



Flow Induced Noise Reduction Techniques for Microphones in Low Speed Wind Tunnels

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Introduction

Have you ever tried to make sound measurements with wind blowing over the microphone? If so, you have probably noticed that the measured sound pressure levels from microphones are affected greatly by the presence of air flow across the microphone diaphragm. The dynamic pressure field measured by the microphone in these cases includes both the acoustic pressure and the pressure induced by the air flow. Wind tunnel noise measurement is a common application in the aerospace and automotive industry where this effect is prevalent. Wind tunnels are used by Aerodynamic Engineers to test aircraft, rocket and automobile models. Using acoustic data gathered from a scale-model in a wind tunnel, the test engineer can estimate the total noise radiation from a full-scale vehicle or component. This can be done over the entire operating speed range of the vehicle at far lower cost than full-scale in-situ measurements.

Additionally, panel testing and interior cabin noise measurements are common applications. Aerospace or automotive engineers will mount microphones outside a moving vehicle to measure noise while the vehicle is in operation. Atmospheric wind noise effects are also very common in environmental noise measurements, for example clear air turbulence (CAT) and other severe weather (tornado or hurricane) detection. So how do we isolate the acoustic field from the air flow pressure to make accurate acoustic measurements?

There are three types of microphone accessories that are commonly used to perform this isolation: grid-caps, windscreens, and nose-cones. Microphones can be placed at any angle with respect to the flow direction. However, the most common orientations have the microphone diaphragm either facing the flow head-on, or parallel to the average flow direction. There are also two types of flow fields: laminar and turbulent. In a laminar flow field, the air flows in parallel layers without disruptions. Think of this as “smooth” flow. In turbulent flow, there are many turbulent eddies, or chaotic changes in flow direction, throughout the flow field. Think of this as a “rough” flow.

In addition to microphones placed in the flow, it is also possible to flush-mount a microphone on a surface. Two types of flush mounted microphones are surface-mounted and side-vented microphones. Side-vented microphones are designed to be mounted through a wall; whereas, surface-mounted microphones do not require any alteration to the measurement surface. Surface microphones are always located in a turbulent flow due to the boundary layer characteristics of the flow and their diaphragms are usually oriented parallel to the flow direction.

The objective of this paper is to show experimentally which microphones and accessories are best used for a given application based on the type of flow and the microphone orientation.

Wind Tunnel Experiments

There are many types of wind tunnels designed for different purposes, generally identified by their operating speed range. Wind tunnels can be classified by their Mach number, the ratio of the air speed in the test section to the speed of sound. Typical wind tunnel classifications are subsonic ($M < .8$), transonic ($.8 < M < 1.2$), supersonic ($1.2 < M < 5.0$), or hypersonic ($M > 5.0$).

An experiment was conducted in the Penn State Aerospace Engineering subsonic wind tunnel facility using both $\frac{1}{2}$ " and $\frac{1}{4}$ " microphones mounted in the flow field and on the boundary surfaces. The wind tunnel facility is a "quiet" wind tunnel; however, the test section is not anechoic. There are noise abatement treatments on the turning vanes of the wind tunnel to minimize the amount of fan noise that is present in the test section. The background noise sound pressure level inside the test section at 0 mph is less than 20 dB in a frequency band from 250 Hz to 20 kHz. Care was taken during the measurements to ensure that no spurious sounds from adjoining laboratories affected the results.

The wind tunnel was set to 0, 10, 25, and 55 mph flow speeds in order to evaluate the effects of the microphone accessories. A speaker was placed upstream of the microphones to simulate a sound source. Two types of surface-mount microphones were evaluated to observe how their background noise level increased with flow speed. All microphones and accessories were manufactured by PCB® Piezotronics. The microphones were all precision, prepolarized condenser microphones with ICP® powered preamplifiers. Table 1 lists the microphones and accessories used in this study and Table 1 shows the overall setup of the microphones within the wind tunnel. Figure 2 shows the microphone orientations and the device used to create turbulence in the wind tunnel near the microphones.

Table 1. Description of PCB® microphones and accessories used in this study with noted orientation.

