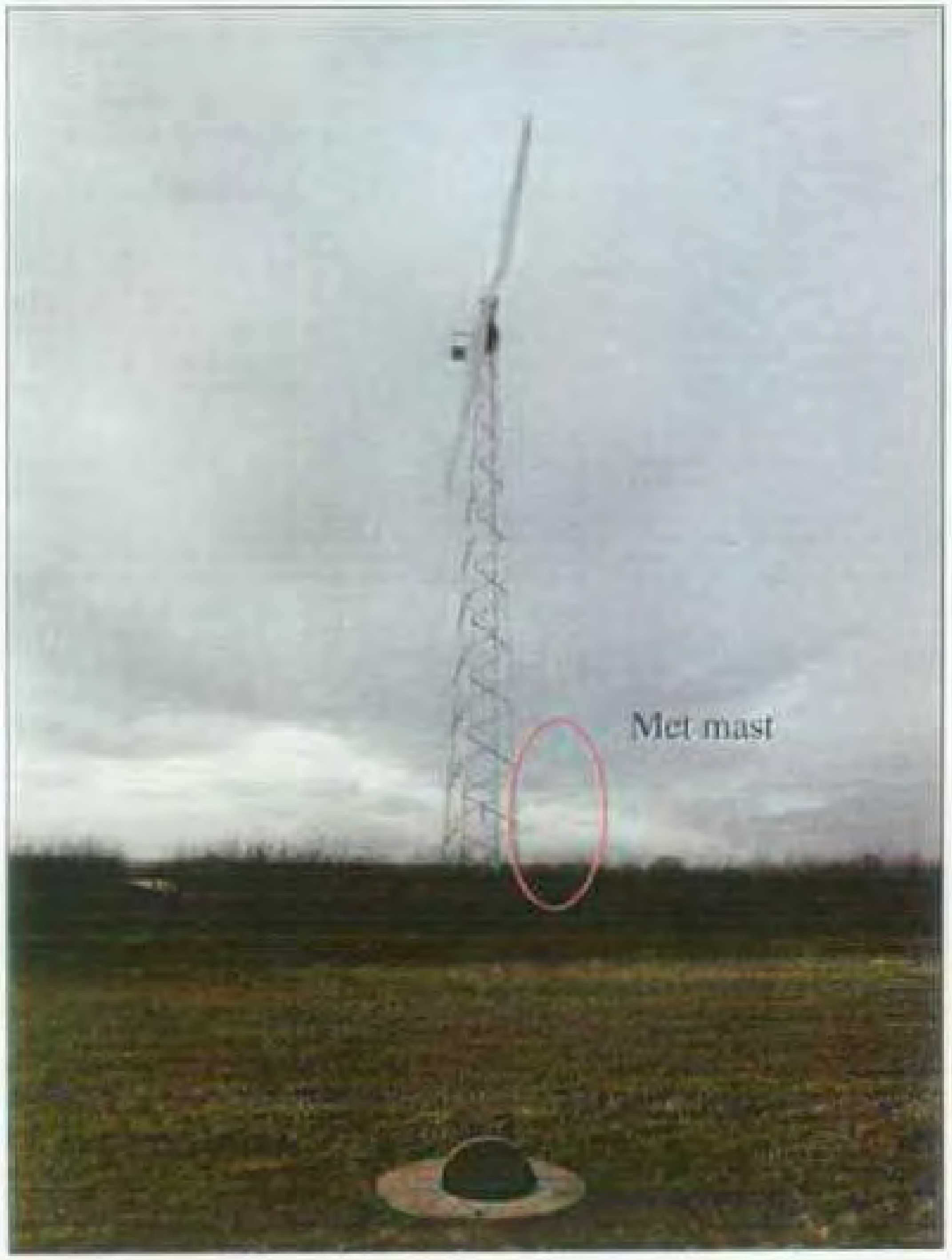
[4] IEC TS 61400-14 Wind turbines – Part 14: Declaration of apparent sound power level and tonality values
International Electrotechnical Commission, 2005

Appendix A
Site Layout


Frisby on the Wreake
Kirby Bellars
Rotherby
Leicester Road
Ash Tree Farm
Kirby Hall Farm
Hickory Lodge Farm
FRISBY AND KIRBY CP
Gaddesby Lane
White Lodge
Gaia-Wind turbine position
Highfields Farm
Kirby Lodge Farm
Messenger's Lodge Farm
Cream Gorse Farm
18
17
16
15

