Attachment C

July 2009

Use of Vestas safety regulations manual against wind project siting

Certain older versions of the "General Precautions" chapter of Vestas' Safety Regulations manuals, including the manual "Safety Regulations for Operators and Technicians — V90-3.0 MW/V100-2.75 MW," warn turbine operators and technicians to stay outside a certain radius from a wind turbine "unless necessary." This language, however, was meant to apply only in the event of specific wind turbine malfunctions or abnormal operating conditions, including a runaway turbine or fire. The warning was never intended to apply to normally operating turbines. Accordingly, the specific warning was misplaced in the manual's "General Precautions" chapter.

Some opponents of wind projects have argued that Vestas' manuals identify a safety zone around a Vestas wind turbine in normal operation. Vestas has no documentation, studies or analysis proscribing a specified safety zone around its wind turbines in normal operation. As a result, Vestas has recently removed the warning from the "General Precautions" chapter in all of its manuals. However, Vestas continues to specify a radius that should be evacuated in case of turbine malfunction or abnormal operating conditions such as a runaway turbine or fire.

Vestas believes decisions related to the siting of wind turbines are best left up to local jurisdictions in consultation with the various stakeholders interested in the specific project. Vestas' Safety Regulations manuals should not be cited as support for any specific safety zone or setback for wind turbines in normal operation.

Wind turbines are sophisticated pieces of equipment and Vestas takes great care to ensure the safety of its equipment, its employees and their communities. As with any sophisticated electric-generation equipment, malfunction or abnormal operating conditions can occur. Nevertheless, Vestas wind turbines in normal operation are safe. Vestas employs thousands of service and maintenance technicians who work safely within close proximity to wind turbines every day.

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Wind Tunnel Testing of Microphone Windscreen Performance Applied to Field Measurements of Wind Turbines

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Abstract

Long-term field measurements of environmental sound levels at rural wind turbine project sites, either prior to construction or after the project is operational, normally show a strong correlation between sound level and wind speed. Unless some other contaminating factor is present, such as man-made noise, flowing water, insects, etc., sound levels will rise with wind speed and diminish during calm periods. The question that arises from this is whether the actual sound level rises and falls due to natural wind-induced sounds or whether wind blowing over the microphone creates a self-generated, false signal. In order to quantitatively address this issue a variety of common windscreens were systematically subjected to known wind velocities in a massively silenced wind tunnel with essentially noise-free airflow. The results of these tests demonstrated that wind does generate a certain amount of false-signal noise in all windscreens and that some work better than others - but in the wind speed range of interest (<10 m/s) it is only the lower frequencies in all of them that are affected by this self-generated distortion. What this means is that A-weighted sound levels measured in moderately windy conditions are largely immune from distortion but that C-weighted levels or levels of low frequency sound in general are significantly skewed upward. Consequently, any casual measurement of sound using a standard windscreen in a windy field will yield ostensibly high levels of low frequency or infrasonic noise - whether a wind turbine is present or not. Such measurements, taken at face value, may be one of the reasons wind turbines are widely, but mistakenly believed to be significant sources of low frequency noise. This paper briefly summarizes the wind tunnel study and applies its findings to actual measurements of an operating wind turbine and the simultaneously measured background sound levels several miles away.

Introduction

Long-term field measurements of environmental sound levels at rural wind turbine project sites, either prior to construction or after the project is operational, normally show a strong correlation between sound level and wind speed. Unless some other contaminating factor is present, such as man-made noise, flowing water, insects, etc., sound levels will rise with wind speed and diminish during calm periods. The question that arises from this is whether the actual sound level rises and falls due to natural wind-induced sounds or whether wind blowing over the microphone creates a self-generated, false signal. In order to quantitatively address this issue a variety of common windscreens were systematically subjected to known wind velocities in a massively silenced wind tunnel with essentially noise-free airflow. The results of these tests demonstrated that wind does generate a certain amount of false-signal noise in all windscreens and that some work better than others - but in the wind speed range of interest (<10 m/s) it is only the lower frequencies in all of them that are affected by this self-generated distortion. What this means is that A-weighted sound levels measured in moderately windy conditions are almost totally immune from distortion but that C-weighted levels or levels of low frequency sound in general are significantly skewed upward. Consequently, any casual measurement of sound using a standard windscreen in a windy field will yield ostensibly high levels of low frequency or infrasonic noise - whether a wind turbine is present or not. Such measurements, taken at face value, may be one of the reasons wind turbines are widely, but mistakenly believed to be significant sources of low frequency noise. This paper briefly summarizes the wind tunnel study and applies its findings to actual measurements of an operating wind turbine and the simultaneously measured background sound levels several miles away.

Environmental Sound Levels and Wind

Long-term field measurements of environmental sound levels at rural wind turbine project sites are often performed in the permitting stage to quantify the background sound level as a function of wind speed for impact assessment purposes. Typically two weeks of 10 minute data are collected at a 6 to 8 positions and then correlated to the concurrent wind speed as measured by 50 m anemometers on one or more met towers within the site area. Consequently, the sound level experienced at ground level is associated with the wind speed well above the surface and similar to what the turbines will ultimately see. A typical survey result is illustrated in Figure 1, where the average site-wide L90(10 min) level is plotted along with the wind speed normalized to the IEC standard [2] elevation of 10 m above grade.

