G.R.A.S.
SOUND & VIBRATION

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Measurements in boundary layers

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G.R.A.S. has developed a wide range of acoustics sensors dedicated to the task of measuring in boundary layers: (1) surface microphones; (2) flush-mount microphones; and (3) a flush-mount Turbulence Screen. In this Application Note we introduce each of the three sensors and present their measurements performed in the boundary layer of a small wind tunnel. We compare and contrast the various approaches and highlight where one is better suited than the others. This Application Note may thus be used as a selection guide for the given suite of aeroacoustic measurement tools.

1. Introduction

Measurements in boundary layers are of increasing importance in particularly the automotive and aeronautical industries. Here, there is an interest in separating the acoustic signal from the flow-induced turbulent noise. Purposes span quantifying the amount of sound power radiated from a structure to sound source localization using an array of microphones.

There may equally be an interest in quantifying the turbulent stresses to which a structure is subjected. Either way, accurate measurements in the turbulent boundary layer are necessary.

Boundary layer theory dictates that measurements must be made *exactly* on the surface of the structure as the statistics of the flow deviate quickly with increasing distance from the boundary. Moreover, care must be taken not to alter the geometry of the structure as such an action may drastically change the flow.

In what follows we describe three methods for conducting acoustic measurements in a boundary layer: (1) surface microphones; (2) flush-mount microphones; and (3) a flush-mount Turbulence Screen. We illustrate each with a schematic drawing.

2. Measurement methods

Surface microphones

A surface microphone is a non-invasive method for measuring in the boundary layer of a structure. It consists of a microphone and preamplifier of small size – a height of 2.5mm – housed in a stream-lined fairing and attached to the surface of the structure through e.g. double-adhesive tape. See the schematic in Figure 1.

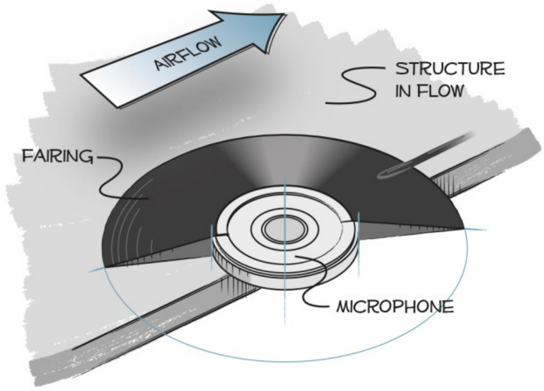

Figure 1. Schematic of surface microphone, 40LS.

The surface microphone is accurate within the frequency range 5Hz – 70kHz and displays a wide dynamic range, roughly 122dB. It is available in a low sensitivity (0.5mV/Pa) and high sensitivity (1.8mV/Pa) version.

Due to its construction, it may be mounted on flat as well as curved structures. It is thus ideal for measurements on irregular geometries and where mounting through the surface of the structure is unwarranted.

Flush-mount microphones

Flush-mount microphones are small microphone-sets (microphone and preamplifier) flush-mounted in the structure of interest. Their form factor allows them to be positioned in confined spaces and narrow structures without sacrificing aerodynamic properties.

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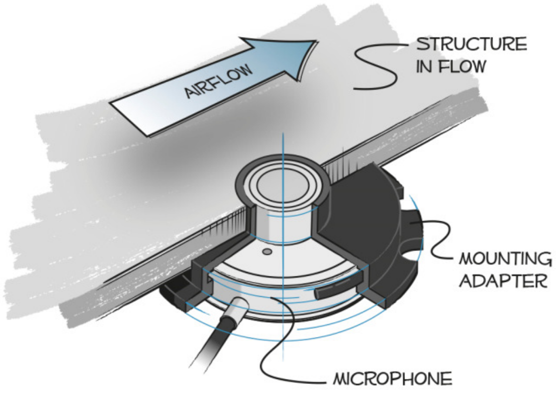

Figure 2. Schematic of flush-mount microphone, 47BX.

They come in sizes ½", ¼" and ⅛", and reflect the precision of standard G.R.A.S. measurement microphones. As such, they reproduce the exact dynamic pressure that exists on the surface of a structure.

Flush-mount Turbulence Screen

The 67TS flush-mount Turbulence Screen comprises a ¼" flush-mount microphone, 47BX, recessed in a dome-like cavity and protected by a flow-dampening wire mesh. See the schematic in Figure 3.

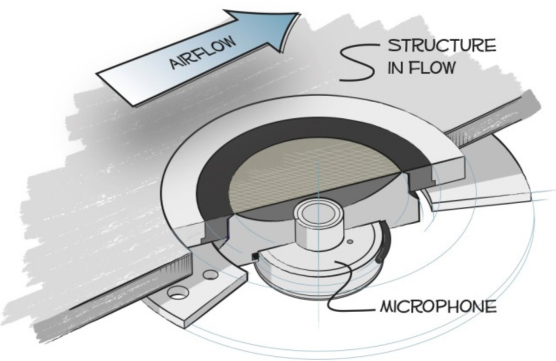

Figure 3. Schematic of flush-mount Turbulence Screen, 67TS.

