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Full Vehicle SEA Model Uses Detailed Sound Package Definition To Predict Driver's Headspace Acoustic Response

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Abstract [472] This paper provides an overview of the building and validation process for an airborne SEA model of a typical automotive vehicle using the AutoSEA2® software. The emphasis is placed on identifying the transmission paths as well as sound package characteristics that are most critical to ensure accurate predictions using SEA. It also compares predictions with experimental results of well-controlled load cases. Correlation between predictions and tests is presented and briefly discussed.

1 INTRODUCTION

Statistical Energy Analysis (SEA) has proven to be an efficient tool to model high frequency acoustic response of a vehicle for many years. Early on, efforts were focused on capturing the global behavior of the vehicle with fairly simple models (~ 50 subsystems). The automotive industry widely accepted a set of rules and guidelines that enable the prediction of the acoustic response at the driver's headspace with fair accuracy. Later on, the 3D modeling method allowed to improve the geometric parameters of the SEA models and enabled the analysts to assess the sensitivity of the driver's headspace Sound Pressure Level response to the car geometry. It was concluded that geometry and sound package definition are the driving modeling factors that influence accuracy of the SEA model. Further developments in the material testing of the sound package content allowed to better characterize the input parameters to the SEA model. A detailed sound package definition including all trim components as well as thickness variation, percentage of coverage and a high understanding of passthroughs are part of the important aspects of modeling that this paper addresses.

The paper is divided in two main sections. Firstly, the model building process is described in detail. Secondly, a typical set of model validation tests are presented along with correlations between these experimental results and AutoSEA2 predictions.

2 MODEL BUILDING

There are several steps in the creation of an SEA model in AutoSEA2. These mostly consist of the definition of the geometry, population of the materials and physical properties databases, definition of the flanking paths and sources as illustrated in Figure 1. These various steps are described in the following sections.

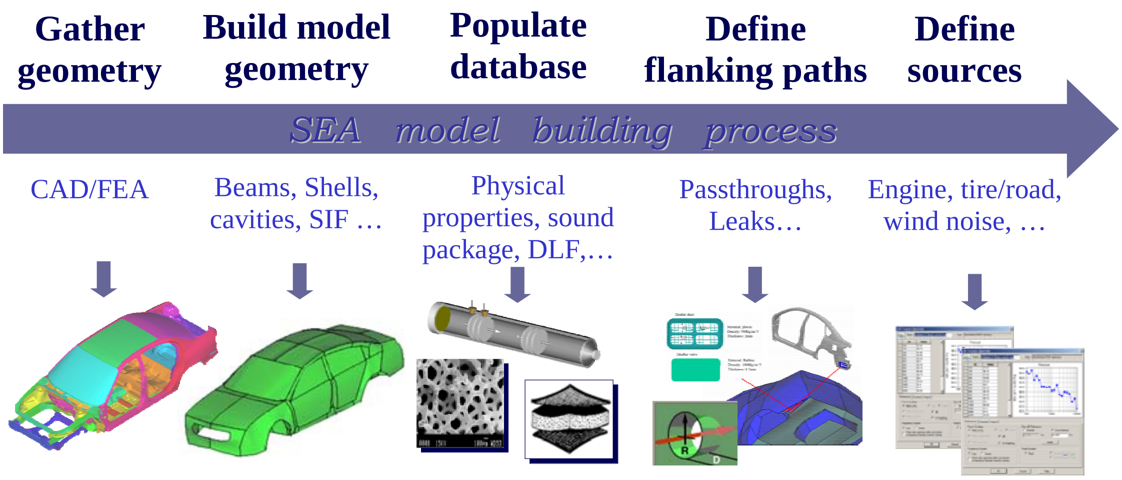

Figure 1: *SEA model building process*

2.1 Geometry

A typical sedan vehicle SEA model in AutoSEA2 includes approximately 500 subsystems and is thus fairly detailed for airborne studies. Although creating models from FEA/CAD geometry is a fairly straightforward process, there are ways to drastically reduce the time required for creating an SEA model of a vehicle by using a template [1]. The template is essentially a generic model for which geometry can be morphed to fit a particular vehicle design. A typical airborne AutoSEA2 model of a vehicle takes advantage of the Template Modeler suite of tools developed for AutoSEA2. The Template Modeler makes extensive use of the 3D environment in AutoSEA2 to ensure better accuracy in the modeling of SEA subsystems geometry [1].