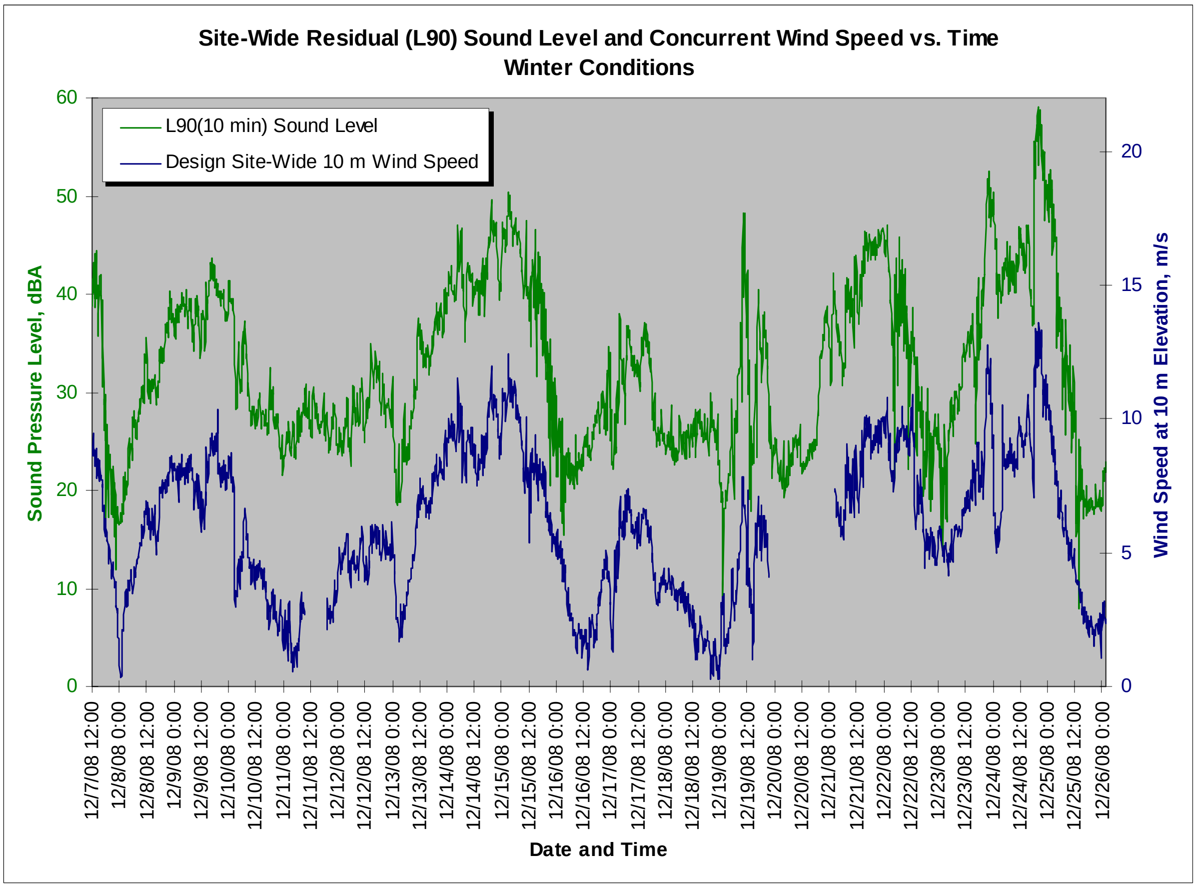

Figure 1 *Measured L90 Background Sound Level Compared to Concurrent Wind Speed - Typical*

The dependency of sound levels on wind speed is subjectively evident in the plot and quantified in the regression analysis in Figure 2 where sound levels are plotted as a function of wind speed rather than time.