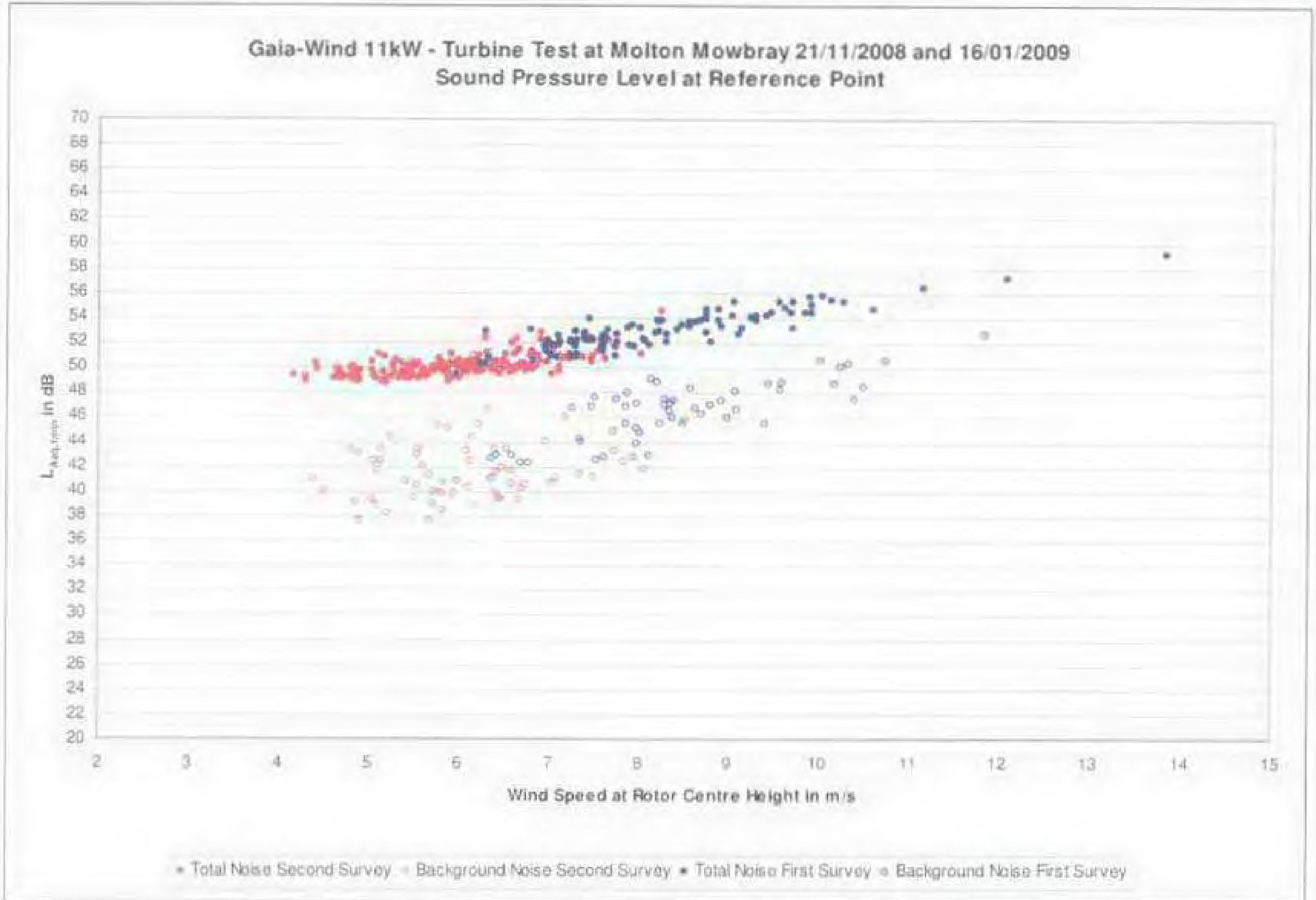
Appendix B
Photos of Noise Measurement Equipment

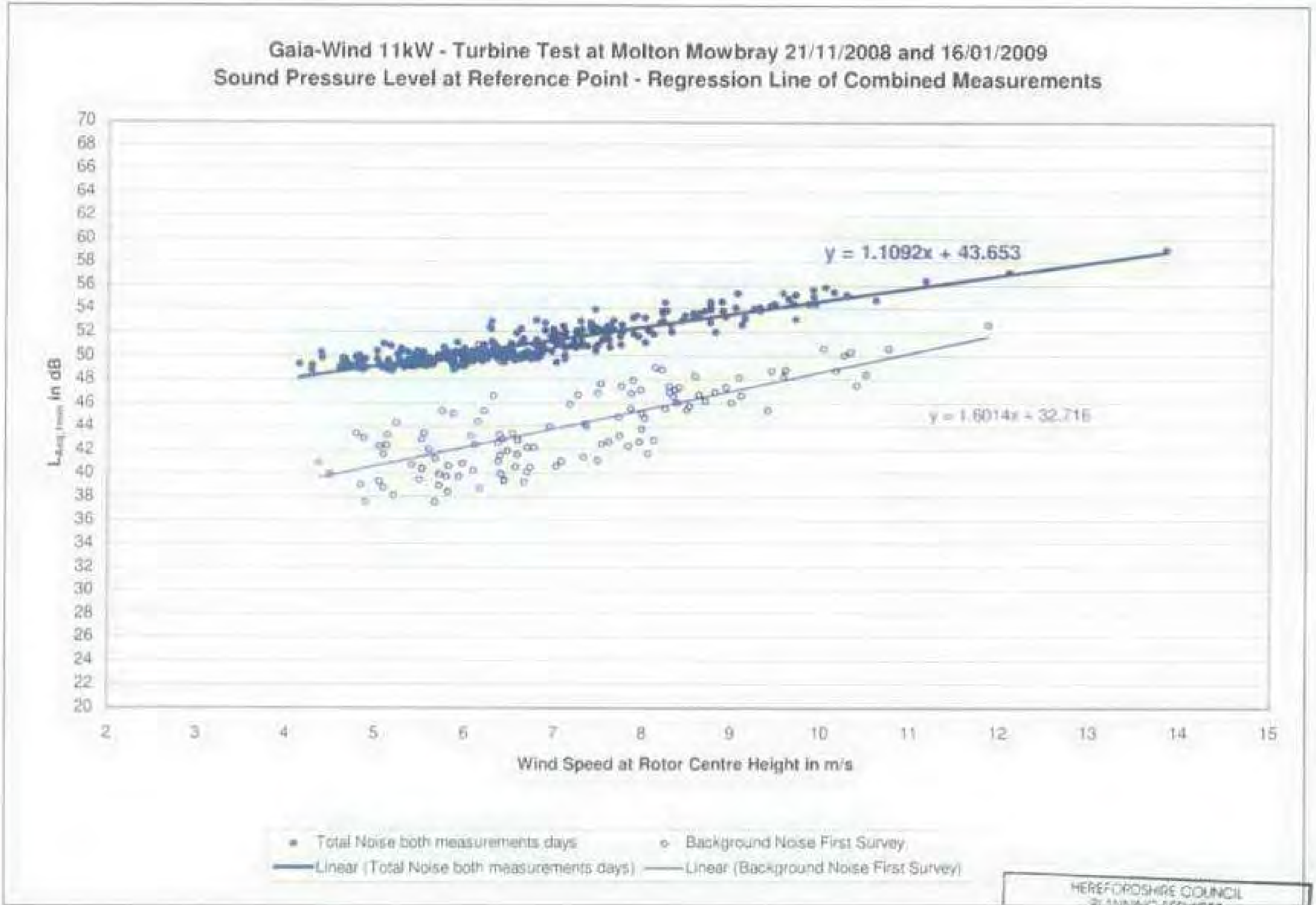
Photographs of Noise Measurement Equipment
(Gaia-Wind Turbine on 21st November 2008)



