## LMS Helps Automaker Attain Best NVH in Class

LMS engineering consultants helped an automotive original-equipment (OEM) manufacturer quickly reduce the noise/vibration/harshness (NVH) levels of a new model to best in class levels. When the OEM first approached LMS, noise levels were about 6 dB higher on its vehicle than their quietest competitor. LMS used source ranking and benchmarking analysis, investigation of critical noise paths, and counter-measure evaluation by frequency-response-function (FRF) testing to determine the root cause. The primary contributors were airborne noise and noise transferred through engine mounts. A new bracket was developed to reduce the engine mount contribution, and trim materials were added to the floor, firewall, and hood. The result was that noise levels were reduced by 8 dB.

**Addressing a Severe Noise Problem**. Soon before the vehicle was scheduled to go into production, the manufacturer identified a severe engine noise problem during full-throttle acceleration. The OEM asked LMS engineering consultants to solve the problem while fulfilling other important requirements. They asked for a competitive analysis of the best competitive vehicle to set targets for interior noise during acceleration. They wanted LMS engineers to compare the current design with the competitive vehicles, identify reasons for the different noise levels, and propose design changes to improve the vehicle. Finally, they asked LMS to deliver a modified prototype vehicle that equaled the NVH performance of the competitor's vehicle.

The OEM selected LMS for this project because LMS has a unique combination of advanced technologies and vehicle experience. LMS uses fast technologies, such as fast-transfer-path analysis (TPA), to quickly identify the general area of the problem and detailed technologies, such as TPA and acoustic-source quantification (ASQ), to understand the noise mechanism in detail and determine the root cause of the problem. The LMS troubleshooting methodology is solution oriented – it moves logically from diagnosis to developing improved designs. While overcoming engineering challenges, LMS engineering simultaneously transfers knowledge to its customer, making it possible to optimize vehicle and subsystem development process.

The traditional approach to addressing interior noise problems uses physical tests that attempt to pinpoint noise sources. For example, a tube may be placed in the air intake to remove nozzle noise from interior noise measurements. Or the intake manifold might be shielded to eliminate shell noise radiated from its housing. The problem with these types of tests is that they provide only approximate indications of the source of the problem. Without an in-depth analysis of the cause of the problem, design engineers typically face a long and expensive trial-and-error process that usually requires making costly modifications whose impact is far from guaranteed.

**Source Ranking and Benchmarking**. LMS engineers began by using source ranking and benchmarking analysis to find the main noise transfer paths on the customer and competitor vehicles. They performed fast TPA on both vehicles by measuring interior noise under clearly defined conditions while disconnecting major noise sources. In less than a week, they were able to determine the proportion of interior noise at each RPM value generated by: 1) airborne noise radiated by engine surfaces; 2) structure-borne noise coming from the engine mounts; and 3) structure-borne noise coming from the driveshaft and propagated to the vehicle through the suspension.

The fast TPA results shown in Figure 1 indicated that the airborne contribution was the largest at 49%, engine mounts contributed 40%, and the suspension accounted for the remaining 11%. The fast analysis technique also determined that the airborne contribution was higher on the customer's vehicle because of a high airborne noise source as well as a high acoustic transfer from the engine compartment to the vehicle cavity. This method, which was developed by LMS Engineering Services, relies on an advanced indirect-source identification method where each noise contribution is considered to be the product of equivalent source strength and equivalent transfer path. It does not provide details such as which engine mounts are primary contributors.

Since the engine mounts were determined to be the primary contributor, a detailed TPA was carried out to obtain more information, particularly the contri-

