03NVC-172

SEA for Design: A Case Study

Allan C. Aubert
Roush Industries, Inc.

John T. Long
Ford Motor Company

Mark J. Moeller
MUG, llc.

Robert E. Powell
Ford Motor Company

ABSTRACT

This paper reports on a case study involving the use of SEA methods in the acoustic design of an advanced design luxury sedan. The power of the analytical method was used to advantage in a case of a vehicle with very challenging NVH targets. Three practical issues are highlighted; review of a method to handle adding components that contribute acoustic absorption, presentation of data to aid vehicle content decisions, and design sensitivity analysis. This effort demonstrates an example in which SEA modeling provided relevant and timely input to the vehicle design team to aid decision making for sound package content.

INTRODUCTION

An advanced design vehicle development effort was undertaken, the NVH design goal being to develop a prototype luxury sedan with properties that would be as good as, or better than the Best in World. Untraditional approaches to achieve this result were allowed, in an effort to discover what technologies needed to improve in this highly competitive market. The challenges to improve performance for road noise were seen to be some of the greatest in this effort. Consequently, a team was assembled which attacked these issues using both experimental and Statistical Energy Analysis (SEA) methods [1-7]. For several manufacturers, it is not common to rely heavily on SEA at an early enough stage to have its results give practical design guidance. This effort was accelerated and focused in its direction to make the highest priority be to support design team decision-making.

At an early stage, it was decided that the SEA modeling would address acoustic forcing and response only, and would neglect structural forcing inputs. These were to be handled by other analytical efforts, using other methods. The primary forcing cases investigated were due to tire / road noise, and the team would only address tailpipe and engine compartment noise as a second priority. The tire noise case used in the reported results involved inputs from all four wheel areas, and was derived from data taken at 45 mph on a smooth test track.

Response location priority was focused on the driver's head space, followed by front and rear passenger head spaces.

This paper reports on three techniques which were found to improve the usefulness, ease of model preparation and timeliness of the SEA results in their benefit to the decision makers of the vehicle sound package design team.

PRESENTATION OF SEA RESULTS

PRIORITIZATION OF SOUND PACKAGE CONTENT

The design team began work starting from a recent model year, production luxury sedan. The SEA model team was able to obtain an SEA model which was nearly representative of this vehicle. Brief early effort was focused to bring the baseline SEA model into correlation with the baseline development vehicle. Targets were set which required extensive improvement in the road noise performance of the vehicle.

Previous modeling efforts would present results in terms of the improvement in response that a candidate modification would produce as compared to the baseline. Because of the drastic changes envisioned, the SEA team realized that this method of assessing the effectiveness of treatments would not lead to the correct conclusions as to whether treatments were needed in order to meet the final targets. A treatment could be shown as ineffective in the baseline vehicle, and yet become very effective when other treatments had changed the balance of acoustic power flow in the system.

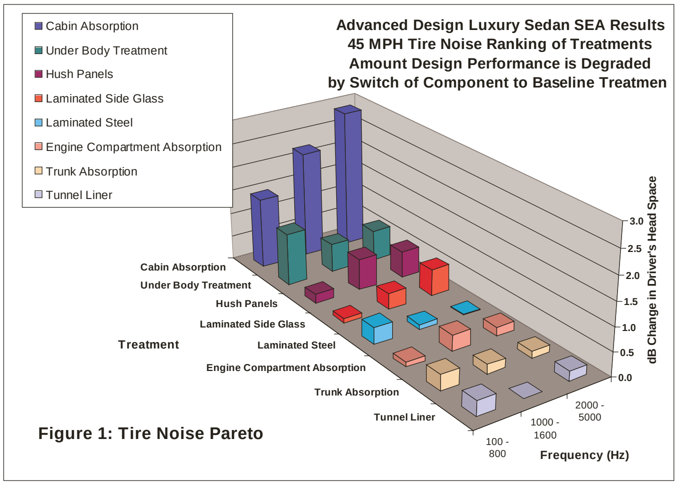

Figure 1: Tire Noise Pareto

A bar chart “pareto” approach was chosen to present model results to the vehicle design team. This approach would display results of a “Max Pack” vehicle, or one which had installed in the SEA model the most effective treatments which were envisioned for the final vehicle. Then the pareto would show the penalty in final vehicle performance experienced by choosing to not include that treatment in the final sound package design. This approach takes advantage of the unique feature of SEA modeling, that sweeping design changes can be rapidly made to an SEA model because of the relatively small amount of information in the model as compared to FEA or other methods.

