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Acoustics and Sustainability:

How should acoustics adapt to meet future demands?

The use of microphone windshields for outdoors noise measurements

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ABSTRACT

Wind induced noise is a problem that affects most outdoors acoustic measurement campaigns. The interaction between the local wind and turbulence with the fixed surfaces of the microphone generates non-acoustic pressure fluctuations at the diaphragm that significantly affect the microphone output. Various types of wind shields are used to overcome this problem, but the benefit of this measure is generally not well quantified. This issue is particularly relevant in the context wind farm assessments, where the dependency of ambient noise as a function of the local wind speed is of primary importance when determining the noise criteria and undertaking the compliance noise measurements at the site. This paper presents the results of wind generated noise testing for a range of commercially available wind shields. It is demonstrated that the principal variable in wind screen performance is the diameter of the windscreen.

INTRODUCTION

In recent years there has been significant growth in wind farm electricity generation across Australia, and in South Australia in particular. The current focus on renewable energy and greenhouse gas emissions reduction is likely to maintain the growth in this sector. At the current time, South Australia has 868 MW of installed or currently under construction wind farm generating capacity. This equates to about two thirds of Australia’s approximately 1300MW of installed wind farm generation capacity.

The South Australian EPA developed the Wind Farm Environmental Noise Guidelines 2003 (EPA 2003) to provide framework for the assessment of wind farm noise in South Australia. The South Australian wind farm noise guidelines were revised in December 2007 (EPA 2007). These guidelines are used nationally for the assessment of most wind farm applications, except in Victoria, where New Zealand Standard 6808 (NZS 6808:1998) is commonly used. A draft Australian Standard for the measurement, prediction and assessment of noise from wind turbine generators is in development and was previously released for public comment (DR07153CP 2007). This standard may in the future be used to assess noise from wind farms.

This paper presents the current practices for outdoor noise measurements, with a specific focus on wind farms. The need for a practical approach for field measurements is outlined, with the practical constraints that must be met in realistic conditions A brief review of selected papers on self noise affecting microphones exposed to wind is then presented. The present experimental work is described and analysed before conclusions are drawn on the use of wind screens for outdoors measurements, and potential scope for future work.

WIND FARM AND OTHER OUTDOORS NOISE MEASUREMENTS

The level of noise that is produced by wind turbines is dependant on the wind speed at the turbines. Generally, as the wind speed increases the sound power level of the turbines also increases. The potential impact of this increase in noise is reduced by the corresponding increase in background noise at the residences due to wind noise in foliage, which assists to mask the wind farm noise.

The SA Wind Farm Noise Guidelines, NZS 6808, and draft standard DR07153CP all account for varying wind turbine and ambient noise by setting wind farm noise criteria at a level above the existing background noise level. The level of the existing background noise is determined by noise logging at the residences adjacent to the proposed wind farm, over the range of wind speeds in which the wind farm will be operating. A noise criterion for each integer wind speed over a range of wind speeds is determined.

Environmental noise measurements are normally conducted at times of low wind speeds (less than 5 m/s), to reduce the influence of wind generated noise on the measurements. The wind generated noise takes two forms; wind-induced microphone self noise, and increased levels of ambient noise from wind interaction with typically foliage.

It is not possible to avoid times of high wind speeds during wind farm background noise measurements, as it is necessary to determine the noise criteria, and hence background noise level (L_{90}), over the range of speeds in which the wind farm normally operates.

Both the South Australian Wind Farm Noise Guidelines 2007 and draft standard DR07153CP require that it is demonstrated that microphone self noise is not adversely affecting the measurement of background ambient noise levels for measurements at wind speeds above 5m/s. However, manufacturer information regarding wind induced microphone self noise is not readily available for all microphone and wind shield combinations.