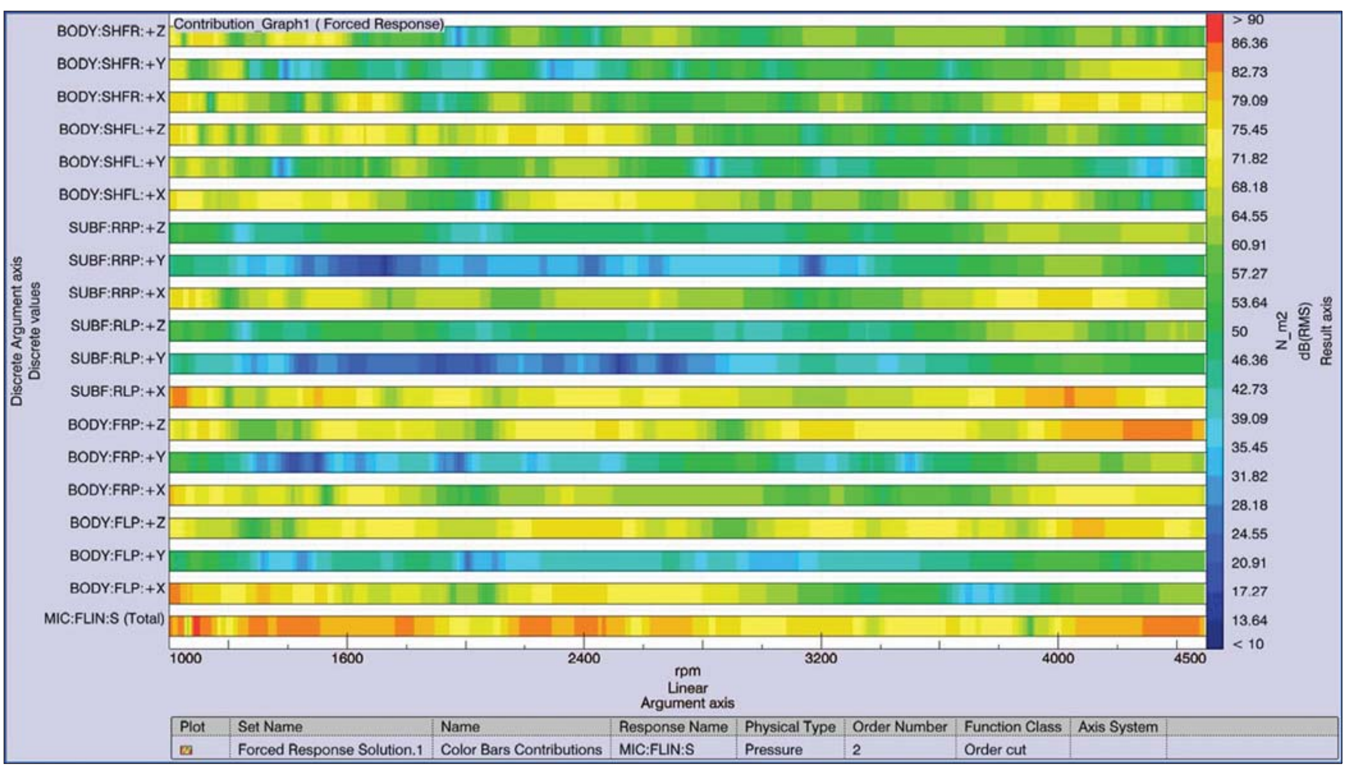


*Figure 1. Fast transfer path analysis allowed LMS engineers to investigate major powertrain contributions to the interior noise.*

*Figure 2. Sensors measure interior noise.*

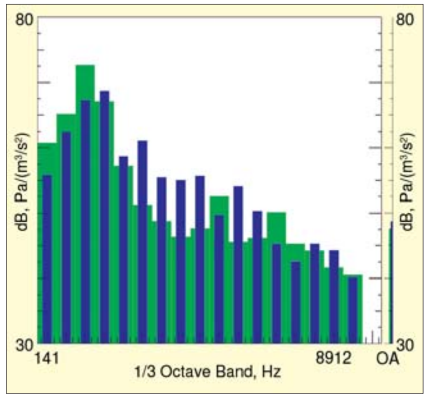


*Figure 3. Acoustic insulation of development vehicle compared with best-in-class competitors.*

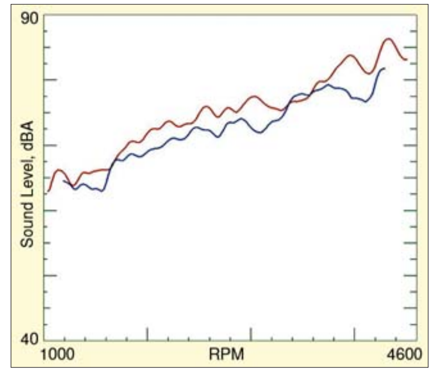


*Figure 4. Overview of global noise level of original vehicle vs. final prototype vehicle developed by LMS.*

bution of each engine mount. LMS engineers measured the transfer path from the source to the interior by exciting the source with a calibrated shaker and measuring the response in the interior. They quantified the source strength with acoustic measurements in the vicinity of the source. Multiplying the strength of the source by the transfer path yields the contribution of the source to the interior noise. The relevant source strengths and transfer path analysis were also done on the competitive vehicles. The two vehicles were compared in terms of construction choices, such as engine mounts and trim materials, to understand the differences. The detailed TPA determined that the right engine mount was the source of most of the noise.