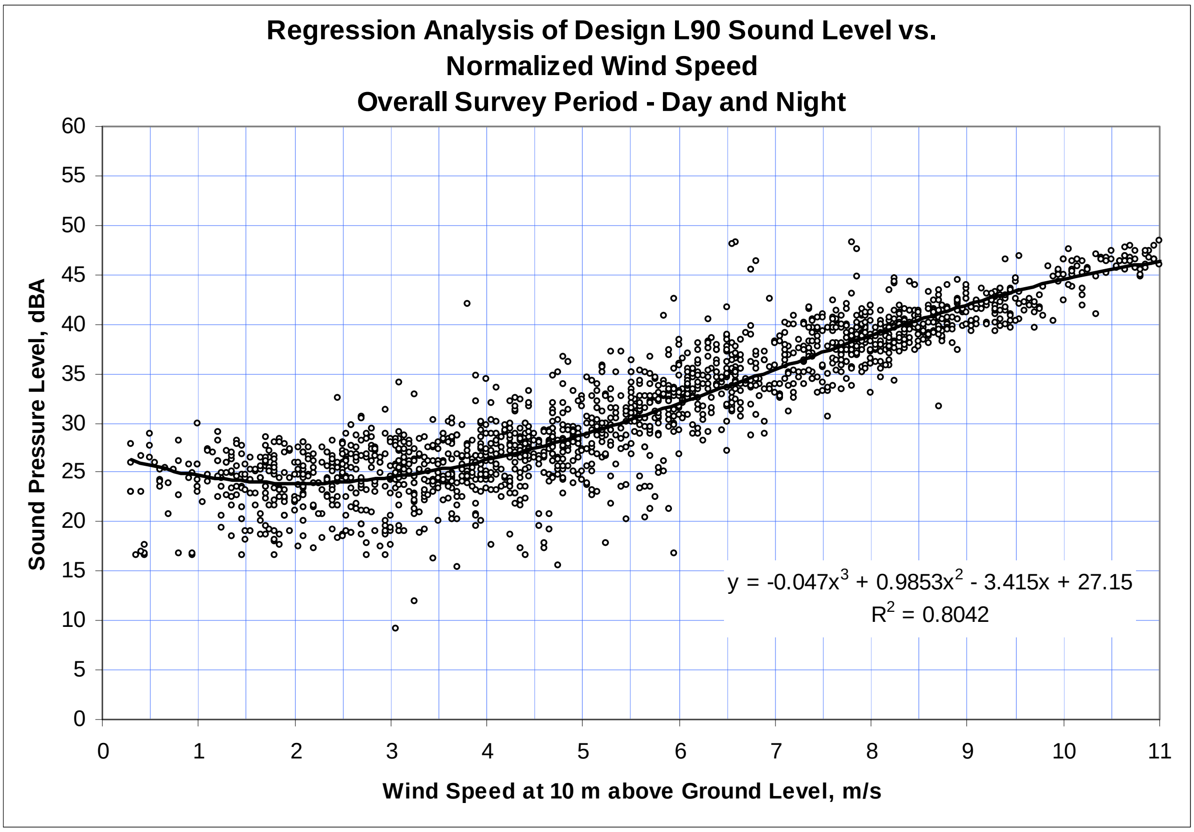

Figure 2 *Regression Analysis of Measured L90 Background Sound Levels and Concurrent Wind Speed – Typical*

The question that arises from this close relationship between sound and wind speed is whether the actual sound level rises and falls due to natural wind-induced sounds, such as trees or grass rustling, or whether wind blowing over the microphone creates a self-generated, false signal - which would conveniently explain the parallel behaviour seen in Figure 1.

Windscreen Testing

In order to quantitatively address this question, a wind tunnel testing program was devised to directly measure the level of microphone self-noise resulting from a known wind velocity for a variety of common windscreens. The complete results of this study have been published in July-August 2008 edition of the *Noise Control Engineering Journal* [1] so only an outline of the methodology and principal results are given below.

The testing was carried out using the acoustical wind tunnel at the Fraunhofer Institut für Bauphysik in Stuttgart (Figure 3), which is massively silenced to virtually eliminate fan noise from the system.

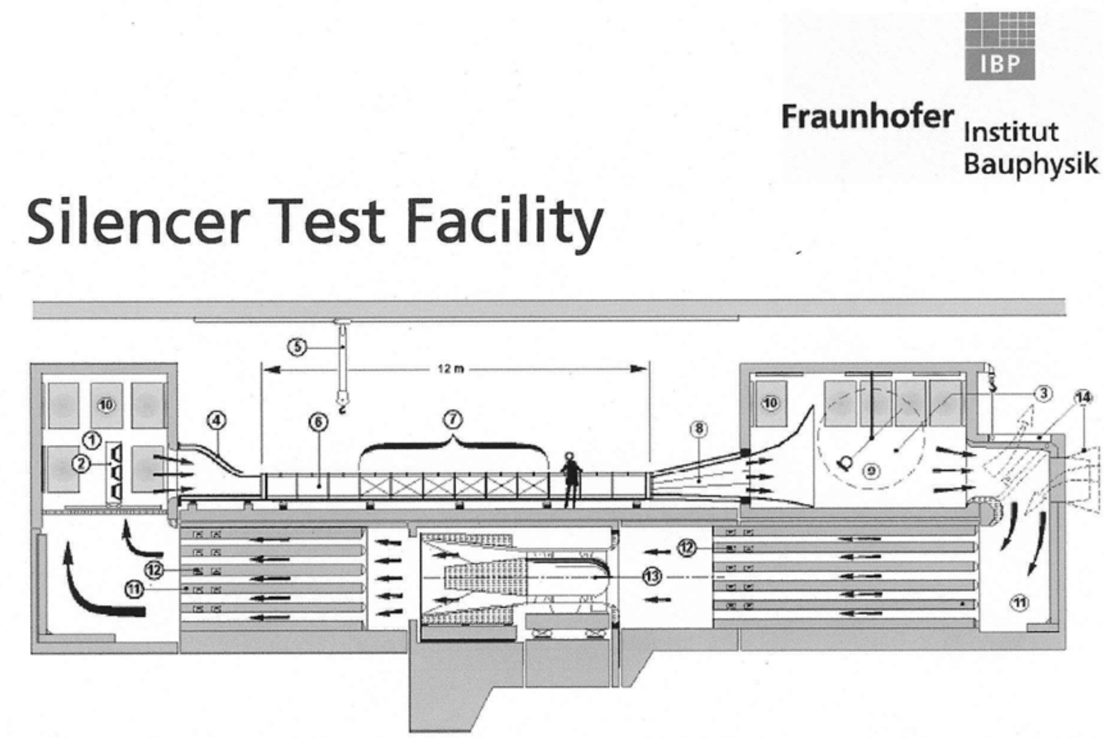

Figure 3 *Cross-sectional View of the Fraunhofer Wind Tunnel*

A series of 9 tests, shown in Figure 4, were run in which 7 windscreens were placed on a typical 1/2" (13 mm) microphone and subjected to controlled wind velocities of 2.5, 5, 10, 20 and 30 m/s normal to the microphone axis. An unprotected microphone and an aerodynamic nose cone were also tested.

