



RENAULT Smart Cocoon Technology vibro-acoustic simulation

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ABSTRACT

RENAULT was the first OEM to introduce mass production Battery Electric Vehicles in Europe with the ZOE in 2012. With the new MEGANE ETECH, RENAULT set the NVH comfort to higher level to match the customer expectation on BEV vehicles. One of the components of the silence of MEGANE is the “Smart Cocoon Technology”, a technology that transforms the battery into an acoustically active element. This innovative solution has been developed to integrate the battery mass in the Transmission Loss. It has drastically improved the floor transparency and damping, thanks to an insulation foam embedded between the body floor and the battery casing.

To support the development of this technology, RENAULT and its CAE partner DASSAULT SYSTEMES are developing simulation methodologies to predict the behavior of the smart cocoon technology on the whole vehicle NVH performance, optimize the performance and weight of the insulation package, and to secure the assembly process. This paper presents in detail each step of this CAE process to assess the NVH performance of the “Smart Cocoon Technology”. Finally, to validate the accuracy of this process, CAE results will be compared with the test measurement from the MEGANE prototype

1. INTRODUCTION

With the development of electrical vehicles, OEMs (Original Equipment Manufacturers) are focusing their R&D resources and investments in the developments of new technologies to improve the quality and comfort of products. One of the keys is to take benefits from the specificity of Battery Electric Vehicles thanks to new concepts and designs, which could drastically change EVs architecture as conceived today. Such changes also translate into new constraints, new functional requirements, and material specifications for other systems or components. From an NVH perspective, for example, the battery mass has a potentially great acoustic benefit for the interior compartment.

For the development of the New Megane Etech RENAULT has developed and patented a technology called “Smart Cocoon” that consist in a layer of highly damped foam placed between the battery top cover and the whole surface of the central floor (Figure 1). Its gains can be felt from 30 km/h. The foam creates a cocoon effect in the passenger compartment worthy of premium vehicles in the benefits of the silence of the passenger compartment, music or passenger discussion. In addition, the “Cocoon Effect Technology” has the advantage of improving lightness. It saves 3 kilos compared to a traditional acoustic insulation solution.

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Figure 1: RENAULT Megane Etech – Smart Cocoon Technology

However, anticipate this benefit is critical to guarantee the most pleasant NVH experience for passengers. Then CAE is key to assess the benefits of the foam. DASSAULT SYSTEMES wave6 software [1] is used at RENAULT to simulate the energy propagation in soft trims for different compression ratio, as well as the structure-borne response and the air-borne insulation effect in the vehicle from low to high frequencies. This paper will present the simulation procedure and the main results of the effect of the “Smart Cocoon” foam.

2. VIBRO-ACOUSTIC MODEL

2.1. Overview of the model

The addition of the compressed foam between the floor and the cover has an effect on the noise inside the vehicle cavity. In order to assess the effect of the foam on the NVH performances, a vibro-acoustic model is built using the commercial software wave6 [1]. The full vehicle is initially modelled using finite elements (FE) (see Figure 2a). A subset including only the battery cover, the vehicle’s floor and the cavity is then extracted, in order to study simpler configurations (see Figure 2b).

The floor is clamped at the position of the weld spots used to connect it to the rest of the car body, while the battery cover is clamped at screw’s holes. Two configurations are analyzed: a first one with an air-gap between the floor and the battery’s cover (initial configuration), and a second one with a block of foam placed in the air gap (Cocoon configuration).

The foam and the air-gap meshes are generated in wave6 starting from the geometries of the floor’s base and the cover surface. A PEM (poro-elastic model) subsystem using the Biot’s model [2] is used to represent the foam. First, a polyurethane foam is used, then a comparison with a different foam materials is proposed.

2.2. Loads

Since the true loads are not yet known (they will be measured during a campaign that is planned before the conference), two different load types are considered. First, a diffuse acoustic field (DAF) is applied below the battery cover. Then, two point forces are applied close to the floor's reinforcements on the engine side of the vehicle. Both loads are random with a constant amplitude spectrum in the whole frequency domain. The authors estimate these type of loads are representative of the ones present on the real car, although normalized and not frequency dependent.

2.3. Calculation of the Thickness Map of the Foam

In the real vehicle, the foam is mounted on the cover and then compressed during the mounting of the floor. The compression of the foam can then locally reach high rates, with a non-negligible modification of the foam's physical properties. For this reason, a spatial modifier is used to account for the local change of properties of the foam. This is handled directly within the wave6 model as explained below.