Microphone Type	Microphone Size	Orientation			Accessories	
		Head On	Parallel	Wall Mounted	Windscreen	Nose-Cone
378B02	1/2"	X	X		079A06	079B21
378C01	1/4"	X	X		079A07	079B20
378A14	1/4"			X		
130B40	1/2"			X		

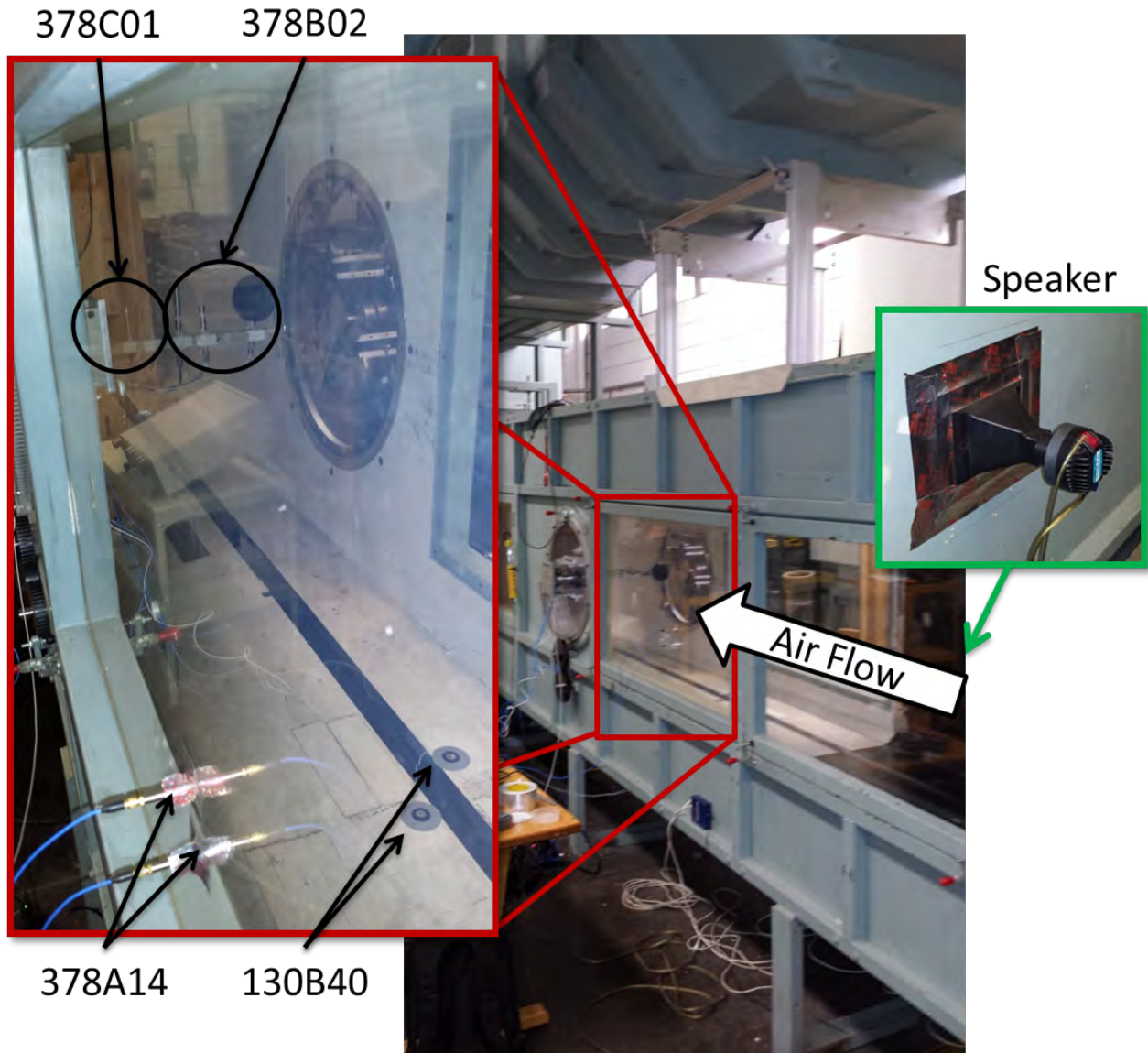


Figure 1. Setup configuration of the wind tunnel showing the relative locations of the 10 microphones and the speaker. The speaker was mounted to the opposite wall of the wind tunnel as compared to the 378A14 microphones.



