AEROACOUSTICS

CUSTOMER
Volvo Cars

INDUSTRY NEEDS
CAE models must be validated. There is an ongoing need to minimize noise factors such as microphone geometry and edges (from microphone and cabling) in boundary layers.

KEY LEARNINGS

- GRAS UTP microphones were validated and shown to provide good results without changes to the material characteristics or vehicle geometry.
- Additionally, they were able to measure in previously inaccessible areas like the crevice between the body and hatchback lid.

GRAS
An Axiometrix Solutions Brand

Volvo: Validating the tools for tomorrow's validations

There are many challenges when acquiring experimental aeroacoustic data. One well-known problem is measuring in and around glass, which would be destroyed by drilling to accommodate traditional flush-mounted microphones. Additionally, making alterations by adding a drillable layer for flush mounting will affect the characteristics of the area under test. Avoiding those problems with traditional surface-mounted microphones will likewise affect the environment. These methods all require corrections that can be time and cost intensive computationally or in the wind tunnel. However, there is an alternative.

ABOUT VOLVO

Since the first car rolled of the production line in 1927, Volvo Cars has been a world-leader in safety technology and innovation. Today, Volvo is one of the most well-known and respected car brands in the world. Recently, Volvo Cars' Wind Noise team investigated a new method for measuring wind-noise sources in and around windows for validating CAE models.

Why look at new tools?

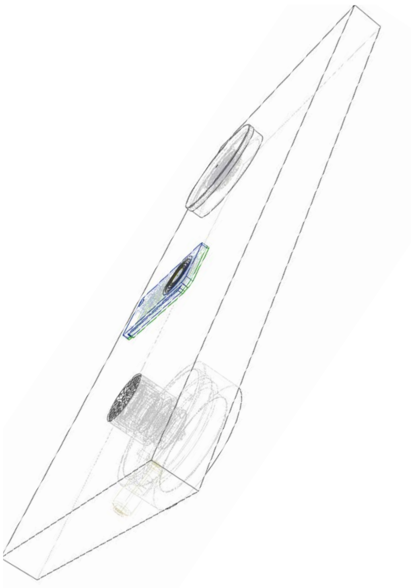
Computer-aided engineering (CAE) is a powerful tool for design engineers. It allows them to evaluate designs earlier in the design phase and reduce the number of prototypes and significantly reduce cost, time and effort. But just as dropping a pile of random car parts into a wind tunnel will not provide useful experimental aeroacoustic data, CAE tools require accurate input data for useful finite element models and subsequent validation of flow-induced noise to provide useful, actionable results.

Measurement and validation using flush-mounted microphones provide excellent correlation between physical objects and computer models, but they are difficult or impossible to use in materials like glass that are destroyed if drilled into or result in modified object dimensions if additional material is added to accommodate the microphone and cabling—and in the process, the material properties (transmissivity, dampening, etc.) of the measured area will be altered.

The team from Volvo, herein represented by Mauricio Massarotti and Pär Harling sought to determine if accurate, actionable data could be acquired without altering the properties of the test vehicle or drilling into it to preserve its aeroacoustic qualities. The microphone of interest for them was the new GRAS Ultra-thin Precision (UTP) microphone that would provide an extremely low profile without drilling or added materials.

For computer modelling, the team used Dassault Systèmes PowerFLOW® coupled with PowerACOUSTICS®, to simulate wind noise sources and predict their contribution to interior noise. PowerFLOW predicts transient flow around the vehicle, and PowerACOUSTICS converts the resulting time-domain pressure signals into structural and acoustic power inputs and predicts the noise inside the cabin. Volvo Cars assessed PowerFLOW and PowerACOUSTICS by performing a successful validation with a primary interest in yaw-sensitivity due to its complexity and direct relation to customer perception.

To acquire the experimental data, they performed a series of wind-tunnel tests using the new GRAS UTP microphone to evaluate its suitability in CAE validation. All of the measurements were made at FKFS Aeroacoustic Wind Tunnel, located in Stuttgart, Germany.



