Acoustic computation of a grommet in a small cabin using finite element analysis

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Abstract:

In the automotive industry, acoustic insulation of the engine compartment is one of the key points for the NVH comfort of vehicles. Grommets of the firewall are an important path of noise from engine to passengers' cabin. Acoustic requirements defined by automotive manufacturers for firewall insulating materials and for grommets are more and more constraining. One of the main indicators used by OEMs to determine the acoustic performance of grommets is the Insertion Loss (IL). It is the difference of the sound pressures between two configurations: a reference and the configuration with the part to be assessed. One way to measure the IL of a part is the use of a small cabin. It consists in a dedicated bench having one emitting room, one receiving room and the tested part at the interface. Suppliers may need to test several prototypes to meet the OEMs' specifications. In this context, the numerical simulation of the small cabin can provide a helpful support in the design phase of the grommets. The finite element software Code_Aster is used in this study. Code_Aster is an open source software developed by EDF (French Electric Company). The open source software Salome is used for the pre-processing (geometry and mesh) and post-processing. A parametric model is developed in order to easily modify the geometry, the mesh or the input data (material properties, frequency range, boundary conditions, ...). The objective is to compare IL computed with different models. Correlation between experiments in small cabin and simulations is achieved up to 10 KHz. It demonstrates equivalent trends of the IL spectra and levels. Numerical results show that the damping factor and the stiffness of materials deeply modify the IL. Several enhancements could still improve the numerical model. Perspectives of the work are to use frequency dependent materials properties as inputs and to take into account acoustic leaks in the simulation.

Mots clefs : Acoustics, Fluid Structure, Automotive, Finite Element Analysis, Insertion Loss

1 Introduction

Acoustic insulation of the engine compartment is an important factor of the NVH comfort of vehicles. With the use of performant soundproofing materials to improve the insulation of vehicles, the firewall has begun an important path of noise from the engine to the passenger’s cabin. For this particular reason, acoustic specifications of OEMs for firewall are more and more constraining, especially for the wiring grommets. The Insertion Loss (IL) is one of the main indicator to determine the acoustic performance of the wiring grommets. The IL is the difference of Sound Pressure Level (SPL) between two configurations: a reference configuration and a configuration with the tested sample. The IL can be measured with the use of the small cabin. It is a specific bench with source cavity and a receiver cavity. The tested parts being at the interface of these two cavities. Suppliers need to test several prototypes and combinations of different geometrical configurations and/or different materials can lead to prohibitive and long-term development to respect the OEM's specifications. One way of improvement of the design development can be the computation of the small cabin. A finite element model of small cabin has been realized with the finite element software Code_Aster. Code_Aster is an open source software developed by EDF (French Electricity Company). The pre-processing and the post-processing have been computed with the open source software Salome. The main purpose of this study is to provide a computational method of the small cabin to determine the IL of wiring grommets from a finite element model.

Firstly, the description of different methods and models used to compute the small cabin is presented. A brief description of the small cabin is given. In order to validate the numerical method, an understanding of the measurement of IL in the small cabin is necessary. Hypotheses of the computational method are then given. Loading, boundary conditions and mechanical properties have been defined to match with the real conditions of the measurement of IL in the small cabin. Two numerical models of the small cabin are set up: a 3D model and a 2D axisymmetric model.

Secondly, a validation of the methods and the models is fulfilled with the correlation between the measurement and the computation. It is achieved with the measurement of a reference, a simple measurement in the small cabin of the steel sheet and the soundproofing materials.

Then, an example is presented with the impact on acoustic performance of the acoustic ring. The acoustic ring is a EPDM ring placed inside the wiring grommet. The measurement in the small cabin showed that this piece has an important impact on the measurement of the IL.

Finally, conclusion and perspectives are presented. Several proposals are given to improve the model: characterization of the frequency dependencies of the materials or enhancements in the computational methods could be some leads to a better numerical model of the small cabin.

