inter-noise 2002

The 2002 International Congress and Exposition on Noise Control Engineering
Dearborn, MI, USA. August 19-21, 2002

Modeling Vibro-Acoustical Behavior of Cockpit Module Using Statistical Energy Analysis (SEA) Method

Lijian (Lee) Zhang
Delphi Automotive System
5725 Delphi Drive, Troy, MI 48098

Denis Blanchet
Vibro-Acoustic Sciences, Inc.
36800 Woodward Ave, Suite 210, Bloomfield Hills, MI 48304

Abstract

To predict the vibro-acoustical behavior of a vehicle cockpit module, a statistical energy analysis (SEA) model was developed using *AutoSEA2*™. This model was constructed to simulate a complete cockpit, including instrument panel, steering system, HVAC, close-out panels, center console with radio and HVAC controls, instrument cluster, and airbag unit. The model was validated via experimental testing. Noise path analysis and design sensitivity analysis were conducted to understand the effect of various design configurations on system vibro-acoustic behaviors. The key advantage of this approach is to predict acoustical performance of the product in the early design phase in an effective and efficient way, which will significantly reduce cost and design lead-time, and improve OEM customers' satisfaction.

1. Introduction

In automotive industries, sound quality and noise related issues have become increasingly important in the past few years. Customers continuously demand products with superior performance and better sound quality at a lower cost. These requests continuously challenge us not only to develop products that meet the customers' needs, but also to deliver them with shorter development cycles at lower costs. For this reason, applications of modeling tools become more important and effective in product development cycles. Statistical Energy Analysis (SEA) is such a tool that allows us to predict and optimize system vibro-acoustical performance in early design phase [1,2]. Using SEA technique, certain acoustical performance can be tested virtually, as soon as the design (geometry and material properties, *etc.*) becomes available. The advantage is not only to reduce design lead time and cost, but also to improve design optimization by selecting the design with the best performance at the lowest cost.

The challenge of SEA application is to develop a valid model that best represents the acoustical behavior of a product, and this challenge becomes even more significant in modeling a system or a subsystem such as a cockpit, comparing to the simulation at vehicle level. To simulate the vibro-acoustical behavior of a cockpit, Delphi Automotive Systems and Vibro-Acoustic Sciences, Inc. have teamed up to develop an SEA model for this purpose. This model is to simulate a complete cockpit, including instrument panel and related trim package, steering system, HVAC, close-out panels, center console with radio and HVAC controls, instrument cluster, and airbag unit. The model is to be used as a template for SEA modeling of any future cockpit products. This article describes the development process and findings.

2. SEA model

The *AutoSEA2*^{TM} software package was used as the primary tool in this project. It was specifically developed for vibro-acoustic design evaluation using a modern graphical user interface and a robust SEA solver [3,4]. The SEA model was created from FEA/CAD geometry data. The model represents primarily airborne paths. Subsystems defined in the model include: instrument panel, knee bolster, closeout panels, HVAC unit, interior cavities, vent ducts, and finally, source and receiver room cavities for transmission loss prediction. The final SEA model contains close to 100 structural subsystems, 12 acoustic subsystems for a total of 325 wave fields modeled.

Figure 1 presents a 3D view of the cockpit module. Black lines represent edges of subsystems. Generally, components of the cockpit shell were modeled as singly curved shell to provide a good representation of the actual geometry of the IP.

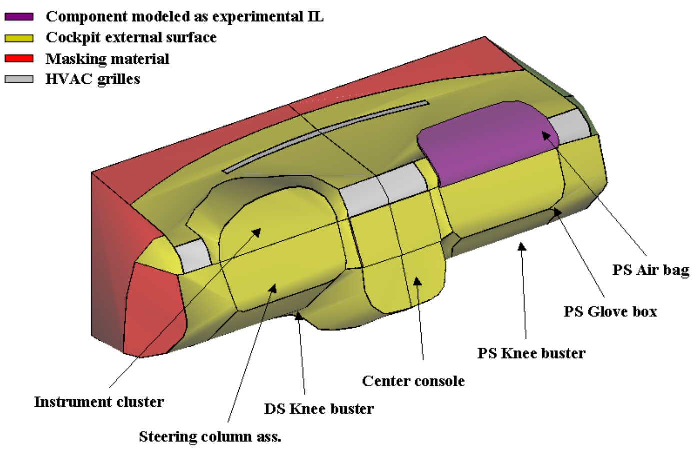

Figure 1: SEA model of the cockpit module

Some components of the cockpit are not easily modeled as SEA subsystems. For the components that are unique and cannot be accurately modeled with the traditional method, a separate transmission loss (TL) test was performed for each of these components and the resulting spectrum was assigned to the appropriate area junction of the SEA model [1].