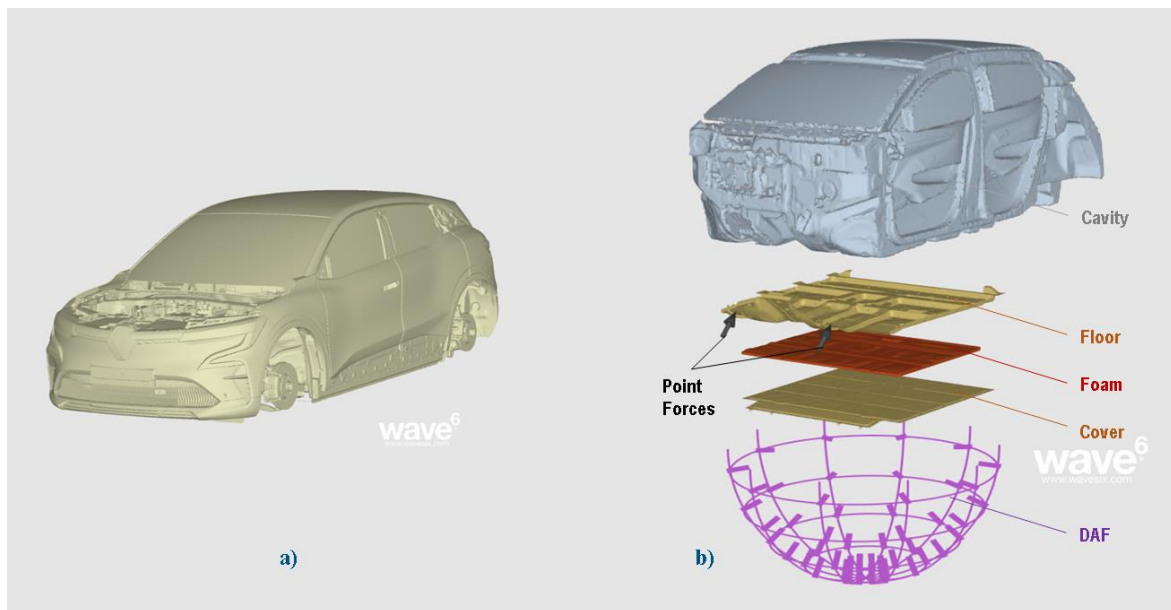


Figure 2: Finite Element Model : a) Full vehicle; b) Subset: Cavity, Floor, Foam, Cover and Loads (Acoustic: Diffuse Acoustic Field; Structural: Point Forces)

The thickness map of the foam is calculated directly in wave6 using the floor and the cover as physical boundaries (see Figure 3). The local thickness is then known at every location of the foam. The local physical properties of the foam is then calculated using a method described for example in [3], and is assigned locally to the foam's finite element group via the spatial modifiers in wave6. In other words, the foam's properties, are adapted locally following the compression ratio of the foam (which was calculated at the previous step). The foam modeled has spatially-varying physical properties.

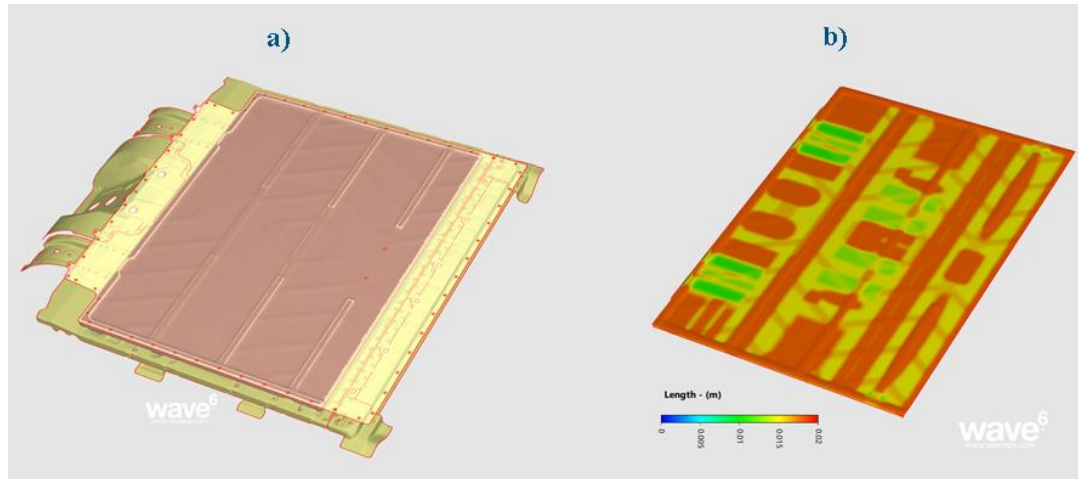


Figure 3: Calculation of the compression ratio of the foam: a) Foam Geometry morphed between the Floor and the battery Cover; b) Thickness map of the foam calculated in wave6

2.4. Coupling Subsystems: Junctions

The FE subsystems are coupled via junctions in wave6. The junctions are created automatically between non-compatible meshes, which facilitates the handling of complex or imperfect geometries. An example is shown in Figure 4, where the junction between the vehicle's cavity and the floor is created with a given tolerance. Similarly, junctions are created between the cover and the foam, between the foam and the floor and between the loads and the structural components: area junction for the coupling with the DAF, point junction for the coupling with point forces.

