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Preliminary SEA model development and acoustic package development for EV's

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ABSTRACT

SEA modelling is a useful tool in the automotive field, since it can provide a good indication of interior noise within the very high frequency range. SEA model generation is a very complex phase in vehicle development and is usually postponed until late in the development phase, when detailed geometry is available. Today on the other hand, a new trend is emerging where SEA modelling at the early stage of a project is becoming important. Having a SEA model available at the early stage of a project can guarantee the correct sound package development in terms of allocated space and mass, but can also help with target definition for different subsystems and help guide engineer's judgment. In the following a new method will be proposed to allow SEA modelling in the early concept phases, it will be shown how this model can be used to define different subsystem targets and to achieve a desired noise level inside the vehicle.

Keywords: SEA, Preliminary Assessment, Acoustic Target
I-INCE Classification of Subject Number: 76

1. INTRODUCTION

Nowadays the acoustic comfort in the automotive sector is becoming more and more critical following the increased expectation of customers. The new era of EV's has raised new challenges regarding noise and vibration in the automotive sector. Electric motors have higher operating frequencies, shifting the resultant noise to an area where the human ear is most sensitive.

The acoustic development, despite the relevance of the topic, most of the time is postponed until late in the development phase. In the early concept phase there are no tools to evaluate the acoustic level inside the cabin. When a new vehicle project commences, no more than a vague idea of mass, space and the type of acoustic package is in the mind of the designer.

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An initial investigation of the acoustic performance is usually performed when the TB is defined and the interior cavity is surrounded by the adjacent structure. Most of the time this leads to a mismatch between the expectation and the reality in terms of acoustic performance.

The acoustic package is designed & developed from scratch, without investigating the effect on the whole vehicle. Each component is considered in isolation and not part of the more complex environment, neglecting the interactions between them.

On the other hand, every issue identified late in the development phase has a high impact in terms of cost and time.

The purpose of this project is to propose a method which establishes the acoustic performance of a vehicle at an early stage of its development, thus avoiding issues later and anticipates criticalities in the vehicle itself. A better knowledge of acoustic behaviour and the availability of a preliminary model can define the acoustic package and drive its development during the early stages of vehicle development.

Due to the complexity of the task the proposed approach will be based on SEA.

2. INTRODUCTION TO SEA

SEA (Statistical Energy Analysis) is a method to analyse systems at very high frequencies. The basic idea of the SEA method is to discretize every subsystem using only one variable, the amount of energy it can store. This amount of energy is calculated with a statistical approach based on similar subsystems. The advantage of this method is the reduced number of variables and the simplified schematic representation of different subsystems.

Compared to other methods, FEM and BEM, the SEA method gives us the capability to increase the frequency range we can analyse.

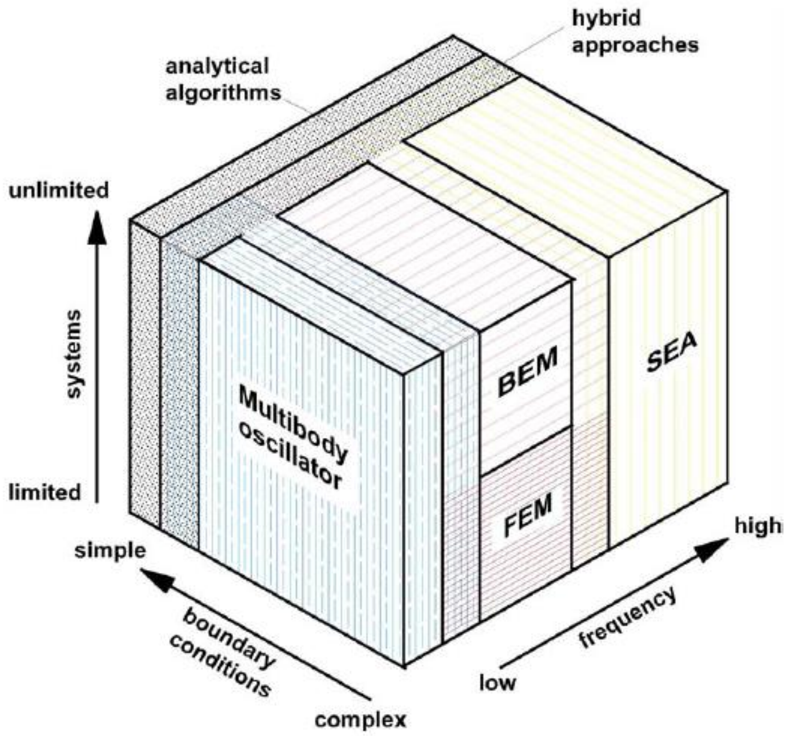

Figure 1: NVH methods vs system complexity, number and frequency range.