TEST 1
NO WINDSCREEN PROTECTION

TEST 2
STANDARD 13mm (1/2") NOSE CONE

TEST 3
NORSONIC MODEL 1212 FOR OUTDOOR MONITORING

TEST 4
GRAS MODEL 41AO FOR OUTDOOR MONITORING

TEST 5
NORSONIC STANDARD 60mm WINDSCREEN

TEST 6
NORSONIC STANDARD 90mm WINDSCREEN

TEST 7
ACO MODEL WS-7-7 (175mm UNTREATED)

TEST 8
ACO MODEL WS-1-80T (75mm TREATED)

TEST 9
ACO MODEL WS-7-80T (175mm TREATED)

Figure 4 *Test Windscreens as Mounted in Wind Tunnel*

The overall test results for the 5 m/s wind velocity case are shown in Figure 5. This plot essentially shows the magnitude of self-generated noise for each windscreen when subjected to a 5 m/s wind.

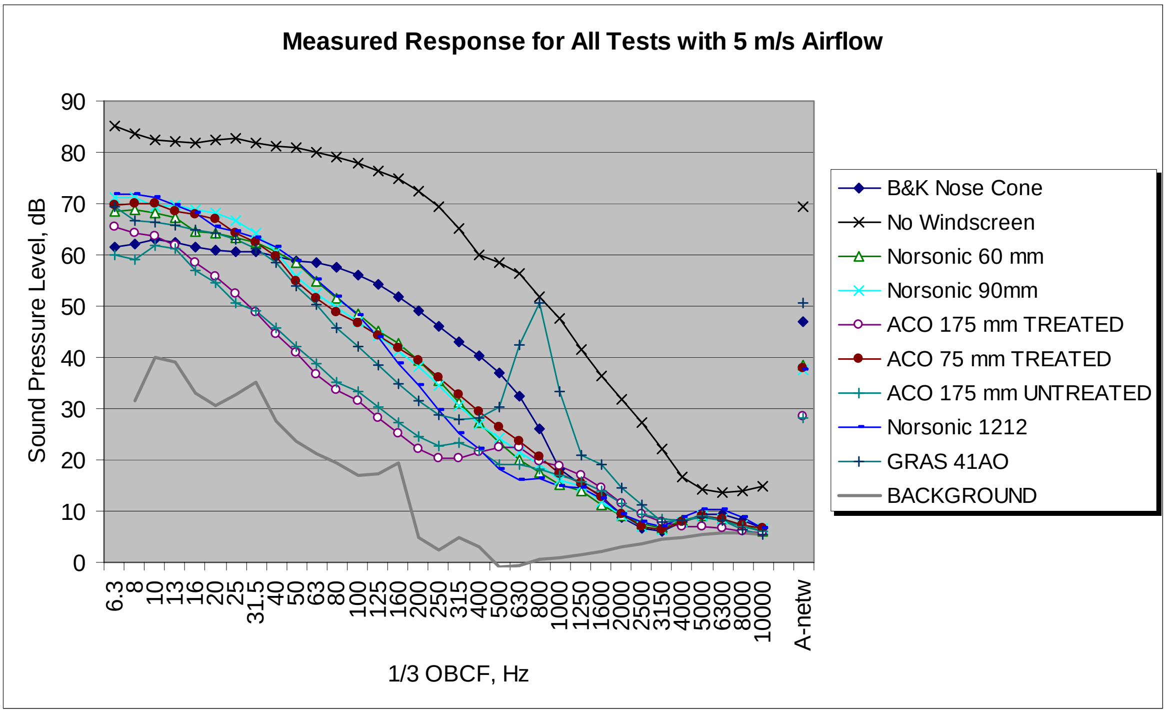

Figure 5 *Test Results – 5 m/s Wind*

Each windscreen or device has a different response but it is the lower frequencies that are most affected in each case. Of key significance are the substantially lower levels of distortion evident in the two larger (175 mm diameter) windscreens. False signal noise is generally 5 to (a very significant) 15 dB lower than the smaller, conventional windscreens in all the lower frequency bands. In terms of overall A-weighted sound levels, the 175 mm windscreens were measured to have a relatively low false signal noise level of about 29 dBA while the windscreens around 75 mm in diameter have a significantly higher distortion level of about 39 dBA for 5 m/s wind conditions. The overall test results for A-weighted self-noise for all wind speeds are shown in Figure 6.

