NUMERICAL PREDICTION OF THE TRANSMISSION LOSS OF LEAKS IN TRIMMED PANELS

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Small holes and pass-throughs can often have a significant impact on the transmission loss of trimmed panels, particularly at mid and high frequencies. The effect of such "leaks" can be included in modelling methods such as Statistical Energy Analysis (SEA) by using various analytical leak models. Such models typically assume a simple cross-sectional geometry in order to calculate the leak TL. However, for more complex configurations, for example, where a pass-through only penetrates certain layers of a multi-layer noise control treatment applied to the panel, a more detailed model is required in order to determine the TL of the leak. In this paper, Foam Finite Elements have been used to create such local models in order to predict the TL of partially trimmed pass-throughs. This local TL can then be used to update a system level SEA model. In addition, the paper demonstrates the widely known result that the TL of a simple hole does not depend on its cross-sectional shape but only its cross-sectional area and length. Results are presented for a number of examples.

INTRODUCTION

Statistical Energy Analysis (SEA) is an established numerical method for modelling the response of complex vibro-acoustic systems over a wide frequency range [1, 2]. A common application of SEA is prediction of interior noise in a vehicle due to external acoustic excitation, along with the design of the interior "sound package" of the vehicle [3]. A typical airborne SEA vehicle model is shown in Fig. 1. The model consists of SEA subsystems that represent plates, cavities and semi-infinite fluid domains. The subsystems are coupled via point-, line- and area-junctions (the latter typically contain multi-layer noise control treatments or NCTs). Acoustic excitation is applied to the exterior of the vehicle and interest lies in predicting the sound pressure level in the driver and passenger head spaces. The SEA model also typically contains leaks to represent holes and pass-throughs in the structure and sound package. Such leaks are important for higher frequencies, where they can sometimes become the primary transmission path.

In order to represent simple leaks such as circular and rectangular apertures, analytical representations of the leak TL can be included in the SEA model [4]. However, in some instances a more detailed description of a leak is required, for example, to confirm that a simple leak model can represent a hole with a complex cross-sectional shape or to update an SEA model, where the leak only penetrates through certain layers of a NCT. For either case, only the local transmission loss (TL) of the leak is needed. This can be computed using a detailed numerical model and used to update a system level SEA model.

This paper presents numerical results for the TL of various leaks. The impact of cross-sectional shape is investigated, for leaks with the same length and cross-sectional area. The influence of sound package on the TL of a leak is then analysed and results for various local models of the leak are discussed. In order to cover a broad frequency range, the Hybrid FE-SEA method [5-7] has been used to perform the numerical simulations in this paper. In these models acoustic finite elements have been used to model the fluid in the local vicinity of the leak. The noise control treatment has been modelled using Foam Finite Elements [7, 8] based on Biot theory and the acoustic half-space on either side of the panel is represented by SEA acoustic fluids. It has been assumed that for the frequency range of interest (i) leak TL is dominated by local properties and (ii) edge effects are negligible. All models have been created in the commercial software package VA One [7].

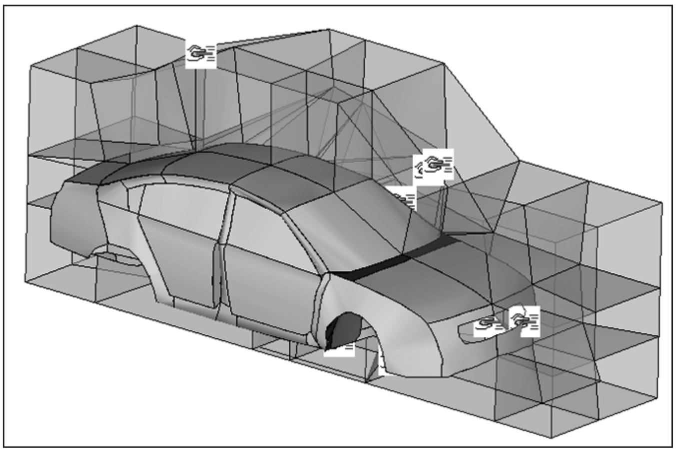

Figure 1. Typical vehicle airborne SEA model.

PREVIOUS STUDIES

A study of the transmission loss of slits and seals for airborne SEA was recently conducted by Cordioli *et al.* [9]. In this work the TL of an automotive door seal was investigated using Hybrid FE-SEA models. 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 and 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 pass-throughs.