The advantage of SEA is to reduce significantly the number of variables required to discretize a subsystem (1 per subsystem) reducing the computational effort. On the other hand, this kind of discretization is a limit for low frequencies.

The energy stored in a subsystem in SEA is estimated based on number of modes in each third octave band, in the hypothesis every mode is equally influent and can store the same amount of energy. When it comes to studying low frequencies, let's say under 315 Hz third octave band, if the subsystem is not big enough, there will not be sufficient modes in the band to have a proper estimation of the energy stored in the subsystem at that frequency band.

2.1. Building SEA model

SEA models usually represent the detailed shape of the vehicle, however according to the general SEA hypothesis this is not required. Of course, having a detailed shape helps in terms of the model being closer to reality and aiding engineering judgment with a representative visual input.

Another relevant aspect of SEA modelling is the acoustic properties of the subsystems involved in the model. The acoustic properties relevant for the model are STL and Absorption. Both can be measured using different approaches or calculated using different methods. The most common one being TMM.

The last element required in a SEA model are the loads to be applied to the structure. Loads are specific for each vehicle and can be measured or simulated. Of course, measuring loads requires a physical vehicle being available which only happens late in the development phase.

In the following we will further investigate each of the parameters required for SEA model building.

3. GEOMETRY

Geometry is the first step required for model creation.

In the spirit of SEA modelling an accurate geometry is not required, in fact no geometry is required at all. As mentioned previously the SEA model is based on energy stored in the subsystem that is a function of modal density (the number of modes in a specific third octave band). The modal density is a function of geometry in a very platonic sense (it also depends on the material, but it is not relevant here); it only depends on the area of the subsystem (corrections according to the perimeter can also be applied, but they are relevant only for line junctions).

According to this it is evident that the only parameter we need to know about is the subsystem area. Knowing the area, the exact shape of the system is not relevant at all; a circular subsystem or a square one have the same properties from a SEA point of view, if they have same area.

3.1. Estimate subsystems area

If we know nothing about vehicle we are going to study then we are unable to estimate the geometry.

When a new vehicle is developed some basic information is typically defined, such as; vehicle type (i.e. SUV or sedan), wheelbase, overall dimensions and number of seats. This level of information is the minimum required to make some initial estimations, by using similar vehicles as reference and starting point.

3.2. Reference background

Since every vehicle is unique in its style, geometry and configuration most of them can be grouped into similar classes. All vehicles within the same class have similar characteristics. Based on this, we can use similar vehicles to evaluate the characteristics of the under-study vehicle.

The data we have for our vehicle is listed in Table 1.

Wheelbase:		*x* [mm]
Max length	Max Width	Max height
x [mm]	*x* [mm]	*x* [mm]
Ground height:		x [mm]
Number of seats:		x
Type of vehicle		*x*
Notes		e.g. Pano roof

Table 1: Overall info for new vehicle

Based on this overview of the vehicle we can establish similar vehicles that we can use as a reference. The list of vehicles with similar characteristics is shown in Table 2.

Land Rover Discovery HSE LUXURY Si6	Volvo XC90 T8 Inscription	Audi Q7 S Line	Kia Sorento LX FWD	Tesla Model X P90D
Chevrolet Tahoe 4WD LTZ	Chrysler Pacifica Touring L	Ford Expedition LIMITED 4X4	Honda Odyssey Elite	Kia Sedona SX
Mercedes GL-Class 450 4Matic	Nissan Rogue SV AWD	Toyota Highlander XLE-V6 AWD	Volkswagen Atlas SEL w/4MOTION	

Table 2: List of reference vehicles

3.3. Relevant geometry

A second point to keep in mind when studying the preliminary SEA model of a vehicle is that not every surface has the same global influence. Some components, such as firewall, floor or glazing, are more relevant than others, like the pillars. The first classification can be done according to the subsystem surface; small area subsystems will be neglected in this preliminary analysis.

