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Measurement of the Self-Noise of Microphone Wind Shields

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Abstract

For outdoor acoustic measurements, wind-induced noise is known to affect the results. In addition to the noise of interest which propagates as acoustic waves, the pressure fluctuations generated by the wind passing over the microphone surfaces are measured by the diaphragm of the microphone. These unwanted pressure fluctuations affect the microphone output, even with relatively light airflow over the microphone. To resolve this problem, microphone wind shields are commonly used, but the measured results are only considered valid below a wind speed dictated by the performance of the wind shield. While a theoretical explanation of the wind shield performance exists, no analysis or measurements have been presented that separate the wind-induced noise from the microphone output. This paper presents the results of anechoic wind tunnel tests of a two-microphone analysis technique that uses the incoherent output power between a microphone within the flow and a microphone external to the flow to estimate the wind-induced component of the noise for various types of commercially available wind shields. It is confirmed that the wind-induced noise can influence the measured noise magnitudes in the low and mid frequency range but is negligible at higher frequencies.

Introduction

Since a microphone may produce wind-induced noise even with light airflow passing it, the environmental conditions for the validity of outdoor measurements is primarily limited by the wind speed. The wind-induced noise can be reduced by the use of wind shields (or screens) while allowing the signal of interest to propagate to the microphone. The accuracy of environmental noise measurements is limited by the performance of the commercially available wind shields in many cases. The topic is especially important for measurements in environments where high wind speeds are present for a significant fraction of the time such as areas adjacent to wind farms or sea shores [2]. Many regulatory procedures currently limit environmental noise measurements to local wind speeds less than 5 m/s.

The mechanisms of wind-induced noise associated with wind shields has been investigated experimentally and analytically [2,3,4,5,7,8,10,11]. One contributor is the so called self-noise associated with wakes generated as a result of interaction of a turbulence-free air flow with the wind shield. Another mechanism generating wind shield induced noise is the interaction of atmospheric turbulence with the wind shield. It has been suggested that atmospheric turbulence is the major factor affecting results of environmental noise measurements [11,12]. Previous laboratory investigations of the performance of wind shields in a low turbulence flow have attributed the measured noise to that of the self-noise mechanism [3,5]. However, the result may be influenced by the noise of the air handling system or jet noise, noise from turbulence in the wind tunnel and other irrelevant contributors or background noise sources. Analysis of measurements made to characterise the performance of wind shields [2,3,4,5,10] also have not attempted to separate the contributions from self-generated noise and noise from pre-existing turbulence not associated with the wind shield. Therefore it is difficult to judge whether atmospheric turbulence has a greater influence than the self-induced noise in practical applications.

This paper is focused on experimental investigation of the self-noise of wind shields due to the interaction of the wind shield with a relatively low turbulence free jet airflow. The results of the investigation allow for characterisation of the relative performance of different wind shields in terms of the self-noise generated by the interaction of the flow with the (bluff body) microphone wind shields.

Wind Induced Noise

Generally outdoor noise measurements have two components: the wind induced noise on the microphones and the noise of interest produced by other sources. The majority of environmental noise measurements are done at low Mach number and the media around the wind shield can be considered as incompressible. Strasberg [10] has shown that in such circumstances noise from cylindrical and spherical windshields can be approximated by universal dependencies where spectral levels are functions of the wind shield diameter, wind speed and frequency only.

The wind induced noise generally consists of two forms of pressure fluctuations: the turbulence provided by the local wind which depends on the atmospheric conditions and terrain properties [11], and the surface turbulence which results from interaction of the microphone with the flow [10]. The use of a wind shield is intended to reduce the unwanted pressure fluctuation from the air flow around the microphone and preserve the original acoustic signal. This paper is focused on the noise associated with the second mechanism, i.e. the self-induced noise generated by the airflow wakes around the wind shield.

Based on previous investigations [9,10,11], it is possible to summarise the findings for the self-noise of conventional spherical wind shields. At very low frequencies (typically less than 5 Hz), the self-noise sound pressure levels are independent of frequency and increase with wind speed. At higher frequencies, up to a value of $f_c = V/3D$, the self-noise levels fall with $f^{-5/3}$, where V is the wind speed and D the wind shield diameter. The self-noise becomes negligible at frequencies above a value of approximately $100V$, assuming a value of 1 mm for the Kolmogrov size [11], due to the dissipation range of the turbulence being encountered.

Previous experimental investigations have not attempted to separate the incident flow turbulence noise and the self-noise components, and the experiments have been performed in facilities designed to minimise the background noise and the noise associated with the flow generation devices [e.g. 3], which by their nature are relatively expensive. Others have used environmental noise measurements with presumed low background levels [2], although flow over grassy terrain and the atmospheric turbulence may create some background noise.

