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VIBRO-ACOUSTIC SIMULATION USING GEOMETRICAL ACOUSTICS IN THE MEDIUM FREQUENCY RANGE INSIDE A CAR CAVITY

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ABSTRACT

We present a vibro-acoustic model well suited to the automotive medium frequency range. The acoustic radiation of surrounding structures into a closed cavity is estimated thanks to an integral formulation coupled to a geometrical approach for the acoustic propagation. This model rests on a partial decoupling hypothesis between the acoustic pressure in the cavity and the vibration of the structure in the medium and high frequency range. The radiation of a mechanically excited, flexible panel, mounted on a rigidified car cavity is modellised and compared to experiments. In addition to the classical comparison of response spectra, the pertinence of the model is shown through a perceptive study, applied to a panel of 36 people. We therein show the good quality of the modellisation, although slight differences (principally coloration) are perceived.

1 - INTRODUCTION

The constant reduction of vehicles development times and costs, that is imposed by the automotive market, make it even more necessary to use numerical models for the prediction of vehicles acoustic behaviour. They enable to reduce the number of prototypes during the conception and development phases, as well as they make it possible to test a great number of technical solutions.

One of the long-term objectives of the vibro-acoustic simulation is to be able to synthesise and listen to the global vehicle performance at any position in the driving compartment, for several life conditions. Our modellisation tools must hence not only contain the vibro-acoutic characteristics of the vehicles, but also provide a relevant information on the perceptive side, for the whole audible frequency range (20-20000 Hz).

Classical numerical methods show weaknesses in providing suitable information at all the audible frequencies. On the one side, the Finite Element Method, well suited to low frequency problems, becomes unadapted to solve dissipative problems like what is found in the middle and high frequency range (300-5000 Hz). On the other side, energetic models, like for example the Statistical Energy Analysis, provide mean energy values which are not sufficient for the listening phase, except if one artificially recreates phases for the signals.

Geometrical models (ray or beam methods) have been widely used in the past decades in concert hall acoustics for pure acoustic applications, dealing with point-like sources. Jean [1] was the first who applied geometrical methods to a structural radiation problem in a room: he treated a weak coupling

case composed of a simply supported plate coupled to a parallelepipedic room, that he compared with a Boundary Element Method.
We developed a radiation model [2] involving integral formalisms and geometrical concepts, quite similar to the approach proposed by Jean [1]. In a first part, we present the methodology as well as the hypotheses field involved. In a second part, we apply it to a simplified automotive case composed of a panel radiating inside a rigidified cavity. In a third part we present comparisons between simulated and measured responses. Lastly, we present the results of perceptive tests conducted on 36 people.

2 - THEORETICAL PART

In the medium and high frequency range (300-5000 Hz) the vibro-acoustic coupling between each panel surrounding the cockpit and the passenger compartment is much weaker than at low frequencies. When dealing with the acoustic radiation of the externally excited panels, it is therefore possible to ignore one side of the fluid-structural coupling that is the effect of the acoustic pressure in the cavity on the structure vibratory field [2]. With this hypothesis, the panel vibration can be evaluated without the presence of the fluid, and imposed on the boundaries of the acoustic propagation problem.
The well-known integral formulation for an acoustic problem is [3]:

$$\gamma p\left(x_f,\omega\right)=\int_{S_f}\left[G\left(x_s,x_f,\omega\right)\frac{\partial p\left(x_s,\omega\right)}{\partial n}-p\left(x_s,\omega\right)\frac{\partial G\left(x_s,x_f,\omega\right)}{\partial n}\right]dS_f \tag{1}$$

Where p is the acoustic pressure, x_f is the fluid point were the pressure in evaluated, S_f is the boundary surface of the cavity, x_s is a point on this boundary, and G is the green function. In this model G is calculated by a beam-tracing algorithm, Ebinaur [4], under all-rigid conditions, and with absorbing treatment included. The boundary conditions for G and p are then the following:

$$\left.\frac{\partial G_g\left(x_s,x_f,\omega\right)}{\partial n}\right|_{S_1}=0, \qquad \left.\frac{\partial G_g\left(x_s,x_f,\omega\right)}{\partial n}\right|_{S_2}=jk\beta\left(\omega\right)G_g\left(x_s,x_f,\omega\right) \tag{2}$$

$$\left.\frac{\partial p\left(x_f,\omega\right)}{\partial n}\right|_{S_1}=\rho_f\omega^2\vec{w}\left(x_s,\omega\right)\cdot\vec{n}, \qquad \left.\frac{\partial p\left(x_f,\omega\right)}{\partial n}\right|_{S_2}=jk\beta\left(\omega\right)p\left(x_f,\omega\right) \tag{3}$$

