MADRID
inter.noise 2019
June 16 - 19
NOISE CONTROL FOR A BETTER ENVIRONMENT

Firewall insulation package simulation and noise auralisation for EV's

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ABSTRACT

EV vehicle are now having a great influence on the market, with the number of vehicles sold increasing every year. For the engineer, the introduction of full electric vehicles means new challenges, a change in paradigms and new goals to achieve. One of the new challenges for engineers operating in the EV field is NVH. One of the main components for electric motor noise reduction in an EV vehicle is the firewall treatment. In the following, a method to simulate the firewall behaviour at component level and vehicle level will be discussed. Since the TL is one of the parameters commonly used to evaluate the quality of a treatment, sometimes when talking with designers, this parameter loses a lot of its efficacy. In these cases, auralisation of the noise can give a better idea about the quality of the treatment and the effect on the interior noise.

Keywords: Simulation, Electric Vehicle, Auralisation
I-INCE Classification of Subject Number: 76

1. INTRODUCTION

In recent years NVH has become one of the most relevant criteria in car design. The increasing number of EV's available on the market has also changed the demands on NVH, creating new challenges for engineers.

The increasing importance of NVH in the design process has created a new necessity for the designer to better understand the NVH requirements and results, for better integration into the vehicle development process.

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Traditionally NVH results have been presented graphically, but latest trends are to make these audible.

From a customer point of view the perceived quality of sound is more important than the absolute value.

In parallel with auralisation, a shift in the NVH paradigm is occurring. The subjective noise is more and more relevant and parameters like sound quality, speech clarity and subjective comfort are replacing the SPL and overall noise levels.

Despite all the changes, some components are still critical and are the focus of engineering analyses. One of the components relevant to EV NVH analyses is the firewall.

New electric motors are different from traditional internal combustion engines in terms of noise generation methods, frequencies, type of noise (e.g. deep noise from combustion engines, high pitched from electric motors); despite the differences, electric motors are still one of the major sources of noise in an EV (most current electric motors have an acoustic power of approximately 115 [dB] at maximum speed).

In the following, a method for firewall analysis and noise auralisation will be presented. The purpose, is to help the engineer design and optimize the firewall behaviour and help the designer understand, with the auralisation process, the quality of noise and capture the differences in NVH treatments.

2. FIREWALL NCT

The firewall in an EV as with combustion engine vehicles is a critical element to protect the driver and passengers from noise originating from the front mounted motor. Whilst a contribution to noise reduction comes from motor encapsulation, the firewall is still a major contributor.

In this scenario, a good design of the firewall NCT is key for a quiet EV. The firewall is also critical from a simulation point of view.

The firewall NCT is a large component with a complex layup and variable thickness (on the same firewall the thickness can be in the 5 mm to 35 mm range). Apart from the previously mentioned factors, the firewall is also an open subsystem, with holes for HVAC, steering column, pedals etc. usually being located on the firewall. The hole distribution is not symmetric making the NCT requirements unsymmetrical as well.

All of these parameters make the firewall a complex subsystem in terms of requirements, lay-up, manufacturing, testing and simulation.

2.1 NCT definition

The classic treatment for a firewall is generally made up of two major components; a foam (with a significant thickness) and a felt (low thickness & aesthetically pleasing).

In the following, two different NCT's will be analysed for a firewall. The first one is a EPDM (3 kg/m^2) layer covered by a light weight foam (60 kg/m^3). The second treatment is made by a PUR foam (60 kg/m^3) plus an epoxy felt (1.5 kg/m^2). The first one proposed is a heavy treatment which maximizes the STL and minimizes the absorption. While the second one is a balance of STL & absorption.

Figure 1: Different NCT for firewall; FOAM + EPDM massive treatment (left); FOAM + EPOXY FELT treatment (right).

The two proposed NCT's work in different ways. The first one is designed to increase the STL with a mass – spring behaviour, the EPDM thickness is constant (about 3 mm) and the thickness of foam is maximized according to the available space for packaging.

The second treatment is developed to balance the STL and absorption behaviour, the STL property is given by the mass – spring behaviour while the epoxy felt on top provides a certain amount of absorption. To balance the phenomena, both the thickness of foam and felt are variable and the optimization process is more complex and less intuitive.

For this paper, we can assume EPDM and EPOXY FELT layers have a constant thickness of 3 mm and 5 mm respectively.

