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Development of a Modeling Technique for Vehicle External Sound Field Using SEA

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Abstract [461] In Statistical Energy Analysis (SEA), the sound field in an acoustic subsystem is assumed to be diffuse and reverberant, that is, there is an equal probability for a wave to travel in any direction with equal wave intensity. Although this has proven to be an efficient way of modeling the interior space of a vehicle [1], it is less suitable for external cavity modeling. The main reasons include: a) high directivity pattern of sources such as tire/road noise, b) grazing angle of incidence of sound waves on some vehicle panels and c) shadowing effects resulting from the geometry of the vehicle. This shadow effect can be modeled in an SEA model in order to account for the geometry of the vehicle and any change in direction of the acoustic wave field. This paper addresses the latter by proposing a new modeling technique that corrects the coupling loss factor (CLF) of exterior acoustic subsystems based on vehicle geometry. The method presented is also validated with experimental data measured in a semi-anechoic chamber. Correlation levels suggest that this technique is an effective way to model the external vehicle sound field and is a good addition to other widely accepted SEA modeling techniques.

1 INTRODUCTION

SEA is widely used in the design of automotive sound packages. During the design process of a sound package, it is necessary to build an SEA model and validate the model against experimental data. The most reliable way of validating the SEA model is to enforce the pressure field all around the vehicle and compare the predicted and measured SPL inside the vehicle. In many cases, once the validation is completed, it is necessary to change the source level, location and the sound package content in order to meet preset targets. This involves A to B comparisons and the use of pressure constraints on the exterior acoustic subsystems is not flexible enough in this case. In order to use the SEA model to predict the external sound field, some modifications must be applied to the model. This paper discusses the ability to use an SEA model to predict the diffusion of energy around a vehicle and proposes a simple method to correct for diffraction effect observed.

2 DESCRIPTION OF THE CONFIGURATION

In this study, a 4door sedan is located in a semi-anechoic room and the external sound field is measured and predicted under controlled excitation. Measurements were done for the driver side only and from the "lower" to "upper" acoustic space around the vehicle as shown in *Figure 1*. The targeted acoustic spaces to validate are the external acoustic subsystems in contact with the windshield, front roof, rear roof and backlite (*Figure 2*).

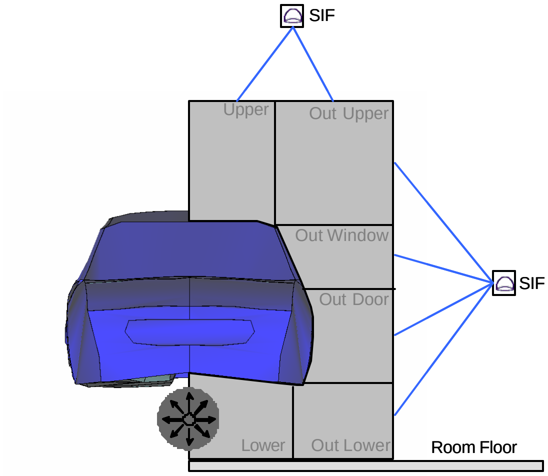

Figure 1: Schematic of the vehicle setup.

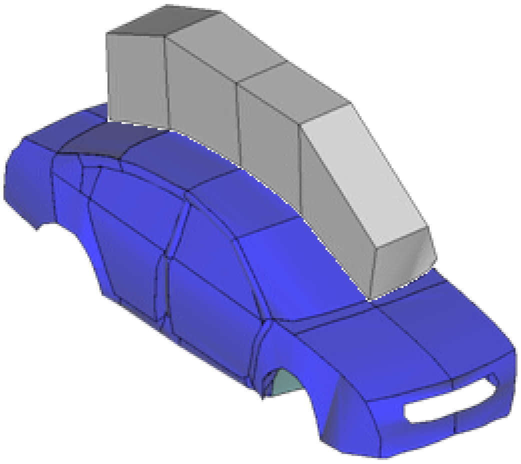

Figure 2: Targeted acoustic subsystems

2.1 SEA Modeling

A full vehicle SEA model was built using AutoSEA2® and following the guidelines described in [2]. The vehicle external sound field is traditionally modeled as a set of acoustic subsystems located all around the vehicle. To model the rest of the semi-anechoic room, a series of semi-infinite fluids (SIF) are connected to all faces of the acoustic subsystems except those facing the floor. The SIFs model the anechoic termination provided by the anechoic part of the room.