The user will start with a template for which subsystem partitioning has been proven effective for typical high frequency modeling of the airborne noise transmission in a given car type such as sedan (c.f. Figure 2). The main task is then to simply relocate a set of master nodes that define the overall boundaries of key geometrical parts such as the corners of the roof, windows, etc… Algorithms have been developed that then automatically morph the whole template geometry based on the subset of relocated master nodes [1].

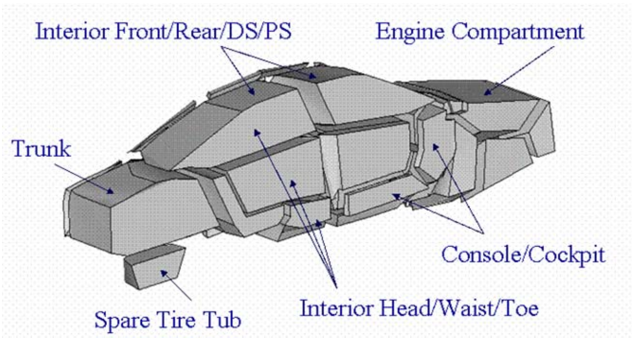

Figure 2: *Typical cavities partitioning of an AutoSEA2 sedan car template*

For airborne studies in automotive vehicles, using a geometric representation of the subsystems is critical to ensure proper modeling of both the non-resonant and resonant noise transmission paths. First, it yields an accurate estimate of the subsystem mass. This mass determines the amount of non-resonant noise transmission through the body panels, a key phenomenon in automotive applications. The resonant noise transmission through a given shell is proportional to its radiation efficiency which is highly dependent on the panel curvature below coincidence. Consequently, the precise definition of vehicle geometry yields an accurate estimate of the radius of curvature of subsystems such as the windshield for which resonant contribution to the interior noise level is significant.

2.2 Physical Properties and Structural Damping

The next critical step in the model building process is to assign the proper physical properties for the various materials and assess the structural damping. The material properties and average subsystem thickness are typically deduced from an FEM model of the body in white.

There are two ways to estimate the damping in a subsystem. If detailed information about the damping treatment is available, then predictive methods can be used. The general laminate formulation [2] in AutoSEA2 enables the user to predict the structural damping due to energy dissipation in the viscoelastic layer(s) of a given subsystem for various wavetypes. For situations in which precise information about the structural damping treatments applied to a given subsystem is not available or when a large part of the energy dissipation within a subsystem occurs at the boundaries (window seals for example), experiment based methods need to be used instead. The Decay Rate and Power Injection Method [3] are available for the estimation of the in-situ (also called apparent) damping of a given subsystem.

The Decay Rate method consists in estimating the average damping of a group of modes, typically within one-third-octave frequency bands, based on measurements of the energy time decay in the subsystem. Usually, an energy time curve is reconstructed from a set of Transfer Mobility measurements performed on the subsystem, and the reverberation time is computed from this data.

The Power Injection Method relies on the measurement of both Input Power $\left(P_{in}\right)$ and Energy $\left(E_A = m \cdot \left\langle V^2 \right\rangle\right)$ of the subsystem to infer its apparent loss factor $\left(\eta_A\right)$ using the following one-subsystem SEA power balance equation (with ω the frequency in rad/s):

$$\eta_{\mathrm{A}} = \frac{P_{in}}{\omega E_A} \tag{1}$$

The results are then imported in AutoSEA2 as damping spectra and applied to the various subsystems. It is important to note that the structural damping of the glasses is particularly critical due to the importance of their resonant contribution to the interior cavity response in the typical frequency range of analysis, i.e. between 400Hz and 10kHz.