The FOAM will be divided into four classes according to the thickness (10 mm / 15 mm / 20 mm / 25 mm) with the following distribution over the surface.

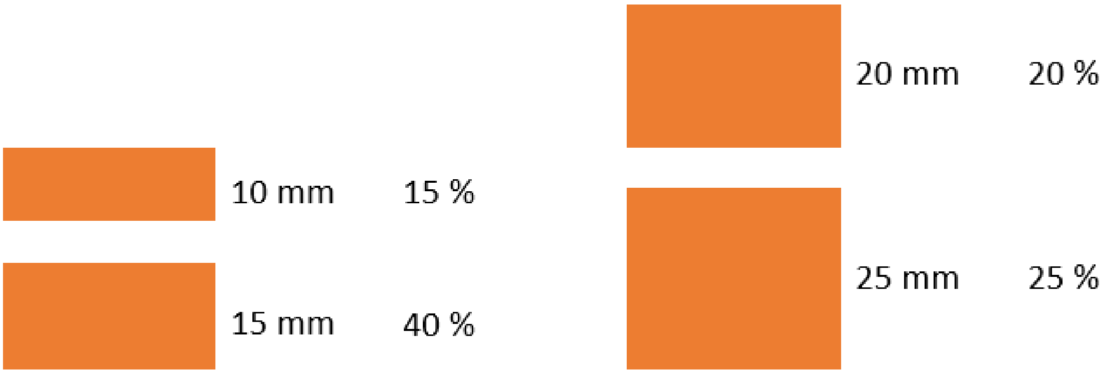

Figure 2: FOAM thickness comparison and percentage distribution over firewall.

3. NUMERICAL SIMULATION

The next step is to simulate the different treatments to capture the differences between them and obtain a comparison between the two different approaches.

To simulate the two different treatments, we will use the TMM method, which can achieve a good accuracy with a relatively short time for modelling. The TMM method uses a set of numerical models to calculate the acoustic impedance using specific material properties. The most common and reliable model is the JCAL (Johnson-Champoux-Allard-Lafarge) for FOAM and EPOXY FELT. EPDM will be simulated as an isotropic material layer.

The TMM method will be used for two reasons; firstly to calculate acoustic properties of NCTs in terms of STL and absorption, and secondly, which is more important for the goal of this paper, is to calculate the real and imaginary parts of acoustic impedance. This parameter will then be used for full vehicle simulation.

3.1 Simulation procedure

The simulation of the NCT acoustic properties will be divided into three steps. The first step is the lay-up definition including the order of the materials, the thickness and the material properties. For the absorption calculation it is important to define the order, with the absorptive layer facing the source. The second step is the simulation for each class of thickness. The last step is the area composition; different thicknesses are combined and weighted according to the coverage percentage.

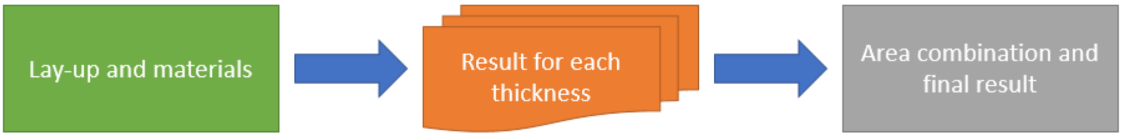

Figure 3: TMM simulation process for different layers.

3.2 AlphaCell model

The simulations have been carried out using AlphaCell, which implements the TMM method.

Every lay-up has been simulated with its own specific properties. The simulation, to be consistent with test (see section 4) was conducted with an incident field over the panel, with an incident angle (θ) limited to 75°.

A correction for finite area was applied using Bonfiglio for both STL and absorption with a panel size of 1x1 metres.

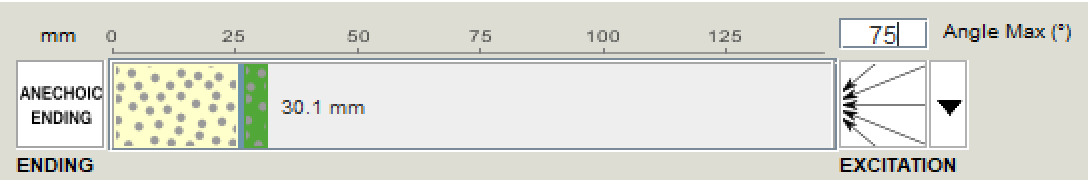

Figure 4: Example of lay-up definition in AlphaCell.