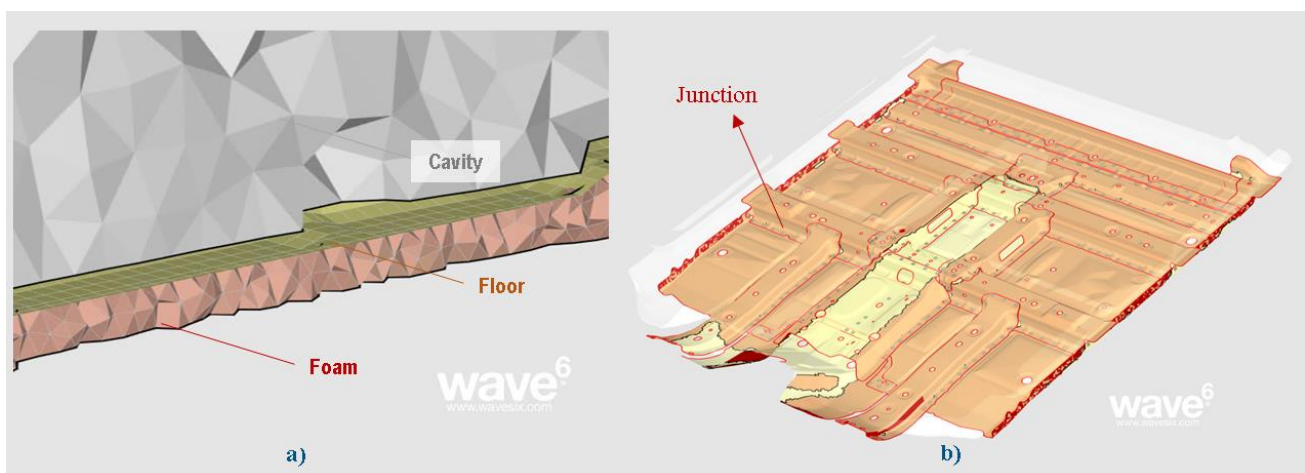


Figure 4: Junctions between subsystems: a) Non-compatible mesh between Floor and Cavity Subsystem (scaled view); b) Junction created in wave6

In the configuration including the foam, the boundary conditions at the junctions between the foam and the structural components (floor and battery cover) involve all degrees of freedom. Different boundary conditions can be set in the junction properties in wave6 and do not require the addition of a layer of air elements to mimic the sliding boundary condition.

3. RESULTS

The FE-PEM model is solved in wave6 using a random analysis type with a uniform frequency step in the band 100Hz - 2000 Hz. The results are then converted to RMS values in 1/3 octave bands using the convert operation in wave6.

The results for the two configurations (with air-gap and with compressed foam) are compared based on skin velocity, acoustic pressure and power levels on the vehicle's floor, battery cover and cavity. The trends are not the same for the airborne and for the structure-borne load types.

Obviously, additional damping on the vehicle's floor is observed when adding the foam, and the following results will aim at estimating the added damping ratio of the floor.

3.1. Velocity and Pressure maps

A first comparison between the two configurations is shown Figures 5 and 6, for an acoustic load (DAF) and in the 250 Hz centered frequency bands. The foam material considered in this section is polyurethane with a relatively high solid density ($\sim 800\text{kg/m}^3$).

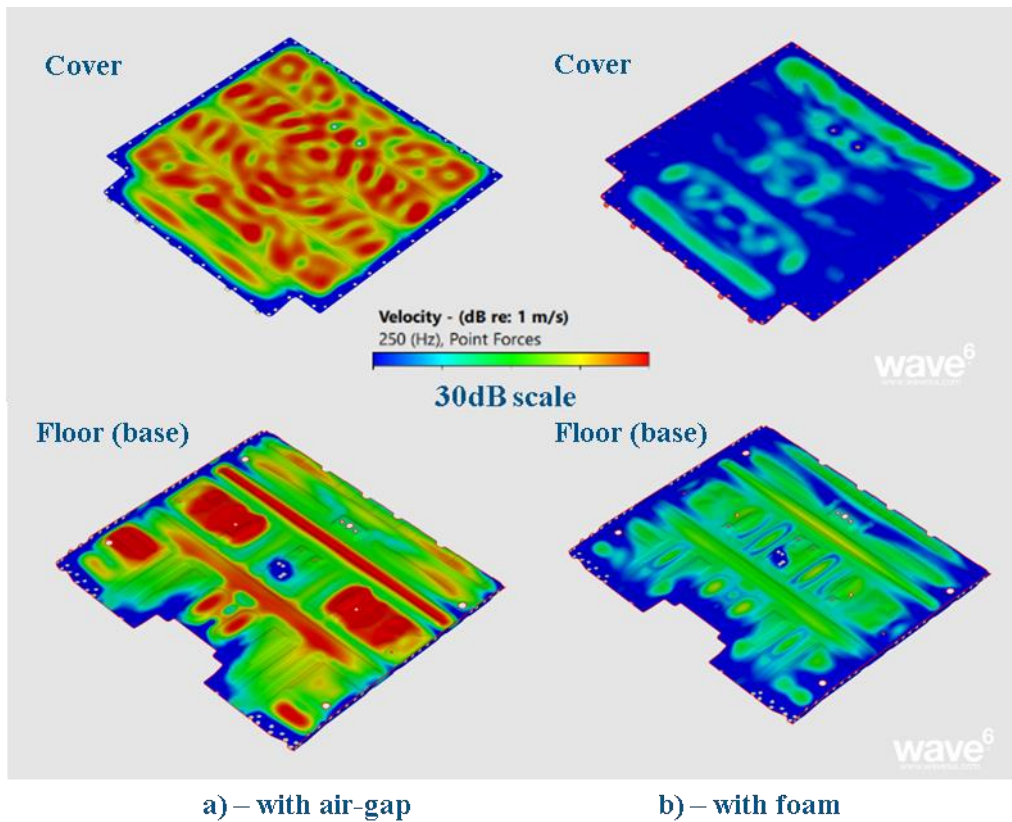


Figure 5: 2D Velocity RMS map (250Hz centered band in 1/3 Octaves): a) Configuration with air-gap; b) Configuration including compressed foam. Acoustic Load applied.

