inter-noise 2002

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

Analysis of Interior Noise of Vehicles Using An Automated SEA Model Building Tool - A Case Study

Robert Unglenieks
Johnson Controls, Inc.
Advanced Engineering – Acoustics
915 E. 32nd St
Holland, MI 49423, USA

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

Abstract

A key goal in the effective use of Statistical Energy Analysis (SEA) has been to reduce the number of expert judgments required by an analyst. This could be accomplished by incorporating high level knowledge into software. Another approach used in the SEA community has been to create templates of a particular vehicle that incorporates accumulated technical knowledge. These templates make accurate results less dependent upon the expertise of individual users. This paper introduces a technology to enable automated interior noise analysis of automobiles using morph-able SEA vehicle models based on 3-D geometry, which include modeling best practices. The productivity improvement gained by reducing model building time will allow more effective use of SEA models in the vehicle development cycle and thus, will improve quality. The end result of this work is to efficiently evaluate interior trim components for sound quality, weight reduction and cost savings. The automated process is presented for two very different vehicles and the validation test results are discussed. Observations of the productivity improvement achieved with this tool will also be discussed.

1. Introduction

This paper presents the "*Template Modeler Method (TMM)*" which allows the automation of the SEA model building process in AutoSEA2^{TM}. It also presents validation data of the resulting SEA models. Benefits from *TMM* are numerous. The most significant are timesavings. Reducing the time needed to build a car model from weeks to days enables the SEA model to be used at an early stage of vehicle design, hence impacting the design at the beginning of its development. Timesaving is the main advantage but not the only significant one. Others benefits include standardization of SEA models in terms of subsystem partitioning database object naming convention, noise paths through junction design, etc.

Also, automatic inclusion of a company's best practices and the elimination of repetitive tedious work of creating subsystems and database elements for each model are other significant benefits. In addition, any SEA model can be considered a template as will be explained below. The "*Template Modeler Method"* can be applied to any SEA model without the need to create any new model to fit the method.

The automation of the model building process with all its benefits increase the ability of the engineer to impact the sound package definition of a vehicle earlier in the design cycle. It builds confidence in the SEA models since they are derived from a well-known template that contains the company's best practices. This paper presents the "*Template Modeler Method"* with emphasis on the validation of SEA models that were created with this method.

2. Template Modeler Method (TMM)

The 3D SEA models created with AutoSEA2^{TM} software are formulated from a family of "subsystems" which are defined by 3D nodes with x,y,z, coordinates [1]. The boundary shape of each subsystem is quite general, being defined by any number of 3D node points. Each subsystem is related to a set of 3D node points from which AutoSEA2 automatically calculates geometric properties such as length, perimeter, area, and volume. One can take advantage of the fact that all subsystems will see their 3D shapes and geometric properties updated automatically if one of their referenced 3D node points is relocated. The same is true for SEA properties. In fact, any AutoSEA2^{TM} model can be transformed into a fully parametric SEA model by automatically controlling the location of a set of nodes relative to a set of reference nodes.

The "*Template Modeler Method"* steps can be summarized as follows (Figure 1):

1. Open a template of generic car geometry (or any SEA model),
2. Automatically create a stick model with reference nodes,
3. Move reference nodes to fit new geometry,
4. Automatically morph to new geometry (non-reference nodes),
5. Mirror to full vehicle model (if needed),
6. Move nodes of non-symmetric subsystems.