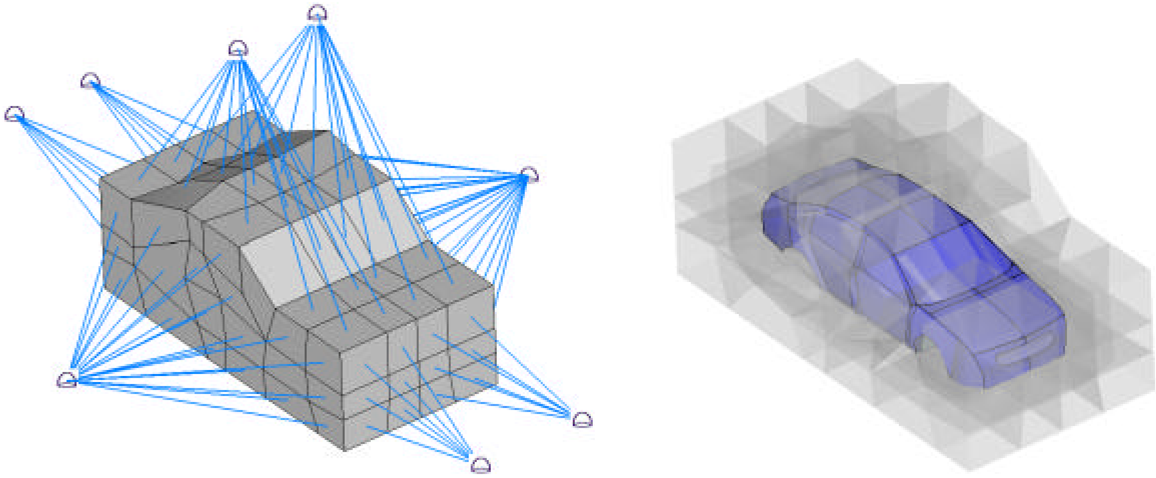

Figure 3: SEA model of external sound field modeled using acoustic subsystems for area close to the vehicle (right) and anechoic termination farther away from the vehicle (left).

This model was validated for headspace internal acoustic response using external acoustic subsystems with constrained pressure levels. Validation results are available in [2]. It was then used to predict the diffusion of energy around the vehicle by removing the constraints on the external acoustic subsystems and therefore predicting the SPL in the external acoustic subsystems. All damping in the acoustic subsystems were set to a value corresponding to an average absorption of 1%. To represent the sources used during testing, the "Lower" front and rear acoustic subsystems are constrained to the SPLs recorded during testing.

2.2 Experimental setup

The vehicle was located in a semi-anechoic chamber and jacked-up at approximately 15 inches from the floor to allow loudspeakers to be placed underneath the vehicle. The SPL was recorded at multiple locations all around the exterior and underbody of the vehicle (Figure 4 and Figure 5). Typically, two to three microphones per acoustic space are used in order to obtain an estimate of the space averaged SPL in each subsystem. Test results are presented in the next section along with SEA predictions.

Figure 4: Speakers underneath center of vehicle

Figure 5: SPL sensor and speaker locations

3 VALIDATION RESULTS

3.1 Propagation using analytical CLF

First, the predicted external acoustic subsystem SPLs are compared with test results. These predictions are done using the classical acoustic to acoustic coupling loss factor (CLF) formulation, the default option in AutoSEA2® [3]. Results shown in *Figure 6* are for the exterior cavities adjacent to the front seat row section of the vehicle. It shows that from the "Lower" to the "Out Upper" location, the SEA model can predict with reasonable accuracy the acoustic response. Here, reasonable accuracy refers to the fact that a simple model is used to model a highly complex sound field where many different physical phenomena are involved. This level of correlation is considered sufficient to trust *A* to *B* comparisons when design changes influence the energy flow in the vehicle or when the source location is modified

It can also be observed that the SEA model cannot predict satisfactorily the change in SPL from the "Out Upper" to the "Upper" acoustic subsystem correctly. In this case, there is a drastic change of direction in the energy path and since SEA considers the sound field in an acoustic subsystem to be reverberant and diffuse, it does not account for this change in direction (shadowing effect). SEA basically considers all cavities shown in *Figure 1* as being assembled in a straight line.