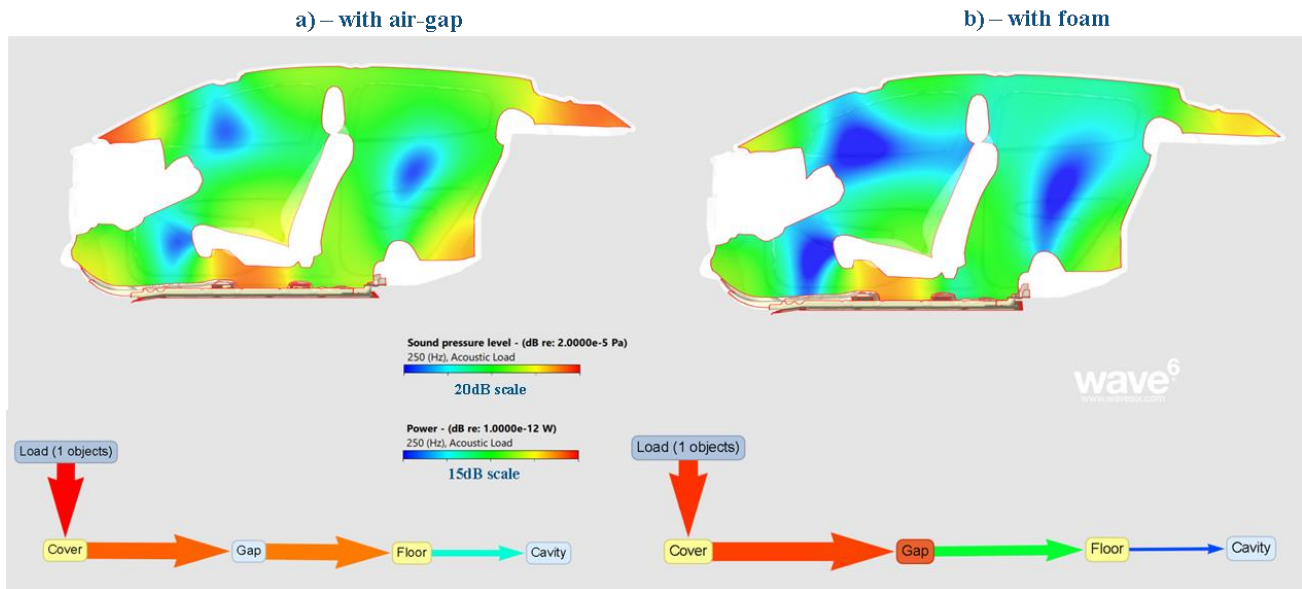


Figure 6: 2D Pressure RMS map and Network diagrams for the acoustic load (250Hz centered band in 1/3 Octaves): a) Configuration with air-gap; b) Configuration including compressed foam.

First, Figure 5 highlights how the vibration velocity of the cover (excited subsystem for this load case) is strongly reduced, resulting in an equivalent reduction of amplitude on the floor's base. Figure 6 shows a consequence of this vibration reduction: the pressure levels (also band-averaged) resulting in the cavity are reduced by ~3 to ~5 dB at every location.

The network diagrams (Figure 6 bottom), directly produced by wave6, show the net exchange of energy between the FE subsystems. In this case there is only one path but this tool can be very useful in case there are different paths in the system. The diagrams clearly show the effect of the foam in the transmission path, the energy transmitted to the floor subsystem is significantly reduced.

Figures 7 and 8 show the same results but with the structural load applied instead of the acoustic load. While the spatial distributions change compared to the acoustic load case, the same comments apply. The vibrational velocity of the floor (excited subsystem for this load case) and the battery cover is reduced, as well as the SPL in the cavity. The network diagrams show, however, a different net exchange of energy between subsystems. This specific foam seems to perform as an absorber of energy from the floor: indeed, more energy is transferred to the foam than to the air gap. This results in less energy being transferred to the cavity, thus reducing SPL levels in the cavity. The way the acoustic pressure reduction is achieved is thus different for the structural load than for the acoustic load.