The construction of the 67TS is such that it suppresses flow noise by integrating away turbulent eddies, and is therefore tailor-made for measurements in boundary layers.

In what follows, we present measurement results with the following set of transducers:

- 40LS, surface microphone;
- 47AX, ½" flush-mount;
- 47BX, ¼" flush-mount; and
- 67TS flush-mount Turbulence Screen.

Specifically, we present their performance in both an anechoic chamber, housed in a baffle, as well as in a small wind tunnel subjected to a range of flow speeds.

3. Pressure Response in a Baffle

We conducted measurements in an anechoic chamber with each of the transducers housed in a baffle. A speaker was placed at a distance of 1m head-on and perpendicular to the plane of the baffle, respectively. See Figure 4 for an overview of the setup.

Figure 4. An overview of the setup in the anechoic chamber. The sound source, seen in the top, was placed on a Ø2m hemisphere. The transducers were flush-mounted in the baffle shown below, centered at the origin of the hemisphere.

We display the measurement results in Figure 5 (head-on) and Figure 6 (perpendicular). Shown are the deviations in dB of each of the transducers from the response of the 47BX. The latter may certainly be considered flat (to within production tolerances) in the frequency region of interest, 100Hz – 10kHz.

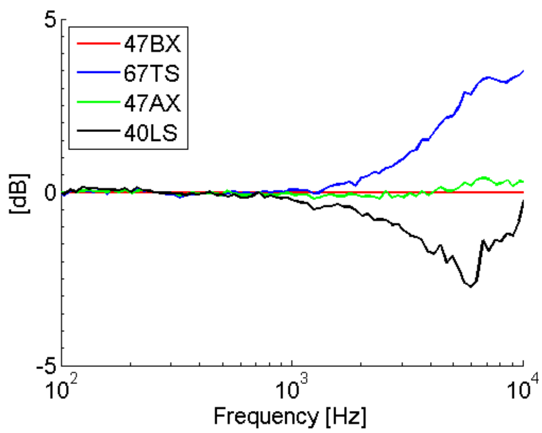

Figure 5. Pressure response of the transducers, relative to that of the 47BX, placed in a baffle and with sound arriving head-on.

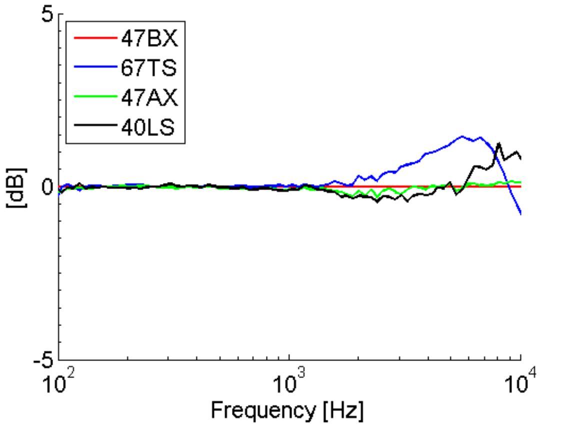

Figure 6. Pressure response of the transducers, relative to that of the 47BX, placed in a baffle and with sound arriving parallel to the plane of the baffle.

The flush-mount microphones are visibly flat in the frequency region of interest, both head-on and perpendicular to the source. The surface microphone, 40LS, and the flush-mount Turbulence Screen, 67TS, on the other hand, deviate at high frequencies due to the geometry of their housing. For sound arriving perpendicularly, however, their deviation is less than ~2dB, thus certainly making them suitable for measurements under such conditions.

4. Flow Response in a Wind Tunnel

Measurements were similarly conducted in a small wind tunnel of cross-sectional dimensions 40cm x 20cm in the constricted portion of the tunnel. The transducers were arranged on a line on a side panel in the direction of the flow. See Figure 7 for an overview of the placement of the transducers.

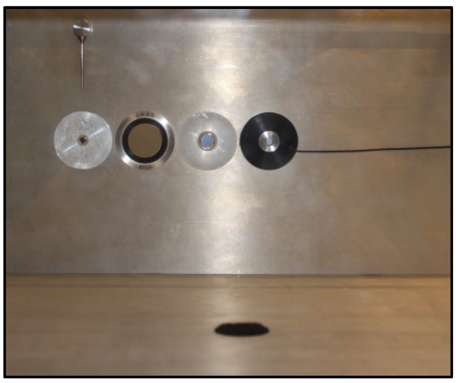

Figure 7. An overview of the setup in the small wind tunnel. From left to right are the following: 47BX (¼" flush-mount); 67TS (Turbulence Screen); 47AX (½" flush-mount); and 40LS (surface microphone). The flow was equally from left to right. In the top is seen a 40SC probe microphone (whose results have not been presented herein); in the bottom is the opening of the sound source, mouth simulator 44AA.

