# Status on state of the art in PEM simulation in the automotive industry

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## Abstract

During the last decade, big progresses were made on software and hardware sides allowing an efficient use of PEM elements to represent explicitly the trims for the FEM simulation of full vehicles. Representing the trims as PEM elements in FEM vehicle models allows a more accurate description of the physical behavior up to 400Hz for structureborne excitations compare to the classical method using the non structural masses and high values of damping in the fluid domain which shows limitation after 200Hz.
This paper will make a review of the state of the art technics for modelling porous and elastic trims with PEM through the existing literature in the automotive industry. The focus will be made on the full vehicles scale interior acoustic for structureborne excitations and on component scale for the analysis of transmission loss. The paper will discuss about the most commonly accepted meshing rules, the latest development of efficient meshing technics. The effect of the boundary conditions on the results will also be studied. Finally an overview of the different results available to the end user to diagnose and evaluate the performances of the design changes implemented in the model will be presented.

## Introduction

The most classical modelling method for the trims in full vehicle FEM models consists in 2 parts: first to model the effect of the trims on the structure, the trim masses are smeared on selected parts of the structure as non-structural mass This method will take account of the transmission effect of the trim through its assuming that the trim has a constant thickness over the selected parts. The damping added to the structure by the visco-elastic behavior of the foam parts is not included here. Local masses are also added to the structure to model trims which are attached at certain points of the structure. It is usually the case for the door panels, headliners, trunk trims. A second part is related to the acoustic domain. A high damping is set to the acoustic cavity to account for the absorption effect of the trims. Damping value is in that case between 10 and 20%. These methods are suitable to get an idea of the effects of the trims up to 200Hz [6]. But it reaches its limits when it is question to go higher in frequency or analyses in detail the local effect of the trims. No local behavior of the trim can be investigated with this method. This technic has limitations to describe correctly the

## Theoretical background

### Porous materials, homogenization and characterization technic

The Biot theory is an homogenization technic developed to represent porous materials. The porous media are divided in two phases, one acoustic phase by fluid density, sound velocity, resistivity, porosity, tortuosity, thermal characteristic length and viscous characteristic length and an structural phase by density, Young's modulus , Poisson's Ratio and structural damping. This has been published by Atalla and Allard in [1,2,3]. Tools have been developed to make the identification of the Biot parameters easier using a simple flow resistivity measurement and an acoustic impedance measurement [4,5].

### Full Vehicle modeling

As described in Figure 1, the trim of a full vehicle analysis can be added to the classical structure/fluid coupled linear system as a trim impedance matrix $\tilde{Y}$ .The dynamic equation of the trimmed vehicle can be written in the following form:

$$\left[\begin{pmatrix} Z_s & C_{sc} \\ C_{sc}^t & A_c \end{pmatrix} + \begin{pmatrix} \tilde{Y}_{ss} & \tilde{Y}_{sc} \\ \tilde{Y}_{sc}^t & \tilde{Y}_{cc} \end{pmatrix}\right]\begin{bmatrix} U \\ P \end{bmatrix} = \begin{bmatrix} F \\ Q \end{bmatrix} \quad (1)$$

Where Zs is the mechanical impedance of the master-structure (car body in white), Ac is the acoustic admittance of the internal cavity. Csc is the surface coupling operator between the untrimmed master-structure surfaces directly in contact with the internal acoustic cavity.

U is the displacement field vector of the master-structure, P the pressure field of the internal cavity; F the external force field applied to the master-structure, and Q represents internal acoustic sources. The matrix $\tilde{Y} = R'YR$ is the transferred impedance matrix of the porous component where R is the transfer operator relating the degrees of freedom of the porous component to the degrees of freedom of the master structure and of the internal cavity.

The linear system of equations (8) is solved using structural and acoustic normal modes. This has the great advantage of keeping the trimmed linear system to be solved at the same size as the initial BIW linear system.

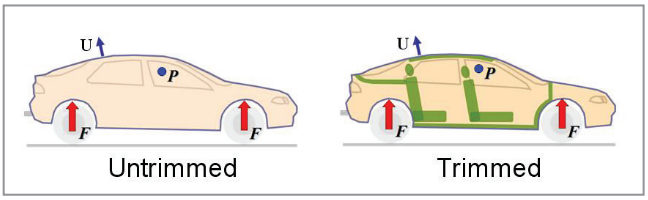


Figure 1: Untrimmed and trimmed configuration

## Application on full vehicle

In 2007, Anciant and al in [6] analyzed the correlation between measurements and simulations for a fully trimmed vehicle. In this case, all the porous trims (seats, carpet, dash insulator…) are represented as PEM elements (Figure 2). A relatively simple representation of the trims using quadratic solid elements was done. A good correlation is observed at several microphones up to 400Hz. On Figure 3 the microphone located at driver's head is displayed. The model could be computed within a reasonable time of a night.

