



## MEASUREMENT OF SOUND IN AIRFLOW

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### Abstract

The suitability of a number of different microphone configurations for making sound measurements in airflow was assessed. When a microphone is immersed in airflow, turbulence within the airflow interacts with the microphone diaphragm causing the microphone to measure a noise level, which is due to the turbulence/diaphragm interaction and is not due to an acoustic wave. This turbulence-induced 'pseudo-noise' is equivalent to background noise and can interfere with sound level measurements if the pseudo-noise level is similar to the level of sound being measured. Instances where pseudo-noise may be a problem include noise measurements made out-doors where the microphone is subjected to atmospheric wind or noise measurements made in wind tunnels or HVAC ducts. In this paper a number of different microphones and microphone treatments were investigated for their suitability for minimizing pseudo-noise.

### INTRODUCTION

When making noise measurements out-doors, or within a HVAC duct or a wind tunnel, measurements are often made using a microphone immersed in airflow. Turbulence within the airflow interacts with the microphone diaphragm causing the microphone to measure a signal. This is known as 'pseudo-noise'. Pseudo-noise affects sound pressure level measurements in a similar way to normal background noise, and should ideally be a nominal level (e.g. 10dB) below the level of sound being measured.

In this paper the pseudo-noise level is defined

$$L_{pn} = 10 \log_{10} \left( \frac{\overline{P_n^2}}{P_{ref}^2} \right) \quad (1)$$

where  $p_{ref} = 20\mu\text{Pa}$  and  $p_n$  is the ‘pseudo-noise’ measured by the microphone which is a function of both the turbulence induced pressure distribution on the microphone diaphragm and the diaphragm’s response to this pressure distribution. The pseudo noise level is defined such that  $L_{pn}$  is equivalent to the sound pressure level of an acoustic wave of root-mean-square pressure  $p_n$  measured by the microphone.

This paper describes an experimental investigation in which the pseudo-noise level measured by a number of different microphone configurations were compared. The microphones used were the Brüel & Kjær 1/2”, 1/4” and probe microphones. A number of Brüel & Kjær nose cones and reticulated foam windscreens were attached to the 1/2” microphone to assess their effect on the measured pseudo-noise level.

Reticulated foam windscreens are known to produce high levels of self-noise which according to Fahy [1] is caused by turbulence induced skeletal vibration of the windscreen. Streamlined microphone nose cones are designed to reduce pseudo-noise by minimising the disturbance to the flow due to the presence of the microphone, and also prevent the turbulent airflow from impinging directly onto the microphone diaphragm. According to Neise [2] nose-cones still transduce any turbulent fluctuations that exist in the on-coming flow.

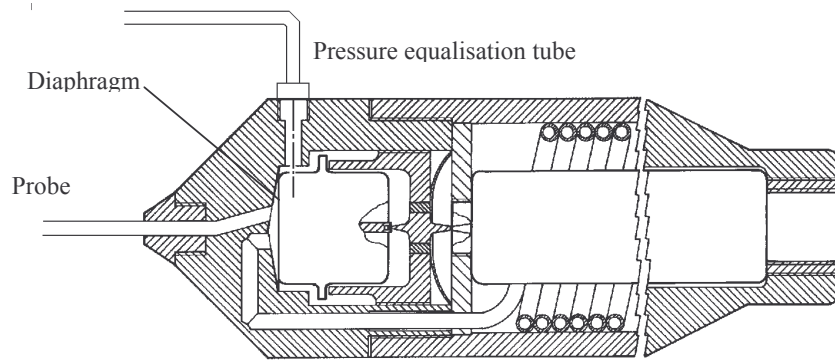
## APPARATUS

Brüel & Kjær 1/2”, 1/4”, and probe microphones were used with a Brüel and Kjær preamplifier (type 2669) and Brüel & Kjær sound analyser (type 2260B) for one-third octave band measurements. The 1/4” microphone was attached to the 1/2” preamplifier by the Brüel & Kjær 1/4” (type UA0035) adaptor. A variety of Brüel & Kjær nose cones and reticulated foam windscreens were available for use. These are summarised in table 1 below.