A speaker, mouth simulator 44AA, was mounted in the center of the base plate in the aforementioned portion of the tunnel and set to output a multitone of sine waves at frequencies defined by the center of the octave bands: 250Hz, 500Hz, ..., 8kHz. Figure 8 shows the response of the transducers to the multitone, with no air flow.

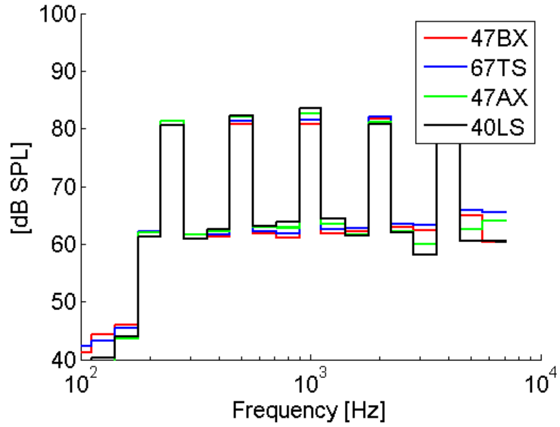

Figure 8. Response of the 4 transducers to a multitone of sinewaves (no air flow), displayed in 1/3rd octave bands. The deviations from one another is primarily caused by the differing placements (see Figure 7).

The wind tunnel was set to provide a wind speed of 20m/s, representative of a car going at a steady speed away from the city center. The consequent measurement result, with the sound source still turned on, is displayed in Figure 9, shown in 1/3rd octave bands.

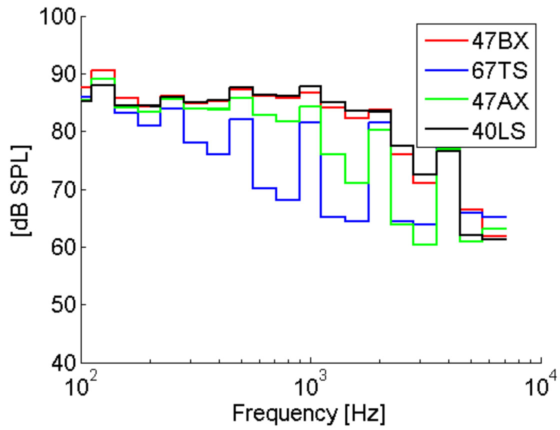

Figure 9. Response of the 4 transducers to the same multitone of pure tones as shown in Figure 8, though with added turbulent noise due to a free-stream velocity of 20m/s. The 67TS flush-mount Turbulence Screen clearly extracts the excited pure tones.

The 47BX and 40LS are largely unable to pick-up the multi-tone, and is drowned by turbulent noise – particularly at low frequencies. The 47AX and 67TS, on other hand, give much improved results. In particular, the 67TS captures nearly all tones in the signal.

Figure 10 shows the difference in dB between the 67TS and the 47AX when placed in the wind tunnel at difference wind speeds (notably having turned off the sound source).

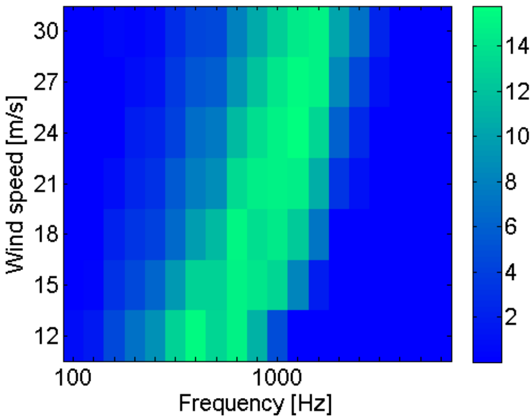

Figure 10. The attenuation of a 67TS flush-mount Turbulence Screen relative to a ½" flush-mount 47AX (in dB), measured at various wind speeds in a small wind tunnel. The effective frequency range of the 67TS changes with wind speed as the apparent size of turbulent eddies is reduced.

At its peak, the 67TS attenuates the turbulent noise by as much as 15dB relative to the 47AX, independent of wind speed. The effective frequency range of the 67TS is clearly correlated with the wind speed, however, as the apparent size of the turbulent eddies is reduced.

5. Conclusion

G.R.A.S. provides a toolbox of methods for measuring in boundary layers. Depending on the parameters critical to the given measurement, an optimal solution exists. The following table attempts to summarize the pros and cons of each of the transducers presented in this application note:

	Surface mic.	Flush-mount	Turb. Screen
Non-invasive mounting	Yes	No	No
Turbulence suppression	No	(Yes)*	Yes
Flat freq. response	(Yes)**	Yes	(Yes)**

* The 47AX ½" flush-mount microphone partially suppresses turbulence, as shown in Figure 9.

** The measured flatness of the surface microphone and flush-mount turbulence screen is shown in Figure 5 and Figure 6.