Validations on the Acoustic Behaviour of a Passenger Car Cavity by FE Simulations

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Summary

In order to validate the Finite Element Modelling of an Acoustic Cavity it is measured the Acoustic Transfer Functions due to Loudspeaker Excitation in a Passenger Car. This is done up to 300 Hz in an empty vehicle in the first place, body-in-white with closures of a C-Vectra as a base for further investigations about the influence of the front and rear seats and the hat trim panel.

Introduction

Predicting the acoustical performance of a vehicle is one of the tasks of simulations as part of the vehicle development process in early stages. Therefore, it is necessary to validate all the parts of the chain of structural born noise as one part of the sound transfer beside the sound transmission. This validation is performed at the Adam Opel AG by several validation projects investigating the applied forces from engine or road excitation, the structural and the fluid transfer path.

Purpose of the Research

One task of this project is to develop general guidelines of modelling an acoustic cavity as there are from the passenger compartment separated volumes like the trunk or modelling the seats and the trim parts. Therefore another task is to show up the influences of these parts to the acoustic transfer functions. Parameter identification of damping of the cavity and the trim parts is also necessary with regard to the sound pressure level of the interior noise.

Measurement Execution

The measurements are accomplished in an Opel C-Vectra. In the first place all interior trim parts and the seats are removed. The excitation sources are three loudspeakers in three different positions (foot compartment of front passenger, foot compartment of left rear passenger and in the middle of the trunk).
The sound pressure levels are measured at 83 positions and referenced to the measured membrane acceleration to get the acoustic transfer functions Pa / (mm/s²). These values are compared to calculated transfer functions.

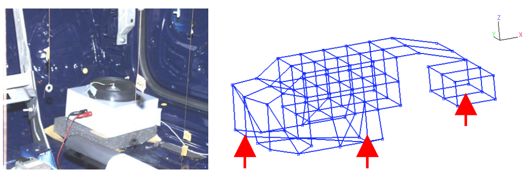

Figure 1: Loudspeaker Excitation Positions

To capture the influences of the different trim parts and the seats, the measurements of the empty vehicle are representing a base for further investigation. Starting with the empty vehicle, the front seats are built in to determine the influence of the seats. In the third step the rear seats with the hat trim panel are built to investigate the influence of separating the trunk from the passenger compartment.

The Finite Element Model

Modal Analysis

The calculation of the sound pressure response is accomplished within NASTRAN by a modal frequency response analysis. This is done in two main steps

- Calculation of real eigenvalues and modes of the structure and the fluid in a separate way
- Calculation of the frequency response recognizing the coupling matrices A_{fs} and A_{sf} as well as damping in the FEA model and the acoustical load $\dot{q}$

$$\begin{bmatrix} [K_s]-i\omega_s[D_s]-\omega_s^2[M_s] & A_{sf} \\ A_{fs} & [K_f]-i\omega_f[D_f]-\frac{\omega_f^2}{c_0^2}[M_f] \end{bmatrix} \begin{Bmatrix} u \\ p \end{Bmatrix} = \begin{Bmatrix} 0 \\ \dot{q} \end{Bmatrix}$$

The acoustical load $\dot{q}$ is defined as

$$\dot{q} = i\omega_f q_o$$

With the volume velocity load q_o

$$q_o = A_{eff} a_0 / i\omega_f$$

The acceleration a_0 is applied to one fluid grid point scaled by the area of the effective membrane A_{eff} of the loudspeaker.

The Vehicle All Empty Model

The cavity model is build using a trim-structure model of the C-Vectra without any trim parts and no seats. Although, the cavity model consists of 9 nearly separated volumes as there are

- The four side door volumes
- The trunk, separated by the hat shelf upper panel
- The two b-pillar volumes combined with the rocker
- The two upper frame volumes combined with the c-pillar

The Vehicle with Front Seats Model

This model is build by including the front seat geometry in the cavity creation-application. This leads to a volume-cut-out of the seats meaning 'there is no air' inside the seats. It is possible to apply acoustical property such as absorption to the inner fluid-surface of the seat-cut-out, which is not performed in this project yet.
The basic properties of this volume-cut-out are no transmission of sound pressure through the seats and a reverberant boundary surface.

The Vehicle with Rear Seats Model

In this model, the trunk volume is separated from the passenger compartment. The transmission of the trunk to the passenger compartment is accomplished by a coupling to the hat trim panel on both sides. Again the seat volume is cut out of the cavity and therefore there is no transmission of sound pressure through the back of the rear seat.

Model Correlation

Because of the decoupled mode calculation of the cavity and the structure, a comparison of the experimental and calculated modes is not useful. Therefore, comparing the acoustic transfer functions (ATF) makes the correlation.

ATF of Vehicle All Empty

The acoustic transfer function in Figure 2 shows the result of measurement and analysis near the driver position.