Microphone	Brüel & Kjær Part No.	Wind noise treatment	Part No.
Brüel & Kjær 1/2”	4189	Sharp nose cone	UA 0386
		Rounded nose cone	UA 0052
		90mm diameter foam windscreen	UA 0237
		65mm diameter foam windscreen	UA 0459
		Elliptical foam windscreen	WQ 1133
Brüel & Kjær 1/4”	4135	Rounded nose cone	UA 0053
Brüel & Kjær probe	4182	-	-

*Table 1 Summary of microphones and wind noise treatments available*

For tests using the probe microphone in airflow, a pressure equalisation tube was used to prevent a large pressure difference occurring across the microphone diaphragm. The probe microphone arrangement is shown in figure 1 below.



*Figure 1 Probe microphone with pressure equalization tube*

A small amount of porous material provided damping of acoustic waves within the pressure equalization tube.

All experiments were undertaken in the low noise wind tunnel in the Department of Mechanical Engineering at the University of Canterbury. A description of the tunnel is given in Kingan and Pearse [3]. Each microphone was held in position in the centre of the exit jet of the wind tunnel using a purpose built microphone holder. The microphone holder was designed to produce a minimum level of aeroacoustic noise but was rigid enough to prevent excessive microphone vibration. The microphone was placed in the centre of the exit jet of the low noise wind tunnel and oriented directly into the airflow. Airflow speeds between 18.9m/s and 29.4m/s were used in this investigation.

To estimate the background noise produced by the wind tunnel at each airflow speed the 1/2" microphone was placed 200mm below the outlet jet directly below the measurement position. The wind tunnel background noise at the microphone position within the airflow was taken to be the sound pressure level measured just outside the airflow. The wind tunnel background noise (sound pressure level) was found to be more than 10dB below the pseudo-noise level measured by a microphone within the airflow for frequencies greater than 160Hz. Thus it was assumed that the pseudo-noise level measured by the microphone immersed in the airflow contained a negligible contribution from the wind tunnel background noise.

## RESULTS

The pseudo-noise measured by the 1/2", 1/4" and probe microphone configurations at 28.0m/s is shown in figure 2 below.