Figure 2. Microphones shown mounted in the wind tunnel in the head-on (left) and parallel (right) orientation, with (lower) and without (upper) the turbulence generator. Flow direction is into the page.

Lowering the System Noise Floor Using Microphone Accessories

Background noise spectra were recorded in one-third-octave (OTO) bands with the wind tunnel speed set to values of 0, 10, 25, and 55 mph. The measured noise spectra at non-zero speed conditions with windscreens and nose-cones were subtracted from the non-zero speed flow noise spectra measured with only a grid-cap. This results in an apparent decrease in the measurement noise floor of the system when using the accessories. Figure 3 and Figure 4 show the decrease in the system noise floor when using the windscreen or nose-cone accessories with respect to only a grid-cap in the head-on and parallel orientation, respectively. Data are presented for both the laminar and turbulent flow regimes, at three speeds, and for two different

microphone types ($\frac{1}{2}$ " and $\frac{1}{4}$ " free-field condenser microphones). The nose-cone accessory was not used in the parallel orientation as that is not its intended use case.

It is shown that the accessories can give up to a 30 dB decrease in the system noise floor in either orientation. As the flow speed increases, the noise floor reduction benefit offered by the accessories extends to higher frequencies. This is because the turbulent boundary layer is excited at higher frequencies with increasing flow speed. In turbulent flow, the windscreen is more effective than the nose-cone at reducing the measurement noise floor. In laminar flow, at these speeds, the windscreen and the nose-cone accessories are nearly equal in their ability to lower the noise floor. It is suspected that in much higher flow speeds than those measured here the nose-cone would be more advantageous than the windscreen due to the fact that it is more robust.

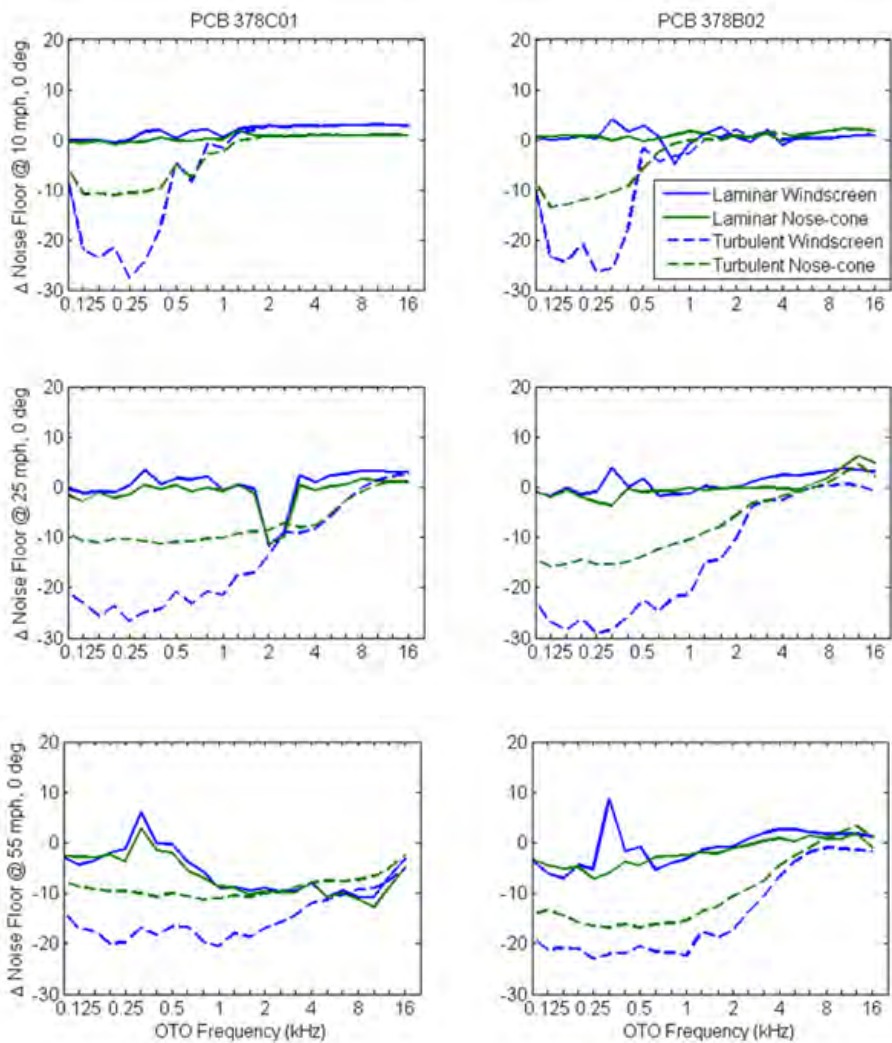


Figure 3. Difference in flow noise between the grid-cap configuration and the windscreen or nose-cone configurations. Data are shown at head-on incidence angle in laminar and turbulent flows for 10, 25, and 55 mph speeds