2 Experiment versus Finite Element Analysis (FEA)

2.1 Description of the small cabin

The small cabin (see Figure 1) is mainly composed by two parts: source cavity and a receiver cavity. The determination of the Insertion Loss (IL) in the small cabin consists in measuring the Sound Pressure Level (SPL) of the two configurations (1).

$$IL(dB) = 20 * \log_{10}\left(\frac{p_2}{p_0}\right) - 20 * \log_{10}\left(\frac{p_1}{p_0}\right) \quad (1)$$

p_2 and p_1 are respectively the transmitted pressure measured in the receiver cavity of the first configuration and the second configuration. p_0 is the reference pressure and it equals to 20 µPa. The IL is always expressed in dB.

In the first one, a 1mm thickness steel sheet is set at the interface between the two rooms of the small cabin. In the second one, the part is tied up in the steel sheet and soundproofing materials (felt layer and a heavy mass layer). Four microphones in the receiver cavity are used to measure the transmitted SPL. The IL is determined by the difference of the transmitted SPL for the two configurations. The higher the IL, the better the acoustic performance of the tested sample is.

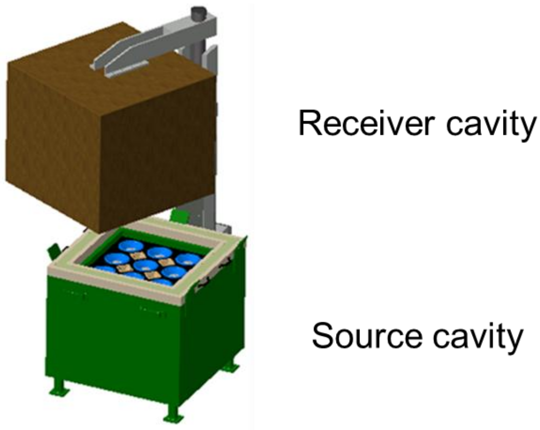

Figure 1. CAD model of a small.

One can observe the source cavity and the receiver cavity of the small cabin on Figure 1.

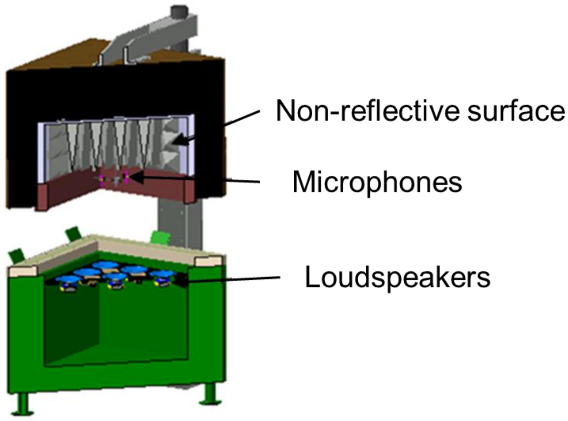

Figure 2: Cross-section of the CAD model of a small cabin.

One can observe on Figure 2 a cross-section of the CAD model of a small cabin. Loudspeakers are placed in the source cavity and the microphones are placed in the receiver cavity. One may remark the non-reflective surface in the receiver cavity to avoid acoustic waves reflection in the receiver cavity.
Wiring grommets allow a path from engine to passengers' cabin through the firewall. The tested parts in small cabin are composed by the wiring grommet, a strand and an insert to tie it to the steel sheet.

2.2 Computational method

The first step of this study is to compute the entire small cabin in finite elements.
The air in the rooms and inside the grommet is computed with fluid elements and the solid elements as 3D or 2D elements ([**Erreur ! Source du renvoi introuvable.**] and [**Erreur ! Source du renvoi introuvable.**]). As the study is a vibro-acoustic problem, an interface is computed between the two types of elements to create a fluid/structure interface in the model. The use of a fluid/structure coupling in Code_Aster involves several constraints on the model and the computational method, as the definition of the damping. In this particular case of the computation of a wiring grommet in small cabin, the damping factor has to be defined as a global value that covers the entire model (fluid and solid elements). So, this value of damping is an important fitting parameter between measurements and computed results of IL.
In order to prevent reflection of acoustic waves in the cabin, an impedance condition is applied on the internal sides of the reception part of the cabin. This impedance condition is taken as equals to ρc (approximately 408 Pa.s/m).