Photographs of Noise Measurement Equipment
(Gaia-Wind Turbine on 16th January 2009)

Appendix C
Noise Data for Calculation of Sound Power Level


Gaia-Wind 11kW - Turbine Test at Molton Mowbray 21/11/2008 and 16/01/2009
Sound Pressure Level at Reference Point
L in dB
Wind Speed at Rotor Centre Height in m/s
Total Noise Second Survey
Background Noise Second Survey
Total Noise First Survey
Background Noise First Survey


Gaia-Wind 11kW - Turbine Test at Molton Mowbray 21/11/2008 and 16/01/2009
Sound Pressure Level at Reference Point - Regression Line of Combined Measurements
y = 1.1092x + 43.653
y = 1.6014x + 32.716
L_Aeq in dB
Wind Speed at Rotor Centre Height in m/s
Total Noise both measurements days
Background Noise First Survey
Linear (Total Noise both measurements days)
Linear (Background Noise First Survey)

NE/100235/F

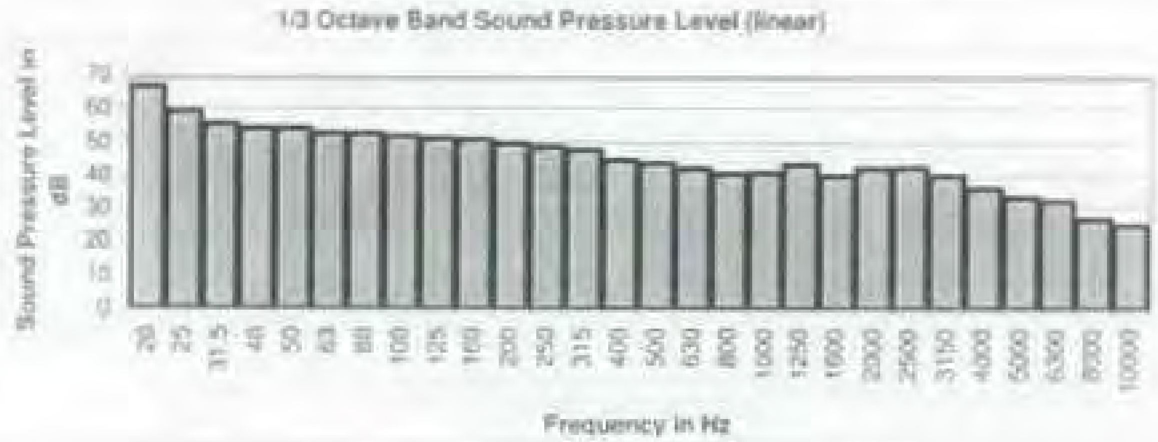
Appendix D
1/3 Octave Band Data

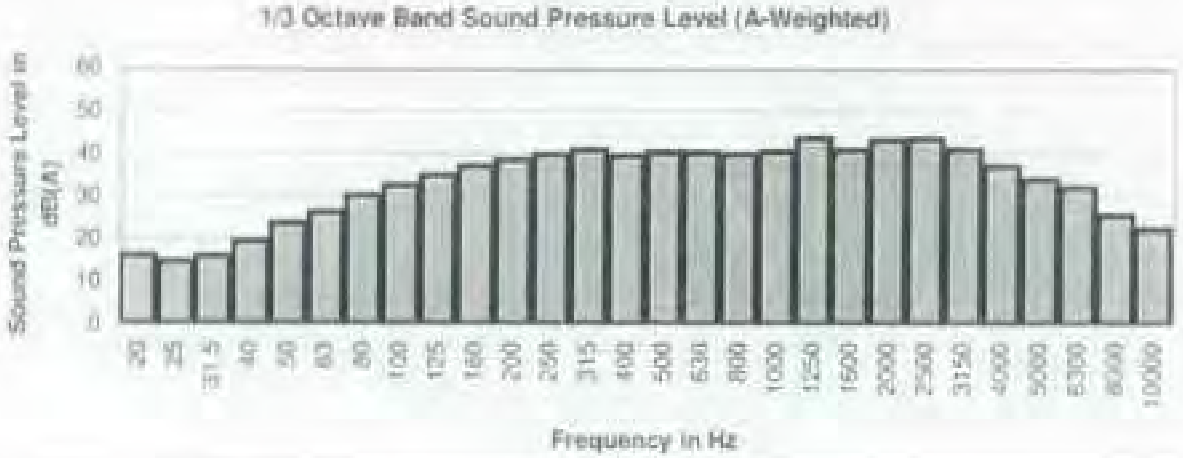
For Reference Wind Speed of 8 m/s at Rotor Centre Height