Approach

An anechoic wind tunnel was used for the wind noise measurements for a range of commercially available microphone wind shields. Details of the wind tunnel can be found in [5]. Parameters of the flow are explored in [6].

Experimental Arrangement

Testing was undertaken in the anechoic wind tunnel (AWT) in the School of Mechanical Engineering at the University of Adelaide, which consists of an anechoic chamber equipped with an air handling system and contraction to provide an open jet with outlet 275 mm × 75 mm. The experimental arrangement is shown in Figure 1, and includes two microphones. Microphone B (response channel) is placed in the potential core of the jet and Microphone A (reference channel) was located out of the airflow. The position of Microphone A was adjusted to minimise the difference between the acoustic spectra measured at the two microphones when the loudspeaker which generates white noise was operated without the air jet. In all measurements, the same type of microphone wind shield was placed on both the microphones such that they would have identical acoustic insertion loss.

The loudspeaker generated a white noise signal with overall sound pressure level (SPL) of approximately 96 dB (60 dB(A)) and 106 dB (70 dB(A)), while the nozzle provided various airflow speeds (2, 4, 6, 8, 10 and 12 m/s). A multi channel data acquisition system was used to record the microphone signals at each wind speed of interest and for each type of wind shield tested. The frequency resolution of the Fast Fourier Transform analysis was 1.5625 Hz.

The outlet of the AWT is an open diffuser, which allows unwanted background noise such as that generated by extraneous noise sources including fluorescent lights and computer fans to be recorded by the microphones. The white noise signal produced by the function generator was amplified to levels 15 to 25 dB above the background noise for the frequency span of interest, except at some frequencies around 10 to 20 Hz. Figure 2 shows autospectra of background and loudspeaker signal without the jet noise present, and reveals that the measured noise from the loudspeaker and the air jet significantly exceeds the contribution from background noise.

Moreau [6] provided the characterisation of the Anechoic Wind Tunnel jet used for the project. It was found that the end of the potential core of the jet was located between 375 mm to 450 mm downstream of the contraction exit-plane. The experimental results for the mean flow velocity within the potential core of the jet, as illustrated in Figure 3, indicate that at the wind shield position at the centre of the jet the flow is highly uniform.

Measurements of the jet centreline turbulence intensity, without the microphone or microphone wind shields present, reveal a turbulence intensity of 0.33% at the contraction exit-plane, and a turbulence intensity of 2% at 200 mm downstream of the contraction exit-plane. This indicates relatively low levels of turbulence were incident upon the microphone wind shields.

Signal Processing

The key concept in the following analysis is that the loudspeaker generated white noise represents the desired acoustic source to be measured, and the wind-induced self noise associated with the microphone wind shield is an extraneous noise source. Hence the concept of coherent and incoherent output power [1] can be used to separate the desired noise source from the extraneous one. In this instance the extraneous noise source will be used to assess the relative performance of the microphone wind shields.

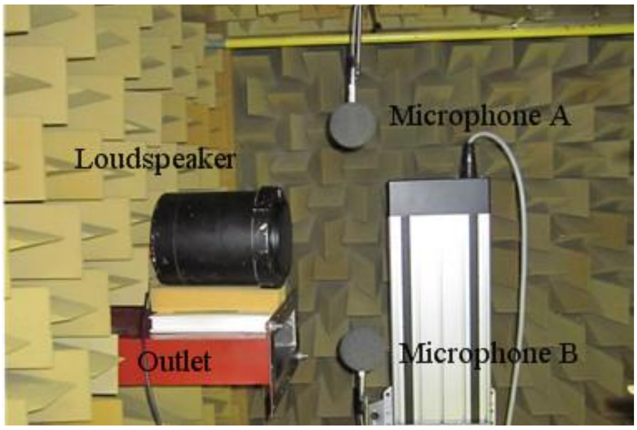

Figure 1. The experimental arrangement, with 90mm wind shields on both microphones.