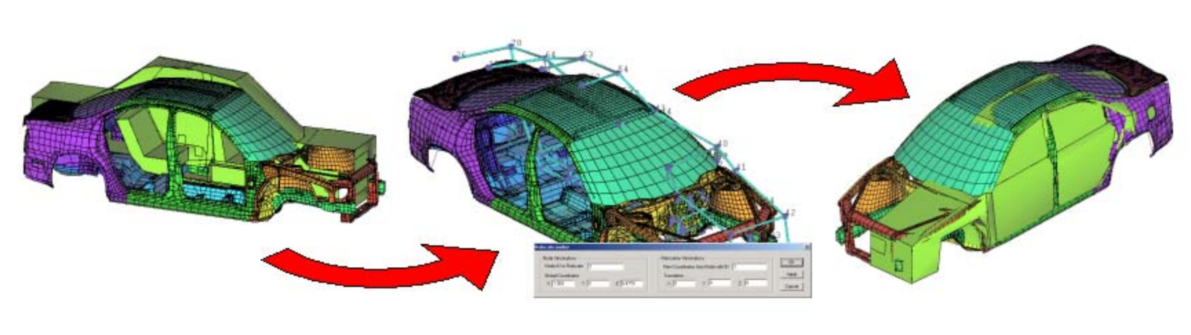

Figure 1: TMM – Load template, create stick model, move selected nodes, morph template.

TMM uses a template to determine the geometric relationships between reference and non-reference nodes. A template can be any SEA model as long as the subsystem partitioning suits the system to be modeled. For instance, the SEA model of a 4-door sedan can easily be morphed from a small entry-level front wheel drive vehicle to a large luxury vehicle. Built-in expertise and best practices should be included in the template in order to pass this knowledge from one model to the other. Different methods can be used to morph a 3D model to a new geometry. Methods based on PID's (Property IDentification numbers) defined in an FEA model have shown promising results but are limited in application. Methods based on manually defined relationships between reference and non-reference nodes are time consuming and tedious to implement even if they provide a significant timesaving compared to building a model from scratch [2]. An alternative TMM approach automatically extracts all geometric relationships between reference and non-reference nodes from the template. The only action the user has to take is to create an input file containing a list of relocated reference nodes and their (x,y,z) coordinates in ASCII text.

Once a suitable template is chosen, a stick model is automatically created to ease the process of relocation of a selected number of reference nodes. By default, all point junctions in the template are considered as reference nodes and are included in the stick model. A stick is generated at the location of each line junction in the template, joining all reference nodes. Once the stick model is created, it is loaded with the final CAD/FEA geometry information and reference nodes are relocated manually. Useful node relocation tools have been developed to ease this process. Any reference node in the stick model can be deleted and will be considered in future steps as a non-reference node. This is useful to limit the number of nodes to manually relocate. Reference nodes ID and their new coordinates are then saved in a text file for future use.

The next step in the *TMM* process is the relocation of the non-reference nodes. This is automatically accomplished by an algorithm that analyzes the template's initial geometry to determine the linear relationship between all non-reference nodes and the reference nodes. The *Template Modeler* then loads the reference node text file and calculates the final location of all non-reference nodes based on the initially stored linear relationships and final location of reference nodes. *TMM* then calculates the final location of all non-reference nodes based on the linear relationships and location of reference nodes. All reference and non-reference nodes are then saved to a text file and can be imported into the template to complete the morphing operation.

The last step in the parametric modeling is to update the full vehicle model with trim information and include any unique components for the vehicle program such as the front-of-dash, instrument panel, cargo area, etc. This step will be the most time consuming in the TMM process.

3. SEA in the Vehicle Development Process

The steps leading up to an SEA model of a vehicle which is ready for design studies can be described by this simplified outline:

1. Obtain representative geometry (CAD/CAE model or direct measurements) of a surrogate or project vehicle,
2. Build the panel and acoustic cavity subsystems,
3. Apply trim information,
4. Apply load cases,
5. Obtain validation data from laboratory or on-road test,
6. Validate model (includes corrections or retest),

7. Model declared ready for use in design studies,

Optionally, if a surrogate vehicle model was built,

8. Morph the surrogate vehicle geometry to a new geometry.

The time from start of the project until initiation of design studies is typically on the order of 2 to 4 months depending on previous vehicle program work available to build on. Steps 3 through 5 are the key tasks of the SEA analyst and typically take the longest to complete. To complete steps 2, 4, and 5, the SEA analyst will require the assistance of program NVH engineer who will work to locate and obtain necessary design and test data for the analyst. During the entire process, a testing facility is employed to deliver all of the relevant validation data in step 6.