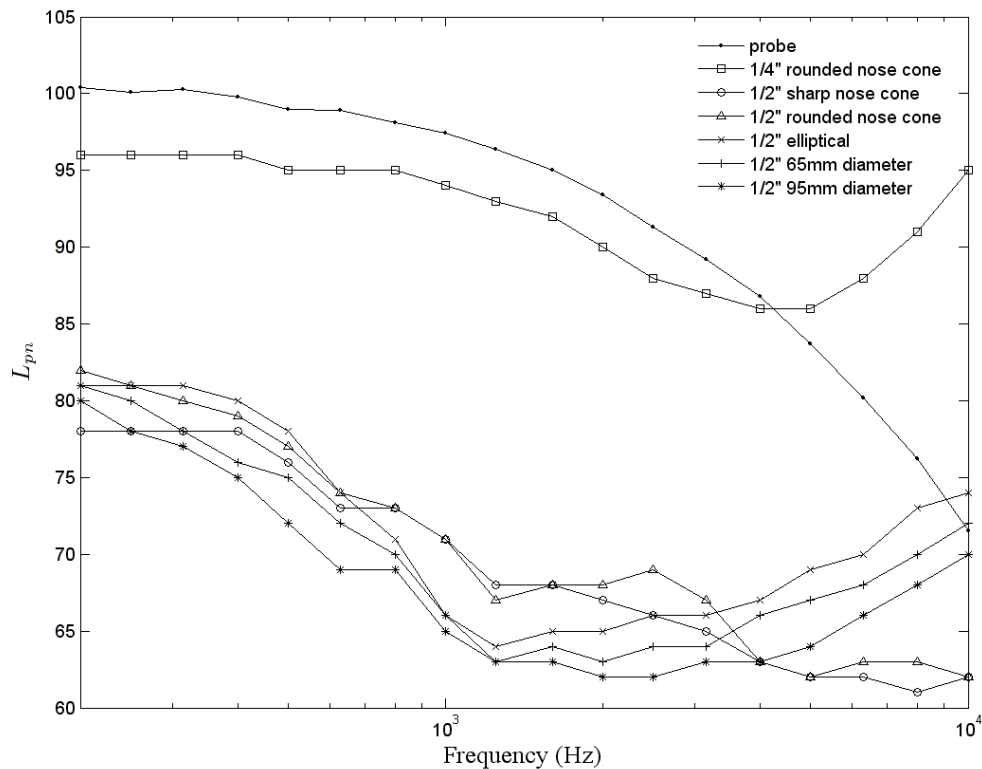


Figure 2. Microphone self-noise measured at 28.0m/s

The 1/2" microphone with rounded and sharp nose cones measured similar pseudo-noise levels at most frequencies. However, the 1/2" microphone covered by the sharp noise cone measured a slightly lower pseudo noise level at some frequencies.

The three cases where the 1/2" microphone was covered by foam windscreens all produced similar pseudo-noise spectra. In general the 1/2" microphone with the 90mm diameter windscreen measured the lowest pseudo-noise level while the 1/2" microphone covered by the 65mm diameter and elliptic windscreens respectively measured pseudo-noise levels ~3dB and ~5dB higher.

At frequencies less than 4000Hz (at 28.0m/s) the 1/2" microphone with the 95mm diameter spherical wind screen measured lower sound pressure levels than the 1/2" microphone with the sharp noise cone. However, at frequencies higher than 2000Hz (at 28.0m/s) the microphones covered by the windscreens measured relatively high pseudo-noise levels that increased with frequency. This phenomenon was almost certainly a result of the physical nature of the foam windscreens. It is proposed that the high levels of pseudo-noise measured by the microphones with foam windscreens was caused by turbulence generated by airflow through the foam windscreen impinging on the microphone diaphragm, or by the skeletal vibration of the foam windscreen as proposed by Fahy [1]. For this reason foam windscreens are inappropriate for the measurement of sound in airflow at high frequencies (greater

than 4000Hz at 28m/s). The 1/4" microphone with a nose cone measured consistently much higher pseudo-noise levels than the 1/2" microphone with the sharp nose cone for all airflow speeds investigated while the probe microphone measured consistently higher pseudo-noise levels than the 1/4" microphone at frequencies lower than 5000Hz (at 28.0m/s).

## ANALYSIS

### Frequency dependence of pseudo-noise

The pseudo-noise measured by a microphone is assumed to be caused by turbulent pressure fluctuations in the airflow interacting with the microphone diaphragm. The frequency  $f$  of the pressure fluctuation caused by the convection of a turbulent eddy of correlation length  $l$  convecting with velocity  $U_c$  past the microphone diaphragm should be approximately equal to  $U_c/l$ . Assuming  $U_c \propto U_\infty$  (where  $U_\infty$  is the wind tunnel airflow speed) the frequency of a microphone's pseudo-noise spectrum should scale according to a Strouhal number type relationship defined below

$$\frac{f\delta}{U_\infty} \quad (2)$$

where  $f$  is the one-third octave band centre frequency and  $\delta$  is a length scale set equal to the microphone diaphragm diameter for the 1/2" ( $\delta = 12.7\text{mm}$ ) and 1/4" ( $\delta = 6.35\text{mm}$ ) microphones.

### Spatial averaging of turbulent pressure on the microphone diaphragm

For frequencies where  $f\delta/U_\infty \sim 1$  the correlation length of the pressure fluctuations on the diaphragm surface are of the same size as the microphone diaphragm and will tend to cancel each other out. This 'spatial averaging' effect will result in a 'drop-off' in the pseudo-noise level measured by the microphone. This drop-off should be related to the ratio of the diaphragm diameter to the turbulence correlation length  $\delta/l \sim f\delta/U_\infty$  (assuming  $l \sim U_\infty/f$ ) i.e. the drop-off in the pseudo-noise measured by a microphone should be a function of the dimensionless frequency  $f\delta/U_\infty$ .