Perspective view of flush-mounted (bottom), UTP (middle) and surface-mounted microphones

Traditional and benchmarking data

The first step in validating new tools is having accurate data to compare with. A very robust model had already been created with flush-mounted microphones and the myriad calculations, corrections and individually crafted mounting plates (for mounting microphones over windows, etc.). This model was used to validate the Ultra-thin Precision (UTP) microphone data. The GRAS UTP 48LX-1 data was also compared to the data acquired by a traditional surface-mounted microphone, the GRAS 40LS, in this case.

Figure 1.
(a) 48LX-1 UTP microphone (1 mm tall) and (b) 40LS microphone (2.5 mm tall).

There are three traditional methods used when placing microphones on glass areas in flow:

1. A surface microphone.
2. An additional plate, such as plexiglas or other drillable surface must be added to accommodate flush mounting.
3. A blind window, where the entire side window has been replaced by a drillable material so that traditional flush-mounted microphones can be mounted from the back.

Any of these methods can function, but they require considerable extra time in fabricating custom-fitted mounting for each measurement vehicle and added uncertainty and further correction and calculations to accommodate changes in material properties (such as skin friction), additional lead and trail edges and alterations to the geometry of the area.

Traditionally you may need to substitute different materials with different acoustic properties in order to accommodate flush-mounting a mic. For example, aluminum, wood or plexiglass for glass. [These materials] have different acoustic properties and vibroacoustic behavior, or even increase noise when in airflow if not properly fitted. In the wind tunnel, time is critical, and those errors cannot occur.

Mauricio Massarotti
Senior Wind Noise Engineer
Volvo Cars

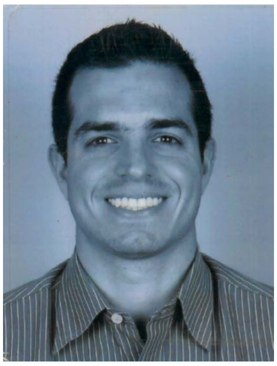


Figure 2 shows one of the plexiglas window sheets created for acquiring the data for comparison. Care was taken to minimize intrusion and tightly fit the blank, but the material is not as stiff as actual glass, so the acoustic properties are not the same as an added layer. Adding a layer of plexiglas adds mass and changes the general absorption behavior. It is also subject to significant noise factors if it vibrates against the glass underneath or impacts the windows transmissivity, as can be seen in Figure 3, for example. Another issue with added layers is that the additional layer must be created for each vehicle, and once created, the microphone location cannot be changed without creating a new plexiglas plate to mount on the vehicle.

Figure 2.
Plexiglas plate with cut-outs for flush-mounting microphones and cables that has some loose areas. Scenarios such as these will likely require reworking.

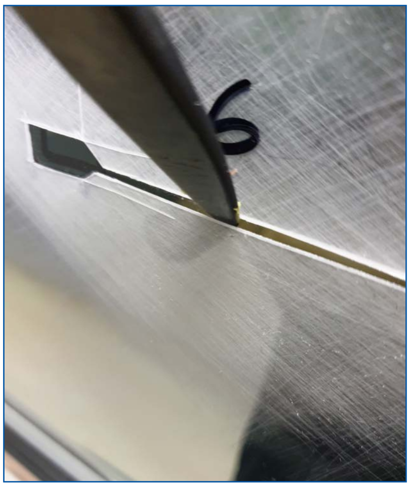
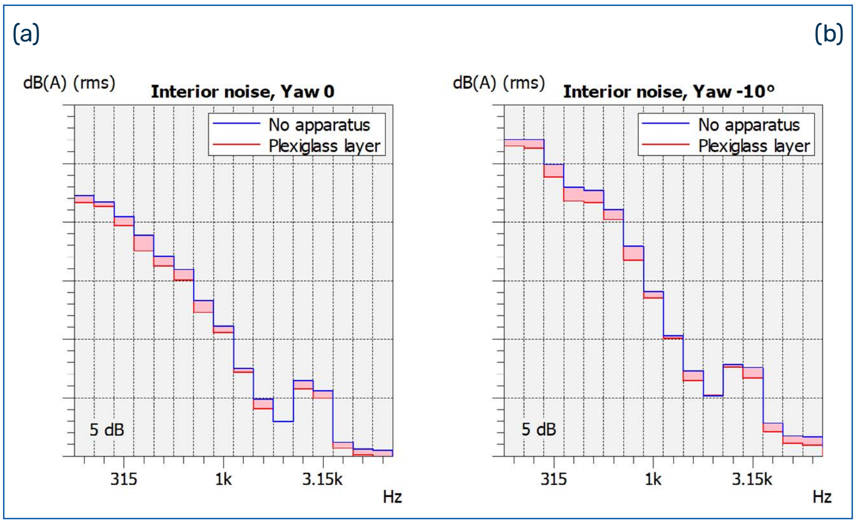