3.1 Implementation of the Old Process

As an example of the current process, a model of a current production, small, entry-level, front wheel drive 4-door sedan was created. This model is used later as a template for the *TMM* morphing tools. The model is a full detail, trimmed, SEA model that has 145 acoustic cavity subsystems (interior and exterior) and 350 panel subsystems; enough subsystems have been defined to capture the main airborne noise path design variables. SEA modeling best practices, e.g., proper representation of floor trim, are also built into the model. This vehicle model took three months to create and validate following the normal process.

The model was fully validated using techniques accepted by the industry as a standard validation procedure [3][4][5]:

1. P/P measurements from noise source locations to many locations in the interior,
2. Reverberation room transparency measurements,
3. Interior absorption measurements,
4. Component level absorption and/or transmission loss measurements,
5. On-road or chassis rolls measurements.

Reverberation room transparency prediction and measurements results are shown in Figures 2 through 5. The driver’s head response is shown in Figure 2 when all of the greenhouse surfaces (roof and glass) are covered with a foam and mass layer barrier system and with the baseline coverage (no covered surfaces) in Figure 4. Shown in Figure 3 is the instrument panel (IP) cavity response that also correlates well to test. The idealized door model, comprising 15 subsystems, correlates reasonably well with the test as shown in Figure 5.

The driver’s head response for an on-road condition agrees well with the predicted response as shown in Figure 6. The SEA load case assumes a coarse road surface radiated noise profile for 35 miles per hour. This load case comes from an existing database and does not match exactly the tire and road surface of the test. The engine noise source is from a direct sound pressure measurement in the engine compartment. Wind noise, tailpipe, and automatic transmission noise are not included in this model but are usually of much lower importance to the driver’s head response for this vehicle test condition compared to the engine and tires.

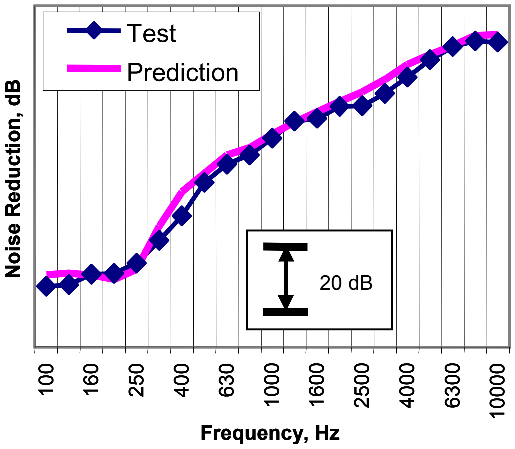

Figure 2: Reverberation room transparency, all greenhouse surfaces covered, driver's head space.

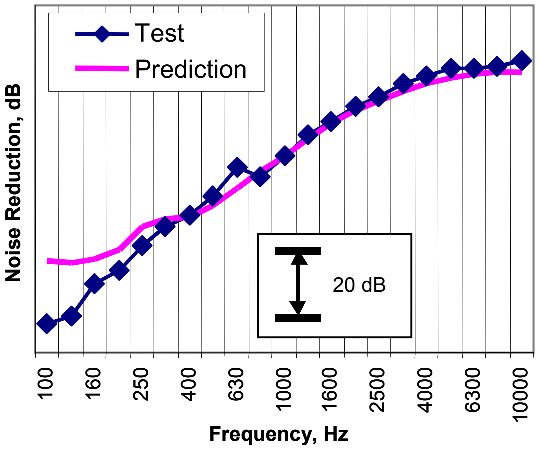

Figure 3: Reverberation room transparency, all greenhouse surfaces covered, inside the IP cavity.

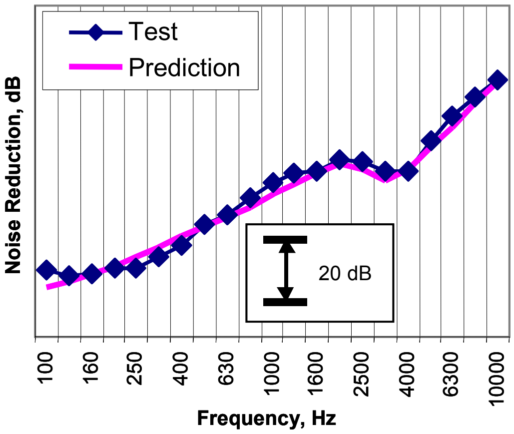

Figure 4: Reverberation room transparency, baseline coverage, driver's head space.