The list of components included in the preliminary analysis is shown in Table 3.

Windshield	Firewall	Floor
Front Door (+ glass)	Rear Door (+ glass)	Tailgate
Roof	Sunroof	

Table 3: List of main components included in SEA model

For these components, based on similar vehicles, we can initially define some relationship between the available info (Table 1) and the area of components (Table 3).

In the following, the relationship is shown between some global sizes and the floor (Figure 2) and between global sizes and closures (Figure 3).

As is shown in Figure 2 and Figure 3 it is possible to observe a relationship between the global size of the vehicle and the area of main components. This relationship is used to define the base geometry definition in our model. The regression equation coming from Figure 2 and Figure 3 will be used to define our model geometry using the input data reported in 1 for the geometry subsystems defined in Table 3.

3.4. Cavity

The physical subsystems included in the model, account for half of the model. The other half is made by the cavity inside the vehicle.

Also in this case, a common SEA model is built up with a reasonable number of cavities (usually between 18 and 24 main cavities). The differentiation of cavities is useful if we want to investigate the acoustic level at different points within the vehicle (in a SEA model we can measure one SPL per cavity).

Usually the cavity subdivision is a standard process, with standard cavities being established over the years. The weak point is that we need the geometry of the interior cabin to create the cavity and then this is split according to the modelling requirements.

The simple model proposed here is made of only two cavities.

The first and biggest one is the main cavity covering the whole vehicle. The second cavity is the one commonly defined as Driver Head Cavity. This cavity is the one where the output is requested.

Cavity schematization is more critical than structural subsystems. For a cavity we need to estimate the volume and the surface area. For surface area we can use the area of the surrounding components, defining the volume is more complicated.

The volume of the cavity will be defined starting with the cavities side area and width. Both of which can be calculated from the analysis of similar vehicles.

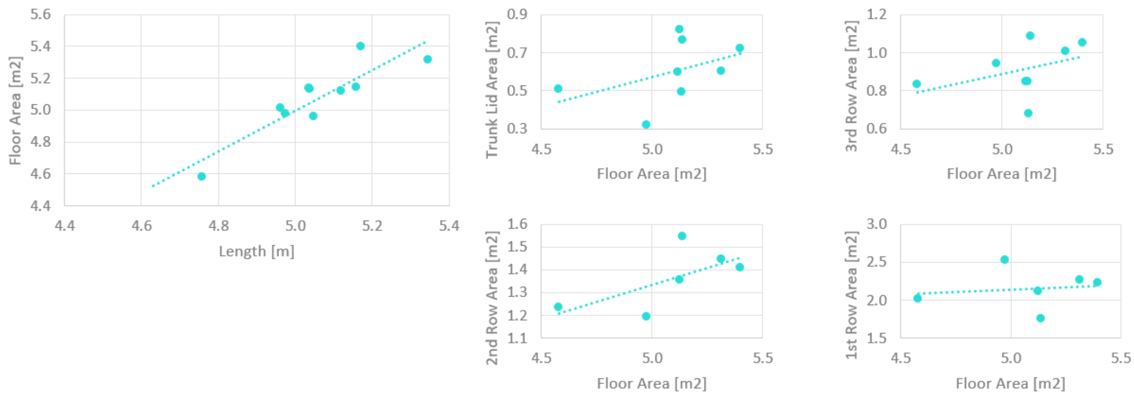

Figure 2: Floor area vs vehicle length.