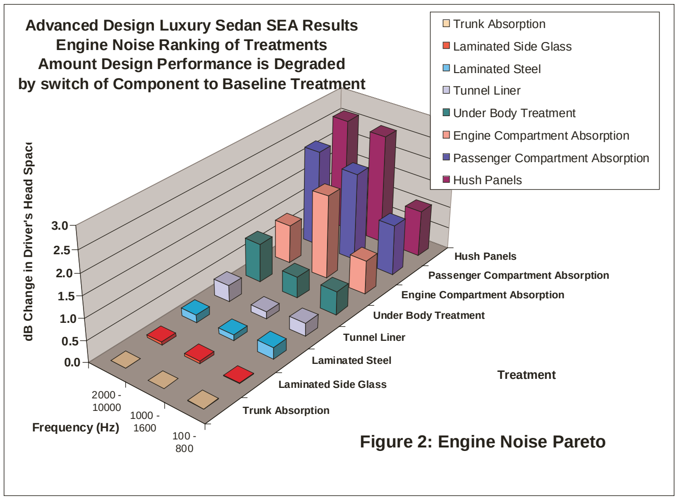

Figure 2: Engine Noise Pareto

Figures 1 and 2 show the final pareto charts for the tire noise and engine noise cases.

In the Figure 1, for tire noise inputs, the pareto chart says that a design decision which leaves the acoustic absorption of the cabin at the baseline levels would degrade the final vehicle performance by 3 dB in the high frequency range. Next in importance is under body treatments. In Figure 2, for engine noise inputs, to remove hush panels from the design would raise the noise levels in the mid- and high frequency ranges by 3 dB. Cabin absorption is the next most crucial design change for this noise source. Since hush panels work to seal the dash and instrument panel space, it is reasonable that they are a significant contributor to cabin noise attenuation in a well-treated vehicle for the engine noise case. However, this result quantified for the vehicle design team the importance of these panels. Earlier data derived from adding them to a baseline vehicle indicated that they added very little to cabin noise performance. However, the SEA team’s conclusion was that the energy flow path treated by the hush panels had become dominant because other treatments found in the fully treated vehicle had reduced the dominant paths of the baseline vehicle.

BOOK KEEPING OF ACOUSTIC ABSORPTION

Acoustic absorption was seen to be at or near the top in importance, among all treatments for the acoustic performance of the vehicle, in all the load cases investigated. The SEA team discovered that proper tracking of sources of acoustic absorption, and assignment of the absorption to the correct acoustic spaces, was a serious issue for a complex SEA model. A book keeping method is needed for this tracking which allows a straightforward way to assign absorption from new treatments applied in a design change. This is an area of SEA modeling which commonly leads to input errors. Though the authors realize that this is not a completely new concept [8], the method chosen to track absorption is here presented.

Sample Absorption Spreadsheet				
Engine Compartment Rear Driver's Side				
Subsystem ID#	10087			
Material ID#	1187			
Treatment=>	Added Hood liner	Measured Engine Compartment Absorption	Added Dash Liner	**New Total Absorption Area:**
Absorption Area =	2.55E+05	2.87E+05	7.00E+04	**6.12E+05**
Frequency	***Alpha Values***			***New Alpha:***
125	0.041	0.3100	0.0210	**0.165**
250	0.094	0.3100	0.0750	**0.193**
500	0.180	0.3100	0.2130	**0.245**
1000	0.383	0.6800	0.4180	**0.526**
2000	0.805	0.7600	0.6020	**0.761**
4000	0.948	0.8800	0.7780	**0.897**
8000	0.924	0.9050	0.8570	**0.907**

Table 1: Absorption Tracking

Absorption spreadsheets were developed to both document and ease the updating of absorption values for the key interior acoustic spaces in the vehicle SEA model. The particular challenge comes that the subdividing of the passenger cabin, engine compartment and trunk, each into multiple air spaces, complicates the computation of acoustic absorption. Treatments typically span the boundaries of more than one acoustic space, while spaces commonly have absorption contributions from more than one treatment. In addition, measurements were made which provided absorption data as a function of frequency for these various treatments. A sample acoustic absorption table is presented in Table 1.