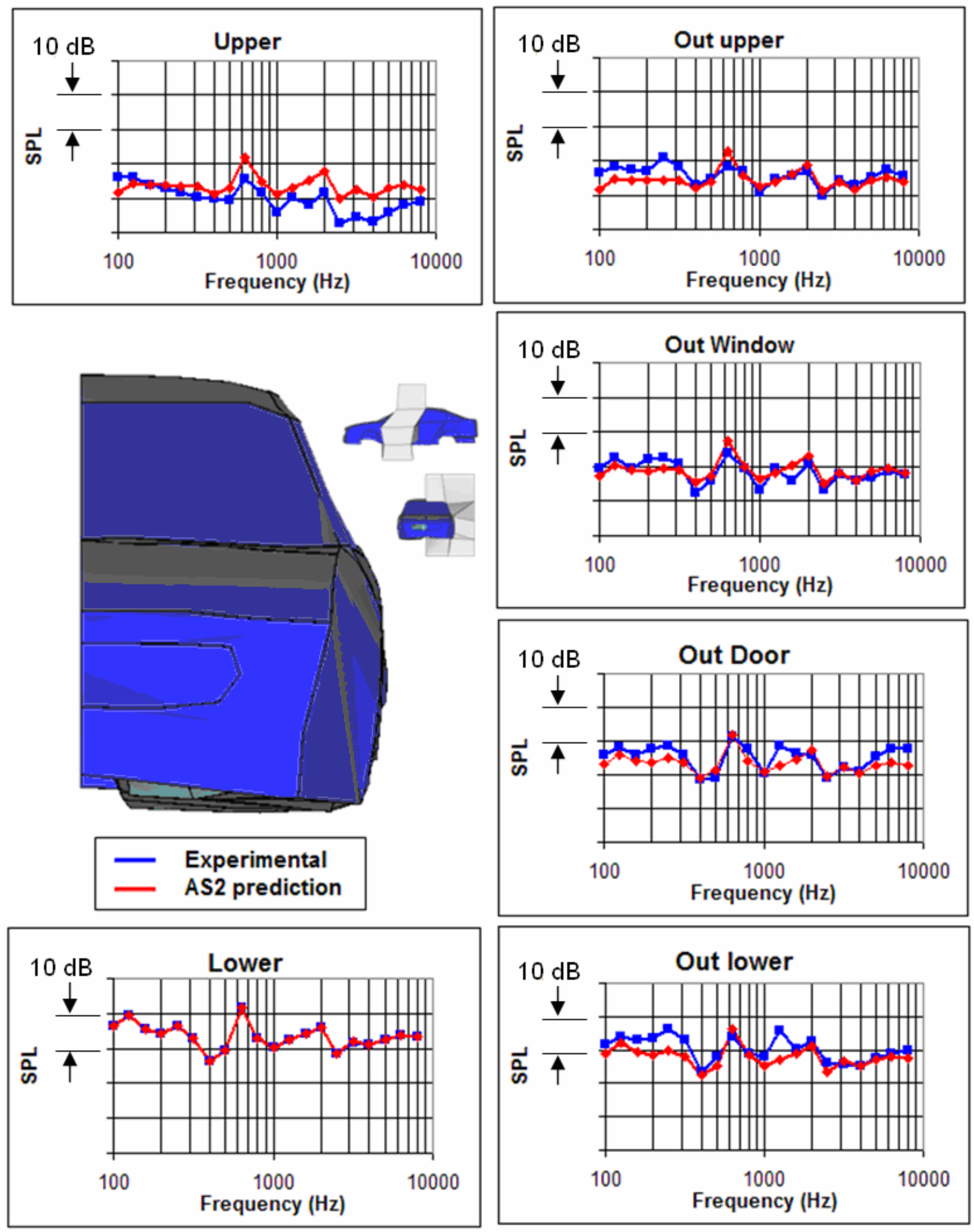

Figure 6: Validation results for front seat row exterior acoustic subsystems

The experimental results in *Figure 7* clearly show that the shadowing effect introduces a frequency dependent phenomenon that decreases the SPL in the "Upper" acoustic subsystem. This observation is confirmed in *Figure 8* and *Figure 9* where the experimental results are shown for selected frequency bands and where deltas between "Out Upper" and "Upper" acoustic subsystems are computed and plot against those frequencies.