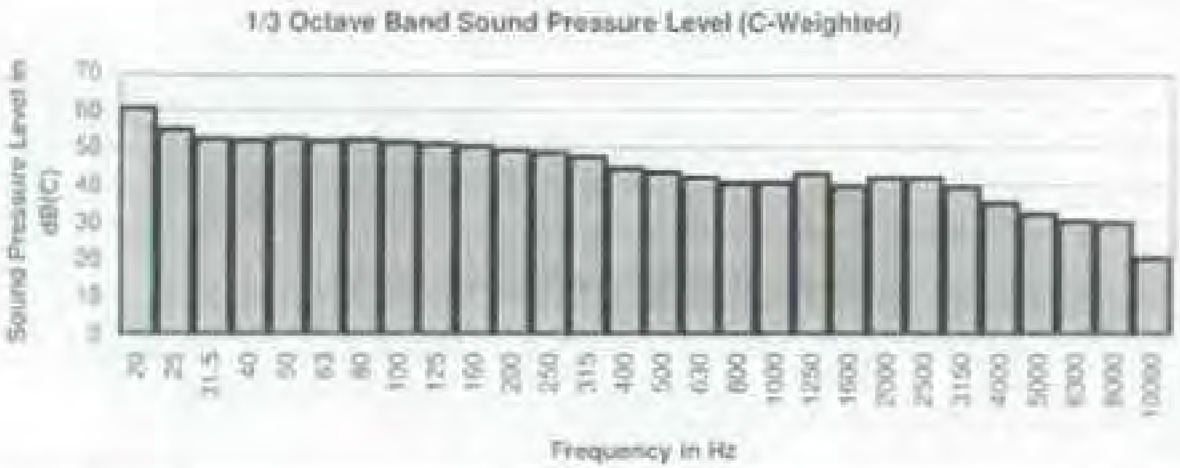
1/3 Octave Band Levels - Sound Pressure Level for a wind speed of 8 m/s at rotor centre height (Measurement Date 21/11/2008)

f (Hz)	$L_{W,1/3\ Octave}$ (dB(lin))	$L_{W,1/3\ Octave}$ (dB(A))	$L_{W,1/3\ Octave}$ (dB(C))
20	66.6	16.1	60.4
25	59.2	14.5	54.8
31.5	55.3	15.9	52.3
40	53.9 *	19.3 *	51.9 *
50	53.8 *	23.6 *	52.5 *
63	52.5 *	26.3 *	51.7 *
80	52.5 **	30.0 **	52.0 **
100	51.6	32.5	51.3
125	51.1	35.0	50.9
160	50.5	37.1	50.4
200	49.4	38.5	49.4
250	48.4	39.8	48.4
315	47.5	40.9	47.5
400	44.3 *	39.9 *	44.3 *
500	43.4 **	40.2 **	43.4 **
630	42.0 **	40.1 **	42.0**
800	40.5	39.7	40.5
1000	40.5	40.5	40.5
1250	43.0	43.6	43.0
1600	39.8	40.8	39.7
2000	42.0	43.2	41.8
2500	42.2	43.5	41.8
3150	39.9	41.1	39.4
4000	35.9	36.9	35.1
5000	33.4	33.9	32.1
6300	32.2	32.1	30.2
8000	26.8	25.7	29.8
10000	24.7 *	22.2 *	20.3 *

* Difference between total noise and bg noise < 6 dB
** Difference between total noise and bg noise < 3 dB, no correction applied

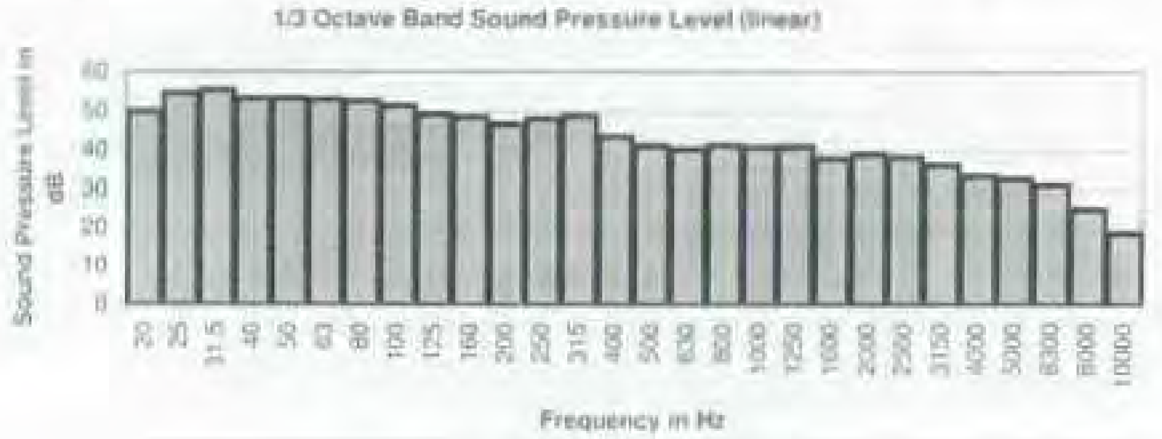


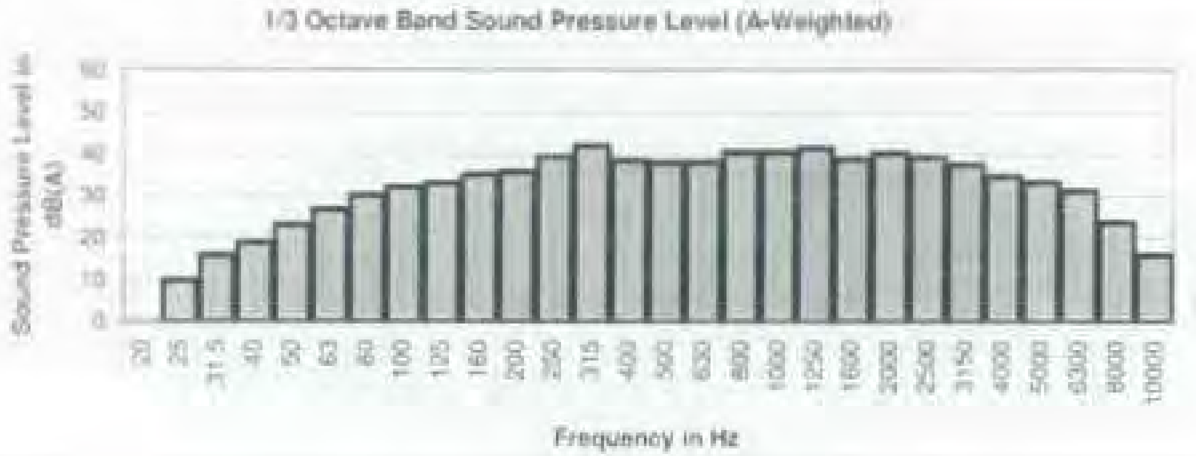




1/3 Octave Band Levels - Sound Pressure Level for a wind speed of 8 m/s at rotor centre height (Measurement Date 16/01/2009)

