Truckmaker Uses Statistical Energy Analysis to Create a Quieter Truck Cab

Craig Birkett, Freightliner LLC, Portland, Oregon

Noise is critical to the performance of larger over-the-road trucks, because quiet cabs reduce driver fatigue. This increases productivity and has a positive impact on safety. In designing the new Cascadia cab, Freightliner used statistical-energy analysis (SEA) to make early design decisions and quickly reach an optimized design for airborne noise control.

The ability to simulate noise levels helped the engineers involved in the project consider the impact of their decisions on noise early in the design process. Engineers evaluated the impact of different types of absorptive materials and traded off their benefits against their costs. They quantified the impact of main and flanking noise paths so that they didn't waste money reducing main paths in situations where the flanking paths would be controlling. The result was that noise on the Cascadia tractor was reduced by 5 to 6 dB below the previous generation and tests show that the Cascadia is one of the quietest cabs in North America.

Up to now, engineers in over-the-road trucking have not made extensive use of SEA, developed primarily for the aerospace and automotive industries. Prototypes take considerable time to build and test and are also expensive. Moreover, the point measurements used to evaluate prototypes provide little information as to why a particular design performs well or poorly. Relatively little design flexibility is available at this late stage, and most of the available options, such as adding tuned absorbers, are quite expensive. Late-stage troubleshooting also runs the risk of delaying vehicle introduction. Consequently, engineers are often forced to settle for less-than-ideal performance, because they didn't have time to shoot for a truly optimized design.

SEA Advantages Relative to Build and Test. SEA offers the ability to estimate noise and diagnose its causes early in the design phase before prototypes have been built. Using SEA, the structure being modeled is split into smaller, interacting subsystems. The response of the structure to different forms of excitation, either mechanical or acoustical, is calculated from the strength of the coupling between subsystems and the distribution of damping. The degree of complexity and the frequency range over which the results are valid are constrained to some extent by the statistical nature of the model. SEA has been used to solve many noise and vibrations problems in the past 35 years since it was developed. Until recently, however, SEA modeling has been difficult and required the services of expert acousticians with specialized degrees. Engineers designing the Cascadia began by building an airborne SEA model of the previous production sleeper cab using the SEA module of VA One software from ESI Group, Bloomfield Hills, MI. This software enables engineers to access the full power of SEA from a simple graphical interface.

The geometry of the SEA model is required to match the actual vehicle, since the dimensions of the various panels affect their acoustic performance. A finite-element model of the cab was used to generate the SEA geometry as shown in Figure 1. The next step was partitioning the geometry into subsystems representing a collection of modes or waves of the same types (see Figure 2). The truck interior was found to vary in sound level by as much as 5 dB so it was decided to create 80 exterior cavities and 30 interior cavities. Two main types of trim were included in the model. One type consists of layouts made of foam, fibers and vinyl barrier. This trim was explicitly modeled based on a description of each layer thickness and its poro-elastic properties. The second type of trim consists of relatively hard wall panels such as the upholstery panels on cab walls and the bunk unit. This type of trim was either modeled as an SEA partition or was incorporated into a noise-control treatment layup applied to the base panel.

Comparing Simulation and Physical Results. Physical tests were done on the previous model to evaluate the accuracy of the simulation model. Several physical experiments were performed on the cab to measure the panel vibration response, interior sound pressure response and the impact of trim changes for air-borne noise sources. Correlation between the tests and predictions was typically very good – above 400 Hz.

Figure 3 shows a comparison of measured acoustic damping factor and simulation results. In the example shown, tests can not easily calculate the low-frequency acoustic damping, because increasing energy is lost through the cab walls at low frequencies. At low frequencies in this case, the SEA model is more accurate. The vibration response at key panels such as the front wall, floor and sidewall was calculated with the SEA model and compared against measured values. The results generally matched well, although some errors in the model were identified and corrected as a result of this analysis. The sound pressure levels inside the cab were measured at most of the large interior acoustic cavities and compared with measurements. The measurements at three or four points were averaged in each cavity as required by SEA theory, and results generally matched within 3 dB from 400 to 5,000 Hz.

Just as important as accurately predicting interior sound and vibration levels is the ability to predict the effect of design changes. Physical testing was used to evaluate the ability of the model to predict the effect of changes in cab trim by changing the upholstery panels in the sleeper region to a hard trim condition by attaching cardboard panels on top of the upholstery. The model accurately tracked the average effect of the change. Other changes showed the SEA model could track the magnitude of changes in SPL (sound pressure level) caused by trim modifications (see Figure 4).