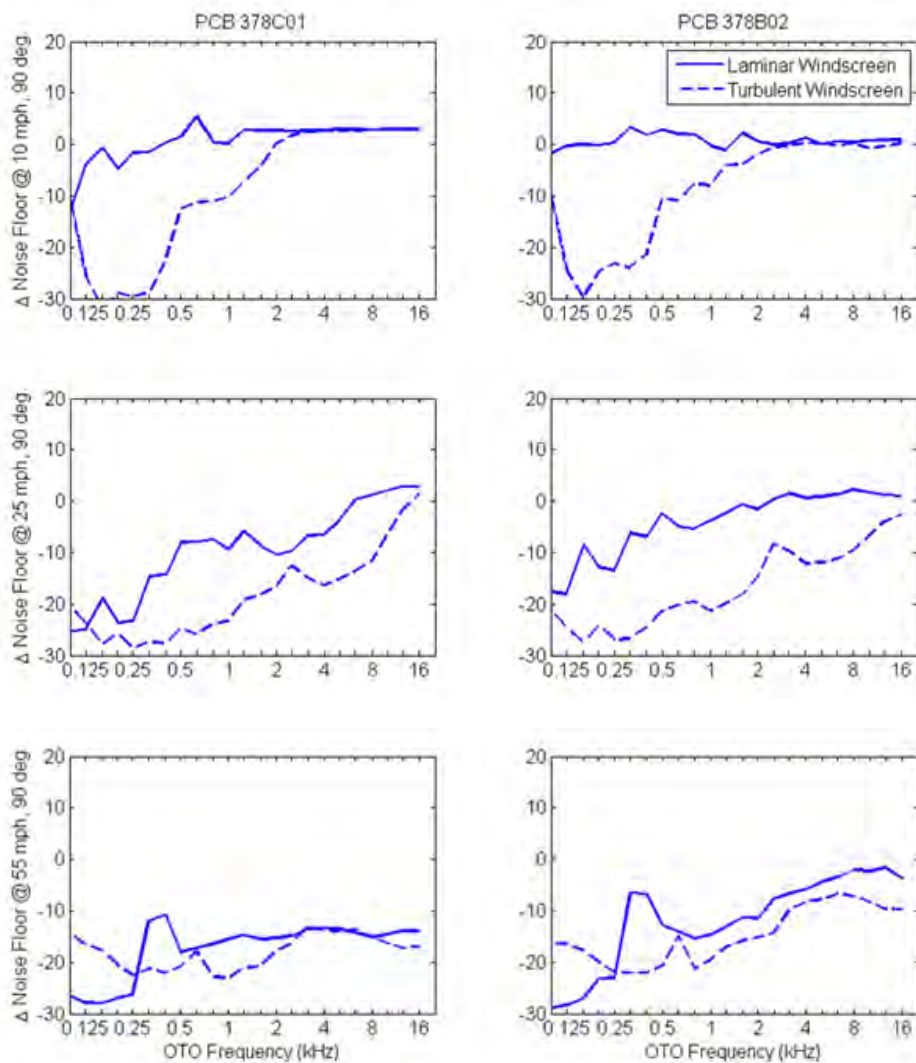


Figure 4. Difference in flow noise between the grid-cap configuration and the windscreen configuration (the nose-cone configuration is not meant for use in the parallel orientation). Data are shown at parallel incidence angle in laminar and turbulent flows for 10, 25, and 55 mph speeds.

