

Evaluation of Trim Absorption to Exterior Dynamic and Acoustic Excitations Using a Hybrid Physical-Modal Approach

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ABSTRACT

The NVH study of trimmed vehicle body is essential in improving the passenger comfort and optimizing the vehicle weight. Efficient modal finite-element approaches are widely used in the automotive industry for investigating the frequency response of large vibro-acoustic systems involving a body structure coupled to an acoustic cavity. In order to accurately account for the localized and frequency-dependant damping mechanism of the trim components, a direct physical approach is however preferred. Thus, a hybrid modal-physical approach combines both efficiency and accuracy for large trimmed body analysis. Dynamic loads and exterior acoustic loads can then be applied on the trimmed body model in order to evaluate the transfer functions between these loads and the acoustic response in the car compartment. The scenario study of installing different trim components into the vehicle provides information on the acoustic absorption and dynamic damping with regard to added vehicle weight by the trim.

This paper demonstrates, through an industrial example, the creation of hybrid model of a trimmed vehicle body, the weakly coupled process of calculating and applying excitation from simplified tire noise on the vehicle's exterior surface, the effect of trim components on the interior noise reduction due to the exterior noise sources.

Numerical results showed significant trim effect in increasing the noise reduction in the frequency interval between 300Hz and 500Hz.

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INTRODUCTION

The numerical study of vehicle vibro-acoustic problems could rely on efficient finite element modeling methods. Several previous papers ([1],[2],[3],[4],[5],[6]) showed both the theatrical aspects and industrial applications of the hybrid modal / physical modeling approach for addressing the complex trimmed body issues. The vehicle body structure and the inner cavity are generally modeled using modal coordinates and the trim components modeled using physical coordinates. The handling of trim effect to the coupled body/cavity system could be achieved using either an energy based approach, or a reduced trim impedance approach. Both approaches were discussed in the paper [5]. This paper also pointed out the intrinsic limitation of the energy based approach that assumes

unchanged structure and cavity modes shapes despite the presence of the trim components. The reduced trim impedance, not constrained by this limitation, received more attention from industry and was applied on large scale industrial applications [6].

In this paper, the reduce impedance approach will be briefly reviewed. Techniques for improving the efficiency of the impedance computation will be introduced and validated with simple cases. Then, this approach will be applied on a large scale industrial model, with excitations coming from mechanical load and air-borne acoustical sources representing simplified tire noise. Trim effects will be evaluated both for local cavity pressure response and global noise reduction level.

REDUCED TRIM IMPEDANCE APPROACH

In a trimmed vehicle body (TB), high damping trim components made of multilayer of elastic and porous materials are inserted to the interior surface of the body structure, separating the structure and the enclosed air cavity volume. The presence of the trim components modifies the vibro-acoustic behavior of the coupled structure/cavity system. Using the reduced trim impedance numerical approach, the trim influence is applied on the untrimmed vehicle through its frequency dependant impedance, reduced to its two surfaces facing the structure and cavity, and projected on their normal modes. A detailed description of this approach can be found in [5] and [10].

The trim impedance is in the form of a dense matrix. The computation of such a matrix often requires considerable resources in terms of RAM and CPU time. The two following sections introduce two techniques that allow reducing this computation effort.

Frequency Interpolation of the Trim Impedance

The trim impedance varies often smoothly according to frequency. This property allows a frequency interpolation of the impedance. In practice, trim impedance can be first calculated on several selected frequency points within the full analyzed frequency range. Linear interpolation is then performed to estimate the impedance on the remaining frequencies. The following numerical example examines the accuracy of this approximation.

A simplified trimmed body (named NASCAR model, Figure 1) comprises a dash trim component and a floor trim component. Both trim components are made two layers of materials: a foam layer facing the body structure and a septum layer separating the foam and the cavity (Figure 2). The body is loaded by a mechanical force, denoted as F_1 .