CAE model of a grommet in a small cabin consists in modelling several components:

- A cabin filled by air
- A grommet in EPDM
- An insert in PA66
- A strand
- A steel metal sheet
- A soundproofing material

The strand is normally composed by several wires passing through the grommet. During small cabin measurements, the strand is covered by mastic in the emission and the receiver cavity. The mastic has the particularity to avoid the acoustic waves to pass through the strand. Thus, only the acoustic performance of the wiring grommet is measured. After a computational validation, the strand is computed as a material with a low Young's modulus.
As explained in the previous section, the soundproofing material is composed of a felt layer and a heavy mass layer. The felt is commonly defined as a porous material in finite element method. However, Code_Aster software does not allow to carry out studies with porous material for now. The felt can be defined either as solid elements or fluid elements. A comparison of IL computed with felt as air (fluid elements) or solid elements (low Young's modulus and low density) has been realized. Despite few differences on IL results, the computation of the felt as air has been chosen. This material could better represent the breath of the soundproofing materials that occurs during measurements. The heavy mass layer is in EPDM.

For the calculation, edges of the metal sheet are clamped. The emission of acoustic waves by loudspeakers in small cabin is closed to a diffuse field. As the Code_Aster software doesn't allow to realize calculation with a diffuse field loading, planar waves loading is applied on several non-collinear surfaces of the cabin. This type of loading permits to get close to a diffuse field condition.
SPL in the receiver cavity of the cabin is measured by four microphones set as a cross at 0.055 m of the grommet. Calculated pressure is taken at the same location as in measurements. Experience in small cabin measurements show that the position of microphones in the receiver cavity is an important parameter. Indeed, two measurements of the same samples with microphones placed at others locations can lead to significant differences between the two measured IL.

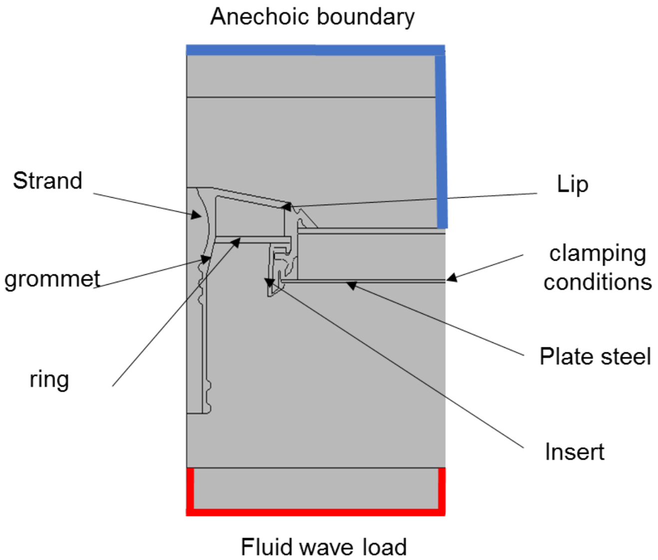

Figure 3: Materials, loading and boundary conditions of a wiring grommet (cross-section).

Measurements in small cabin are performed from the third octave centre frequency of 100 Hz to the third octave centre frequency of 10 kHz. The size of the elements in the mesh of the model highly depends of the frequency. In order to obtain acceptable results, it is strongly recommended to have an element size equal to the sixth of the wavelength. The upper frequency for a calculation to the center frequency of 10 kHz is 11.225 kHz. At this frequency, air wavelength equals to 0.03 m. Thus, the maximal size of elements for the mesh is about 0.005 m.

2.3 Models

A 3D model is realized from the CAD model of the wiring grommet. The main drawback of a 3D model is the number of degrees of freedom (dof) required for the calculation.