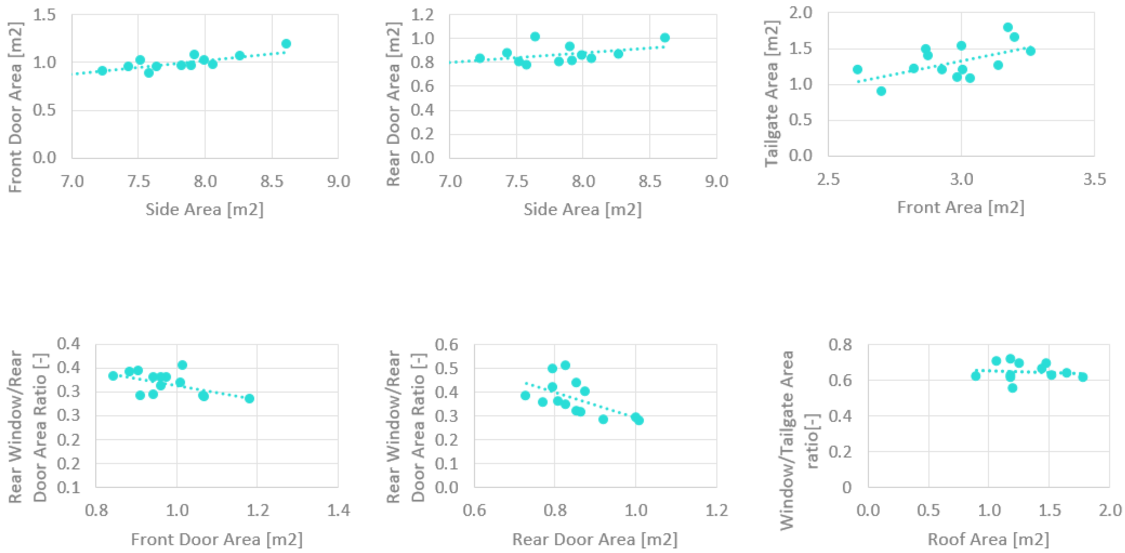

Figure 3: Closure area vs side area

4. SUBSYSTEMS PROPERTIES

Once the geometry has been defined, the second step is to assign the properties to the different subsystems.

The properties relevant for a SEA model are; (1) STL applied to structure subsystems & (2) Absorption applied to cavities.

4.1. STL

STL is the property of the structure to avoid noise transmission. It is a property of the structure and is dependent on; material, thickness & boundary conditions. The STL can be measured or simulated using different methods.

STL measurement can be performed using two methods. The first one is by using an impedance tube (also known as Kundt tube). Whilst the second, and most accurate is using the two chambers method (anechoic-reverberant combo is the most common) following the UNI EN ISO 15186 procedure.

When a STL measurement is not available some numerical models are available to predict the structure behaviour. The STL simulation is a critical topic and the results must be validated carefully. Using the TMM approach it is possible capture results with a high level of accuracy if the appropriate model for impedance is used (the suggested one is JCA model).

On the other hand, the STL applied to each subsystem cannot be simulated if no information is provided about the package concept. In this case where no information is provided about the layup an initial assumption can be made using the mass law. Even if mass law can't be used an estimation can be made based on similar vehicles and previous analysis.

The simplified SEA model proposed can also be used to provide a preliminary general idea about the STL required for each subsystem to achieve the desired acoustic comfort inside the vehicle. In this case the STL for each subsystem is the desired output from a "target cascading" process.

4.2. Absorption

The second property required for the model set-up is the Absorption. As per STL, different methods can be used to measure or estimate this parameter.

The measurement of absorption can be performed in an alpha cabin (also known as Sabine cabin) or by using the impedance (Kundt) tube. Regarding the numerical method, also in this case as for STL the model used for impedance calculation is critical for a good result if combined with exact material properties (JCA model is the suggested one).

The absorption coefficient can be defined in two different ways, as absorption or as DLF (Damping Loss Factor). Both methods are equivalent and lead to the same result.

The absorption for the cavity can be calculated starting from the components included in the cavity using the Sabine equation.

$$\alpha = \frac{\sum \alpha_i A_i}{\sum A_i}$$

The calculation of an equivalent absorption coefficient can be done for different cavities (main and driver head) including the biggest components surrounding the cavities themselves (a list of used components is shown in Table 4).

Using the Sabine equation and knowing the area and absorption of each component we can calculate the overall value for both cavities.

Driver head cavity		
Side windows	Windshield	Roof / Sunroof
Main cavity		
Floor	Firewall	Glasses
IP	Console	Seats
Doors	Tailgate	Roof / Sunroof

Table 4: Element included in driver head cavity and main cavity for absorption calculation

5. LOADS

After geometry and properties, the last element required for a SEA model are the loads to apply to the model.

Loads are crucial in every model and even more so in SEA modelling. Unlike the geometry and the properties, the loads can't be estimated for a new vehicle based on general information and preliminary knowledge of the model. Loads can be measured in a semi anechoic chamber using a flux source or simulated using BEM method (the most efficient one is the fast multipole BEM).