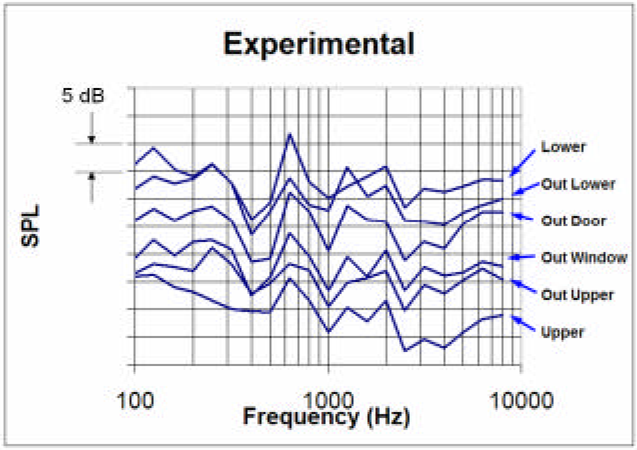

Figure 7: Experimental results for front seat row exterior acoustic subsystems

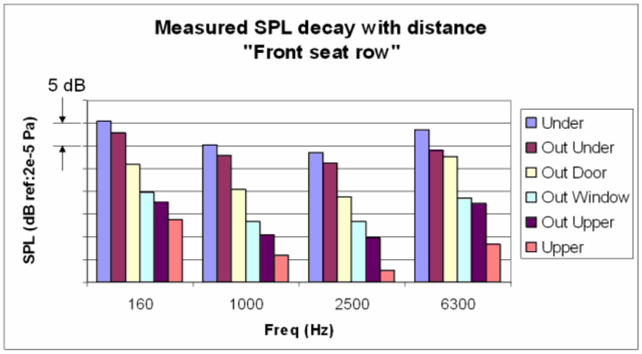

Figure 8: Decay of SPL from one acoustic subsystem to the other

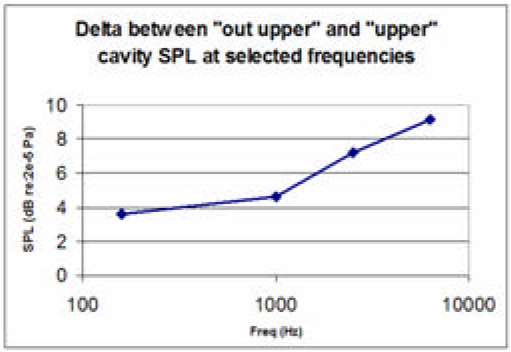

Figure 9: Decay of SPL between "Out Upper" and "Upper" acoustic subsystem

3.2 Correction for shadowing effect

It is therefore necessary to introduce a correction to the predicted SPL in the “Upper” acoustic subsystem. One simple way to correct the amount of energy entering this cavity is to reduce the CLF between the 2 cavities in question. The corrected CLF must decrease the level of energy entering the “Upper” subsystem as frequency increases. It has been found that a line junction formulation provides the appropriate slope to the CLF. This formulation is consistent with modeling the acoustic diffraction around the body edge as a line source.

From the modal approach formulation for line junction CLF found in [4], one can derive the following expression for a line CLF between 2 acoustic subsystems where $k_1 = k_2$:

$$\bar{h}_{12}^{line} = \frac{L_j k}{4 p w n(w)} \frac{b_{corr}}{2^{1/4}} \tag{1}$$

where **L_j** is the length of the line junction (edge acting as an line source), **k** is the wavenumber of the acoustic subsystems, *w* is the frequency of oscillation, ***n(w)*** is the modal density of the initial acoustic subsystem and b_{corr} is a correction factor. *Figure 10* shows a comparison between analytical acoustic to acoustic CLF based on area junction and corrected CLF using line junction formulation for different values for $b_{corr.}$ In order to determine which value of the correction factor should be used, the new CLFs for b_{corr} values of 0.1, 0.5, 1, 5 and 10 were applied to the junctions of the SEA model as shown in *Figure 11* replacing the default CLF values.