Inside the IP, the HVAC unit with attached ducting and the glove box volume are modeled independently. Other components such as steering column are not modeled explicitly since these do not contribute to the transmission loss of the cockpit. Nevertheless, the volume of these components is subtracted from the inner cavity to get a better estimate of the true inner volume of air in the cockpit module. In the cockpit module studied, the percentage of the space occupied by air in HVAC unit was obtained and this volume was applied to the HVAC unit cavity in the SEA model. A firewall is attached at the back of the cockpit to simulate the acoustic effect of the inner cavity inside the cockpit. The firewall is a 1mm thick sheet metal without holes. The studied cockpit has a fiber layer facing the firewall and was modeled as a noise control treatment in the SEA model.

Acoustic damping loss factor (DLF) of the interior cavities was derived from decay rate measurements conducted without the absorption material facing the firewall (fibrous material) to facilitate testing and to characterize the plastic interior surfaces. The average experimental DLF served as a reference to determine the correct amount of absorption to assign to each faces in the model. This corresponds to the absorption contribution from the plastic parts, cables and other discontinuities actually present in the cockpit. The surface absorption coefficient is derived from the SEA model and classical room acoustics following [5]:

$$\eta(\omega) = \frac{AC_o}{4\omega V}\alpha(\omega) \tag{1}$$

where

$$\alpha(\omega) = \frac{\sum_i \alpha_i(\omega) A_i}{\sum_i A_i} \tag{2}$$

In equation 1, A is the total area, C_o is the speed of sound, ω is the center band frequency (rad/sec), α is the average absorption, and the indices i in equation 2 relates to individual faces of the acoustic cavity. A structural damping loss factor (DLF) spectrum is assigned to each structural subsystem. Decay rate (or reverberation time) measurements were performed on different structural parts of the cockpit for this purpose. The coupling loss factors (CLF) are computed analytically using wave transmission theory [6], based on the geometrical properties of the junction, the physical properties of the connected subsystems, and the angles of incidence of the transmitted waves with respect to the junction. Leaks around components of the cockpit module were evaluated by visual inspection and assign to appropriate area junction of the model. In the SEA model, the cockpit module is placed in a virtual Transmission Loss Suite (TLS) that has the same geometry and acoustic character as the actual chambers used to measure the experimental results as shown in Figure 2.

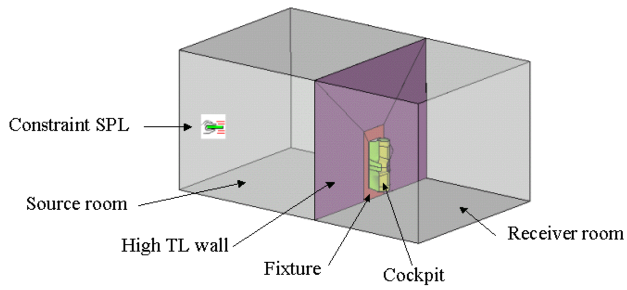

Figure 2: View of the virtual Transmission Loss Suite (TLS) “Cockpit side”

A fixture that fills in the gap between the cockpit and the high TL wall separating the two rooms was also modeled. The experimental averaged SPL in the source room was used in the model. This allowed for a comparison of interior cockpit SPL comparison between experimental and predicted values. All transmission loss predictions in this paper are related to the energy ratio of the two rooms by [7]

$$TL = 10\log_{10}\left(\frac{1}{\langle\tau\rangle}\right) = 10\log_{10}\left(\frac{A_c\omega}{8\pi^2 n_1\eta_2 c_1^2}\left(\frac{E_1}{E_2} - \frac{n_1}{n_2}\right)\right) \qquad (3)$$

3. Testing conditions and procedures

Attachment points are located at both ends of the cockpit module and were used to hang it in place to avoid any preload on the fixture itself. To monitor SPL inside the module, three microphones were used. Care was taken in designing the fixture between the cockpit and the high TL walls separating the two large rooms to ensure a high TL compared to the tested cockpit. Experimental results from 200 to 4000 Hz are used for model validation since this is the primary range of interests of this model.

Numerous configurations were tested in order to properly validate the model. Only selected results are presented in this paper and listed in Table 1, with the baseline representing the cockpit module ready to be installed in a vehicle.