2.3 Passthroughs and Leaks

Other parameters that usually significantly contribute to the airborne sound transmission and thus require to be precisely modeled are the passthroughs and leaks. The passthroughs can be modeled as rubber panels and are typically found in the dash, doors and quarter panel assembly (Pressure Release Valve). Leaks are also modeled. Their noise transmission characteristics can be inferred from their geometry, in which case they are modeled as rectangular or circular apertures slits. Alternatively, they can be user-defined based on a transmission loss spectrum and an effective area.

2.4 Sound Package

The modeling of the sound package of a vehicle is one of the key areas that will greatly influence the accuracy of the SEA predictions. The foam module of AutoSEA2 enables the user to define any kind of poroelastic materials layup to model typical vehicle Noise Control Treatments (NCT). Poroelastic materials, such as foam or fibers, are defined based on a set of measurable physical properties [4] such as density, flow resistivity, porosity, etc. Septum and solid layers are also available to model trims with a barrier type of layer. Alternatively, when the physical properties of the trim are unknown, a user-defined NCT for which performance is defined as a surface absorption and insertion loss is available. The latter constitutes an effective method when the user wants to base the description of the trim on measured performance. However, user-defined NCTs are not as convenient as regular layup models for trim optimization purposes since the simulation will not provide guidelines on how to design the trim.

The typical procedure when modeling the sound package of a vehicle initiates with the direct or indirect measurement [5] of parameters characterizing the various layers of poroelastic materials constituting the trim. Once the materials and their properties are in the AutoSEA2 database, it becomes possible to define the layups constituting the various trim components such as floor carpet, headliner, dash absorber, pillars and doors trim, etc…

The final critical step in the modeling of a sound package is to obtain the spatial distribution of its layup in case it varies across the trim surface, which is often the case for automotive applications. Typically, a Multiple Noise Control Treatment (MNCT) is created and composed of several Noise Control Treatments. Each NCT represents a unique combination of layups and associated thicknesses corresponding the trim of interest in a given region of the vehicle. Each NCT is also associated a percent coverage area specific to the subsystem on which it is applied. The overall absorption and insertion loss properties of the MNCT then correspond to an area weighted average of all its NCT constituents. Such MNCT is finally applied to the subsystem it corresponds to.

3 MODEL VALIDATION

Several methods can be applied to validate the airborne SEA model of a full vehicle. The most powerful one consists in performing transmission loss measurements of various sub-assemblies of the vehicle such as the dash, the doors and validate the AutoSEA2 model, one sub-assembly at a time. Alternatively, partial transparency tests can be performed to validate critical transmission paths separately such as the windows. An other typical method, closer to operating load conditions, consists in using an acoustic source to excite a major source cavity such as the engine compartment or a wheel house and record both exterior and interior SPL levels. The SEA predictions of the interior SPL can then be validated against experimental results by enforcing the exterior cavities SPL in the model with measured data. This ideal load method is the object of the discussion below where the exercise was performed on a Nissan sedan vehicle.

3.1 Controlled Load Case

For the experimental results shown in the next section, the vehicle was located in a semi-anechoic chamber and jacked-up at approximately 15 inches from the floor so that loudspeakers can be placed underneath the vehicle. Three ideal load cases were measured and consisted in the successive acoustic excitation of the engine, front wheel house and rear wheel house cavities as illustrated in Figure 3. For each ideal load test, the SPL was recorded at multiple locations outside the vehicle, not only in the excited cavity, but also all around the exterior and underbody (c.f. Figure 3). Typically, two to three microphones per constrained SEA cavity are used in order to obtain an estimate of the space averaged SPL in each subsystem. The interior cavity SPL was recorded in a similar fashion with approximately 7 pairs of microphones. The typical total sensor count for ideal loads testing ranges from 60 to 80 sensors.

