Windnoise: Coupling Wind Tunnel Test Data or CFD Simulation to Full Vehicle Vibro-Acoustic Models

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Abstract

Wind noise has become in recent years a significant contributor to perceived sound inside automobiles. Many methods are nowadays available to couple wind tunnel or CFD (Computational Fluid Dynamics) data to a full vehicle vibro-acoustic model. This paper presents an overview of these methods and focuses on one specific method which allows the test or CFD data to be used as the source of a SEA (Statistical Energy Analysis) full vehicle model. The paper presents the wind tunnel test data available and how it is used to describe the pressure fluctuation as a SEA (Statistical Energy Analysis) source. It also describes the full vehicle SEA model used and how detailed laminated glasses models were created. SPL (Sound Pressure Level) inside the vehicle for simulation and test are compared. Finally, design changes are introduced by modifying glass thickness and construction and comparison between simulation and test results are also presented.

Introduction

This paper presents work related to wind noise modelling. SEA models are used routinely to assess vibro-acoustical behaviour of cars. To predict wind noise using these models, one needs to take special care of the source representation. There are many ways to represent aeroacoustical sources [1,2,5,7]. In this paper, the DeJong empirical approach is used and validated against test data. Once a model is validated the true research work can start. In this case it was mainly research of transfer paths, design changes on the outer surface, which generate other aeroacoustical load, and glass properties variations.

Overview of existing modelling methods

There are many different methods available to represent and couple the turbulent pressure around a car body to a vibro-acoustic model.

Source data	Source representation	Vibro-acoustic model
Wind tunnel or CFD	Corcos	SEA
Wind tunnel or CFD	Corcos	FE/SEA Coupled
Wind tunnel or CFD	Empirical	SEA
CFD	FSP on panel modes	FE/SEA Coupled

Table 1: Overview of source modelling and coupling methods between fluctuating surface pressure and a full vehicle vibro-acoustic model

The turbulent pressure field can be either measured using a wind tunnel or predicted with CFD. This turbulent pressure field can then be represented by an empirical method such as the one published by DeJong [1,5]. It can also be represented by a Corcos model or finally the fluctuating surface pressure (FSP) can be projected onto the modes of a FE (Finite Element) panel. These different source representations can be coupled to various vibro-acoustic models: pure SEA or a mixture of SEA and FE. Table 1 provides an overview of these methods.

The empirical approach used

Pressure fluctuation spectra obtained from wind tunnel measurements were used as the basis for source modelling using DeJong's approach.

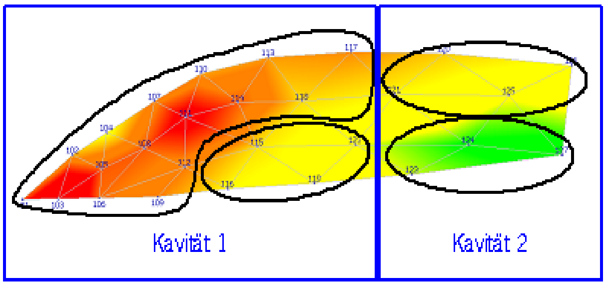

Figure 1: SPL fluctuation on side glass.

Pressure fluctuation measured by flush-mounted microphones are caused by turbulent eddies traveling downstream along the car. This excitation is not uniform, it varies with time and space. To use this excitation with an SEA model, it is necessary to develop a proper representation of this excitation.

The DeJong's source representation method uses two different exterior cavities. The first cavity next to the car's outer skin represents the turbulent layer. Its thickness *d* is the characteristic length of the flow separation. This cavity has the same physical properties as air except the wavespeed, which is equal to the convection velocity Uc (Uc is the velocity of the turbulent eddies). It is connected to the car model through the resonant and non-resonant paths and is also coupled to the cavity representing exterior acoustics. The turbulent layer cavity is constrained with measured area averaged SPL (Sound Pressure Level). The second cavity, which represents the exterior acoustics, has the physical properties of air and is coupled to the outer skin of the car model through the resonant path only. The DeJong's source model was applied to a full vehicle airborne SEA model that has already been validated. The commercial software VA One was used.

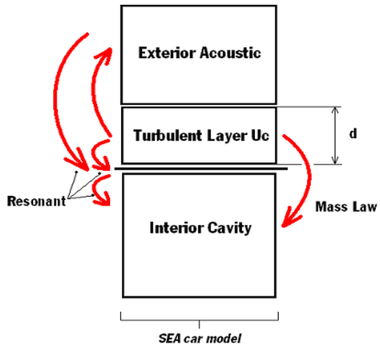

Figure 2: Overview of DeJong's approach.