INFLUENCE OF ACOUSTIC LEAK ON THE TL OF A TRIMMED PANEL

This 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 Fig. 2. A noise control treatment layup consisting of 20mm melamine foam and a 1.5kg/m^2 septum has been applied to the steel plate. A circular leak with a diameter of 10mm diameter is added to the steel plate using an analytical formulation [4]. 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.

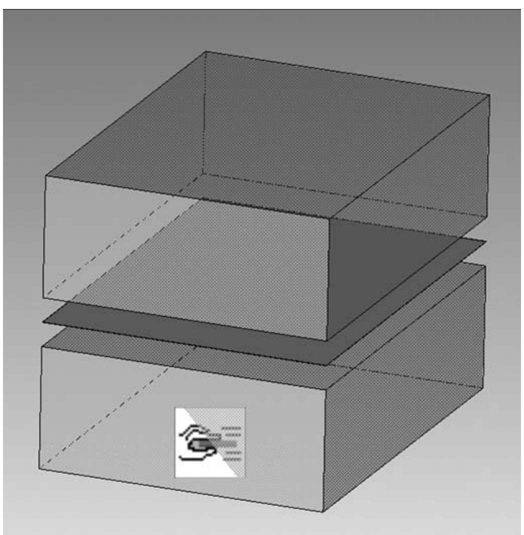

Figure 2. SEA model used to predict TL through a steel plate of dimension 1.64m×1.19m×0.001m with a NCT layup consisting of 20mm of melamine foam, a 1.5kg/m^2 septum and a 10mm diameter "leak".

The predicted TL results are shown in Fig. 3 for four configurations of bare and trimmed panels with and without a leak. 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 30mm depth and 10mm diameter) is plotted in Fig. 4. The curve can be used to show typical characteristics of the leak TL. Below approximately 1kHz the TL of the leak is fairly constant and is determined by "aperture" effects. Above approximately 10kHz 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 44dB in this example since the TL is normalized to the overall area of the panel). Between 1kHz and 10kHz various local acoustic resonances of the leak occur.

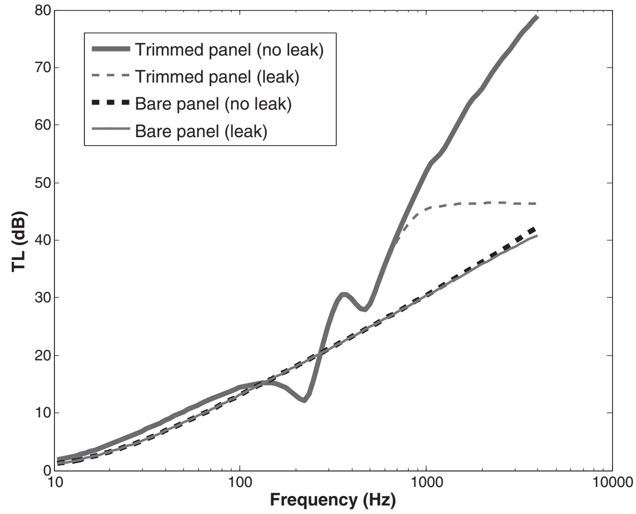

Figure 3. Influence of a leak on the TL of bare and trimmed panels.

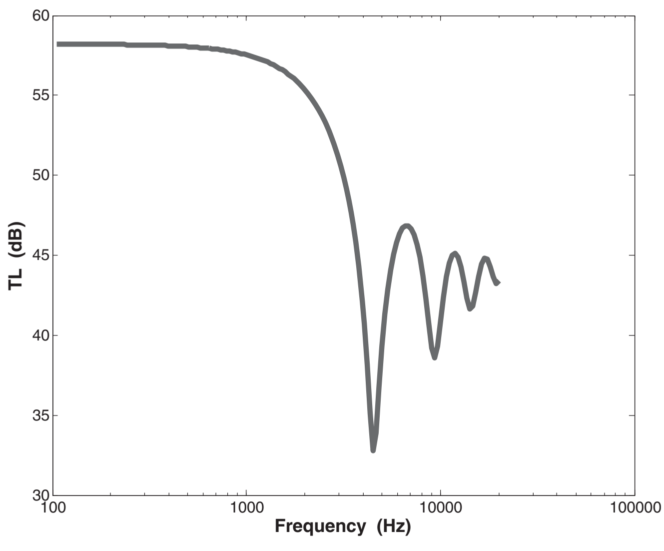

Figure 4. Transmission loss (normalized to panel area) for a rigid panel with a single circular pass-through having 10mm diameter and 30mm depth.