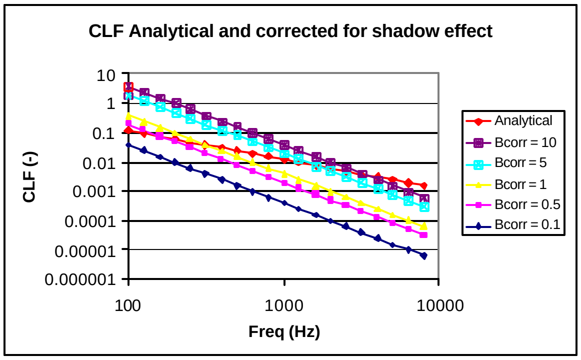

Figure 10: Comparison between analytical area junction CLF and different values of b_{corr} for the corrected CLF

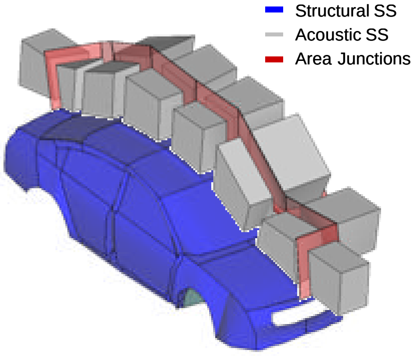

Figure 11: Area junctions where CLF are corrected (only driver side shown for clarity)

Results for different correction factors are presented in *Figure 12*. It can be shown that a correction factor of 1 is appropriate to properly correct for the diffraction effect from the "Out upper" and the "Upper" acoustic subsystem.

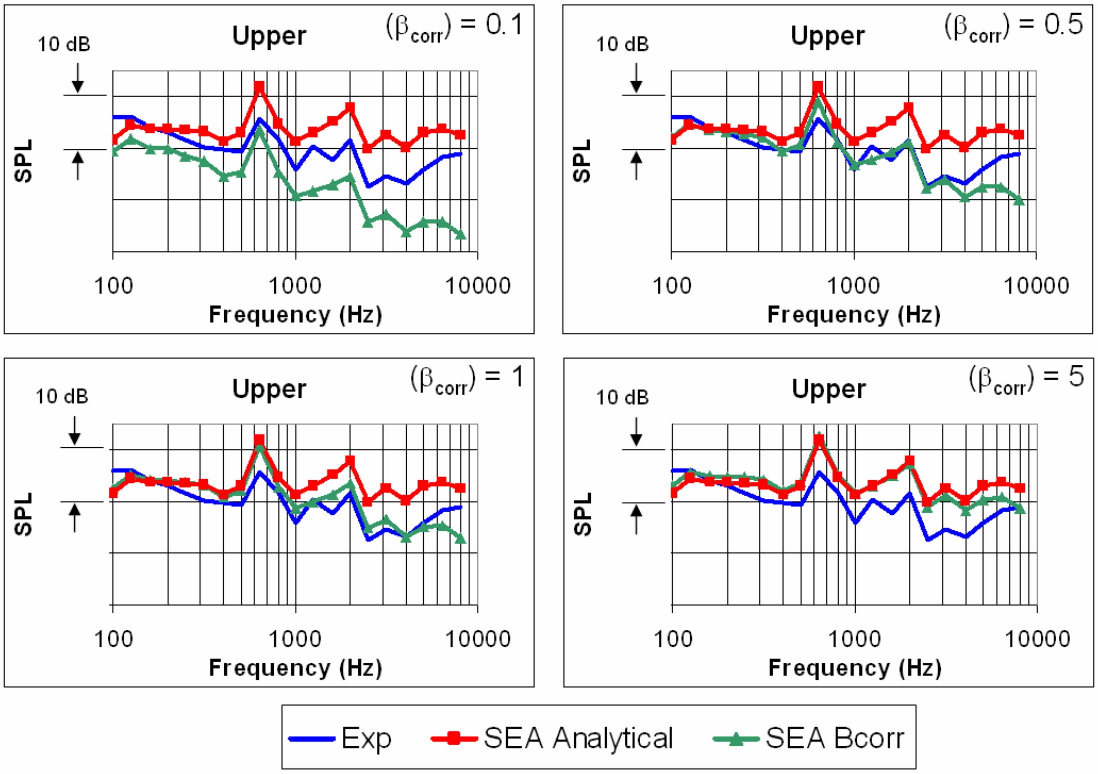

Figure 12: Comparison of different CLF correction factors on "Front seat row Upper" acoustic subsystem SPLs

Validation results for the other targeted acoustic subsystems show similar correlation levels and suggest that this method can be used to model the diffraction effects for the windshield, front and rear roof and backlite acoustic subsystems (Figure 13).