S_1 is the fluid-structure interface (we suppose here that it is non-absorbing), S_2 is the cavity boundary treated with absorbing material, β is the absorbing material's specific admittance, and w is the displacement field on the structure.
Inserting (2) and (3) in (1) eliminates the admittance terms, and we finally get:

$$\gamma p\left(x_f,\omega\right)=\int_{S_f}G_g\left(x_s,x_f,\omega\right)\rho_f\omega^2 w\left(x_s,\omega\right)dS_1 \tag{4}$$

This equation is discretized on a boundary element mesh of the fluid-structure interface. For all nodes x_s of this mesh, the Green function is calculated with the beam-tracing algorithm using a combination of a deterministic algorithm (up to reflection order 10) and statistical algorithms for reverberation and diffusion. The displacement field w can be calculated with a BEM approach for the individual panels surrounding the cavity.

3 - APPLICATION TO AN AUTOMOTIVE CASE

The radiation model is applied to a simplified automotive case, composed of a flexible panel mounted on a cavity rigidified with concrete walls, as shown in Figure 1. The absorbing configuration is composed of a unique type of material.
The structure is excited mechanically with a shaker.
For this validation case, we measured the vibration of the panel in decoupled conditions with an Electronic Speckle Pattern Interferometry (ESPI) measurement system [5], in order to minimise the error in the model entries. This measurement gives us a spatially detailed, normalized modal base of the panel.
In a predictive model the vibration would naturally come from calculations.
The structure and cavity meshes are shown in Figure 2. The fluid-structure interface is meshed with a classical criterion of $\lambda/6$, where λ is the wavelength of the maximum is the wavelength of the maximum frequency studied. frequency studied. The cavity boundary mesh is quite fine for a beam-tracing approach (element sides around 10 cm length).

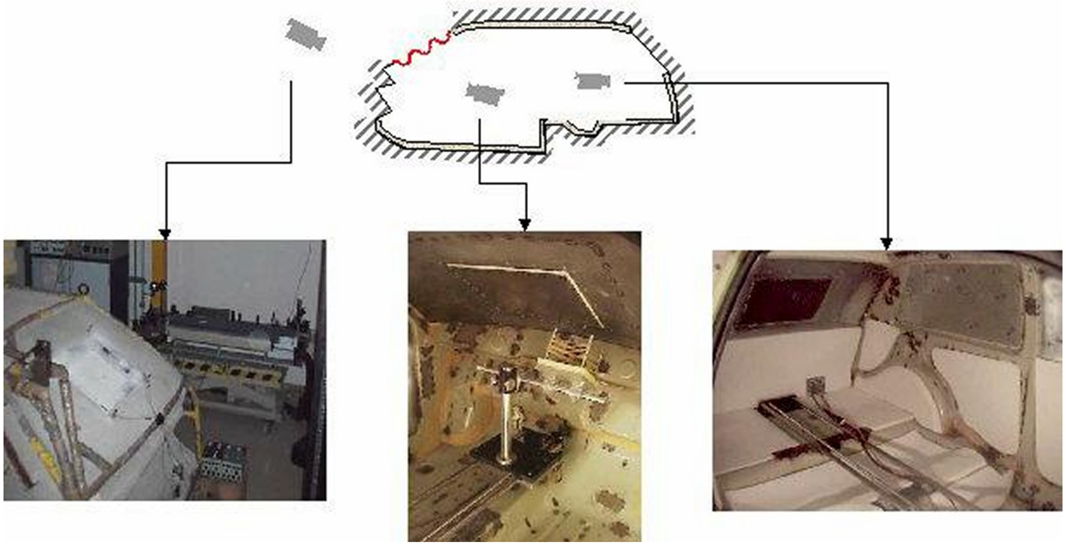

Figure 1: Diagram and photographs of the test structure.