f (Hz)	$L_{W,1/3\ Octave}$ (dB)	$L_{W,1/3\ Octave}$ (dB(A))	$L_{W,1/3\ Octave}$ (dB(C))
20	49.8 *	-0.7 *	43.6 *
25	54.5	9.8	50.1
31.5	55.5 *	16.1 *	52.5 *
40	53.4 *	18.8 *	51.4 *
50	53.4 **	23.2 **	52.1 **
63	53.1 **	26.9 **	52.3 **
80	52.7 **	30.2 **	52.2 **
100	51.3 *	32.2 *	51.0 *
125	49.3 *	33.2 *	49.1 *
160	48.4	35.0	48.3
200	48.7	35.8	46.7
250	48.1	39.5	48.1
315	48.6	42.0	48.6
400	43.3	38.5	43.3
500	41.1	37.9	41.1
630	40.2	38.3	40.2
800	41.4	40.6	41.4
1000	40.7	40.7	40.7
1250	41.0	41.6	41.0
1600	37.9	38.9	37.8
2000	39.0	40.2	38.8
2500	38.2	39.5	37.9
3150	36.2	37.4	35.7
4000	33.6	34.6	32.8
5000	32.8	33.3	31.5
6300	31.3	31.2	29.3
8000	24.8	23.7	27.8
10000	18.6 *	16.1 *	14.2 *





* Difference between total noise and bg noise < 6 dB
** Difference between total noise and bg noise < 3 dB, no correction applied

Appendix E
Spectra for Tonality Assessment

For Reference Wind Speed of 8 m/s at Rotor Centre Height

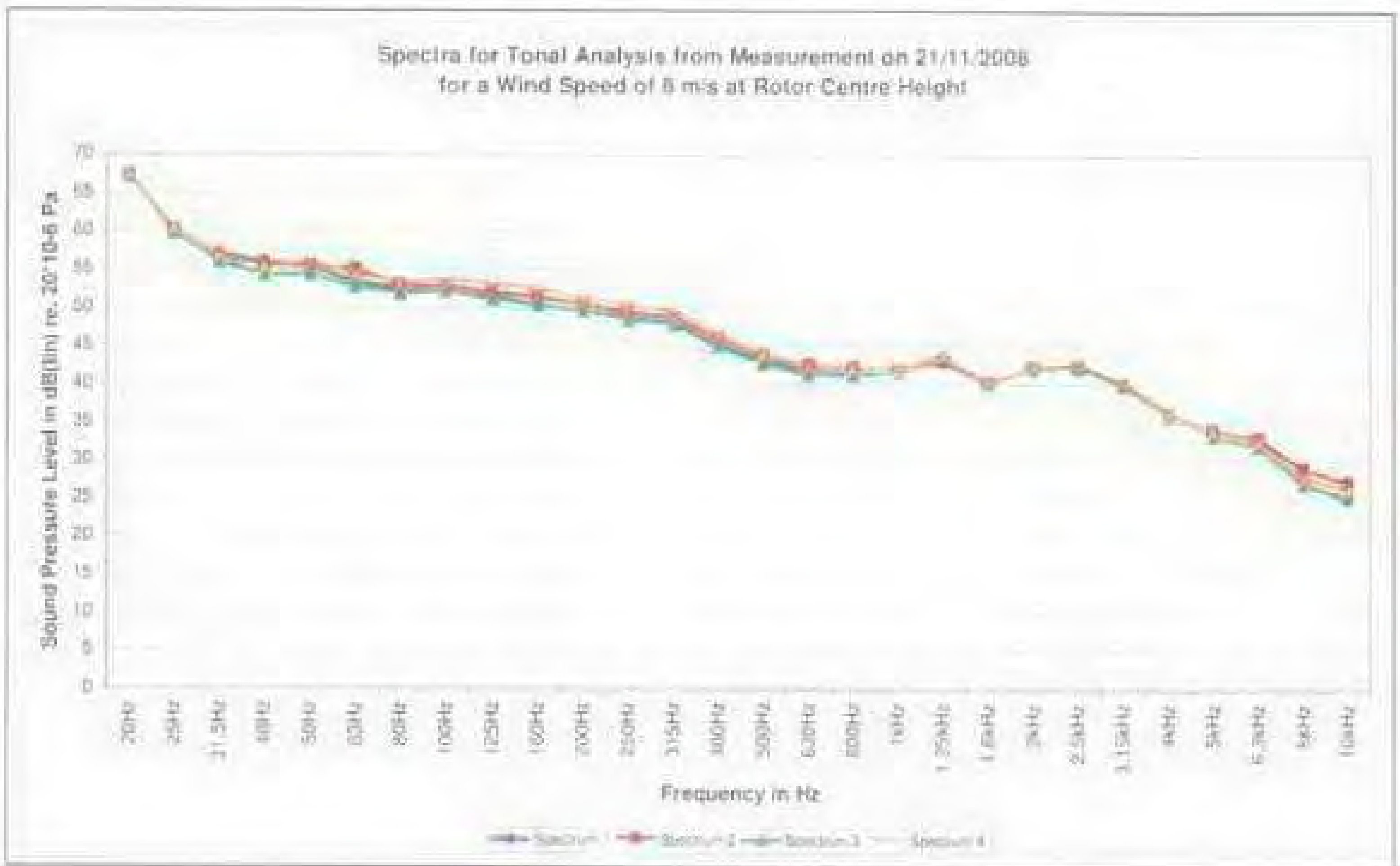


Figure 1: Linear 1/3 Octave Band Spectra for Total Measured Noise at Reference Point on 21/11/2008