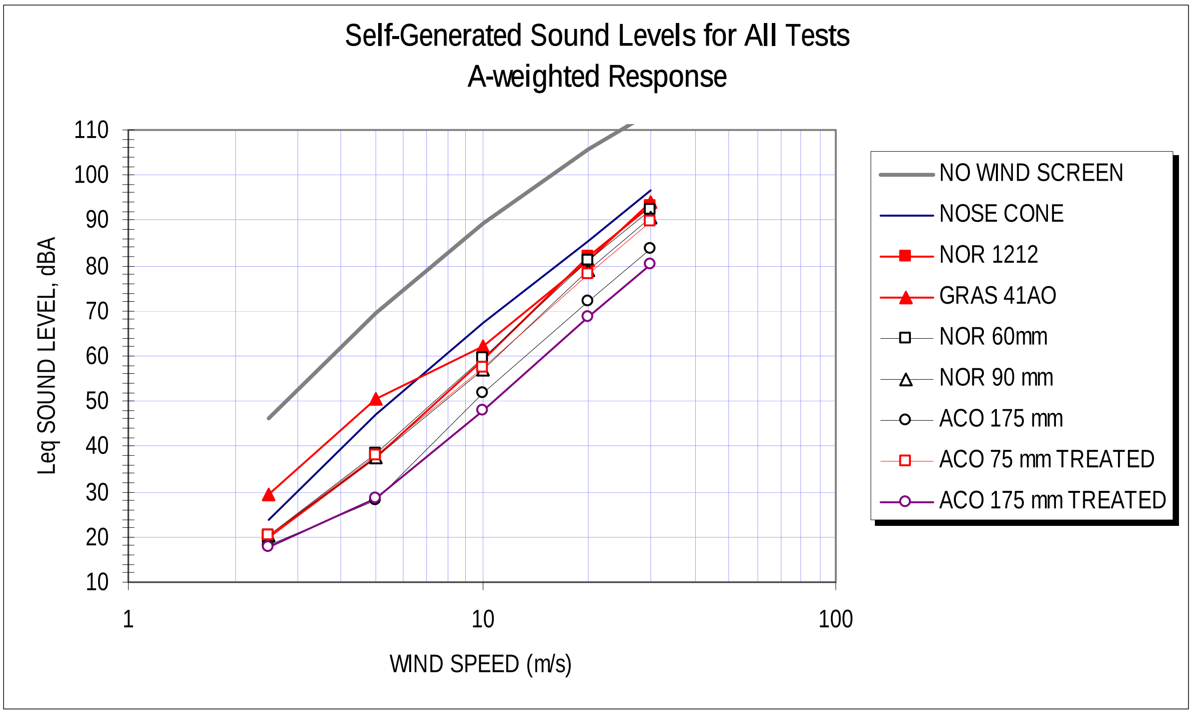

Figure 6 *Test Results – A-weighted Self-Noise as a Function of Wind Speed*

This plot shows that the larger (175 mm) windscreens yield the best results and have minimal levels of flow noise distortion at wind speeds below about 5 m/s, which are normally of the most relevance to wind project design assessments. A correction algorithm can be developed for any of the windscreens tested from the Figure 6 data. For the 175 mm ACO WS7-80T the magnitude of overall A-weighted self-noise can be calculated from Eqn. (1).

$$L_{pA} \text{ (flow–induced noise)} = 27.4 \ln(v) - 10.7 \text{ dBA} \qquad \text{Eqn. (1)}$$

Where v = the flow velocity at the microphone, m/s

Application to Field Measurements

If the wind speed at microphone height is monitored along with sound levels, the measurements can be corrected for self-induced distortion. The use of a large windscreen, however, such as the 175 mm diameter model, typically results in a situation where the A-weighted sound levels need little, if any, adjustment. As an example, the survey data from Figure 1 is re-plotted below along with the measured wind speed at microphone elevation and the corrected sound level where self-noise has been subtracted from each as-measured value depending on the wind speed occurring during that measurement. There are only a few places during the entire two-week survey period when the wind speed at 1 m was great enough to cause the self-noise level to approach the actual sound level and engender the need for a small correction. For most of the survey the magnitude of the adjustment is largely negligible. This figure also illustrates the common result that the wind speed at 1 m generally remains fairly low - in the 3 to 4 m/s range for the most part – and below what might be expected from the IEC 61400-11 shear curve [2], even when the high elevation/10 m wind speed becomes quite significant.

