Loudspeaker Simulations in a Car Cabin

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Abstract: For automotive applications, simulation methods are used to optimize the position and orientation of speakers to get the best acoustic performance. The goal of this study is to improve the audio simulation accuracy. Comsol Acoustics module and Livelink in Matlab were used to simulate the sound pressure generated by a loudspeaker in a car cabin. To validate the simulation results, a comparison between simulated and measured sound pressures was performed. For this comparison, the pressure was simulated and measured on a 6 microphone arrays located at the 4 seat positions. For each microphone array, the averaged pressure was used for the comparison. All boundary wall conditions were defined with a frequency dependant absorption coefficient. Starting with the absorption coefficient described in the literature, one major activity was to optimize those values to get the best correlation between the measured and the simulated sound pressures. The comparison of the pressures shows that the acoustic module can perform an accurate speaker simulation.

Keywords: acoustic, car cabin, loudspeaker, accuracy

1. Introduction

For automotive applications, simulation methods are used to optimize the position and orientation of loudspeakers to get the best acoustic performance in the vehicle interior[1][2]. Systems Engineers use the following process to reach the best audio allowances:

- Sound pressure measurement on the 4 seat positions (use of a 6 microphones arrays)
- Equalization of the amplitude of the measured sound pressure with different filtering methods (Finite Impulse Response, Infinite Impulse Response). For each audio channel, the delay is also optimized.

The use of numerical methods to predict the sound pressure allows to import simulated data for the Equalisation process. This means that the audio performances optimization can be done without a real car. The simulation process allows to add freedom in design decisions and to lower the cost of any design changes.

To move from the use of measured to simulated sound pressures, the simulation accuracy has been checked and optimized. For the optimization process, the major scope of this study was the optimization of– the absorption coefficients defining the acoustical properties of the vehicle boundaries.

2. Governing Equations

From the definition of the boundary impedance

$$z = \frac{p}{u}$$

It is possible to obtain a relationship for z in terms of either p or u using**:**

$$\frac{\partial p}{\partial n} = -\rho \frac{\partial u}{\partial t}$$

where ρ is the air density and n is a vector normal to the boundary surface at each boundary discretisation point. The reflection coefficient R can be computed as:

$$z = \rho c \frac{1+R}{1-R}$$

The absorption coefficient α can be computed as:

$$R = \sqrt{1-\alpha}$$

3. Numerical Model

3.1 Finite Element Model

The modeling is based on a full domain discretisation approach. At each node, the FEA algorithm approximates the steady state Helmotz equation. The acoustic field at each mesh point varies harmonically with time. There are several ways to get car cabin description, one is CAD another one is a scan. Scanning tools and signal processing speed enable nowadays an efficient usage of a 3D scan. This method was used to get the interior geometry of a vehicle. In terms of geometry definition, the scan is less accurate than the original CAD data delivered by the automotive industry, however those inaccuracies are negligible having considered the upper frequency limit of the simulation.

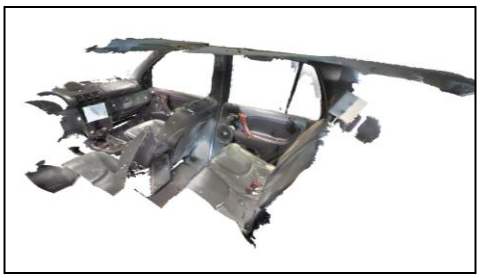

Figure 1: 3D scan of the car cabin

A postprocessing algorithm implemented in Matlab allowed to move from the point cloud (3D scan) to the cabin mesh. This mesh was imported into the HyperMesh software (Altair product) for optimization (removing few elements with a high aspect ratio and duplicated elements). The elements size was around 6 cm to be able to reach an upper frequency limit equals to 1 kHz (6 nodes per wavelength). An overview of the mesh is shown in figure 2.