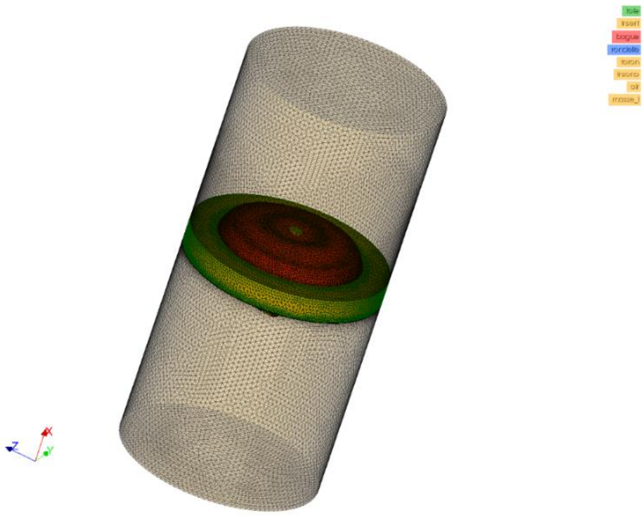

Figure 4: Mesh of the 3D model of the small cabin with the wiring grommet.

The representation of the entire small cabin with the suitable size of elements would provide a prohibitive time of calculation with more than one-million-and-a-half degrees of freedom.

A solution to avoid a too important number of degrees of freedom is to compute the small cabin in an axisymmetric model. This model is a 2D model where only the half section of the small cabin and the wiring grommet are computed. Keeping in mind that the main aim of this study was to easily compare different configurations of grommets, the axisymmetric model could be more convenient (faster computation and easier to set up).

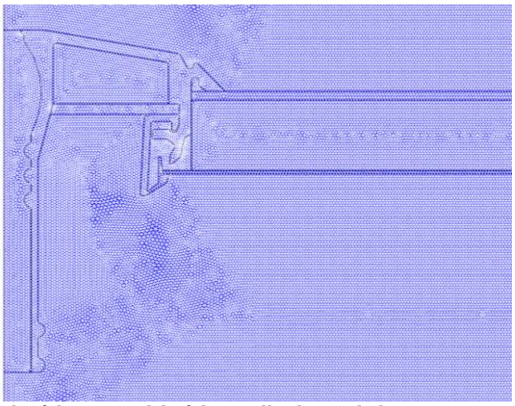

Figure 5: Mesh of the 2D model of the small cabin with the wiring grommet (zoom).

The advantage of this model is the low number of degrees of freedom required to perform the calculation. This value can easily be divided by ten in comparison with a 3D model. Moreover, this 2D model allows to refine the mesh in order to check the accuracy of the model with a convergence test.

3 Validation with reference

As first result, a correlation of the 3D model and axisymmetric model is realized from measurements of reference in small cabin. The aim of this comparison is not to perfectly fit the measurements but to check that the two computed models follow the same trends than the measurement.
Before any analysis, one may consider the prominent impact of acoustic leaks that occur during small cabin measurements.
The reference of the small cabin equals a measurement of the transmitted SPL of the set of a full steel sheet and soundproofing materials on one hand and a measurement of the transmitted pressure of the steel sheet only on the other hand.
The computation of the reference allows to validate the calculation methodology with a simpler model than the one with the wiring grommet. Loading, boundary conditions and fluid/structure interface as explained in the previous chapter have been validated. Moreover, this correlation also validated the use of axisymmetric model instead of a 3D model.
A first calculation of the 3D model has been realized. The meshing of the entire small cabin in the frequency range of the measurements (i.e. a maximal size of elements of 0.005m) leads to a model with a too important number of degrees of freedom to complete the calculation. The aim of this validation was to fit computation with measurements for all the frequency ranges. Choice of reducing the dimensions of the small cabin has been made to decrease the number of degrees of freedom in the model. Thus, the 3D model has been reduced to a small cabin of 0.5m width (instead of 0.9m). The height has also been reduced. The final 3D model has approximatively 100 000 degrees of freedom.
In order to validate the use of the axisymmetric model to compare different grommets, this model is reduced to the same dimensions of the small cabin than the 3D model. Results are presented Figure 6. The axisymmetric model has less than 10 000 degrees of freedom.

