# Influence of hoses on the sound field of engine compartments

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## Introduction

During the development of new vehicles one cannot underestimate the importance of simulations and similar analysis tools. The goal of the BTPA/BTPS (binaural transfer path analysis/synthesis) is the evaluation of constructive changes of the powertrain in early stages of development and their influence on the interior sound field. For this purpose it would be desirable for all the acoustic and vibro-acoustic transfer paths from the source to the passenger's ears to be known. To accomplish this task, the airborne sound radiation of vibrating panels in engine test benches can be measured as well as simulated with the help of finite element models.

The free-space sound radiation of engines has already been analysed in scientific literature, but some questions about the influence of the engine compartment still remain.

For the exact simulation of sound fields, the correct description of the boundary conditions is of major importance. Although the characterisation of the behaviour of the surfaces is well known, the consideration of fluid-filled hoses is not fully understood.

In this work, an experimental analysis was made in a built 1:2-model of an engine compartment and the influence of the hoses was analysed. The experimental data was then used as basis for simulations with a finite element model of the engine compartment.

## The sound field

Goal of this study is to check if a hose filled engine compartment can be modelled with an approach of a viscous medium. In previous research [1] it was shown that it is possible to simulate the sound field of an empty engine compartment. But the engine compartment of cars is filled with hoses and cables and it is obvious that these fillings have an influence on the sound field. In order to build a CAD model, a meaningful data base is necessary.

### Measurement

For the measurement of the sound pressure level inside the model two capacitor microphones were placed inside aluminium tubes (Fig.2). To excite the sound pressure, the engine block is equipped with two loudspeakers, which can be controlled separately. Through four holes in the front wall we successively determined the data for four insertion depths (85mm/105mm/150mm/185mm) (Fig.2) and the different speakers, two positions (Fig.1) at the same time. To obtain the real transfer functions without influence from the speaker, it was necessary to scan the membrane of the speakers with a laser vibrometer and to eliminate the speakers transfer function from the measured transfer functions in the post processing phase.

These measurements were made for different filling degrees of rubber hoses (table 1).

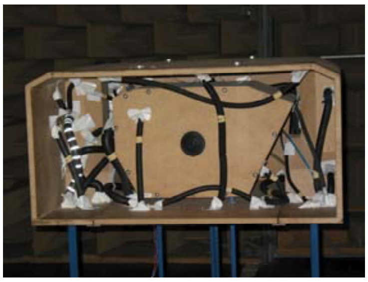

**Figure 1:** hoses filled model of the engine compartment

**Figure 2:** model of the engine compartment and the slots with the measurement microphones

| hoses | volume / litre | Filling degree / % | Surface / $m^2$ | Surface / % |
|---|---|---|---|---|
| 1 | 1,4336 | 1,02 | 0,278 | 6,81 |
| 2 | 2,0315 | 1,44 | 0,417 | 10,21 |
| 3 | 3,2526 | 2,31 | 0,638 | 15,63 |
| 4 | 4,5046 | 3,20 | 0,872 | 21,35 |
| 5 | 5,1514 | 3,66 | 0,974 | 23,85 |

**Table 1:** model of the engine compartment and the slots with the measurement microphones

### Measurement results

The measurement results are very interesting. Fig. 3 shows three features:

1. Below 1 kHz there is no significant difference between the empty and the filled cavities.
2. In the frequency range of 1-3 kHz the sound pressure level of the filled rooms decreases with nearly constant slope. For the highest filling degree this decrease reaches 6 dB.
3. Above 3 kHz the difference remains constant.