Because of the small size of the probe microphone (the internal diameter of probe is 1mm) the effect of spatial averaging of turbulent pressure fluctuations on the probe tip should have been much less than that which occurred on the 1/2" and 1/4" microphones. The pseudo-noise measured by the 1/2" and 1/4" microphones ( $p_n$ ) should scale with the pseudo-noise measured by the probe microphone ( $p_{n,p}$ ). Thus a scaled pseudo-noise level  $L_s$  was defined

$$L_s = 10 \log_{10} \left( \frac{p_n^2}{p_{n,p}^2} \right) \quad (3)$$

Any spatial averaging effects on the 1/2" and 1/4" microphones should be observed as a drop-off in  $L_s$ .  $L_s$  is plotted against  $f\delta/U_\infty$  for the various 1/2" and 1/4" microphone configurations in figure 3 below.

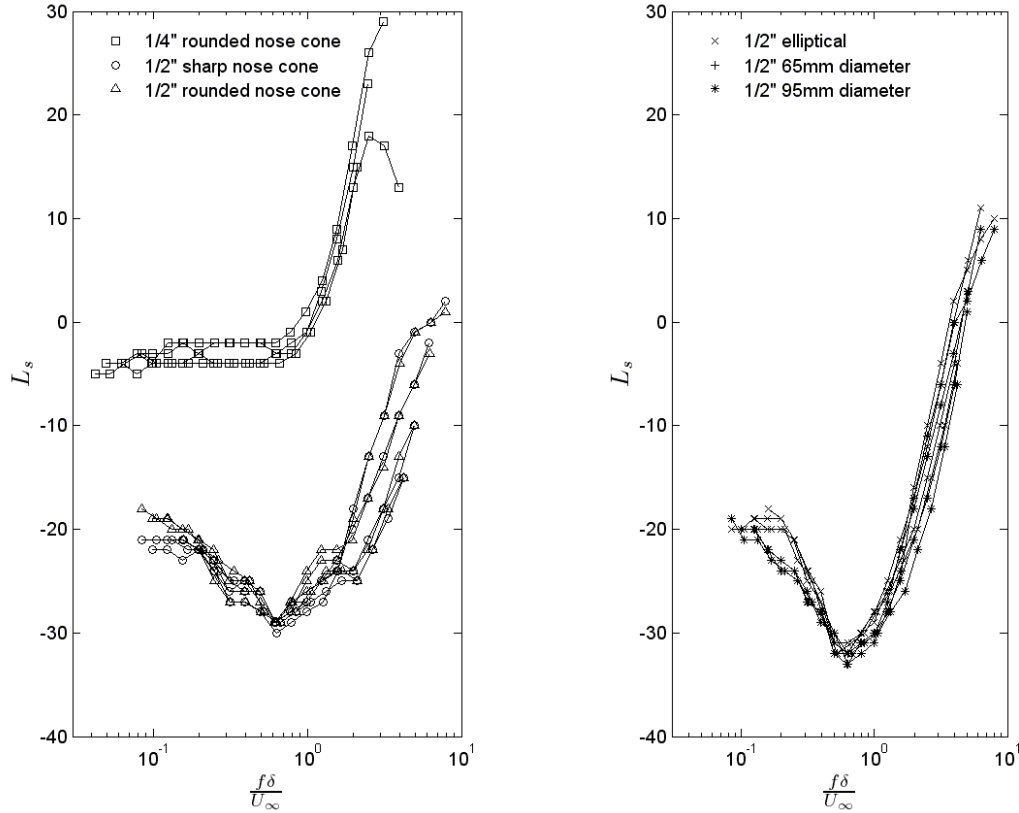


Figure 3. Scaled pseudo-noise level  $L_s$ : microphones with nose cones (left), microphones with windscreens (right)

For frequencies higher than  $f\delta/U_\infty \sim 0.7$ , it is proposed that self-noise produced by airflow over the various microphone coverings (see sections below), resulted in high pseudo-noise levels being measured by all microphone configurations.