Figure 3.
Graphs show sample interior data for a measurement with and without additional material in two different flow conditions (a) and (b), demonstrating the damping from added plexiglas.

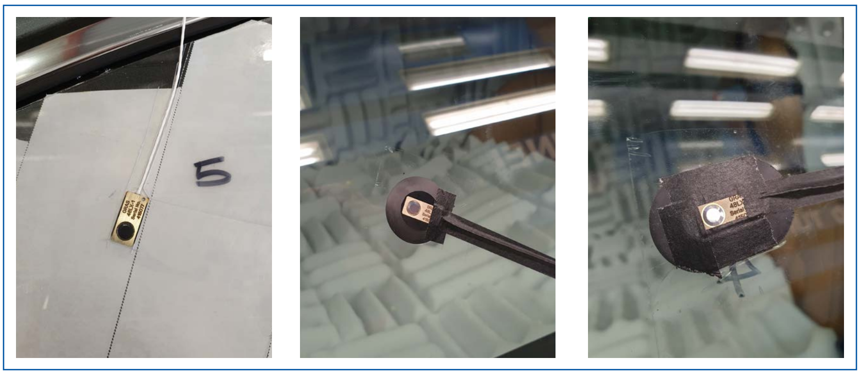


Procedure

For comparison, the UTP microphones were tested in a variety of setups:

- Creating a plexiglas plate to enable a completely flush mount, i.e., most time-consuming and intrusive solution (Fig. 4 left)
- Mounting directly on the window surface with the UTP rubber fairing with edges and cables flushed out with tape (Fig. 4 right)
- Mounting directly on the window surface using the docking station flushed with tape (Fig. 4 middle) and not flushed-out (not shown)
- Attaching the microphone directly on the window, i.e., the least time-consuming and intrusive solution (not shown)

Figure 4.
Three of the mounting methods tested. Left: Flush-mounted in a Plexiglas plate. Middle: Adhered to the window with the docking station flushed with tape. Right: Mounted directly on the window with rubber fairings flushed out with tape.



The UTP microphones were also tested under different conditions, including variations in:

- Wind speed
- Vehicle yaw
- Microphone location (additionally including the body-hatchback cavity)

The measurements taken for each of the setup and condition variations were compared to benchmark data and control surface-microphone data. As it can be seen in the sample data in Figure 5 and Figure 6, design-change effects can be captured quite similarly in flush and non-flush conditions. Figure 5 shows a design modification on the A-pillar measured in 1 mm-overflush condition (no plexiglas), and Figure 6 in flush condition (plexiglas). The measured differences are quite similar. However, there is a considerable difference in the interior noise due to the added material and difference in transmissibility (as seen in Fig. 3).

> *The biggest issue validating conventional mics at 2.5 mm height is how their geometry will affect the flow and consequently the measurement. The 1 mm microphone overcomes that geometry problem.*
>
> Mauricio Massarotti

Figure 5.
Design modification on the A-pillar measured in 1 mm-overflush condition (no plexiglas plate) in three different positions on the window.