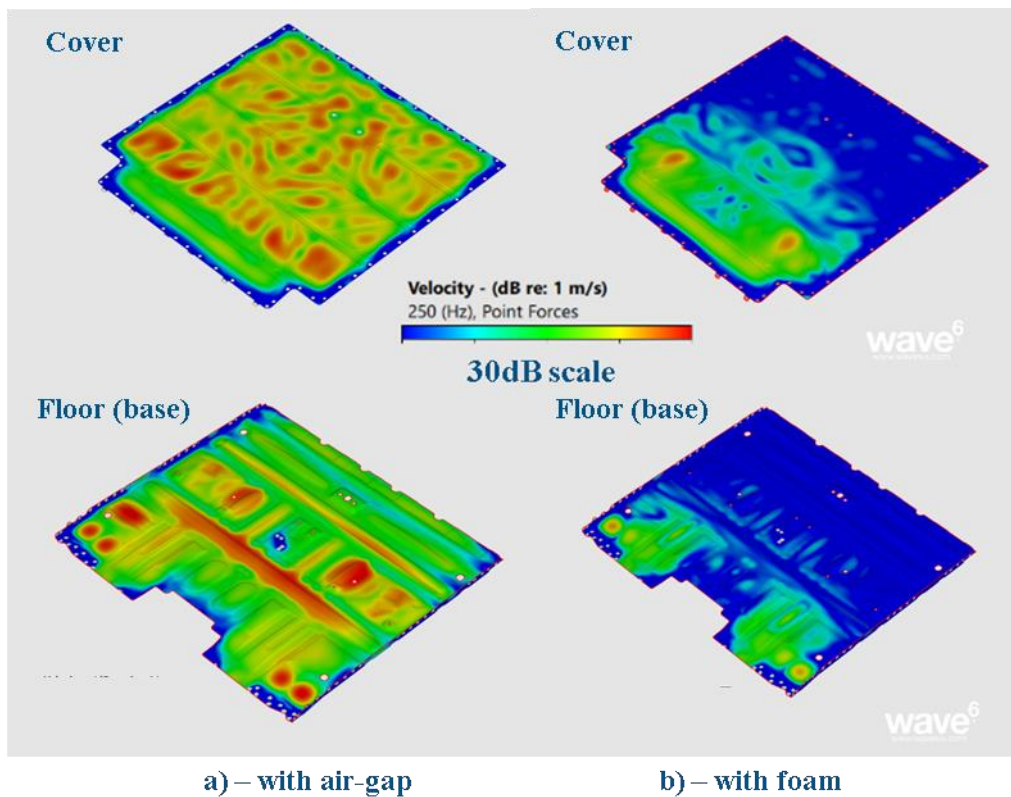


Figure 7: 2D Velocity RMS map (250Hz centered band in 1/3 Octaves): a) Configuration with air-gap; b) Configuration including compressed foam. Structural Load applied.

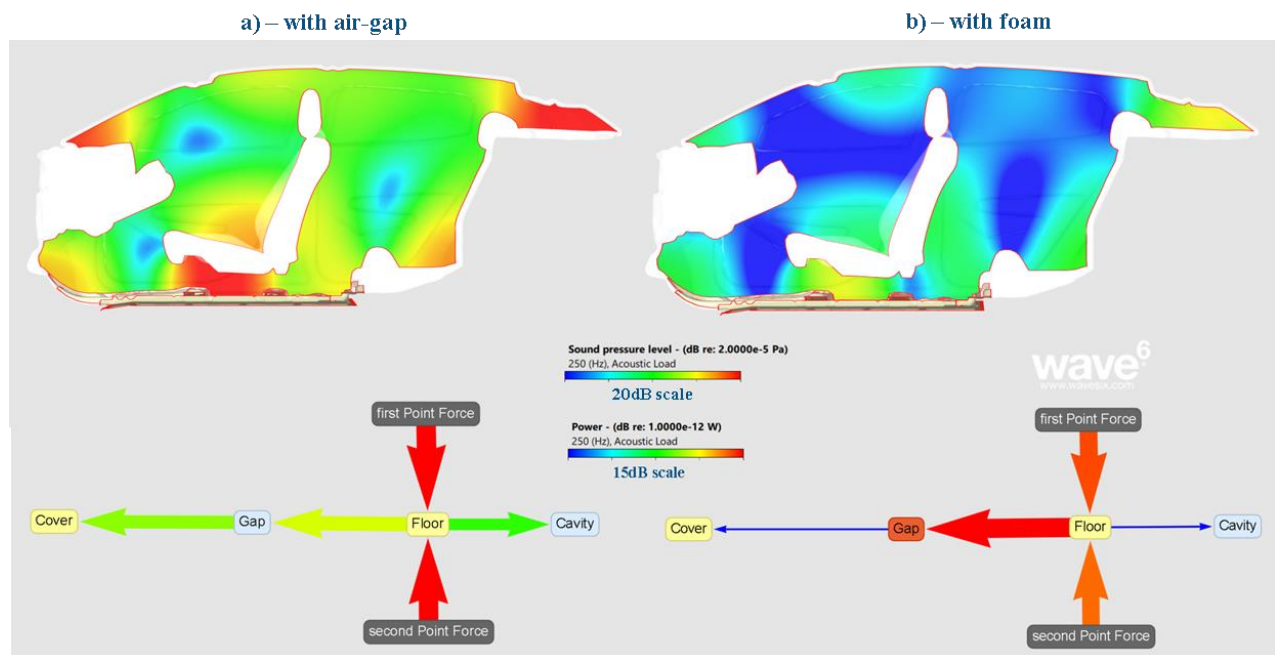


Figure 8: 2D Pressure RMS map and Network diagrams (250Hz centered band in 1/3 Octaves) for the structural load: a) Configuration with air-gap; b) Configuration including compressed foam.

3.2. Power, Velocity and Pressure spectra

For each normalized load and for the configurations with and without foam, the power received in the cavity (“input power”) is calculated (Figure 9). It can be observed how the addition of the compressed polyurethane foam strongly reduces the power, especially at low frequencies (<400 Hz), for both load cases (acoustic load and structural load).

