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Modeling the Transmission Loss of Passthroughs in Sound Package using Foam Finite Elements

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ABSTRACT

Holes and passthroughs can often have a significant influence on the overall Transmission Loss (TL) of a trimmed panel, particularly at mid and high frequencies. In order to optimize a given sound package it is therefore necessary to account for holes and passthroughs in a model. In a Statistical Energy Analysis (SEA) model the passthroughs can be described using "leaks" applied to various area junctions. The TL of each leak is then calculated using analytical formulae (based on circular or rectangular holes). In some instances it is useful to obtain a more detailed model of the TL of the passthrough. This includes, for example, situations in which the passthrough only penetrates certain layers of a multi-layer noise control treatment. In this paper, the use of local Hybrid FE-SEA models with Foam Finite Elements (PEM subsystems) are used to model the TL of partially trimmed passthroughs. The predicted TL can then be used to update a system level SEA model. A number of numerical examples are presented and the results are discussed.

INTRODUCTION

SEA is often used to predict interior vehicle noise due to airborne noise sources and to optimize vehicle sound package [1]. Figure 1 shows a typical airborne SEA vehicle model. The model consists of a number of structural plates, acoustic cavities and semi-infinite fluid domains (SIFs). Acoustic excitation is applied to the various exterior cavities surrounding the vehicle and the acoustic response predicted at the driver and passenger headspace locations. The model includes a detailed description of the multilayer foam and fiber treatments contained within the vehicle (the vehicle “sound package”). These treatments are typically modelled analytically in the SEA model, add damping/absorption to the individual subsystems and provide isolation between the structural and acoustic subsystems. A typical airborne SEA model may also contain a number of “leaks” to describe acoustic transmission through holes and passthroughs in the main structural components. At higher frequencies these leaks can become important transmission paths as discussed in the following sections.

In an SEA model the TL of a leak can be described using analytical models of apertures with simple cross-sectional shapes [2] (for example slits, circular holes and rectangular holes). These formulations typically provide a good description of the transmission through a given leak. However, situations sometimes exist in which a more detailed representation of a given leak is needed (either to confirm the accuracy of a simplified model or to update an SEA model with more detailed information about the leak TL).

The first situation occurs when the leak has a complex cross-sectional shape. The second situation occurs when a foam and fiber treatment partially covers the leak, or there is a partial hole in the treatment (for example a passthrough that goes through the mass layer of a decoupler but not through the panel). In such situations it is of interest to investigate the local TL of the leaks and passthroughs using more detailed local models.

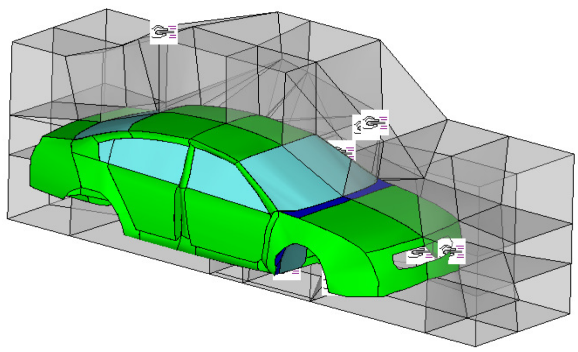

Figure 1. Typical Vehicle Airborne SEA model

This paper provides a numerical investigation of the TL of various leaks and pass-throughs. Numerical studies are performed to determine the impact of cross-sectional shape on the TL of various leaks. The effects of sound package on the TL of a leak is then investigated using a number of detailed local models. In order to efficiently calculate the TL of the various leaks across a broad frequency range, a Hybrid FE-SEA approach is used [3-5]. Models are created that consist of the following subsystems: (i) Acoustic Finite Elements are used to model the leak and portions of the surrounding near-field, (ii) Foam Finite elements are used to model any treatments applied to the leak [5,6], and (iii) the acoustic domain on either side of the leak (and the diffuse acoustic field loading on the source side of the leak) is represented by SEA acoustic fluids. The models are created in the commercial software package VA One [5].

