An investigation of Different Secondary Noise Wind Screen Designs for Wind Turbine Noise Applications

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ABSTRACT

The use of diaphragm type microphones with the typical foam windscreen ball for outdoor noise measurement applications are mostly restricted to wind speeds below 4 to 6 m/s. This is due to the extra noise induced into the microphone, particularly at low and infrasonic frequencies, as a result of the wind excitation on the diaphragm. For wind turbine noise measurement applications, it is often necessary to measure the turbine noise under the typical operating conditions with wind speeds up to 12 m/s. This introduces a problem in the measurement system, as the normal microphone setup and windscreen are not adequate at these elevated wind speeds. Secondary windscreens, such as for example that prescribed by IEC 64100-11, "Acoustic noise measurement techniques" imparts their own problems including ridged body motion of the windscreen structure due to turbulence. Also, ground plane secondary windscreen measures the noise at ground level, instead of at ear level. This study investigates the use of several secondary windscreens with microphones capable of measuring at infrasonic frequencies for measuring wind turbine noise at elevated wind speeds. The result was that no windscreen provided a full solution to the problem. Specific recommendations for additional windscreen design and investigation are included.

Keywords: Infrasound, Wind Screen, Wind Turbine Noise I-INCE Classification of Subjects Number(s): 08.4, 14.5.4, 21.8.1, 71.1.1

1. INTRODUCTION

The measurement and characterization of noise from wind turbines is not an easy task. The measurement locations are almost always in the very far field, due not only to the height of the very tall turbine structures, but also due to the long source to receiver distances. Further, noise measurements are conducted in the outdoor environment which can at times be harsh and in the presence of high wind speeds, which under normal circumstances would preclude the validity of environmental noise measurements. In fact, it is during periods of higher wind speeds that wind turbines produce the greatest levels of environmental noise.

Several sources of noise exist due to the operation of the large-scale wind turbine. These include aerodynamic noise from the turbine blades interacting with the turbulent airflow as well as the interaction between the resulting flow from the moving blades and the stationary tower structure. A second source is mechanical noise from the internal machinery located inside the nacelle structure and electrical hum from the associated power transformers.

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The frequency spectra from these sources are also varied. Aerodynamic noise from the blade and reaction with turbulent flow is typically broadband and higher in frequency. The mechanical noise can also be somewhat broadband, but is also typically tonal in nature.

Very low frequency noise, or infrasound, which has frequencies below 20 Hz, is the result of the moving air from the turbine blade is slowed down by the presence of the tower as the blade passes by. The frequency of this noise is directly associated with this blade pass by frequency. This very low frequency sound also has the ability to travel far distances compared to higher frequency noise and does not attenuate due to the presence of absorbent ground cover like higher frequency sounds do. It also has the ability to penetrate into structures such as houses, which is purported by some to result in unpleasant effects to the inhabitants.

The measurement of the above described sound generations cannot be ignored, particularly from a compliance perspective, which necessitates the use of noise measurement microphones. Wind induced excitation of the microphones diaphragm can have a detrimental affect on noise measurements for wind speeds above 4 m/s when using a typical foam windscreen ball. This poses a problem when measuring wind turbine noise, as this is commonly done for wind speed up to approximately 12 m/s. It has been shown that the dominant source of turbulent pressure fluctuations experienced by an outdoor microphone is the intrinsic turbulence in a flow rather than the fluctuating wake behind the windscreen [1]. Also, since the wind velocity turbulence spectrum is heavily weighted to low frequencies, this poses a problem in the results for low frequency measurements, typically below 16 Hz. Consequently, it can be difficult to distinguish between wind turbine noise and wind-induced noise [2]. This issue can be partially addressed by using a secondary windscreen in conjunction with the typical primary windscreen. The result is a layer of air between the two windscreens, which provides a region for viscous dissipation to reduce the turbulence generated behind the first windscreen layer [1]. The failure to use such a secondary windscreen has probably resulted in measurement errors of significantly greater than 10dB (corresponding to a doubling or more of allowed noise loudness) [3].