Although windscreens can reduce flow noise, windscreens can also introduce an insertion loss into your measurement system. That is to say, some small portion of the acoustic energy is absorbed in the foam windscreen prior to the pressure wave arriving at the microphone diaphragm. This may slightly lower the sound pressure levels that are measured, so it is important to characterize the insertion loss of the windscreen up front, even though it is usually small. In a separate experiment, two microphones (PCB 378B02 and PCB 378C01) were placed in a stationary acoustic field in a reverberant chamber and data were recorded with and without the windscreens present. The data in Figure 5 show that for these windscreens, the insertion loss is from 0-to-2 dB, and varies with frequency. This type of data should be recorded for each windscreen, as the insertion loss may vary slightly from part-to-part.

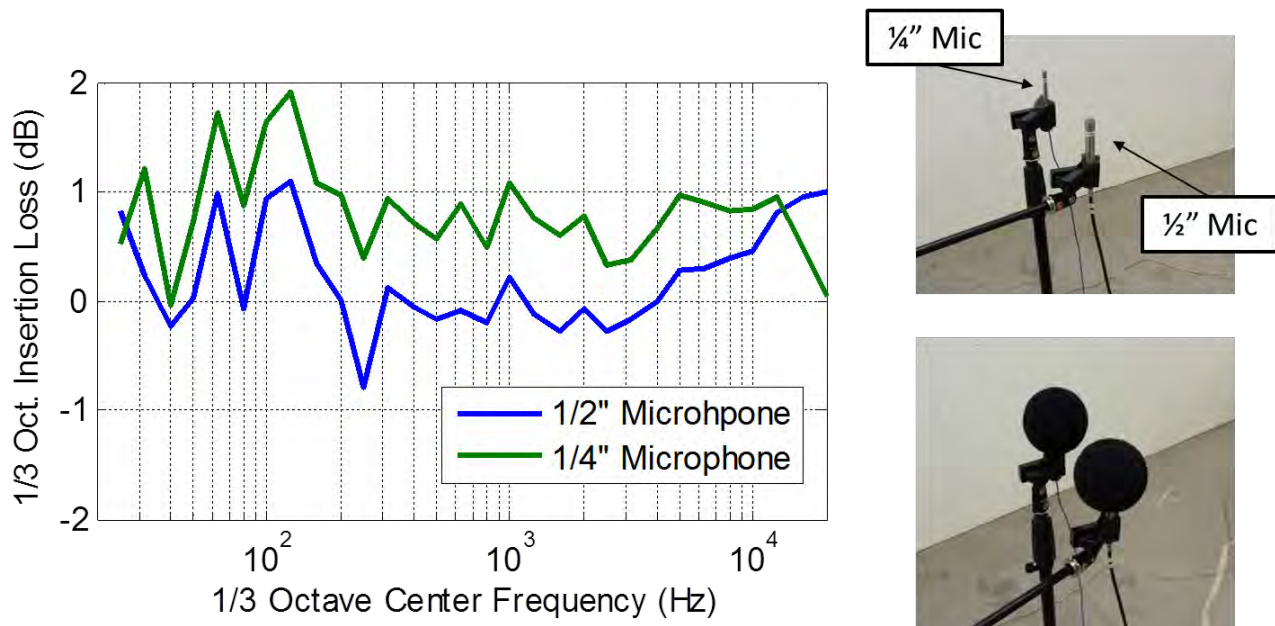


Figure 5. An example of an insertion loss measurement using a ¼” and ½” microphone in a reverberant chamber. The data show slightly increased insertion loss due to the ¼” windscreen (left). Photos of the experiment are shown without windscreens (upper right) and with windscreens (lower right).

Examples of Noise Floor Measurements Using Surface Mount Microphones

Two types of surface mount microphones were also evaluated, a side-vented pressure microphone mounted through the wind tunnel wall, and a low profile surface microphone adhered to the tunnel floor with manufacturer-provided tape rings. Since these are surface mounted microphones, they are always located in the turbulent boundary layer, so no laminar flow data is reported. Representative turbulent flow noise background spectra were recorded, and are shown in Figure 6. The narrowband peaks that exist in this data (for example at 315 Hz in the 55 mph data) should be ignored, as they are resonance characteristics of the particular facility, and not related to the broadband flow noise floor of the microphone. It should also be noted that the high frequency noise floor of this measurement (~28 dB) is the noise floor of the facility, and not of the microphones. The noise floor of the side-vented pressure microphone is much lower, 25-30 dB at some frequencies, than that of the low profile surface microphone at all flow speeds.