PREVIOUS STUDIES

A study of the transmission loss of slits and seals for airborne SEA was recently conducted by Cordioli et al. [7]. In this work the TL of an automotive door seal was investigated using Hybrid FE-SEA models as shown in Figure 2. It was found that the inclusion of the acoustic "channel" before and after the seal can have a significant impact on the overall TL of the seal. It was also shown that for "slits" a Hybrid FE-SEA model provided a quick way to model the slit TL. The TL of a seal with a realistic and simplified channel geometry is presented in Figure 3. It is shown that the geometrical complexity of the channel does not have a significant impact on the TL of the slit (the TL scales with the overall length and cross-sectional area of the channel). The current paper uses a similar modelling approach but applied to trimmed passthroughs.

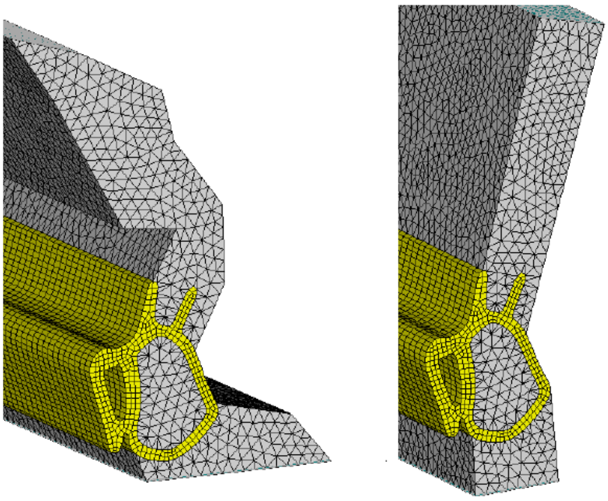

Figure 2. Hybrid FE-SEA model used to predict TL of a seal inside a realistic channel (left), and a simplified channel (right)

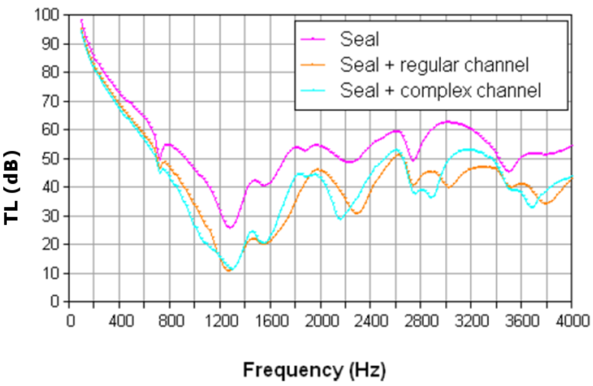

Figure 3. Predicted TL of seal with different channel geometry

INFLUENCE OF ACOUSTIC LEAK ON THE TL OF A TRIMMED PANEL

The following section provides a simple example of the influence of a leak on the TL of a simple panel. Consider a 1mm thick steel plate between two air filled cavities shown in Figure 4. A noise control treatment layup consisting of 20 mm melamine foam and a 1.5 kg/m^2 septum has been applied to the steel plate. A circular leak with a diameter of 10 mm diameter is added and penetrates both the panel and the foam. An SEA model of the system is created that contains two cavity subsystems (with overridden volumes to simulate large reverberant rooms), one plate subsystem and the leak in the area junction between the panel and the cavities. The predicted TL results are shown in Figure 5 for four configurations of bare and trimmed panels with and without a leak.