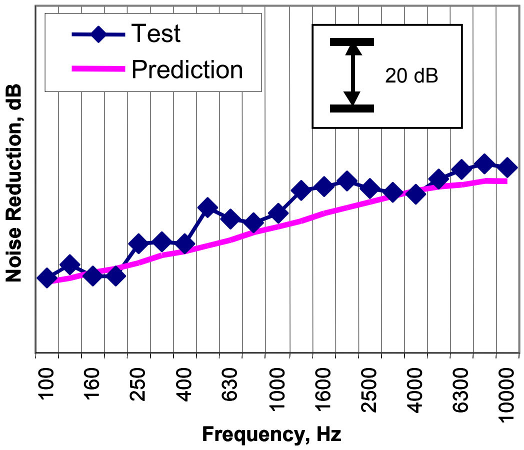

Figure 5. Reverberation room transparency, baseline coverage, inside front door cavity.

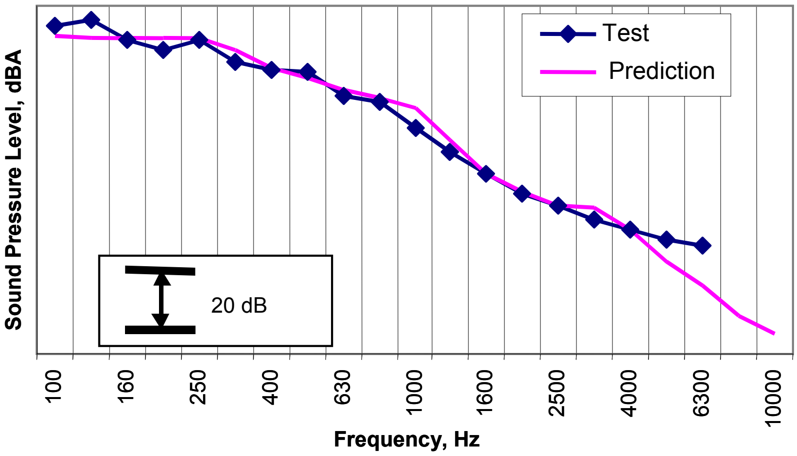

Figure 6: On road, coarse surface, 35 mph, driver's head space.

The barrier to rapid completion of a model using the traditional process is often the speed of the SEA analyst building the model. The analyst was able to request design information, e.g., trim information, early in the process and continue building subsystems. When it was finally required to input the necessary trim data, up to a month or more after the start of the process, the data were available.

A purpose built model for a particular vehicle could have errors introduced by the analyst during assembly that degrade model quality. For example, new techniques for modeling a particular subsystem or collections of subsystems may or may not be implemented by the analyst. An analyst could forget to model an applied trim or model it incorrectly. In some cases, an analyst has even forgotten to include a critical subsystem. These are just a few of the errors generated by an analyst that will degrade quality. With a complete and fully validated template, these types of errors can be avoided resulting in better model quality.

3.2 Implementation of the New Process: *TMM*

The new *TMM* process involves the use of the standard template and the morphing tools. A template that can be morphed easily with the software tools can dramatically reduce the time to build the model. Instead of two months of continuous work, that time is reduced to less than a week of sporadic activity. The majority of time is spent locating the necessary geometry and trim information. The barrier to rapid model development is no longer the speed of the analyst building the model but the ability to locate and retrieve design data quickly.

To continue the earlier example, the original car model is used as a template and morphed to a new geometry of a current production, large, rear wheel drive, luxury 4-door sedan. It was necessary to recreate a half dozen subsystems, both acoustic cavities and panel subsystems, to better capture the physics of the new vehicle. However, these changes were relatively minor. The model was fully morphed and updated with new trim information within five days of full-time work. Fifteen days of half-time work were spent validating the model. It is still necessary to incorporate vehicle-specific implementation issues, e.g., leaks around a trim element, but a majority of the analyst's time is spent in that activity rather than subsystem creation.