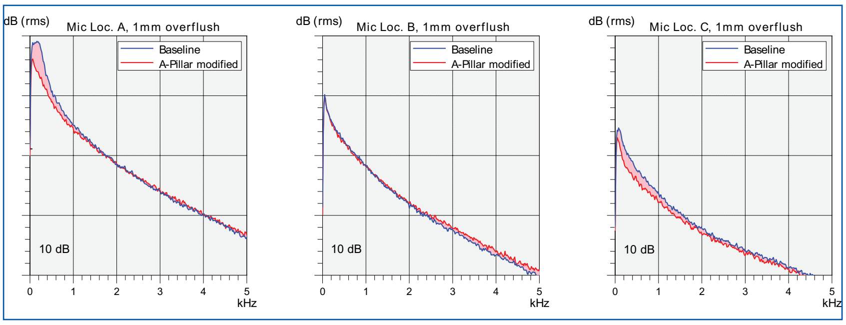
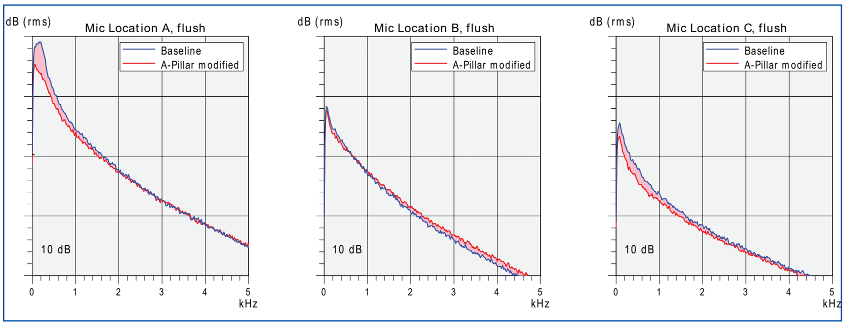


Figure 6.
A design modification on the A-pillar measured in flush condition (plexiglas) in three different positions on the window.



> *The click-in fairings make it easy to handle such small microphones.*
>
> Mauricio Massarotti

Mauricio noted that the diminutive size of the microphone does require some extra attention with handling, especially the cabling, but it also provided some unexpected benefits. The microphone is small enough to measure in places where it was previously not practical and required complex prototyping, such as in the hatchback cavity (space between the hatchback door and the body of the vehicle; Fig. 7).

Figure 7.
During the process, an unexpected benefit was found. The small microphone size opens up new measurement locations such as the hatchback cavity.

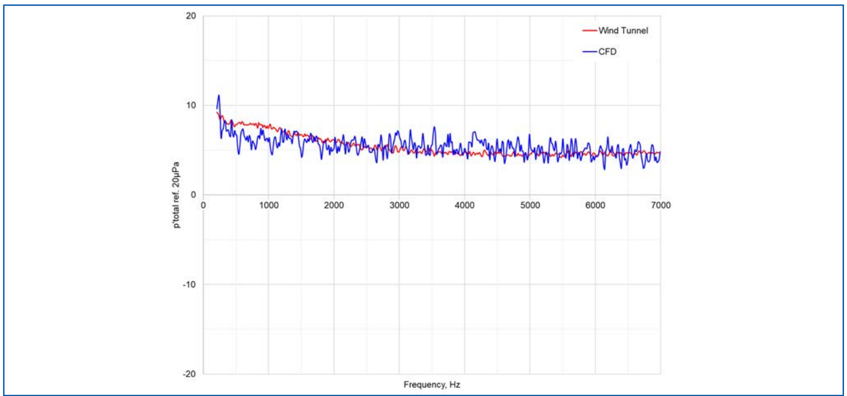
> *The geometry of thicker mics must be compensated for. Traditionally there was a need to build additional structures to offset or "hide" the additional height. This cannot be done on the fly, so the UTP and its 1 mm profile allow changes to happen quickly because of its mounting options and the independence from an additional custom apparatus for each vehicle, and requires only a fraction of the setup time for new cars.*