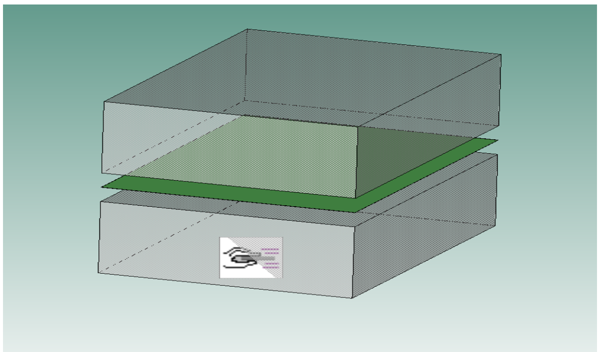

Figure 4. SEA model used to predict TL through a steel plate of dimension (1.64 x 1.19 x 0.001) m with a NCT layup consisting of 20 mm of melamine foam and a 1.5 kg/m2 septum and a 10 mm diameter "leak"

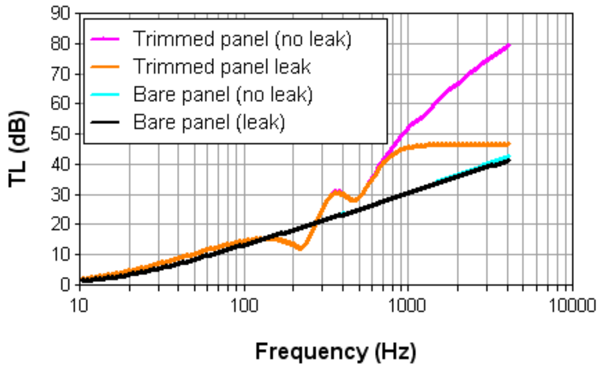

Figure 5. Influence of a leak on the TL of bare and trimmed panels

It can be seen that, for this model, the leak is the dominant transmission path above approximately 1 kHz when the panel is trimmed. This is not the case with the bare panel where the 'weak' path is still the panel itself.

The TL curve for a different leak (with 30 mm depth and 10 mm diameter) is plotted in Figure 6. The curve can be used to show typical characteristics of the leak TL. Below approximately 1 kHz the TL of the leak is fairly constant and is determined by "aperture" effects. Above approximately 10 kHz the local TL of the leak tends to zero and the TL is determined by the "area" of the leak (the TL tends to approximately 44 dB in this example since the TL is normalized to the overall area of the panel). Between 1 kHz and 10 kHz various local acoustic resonances of the leak occur.

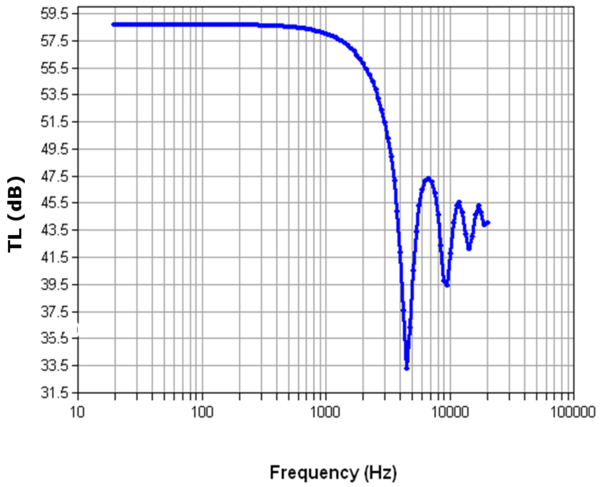

Figure 6. Transmission loss (normalized to panel area) for a rigid panel with a single circular passthrough having 10 mm diameter and 30 mm depth

INFLUENCE OF CROSS-SECTIONAL SHAPE ON UNTRIMMED LEAK

The previous examples considered a leak with a simple cross-sectional geometry modelled analytically. The following section considers the TL of leaks with more complex cross-sectional shapes. The leaks shown in Figure 7 were selected; each has the same depth and cross-sectional area but different cross-sectional shapes. Various Hybrid FE-SEA models were created for the leaks as shown in Figure 8. The leaks are represented by Acoustic Finite Elements (this allows any leak geometry to be investigated, including situations in which the cross-sectional area of the leak varies throughout the depth of the leak). The Acoustic FE subsystems are then connected to SEA semi-infinite fluids (SIFs) using "Hybrid Area Junctions". A "baffled" boundary condition option was selected for these Hybrid Area Junctions. Each SIF then describes a (complex and full) radiation impedance looking into a baffled half space. A diffuse acoustic field was applied to the source side (the DAF is represented by a reciprocity relationship as discussed in [8]). The advantage of the Hybrid FE-SEA models is that they solve very quickly (the models in this example solved in a matter of seconds).