Acoustic absorption from multiple sources follows the simple equation below. Sα is the total acoustic absorption in metric Sabines.

$$S\alpha = \sum_i S_i \alpha_i \tag{1}$$

S_i is the absorbing surface area of treatment i, and α_I is the acoustic absorption coefficient of that absorbing area i. The SEA input accepts S, the total absorbing area for an acoustic space, and α, the absorption coefficient of that area, which may be frequency dependent. The spreadsheet in Table 1 makes use of this relation to first compute the combined area of absorbing treatments, and then makes use of that area to compute the needed frequency dependent α (alpha, or absorption coefficient) to give the right total acoustic absorption to the space.

DESIGN SENSITIVITY ANALYSIS

A special version of one of the major US SEA codes has been developed to support design sensitivity analysis (DSA). This automates the process of performing several runs on a model with slightly different values of a design parameter, to determine the sensitivity of the final result to changes of this parameter. Full optimization in a design space can be performed by choosing a set of design variables to optimize over, and assigning cost functions to each one. Then the code will search through the range of allowable values for each design variable to minimize the cost and maximize the performance of the design.

The SEA team reached a point where the more obvious treatments had been chosen and implemented in the design of the luxury vehicle. Yet the performance objectives had not been met. It was decided to perform a design sensitivity analysis in order to look for the most sensitive parameters in the vehicle acoustic design, in order to prioritize further efforts to achieve the acoustic targets. A brainstorming session was used to list all model variables that were thought to have any significant influence on the vehicle acoustic noise attenuation (ANA). A list of 30 key variables was developed. The DSA software then needed to be fed the information of which parameters in the SEA model defined each model design variable. Variables included panel thicknesses, areas, and absorption values. The DSA analysis is also affected by the load case used.