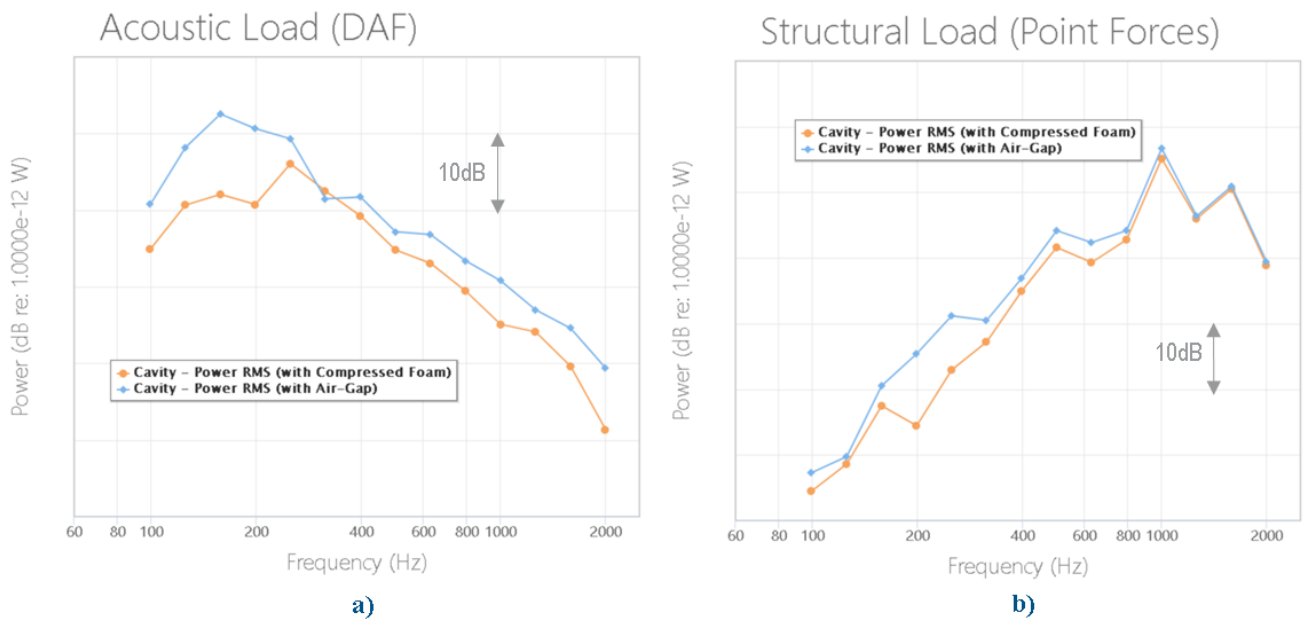


Figure 9: Power Input spectrum in the vehicle cavity (RMS values in 1/3 Octaves): a) Acoustic Load; b) Structural Load.

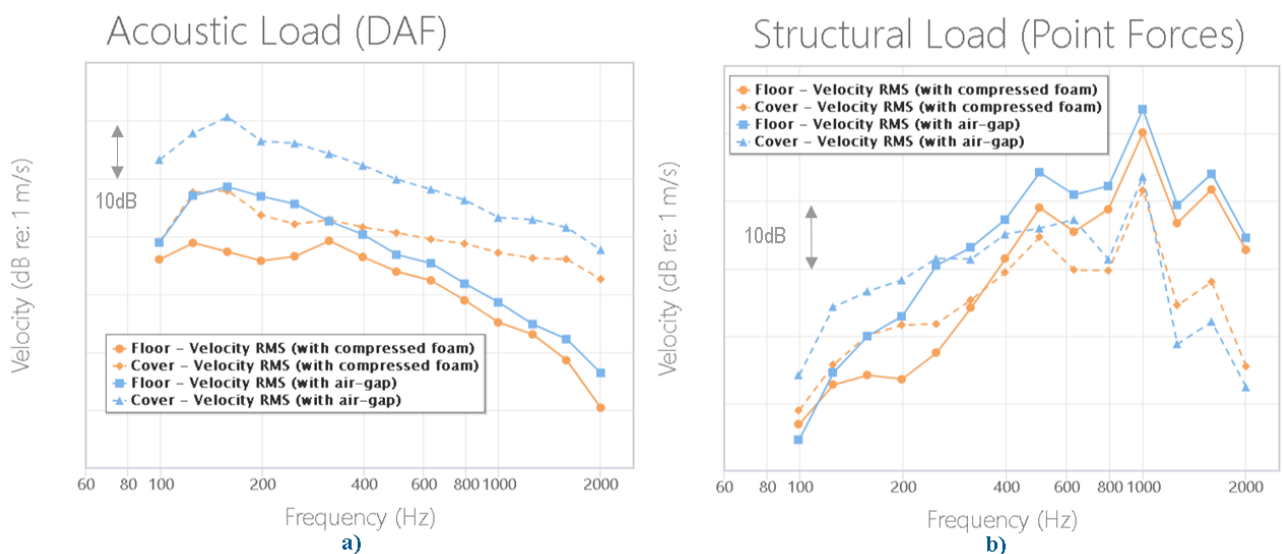


Figure 10: Space averaged velocity spectrum in the on the battery cover and the floor (RMS values in 1/3 Octaves): a) Acoustic Load; b) Structural Load.