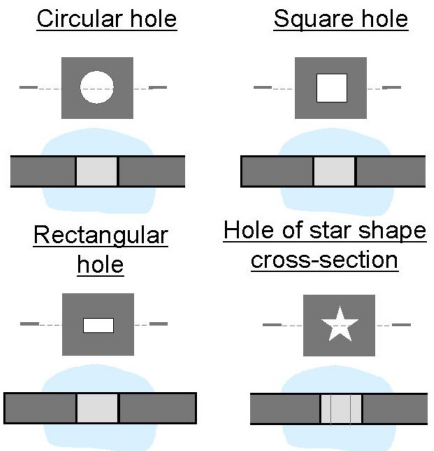

Figure 7. Examples for passthroughs having simple and complex cross-sectional shape

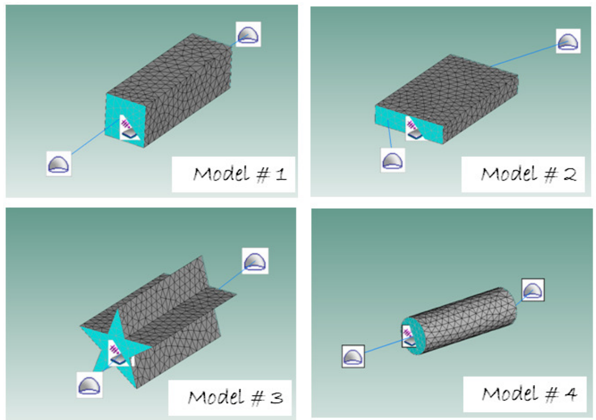

Figure 8. Hybrid FE-SEA models of leaks with the same cross-sectional area and depth but different cross-sectional shapes.

The TL predicted by the various Hybrid models is shown in Figure 9. It can be seen that the TL curves are almost identical, highlighting that (for frequencies at which the wavelength is large compared with the dimension of the leak) the TL is insensitive to the cross-sectional shape of the leak.

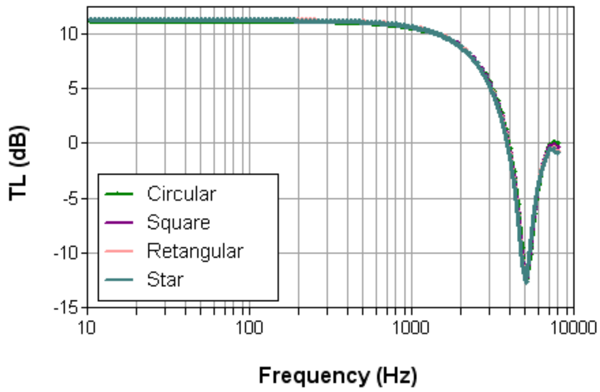

Figure 9. TL of leaks with different cross-sectional shape

The TL of the leaks is compared with the analytical prediction of a simple circular leak in Figure 10. There is close agreement between the Hybrid result and analytical results (the small differences are perhaps due to the simplifying assumption adopted in the analytical model that the pressure within the leak is uniform across the leak cross-section).

The results in this section are consistent with the standard SEA practice of using a simplified leak formulation to describe leaks with different cross-section.