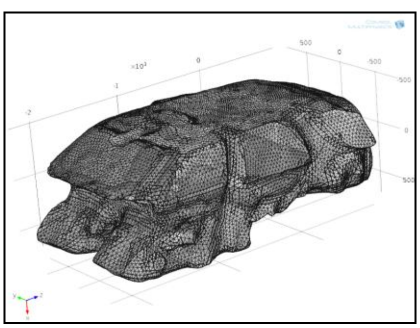

Figure 2: mesh of the car cabin

The loudspeaker is modeled as a rigid flat piston. This approach is valid below 1kHz since the speaker membrane is rigid. The piston location and orientation is the same as for the real speaker. The area of the flat piston is equal to the efficient surface of the speaker.

Since the air particles move at the same speed as the piston at the interface, the pressure Acoutics module in Comsol can be used. The speaker motion is defined with a normal acceleration.

3.4 Material Database

To simplify our simulation model, only 6 materials were used (see table 1):

Material number	Boundary
material 1	glass
material 2	floor
material 3	seats (without headrests)
material 4	headrests
material 5	steering wheel
material 6	other components as door, roof, instrument panel

Table 1: list of components for the material definition

The figure 3 shows in green the boundaries corresponding to the material 1.

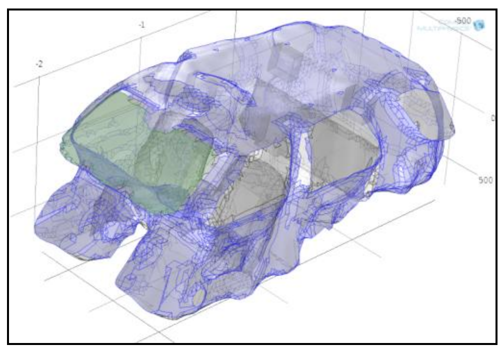

Figure 3: material selection in Comsol (material 1)

As a starting point for the boundary optimization process, absorption coefficients introduced by Cox[3] were used. The table 2 shows the initial absorption coefficients value used for the optimization process.

Frequency values (Hz)	125	250	500	1000
material 1	0.35	0.25	0.18	0.12
material 2	0.03	0.09	0.20	0.54
material 3	0.45	0.60	0.73	0.80
material 4	0.45	0.60	0.73	0.80
material 5	0.04	0.05	0.11	0.18
material 6	0.04	0.05	0.11	0.18

Table 2: initial absorption coefficients

4. Livelink in Matlab

To perform the calculation of the flat piston normal acceleration (complex value), the Livelink module was used. The main interest of the Livelink is to simplify the pre-processing and post-processing activities. Because the speaker was mounted on a fully rigid enclosure, a Lumped Parameter Model (LPM) was used to compute the speaker motion (frequency dependant). The input parameters for the LPM simulation are:

- the voltage at the voice coil terminals
- the stiffness of the suspension (Kms including the surround and the spider)
- the surface of the speaker membrane (Sd)
- the weight of the moving mass (Mms)
- the resistance of the voice coil (Rscc)
- the force factor (Bl)
- the mechanical Q factor (Qms)
- the volume of the enclosure where the speaker is mounted

The Livelink allows to launch a single or a multiple speakers simulation.

5. Car Measurement

For this study, a Mercedes Benz ML car was used. A 5.5 inch automotive woofer was mounted on a rigid enclosure located around the driver seat. The dimension of the enclosure is 205x25x105 mm (volume of 5.4 liters).

Figure 3: loudspeaker in the vehicle interior

A 6 microphones array was used to measure the sound pressure on the 4 seat positions (Arrays A, B, C and D).

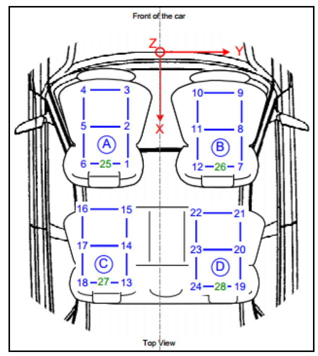

Figure 5: Top view for the microphone array

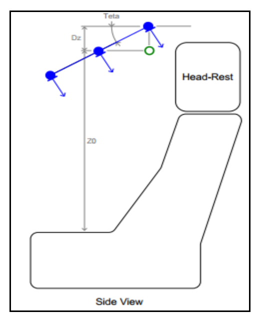

Figure 6: Side view for the microphone array

For the measurement, the combination of the vehicle interior and the loudspeaker can be assumed as a time invariant system with a transfer function. With the use of a low voltage at the speaker terminals, the transfer function is mainly linear. Audio measurements were performed with a sweep sine. This robust and fast method was introduced by Angelo Farina[4].

