

Flow Induced Noise Reduction Techniques for Microphones

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Wind tunnel noise measurements are a common application in the aerospace and automotive industries. The measured sound pressure levels from microphones are affected greatly by the presence of air flow across the microphone diaphragm in these cases. The dynamic pressure field measured by the microphone includes both the acoustic pressure and the pressure induced by the air flow. There are three types of microphone accessories that are commonly used to perform wind noise isolation: grid-caps, windscreens, and nose-cones. In this study, each of these microphone accessories is tested in a wind tunnel using 1/4 inch and 1/2 inch microphones in turbulent and laminar flows at flow speeds up to 55 mph and in both head-on and parallel diaphragm orientations. Two types of flush mount microphones, a surface mount and a side-vented pressure microphone, are also evaluated. The effects of background flow noise on the microphone measurements is shown for all conditions and a case study is presented with an arbitrary acoustic source. Finally, recommendations are presented for which accessories are best used in different measurement situations.

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 the microphones are affected greatly by the presence of airflow 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 airflow. Wind tunnel noise measurements are a common application in the aerospace and automotive industries 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, such as clear-air turbulence (CAT) and other severe weather (tornado or hurricane) detection. So how do we isolate the acoustic field from the airflow 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, while 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

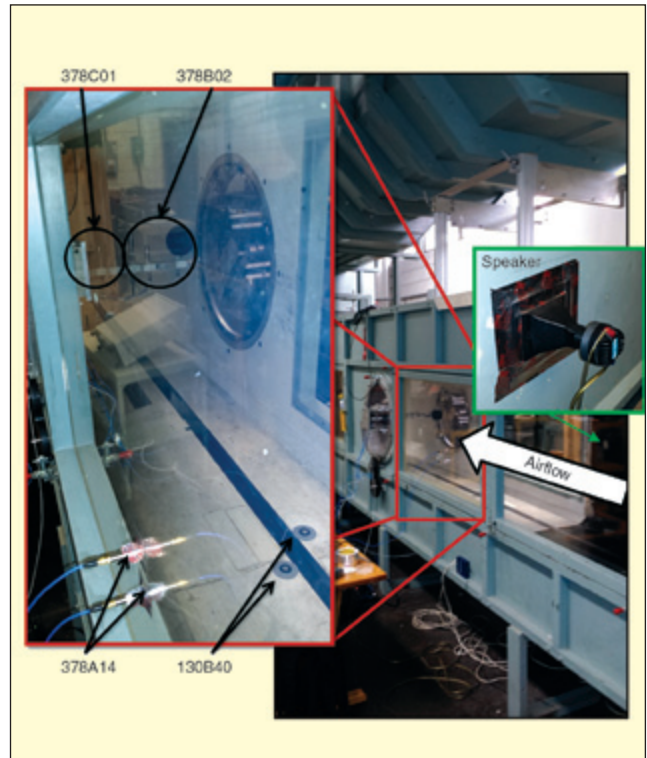


Figure 1. Setup configuration of wind tunnel showing relative locations of 10 microphones and speaker; speaker mounted to opposite wall of wind tunnel as compared to the 378A14 microphones.

characteristics of the flow, and their diaphragms are usually oriented parallel to the flow direction.

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

Wind Tunnel Experiments

There are many types of wind tunnels designed for different purposes, and they are generally identified by range of operating speed. Wind tunnels can be classified by their Mach number M , the ratio of air speed in the test section to the speed of sound. Typical wind tunnel classifications are subsonic ($M < 0.8$), transonic ($0.8 < M < 1.2$), 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 1/2- and 1/4-inch microphones mounted in the flow field and on 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

Table 1. Description/orientation of PCB microphones and accessories.

| Microphones | | Orientation | | | Accessories | |
|-------------|--------|-------------|----------|------------|-------------|-----------|
| Type | Size | Head On | Parallel | Wall Mount | Windscreen | Nose Cone |
| 378B02 | 1/2 in | x | x | | 079A06 | 079B21 |
| 378C01 | 1/4 in | x | x | | 079A07 | 079B20 |
| 378A14 | 1/4 in | | | x | | |
| 378B40 | 1/2 in | | | x | | |