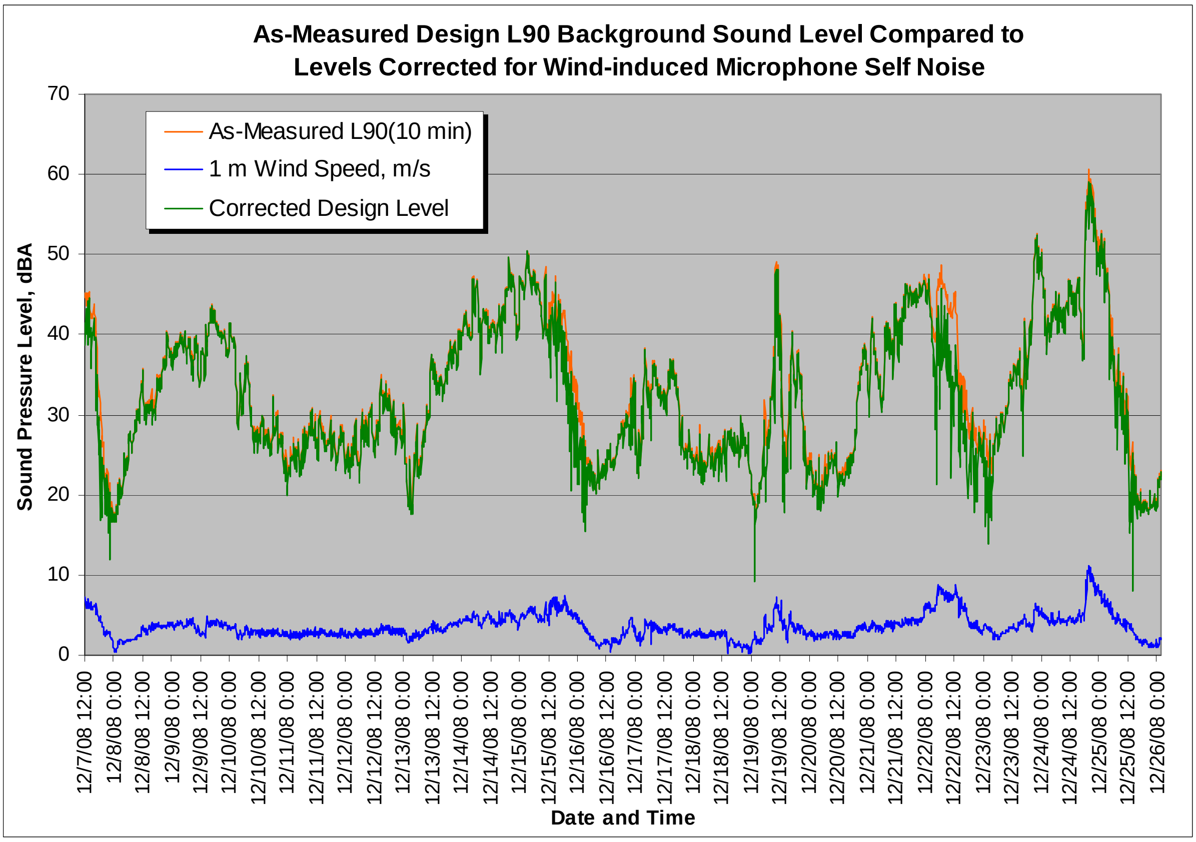

Figure 7 *Survey Results from Figure 1 Corrected for Self-Induced Noise Based on Measured Wind Speed at Microphone Height (1 m)*

Beyond simple A-weighed sound levels, the wind tunnel study results can also be used to evaluate the frequency content of field measurements made in the presence of flow or wind. As with the overall sound levels illustrated in Figure 6, it is also possible to develop an algorithm to calculate the self-noise level as a function of wind speed for each 1/3 octave band for each windscreen tested. Figure 8 shows one of 10 monitoring stations arrayed around a fairly isolated turbine at an open site in a soybean field in the Midwest. This position is 1000 ft. (305 m) away and employs a 175 mm treated windscreen.

Figure 8 *Field Sound Level Monitor 1000 ft. from a Typical Turbine with 175 mm Treated Windscreen*

An identical monitor was also set up in an identical soybean field 3 miles from the project area and completely isolated from any turbine noise. The sound level spectra measured at the same time at this remote position and at the 1000 ft. position on a day when the hub height wind was 13 m/s and the 1 m wind speed was 6 m/s are plotted below.