INFLUENCE OF CROSS-SECTIONAL SHAPE ON UNTRIMMED LEAK

The previous examples considered a leak with a simple cross-sectional geometry modelled analytically. This section considers the TL of leaks with more complex cross-sectional shapes. The leaks shown in Fig. 5 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 Fig. 6. 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 describe 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 [10]). 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).

The TL predicted by the various Hybrid models and the TL predicted for a circular leak by an analytical model are shown in Fig. 7. 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. 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.

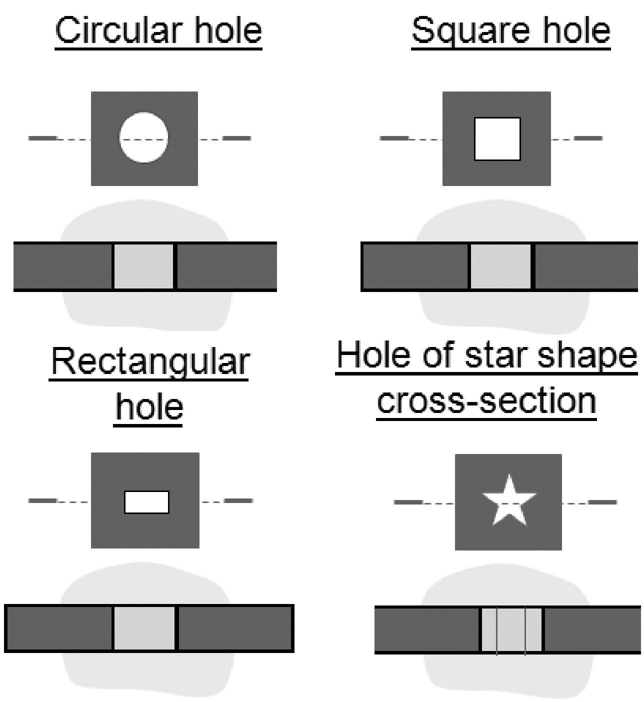

Figure 5. Examples for pass-throughs having simple and complex cross-sectional shape.

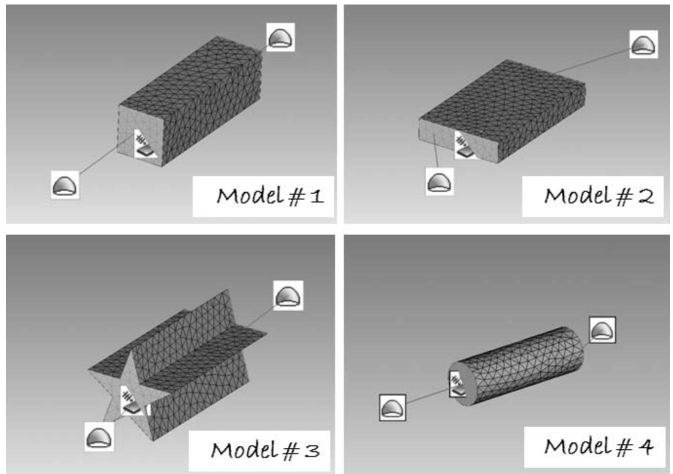

Figure 6. Hybrid FE-SEA models of leaks with the same cross-sectional area and depth but different cross-sectional shapes.

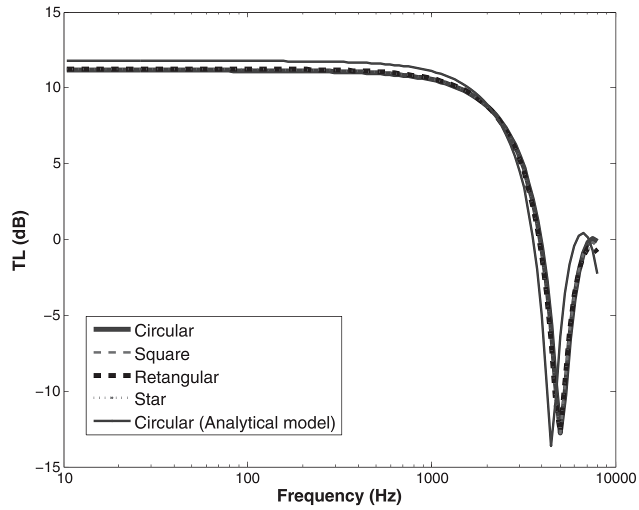

Figure 7. TL of leaks with different cross-sectional shape using a Hybrid FE-SEA model and of a circular leak using an analytical model.