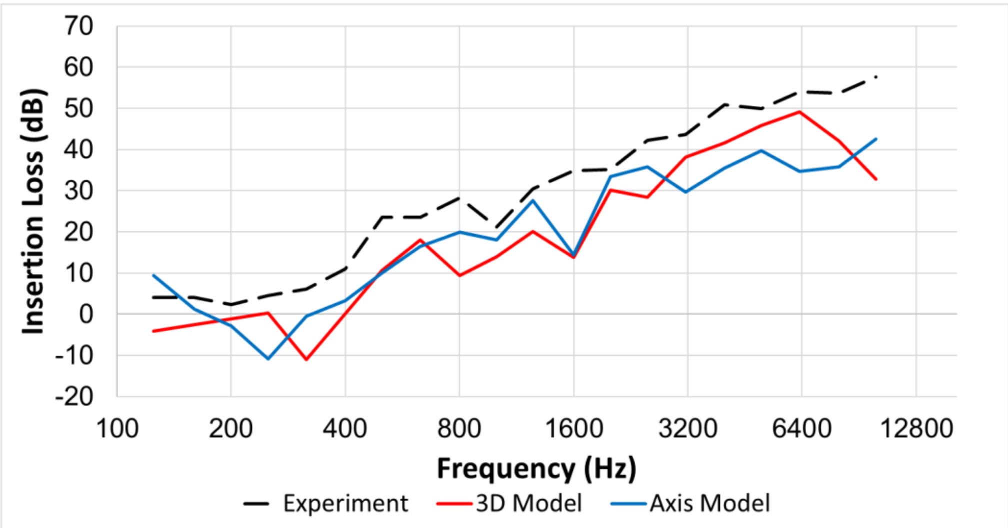

Figure 6: Measured IL (red curve) and computed IL for different models (3D model in black and axisymmetric model in blue) of the reference.

One may observe that the two computed IL are lower than the measured IL for most of the frequency range. Also, the three curves of IL follow the same slope.

4 Example: Impact of acoustic ring

After the validation of the calculation method, a study case is fulfilled. In order to increase acoustic performance of grommets, an acoustic ring in EPDM is added. Measurements in small cabin show significant improvements of IL results.

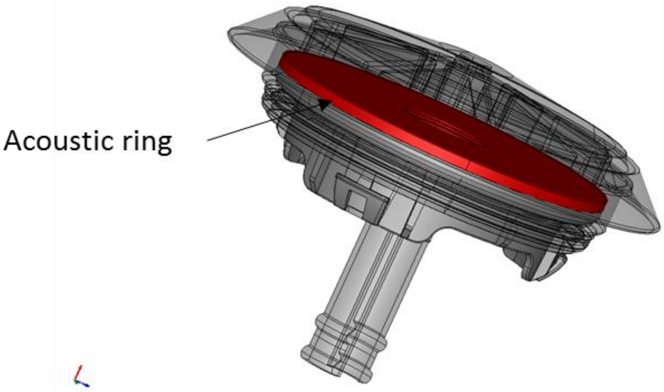

Figure 7: View of the wiring grommet (transparent) and the acoustic ring (red).

Comparison on the impact of the acoustic ring is realized on several configurations of grommets. The purpose of this example is to compare computed results of IL with and without acoustic ring. Along with the IL results, another indicator is used to evaluate the acoustic performance of a wiring grommet. This indicator is the mean value of the IL from the center frequency of 400 Hz to 6.3 kHz.
The measured IL is shown in Figure 8 and the computed IL is shown in Figure 9.

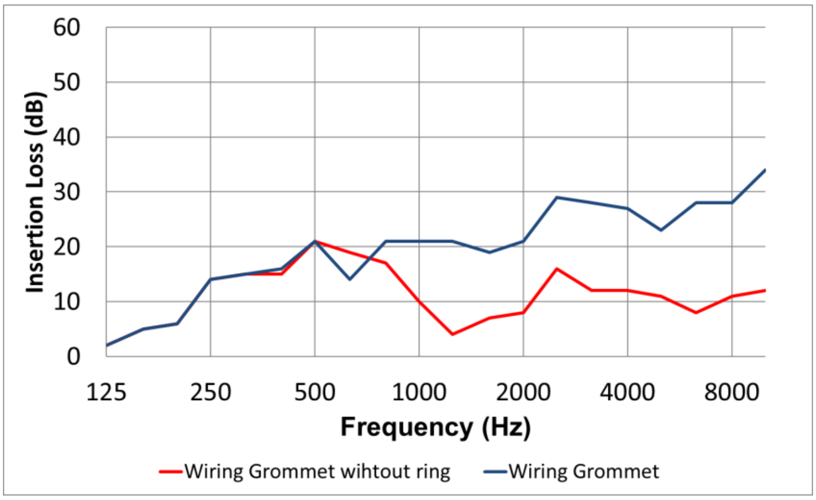

Figure 8: Measured IL of the grommet with the acoustic ring (blue curve) and without the ring (red curve).