This investigation reviews some of the solutions that have been used by others for measuring wind turbine noise in addition to presenting noise data collected simultaneously of an operating wind turbine using four different windscreen options to find a best solution. Also of interest in the ability to adequately measure and evaluate wind turbine noise as a full frequency spectrum of a wind turbine's noise emissions. That is, the very low frequency noise at the band pass frequency of just over 1 Hz to the upper audible frequency for human hearing of 20 kHz. While microphones have existed which can either measure very low and infrasonic frequencies for some time, as have also "full range" microphones typically rated between 6 Hz and approximately 20 kHz. In evaluating the different windscreen configurations, this study will use a new comprehensive full frequency microphone having a reported range between 0.02 Hz to 20 kHz. A comparison of the measured results using three different microphone designs is also given.

2. Background

The following is a review of some of the typical secondary windscreens that have been used by others for the measurement of wind turbine noise. While these reports were not necessarily for evaluating noise within the infrasonic range, they do provide valuable insight to the state of art of measuring wind turbine noise in windy conditions.

A report prepared by the Danish Electronics Light and Acoustics (DELTA) for the Danish Energy Authority [4] made a recommendation that a, "secondary windscreen may be used when it is necessary to obtain an adequate signal to noise ratio at low frequencies in high winds. For example it can consist of a wire frame of approximate hemispherical shape, at least 450 mm in diameter, which is covered with a 13 mm to 25 mm layer of open cell foam with a porosity of 4 to 8 pores per 10 mm. The secondary hemispherical windscreen shall be placed symmetrically over the smaller primary windscreen." A photo of the prescribed windscreen is given in Figure 1. However, the noise measurements conducted using this setup were made with a 20 Hz high-pass filter, so no analysis of its performance at frequencies in the infrasound region was conducted. This setup also employs a microphone mounted to a ground board, which is not entirely indicative of wind speeds and sound levels at ear height.

Figure 1: DELTA H Secondary Windscreen using a Wire Frame and Reinhardt Cloth [4]

Another study [5] reported experience with different types of windscreens. An almost spherical wire frame with a cover of Rycote Windjammer cloth was used for noise measurements from wind farms at microphone heights around 1.6 m above terrain with good results. The investigated frequency range was from 20 Hz to 10 kHz. The windscreen is shown in Figure 2. The use of the spherical windscreen resulted in a 20 dB drop in background noise between 50 Hz and 100 Hz for wind speeds at 8 m/s. Again, the study did not include infrasound measurements.

A British study by Bullmore et al. [6] which investigated wind farm noise prediction methods, used an alternative shaped secondary windscreen which was cylinder in shape with a domed top. The open cell foam cylinder was approximately 10 mm thick, 170 mm in diameter and was 300 mm tall. A lower disk having a thickness of 40 mm open cell foam completed the enclosure. This design is based on recommendations by Davis [7] from his book, "Noise Measurements in Windy Conditions". It was reported that the expected insertion loss for this design to be less than 1 dB between the frequencies of 50 Hz to 5 kHz.

An innovative approach was taken by Turnbull et al. [8] using a below ground surface method to measure outdoor infrasonic noise. This method included a dual windshield arrangement, with an open cell foam layer mounted over a test chamber and a 90mm diameter primary windshield used around the microphone. Figure 3 illustrates the microphone mounting arrangement. Using an external sound source capable of producing noise at 8 Hz, the performance of the underground method was compared to simultaneous measurements using the IEC 64100-11 above ground setup. It was found that the measured levels inside and outside of the chamber was consistent at all of the frequencies produced by the signal generator. It should be noted that such a setup is somewhat more arduous to deploy given that a large chamber must be dug below the surface of the ground which would make following the downwind position of a wind turbine's nacelle difficult during changing wind directions

Figure 2: Immersion Measurements using a Spherical Windscreen [4]