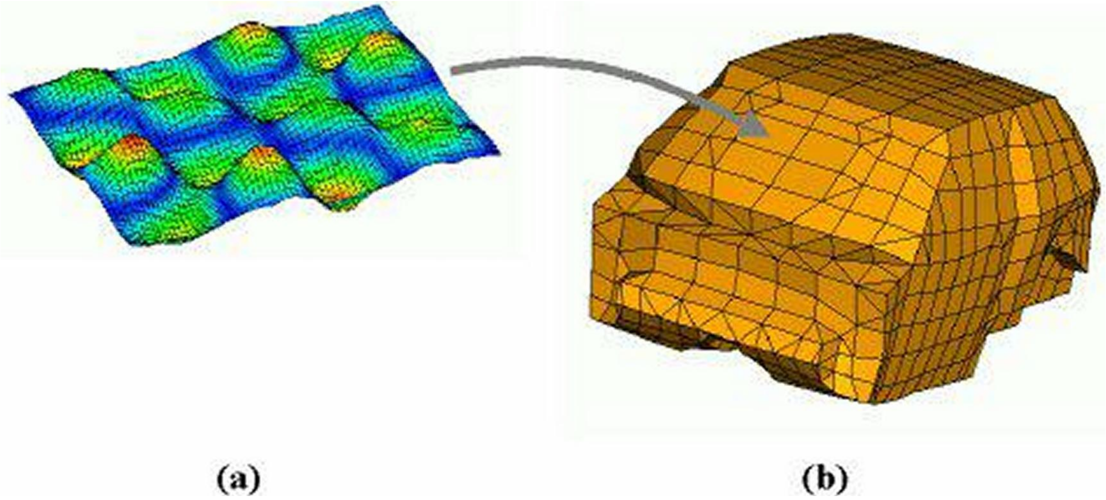

Figure 2: Panel mesh (a) and cavity mesh (b).

4 - EVALUATION OF THE MODEL QUALITY

The calculated and measured Frequency Response Functions (between the pressure radiated and the injected force) are shown on Figure 3 for one point in the cavity. Except for the shaded region where the difference is due to experimental problems, the calculation are in very good agreement with the measurements. It should be noted that the resonance peaks are often overestimated by the calculations, which we attribute to the approximations of the geometrical model. For low frequencies (here below 300 Hz) the geometrical approach is known for being inaccurate.

The associated impulse responses were convolved to a source signal typical of the automotive context, and submitted to a panel of 36 people. Triangular perceptive difference tests were performed: this is a very strict procedure for evaluating if differences are perceived between measurements and calculations. The statistical treatment of the subject responses shows that the two signal are significantly perceived differently (statistically speaking), principally because of slight coloration differences. However, when the shaded region in Figure 3 is filtered out, 61% of the subjects reported major difficulties for judging, which shows the pertinence of the modellisation.

5 - CONCLUSION

We presented a radiation model for structures coupled to a closed cavity in the medium frequency range, which relies on integral and geometrical concepts. The advantage of this model is that it provides all the necessary information for noise synthesis in the medium and high frequency range.

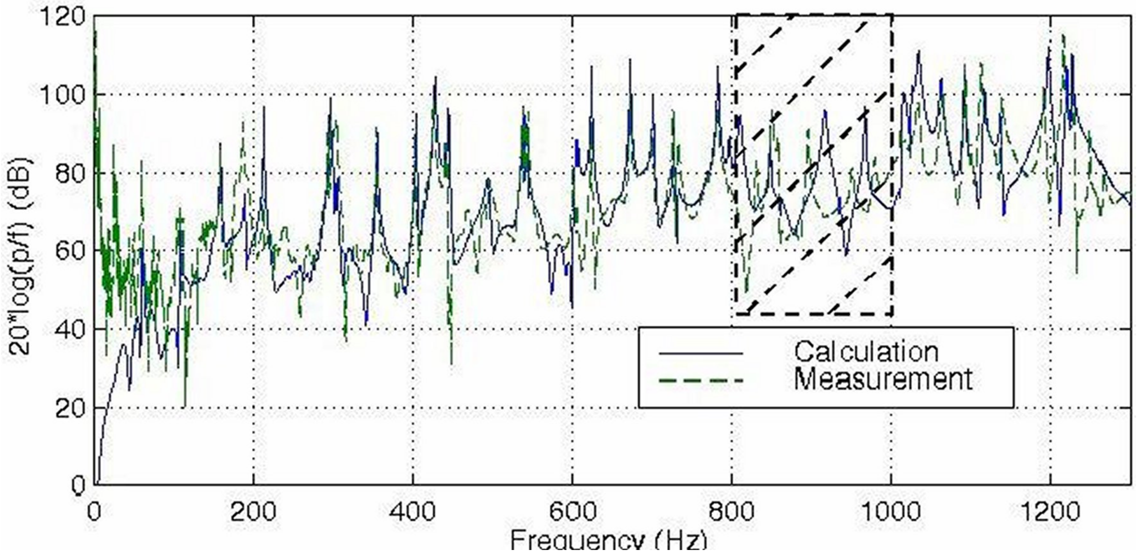

Figure 3: FRF pressure in the cavity / force injected to the structure.

The formalism was applied to an automotive case, for which measurement and calculation gave good agreement on perceptive criteria.
Some improvements in the beam-tracing algorithms, for example the possibility of dealing with curved facets, should improve the quality of the model in the future.

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