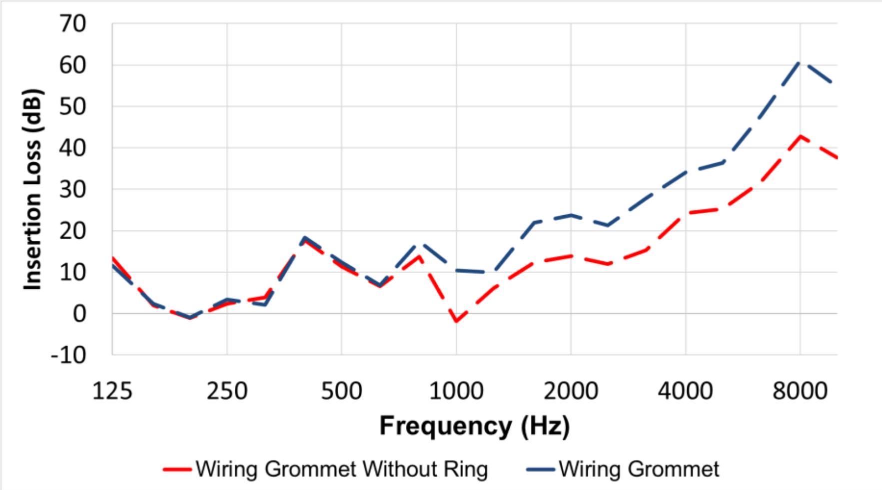

Figure 9: Computed IL of the grommet with the acoustic ring (blue dotted curve) and without acoustic ring (red dotted curve).

Firstly, one may observe the low impact of the acoustic ring impact at low frequencies. This observation can be explained by the wavelength of the acoustic waves at these frequencies and the thickness of the acoustic ring. In middle frequencies and high frequencies, the impact of the acoustic ring is more significant with a difference of IL of about 20 dB in very high frequencies. The same phenomenon can be observed in measured IL. The chosen indicator (mean value of IL) gives a difference of almost 8 dB between the two configurations. The same value was found during the measurements.

One of the interest of the computational method is the possibility to visualize results of pressure or displacements at every node of the model. For a better understanding of the IL, Figure 10 and Figure 11 shows the pressure in the air for the two configurations (with and without the acoustic ring). The white parts on figures represent solid elements and the felt.

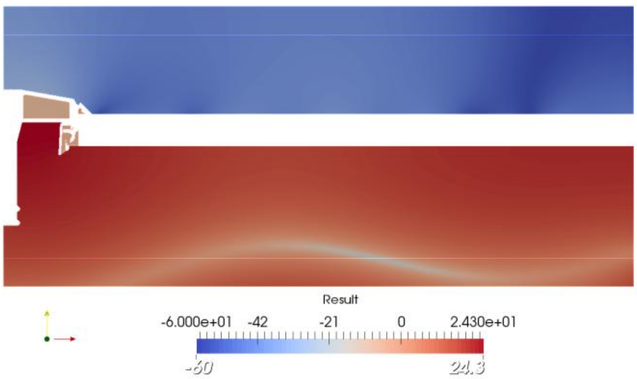

Figure 10: Visualization of the computed pressure (dB) in the small cabin at the center frequency of 1 kHz for the configuration with the acoustic ring.

One can observe the direct impact of the ring with a decrease of the pressure inside the air cavity of the wiring grommet. The wave front is also visible in the source cavity.