Figure 4 shows the typical AlphaCell lay-up with the ending definition (the anechoic ending was used for STL calculation and rigid ending for the absorption calculation) and the NCT with absorptive layer facing the source. On the right we have the source definition (diffuse field) and a maximum angle of 75°.

The model is a critical point during the development phase. Unlike other simulation methodologies TMM is more sensitive to material properties. Literature provides a huge amount of information regarding the testing of material properties required for TMM modelling.

Another important element in TMM modelling are the boundary conditions combined with the size of samples. TMM is usually used for infinite elements and some corrections must be applied to take in account the finite sizes of the element.

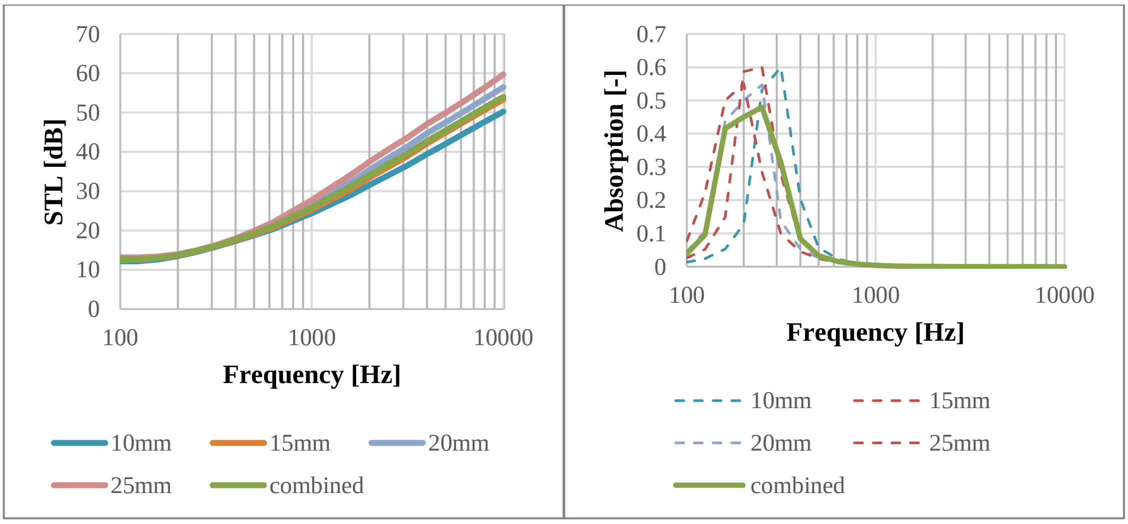

Figure 5: Results for FOAM + EPDM; STL (left), Absorption (right).

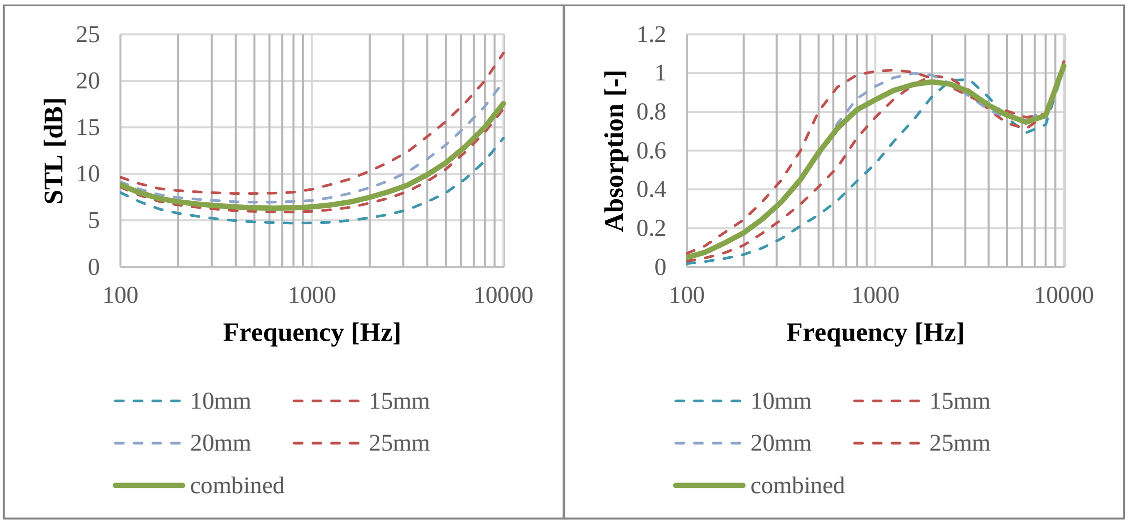

Figure 6: Results for FOAM + EPOXY FELT; STL (left), Absorption (right).