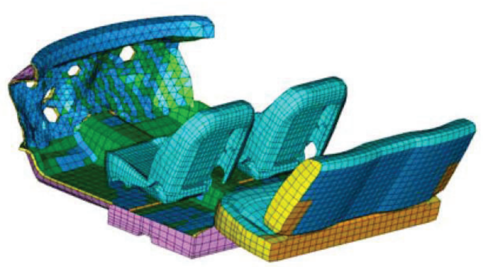

Figure 2: Anciant and Al, interior trim models

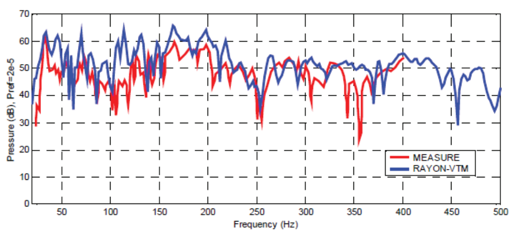


Figure 3: Anciant and Al, SPL correlation at driver's head

Between 2007 and 2014, many improvements have been done on the software implementation (in terms of parallelization, modular approach for the computation of the trim impedance matrices…) and the hardware allowing the creation of much more detailed models. Since 2012, the PEM element formulation is integrated in ESI group VPS software [7] allowing a much more efficient use of the hardware and giving the possibility to compute more detailed models and get more output possibilities

In 2014, Caillet and al in [8] presented a much more detailed model to study the influence of the porous trims (dash insulator, carpet, headliner, seats…) and the influence of the plastic trims (like trunk trim panels, pillar trims package tray) on the response of a full vehicle trimmed body model to a structureborne excitation. With the PEM method, it was possible to investigate several configurations (modifying the boundary conditions or trim properties) in the vehicle as displayed in figure. On the excitation point, no difference is observed as the trims are light compare to the trims. On the microphone side, an influence is clearly seen. It shows that it is important to define precisely the conditions and that the method has more possibilities as the classical ways of representing the trims in FEM full vehicle models

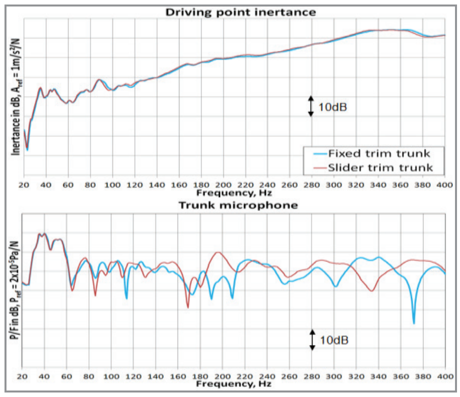


Figure 4: Caillet et al, Influence of structural boundary conditions

## Application on component model

It is possible to investigate the performances of a vehicle component by replicating a TL test. In such a model, the source and receiver domains are represented with BEM fluids, the structure as FEM and the trim component part as PEM.

Rondeau and al. [9] studied the influence of integrating the instrument panel within the transmission loss model. The instrument panel is integrated in the model with PEM elements. Its influence will be taken into account within the impedance matrices computed from the PEM elements. The sensitivity of the model to the addition of the instrument model is the same as the reality. Figure 5 illustrates the integration of the instrument panel and the sensitivity of the model to the modification.

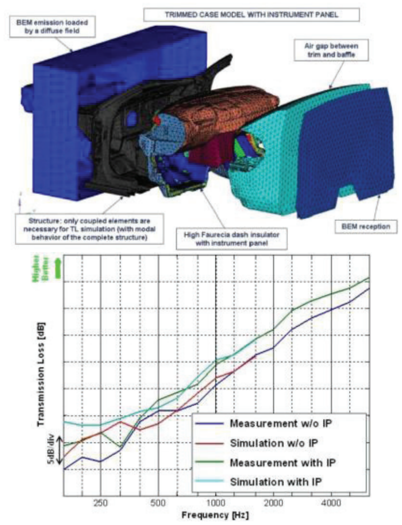


Figure 5: Rondeau et al, FEM/PEM/BEM TL simulation vs measurements, include cockpit in model

## Conclusion

The PEM method is a very good way integrate poro-elastic trims in FEM models. This method allows realistic prediction of influence of the trims for a full vehicle model or a component. Engineers can rely on it to investigate new virtual trim concepts instead of creating several prototypes.

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