Mauricio Massarotti

Computer-modeled accuracy assessment

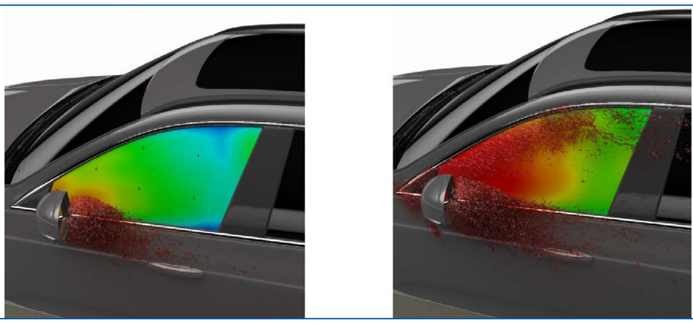
Accuracy with the computer model was assessed by comparing the side glass microphone averaged spectra of the GRAS UTP microphone experimental data to the PowerFLOW simulations. Each spectra shown in Figure 8 is an average of multiple locations distributed across the side window exterior. In this scenario, UTP microphone were mounted with fairings directly on the side glass as in Figure 4, middle—no additional materials were used. Model geometry and boundary conditions were matched to the experimental setup. There was excellent agreement between the experiment and simulation. This provided confidence in using both these tools efficiently in the vehicle development process. The fast mounting and low intrusiveness of the UTP microphones is particularly useful as they do not impose topology adjustments in the CAE model.

Figure 8.
Spectra, average of multiple locations distributed on the side window exterior.



Advanced noise source identification and visualization capabilities in PowerACOUSTICS® such as flow-induced noise detection (FIND) and acoustic wavenumber filter were used to identify flow-induced acoustic noise sources. These visualizations enable engineers to gain insight into behavior of key turbulent flow structures and corresponding noise sources for targeted shape design improvement (Fig. 9).

Figure 9.
FIND acoustic noise sources with acoustic dB map on the side glass for 354-707 Hz frequency band, 0° Yaw and -10° Yaw with marked microphone locations.



Findings

Mauricio and his team found that the UTP microphone's minimal height profile and rigid attachment provided by the fairings responded similarly to a total flush-mount microphone condition, particularly in regions with fully developed turbulent boundary layers (TBL) and detached flows such as A-pillar vortex regions. The best mounting method was found to be mounting directly on the window surface with the rubber-fairing edges and cables flushed out with tape. They also noted that the ease of mounting the microphones on top of the glass surface (with no additional layer of plexiglas) significantly reduces experimental complexity and cost, and minimizes error factors from the potential addition of materials, which can alter panel stiffness and geometrical representativeness.

Conclusion

In summary, GRAS UTP microphones' low profiles and acoustic characteristics in flow provided good matching for hydrodynamic and acoustic fields between wind-tunnel testing and computational fluid dynamics (CFD) simulations using the microphones with the fairing setup. UTP microphones also have the added benefit of not needing the layer of plexiglas, which not only reduces the time in testing, but stays truer to the acoustic properties of glass.

The tests with UTP microphones also provided data that showed:

- Stable, repeatable signal
- Successful capture of yaw effects in different locations (local flow phenomena)
- Higher high-frequency content and lower low-frequency content than 40LS (<1–2 kHz)—this was expected due to the smaller size of the diaphragm (high frequency) and the lower protuberance (low frequency)
- Can capture design modification effects locally in the side window
- Higher signal-to-noise ratio compared to measurement with additional apparatus for mounting (better captures design modifications)
- No alteration to sound transmission through windows versus adding a plate (cavity, plate vibration and mass dampening)
- Minimal microphone size negates the need to incorporate them in the model. Only one simulation is needed and then you can change measurement points without having to run a new simulation

For more information, please contact marketing@GRASacoustics.com.