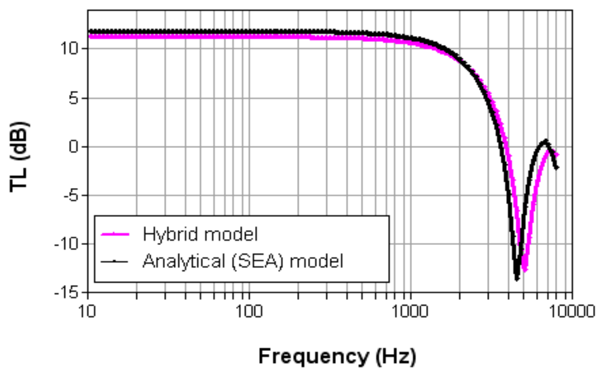

Figure 10. Comparison of the transmission loss for a circular passthrough having 10 mm diameter and 30 mm depth using a Hybrid FE-SEA model and an analytical model

MODELING A TRIMMED LEAK: FULL PANEL MODEL

Consider now the problem of applying a layered noise control treatment over a given leak. In principle, a model could be created in which the panel is modelled in detail using Structural Finite Elements, the trim modelled with Foam Finite Elements and SEA fluids applied to either side to model the TL. This is investigated in the current section.

A Hybrid model of the previous flat trimmed panel has been developed using foam finite elements to represent the trim and structural finite elements to represent the panel. The air is modelled using SEA semi-infinite fluids on either side of the panel. 700 structural modes have been extracted to represent the response of the steel panel. The foam is represented by approximately 70,000 foam finite elements. The model is shown in Figure 10. Results for the same configuration have also been obtained using an SEA model, where the air is represented by SEA acoustic cavities, the panel is represented by an SEA plate and the trim is described with the standard SEA transfer matrix approach for poroelastic layups. For the Hybrid FE-SEA model, a frequency range from 10 to 1,000 Hz has been considered, where 80 frequency points were computed. For the pure SEA model, a frequency range from 100 to 5,000Hz has been investigated. On a 4 core 64-bit machine with 2.2 GHz clock frequency and 8 GB of RAM, the detailed Hybrid model required approximately 70 hours to solve, whereas the simple SEA model required 5 seconds. The majority of the computational expense of the Hybrid model was associated with the explicit representation of the trim using foam finite elements (the computational time may be reduced through the use of frequency interpolation but this was not employed in the current example).

The results for the TL of the trimmed and untrimmed panels are presented in Figure 11. The models are in close agreement across the common frequency range. However, the example highlights that the use of a detailed finite element model of the entire panel may result in long solve times which may not be practical for quick design studies. It is therefore natural to question whether a detailed model of an entire panel is needed in order to assess the TL of a trimmed leak. The following sections investigate this in more detail.