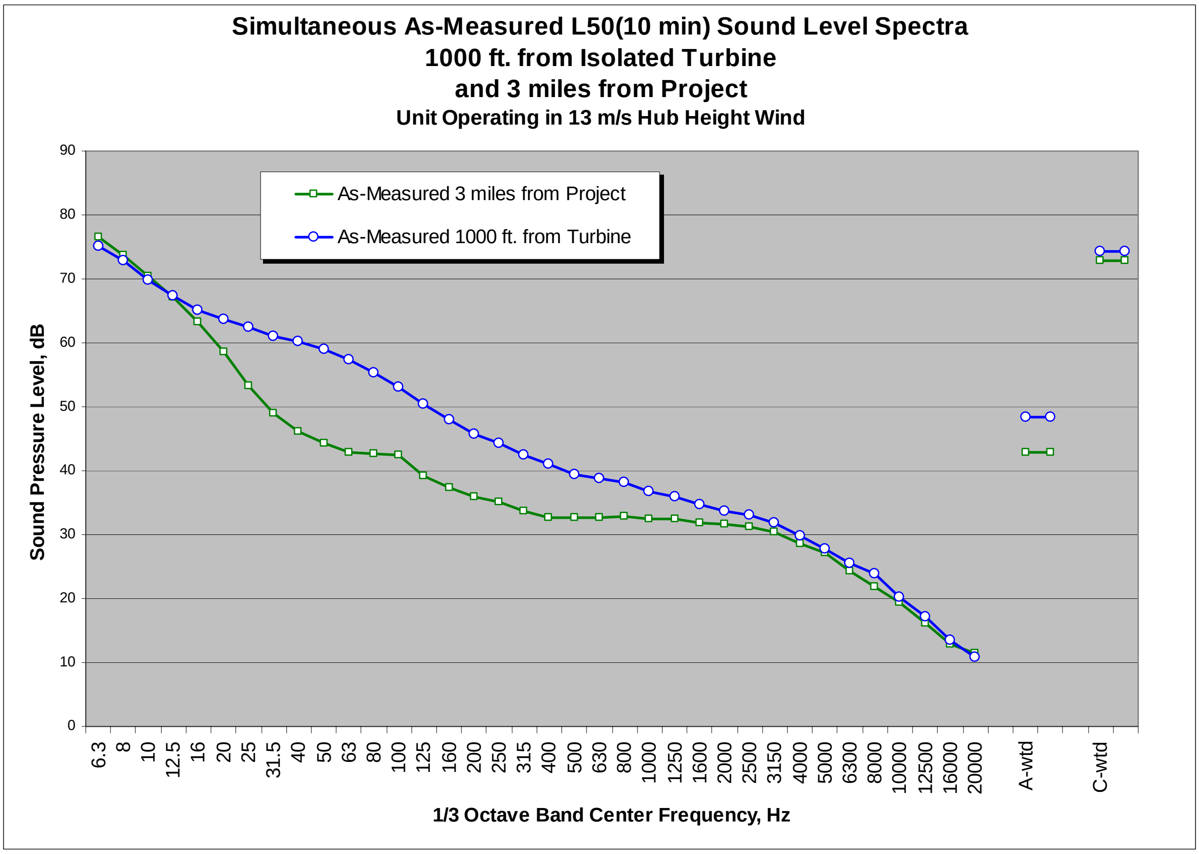

Figure 9 *As-Measured Frequency Spectra 1000 ft. and 3 miles from Isolated Turbine*

This plot shows suspiciously similar levels of very low frequency noise and both measurements have similare C-weighted levels: 74 dBC near the turbine and 73 dBC miles away. Clearly, the lower frequencies in both spectra are displaying false signal noise. In Figure 10 the self-noise level for the WS7-80T windscreen subjected to a 6 m/s normal flow velocity is plotted against the as-measured spectrum at the remote, background position miles from the project. Below about 200 Hz the two levels are intertwined, meaning that the low frequency content of this measurement is completely spurious – to the extent that a reasonably valid correction cannot even be calculated. An actual C-weighted sound level for this measurement can only be very roughly estimated at somewhere around 48 dBC, which, even if not precisely correct, makes much more sense. Because all of this distortion is occurring below 200 Hz, the A-weighted sound level is only minimally affected and its corrected value is only about 1 dBA lower than the as-measured value.

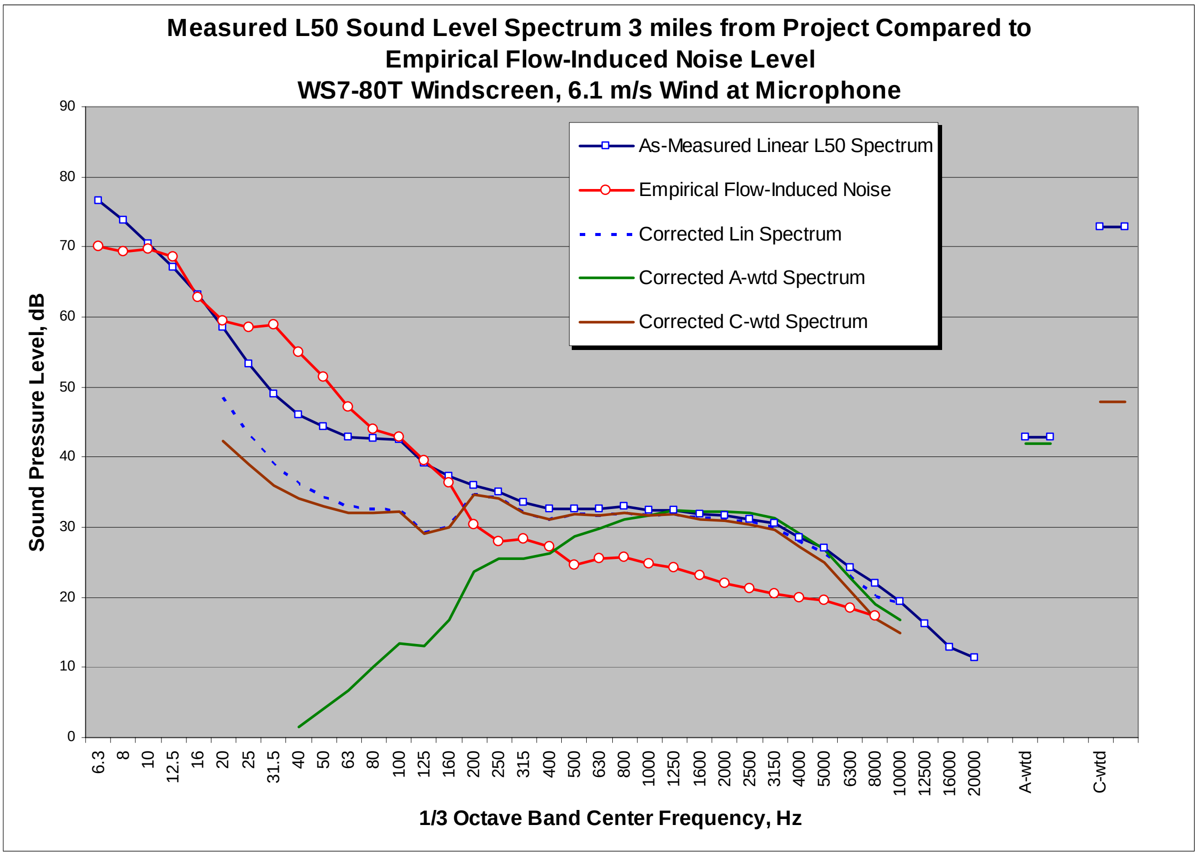

Figure 10 *Measured Frequency Spectrum 3 miles from Isolated Turbine Adjusted for Self-Noise*

At the position close to the turbine (Figure 11) the self-noise sound level meets the as-measured level at a much lower frequency of about 40 Hz because, in this case, measuring fairly close to a turbine operating at essentially full power, there is a moderate amount of actual acoustic energy in mid- and low frequencies. The as-measured levels below 40 Hz can be roughly corrected based on the empirical flow-noise level to yield a more accurate C-weighted sound level. In any event, it is clear that the measured sound levels in the lowest bands are false signals that have nothing to do with the turbine.