When measured, the loads are accurate but a physical model is required. Usually a physical vehicle is only available late in the development phase, so waiting for measured loads is not suitable.

Numerical simulation can be performed without a physical vehicle, but with a greater uncertainty in the results. The numerical simulation still requires a full vehicle model of the exterior and is usually derived from CFD. However, this is not normally available in the very early concept phase of vehicle development and this method is not suitable for the purposes of this paper.

To overcome the problem of loads, we can use loads coming from another vehicle. If the loads are defined for a specific vehicle, the hypothesis made is that the major transmission paths are the same for different vehicles.

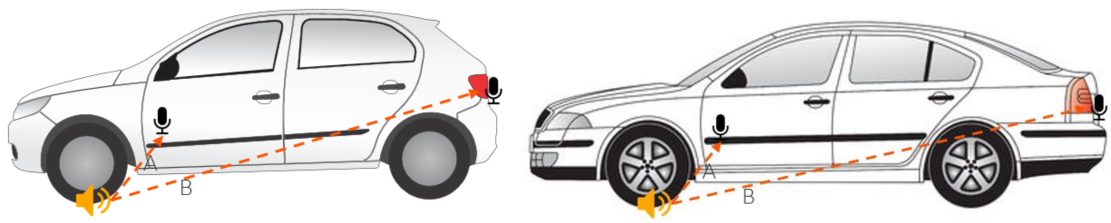

Figure 4: Path comparison for different vehicles

As shown in Figure 4 where the tyre noise is used as a reference. For two different vehicles, the path A is similar in terms of length and geometry and it is also the most relevant path for noise inside the driver head cavity.

Looking at Figure 4, it is also evident that path B is different for the two vehicles. However, path B is less relevant for noise inside cabin when compared to path A and as a result has a negligible effect on the overall resultant noise inside the driver head cavity.

This assumption allows us to define a general load case for each vehicle and a fast way to compare between different vehicles. Of course, there are different ways to define the load case, the simplest one is to define a specific pressure for each surface.

The loads used in this case are measured on a rolling road with PT on and wheels rotating, so the result includes the noise coming from the electric motor and the tyre noise.

6. SEAM MODEL

After defining all the elements required in the model, we can start to develop the model using SEAM.

The model definition phase is critical because having no geometry can be more complex and susceptible to errors.

In the following, the procedure used for model building in SEAM will be shown.

6.1. Introduction to SEAM

SEAM is a software for SEA modelling developed by Cambridge collaborative Inc. One of the benefits of this software is we don't need any geometry to build our model. SEAM, according to SEA general principles, doesn't require an exact geometry for different components. Surfaces (for solid subsystems) and volumes (for cavities) are the only required parameters for geometry definition. Perimeters for solid subsystems and surface areas for cavities can also be provided to increase model accuracy.

For cavities, it is mandatory to provide the DLF since SEAM can't accept the average absorption coefficient for the whole cavity.

6.2. Cavities

The first element we will build in SEAM are the two required cavities. For each cavity, we will provide the volume, the material (Air) and a DLF curve calculated using the Sabine equation. Different combinations of interior elements can be defined and tested using this model by changing the DLF curves for the cavities.

6.3. Structural subsystems

Structural subsystems are defined in terms of area junctions. For the structural subsystem in SEAM we need to define the area (and optionally the perimeter) and the STL. We can provide both parameters in an area junction.

The STL for the subsystems must include the structure contribution plus the NCT one. Since we don't have the real structural subsystem, the structure must be included in the STL curve.

To do this a preliminary assumption about the thickness of the various parts must be made in order to build a correct model.