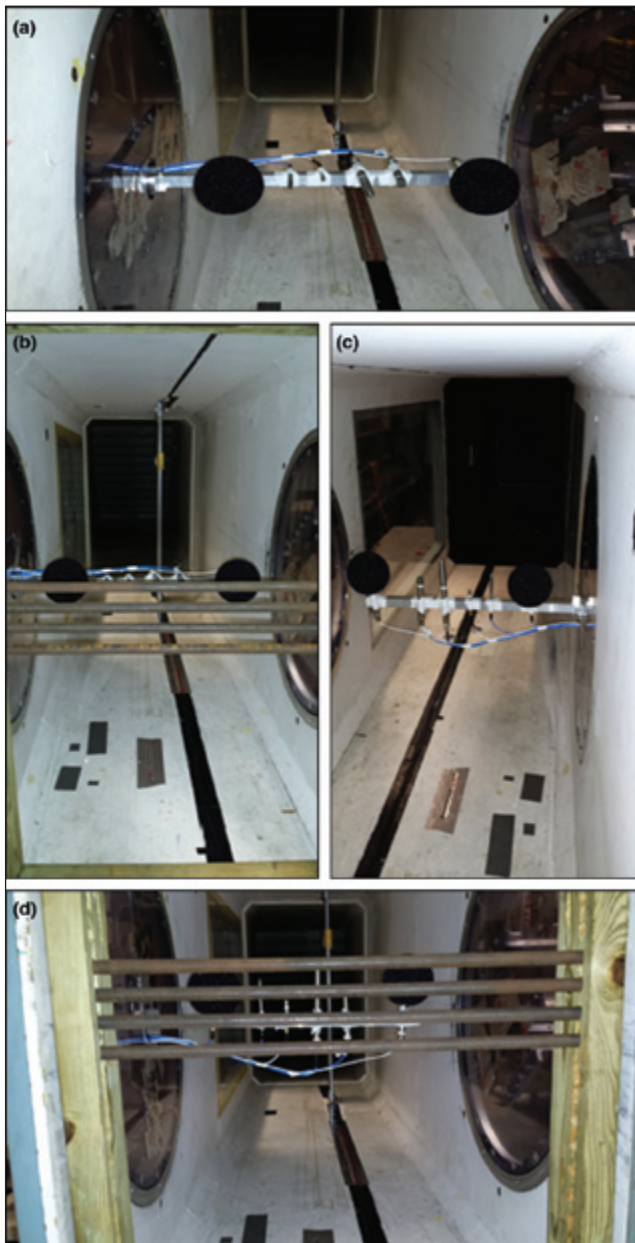


Figure 2. Microphones shown mounted in wind tunnel in head-on (b) and parallel (c) orientation, with (d) and without (a) the turbulence generator. Flow direction is into the page.

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 to evaluate the effects of 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 along with the overall setup of the microphones within the wind tunnel and Figure 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.

Lowering the System Noise Floor

Background noise spectra were recorded in one-third octave bands with the wind tunnel speed set to 0, 10, 25, and 55 mph.