4. TESTING

To validate the results obtained with the numerical model a test was conducted on both NCTs. The tests were performed on full scale samples.

The STL testing was performed on full scale sample in two chambers; The absorption coefficient was measured in the impedance tube.

4.1. STL test

The STL was tested with the two chambers method with the anechoic – reverberant combo. The test was conducted according to the UNI EN ISO 15186 for STL measure.

According to the normative the noise is generated in the reverberant room with a dodecahedral source and measured with a rotating microphone; in anechoic room the sound intensity has been measured with a PP probe and averaged over the surface.

The results obtained from test were compared with numerical results (see Figure 7) showing a good level of correlation.

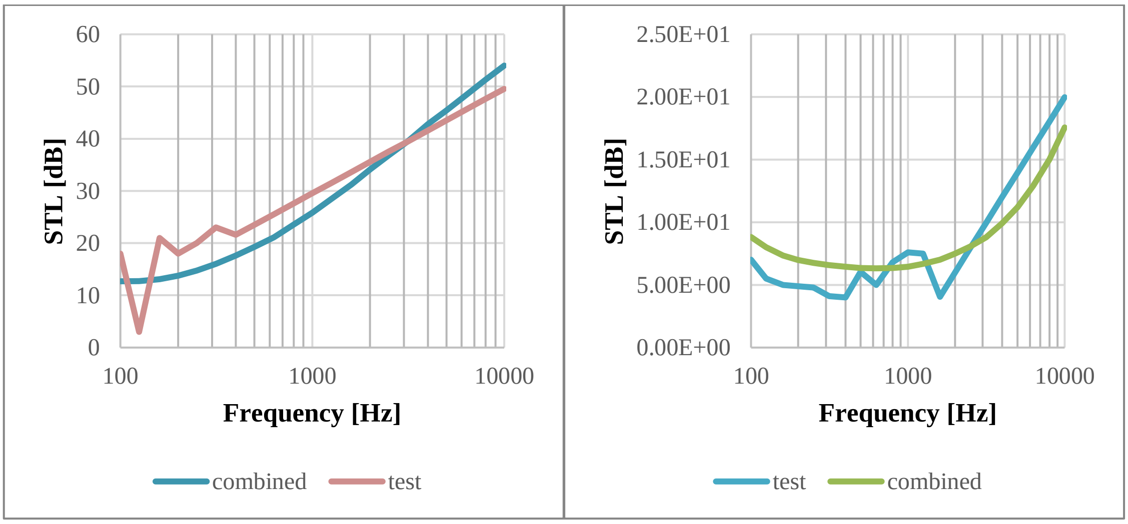

Figure 7: STL comparison. Foam + EPDM (left) and Foam + Felt (right)

4.3.3 Absorption test

The absorption was measured in an impedance (Kundt) tube. This technique provides a good result quality with a relative simple set-up and short test time.

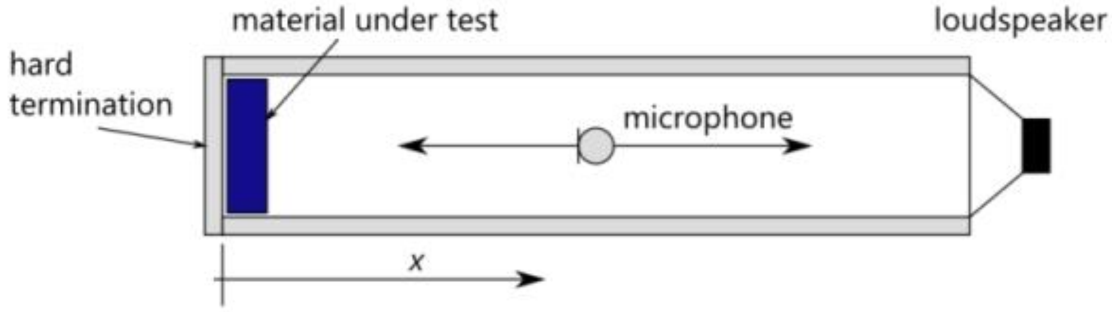

Figure 8: Kundt tube set-up for absorption measurements

The material, in Kundt tube is placed on one end of the tube, while the source is placed on the opposite end. The absorption is then measured with two microphones.