For frequencies lower than  $f\delta/U_\infty \sim 0.7$ , all 1/2" microphone configurations exhibited a drop-off, or decrease in the pseudo-noise level with increasing frequency. It is hypothesized that this drop-off was caused by spatial averaging of turbulent pressure fluctuations over the microphone diaphragm. No drop-off was observed for the 1/4" microphone. This could have been due the relatively high level of self-noise produced by the 1/4" nose cone relative to the 1/2" nose cone (an equivalent value of  $f\delta/U_\infty$  corresponds to twice the velocity for the 1/4" microphone compared to the 1/2" microphone).

The relatively high pseudo-noise level measured by the probe microphone was probably due to a relatively low level of spatial averaging of pressure fluctuations on the probe tip and was exacerbated by the probe being oriented directly into the airflow (the 1/2" and 1/4" microphones were protected from turbulence impinging directly onto the diaphragms by nose cones or windscreens).

#### **Nose cone self-noise**

At frequencies higher than  $f\delta/U_\infty \sim 0.7$  microphones with nose cones measured relatively high pseudo-noise levels. The source of this self-noise is unknown.

#### **Windscreen self-noise**

For the 1/2" microphone with a foam windscreen, above a dimensionless frequency of  $f\delta/U_\infty \sim 0.7$ , a relatively high pseudo-noise level which increased with frequency, was measured. It is assumed that this was caused by (1) turbulence generated by airflow through the foam windscreen interacting with the microphone diaphragm or by skeletal vibration of the foam windscreen as proposed by Fahy [1].

The diameter and geometry of the windscreen influenced the level of self-noise measured by the microphone, with the microphone with the larger diameter windscreen measuring relatively lower pseudo-noise levels (as might be expected).

### **CONCLUSIONS AND FUTURE WORK**

The self-noise measured by a Brüel & Kjær 1/4", 1/2" and probe microphones and their associated wind treatments was measured. The 1/2" microphone covered by the sharp nose cone (Brüel & Kjær part no. UA0386) recorded the lowest pseudo noise levels over the widest frequency range.

Spatial averaging of turbulence impinging on the diaphragm of the 1/2" microphone is believed to have reduced the measured pseudo-noise level for frequencies less than  $f\delta/U_\infty \sim 0.7$ . This contributed to the 1/2" microphone measuring significantly lower pseudo-noise levels than the 1/4" microphone.

Self-noise produced by the nose cones on the 1/2" and 1/4" microphones increased the pseudo-noise level measured by microphone configurations for frequencies greater than  $f\delta/U_\infty \sim 0.7$ . The nose cones prevent airflow from impinging directly onto the microphone diaphragm, however, turbulent pressure fluctuations convecting past the gauze screens are still measured by the microphone.

It is proposed that the probe microphone measured relatively high pseudo-noise levels because (1) turbulence within the airflow impinged directly onto the probe and (2) the small size of the probe reduced any spatial averaging effects.

For frequencies lower than  $f\delta/U_\infty \sim 0.7$ , the 1/2" microphone covered by a foam windscreen measured relatively low pseudo-noise levels. However, microphones with foam windscreens appear to be inappropriate for acoustic measurements in airflows

(of the speeds used in this investigation) as they produce relatively high levels of pseudo-noise at frequencies greater than  $f\delta/U_\infty \sim 0.7$ .

The sources of microphone pseudo-noise are not well understood. This paper has described a preliminary study in which a number of hypotheses regarding the causes of microphone pseudo-noise were presented. However, these hypotheses require further experimental validation, which will be the subject of a future study. Further future work will include determining the pseudo-noise measured by Brüel and Kjær 1" and 1/8" microphones immersed in airflow, and relating these measurements to the turbulence in the airflow (measured using a hot-wire). It is hoped that this will reveal a scaling law which could be used by investigators to accurately calculate the level of self-noise measured by a microphone configuration for particular airflow conditions (airflow speed and turbulence level). These laws could be used by future investigators to select a microphone configuration that measures a minimum level of pseudo-noise for sound measurements in airflow.

### ACKNOWLEDGEMENTS

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