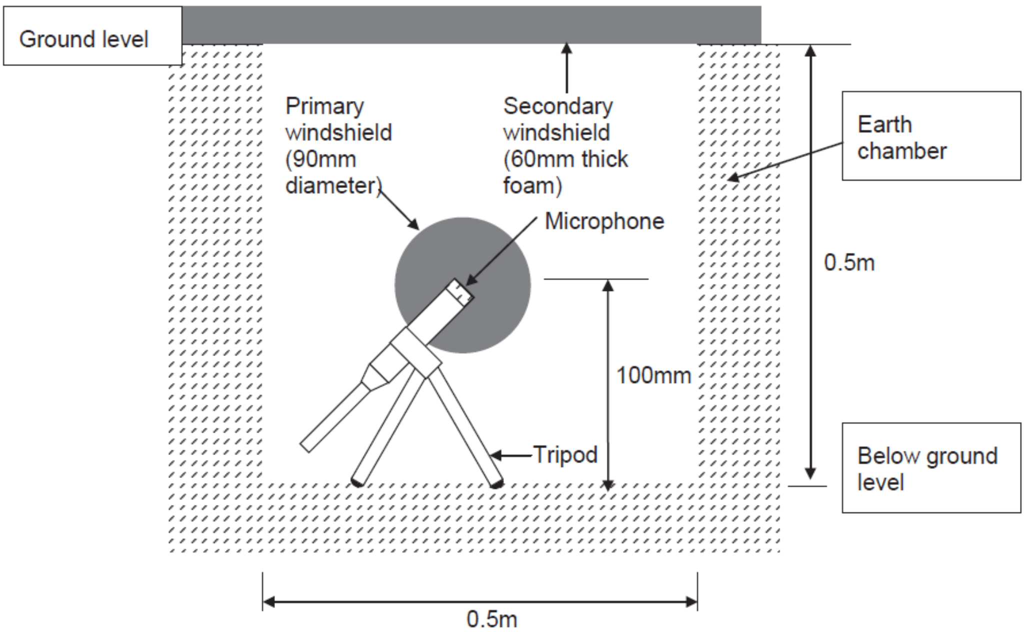

Figure 3: Schematic of Underground Microphone Mounting for Infrasound Noise Measurements [8]

3. Approach

The current research has several goals in mind. The primary goal is to evaluate the performance of several secondary windscreens to adequately shield the microphones from the affects of wind induced excitation and noise. For this, three secondary windscreens, used in conjunction with a standard 90 mm primary windscreen, where tested while measuring the noise from an operating wind turbine.

Measurements were conducted on a wind turbine located in Scandinavia. The wind speed during the periods of noise acquisition was approximately 8 m/s. These conditions were considered favourable for the tests given that the measured data was to be used for other simultaneous investigations. Further, these conditions provided adequate wind noise exposure at the microphones while at the same time operating the wind turbine at a typical speed.

The microphones were located 80 meters from the base of the turbine tower as shown in Figure 6. The first windscreen on the left is a Bruel & Kjaer Type UA-2133 ground secondary windscreen. This windscreen was designed and manufactured to comply with the requirements of standard IEC 64100-11, intended for the determination of sound power emissions and tonality of wind turbines. The windscreen is approximately 0.75 m in diameter and constructed of a wireframe covered by an acoustically transparent material. The wireframe sits atop a dense wood base. The microphone is partially inset into the base and has a hemispherical 90 mm primary windscreen. The advantage of this windscreen is that the microphone is located on the ground where the wind speed is reduced; conversely, the noise measurement here is not necessarily indicative of the resulting wind turbine noise at ear level.

Figure 6: Photo of three Secondary (with Primary) Windscreens tested and Standard Primary Windscreen

The next windscreen is a commercially available British windscreen purported to be recommended by the British Wind Energy Association for outdoor wind turbine measurements, although no reference was found to support this statement. The foam cylindrical structure is approximately 10 mm thick and 300 mm tall. The microphone is located approximately halfway up the cylinder with also a primary windscreen.

The third windscreen from the left is a spherical design constructed by the University of Windsor in Canada. It has an approximate diameter of 400 mm and, like the ground screen, is constructed by a wire frame covered by acoustical transparent material. The microphone is located in the centre of the sphere and has a 90 mm primary windscreen. The design of the sphere was such that it is mounted in a suspension to minimize any structural excitations. Care must be taken though to ensure that it does not move due to the wind.