WIND NOISE IN MICROPHONES

Wind induced microphone self noise is caused by two distinct phenomena: the pressure fluctuations induced at the microphone diaphragm by turbulence in the flow, and those induced by the turbulent wake of the microphone. The former are determined by the atmospheric conditions and terrain properties (van den Berg 2006), while the latter are determined by the microphone shape and local wind speed. The interaction between the turbulent flow and the solid boundaries of a sensor creates pressure fluctuations at the interface, which result in unwanted pressure signal at the microphone diaphragm. The purpose of a wind screen is to reduce the effect of local induced microphone wind noise while allowing the acoustic signal to propagate to the microphone diaphragm with minimal attenuation. The volume of stagnant air trapped in the volume of a wind screen reduces wind noise in two ways:

1- The influence of the near field pressure fluctuation generated at the screen surface decreases with increasing screen diameter,

2- At high enough Reynolds numbers, the relatively large surface area of the screen supports a number of uncorrelated aeroacoustic sources created by the interaction between the flow and the surface, the effect of which statistically cancels out at the microphone diaphragm, which may also act as a low pass wavenumber filter at high frequencies. The small scale turbulent eddies, associated with high frequency fluctuations, are averaged out over the relatively large surface of the microphone.

These mechanisms indicate that the largest possible wind screens should be used to minimise wind screen noise, and that the screen size should be considerably larger than the characteristic length scales of the turbulence it creates to effectively average out the local pressure fluctuations at the surface of the screen. The remainder of this paper provides quantitative information on the effect of these parameters on the level of unwanted wind noise affecting outdoors acoustic measurements.

Strasberg (1987) developed an empirical model of wind screen noise from a dimensional analysis of experimental results reported by several other authors. He found that the pressure power spectral density (PSD) normalised by the dynamic pressure ρU^2 , successfully reduced the experimental data at low frequencies when plotted against the Strouhal number ($S_t = fD/U < 5$). Here ρ is the air density, U the flow velocity, f the frequency and D the wind screen diameter. Strasberg found that the windscreen noise was approximately proportional to the inverse of the windscreen diameter, which is consistent with a technical note published by RION on their open cell polyurethane foam wind screens. Strasberg also found that the Reynolds and Mach numbers had little influence on the data reduction. He developed the following model of the wind screen noise spectrum level:

$$L_p=21+63 \text{ Log } U - 33 \text{ Log } f - 23 \text{ Log } D \qquad (1.)$$

Strasberg acknowledged that the good fit of the proposed model relied on measurements that were taken by moving microphones through "substantially quiet air", and it can be anticipated that any turbulence in the incoming flow would introduce significant discrepancies between model and measurements. Strasberg also noted that his model was inadequate at high frequencies, where the structure of the screen material was likely to play an important role in the generation of wind screen noise. It is also interesting to note in this model that the mean square pressure is approximately proportional to the sixth power of the wind speed, which is the characteristic feature of the far-field dipole noise that results from the interaction between turbulent flows and rigid boundaries (Curle, 1955). This feature is also consistent with the measurements reported in the RION technical note.

WIND TUNNEL MEASUREMENTS

A series of commercially available microphone wind screens were tested in the small anechoic wind tunnel at the University of Adelaide. This facility is made of a small rectangular (275 mm x 75 mm) open jet located in an anechoic enclosure. An overview of the facility can be found in Leclercq *et Al.* (2007), and a drawing is shown in Figure 1.

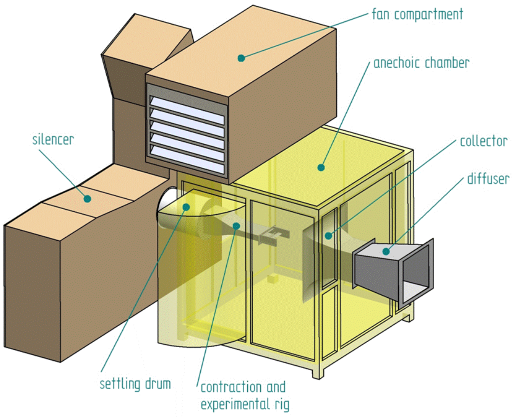

Figure 1 The Anechoic wind tunnel used for the present experiments

The interested reader is also referred to Chong *et Al.* (2008) for an extensive description of the design and performance assessment of an open jet anechoic wind tunnel, which, although much larger than the one used here, is similar in terms of design.