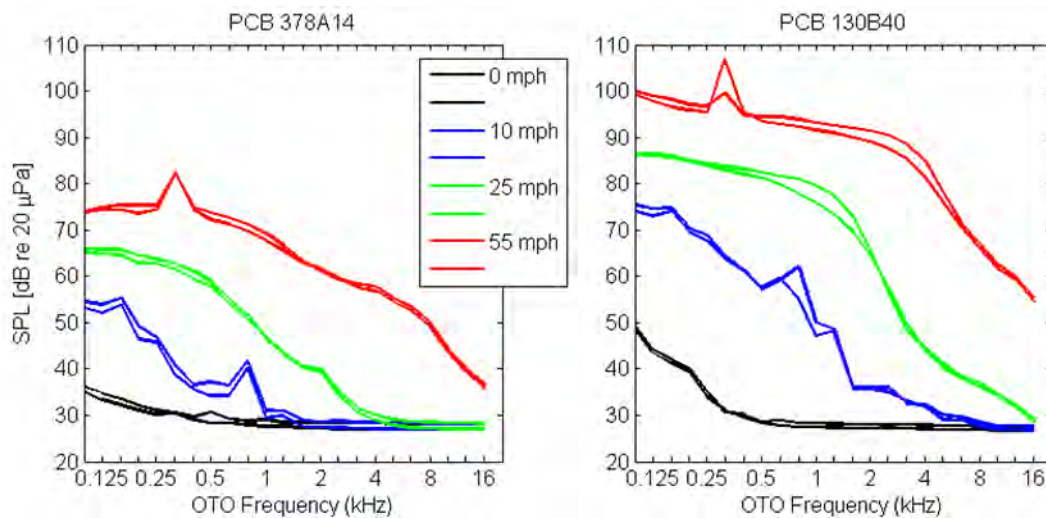


Figure 6. Background flow noise spectra at 0, 10, 25, and 55 mph. The black, 0 mph, curves represent the absolute noise floor of the wind tunnel. Two curves are present for each speed representing each of two microphones placed near each other. Note that narrow peaks in these spectra are due to resonant behavior of the wind tunnel at specific frequencies.

Example: Measuring A Known Signal In Flow Noise

Finally, the speaker source was used to demonstrate how the windscreen and nose-cone accessories can be used to measure a signal with very low signal-to-noise ratio, see Figure 7. The noise source spectrum is shown as the black curve in all plots. It is a bandpass white noise signal between 1 and 5 kHz in frequency with sound pressure level of approximately 60 dB in each one-third-octave band. For this source, using a 1/4" microphone, the signal would not be measureable in either orientation without a windscreen or a nose-cone accessory (left graphs in Figure 7). The 1/2" microphone in the head-on orientation may be able to detect the signal with only the grid-cap (top-right graph in Figure 7); however, much better results are obtained when the windscreen or nose-cone are used. The 1/2" microphone in the parallel configuration requires a windscreen in order to measure this signal with any degree of accuracy (bottom-right graph in Figure 7).