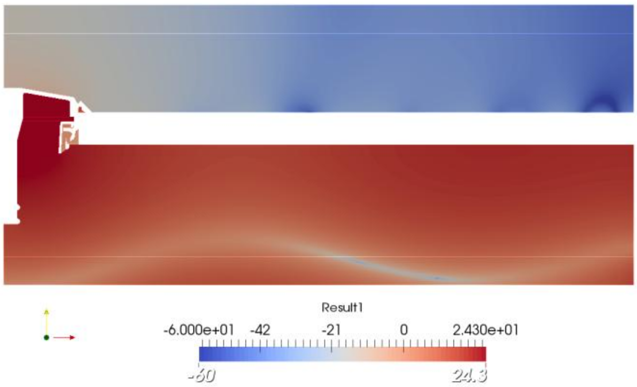

Figure 11: Visualization of the computed pressure in the small cabin at the center frequency of 1 kHz.

In comparison with the configuration with the acoustic ring, one can observe that the computed pressure around the wiring grommet in the receiver cavity is higher than the one obtained with the acoustic ring configuration.

The displacements in solid elements are given in Figure 12 for the two configurations.

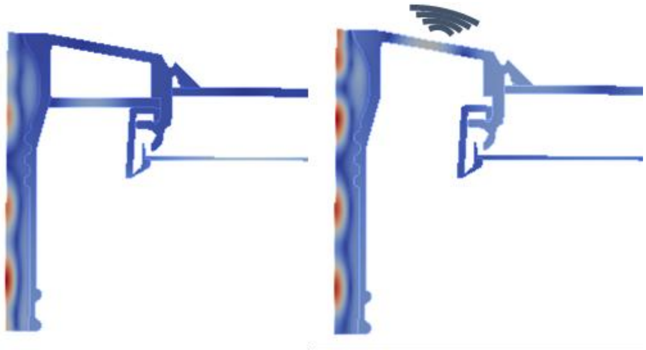

Figure 12: Visualization of displacements of solid elements for the two configurations (right with acoustic ring, left without acoustic ring) at 1 kHz (zoom).

As for the computed pressure in the air, the visualization of the displacements of solid elements can be helpful to understand the vibro-acoustic phenomenon. In this figure, the range color is from blue to red, where blue values are for lower displacements. One may observe the displacements of the lip of the grommet is more important in the configuration without acoustic ring.

Conclusion and perspectives

A finite element model of the small cabin has been realized with the open source finite element software Code_Aster. In order to validate the computational method, two different models have been realized, a 3D model and an axisymmetric model. The limitation of 3D model appears due to the important dimensions of the small cabin and the large frequency band of the measurement for the determination of the IL. As long as the wiring grommet is symmetric, the 2D model provides same trends of results than the 3D model, with ten times less degrees of freedom. This parameter is quite important and allows the user to launch a set of several configurations of wiring grommets in order to highlight indicators (geometrical configuration, material properties, etc.) that could improve the acoustic performance of the wiring grommets.

A study case of the impact of the acoustic ring has been realized. This specific case gives an example of possible application of the parametric model. Indeed, the results of IL from the measurements and the computation are quite similar. The indicator used to evaluate the acoustic performance of the

wiring grommet, the mean of the IL between 400 Hz and 6.3 kHz, is equal for the measurements of the calculation.
Despite promising first results, enhancements could still improve the finite element model. The application of a global damping factor to the entire model is a limitation for a good correlation between the measurements and the computation. This problem seems to occur when the fluid/structure interface has several different surfaces, as in the present vibro-acoustics. Thus, other ways of computation of damping factor are possible in Code_Aster and have to be explored.
The characterization of the mechanical properties of the EPDM with frequency dependencies could also improve the accuracy of the correlation between the measurements and the computation. Some viscoelastic material could have differences on its mechanical properties that could change the behavior of the material at various frequencies.
An entire parametric model could also be realized. The geometry, the mesh and the calculation configuration could then easily be modified in a Python file. This type of model allows the user to realize several calculations of wiring grommets.
Another way of improvement is the computation of the felt as a porous material. As the Code_Aster software is open-source, one can add a tailor-made development of the porous material computation as existing in commercial finite element software.

References

[1] D. Leray, Y. Goth, "Acoustic Calculation with The Free Solver Code_Aster," International Compressor Engineering Conference, 2012
[2] Code_Aster documentation, “Vibro-acoustic Elements”, R4.02.02, 2013