The anechoic enclosure was not designed to efficiently block ambient laboratory noise, as can be seen in Figure 2, where the tones from fluorescent lights and computer fans can be observed in the background noise measurements. The planned construction of an acoustically treated collector that will close the air circuit is expected to greatly reduce this unwanted noise. However, the wind tunnel in its present configuration performs adequately for the proposed measurements, and data obtained in conditions where the background noise was less than 12 dB below the measurements are not reported so that the reported results are not measurably affected by background noise. The test section dimensions do not allow measurements to be carried out in the potential core of the jet, where the measured turbulence intensity is less than 0.1%. It was instead decided to carry out the tests immediately downstream of the potential core, where turbulent intensity is high but the mean velocity profile is adequate. It should also be noted that the significant blockage area ratio of each wind screen results in a strong modification of the incoming flow around the tested wind screens.

Experimental set-up

The tested wind screens are listed in Table 1

Table 1 Wind screens used during the tests

No.	Diameter mm	Reference
1	50	Ellipsoidal of generic brand
2	90	Spherical type 1 - Manufacturer A
3	90	Spherical type 2 - Manufacturer A
4	90	Spherical - Manufacturer B
5	90	Spherical - Manufacturer C
6	65	Spherical - Manufacturer B
7	--	N/A
8	30	Ellipsoidal - Manufacturer A

Two microphone types were used for the present measurements, as shown in Table 2. The table shows that two half-inch and a one-inch microphones were used to determine the effect of diaphragm surface area on windscreen noise. An additional quarter inch microphone was also used but the corresponding results are not presented in this paper due to the relatively high noise floor noise floor it presented.

Table 2 microphones used for wind tunnel measurements

Channel	Type	Function
1	B&K4190	Ambient noise in anechoic room
2	B&K4190	Wind screen noise measurement
3	B&K4145	Wind screen noise measurement

Signals were recorded at 44.1 kHz over a duration of 20 seconds, using a Head Acoustics 1369 Squadriga recording unit. Subsequent analysis was carried out in Matlab using the PWELCH function, where the Fast Fourier Transforms (FFT) were taken over 16384 points with an overlap of 50%, which produced Power Spectral Densities (PSD) estimated over 106 averages approximately, and a frequency resolution of 2.7 Hz.

Background noise measurements were carried out at all three microphones without flow. Levels of 17 dB(A) and 14 dB(A) were measured at the half inch and one inch microphones, respectively.