With structural loads, this reduction tends to zero at high frequencies, while it is still present for acoustic load. However, it must be noted that the floor itself is excited in the case of structural loads and is directly adjacent to the cavity.

The presence of the foam also affects the space averaged velocity spectra of the battery cover and the floor. The figure 10 shows a strong reduction of vibrational level across the full frequency range regardless of the load cases. At low frequencies, the vibrational velocity can drop by more than 10dB, resulting in less energy being transferred to the cavity. For example, the pressure at the passenger's ear Figure 11 shows exactly the same trends observed for the injected power in the cavity, with SPL reduction peaks of ~20dB_A.

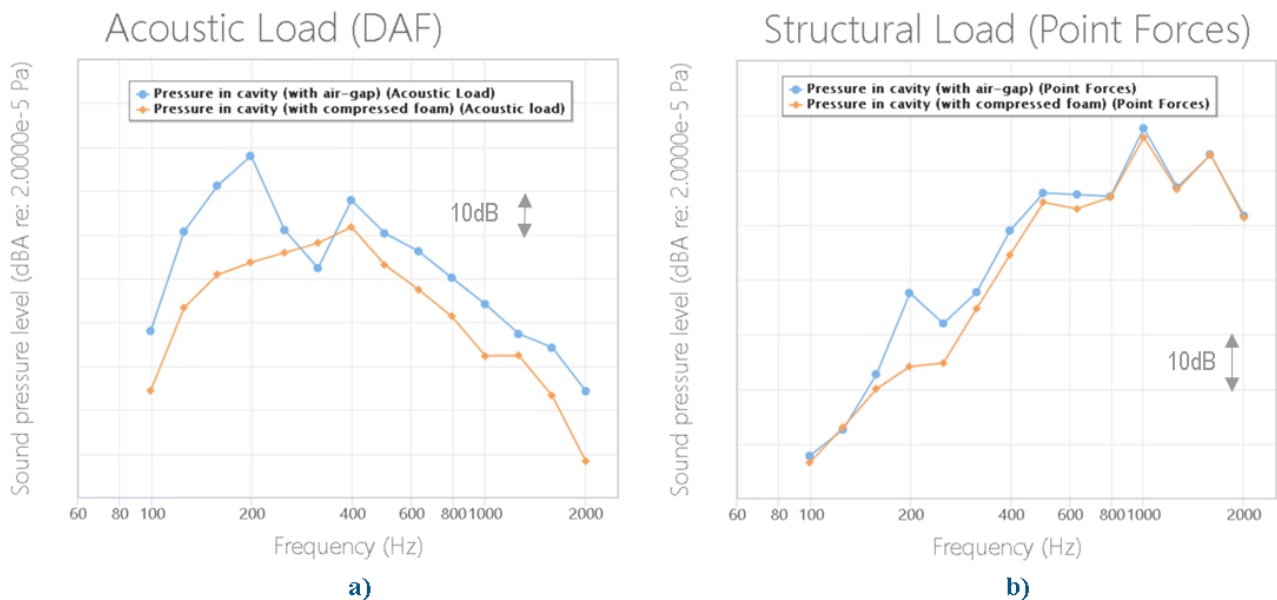


Figure 11: Pressure at driver's ear in dBA (RMS values in 1/3 Octaves): a) Acoustic Load; b) Structural Load.

3.3. Effect of the foam material properties

The foam material plays an important role in the performance of the optimized configurations. In addition to the PU foam used in the simulations shown in the previous section, it is here considered an additional SDF foam material (provided by Treves Group) and a standard melamine foam. While the material properties of the foams cannot be presented here for sake of confidentiality the table 1 show the relative order of magnitude of the foams used in the model.

The power input spectrum in the cavity for an airborne source (Figure 12) shows an increased drop of power for the configuration with the SDF foam material. On the other hand, the configuration with melamine foam shows a benefit only for the lowest frequency bands, while inducing a higher power input in the vehicle cavity above 300-400Hz.

	Melamine	PU foam	SDF foam
Solid density	1	~80	~5
Solid Young modulus	1	~0.6	~0.1
Solid Poisson's ratio	1	~0.5	~0.75
Solid DLF	1	~1	~2
Flow resistivity	1	~3	~5
Porosity	1	~0.93	~0.95
Tortuosity	1	~1.4	~1.9
Viscous length	1	~0.1	~0.2
Thermal length	1	~0.1	~0.05

Table 1: Relative Biot parameters of the foam used in the model

In the case of the melamine, an additional configuration with an uncompressed uniform foam is studied to highlight the effect of the non-uniform compression ratio (Figure 12). While the effects of the compression are negligible at low frequencies, they tend to be impactful above 300Hz.