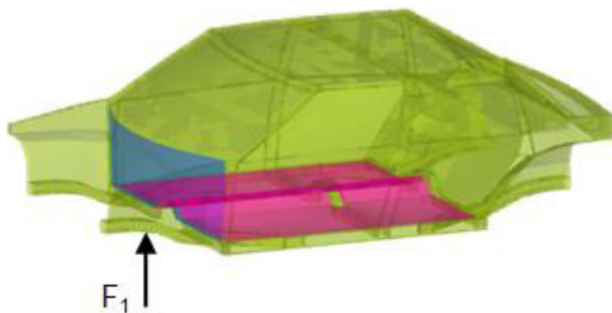


Figure 1. NASCAR, simplified trimmed body model

The square pressure (SP) in the cavity is calculated from 70Hz to 250Hz. Three different computations were performed: 1), trim impedance calculated every 2Hz and cavity SP calculated every 2Hz; 2), trim impedance calculated every 10Hz, then impedance value interpolated to every 2Hz and cavity MSP calculated every 2Hz; 3), trim impedance calculated every 10Hz and cavity SP calculated every 10Hz.

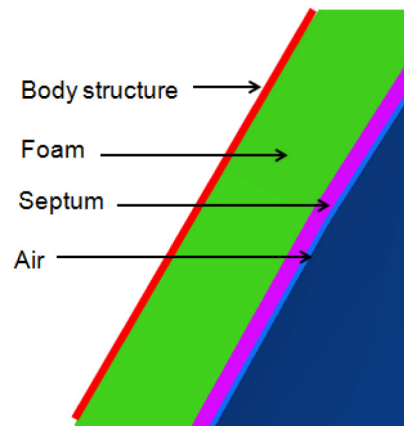


Figure 2. Double layer trim components in the NASCAR trimmed body model

Figure 3 shows the cavity SP obtained by the three different computations. The results show that the impedance interpolation provides very good approximation.

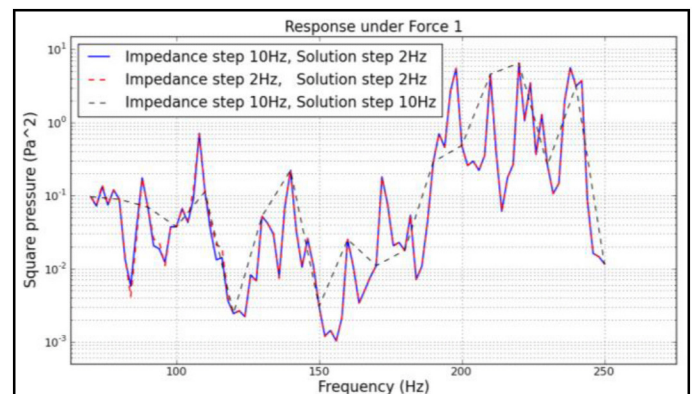


Figure 3. Cavity square pressure results of the NASCAR model. Comparison is made between configurations w/t and w/o trim impedance interpolation

Table 1 summarizes the computation times for the trim impedance and for the cavity pressure results. It can then be concluded that using a frequency interpolation for trim impedance while keeping high frequency resolution for the final frequency response solution could offer both accuracy and efficiency.

Table 1. Computation time of NASCAR model; comparison made between different frequency resolutions for time impedance computation and cavity frequency response computation

	Frequency step = 2Hz	Frequency step = 10Hz
Trim impedance	24 minutes	4.8 minutes
Modal frequency response solver for cavity pressure (modal reduction time not included)	1.5 minutes	15 seconds

Trim Component Partitioning

The trim partitioning consists of sub-dividing each trim component into several partitions and evaluating the impedance of each partition individually. The assumption is then that different partitions are isolated from each other. The total computation time can be reduced when using trim partitioning.

The validity of partitioning technique in terms of results accuracy is again verified using the trimmed NASCAR model. [Figure 4](#) shows the dash trim and floor trim both partitioned into four sub-regions. The results of cavity pressure obtained using un-partitioned trim components and partitioned ones are compared in [Figure 5](#).