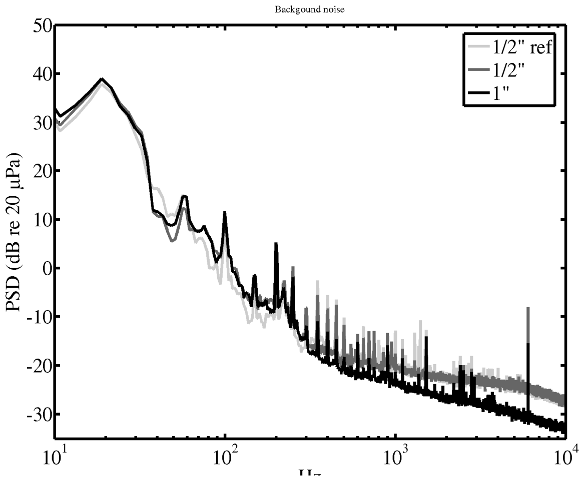

Figure 2 Background noise PSD measured by the three microphones

Results and analysis

Wind screen performance

Figure 3 shows the pressure PSD measured by a ½" microphone in a 10 m/s jet, using the wind screens listed in Table 1. All spectra present a low frequency rounded peak, which can be associated with large scale turbulent structures in the open jet, similar to the very low frequency signals picked up in atmospheric boundary layer noise measurements. The figure shows that the levels of the measured spectra are largely determined by the diameter of the wind screen, which supports the non-dimensional analysis introduced by Strasberg (1987), where the Strouhal number is the dominant non dimensional parameter. Another aspect differentiating the wind screens performance is the presence of a hump at higher frequencies, which could be associated with the properties of the screen surface, such as foam roughness or the presence of an outer structure. As expected from the turbulent nature of the flow, the present data are not well represented by Strasberg's model, but some of the model's features remain consistent despite the significant differences in the experimental conditions.

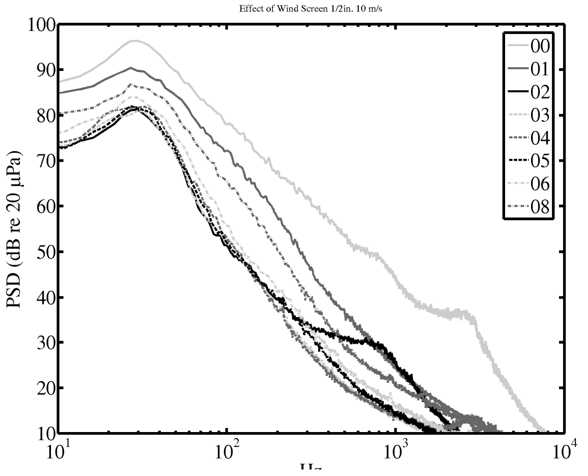

Figure 3 Pressure PSD measured in a 10m/s flow by a 1/2" microphone with various wind screens listed in Table 1

Flow speed

The effect of flow speed on wind screen noise spectrum is shown in Figure 4. The round peak at low frequencies appears to be determined by the Strouhal number based on the flow speed and the height of the nozzle exit plane (75mm).

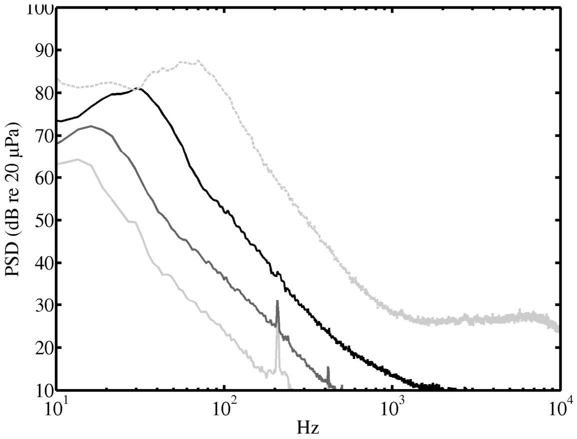

Figure 4 Effect of the flow speed on the measured pressure PSD. 1/2" microphone with wind screen 3. Wind speeds are, in order of increasing levels: 4, 6, 8 and 10 m/s

As pointed out previously, the empirical model developed by Strasberg indicates a dependency of the wind screen noise level on approximately the 6th power of the flow velocity. Figure 5 shows a logarithmic representation of the A-weighted measured sound pressure level as a function of flow speed for all tested wind screens. The A-weighted ambient noise levels as measured by the reference microphone located in the anechoic chamber away from the flow are also reported in the figure. This figure shows that the 6th power law, illustrated by the two continuous straight lines, is very closely followed with the bare microphone, and that the slope is slightly steeper for wind screen noise, which is in good agreement with the coefficient of 63 in Strasberg's model (1).