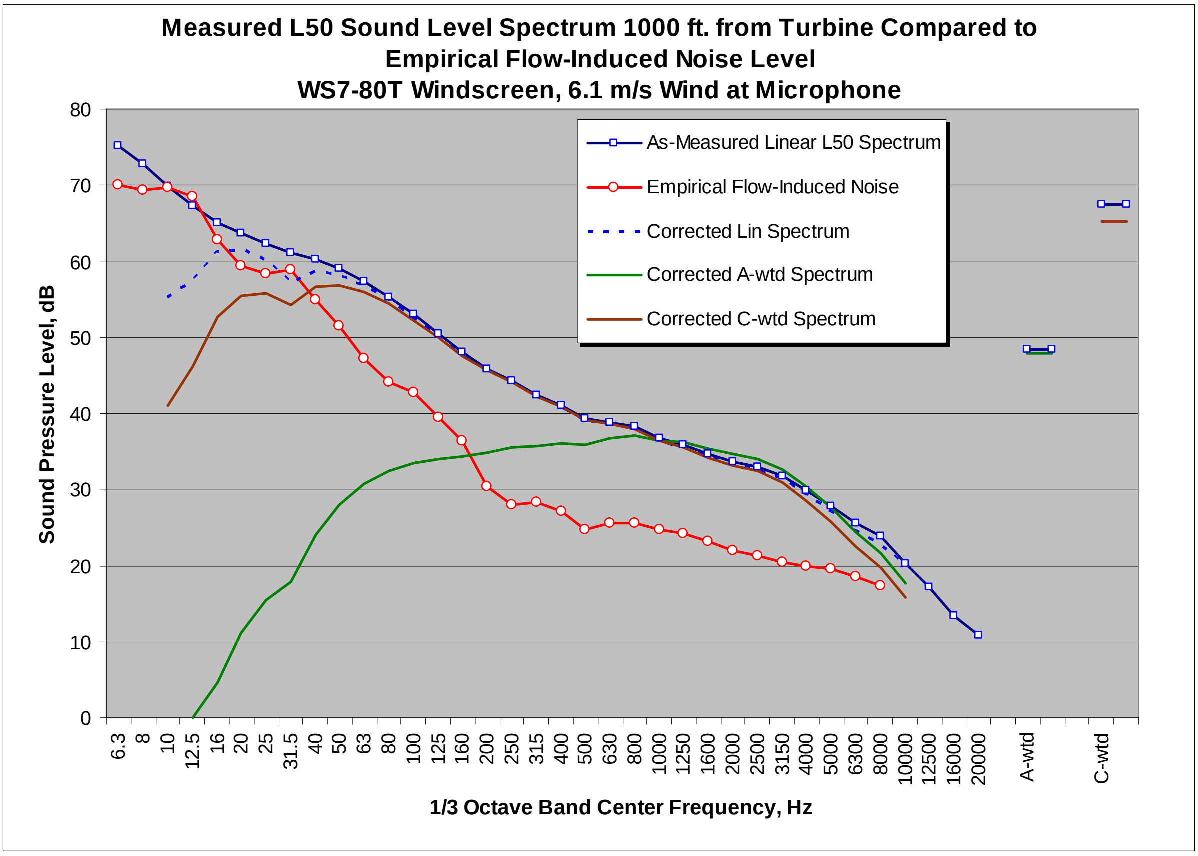

Figure 11 *Measured Frequency Spectrum 1000 ft. (305 m) from Isolated Turbine Adjusted for Self-Noise*

Conclusions

An empirical wind tunnel study of the self-noise distortion due to airflow penetrating windscreens and creating false signal noise revealed that flow noise only has a significant contaminating effect on the low frequency portion of the spectrum. Consequently, measurements made under moderately windy conditions – a virtual necessity for wind turbine analyses - will exhibit erroneously high levels of low frequency noise, which may be one of the principal reasons wind turbines are widely, but mistakenly believed to produce substantial levels of low frequency and infrasonic sound. Because this wind-induced distortion essentially occurs in the lower frequencies, A-weighted sound levels are generally immune from any significant degradation in accuracy as long as an extra-large windscreen on the order of 175 mm in diameter is used and the wind speed at the microphone position is below about 5 m/s. Some distortion in A-weighted levels will begin to occur above this wind speed even with a large windscreen but can be corrected out using the wind tunnel study results. Conventional windscreens in the 75 to 90 mm size range are much less effective and prone to significantly greater error in measuring both A and C-weighted sound levels in the presence of airflow.

References

1. Hessler, G. F., Hessler, D. M., Brandstätt, P., Bay, K, "Experimental study to determine wind-induced noise and windscreen attenuation effects on microphone response for environmental wind turbine and other applications", *Noise Control Engineering Journal*, J.56, July-August 2008.
2. International Electromechanical Commission (IEC) 61400-11:2002(E) *Wind Turbine Generator Systems – Part 11: Acoustic Noise Measurement Techniques*, Second Edition 2002-12.