The microphone on the far right used a standard 90 mm primary windscreen only, mounted on a tripod. The reason for this setup was to provide insight on the performance of the secondary windscreen relative to this reference.

The microphones used in all windscreens were full range infrasonic microphones. That is, the microphones had a linear frequency response within 3 dB from approximately 0.2 Hz up to 20 kHz. The reason for using these microphones was to ensure that good infrasonic data was collected to represent any wind excitations on the windscreen setups. To demonstrate the suitability of this full range microphone, another test was performed using this microphone alongside a classical infrasonic microphone and a standard full range microphone, used most often for noise measurements where the human audible frequency range is of interest. The results of this test is given in Figure 7 where the higher noise floor is seen at higher frequencies for the classic infrasonic microphone (Type 4193), and similarly, the elevated noise floor at the lower frequencies for the standard full range microphone (Type 4189). The true full range infrasonic microphone (Type 4964) demonstrates its linearity across the entire frequency range when compared to the other two microphones.

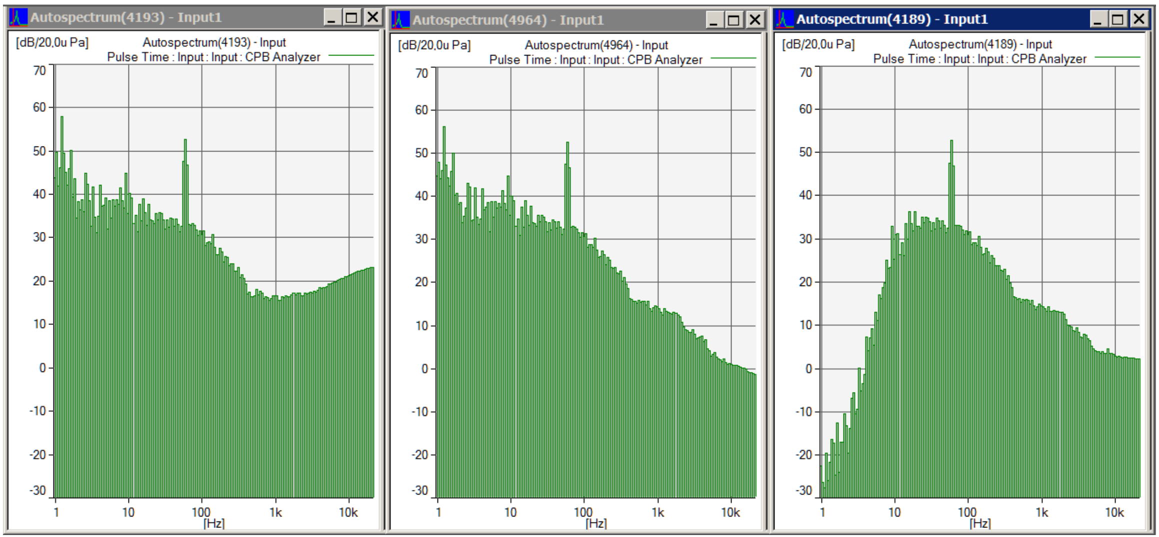

Figure 7: Comparative Results of Microphone Frequency Response of a classical Type 4193 Infrasonic Microphone (left) to a Full Range Type 4964 Infrasonic Microphone (centre) to a Classical Full Range Type 4189 Microphone (right)

4. Results

Figure 8 is an FFT graph of the wind turbine noise measured at the four microphones using the various described windscreens. The wind speed during the measurement period remained at an approximate average of 8 m/s. Using the Type 4964 microphones, frequency spectra between 1 Hz and 160 Hz is shown. It is clearly demonstrated that the three microphones using the secondary windscreens performed much better than the microphone having the primary windscreen only. Given in Table 1 is the effective drop in measured background noise for each of the three secondary windscreens compared to the microphone having the 90 mm primary windscreen only.