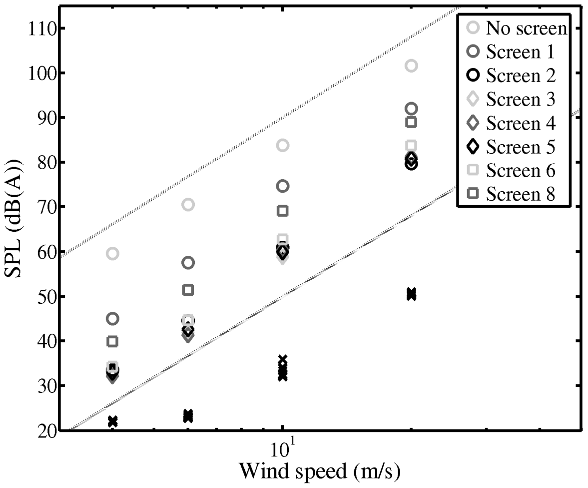

Figure 5 A-weighted overall sound pressure levels as a function of wind velocity. The two straight lines indicate a sixth power law dependency. The 'X' symbols indicate the ambient levels in the room 0.5 m away from the flow.

It is also interesting to note that the relative noise reduction is relatively weakly dependent of the wind speed. For example, sample 4 provides a wind noise attenuation of 23 to 28 dB(A), which is also consistent with the value of 25 dB (a) reported in the technical note published by RION. A similar consistency is also found with the overall A-weighted wind screen noise levels.

Microphone diameter

It is well documented that spatial averaging over the surface of the microphone membrane creates a very efficient low-pass wavenumber filter (Corcos 1964, Schewe 1980) when measuring the pressure in turbulent flows such as boundary layers. As described previously, the surface of the wind screen plays a similar role in averaging out the pressure fluctuations associated with turbulent eddies that are smaller than the wind screen itself. However, the area of the microphone diaphragm is in this case no longer expected to play its filtering role, as long as the flow through the screen is comparatively slow, as in the case of most commercially available wind screens. The spectra reported in Figure 6 for two wind speeds and two microphone diameters shows very little difference between the spectra obtained with a 1" and a half inch microphone.

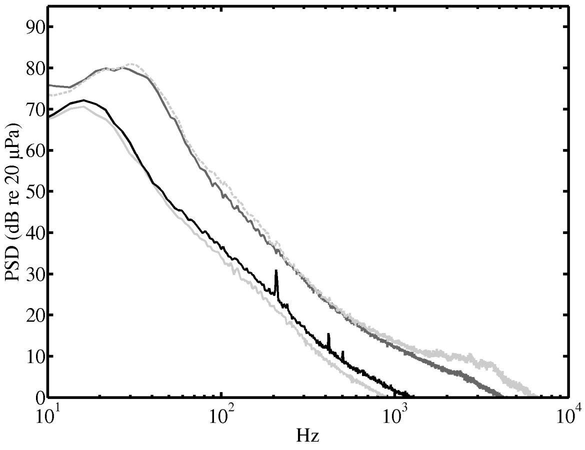

Figure 6 Effect of the diameter of the microphone membrane on measurements at 6 m/s and 10 m/s, windscreen 3 used on the one-inch and half-inch microphones.
Bottom curves: 6 m/s; —: ½”; —: 1”
Top curves: 10m/s; —: ½”; —: 1”

This contrasts with the interpretation of Pearse and Kingan (2006), who attributed the high frequency rise contents of the signals measured by a half-inch microphone with three foam wind screen sizes to the direct interaction between the turbulent flow through the wind screen and the diaphragm, thus giving rise to the spatial averaging effect mentioned previously. Although this explanation was not investigated further with a microphone of different diameter, a possible explanation for the differing conclusion may be that their tests were carried out at a flow speed of 28 m/s, where flow through the wind screen may have become a significant source of diaphragm excitation, although it is anticipated that the foam would dramatically reduce the mean wind speed for most commercially available professional foam screens. In the present case however, it appears that the measured windscreen noise is created by the turbulent interaction at the surface of the windscreen, and the high-frequency components are determined by the surface roughness of the screen.