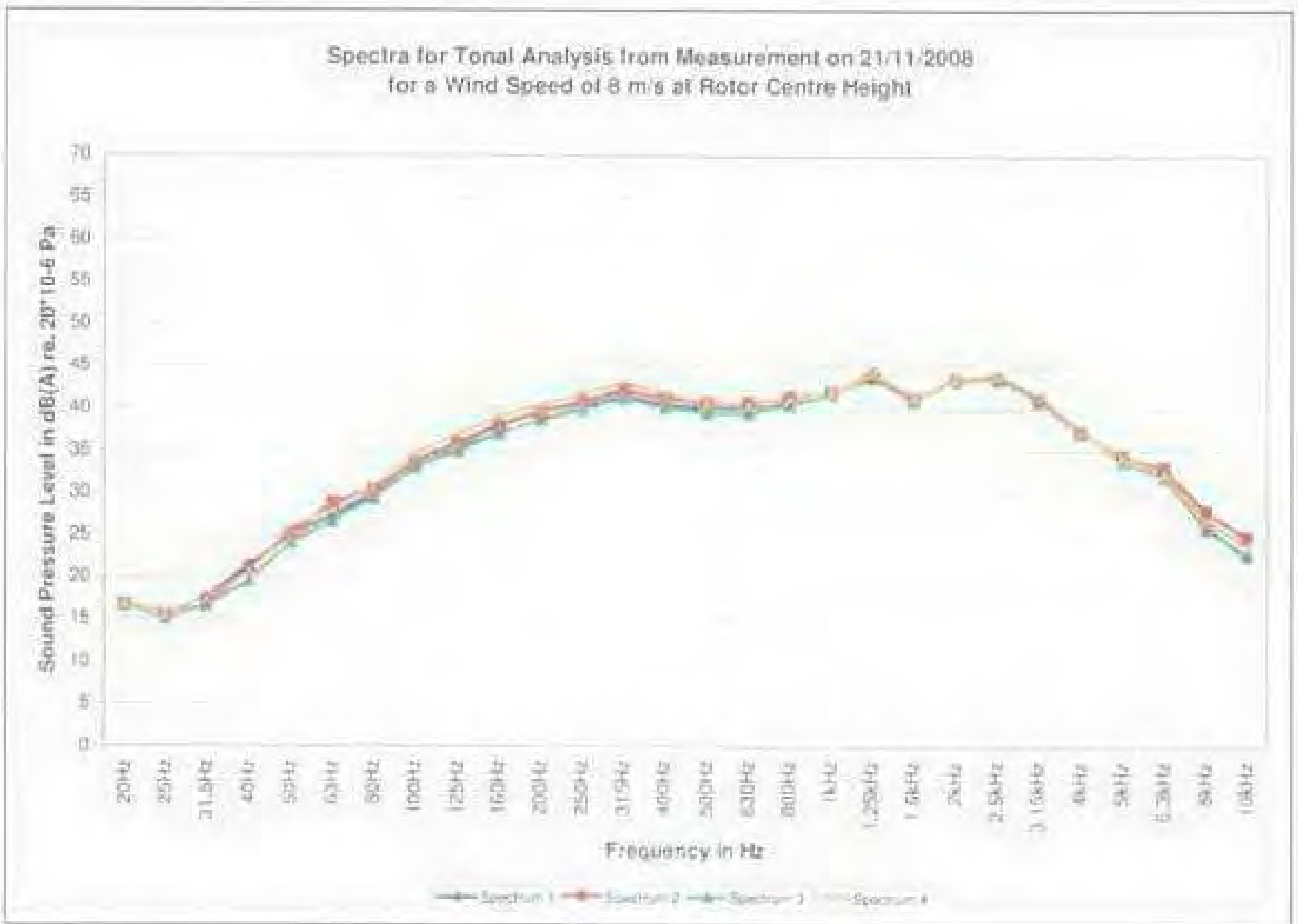


Figure 2: A-Weighted 1/3 Octave Band Spectra for Total Measured Noise at Reference Point on 21/11/2008