Comparison of simulation with tests

Figure 3 shows a typical comparison between measured and predicted SPL inside the car. This comparison was performed on a large number of speeds, yaw angles and design changes. Agreement in these cases was similar to the one presented. The discrepancy observed from 4 kHz is due to the microphone size effect [2].

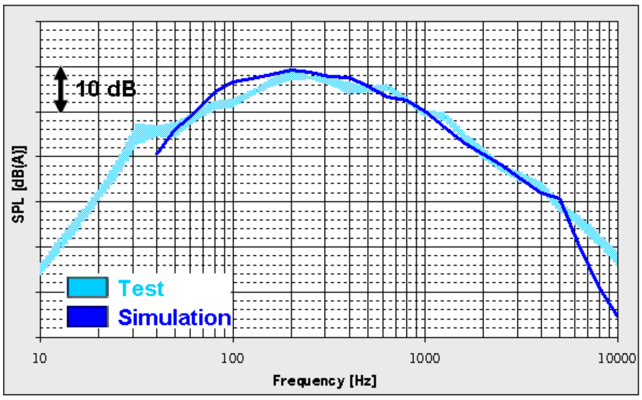

Figure 3: Comparison of simulation with wind tunnel measurement at 140 km/h.

Design changes

Design changes in windshield and side glasses have a significant impact on the perceived sound mainly around glass coincident frequency. Parameters that can be changed to improve interior noise are: physical properties of glass and physical properties of PVB (polyvinyl butyral). For representing laminated glasses in the SEA model the "General Laminate" model implemented in the commercial software VA One was used. The following parameters can be modified within this model: material properties of glass (E-modulus, Poisson's ratio, density), its thickness and damping loss factor spectra (DLF), material properties of PVB (shear modulus spectra, Poisson's ratio, density), its thickness and DLF spectra. Figure 4 and 5 show comparisons of interior SPL for different types of windshield glasses (with and without acoustic damping foil). Replacing the regular PVB layer by an acoustic PVB foil increases mass therefore slightly improving glass performance on the whole frequency range. It also decreases resonant transmission close to the glass coincidence frequency due to added damping in this new laminated glass.

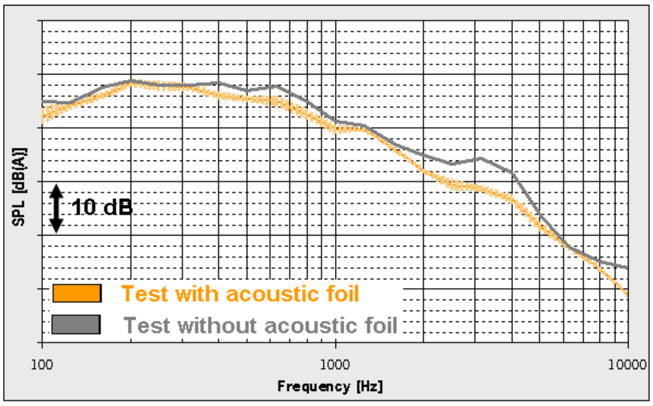

Figure 4: Comparison of different windshield variants -test.

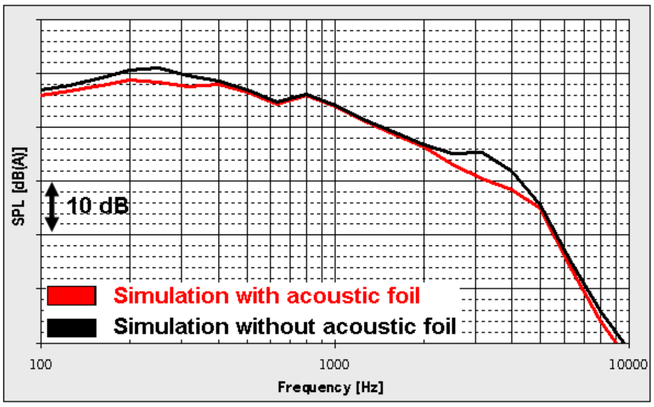

Figure 5: Comparison of different windshield variants - simulation.

Conclusion

This paper presented an overview of different wind noise modelling methods and focused on the empirical method derived by DeJong. This method proved itself to be easy to use and reliable over a broad range of wind speeds. Future research will aim at coupling CFD pressure fluctuation spectra and modes of FE plates within full FE/SEA models.

References

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