MODELLING 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 Fig. 8. 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 1,000Hz 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 2.2GHz clock frequency and 8GB 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).

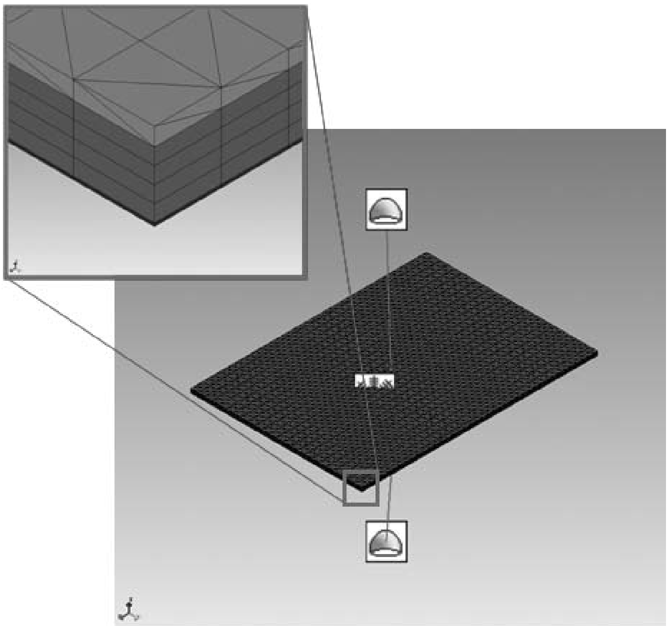

Figure 8. Hybrid FE-SEA-PEM model of a trimmed panel.

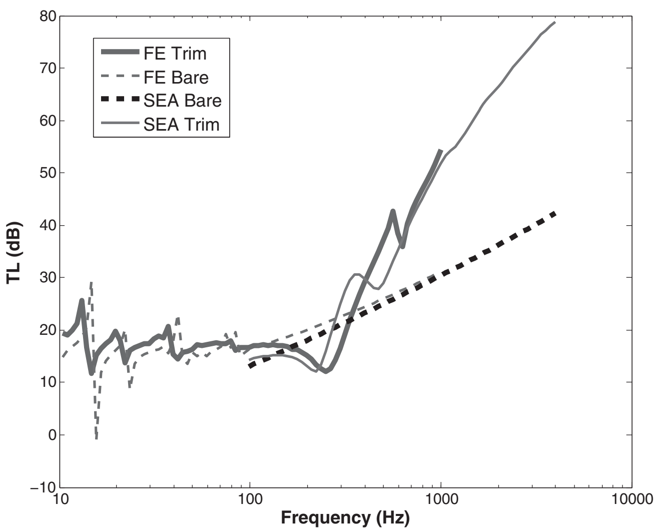

Figure 9. Comparison of the transmission loss obtained from pure SEA and Hybrid FE-SEA-PEM models for an untrimmed and a trimmed panel.

The results for the TL of the trimmed and untrimmed panels are presented in Fig. 9. 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.

MODELLING 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 characterise 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 Figs. 10 and 11. 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).

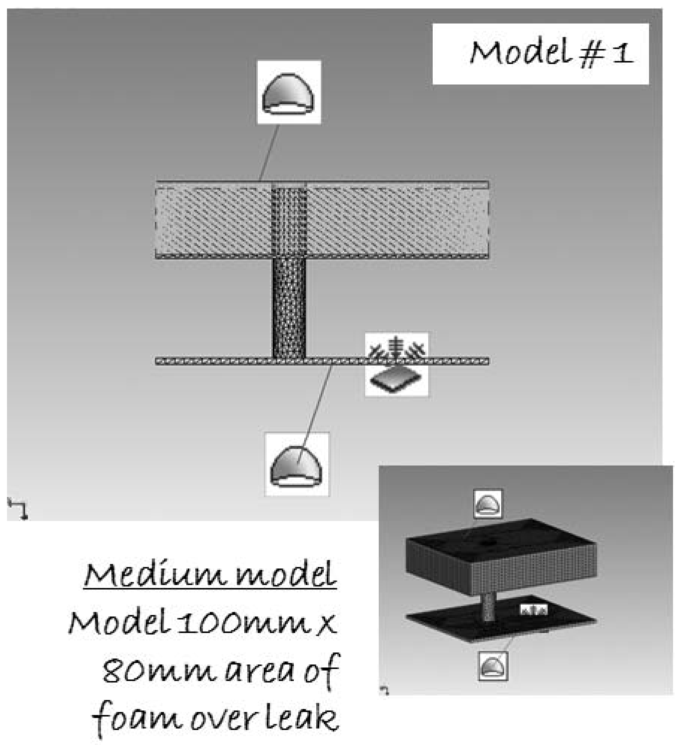

Figure 10. Hybrid FE-SEA model of trimmed leak (medium sized model).