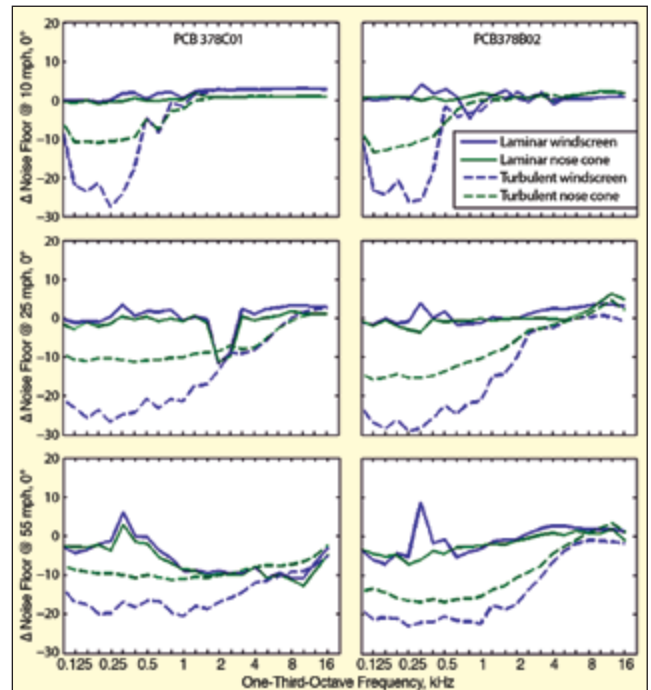


Figure 3. Difference in flow noise between grid-cap configuration and the windscreen or nose-cone configurations; data shown at head-on incidence angle in laminar and turbulent flows for 10, 25, and 55 mph speeds.

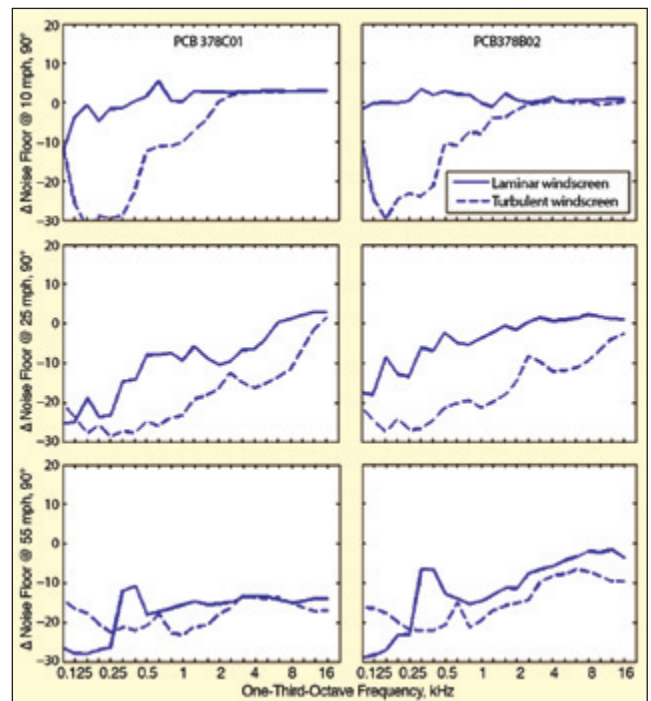


Figure 4. Difference in flow noise between grid-cap and the windscreen configurations (the nose-cone configuration is not meant for use in parallel orientation); data shown at parallel incidence angle in laminar and turbulent flows for 10, 25, and 55 mph speeds.

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. Figures 3 and 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 (1/2-inch and 1/4-inch, free-field condenser microphones). The nose-cone accessory was not used in the parallel orientation, since that is not its intended use.

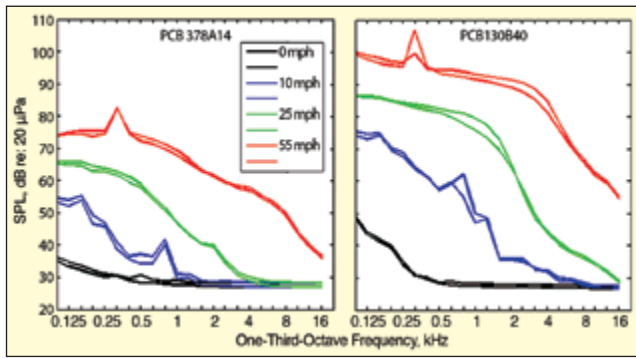


Figure 5. Background flow noise spectra at 0, 10, 25, and 55 mph; black, 0-mph, curves represent the absolute noise floor of wind tunnel; two curves are present for each speed representing each of two microphones placed near each other; narrow peaks in these spectra are due to resonant behavior of wind tunnel at specific frequencies.