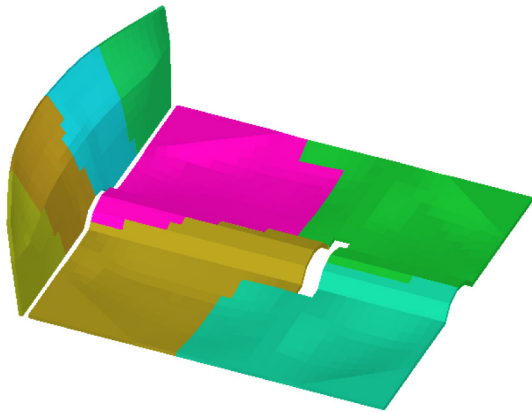


Figure 4. Partitioning of trim components in the NASCAR model

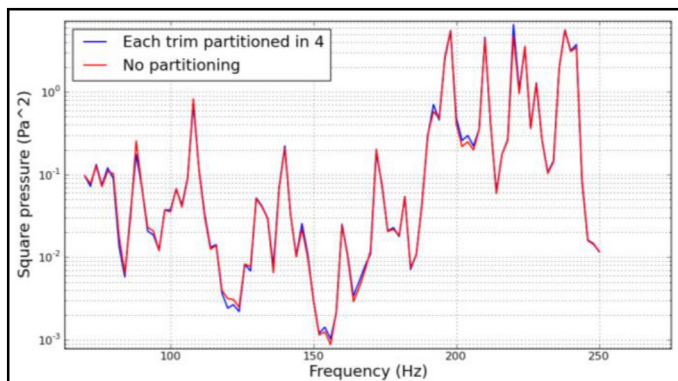


Figure 5. Cavity square pressure results of the NASCAR model. Comparison is made between configurations w/t and w/o trim partitioning

Table 2. Computation time of trim impedance of the NASCAR model; comparison made between trim partitioning and no partitioning

	No trim partitioning	Trim components partitioned into 4 sub-regions
Computation time of trim impedance per frequency point	65 seconds	33 seconds

STRUCTURE-BORNE AND AIR-BORNE ANALYSES OF A PASSENGER CAR'S TRIMMED BODY

The studied TB model is a passenger car of Hyundai Motor Corporation. Two analyses were performed:

1. Structure-borne analysis ([Figure 6](#)). In this configuration, unit mechanical loads are applied at different locations of the body. Sound pressure level (SPL) is calculated at selected locations inside the car (microphone positions at driver's ear and passenger's ear).
2. Air-borne analysis ([Figure 7](#)). This analysis is performed in two steps, following the same process described in a work done by Nissan Motor [6]. In a first step, monopoles close to the tires' leading and trailing edges are set as simplified tire noise source. Due to the acoustic radiation and scattering effect, these sources generate acoustic pressure on the body surface. In a subsequent step, this surface pressure acts as excitation to the TB's vibro-acoustic system.

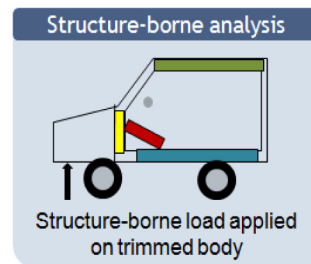


Figure 6. Schematic image of structure-borne analysis

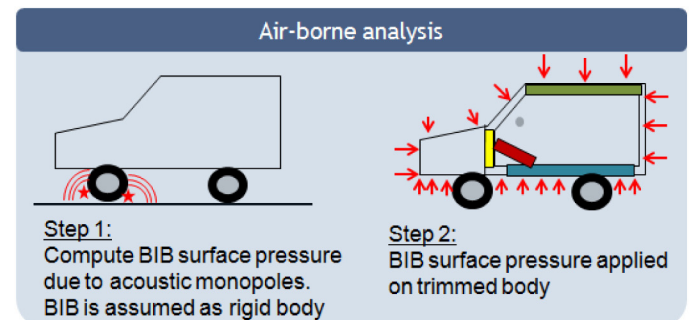


Figure 7. Schematic image of air-borne analysis

Body and Cavity Models - Untrimmed Vehicle

Both the Body in Blue (BIB) and the enclosed cavity are available in NASTRAN models.

The BIB FE mesh has about 2.3 million structure nodes, comprising mainly quadrangle shell elements with varied material and thickness. A modal reduction using MSC Nastran SOL 103 extracted the free body modes up to 600Hz, with 3671 modes calculated (rigid body modes included). [Figure 8](#) shows the body FE mesh and one of its modes.