Shown in Figures 7 through 10 are early validation results from the large, luxury 4-door sedan for the same acoustic spaces as the small sedan discussed earlier. The data are for an early level of model correlation using trim data from an existing database. Further refinements of some trim elements using directly measured properties, instead of the information contained in an existing database, will improve the correlation. In spite of this, the correlation is quite good.

The on-road performance for the morphed template is shown in Figure 11. Once again, the tire noise load case comes from an existing database and does not exactly match the tire/road surface combination of the test data. The model for this analysis case was an improved version of the transparency model; the model includes measured headliner, seats, and other absorber pads random incidence sound absorption coefficients rather than the database properties.

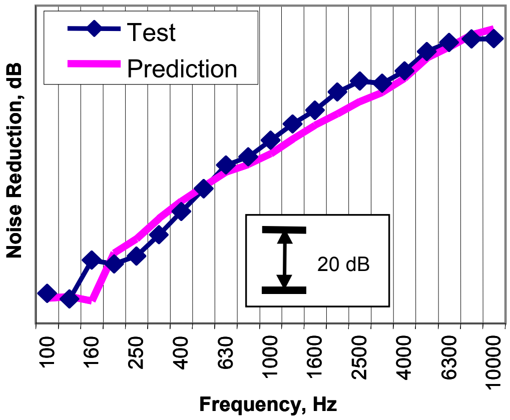

Figure 7: Reverberation room transparency, all greenhouse surfaces covered, driver's head space.

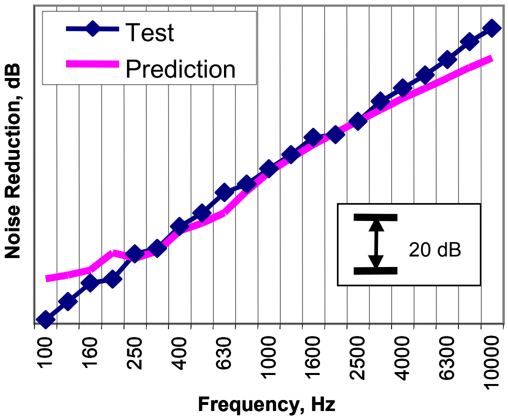

Figure 8: Reverberation room transparency, all greenhouse surfaces covered, driver's side IP cavity.

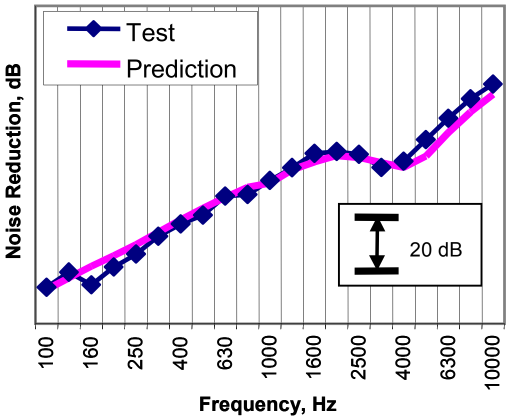

Figure 9: Reverberation room transparency, baseline coverage, driver's head space.

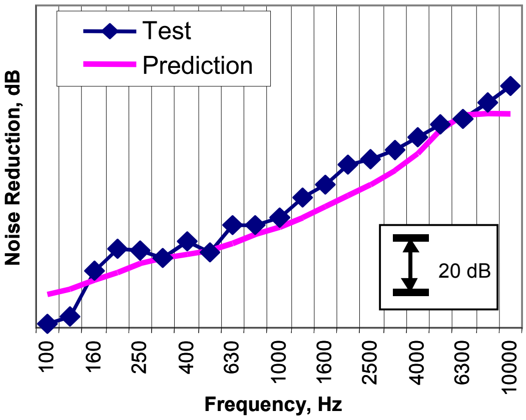

Figure 10: Reverberation room transparency, baseline coverage, driver's door cavity.