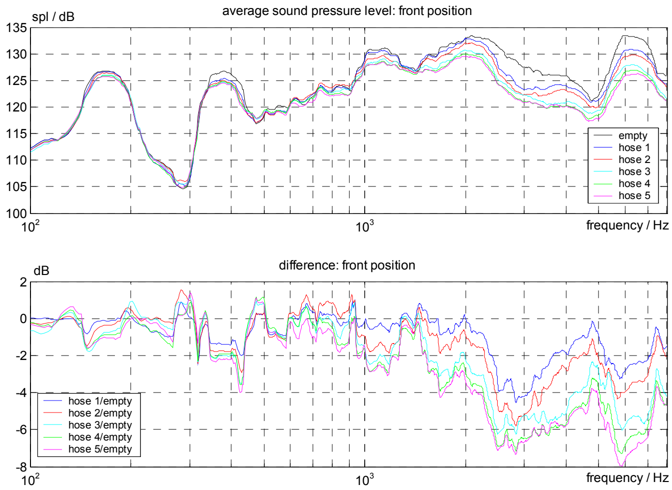


**Figure 3:** Sound pressure level (top) and difference to the empty room.

## Simulation

The engine compartment was discretised with a tetrahedron volume mesh. The mesh has about 20000 nodes and 85000 elements. The maximum distance between two nodes is 20 mm. Accordingly the upper critical frequency of this mesh is 2,9 kHz [2].

The simulation was done with our own FEM simulation tool "soundsolve" [3].

# The computer model

For the transfer behaviour of the engine compartment, the influence of the hoses and cables can be neglected for frequencies of up to 1 kHz. For the frequency range above this limit the influence of a representative medium should be considered.

The measurement shows that in the frequency range from 1 kHz to 3 kHz the sound pressure level decreases. The decrease depends on the filling degree and the distance between the position of the stimulation and the measurement position. Close to the source a high degree of direct sound will be present. So the influence of the medium is not so significant. Thus it can be assumed that the hoses behave like a medium with viscous losses.

## Medium model

In first approximation the medium effect is modelled by a representative surface absorption. To account for the relative geometrical correspondence of surface absorption and volume losses, the total absorption is assumed to be

$$A = \alpha S + 4mV \qquad (1)$$

similar as in room acoustics.

Thus the attenuation constant "m" can be replaced by an absorption coefficient "α" on the surface:

$$\alpha_{medium}(f, f.d.)\, S = 4\, m_{medium}(f, f.d.)\, V \qquad (2)$$

In this equation the attenuation constant "m" represents the imaginary part of the wave number:

$$m_{medium} = 2\,\mathrm{Im}(\underline{k}) \qquad (3)$$

## Simulation results

Currently, the used FEM solver cannot deal with a lossy medium. We are still working on the implementation of this feature. Therefore the only possibility of modelling the medium is to change the absorption coefficient of the walls. In fig. 4 a simulation result with a different "$\alpha_{medium}$" for the frequency range from 1 kHz. to 3 kHz is shown.

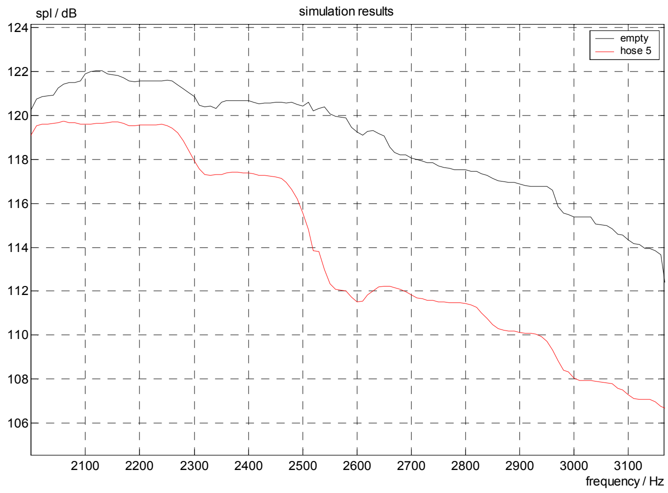


**Figure 4:** simulation results in the region between 2 and 3 kHZ (smoothed 1/12 octave)

# Conclusions

A complete FE mesh containing all details of the engine and fillings would create an enormous amount of memory space and computing time. The possibility of replacing the fillings by a representative medium seems to be worthwhile.

The hose-filled engine compartment has a manageable behaviour. There are two possible ways of modelling the losses in numerical simulations. The implementation of an FEM solver which handles viscous losses of a representative medium seems to be worthwhile to study further.

## References

[1] Kellert, T. et al.: Das Schallfeld in einem KfZ-Motorraum, Fortschritte der Akustik, DAGA 2003, Aachen 2003

[2] Silvester, P. P.; Ferrari, R. L.: Finite elements for electrical engineers - Cambrigde 1996

[3] Franck, A.; Modale und direkte Finite-Elemente-Methoden in der Akustik: Ein Vergleich, Fortschritte der Akustik, DAGA 2003, Aachen 2003