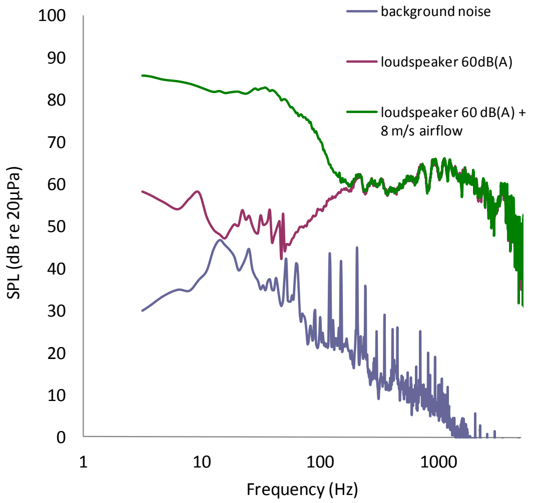

Figure 2. SPL spectra of background noise, loudspeaker generated white noise signals, and air handling system operating.

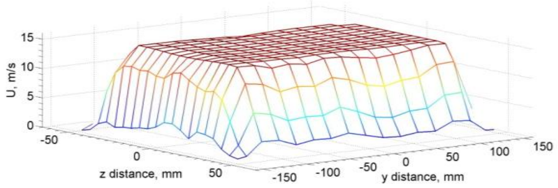

Figure 3. Mean velocity measured at 225 mm downstream from the jet exit-plane, with a jet centreline velocity of 15 m/s, from [6].

It is assumed that the noise measured by the microphones is affected by inputs from the air handling system, noise from the jet, the loudspeaker and background noise. The wind shield noise resulting from interaction of the wind shield and the jet is assumed to be localised around the microphone. Any noise present in the jet due to the air handling system is assumed to be detected by both microphones A and B. It is assumed that the self-noise measured at microphone B is not correlated with any other inputs. Reference microphone A is not affected by the airflow and microphone B is positioned in the core of the jet as described previously. When the jet was not operating, the measured background levels were practically identical at the two microphones, as was also the case for the loudspeaker in operation.

The coherence provides a measure of degree of linear dependence between the two signals [1]. Coherence between the microphones is defined as

$$\gamma^2(f) = \frac{|G_{AB}(f)|^2}{G_{AA}(f)G_{BB}(f)} \tag{1}$$

where $G_{AA}(f)$ is the reference autospectrum of Microphone A, $G_{BB}(f)$ is the response autospectrum of Microphone B, and $|G_{AB}(f)|$ is the modulus of the cross-spectrum between the signals.

The signal recorded from the reference channel ($G_{AA}(f)$) contains the background noise, air handling system and jet noise and white noise produced by the loudspeaker. The response channel ($G_{BB}(f)$) in addition has contribution from the wind noise. If the contribution from the wind noise is negligible, the coherence between the channels should be unity.

The incoherent component between the two signals is the wind induced noise and can be represented by the incoherent output power (IOP) defined by

$$IOP(f) = \left(1 - \gamma^2(f)\right)G_{BB}(f) \tag{2}$$

which in this instance gives the part of the response autospectrum $G_{BB}(f)$ which is not correlated with the reference signal $G_{AA}(f)$.

It should be noted that extraction of the wind induced noise using the coherence analysis may not necessarily require an anechoic chamber since background and other noises will be automatically taken into account as a part of the coherent output analysis.

Microphone Wind Shields Tested

The major characteristics of the wind shields tested are listed in Table 1 and shown in Figure 4.

No.	Diameter mm	Reference
1	45	Ellipsoidal
2	60	Spherical-Manufacturer A
3	75	Spherical-Manufacturer B
4	90	Spherical-Manufacturer A
5	180	Spherical-Manufacturer B
6	Windpac	Special shape-Manufacturer C

Table 1. Wind shields used for the measurements.

(a) (b)

Figure 4. Photographs of wind shields used for the measurements: a) 180 mm spherical, and b) Windpac.

Results

With only the loudspeaker operating (and no flow), the coherence between the two microphone signals is high and almost unity across the whole frequency span considered in the analysis, as shown in Figure 5. This result indicates that the combined loudspeaker noise and background noise are highly coherent even if the microphones are not placed close to each other. Figure 5 also shows the measured coherence with both the jet and loudspeaker operating, and reveals that the coherence between the two microphone signals in the presence of the wind noise varies significantly in the low to mid frequencies depending on the type of the wind shield. In Figures 5 to 9, “no” refers to no wind shield.

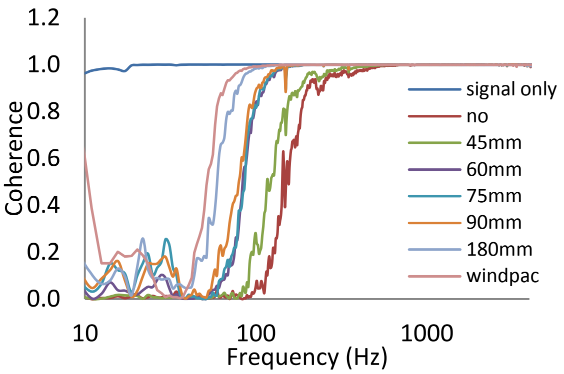

Figure 5. Coherence at wind speed 8m/s, for different wind shields.