APPLICATION TO WIND FARM NOISE

To determine the validity of the wind tunnel tests and conclusions drawn from these, the same collection of wind screens were used for noise measurements in a wind farm. The noise measurements were carried out according to the South Australian Wind Farm Noise Guidelines, using a cup anemometer and microphones placed on a stand 1.5m above the ground. The weather conditions on the allocated measurement day were such that the measured wind speed at the microphone level was quite low, and the highest wind speed at which meaningful data could be extracted was between 3.5 and 3.9 m/s. However, the data indicated the same trends as those reported in Figure 3, where the levels of wind noise reduction with reference to the bare microphone were comparable to those measured in the wind tunnel.

Although more extensive measurements are required to allow for a broader range of wind conditions, the data obtained from preliminary wind farm noise measurements support the results and conclusions obtained in the wind tunnel.

It is not possible to use the A-weighted noise levels presented in Figure 5 to directly determine the wind induced microphone self noise level during wind farm background noise monitoring. The level of wind induced microphone self noise will vary from site to site for the following reasons:

1- Wind speed data for the background noise analysis is obtained from the wind farm wind mast at a height of 10 metres above ground level, while the microphone is located at a height of 1.2 to 1.5m above ground level. For open flat terrain, wind speeds at 1.5m height are only approximately two thirds of the speed at 10m. Monitoring locations surrounded by significant vegetation are likely to experience wind speeds of less than half the speed measured at 10 metres height at the wind mast.

2- The wind farm wind mast is normally located on the highest ground, where wind speeds are greater than in the valleys, where the residences are often located.

3- Background (L_{90}) noise measurements are undertaken during wind farm noise measurements but are compared to average wind speed data. Calculation of wind-induced microphone self noise based on the wind speed exceeded for 90% of the measurement period might therefore be more appropriate.

Further work will be undertaken to determine the importance of the above factors, with the aim of developing a method for determining the influence of wind-induced microphone self noise on measurements in the field.

CONCLUSION

The experimental results obtained in the Small Anechoic Wind tunnel at the University of Adelaide support the following conclusions regarding spherical or ellipsoidal open-cell foam microphone wind screens:

- Wind screen diameter is the single most important parameter determining the efficiency of a wind screen.
- Microphone diameter has no significant effect on the measured level of wind screen noise.
- Wind screen noise attenuation decreases very slightly with increasing wind speed
- Wind-induced microphone self noise varies with the 6th power of the flow speed

As a note of caution, however, it is anticipated that the wind screen may increase self noise at very low frequencies because of the turbulent wake it creates and the very large acoustic wavelength in this frequency range. This, however, is not likely to affect general purpose noise assessments, for which the A weighting is extensively used, but is likely to be a concern when very low frequencies are of interest, as for example in the case of atmospheric boundary layer measurements (van den Berg 2006).

One of the main features of this study is the good level of agreement between measurements conducted in various conditions and conclusions drawn in previous publications. This indicates that there is strong potential to determine the wind noise associated with most open cell foam wind screens of regular shape.

Three frequency ranges have been identified. In the 20Hz-2000Hz frequency range, the spectrum is largely determined by the dynamic pressure and Strouhal number associated with the wind screen diameter, and it is anticipated that the high frequency behaviour is determined by the details of the foam material. The magnitude of very low frequency components of wind screen noise are determined by atmospheric turbulence, which is very dependent on local conditions. However, this is likely to have a minor impact on A-Weighted spectra, which are commonly used in regulatory documents such as the South Australian EPA's guidelines on wind farm noise measurements.

In light of these observations, a wind screen noise model could be developed for most commercially available products and used in the field to highlight potential issues with outdoors noise measurements. Subsequent work will focus on the development of wind screen noise models that may assist with extending the range of wind speeds over which measurements can be taken. The purpose of this work is to derive simplified criteria to determine the validity of noise measurements based on the measured noise levels, wind speed at the microphone, and type of wind screen used.

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