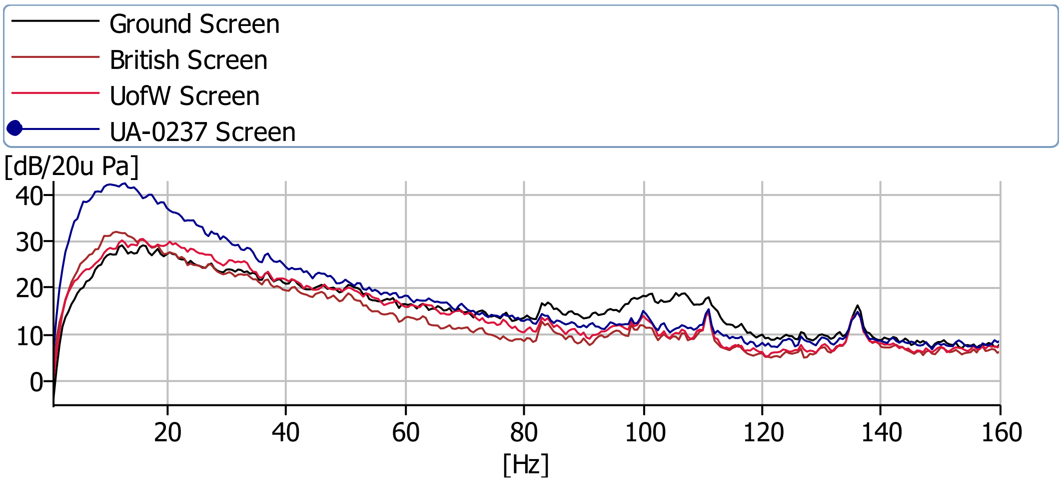

Figure 8: Infrasonic and Low Frequency FFT Spectra for three Secondary/Primary Windscreen combinations and one Primary only Windscreen at 8 m/s Wind Speed

Table 1 – Effective Drop in Measured Background Noise (dB) for the three Secondary Windscreen Setups when compared to the Primary only Windscreen, measured at 8 m/s Wind Speed

Windscreen Description	Background Noise Reduction (dB) Compared to the Primary Windscreen
Ground	9.5
British	8.7
UofW	5.7

While the three secondary protect microphones produced similar results, an interesting difference having a higher sound pressure level between approximately 82 Hz to 120 Hz is seen with the ground secondary windscreen. While one might initially believe this to be the result of perhaps wind induced resonance of the relatively large hemispherical windscreen structure, data shown in the Campbell plots given in Figure 8 suggest differently. This, as well as vibration data collected on the turbine tower structure (not presented in this paper) suggests that the snaking spectral line is an emission due to the operation of the wind turbine. The interesting observation from this outcome is that the same spectral line is not nearly as prominent at the other three microphones. A logical explanation for this could be a greater realized insertion loss due to the affect and presence from the other microphone windscreens.

As stated above, Figure 9 is an illustration of four Campbell plots showing the frequency spectra for each microphone with respect to time. Given the quasi-steady nature of the wind turbine noise over the two minutes measurement period, the Campbell plots can be used to differentiate the quasi-steady signal of the wind turbine noise from the narrow broadband wind induced noise levels. It is interesting to note the snaking spectral line from the wind turbine noise centred at approximately 100 Hz. This line is most evident from the ground windscreen microphone data, and secondly from the UofW windscreen data. The ground windscreen also shows the lowest infrasonic broadband noise, presumably wind induced with the primary windscreen results showing the most. The other two secondary windscreens also performed mostly equally better than the 90 mm ball. These conclusions are for the most part supported by the data given in Figure 7 and Table 1.