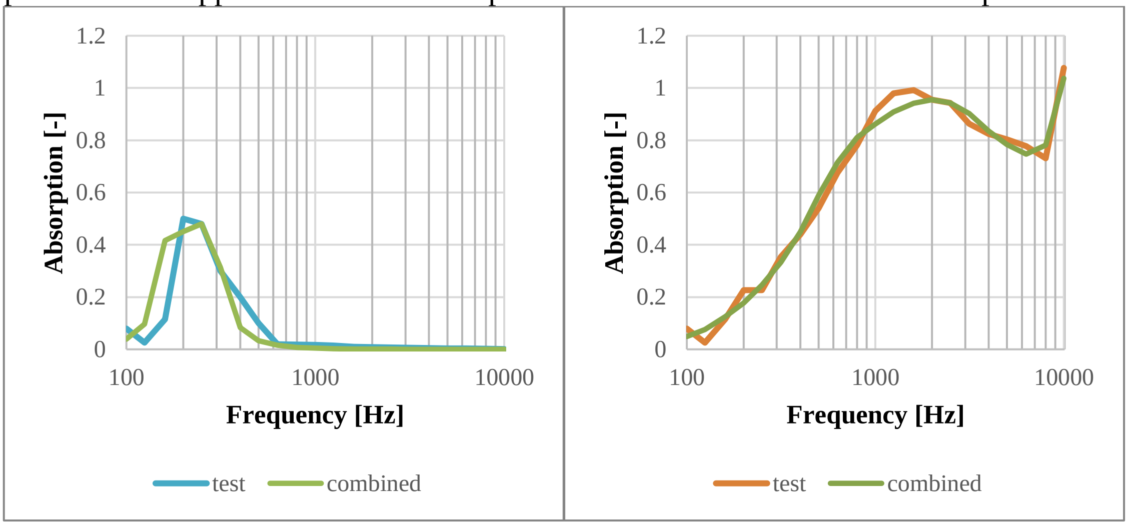

Figure 9: Absorption comparison. Foam + EPDM (left) and Foam + Felt (right)

5. FULL VEHICLE SIMULATION

When the NCT has been defined we can move onto the next step, the full vehicle model simulation. The purpose of this step is to calculate the transfer function from the motor to the driver head position. The transfer function is required for the last step, the auralisation.

For full vehicle simulation we will use OptiStruct as a solver to run a frequency response analysis. Using a TB model, we can apply unary excitation in the engine bay cavity to simulate the input noise of the motor and read the output SPL in the driver head position.

The TB structural model will be coupled with an air cavity model inside the vehicle using an ACMODL card. The engine bay cavity was also modelled and added to the TB. This cavity will be loaded with a unary excitation at the COG of the motor. The motor noise propagates in the engine bay cavity hitting the firewall, and the noise is transmitted through the firewall into the vehicle cavity. To simulate the motor noise source an ACSRCE card was used. It can be defined providing the input node(s) for the pressure and the value of pressure versus frequency. Optionally a phase delay can be provided.

Figure 10 shows the TB configuration used for the analysis, where the structure surrounds the engine bay cavity and the vehicle cavity.

In the vehicle cavity a few small cavities have been defined; Seats have been included in a different set of cavities with different properties. Ears of the driver and passengers have been isolated for output purposes but are connected with the main vehicle cavity (coincident nodes interface) and have the same property.