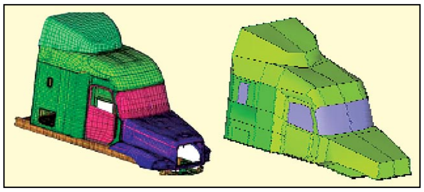

Figure 1. FEA and SEA models of the truck cab.

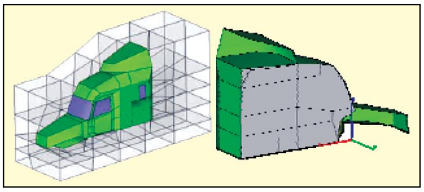

Figure 2. Exterior and interior cavity partitioning.

Designing the Next-Generation Cab. Once the current production vehicle had been validated, the model was modified to represent the next-generation cab, which was then early in the design process. This was done by a combination of moving nodes and recreating some subsystems. In particular, the large number of changes to the front wall in the next-generation cab required that the interior and engine acoustic cavities be recreated. The ability to estimate the noise and track its sources early in the design helped different groups work together to make improvements. For example, there are many holes in the front wall, the panel between the engine and the cabin, to allow for hoses and mechanical and electrical connections. The simulation showed that cumulatively these holes were responsible for a substantial portion of the noise. The holes were the responsibility of many different engineers who, for the most part, had never paid attention to noise in the past, because they had no way to measure it. For the first time on this project, a noise budget was developed for the front wall. Designers were asked to meet targets, so they made better decisions as a result.

Of course, noise cannot be completely eliminated from the cab, so absorptive materials are used to help reduce its impact. The challenge is that there are many alternatives to consider in terms of the types of absorptive materials used and where they are placed. When these issues were addressed during the prototype phase, the little time that was available to consider alternatives and decisions made earlier in the design process often limited the options that could be considered. In the design of

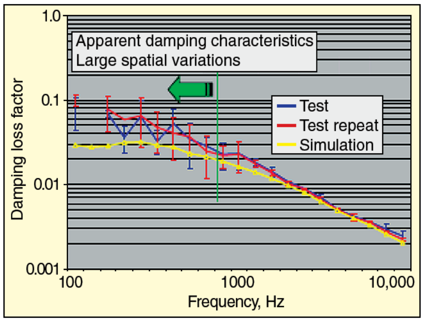

Figure 3. Simulation predicts apparent acoustic damping loss factor.

the Cascadia, on the other hand, engineers considered a wide range of alternatives in the placement of absorptive materials, balancing noise reduction against cost to obtain the greatest noise reduction per dollar. The ability to quantify the benefits of various alternatives led to the conclusion that the addition of an absorptive headliner would provide a substantial improvement

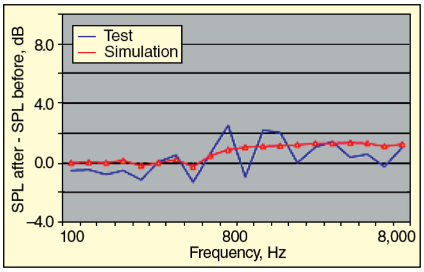

Figure 4. Passenger's side waist cavity response to trim change.

in noise. The simulation results made it easy to convince management that the cost was justified. The simulation results were also used to make decisions on the type of floor materials used in the new cab.

Importance of Material Properties. The simulation model demonstrated the sensitivity of noise levels to material properties. Based on these results, Freightliner improved and standardized its testing procedures and enlisted acoustic specialists to advise designers in interpreting the data. Freightliner engineers also used the simulation results to identify several situations where they had reduced primary noise paths to or close to the point where flanking or side paths controlled the noise. In these situations, further improvements to the primary noise paths would have little or no benefit so the decision was made not to waste money by further improvements to the primary paths.

The mix of simulation and physical testing used on this project provided spectacular results. Not only were noise levels substantially reduced from the previous-generation cab, but testing also showed that the Cascadia cab was the quietest of all the benchmark cabs measured. Marketing for the Cascadia cab has emphasized the improvements: "A truck that rides like a quiet luxury car and reduces driver stress and fatigue."

The author can be reached at: craigburkett@freightliner.com.