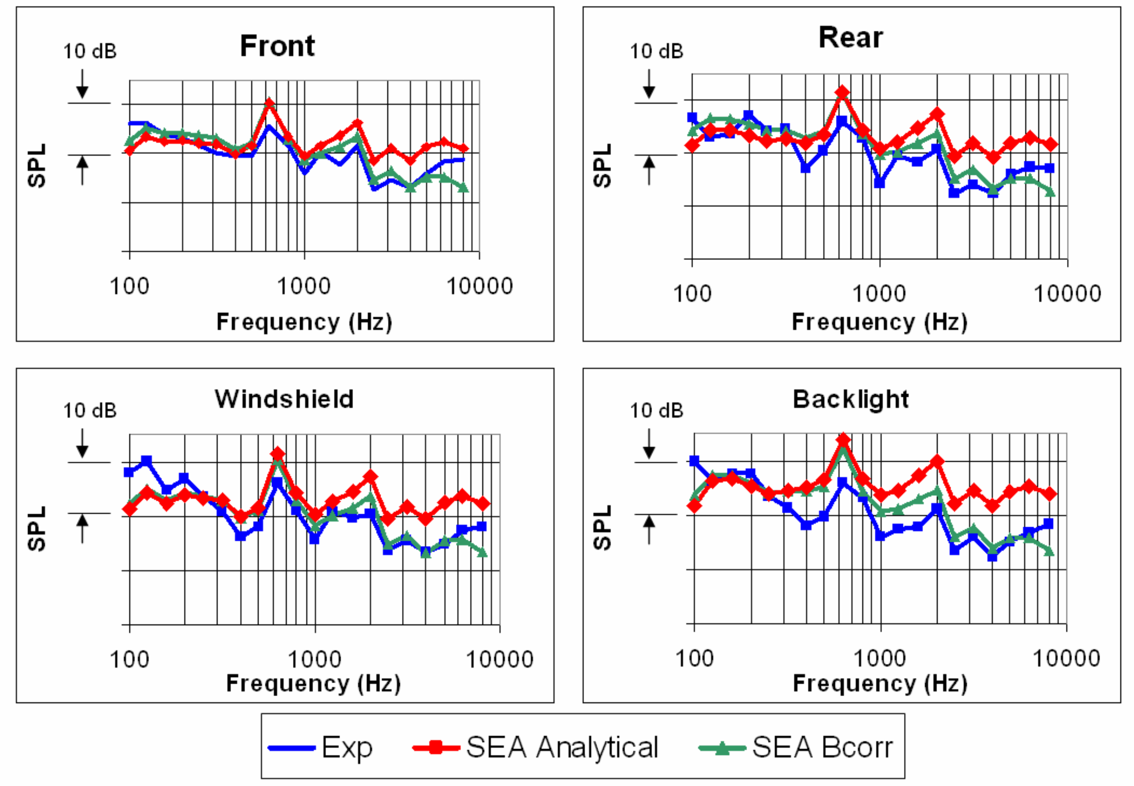

Figure 13: Targeted exterior cavity SPL correlation using $b_{corr} = 1$.

4 CONCLUSIONS

The diffusion of energy predicted from an SEA model was compared with test. It was demonstrated that for some location around the vehicle, the classical SEA model was unable to predict the right level of energy. A method to account for the shadowing effect that occurs between the side and the top of the vehicle external acoustic subsystem was presented.

ACKNOWLEDGEMENTS

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REFERENCES

[1] F.J. Fahy, "A note on the subdivision of a volume of air in a vehicle enclosure into sea subsystems", *J. Sound Vibrat.* 271 (3-5), pp. 1170-1174, (2004)

[2] A. Charpentier, D.Blanchet and K. Fukui, Full Vehicle SEA Model Uses Detailed Sound Package Definition To Predict Driver's Headspace Acoustic Response, in Proceeding of Internoise 2004, Prague, 2004

[3] AutoSEA2 Theory Manual, Vibro-Acoustic Sciences, Inc., Revision 0. March 2001.

[4] R. Lyon and R. DeJong, "Theory and Application of Statistical Energy Analysis", Butterworth-Heinemann, 1995.