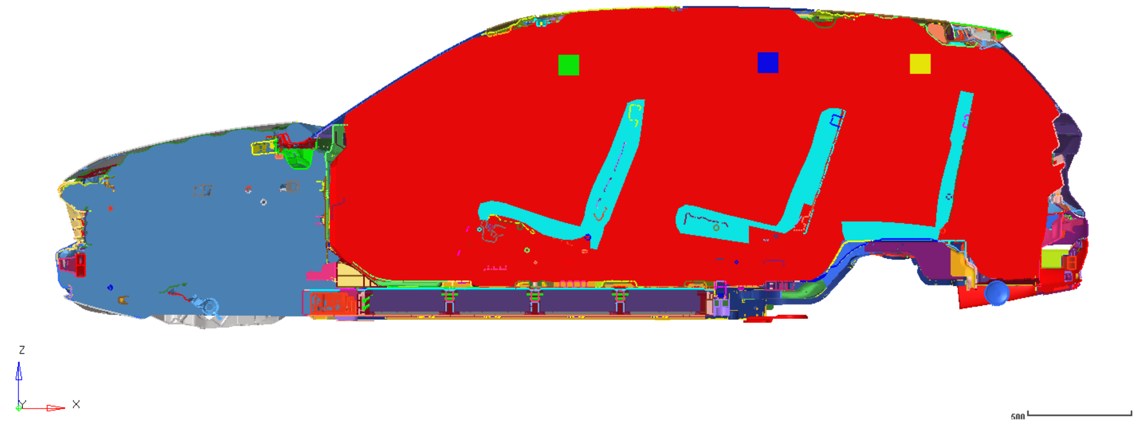

Figure 10: TB side view section

Due to the model complexity the analysis was limited to low frequency range (up to 2500 Hz). To reduce the computational cost, the number of points chosen during the analysis was limited to 5 per third octave band since we need an output in third octave bands to auralise the noise.

The solution used was the MFREQ which calculates the frequency response based on a normal modes analysis (EIGRA card). It’s faster than DFREQ solution (directly calculate response inverting stiffness, mass and damping matrices) with a small loss of accuracy.

5.1. NCT simulation

The NCT will be simulated using CAABSF element. These elements require the acoustic impedance which can be calculated with AlphaCell or measured with a Kundt tube. The real and imaginary parts of the acoustic impedance for both treatments are shown in Figure 11 and Figure 12.

The acoustic impedance can be defined in OptiStruct using the PAABSF property. The property requires the real and imaginary part of the impedance to be defined as separate TABLED1 entries. To complete the property definition, the static stiffness is also required and the ρc, where ρ is the density and c the speed of sound, must be defined for the cavity attached to the CAABSF elements assigned to PAABSF property.

5.2. Results

TB model was run using parameters defined previously in three different configurations. The first one is with bare firewall; the second and third respectively with first and second NCT.

The requested output was the SPL in driver head cavity. The output was requested not in a single point but over a small volume enveloping the driver head positions and then averaged to provide a single response curve. The curve obtained was translated into third octave curve.

Results of TB model are shown in Figure 14.

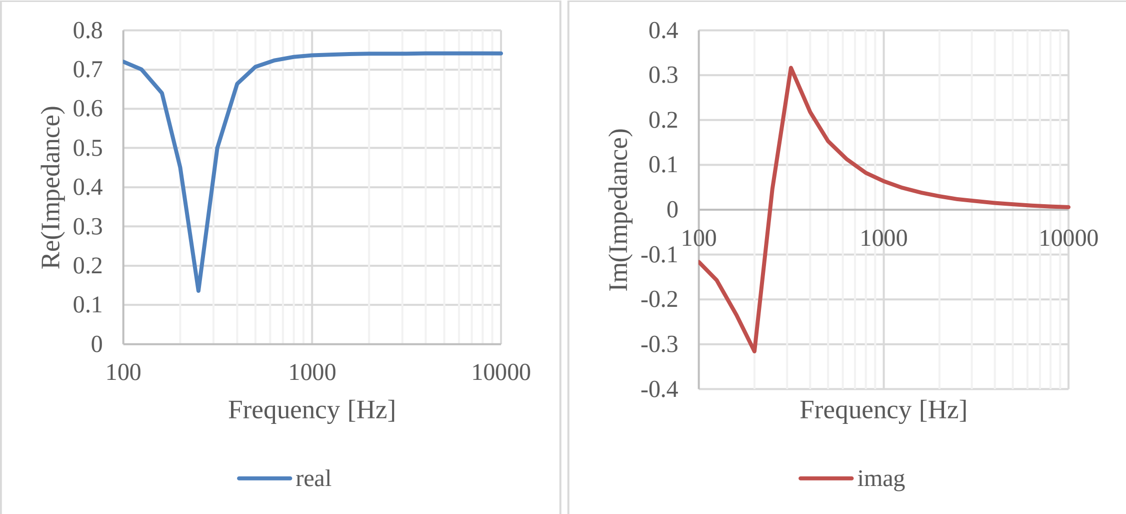

Figure 11: Real and imaginary part of acoustic impedance. Foam + EPDM.