Figure 6 shows the measured incoherent output power for the 60 dB(A) and 70 dB(A) loudspeaker regimes. These results, representing the wind noise, are not sensitive to change in the level of the loudspeaker signal. The curves in Figure 6 are similar to each other qualitatively and quantitatively within 2dB. This comparison confirms that the method used to separate the wind induced noise from the total noise is reliable, as the wind induced noise is practically independent of the level produced by the loudspeaker and is controlled by the velocity of the airflow. Thus the incoherent part of the total output is only associated with the wind induced noise.

Figures 7 to 9 show the measured incoherent output power for the various wind shields at wind speeds of 8, 10 and 12 m/s, and Figure 10 compares the measured incoherent output power for the 90 mm wind shield at a range of flow speeds. The results indicate that for all the wind shields tested the wind noise may control the measured overall sound pressure levels at low frequencies and in the infrasound region. At higher frequencies where the wind noise is negligible, the deviation of the coherence from unity becomes too subtle to provide a reliable estimate of the wind shield noise, and the incoherent power results represent numerical noise.

The results are generally in qualitative agreement with trends expected from the literature. The wind induced noise increases with an increase in the wind speed. Wind noise is more effectively attenuated by wind shields with larger diameter, however there is a saturation zone where an increase in the wind shield diameter from 60 to 90 mm provides only a minor decrease in the wind induced noise. This may be due to the finite extent of the contraction outlet and the jet, such that wind shields with diameters greater than 75 mm are not fully immersed in the potential core of the jet. The spectra of the wind noise demonstrate a complex dependence in the frequency domain. The levels vary little at very low frequencies and have a particular local maximum/trend change point after which the spectrum can be approximated by a straight line if the frequency is represented in a logarithmic scale, the slope of which is dependent on the wind shield dimension.

Conclusions

A technique utilising the incoherent output power between two microphone signals to measure the wind-induced noise of microphone wind shields was developed and tested in an anechoic wind tunnel. Although the technique shows significant potential, further quantitative analysis of the results is required, and is the subject of current work.

Acknowledgments

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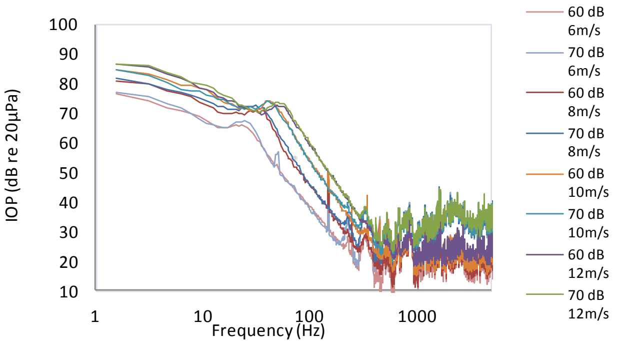

Figure 6. Wind-induced noise (90mm wind shield, various wind speeds, sound field 60dB and 70dB)

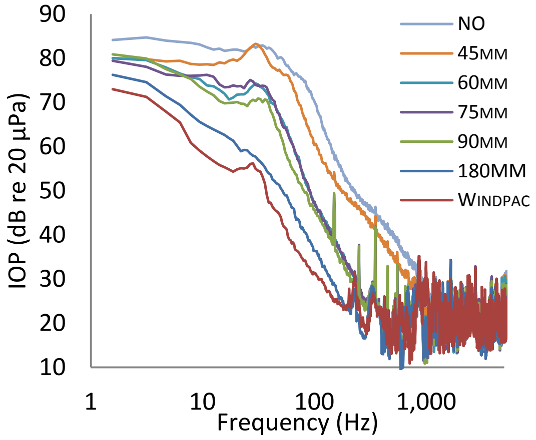

Figure 7. IOP at wind speed of 8 m/s, for various wind shields.

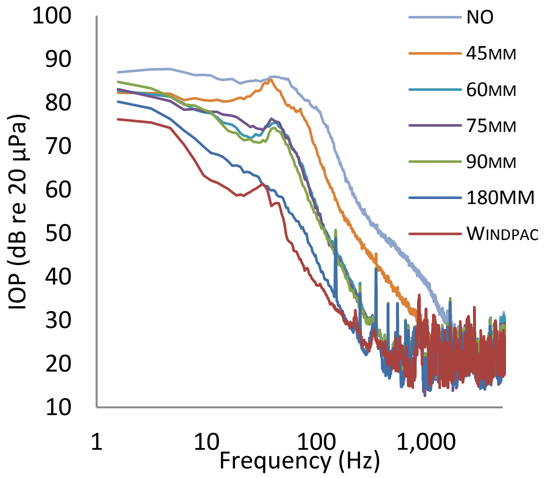

Figure 8. IOP at wind speed of 10 m/s, for various wind shields.