6. Sound Pressure Comparison

This section presents the sound pressure comparison between the measured and simulated sound pressures.

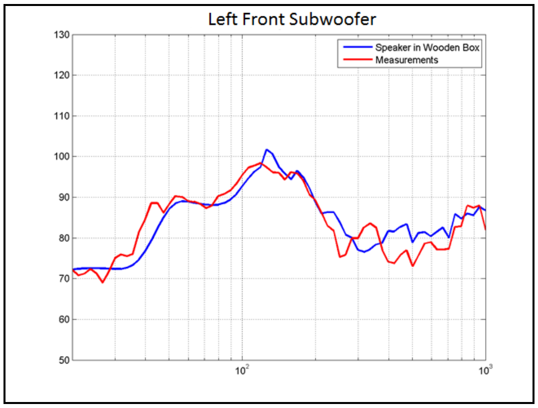

Figure 7: Sound pressure on Array A

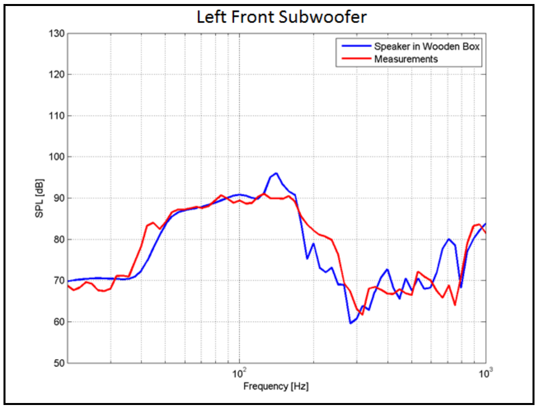

Figure 8: Sound pressure on Array B

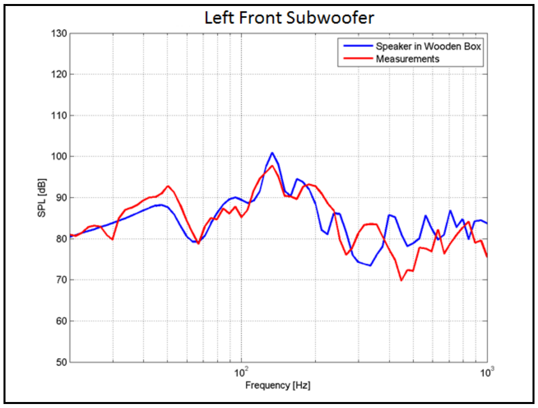

Figure 9: Sound pressure on Array C

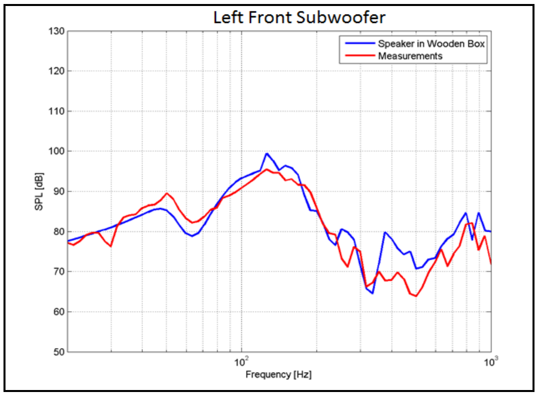

Figure 10: Sound pressure on Array D

A relative difference shows that 62% of the predicted frequency bins have a difference less than +/- 3 dB.

7. Conclusions

Even if our simulation model include few geometry approximations, the acoustic module of Comsol can be used to perform an accurate acoustic simulation for a loudspeaker mounted on a rigid box in a vehicle interior. Increasing upper frequency limit could be a complementary study. In this case, a more complex simulation model using the acoustic structure interaction should be used (the speaker membrane could not be modeled as rigid piston)

9. References

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10. Acknowledgements

Acknowledgements to S. Alumkal for the measurement of sound pressure in the vehicle (Harman Becker Automotive Systems, VPDT, Straubing, Germany)