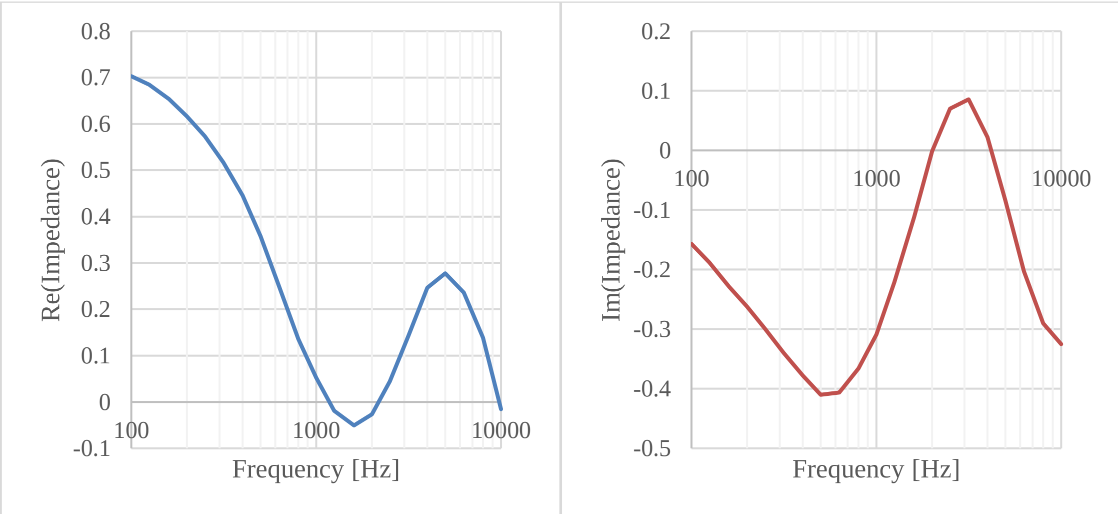

Figure 12: Real and imaginary part acoustic impedance. Foam + Felt.

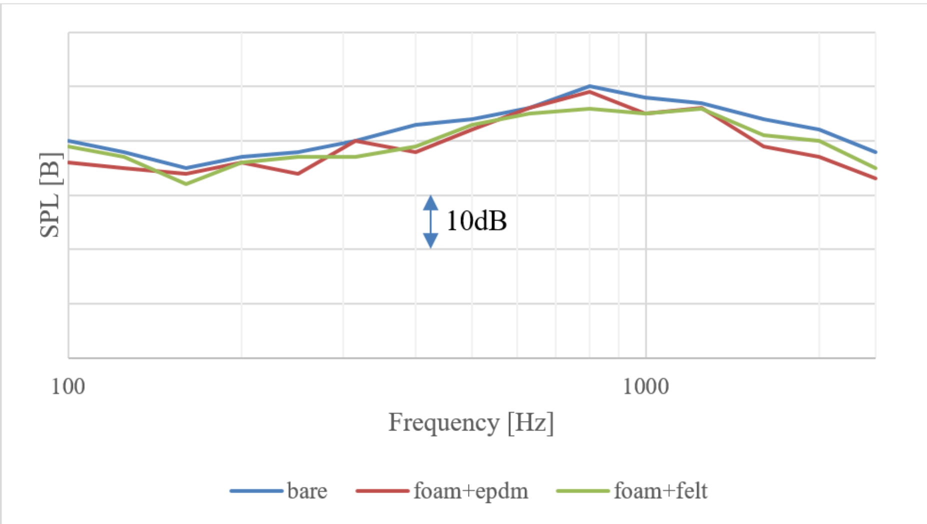

Figure 13: TB model results

6. AURALISATION

The last step to perform is the auralisation process, to make the noise audible. This can be performed in AlphaCell using the convolution method.

The auralisation process is not a complex operation, but has high computational cost and the complexity of convolution integral resolution makes it hard to perform and not easy to implement.

To perform auralisation in AlphaCell we need three different input data: two of them, the input noise source wave file and the transfer function between source and receiver, are mandatory but the third one, the IIR of the receiving environment is optional.

The noise source was registered directly on board of vehicle using a microphone placed close to the motor in the engine bay during a ramp-up acceleration. The transfer function between source and receiver point can be calculated according to results of section 5.2 and can be defined as the delta between the output SPL and input SPL. The one specific for our model is shown in Figure 14.