References

[1] Bendat J.S., Piersol A.G., *Random data: Analysis and measurement procedures*, John Wiley & Sons, New Jersey 2010, Chapter 5, 135-138.

[2] Cooper J., Leclercq D., Stead M., Wind induced aerodynamic noise on microphones from atmospheric measurements, *Proc. ICA 2010*, Sydney, Australia.

[3] Hessler G. F., Hessler D. M., Brandstatt P. and Bay K., Experimental study to determine wind-induced noise and wind screen attenuation effects on microphone response for environmental wind turbine and other applications, *Noise Control Eng. J.*, 56(4), 2008, 300-309.

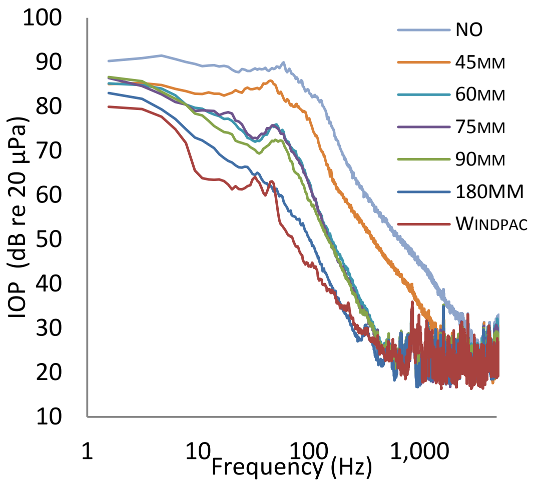

Figure 9. IOP at wind speed of 12 m/s, for various wind shields.

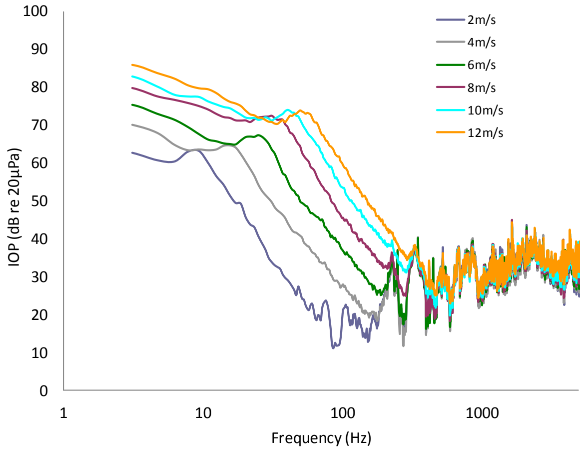

Figure 10. IOP measured for 90mm wind shields, at various wind speeds.

[4] Hosier R.N., Donovan P.R., Microphone Windscreen Performance, *National Bureau of Standards Report NBSIR 79-1599*, 1979.

[5] Leclercq D., Cooper J. and Stead M., The use of microphone windshields for outdoors noise measurements, *Proc. AAS Conf. Acoustics 2008*, Geelong, Australia.

[6] Moreau D. J., Anechoic wind tunnel jet characterisation, unpublished report, University of Adelaide, Australia, 2011.

[7] Morgan S., Raspet R., Investigation of the mechanisms of low-frequency wind noise generation outdoors, *J. Acoust. Soc. Am.*, 92, 1992, 1180-1183.

[8] Morgan M.S., An investigation of the sources and attenuation of wind noise in measurement microphones, Dissertation, 1993, University of Mississippi.

[9] Plate E.J., Wind tunnel modeling of wind effects in engineering, in *Engineering Methodology*, edited by Plate E.J., Elsevier Scientific Publishing Company, Amsterdam, 1982, 573-639.

[10] Strasberg. M., Dimensional analysis of wind screen noise, *J. Acoust. Soc. Am.*, 83(2), 1988, 544-548.

[11] Van den Berg, G.P., Wind induced noise in a screened microphone, *J. Acoust. Soc. Am*, 119(2), 2006, 824-833.

[12] Wilson D.K., Thomson D.W., Acoustic propagation through anisotropic, surface-layer turbulence, *J. Acoust. Soc. Am*, 96, 1994, 1080-1095.