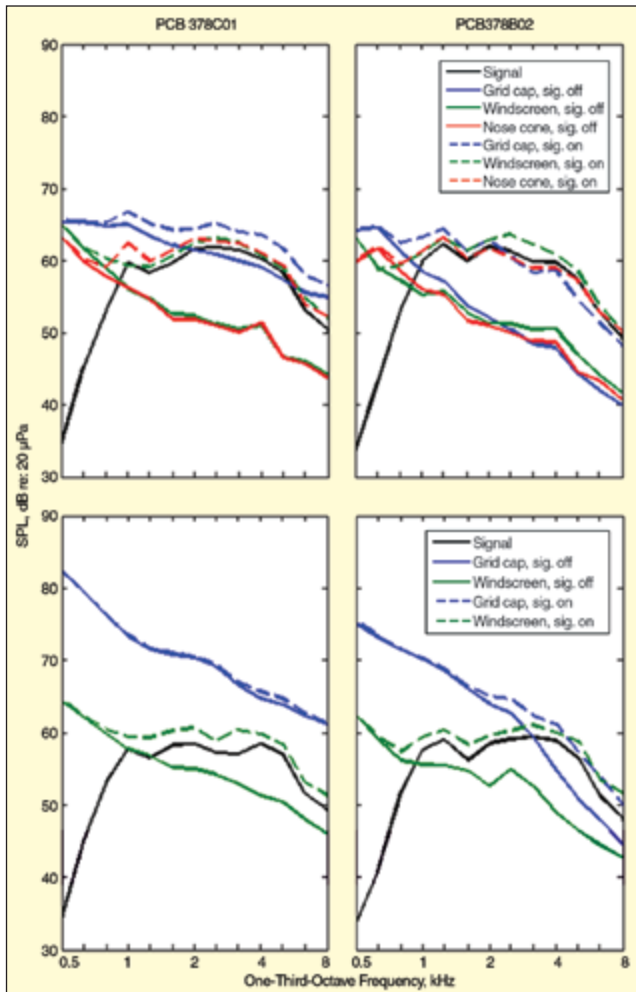


Figure 6. Low-level sound source plus flow noise at head-on (top) and parallel (bottom) incidence angle in 55-mph laminar flow comparing grid-cap, windscreen, and nose-cone accessories.

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. 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. We suspect 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.

Measurements with Surface-Mounted Microphones

Two types of surface mount microphones were also evaluated,

Table 2. Recommended microphones and accessories based on flow and mounting conditions for PCB instrumentation evaluated.

| 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

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 are reported. Representative turbulent flow noise background spectra were recorded and are shown in Figure 5. The narrow-band peaks that exist in this data (for example at 315 Hz in the 55-mph data) should be ignored, since they are resonance characteristics of the particular facility and not related to the broad-band flow noise floor of the microphone. 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. Note that the roughly 30 dB apparent noise floor is a result of the ambient noise in the facility and not the measurement noise floor of the microphones.

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 6). The noise source spectrum is shown as the black curve in all plots. It is a band-limited 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-inch microphone, the signal would not be measurable in either orientation without a windscreen or a nose-cone accessory (left graphs in Figure 6). The 1/2-inch microphone in the head-on orientation may be able to detect the signal with only the grid cap (top right graph in Figure 6); however, much better results are obtained when the windscreen or nose cone are used. The 1/2-inch microphone in the parallel configuration requires a windscreen to measure this signal with any degree of accuracy (bottom right graph in Figure 6).

Recommendations

When a microphone is to be located within an airflow 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, to surface mount the side-vented pressure microphone, a hole must be available in the test structure. In cases where a non-destructive test is required, the low-profile surface microphone is a good choice. Table 2 summarizes the applications for the microphones and accessories tested.

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