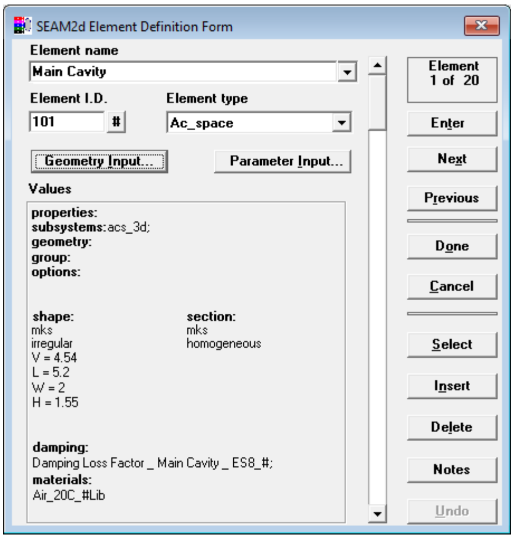

Figure 5: Example of defined cavity in SEAM

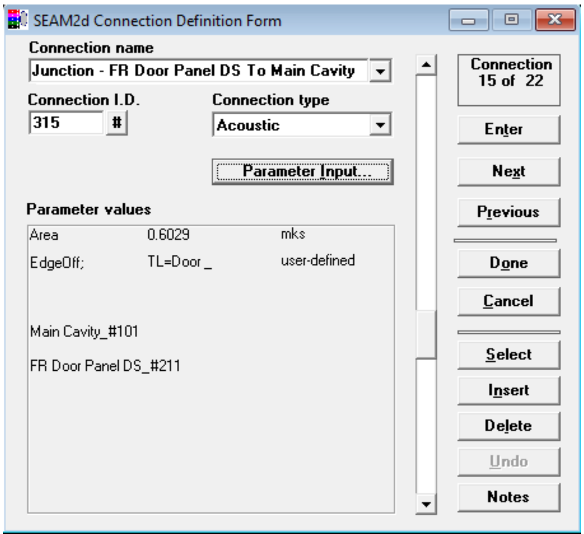

Figure 6: Subsystem defined as junction in SEAM

6.4 Loads in SEAM

The last element to define is the load. The load is defined as SPL applied directly to the specific subsystem.

7. RESULTS

The model built in SEAM can be used to calculate the interior noise if the STL and absorption are known, or by reversing the process, can be used to calculate the STL and absorption for each subsystem if the target noise is defined (target cascading process).

In Figure 8 the result for SEAM model is shown.