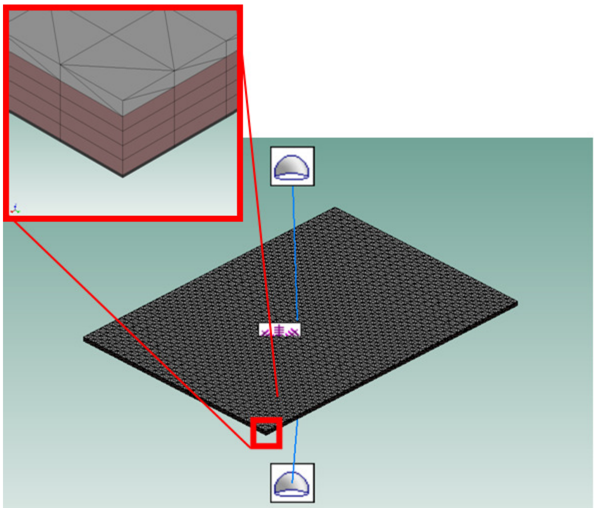

Figure 11. Hybrid FE-SEA-PEM model of a trimmed panel

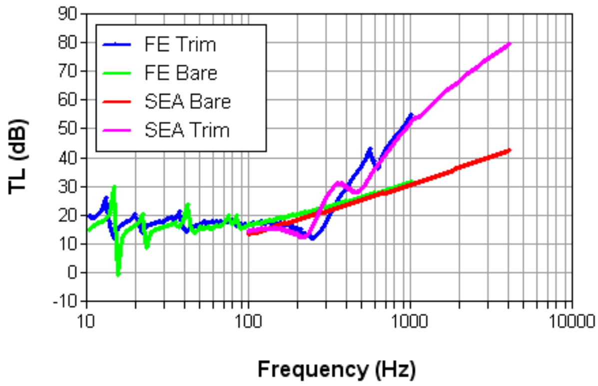

Figure 12. Comparison of the transmission loss obtained from pure SEA and Hybrid FE-SEA-PEM models for an untrimmed and a trimmed panel

MODELING A TRIMMED LEAK : LOCAL MODELS

An alternative approach to modelling an entire panel is to create a local model of a leak that includes the trim in the "local" vicinity of the leak. A question that then arises is "*how much of the surrounding trim do I need to include in a local model to characterize the effect of the trim on a given leak?*". In this section this question is addressed by comparing the results from two different Hybrid models of a trimmed leak. The models are used to assess the sensitivity of the TL to the amount of foam that is modelled.

The Hybrid models are shown in Figure 13 and Figure 14. The leak is modelled with acoustic finite elements as before. The foam and septum in the vicinity of the leak are modelled with foam finite elements. SEA SIFs are then added to model the source and receiving sides of the leak. The difference between the two Hybrid models is that the first model is larger than the second model (the first model includes a larger cross-sectional area than the second model).

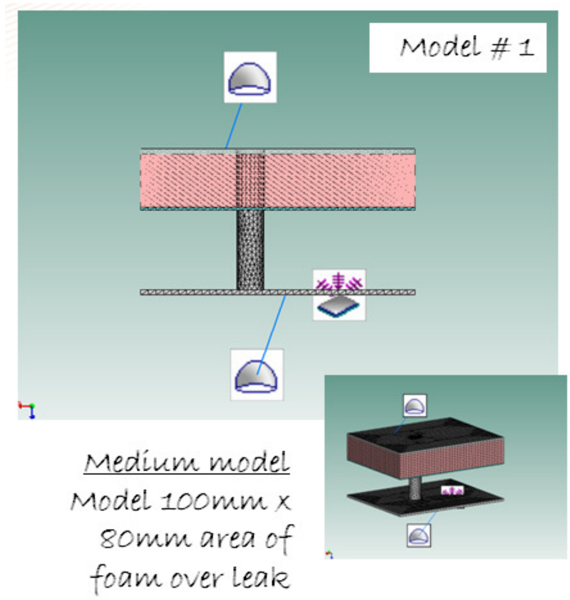

Figure 13. Hybrid FE-SEA model of trimmed leak (medium sized model).

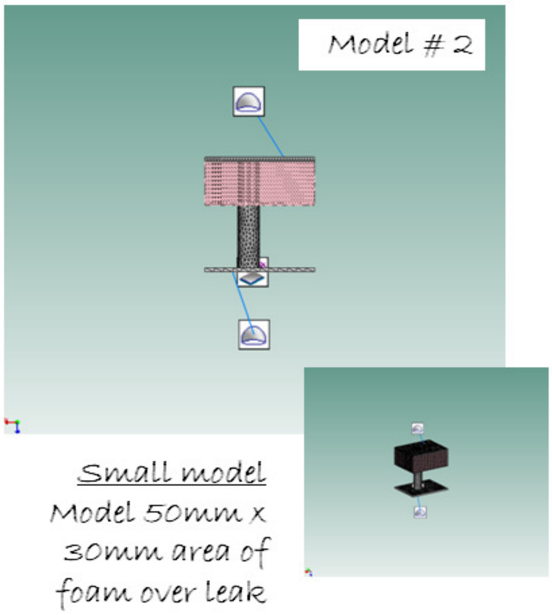

Figure 14. Hybrid FE-SEA model of trimmed leak (small model)