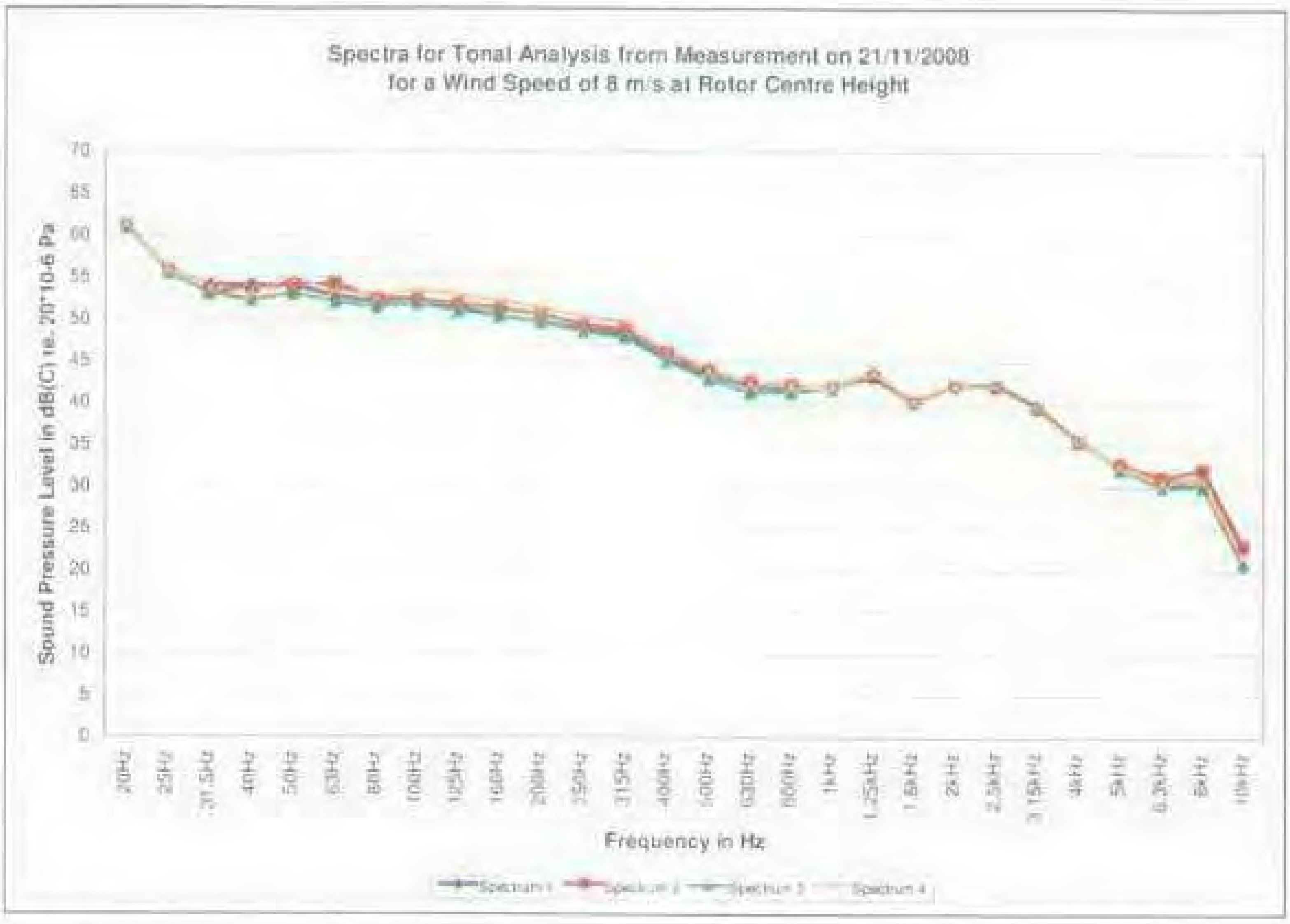


Figure 3: C-Weighted 1/3 Octave Band Spectra for Total Measured Noise at Reference Point on 21/11/2008