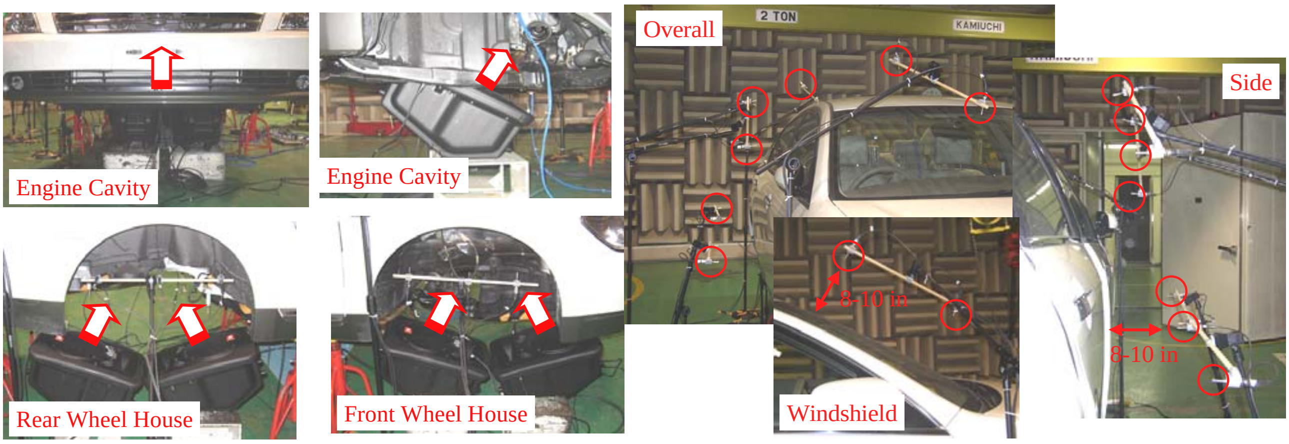

Figure 3: *Typical loudspeaker and microphone locations for ideal load testing*

The recorded SPL all around the vehicle is then used to create a load set in the AutoSEA2, which consists in constraining the SPL of key exterior cavities. The constrained cavities are illustrated in Figure 4.

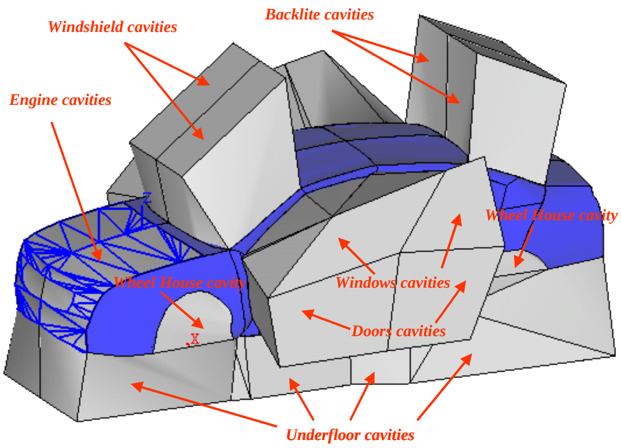

Figure 4: *Exterior cavities for which SPL is constrained with measured data*

3.2 Validation Results

The AutoSEA2 model is able to predict the space and frequency averaged pressure response in the interior of the vehicle, which is typically partitioned in front, rear headspace, waist and legroom regions.

The simulation results are compared against measured data, typically in one-third octave bands between 315Hz and 8kHz. The predictions are within 3dB of the measured headspace response across a wide frequency range as illustrated in Figure 5 for various ideal load case scenarios.

In addition to the headspace response, the SEA model is capable of predicting trends in other regions. For example, higher sound pressure levels are usually observed in the legroom region. The partitioning of the interior vehicle cavities into headspace, waist and legroom cavities, although violating the SEA assumption of weak coupling between subsystems [6], typically yields good correlation results between tests and predictions not only at the headspace, but also in other regions of the interior space as illustrated in Figure 5.