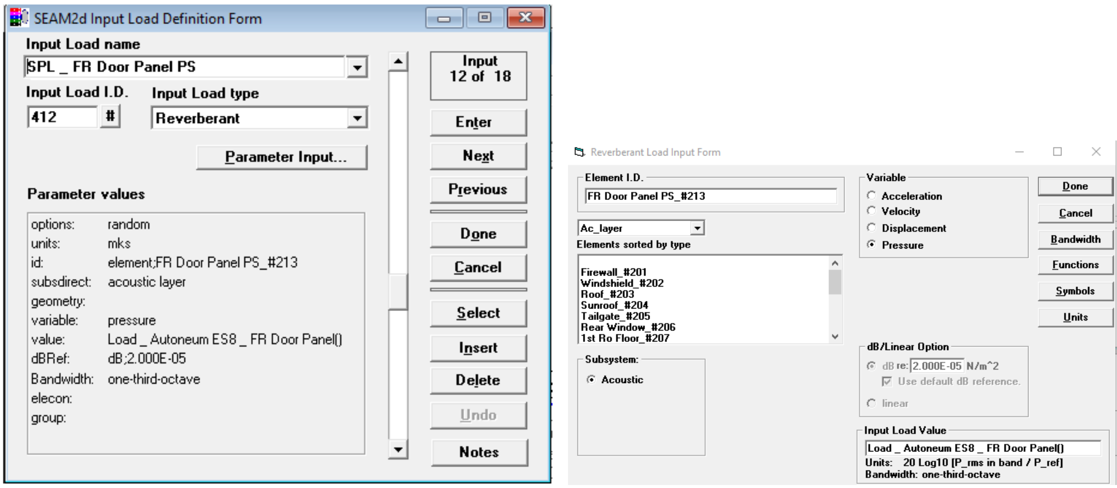

Figure 7: Load definition in SEAM

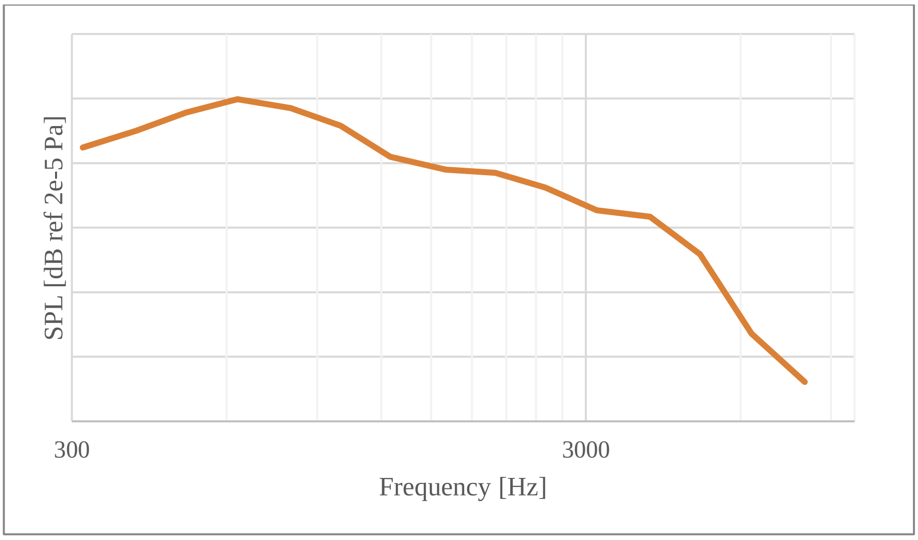

Figure 8: SEAM results for current model

8. MODEL VALIDATION

The model proposed can be used to calculate the noise response in the very preliminary phase when no geometry is available and a complex SEA model would not be feasible.

To ensure the quality of the model developed, a full SEA model has been developed in VAOne to compare the results with the ones provided by the simplified model. The VAOne model has been developed from the TB geometry and accurate cavities to guarantee the reliability of the model itself. VAOne model is constructed using 20 cavities and circa 60 subsystems.

In Figure 9, it is shown the comparison between the SEAM simplified model and the VAOne complex model.

9. CONCLUSION

The simplified model proposed has the advantage of being both easy & quick to create. This simplicity also makes it easy to modify, so different scenarios can be assessed quickly.

The model can also be used for preliminary target cascading of the major subsystems within the vehicle acoustic package. This ensures we can study different components with reciprocal interactions.

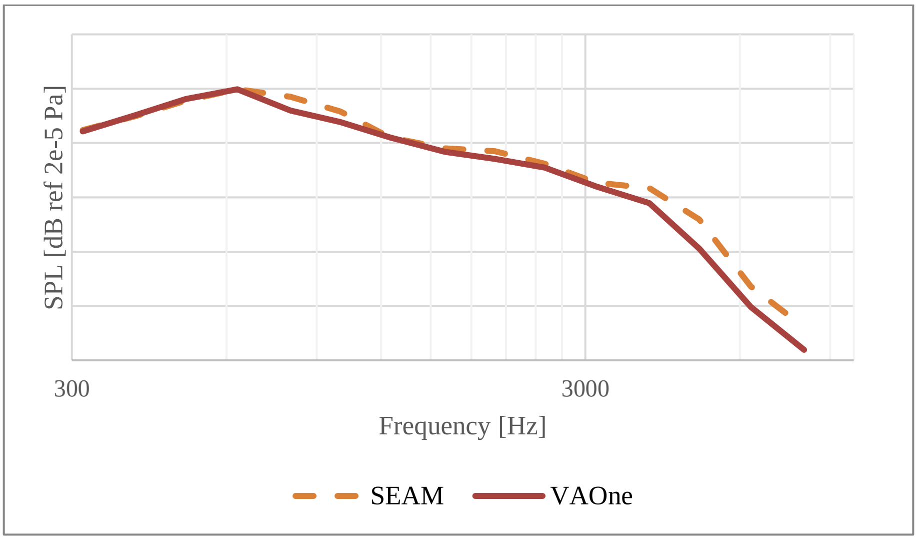

Figure 9: VAOne and SEAM results comparison for SEA model

All of this can be obtained whilst only sacrificing a small amount in terms of results quality and accuracy when compared to the full SEA model (as shown in Figure 9).

On the other hand, the model doesn't consider some crucial elements like pillars, sills and side panels, which if considered together have a relevant surface area. The second aspect not previously mentioned is regarding leaks in the vehicle. For some elements, such as the firewall they can be included in the STL curve. However, it is more complex to consider leaks coming from closures (doors, tailgate).

A special focus must be made on the STL curve, which must contain the structure contribution and not only the NCT one.

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