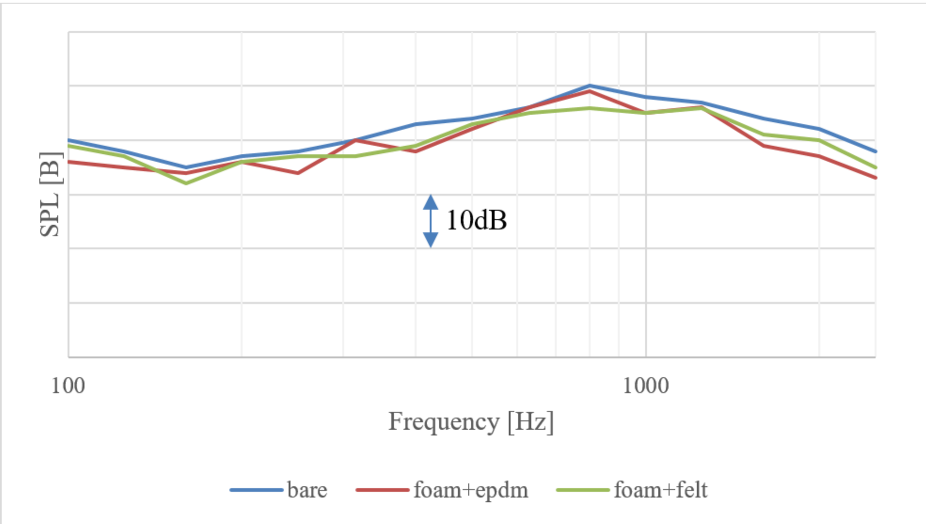

Figure 14: Transfer function from motor to driver head

The last parameter, the IIR of the receiving environment is optional and will not be used in this case. Since AlphaCell itself provides a simple way to evaluate the IIR for a cavity the proposed method is valid for large volume cavities. Standard vehicle cavity volume is in the range of 1.5 to 3 m^3 and is far away from the one proposed by AlphaCell (39m^3 and 411m^3). To avoid any error or unexpected behaviour due to this volume discrepancy the IIR of the cavity will be neglected.

Figure 15 shows the AlphaCell auralisation panel. From left to right, we can input the noise source file, the file with the transfer function and the cavity IIR file.

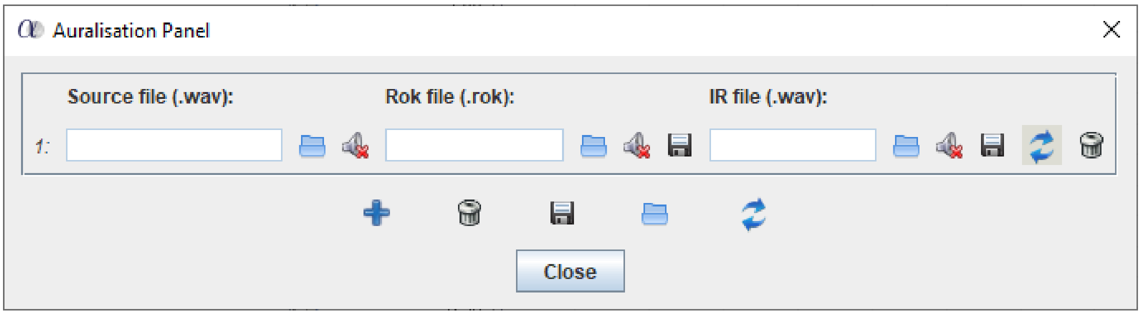

Figure 15: AlphaCell auralisation panel.

The output of the auralisation process is an audible file. From acoustic point of view the difference between the two files is clear and can be appreciated.

7. CONCLUSIONS

The aim of this study was based on two aspects; in the first part a method for firewall NCT simulation was proposed using AlphaCell and validated using test data. In the second part the data coming from the AlphaCell simulation, the acoustic impedance, was used to calculate the transfer function from source to receiver in the TB model and then used for noise auralisation.

The first part shows a good correlation between the numerical and experimental data, providing a reliable method for NCT simulation. The second part provides a way to hear the noise and also the differences between different treatments. Providing a useful tool for designers and engineers to drive the acoustic package development.

The work proposed in this paper is still on going with the need to increase the accuracy and reliability of the model. This will be done in two ways, the first one is the IIR simulation for small volume cavities to include this parameter in auralisation process; the second one is the introduction of all NCT inside the vehicle (floor, door trims, headliner, etc.) to increase the accuracy of the transfer function.

8. REFERENCES

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