For the two models, the dimensions of the cut-out were chosen to be 100 mm x 80 mm and 50 mm x 30 mm, respectively. The TL from both models is presented in Figure 15 along with the TL of an "untrimmed" leak. It can be seen that, for this model, above approximately 300 Hz the results from the two models are identical. Below 300 Hz the results are sensitive to finite size effects and the TL depends on the boundary conditions applied to the edge of the foam. At first sight this might suggest that it is necessary to use a larger model to characterize the insertion loss that the treatment applies to the leak TL. However, as discussed in previous sections, the TL of a leak is often dominant at higher frequencies. In such instances it may therefore be possible to use a local Hybrid FE-SEA model to characterize the insertion loss that the trim applies to the leak.

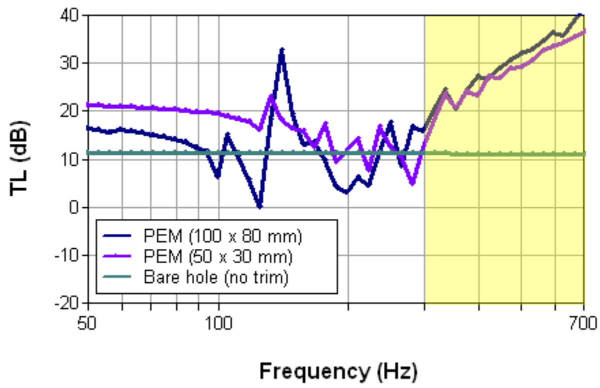

Figure 15. Comparison of the TL of a trimmed leak predicted by Hybrid models (shaded area indicates frequency range of interest for typical leak)

CONCLUSIONS

This paper has presented a number of methods for creating detailed local models of leaks. The main application of the current work is updating system level SEA models with information from detailed local Hybrid FE-SEA-PEM models. It was demonstrated that (at lower frequencies) the TL of an untrimmed leak is insensitive to cross-sectional shape and only depends on overall cross-sectional area and depth. The use of local Hybrid FE-SEA-PEM models were then investigated for modelling the TL of a trimmed leak. For the configurations in the current paper the use of smaller local models provided similar estimates of TL at higher frequencies indicating that it is not necessary to model an entire panel in order to characterize the TL of a trimmed leak. While the current paper focused on simple trim layups, the proposed approach is expected to be applicable to more complex layups involving partial coverage and complex cut-outs within the treatment.

ACKNOWLEDGEMENTS

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REFERENCES

1 A. Charpentier, D. Blanchet and K. Fukui, "Full Vehicle SEA Model Uses Detailed Sound Package Definition To Predict Driver's Headspace Acoustic Response", *Proceedings of INTERNOISE 04*, Prague, Czech Republic 2004
2 M.C. Gomperts, "The sound insulation of circular and slit-shaped apertures", *Acustica* **14**, 1–16 (1964)
3 P.J. Shorter and R.S. Langley, "Vibro-acoustic analysis of complex systems", *J. Sound Vib.* **288**(3), 669-700 (2005)
4 V. Cotoni, P.J. Shorter and R.S. Langley, "Numerical and experimental validation of a finite element – statistical energy analysis method", *J. Acoust. Soc. Am.*, **122**(1), 259-270 (2007)
5 VA One 2010, © The ESI Group, www.esi-group.com
6 N. Atalla, R. Panneton and P. Debergue, "A mixed pressure-displacement formulation for poroelastic materials" *J. Acoust. Soc. Am.*, **104**(3), 1444-1452 (1998)
7 J. Cordioli, "Numerical investigation of the TL of seals and slits for airborne SEA predictions", *Proc. SAE NVH conference,* 2009
8 P.J. Shorter and R.S. Langley, "On the reciprocity relationship between direct field radiation and diffuse reverberant loading", *J. Acoust. Soc. Am.*, **117**(1), 85-95 (2005)