Table 1: Description of the different testing configurations

Conf #	Description
1	Baseline + No Leaks + No Fiber
2	Baseline + No Leaks + No Fiber + No Firewall
3	Baseline + No Fiber + No Firewall
4	Baseline + No Leaks + No Closeout

4. Validation of the SEA model

To first validate the model, configuration 1 was chosen since the DLF of the inner cavity was measured in these conditions. Configuration 1 represents the cockpit module with all leaks sealed and absorption material removed. Configuration 2 is the same as 1 except that the firewall has been removed. Configuration 3 is the same as 2 where leaks have been unsealed. The SEA model predicts correctly the trend and the levels of transmission loss for all these configurations (Figure 3, 4, and 5). To fully validate the model, a drastic change was introduced by removing the closeout panels. Figure 6 shows a good correlation between the SEA prediction and the test data of configuration 4. Removing the closeout panels has introduced at least a 40dB change in noise reduction. However, Figure 6 shows that this SEA model can accurately predict this drastic change in the cockpit module TL without loss in accuracy.

5. Noise Path Analysis

A noise path analysis was conducted on the cockpit module SEA model with the configuration 3. Figure 7 shows the contribution of the 10 main paths to the receiver room. Leaks are unsealed in the configuration studied and they are significant contributors to the power getting in the receiver room. In order to increase the acoustic transmission loss of the cockpit module, the appropriate contributions identified in Figure 7 should be reduced starting with the leak around the glove box. The next weakest paths are the close-out panels followed by the leaks around the closeout panels. Next weak paths are the instrument cluster, instrument panel top and leaks in the lower part of the cockpit module.

A noise path analysis was also conducted with configuration 2. This configuration is the same as configuration 3 except that the leaks are sealed. It shows that the main noise paths are the closeout panels. Both closeout panels (driver and passenger side) are made of one layer of plastic as opposed to the IP external skin which has a layer of foam on top of its plastic construction. This clearly indicates that acoustical treatment on these panels will effectively inprove global noise reduction of the cockpit module. Among the other main contributors are the instrument panel top with its large surface of transmission. Also significant are the instrument cluster, the center console and knee buster components.

6. Conclusions

- The SEA cockpit model accurately represents the vibro-acoustical behavior of the cockpit module. The model accurately predicts the drastic changes of noise reduction with consistent accuracy.
- This model can be effectively used to enhance design optimization to improve noise reduction, shorten design leadtime, and minimize costs.

References

1. Lyon, R., and DeJong, R., *Theory and Application of Statistical Energy Analysis*, Butterworth-Heinemann, 1995.
2. Fahy, F., “Statistical Energy Analysis”, *Noise and Vibration*, ed. R. White, Horwood, 1982, Chapter 7.
3. *AutoSEA2 Users Guide*, Vibro-Acoustic Sciences, Inc., Revision 3, July 2001
4. *AutoSEA2 Theory and Quality Assurance Manual*, Vibro-Acoustic Sciences, Inc., in press.
5. Wilson, C, E., *Noise control, Measurement, analysis and control of sound and vibration.* Krieger Publishing Company, 1994, Chapter 2.
6. Langley, R., and Heron, K., “Elastic wave transmission through plate/beam junctions,” *Journal of Sound and Vibration*, 143(2), pp. 241-253, 1990.
7. Shorter, P., *Calculating transmission loss in an SEA model*, Technical Memorandum no: VAS-1066-01, Vibro-Acoustic Sciences, Dec 2000

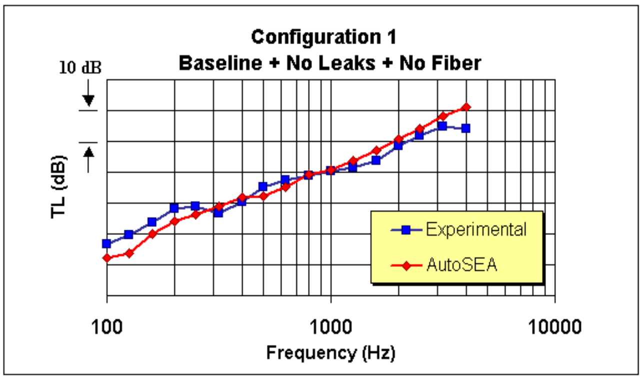

Figure 3: Transmission loss of configuration 1

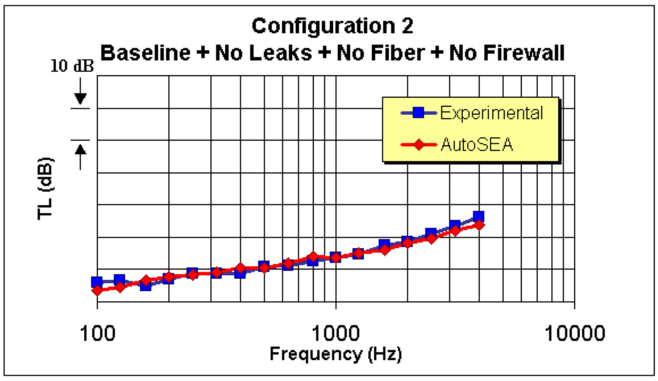

Figure 4: Configuration 2 (same as 1 + no firewall)