For the two models, the dimensions of the cut-out were chosen to be 100mm×80mm and 50mm×30mm, respectively. The TL from both models is presented in Fig. 12 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.

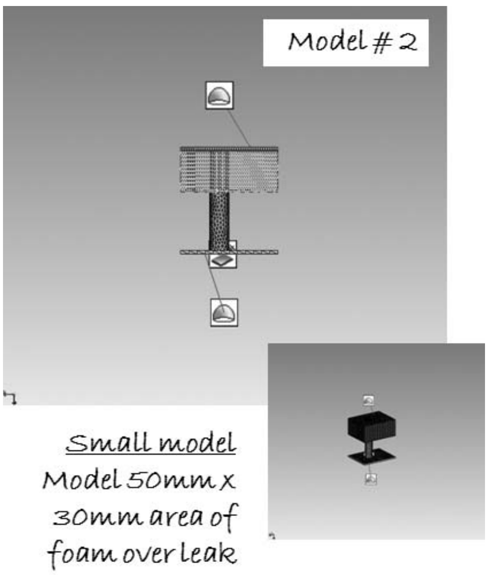

Figure 11. Hybrid FE-SEA model of trimmed leak (small model).

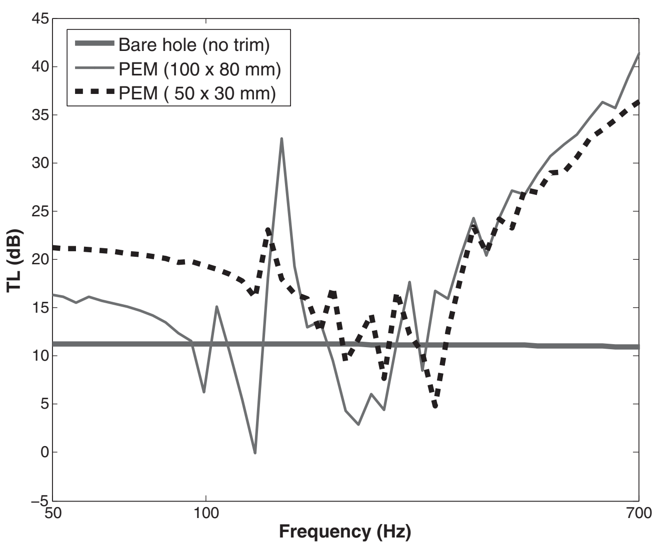

Figure 12. Comparison of the TL of a trimmed leak predicted by Hybrid models (frequencies over 300 Hz of interest for typical leak).

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 was 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.

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REFERENCES

[1] R.H. Lyon and R.G. DeJong, *Theory and Application of Statistical Energy Analysis*, Butterworth-Heinemann, Newton, MA, 1995

[2] R.J.M. Craik, *Sound Transmission through Buildings using Statistical Energy Analysis*, Cambridge University Press, UK, 1996

[3] A. Charpentier, D. Blanchet and K. Fukui, "Full Vehicle SEA Model Uses Detailed Sound Package Definition To Predict Driver's Headspace Acoustic Response", *Proc. INTER-NOISE 2004*, Prague, Czech Republic, 22-25 August 2004

[4] M.C. Gomperts, "The sound insulation of circular and slit-shaped apertures", *Acustica* **14**, 1-16 (1964)

[5] P.J. Shorter and R.S. Langley, "Vibro-acoustic analysis of complex systems", *J. Sound Vib.* **288**(3), 669-700 (2005)

[6] 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)

[7] VA One 2010, © The ESI Group, www.esi-group.com

[8] N. Atalla, R. Panneton and P. Debergue, "A mixed pressure-displacement formulation for poroelastic materials" *J. Acoust. Soc. Am.*, **104**(3), 1444-1452 (1998)

[9] J. Cordioli, V. Cotoni and P. Shorter, "Numerical investigation of the transmission loss of seals and slits for airborne SEA predictions", *Proc. SAE NVH Conference*, 19-21 May 2009, St Charles, Illinois, USA, SAE 2009-01-2205

[10] 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)