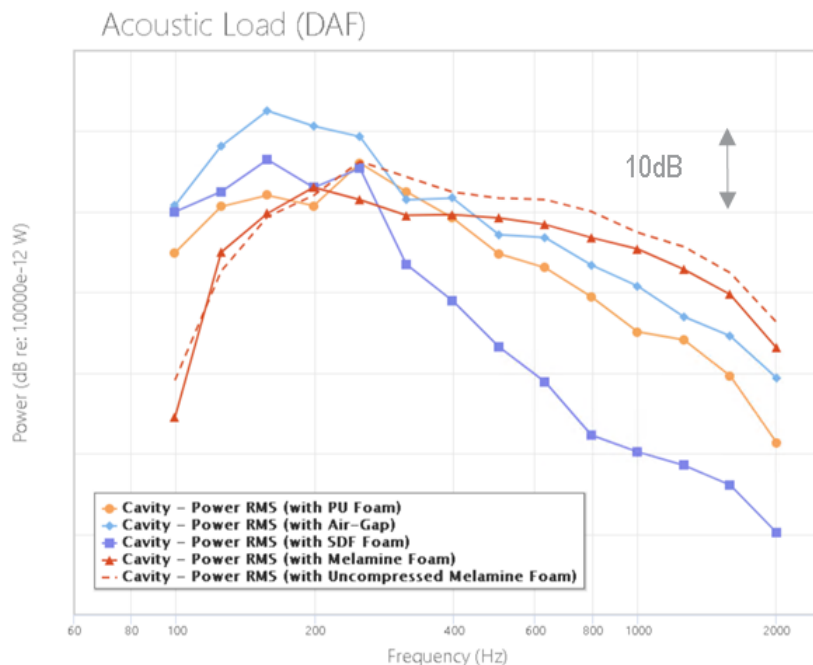


Figure 12: Power Input spectrum in the vehicle cavity (RMS values in 1/3 Octaves). Acoustic Load applied.

3.4 Additional damping on the vehicle floor

One of the reasons why the configuration including the foam between the battery cover and the floor is more performing (less energy transferred to the vehicle cavity, thus more acoustic comfort), is that the presence of the foam add effective damping in the structure. This additional damping of the floor can be estimated using the energy calculated in the floor subsystem for each configuration. The energy is one of the possible results of a FE subsystem in wave6. In particular the damping ratio between the two configurations is estimated using Equation 1:

$$\frac{\eta_{(\text{with foam})}}{\eta_{(\text{with air})}} = \frac{E_{(\text{with foam})}}{E_{(\text{with air})}} \quad (1)$$

where η is the damping factor of the subsystem (here the floor), E is the energy calculated in the subsystem.

The estimation is performed only with structural loads to estimate the fully resonant transmission within the assembly, instead of using the acoustic load which induced a mixes resonant and non-resonant transmission. Figure 13 shows the damping ratio of the floor between the two configurations, for both PU and SDF foam materials. As observed previously for the input power in the cavity, the strongest effects are observed at low frequencies (<400 Hz) while the damping ratio gradually tends to 1 for higher frequencies.

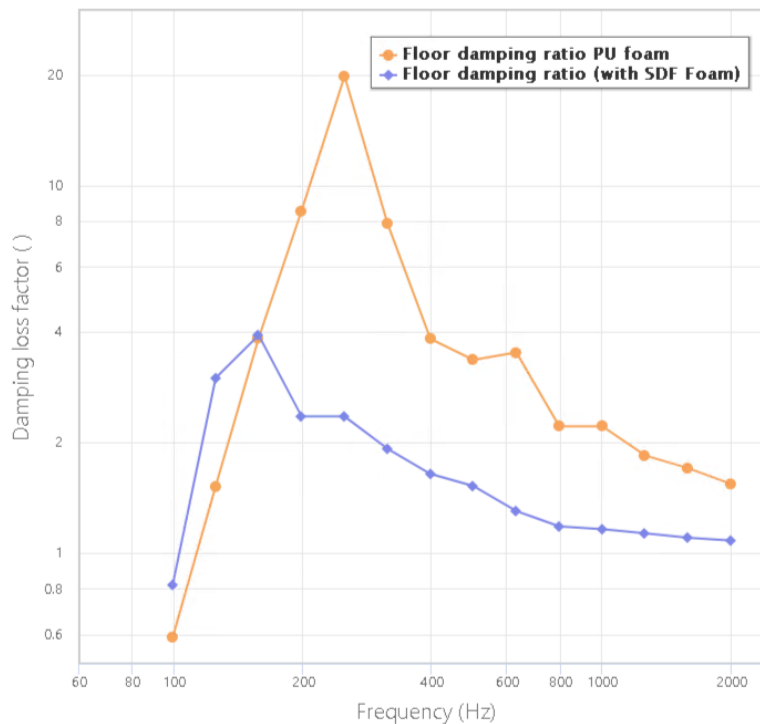


Figure 13: Damping ratio spectrum on the floor (RMS values in 1/3 Octaves).



4. CONCLUSIONS

To meet the needs of the fast-changing automotive industry, new development techniques including the use of numerical engineering must be applied. DASSAULT SYSTEMES wave6 enable RENAULT to assess the performance of the “Smart Cocoon” technology of the new Megane Etech.

For structure-borne transmission the foam creates additional damping on the floor that reduces the transmission of the road-noise in the passenger cabin. At the same time the foam enables to couple the traction-battery mass to the floor which drastically improves transmission loss capabilities and the air-borne insulation.

It is important to consider that phenomena other than the addition of damping on the floor and cover need to be studied. For instance the influence of the pre-stress of the cover and the floor, via the presence of the foam, can have an impact on the energy transfer. The perspectives on the simulation point of view are to include the pre-stress induced by the presence of the compressed foam, and to simulate the response of the full car with more realistic load cases.

5. ACKNOWLEDGEMENTS

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6. REFERENCES

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