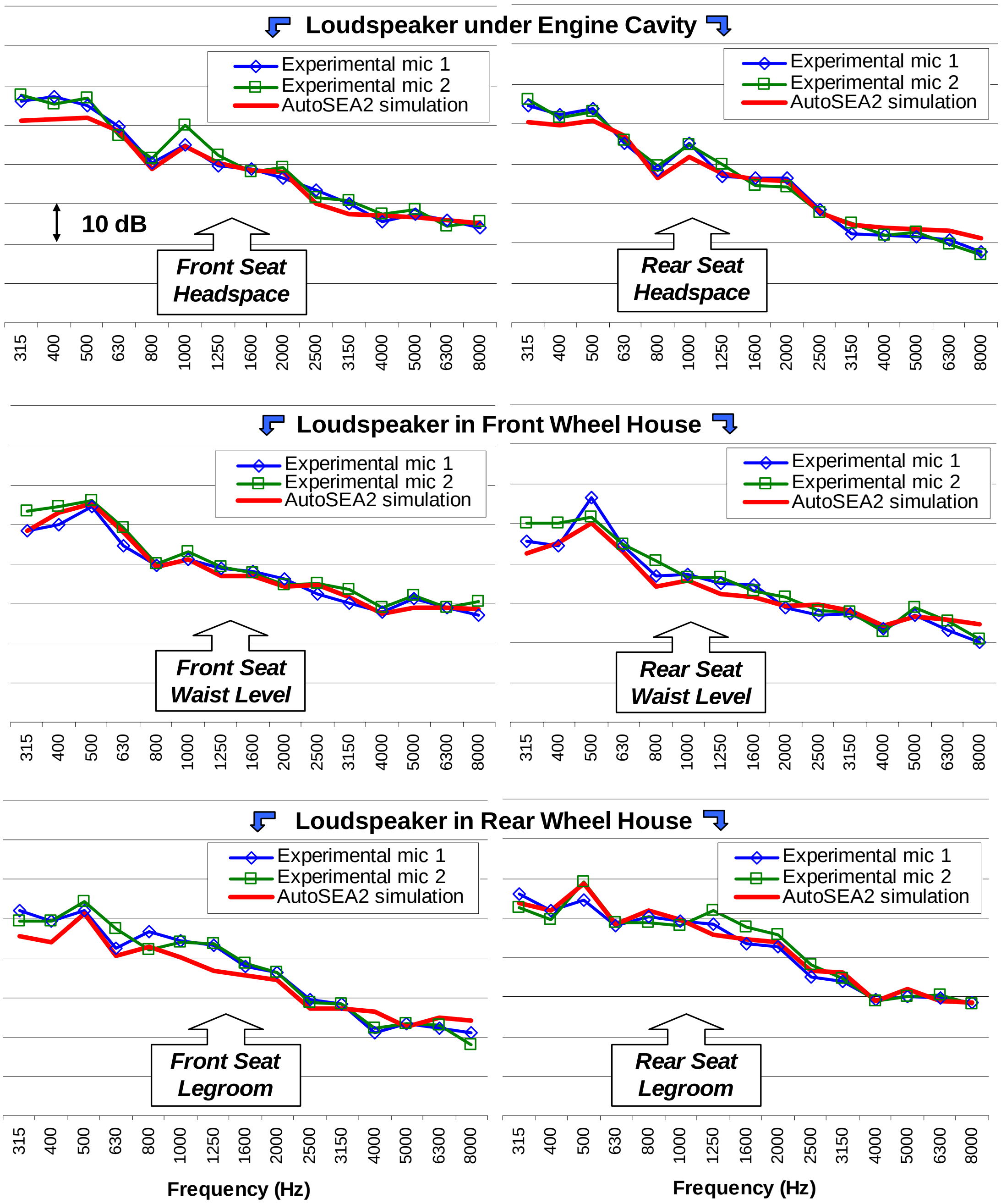

Figure 5: *Interior cavities SPL validation results for various load cases*

4 CONCLUSIONS

This paper described the different steps necessary to accurately represent a full vehicle using SEA for airborne noise predictions. It was shown that AutoSEA2 and the Template Modeler method help to build a detailed and accurate SEA model geometry of a vehicle in a matter of days. It was pointed out that one of the critical areas of the modeling is the proper definition of the vehicle sound package, which is greatly facilitated by the use of Multiple Noise Control Treatments in AutoSEA2. Finally, comparisons between AutoSEA2 simulations and experimental results for several well controlled load cases have shown that SEA is capable of predicting the interior sound pressure level with reasonable accuracy (3dB) across a wide frequency range (300Hz to 8kHz).

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