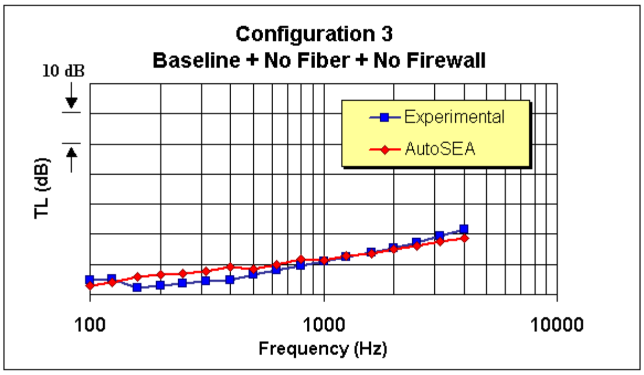

Figure 5: Configuration 3 (Same as 2 + leaks)

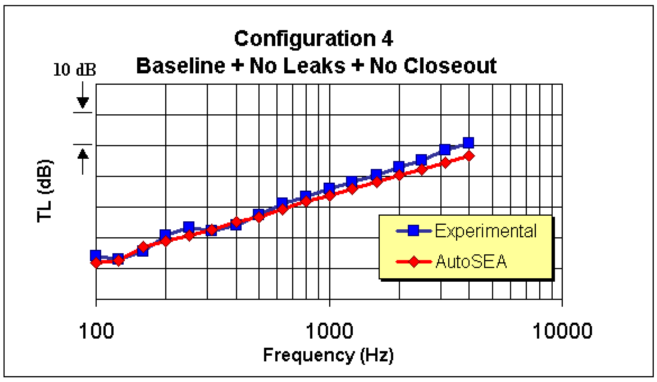

Figure 6: Configuration 4 (Drastic change)

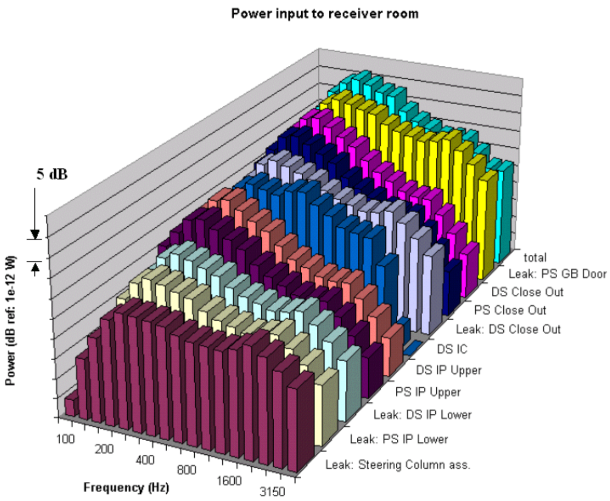

Figure 7: Power inputs to receiver room (Configuration 3)

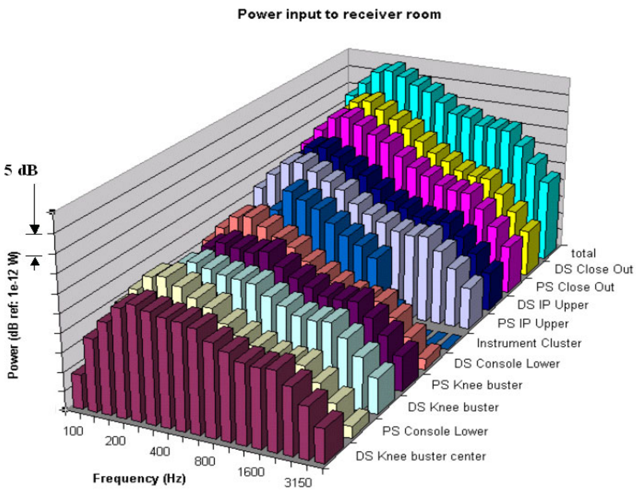

Figure 8: Power inputs to receiver room (Configuration 2)