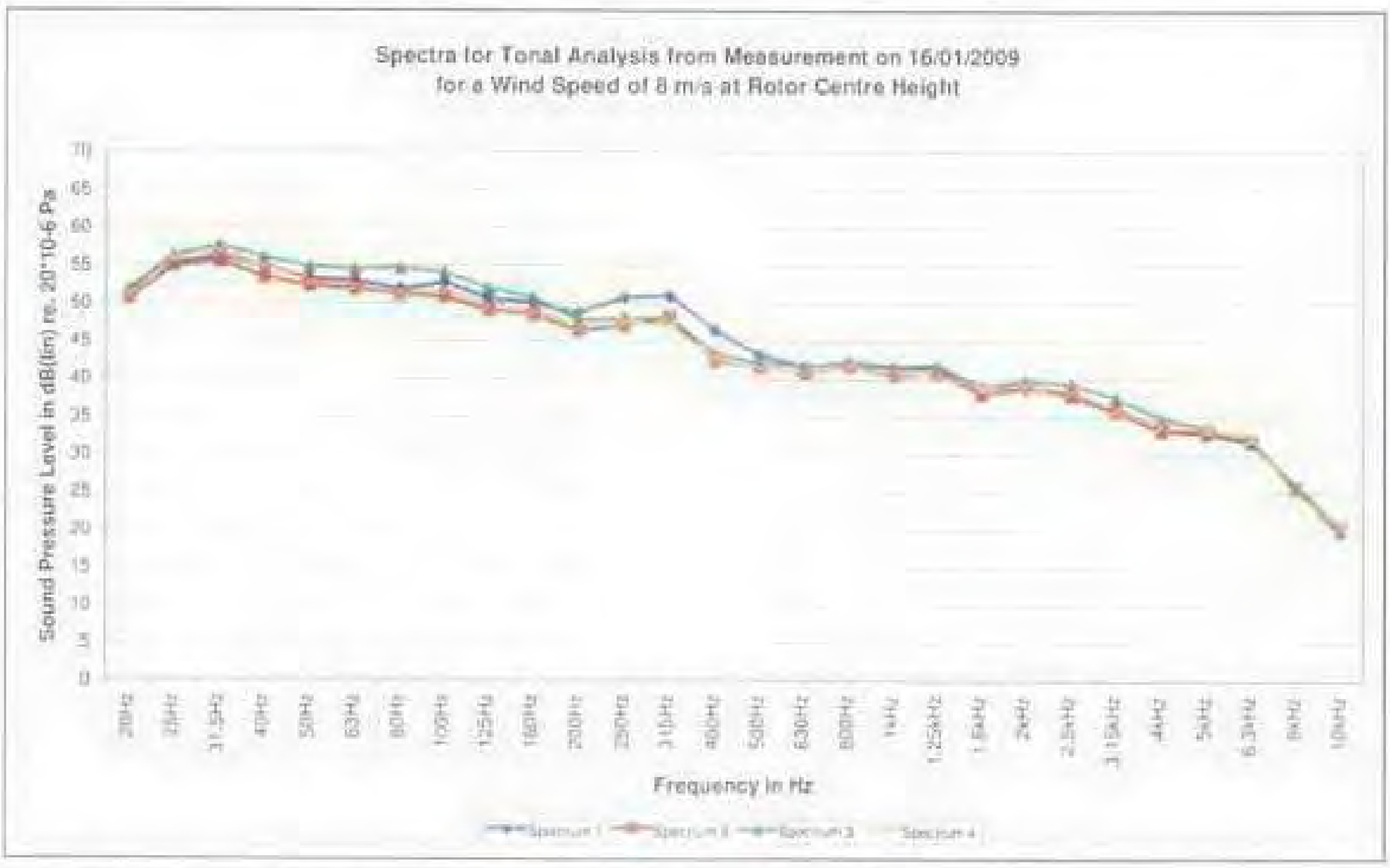


Figure 4: Linear 1/3 Octave Band Spectra for Total Measured Noise at Reference Point on 16/01/2009

Figure 5: A-Weighted 1/3 Octave Band Spectra for Total Measured Noise at Reference Point on 16/01/2009

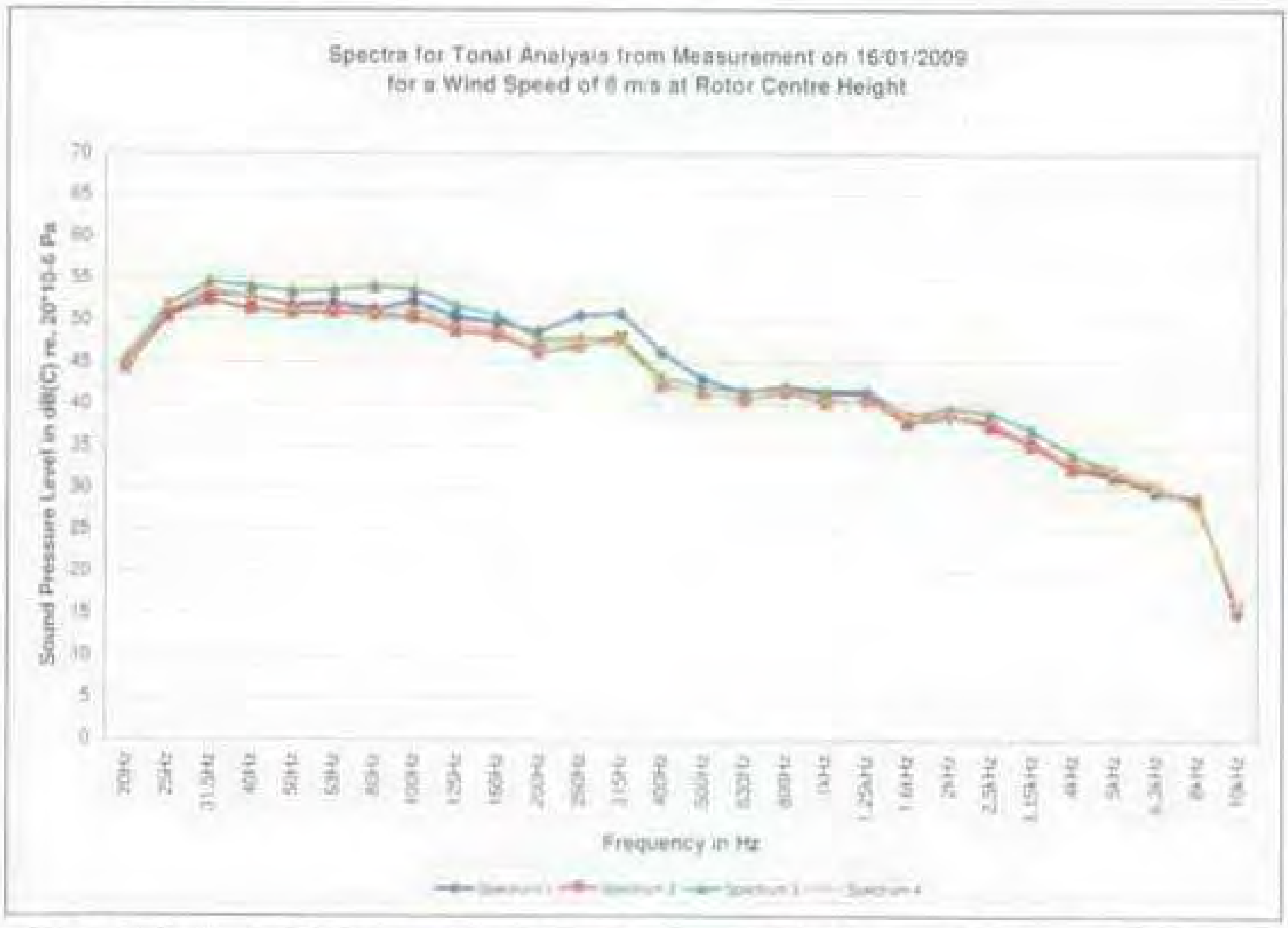


Figure 6: C-Weighted 1/3 Octave Band Spectra for Total Measured Noise at Reference Point on 16/01/2009

Appendix F
Noise Label

For Reference Wind Speed of 8 m/s
at Rotor Centre Height

Acoustic Noise Levels				
Turbine Make:	Gaia-Wind Ltd	Model:		GW 11
NOISE EMISSION LEVEL				NOISE PENALTY
Sound Power $L_{Wd,8m/s}$	88.1 dB(A)	Noise Slope, SdB (dB/m/s)	1.015	NO

HM: 2064/R1
Melton Mowbray Turbine Test

Tested and Issued by:
Hayes McKenzie Partnership Ltd.
February 2009