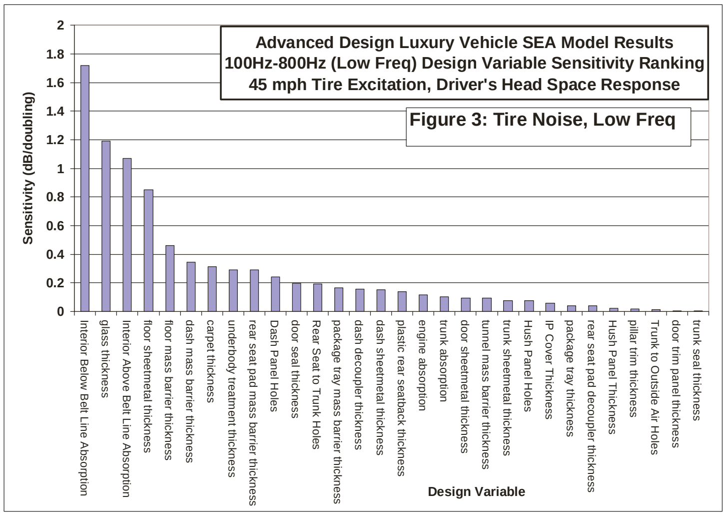

Figure 3: Tire Noise, Low Freq

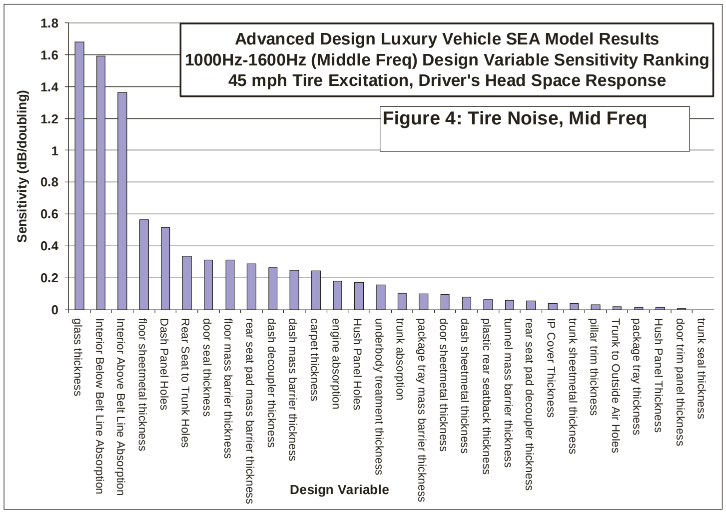

Figure 4: Tire Noise, Mid Freq

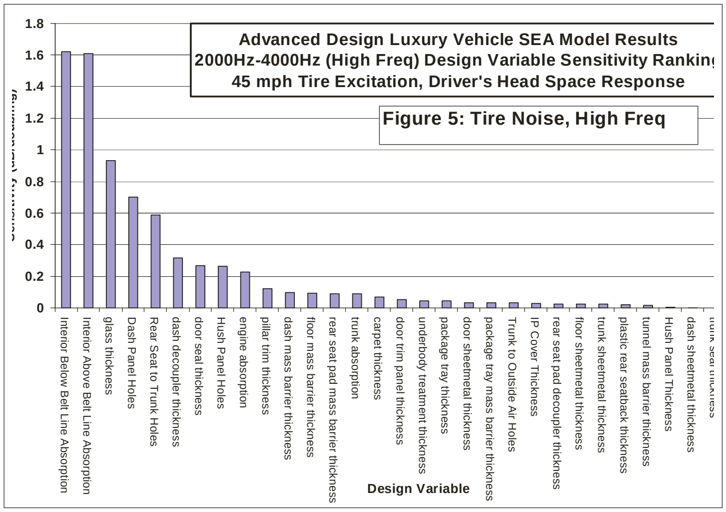

Figure 5: Tire Noise, High Freq

Figures 3 – 5 show the DSA results for the Tire noise load case in the three frequency regions. The scale of the bars is the number of dB's the noise level in the driver's head space would change with a doubling of the property. In Figure 3, the most sensitive parameter is the interior absorption below the belt line, which would drop the head space acoustic response by about 1.7 dB with a doubling of the absorption.

Cabin absorption has been broken into two separate bars, and otherwise would be the dominant factor in all frequency ranges. In the mid-frequency range, the glass thickness jumps ahead, while at high frequencies, absorption ranks first and second.

Another use of this analysis is to see which factors have little effect on the performance of the sound package design. These items appear on the right side of these bar graphs, and represent items that could be reduced or omitted for the sake of weight or cost savings without degrading performance.