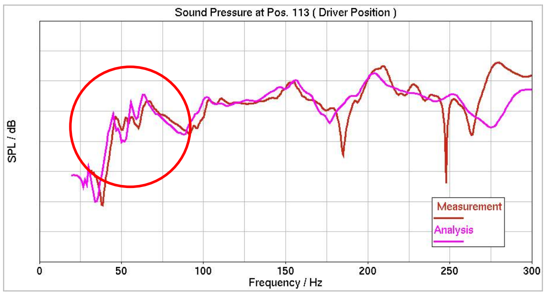

Figure 2: ATF at Position 113

The ATF of the measurement and the analysis in the frequency range of 50 to 60 Hz show up three peaks although the cavity just has one eigenmode at 55 Hz. This indicates the resonance of the structure due to the loudspeaker excitation in the measurements as well as the acoustic load in the FE model. To ensure the fact of structural resonance, acceleration measurements at the hat upper panel were made. This resonance effect is also visible in Figure 3.

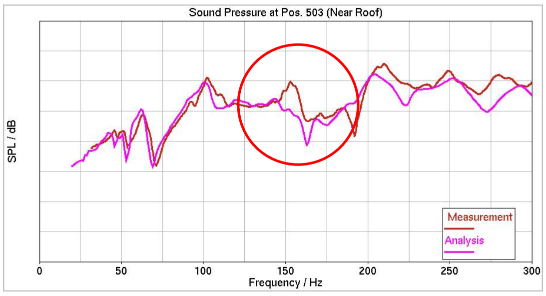

Figure 3: ATF at Position 503

This ATF measured and calculated near the roof shows the influence of the structural resonance at 150 Hz. This was also visible by changing the binding of the roof traverse beams to the roof. Despite those difficulties due in fitting the calculations to the measurements, the ATFs fit well enough for investigations of other influences.

ATF of Vehicle with Front Seats

Figure 4 shows once the influence of the front seats in the measurements and below the influence of the seats in the analysis.
The ATF of the front seat measurement is slightly shifted to lower frequencies. The level and the height of the peaks is quite the same. The same effect is present in the analysis as well.

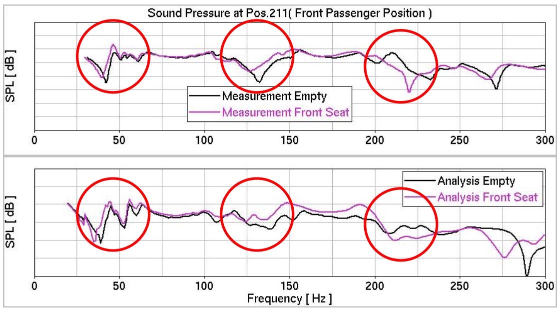

Figure 4: ATF at Position 211

ATF of Vehicle with Rear Seats and Hat Trim Panel

The effect of decoupling the cavity of the trunk off the passenger compartment is shown in Figure 5, the ATF at then position 903 at the trunk. All over the frequency range the level of the transfer function is lower except for the frequency range at 175 to 190 Hz. The peaks are at different frequencies as well.

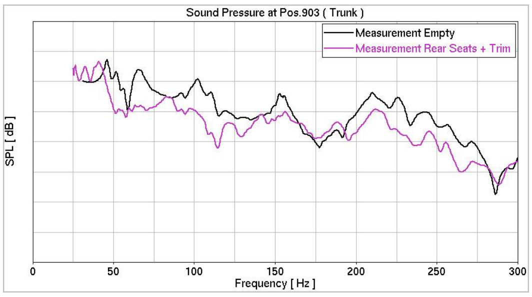

Figure 5: ATF at Position 903

The same trend is also visible in the analysis, shown in Figure 6. But the level of the calculated ATF of the rear seat model is to low compared to the measurements.

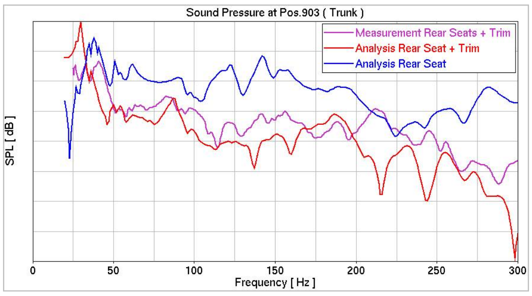

Figure 6: ATF at Position 903

This indicates that the decoupling of the trunk compartment is too much. This may come once by the modelling of the rear seats, because of no transmission due to any air in the seat volume, as well as the modelling of the hat trim panel.

Conclusion

The effect of structural resonance is present all over the frequency range. Especially at grid points close to the structure, a local effect is determined. In case of the empty vehicle it is shown that the detailed modelling of the cavity is necessary for validated results. This needs to be determined in case of the full vehicle.
The ATF of the vehicle with seats showed, that the basic effect of shifting the peaks to lower frequencies is already accomplished by just cutting out the seat volume. Although, further investigations about an alternate seat modelling needs to be done, as there are including an absorption model as well as including a heavy air seat model or real structure model of the seats.