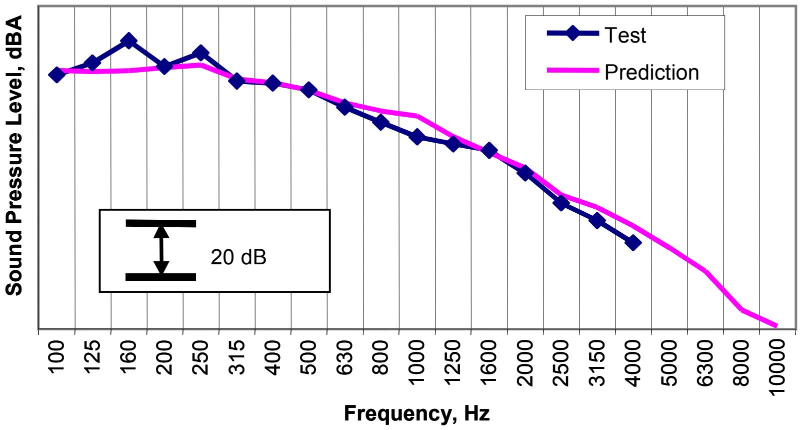

Figure 11. On road, coarse surface, 35 mph, driver's head space.

4. Conclusion

Compared to over 60 days of near full-time activity with the old process, the new process's time of under 15 days from project initiation to beginning of design studies is a dramatic increase in capability of SEA modeling to affect vehicle design. With a template that does not require validation, design studies can begin as early as 5 days from project initiation.

Improvements in model quality are also realized through this methodology. The model used as the template incorporates modeling best practices based on published data and internally developed methods that have refined over many years of SEA modeling of automotive systems. Since the template is only morphed to a new geometry, missing subsystems, improper definition of a subsystem or improper trim, missing subsystem-to-subsystem junctions, or other gross modeling errors are eliminated.

A morph-able template also allows much more elaborate design studies to be carried out. In the past, it could take weeks to evaluate a complete redefinition of the vehicle such as the green house of the vehicle (roof, glass, overhead system, and supporting pillars) or lengthening of the entire vehicle, for acoustic impact. The morphing tools and the templates allow these types of studies to be carried out in a few days.

A further benefit of the *TMM* process is the ability to create a library of vehicles that may not be part of a current project. In the past, limited manpower resources made such a library impossible to create and models were built on a case-by-case basis. Since the start of the original project, the original 4-door sedan template has been further morphed to an SUV, minivan, and pick-up with relatively little manpower resources.

It is the power of the morphing technology that allows the efficiencies and quality improvements. The template is not the main factor in the improvements. It is the combination of the template, node manipulation scripts, and the software morphing tools that makes for a powerful and effective methodology for quality SEA modeling.

Acknowledgements

The authors would like to acknowledge the excellent work of the Johnson Controls WAVE Lab who acquired the validation data.

References

1. P. Bremner, T. Burton, and A. Cunningham, “AutoSEA2 - A new design evaluation tool for noise and vibration engineering”, *Proc. 1999 ASME Design Engineering Technology Conferences*, September 12-15, 1999, Las Vegas.
2. D. Blanchet, A new automated SEA tool for the analysis of interior noise of automobiles, *Proceedings of Internoise 2001,* 2441-2445, 2001
3. D. Wang, G. Goetchius, and T. Onsay, Validation of a SEA Model for a Minivan: Use of Ideal Air- and Structure-Borne Sources, *Proceedings of the 1999 SAE Noise and Vibration Conference, Volume 1,* 381-388, 1999.
4. T. Onsay, D. Wang, and G. Goetchius, Statistical Energy Analysis (SEA) of Air-Borne Tire/Road Noise in a Minivan, *Proceedings of Noise-Con 98, 537-542*, 1998.
5. A. Parrett, J. Hicks, T. Burton, and L. Hermans, Statistical Energy Analysis of Airborne and Structure-Borne Interior Noise, *Proceedings of the 1997 SAE Noise and Vibration Conference, Volume 2,* 801-810, 1997.