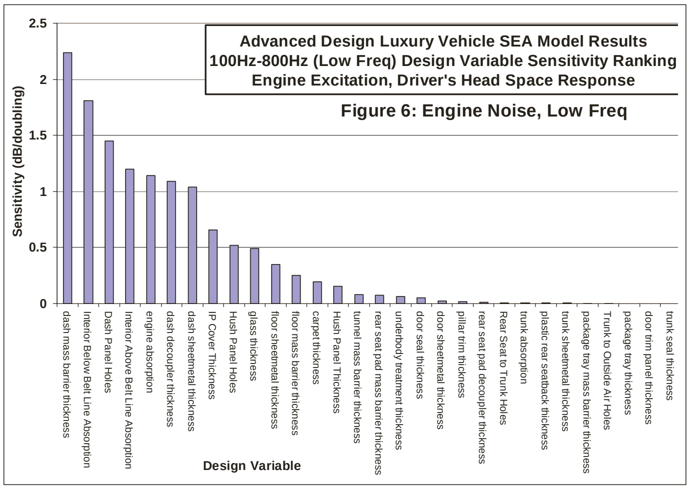

Figure 6: Engine Noise, Low Freq

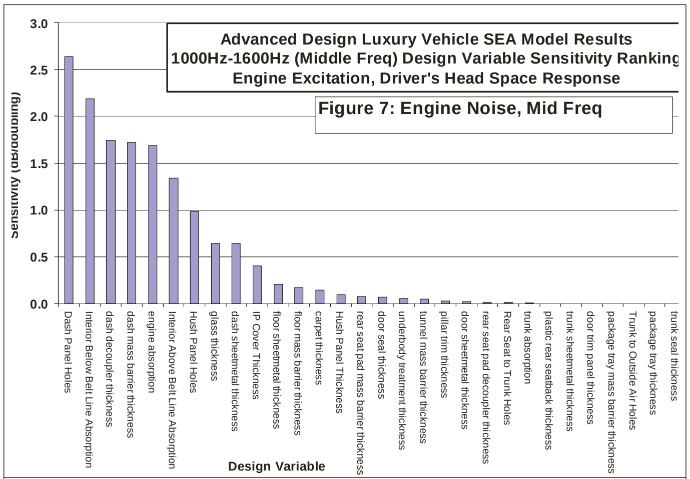

Figure 7: Engine Noise, Mid Freq

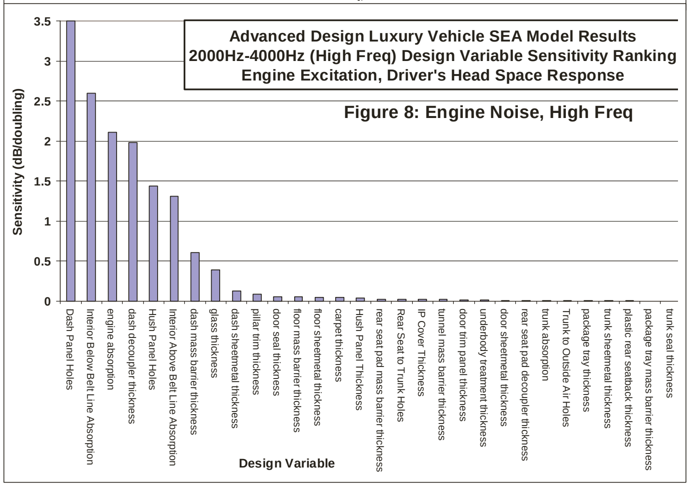

Figure 8: Engine Noise, High Freq

However, items that have little effect for one load case may, in fact, be dominant for other load cases.

Figures 6 – 8 show the DSA results for the engine noise load case. It is interesting to see that dash panel holes are a dominant sensitivity at high frequencies, yet decrease rapidly at lower frequencies. Absorption is a key sensitivity in this load case as well as in the tire noise load case. Again, if all cabin absorption were lumped together into one variable, it would be the dominant one in all frequency ranges.

DSA results were seen here to provide useful direction to the vehicle design team in their quest to achieve difficult acoustic performance targets.

CONCLUSION

This paper presented a case study in the use of SEA methods to assist in the acoustic design of an advanced design luxury sedan. Several lessons learned were presented.

A “pareto” approach to presenting the relative effectiveness of treatments as compared to an analytically developed “Max Pack” treatment gave important clues as to the importance of various treatments at an early stage in the design. The fact that this analysis was performed and presented in under a week showed the power of SEA methods for rapidly answering design questions.

A method for book-keeping of the acoustic absorption for important acoustic spaces was presented. The key cabin space in an automotive SEA model is typically subdivided into several space subsystems. This complicates the application of acoustic absorption from treatments that may span the boundaries of several acoustic subsystems.

A design sensitivity analysis was run, and the results presented. This analysis method provided very helpful direction late in the program to assist in the final stages of meeting very challenging noise targets.

ACKNOWLEDGMENTS

The authors wish to acknowledge the support, direction, and work provided my many other individuals during this lengthy effort. Many thanks go out to Rob Unglenieks of Johnson Controls for much of the measured data used in this report. Also, Kevin Blauwkamp of Johnson Controls provided many hours of effort in managing the original effort for JCI. Finally, thanks for the SEA modeling efforts and creativity of Jeremy Lipton of Roush, and Rob Crawford (now of Toyota).

REFERENCES:

1. R.G. DeJong. ,” A study of vehicle interior noise using statistical energy analysis”, SAE paper 850960, 1985.
2. M.J. Moeller and R.E.Powell, "Review of statistical energy analysis (SEA) applied to the automotive industry 1985 to 1997", Noise-Con 98.
3. Thomas, R.S., Pan, J., Moeller, M.J. and Nolan, T., `Improving SEA Models Using Quality Technology,` Noise Control Engineering Journal, January, 1997.
4. Huang, X., Moeller, M.J., Lee, J, and Powell, R.E., `Application of Statistical Energy Analysis (SEA) to the Development of a Light Truck Sound Package,` IUTAM Symposium on Statistical Energy Analysis, July 1997.
5. Wang, D, Goetchius, G., and Onsay, T, ‘ Validation of a SEA Model for a Minivan: Use of Ideal and Structure-Borne Sources,’ SAE Noise and Vibration Conference, SAE Paper 1999-01-1697, Traverse City, Michigan, May 1999.
6. Bharj, T., Lee, J.J., DeJong, R., and Keller, T., ‘Accuracy of Statistical Energy Analysis (SEA) Model to Evaluate Vehicle Noise Concerns,’ Internoise, Fort Lauderdale, FL., Dec. 1999.
7. Moeller, Mark J., Thomas, Robert S., and Powell, Robert E., “An Assessment of SEA Model Quality,” SAE Paper 2001-01-1624, Traverse City, Michigan, 2001.
8. S. Wang, G. Ebbitt, R. E. Powell, "Development of a Generic Truck SEA Model with EFEA – SEA Hybrid Exterior", Proceedings of Inter-noise 2002, N369, Dearborn, Michigan, August, 2002.