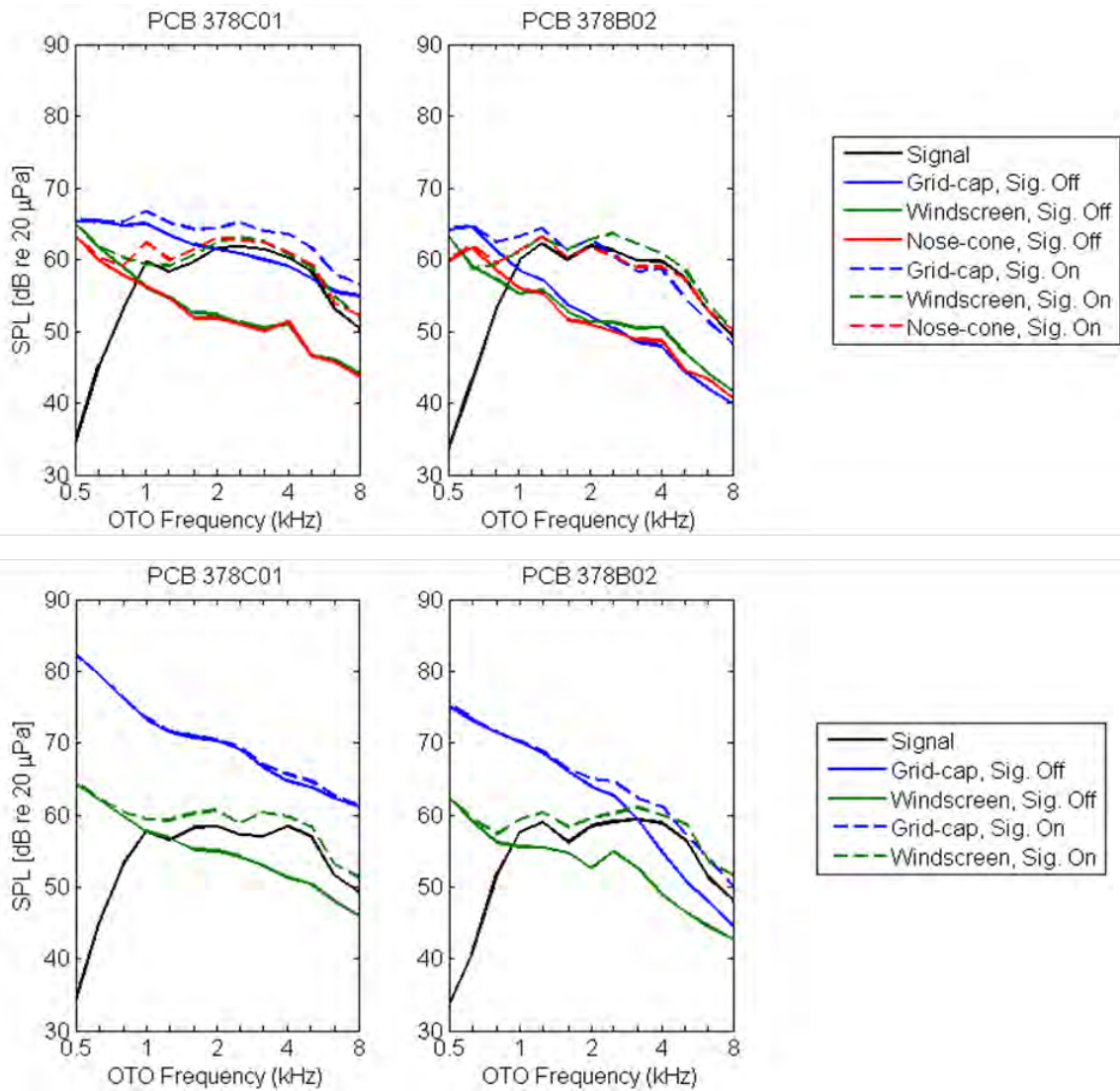


Figure 7. Low level sound source plus flow noise at head-on (top) and parallel (bottom) incidence angle in 55 mph laminar flow comparing grid-cap, windscreen, and nose-cone accessories.

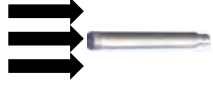






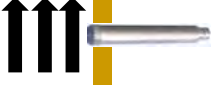


Recommendations: Which Microphones and/or Accessories Should You Choose?




When a microphone is to be located within the flow field, it is recommended as best practice that a windscreen or nose-cone accessory always be used when taking acoustic measurements. In head-on laminar flow, the nose-cone accessory is the best choice. In all turbulent flow and parallel orientation laminar flow, the windscreen accessory is the best choice. The microphone diameter should be selected based on the desired total system noise floor and frequency response requirements, since the windscreen and nose-cone accessories are equally as effective, regardless of microphone size.

When selecting surface mounted microphones, the side-vented pressure microphone is a better selection, with respect to noise floor, than the low profile surface microphone. However, in order to surface mount the side-vented pressure microphone, a hole must be bored in the test structure. In cases where non-destructive

test is required, the low profile surface microphone is a good choice. Table 2 summarizes the use cases for the microphones and accessories tested in this study.

Table 2. Recommended microphones and accessories based on flow conditions and mounting conditions for the PCB® instrumentation evaluated in this study.

Microphone	Mounting	Laminar Flow Speed		Turbulent Flow
		<25 mph	>25 mph	
378B02 378C01	Head-On 			
	Parallel 			
378A14	Through 			
130B40	Surface 			

 Windscreen	 Nose-cone	 Grid-cap
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