**Detailed Investigation of Critical Noise Transfer Paths**. Next, an investigation was performed of the critical noise transfer paths. Structure-borne transfer path analysis was performed by combining a force-identification procedure with FRF measurements. The quality of engine airborne isolation was evaluated by calculating a transmission coefficient based on FRF measurements. The FRFs were measured reciprocally by exciting the car cavity with a calibrated volume velocity source and measuring the response at various locations around the trim. Reciprocal measurements were performed by using calibrated volume velocity sources, which makes the measurements faster. The volume acceleration sources were active, and the panels were passive. Microphones were placed on the trim surface and below the trim on the sheet metal. The tests measured FRF trim pressure per volume acceleration, FRF steel/aluminum pressure per volume, and ratio averaged over surfaces and sources.

The consultants then used ASQ to accurately identify the interior panels that contributed the most to noise. This was done using artificial excitation to reduce the time required relative to operational testing. Acoustic excitation was performed with an acoustic source and structural excitation with a shaker. The vibro-acoustic transfer function was measured from the acoustic sound source on the engine surfaces to the panels that can contribute to the interior noise, including the firewall, floor, front window, and side windows. Then the acoustic transfer functions were measured from the radiating panels to the target microphone positions. The ASQ showed the important panels were the upper firewall and front floor. Once the critical panels were identified, their excitation was traced back to acoustic or structural resonance phenomena. Combining these sources with measured FRFs made it possible to quantify the impact of the different sources of interior noise.

The detailed investigation of the critical noise path showed that acoustic transmission through the firewall was much higher on the customer vehicle than on the competitive vehicle. The resonant frequency of the firewall was higher on the customer vehicle so it only isolates high-frequency noise. For a structural excitation, the upper part of the firewall and front floor contributed most of the interior noise. For acoustic excitation, on the other hand, the upper firewall was the dominant source. At the critical frequencies of the structural modes, the firewall and front floor were again the largest contributors due to the high acoustic sensitivity of these locations. A running mode analysis was performed to identify the root cause of the right engine mount contribution. The results highlighted the large impact of structural modes on the part, indicating the need for stiffening.

**Evaluating Countermeasures with FRFs**. The next step was making simple modifications to see how they affected critical transfer mechanisms before investing time and money needed to make realistic changes. Structural modifications were performed to try to change the acceleration levels of the panels to affect the resonant behavior and radiation to the microphones. Acoustical modifications were also done to try to insulate the cabin by adding a mass-spring system on the vibrating panels. For example, engineers weakened engine mounts by drilling holes in them, added damping treatments to interior trim panels, added a combination of foam and insulating fabric to the firewall to isolate airborne noise from the engine, and stiffened an engine bracket by welding a beam to it.

**Validation of Countermeasures**. The simple countermeasures were then evaluated using FRF testing. The local damping layer had a minimal effect on FRFs, but increasing the isolation with a combination of a layer of foam and a heavy damping layer had a major positive impact. Those simple modifications were then converted into realistic modifications that were acceptable from the standpoints of weight, packaging, static stiffness, and durability. In addition, a new bracket was designed to reduce the engine's structure-borne contribution.

The results shown in Figures 3 and 4 exceeded the OEM's expectations. At the end of the project, LMS delivered a prototype vehicle that exceeded its best-in-class competitor in NVH performance. The level of high-frequency noise was substantially reduced. Levels of all engine orders were also considerably lower. The overall noise level was reduced by up to 8 dBA at the driver's outer ear. This application demonstrates that LMS Engineering Services has the vehicle knowledge, experience, technology, processes, people, facilities, and project management skills to take full responsibility for vehicle NVH performance.

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