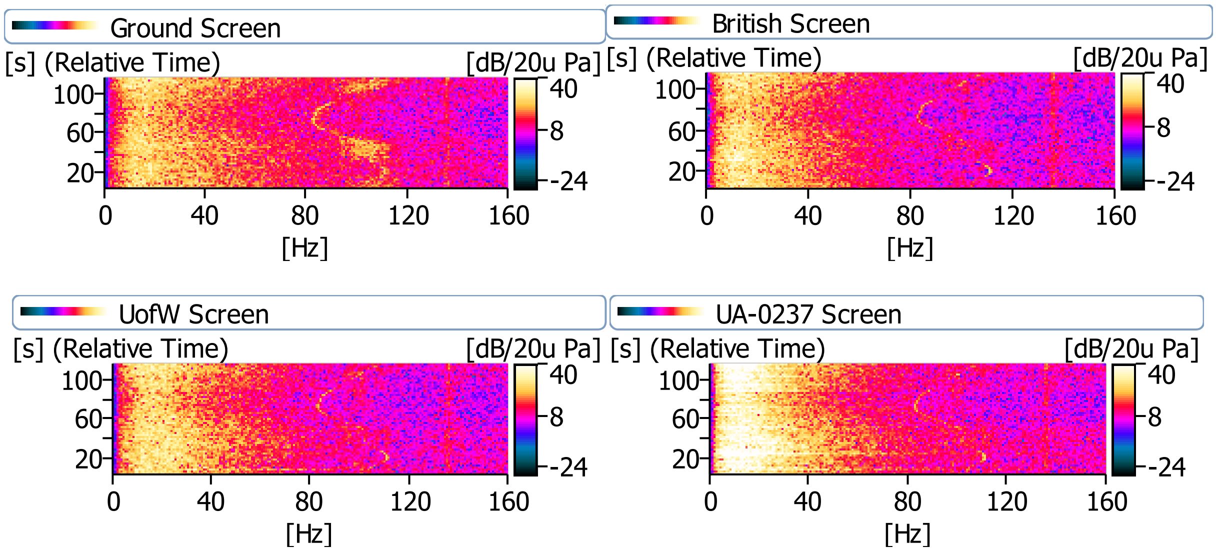

Figure 9: Campbell Plots for the Microphones Protected by the three Secondary/Primary Windscreen combinations and one Primary only Windscreen, measured at 8 m/s Wind Speed

5. Conclusions and Recommendations

Upon review of the results, it is concluded that all three secondary windscreens performed well relative to each other. Further, the performance of each of the three secondary windscreens was shown to be significantly better than the results using the 90 mm primary windscreen alone. A second conclusion that can initially be drawn is that a simply constructed windscreen, such as that of the UofW windscreen, can provide adequate performance compared to a commercial secondary windscreen device.

In light of the above conclusions, it is acknowledge that differences in the resulting data is seen for the ground windscreen which is not as evident in the results measured by the other three microphones. This might be the result of varying insertion loss properties between the different designs. Being a commercial product, the insertion loss data for the ground windscreen can be readily found on the manufacturer's website. This is not the case for the other tested secondary windscreens. As such, it is recommended that additional tests be performed to determine the realized acoustic insertion loss for the remaining windscreens to determine if this was an influencing factor.

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REFERENCES

1. Morgan, S., Raspet, R. (1991). Investigation of the mechanisms of low-frequency wind noise generation outdoors. *Journal of the Acoustical Society of America*, *92(20)*, 1180-1183.
2. Hansen, K., Zajamsek, B., Hansen, C. (2014). Identification of low frequency wind turbine noise using secondary windshields of various geometries. *Noise Control Engineering Journal, 62(2),* 69-82.
3. Cox, R., Unwin, D., Sherman, T., (2012) Technical Report – Wind Turbine Noise Impact Assessment Where ETSU is Silent. UK.
4. Sondergaard, B., Ryom, C. (2008) Low Frequency Noise from Large Wind Turbines Sound Power Measurement Method, Horsholm, Denmark: Danish Energy Authority.
5. Jakobsen, J. (1997). Investigations of Wind Screens, Insertion Loss and Attenuation of Wind Noise, Horsholm, Denmark: Danish Electronics, Light and Acoustics.

6. Bullmore, A., Adcock, J., Jiggins, M., Cand, M. (2007). Wind Farm Noise Predictions: The Risk of Conservatism. *Second International Meeting on Wind Turbine Noise.* Lyon, France.
7. Davis, R.A. (1996). Noise Measurements in Windy Conditions. *ETSU W/13/00386/REP,* Lower MC.
8. Turnbull, C., Turner, J., Walsh, D. (2012). Measurement and Level of Infrasound from Wind Farms and Other Sources. *Acoustics Australia, 40(1),* 45-50.