VIRTUALLY TUNING AN AUTOMOTIVE AUDIO SYSTEM

Experts at HARMAN are using physical experiments in conjunction with mathematical modeling and numerical simulation to improve the development process for the latest vehicle infotainment technology.

By **LEXI CARVER**

TODAY'S VEHICLES OFFER DAZZLING electronic entertainment possibilities, from smartphone connectivity to interactive displays and video screens. HARMAN is the market leader in these connected car setups, equipping more than 80% of the world's luxury cars with premium audio systems.

Each vehicle model requires a unique configuration, and HARMAN's team of acoustic and simulation specialists ensure that different components and car acoustics are accounted for in their design process. Details such as the ideal placement and orientation of speakers, speaker packaging, and driver enclosure geometry such as car doors all influence the sound quality.

The team uses physical experiments in conjunction with numerical analysis to accelerate product development by virtually "tuning" their systems before ever creating a live prototype. This saves time on physical testing, and allows virtual tests to replace in situ listening, so that the team can design their products even before the final car designs are complete.

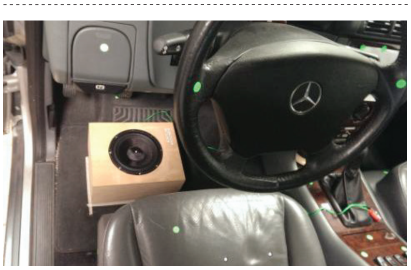

Figure 1. Loudspeaker positioning in the vehicle interior.

"We may become involved very early in the car development process, when a vehicle designer has not yet decided what is required from the audio system," explains Michael Strauss, senior manager of Virtual Product Development and Tools (VPD) at HARMAN. "Or we may only have basic details such as the size and volume of the car cabin. Yet frequently we need to present a concept within a few days, creating a tricky challenge to meet our clients' requirements and deliver high-quality systems."

SIMULATION AND EXPERIMENTS TEAM UP FOR CUSTOMER SATISFACTION

TO PROVIDE CUSTOMERS with a response that is both quick and accurate, engineers at HARMAN turn to mathematical modeling in COMSOL Multiphysics® software. "We needed capabilities for mechanical, acoustic, and electrical simulations in one integrated environment, and we wanted a program that would free up the time and effort spent on creating and updating our own tools," says François Malbos, senior acoustics engineer at HARMAN.

"The multiphysics approach is one of the most important parts of the virtual product development process," says Michał Bogdanski, project leader in virtual product development at HARMAN. "We can explore how the acoustic behavior of a loudspeaker relates to any part of a vehicle structure — for example the stiffness of a door — and then provide design guidelines to our customer."

In one case, they both measured and simulated the sound pressure levels generated by a loudspeaker in the cabin of a Mercedes-Benz ML car (see Figure 1) in order to validate their numerical models and later use them to optimize acoustic equipment. "Car cabin simulations are among the most challenging to run because they cover many different areas of physics," explains Strauss. Fortunately, COMSOL® software offers options to couple together the acoustic, mechanical, and electrical effects throughout the system.

To support companywide engineering efforts, Strauss' team established a library of validated models and known solutions that allows for performance predictions of a wide variety of loudspeaker configurations. "We are able to offer everything from a high-level trend analysis to a detailed design examining the performance of a subsystem," he continues.

ANALYZING VEHICLE LOUDSPEAKER PERFORMANCE

IN ONE STUDY, ENGINEERS AT HARMAN used COMSOL to create a simulation of a car cabin's sound system in order to optimize the speaker acoustics, specifically for low-frequency soundwaves. They then designed a series of tests to validate the model. Once validated, the model would allow the HARMAN team to deduce the best loudspeaker setup for a given car.

In validation tests, a loudspeaker

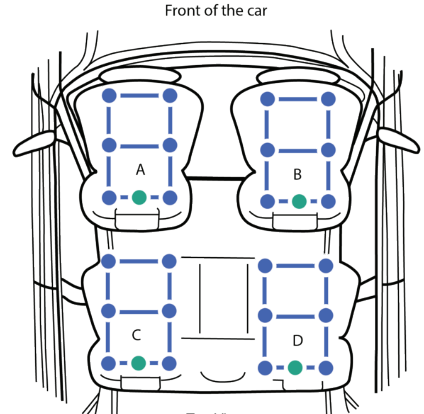

Figure 2. Top view of the microphone arrays positioned at four different locations.

Figure 3. HARMAN's 3D scan of the car cabin.

was mounted on a rigid enclosure near the driver's seat of the car. Four sets of microphone arrays throughout the cabin served to measure average sound pressure levels at each location (see Figure 2).

For frequencies below 1 kHz, the loudspeaker was represented as a rigid flat piston tied to a simplified lumped parameter model (LPM) taking into account the voltage at the voice coil terminals and the stiffness of the suspension and speaker membrane surface. The geometry was generated from a manual 3D scan (see Figure 3). Using a preprocessing algorithm implemented in MATLAB® software and an add-on product to COMSOL® called LiveLink™ *for* MATLAB® that creates a bidirectional link between the two programs, the team converted the point cloud created by the scan into a surface mesh of the car cabin (see Figure 4) and created an optimized mesh for studying acoustic pressure waves.

The simulation analyzed the interaction of the sound waves generated by a speaker with the different materials of the windshield, floor, seats, headrests, steering wheel, and other sections of the car such as the roof, doors, and instrument panels, each of which have different absorption properties.

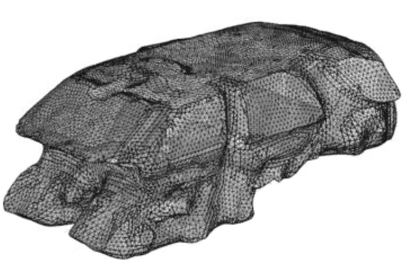

Figure 4. Surface mesh of the car cabin.

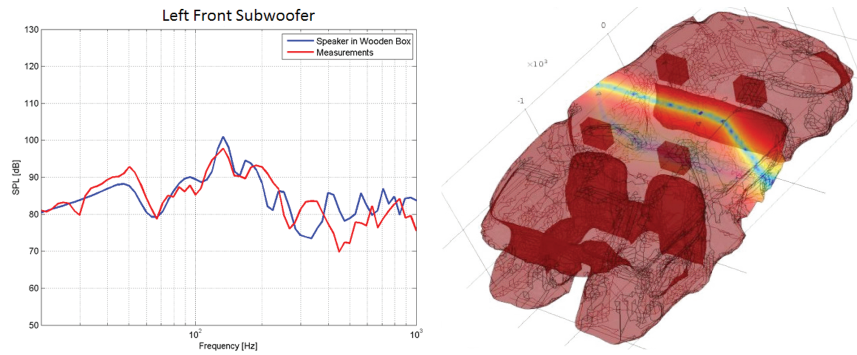

Figure 5. Sound pressure levels for one microphone array (left) and throughout the cabin (right).

OPTIMIZING THE ACOUSTIC MODEL

IN ADDITION TO ACCOUNTING for many different materials, the team also defined speaker membrane motion and acceleration based on the volume of the enclosure using LiveLink™ *for* MATLAB®, and developed special MATLAB® software scripts to simplify the preprocessing and postprocessing activities.

"Everything is fully optimized and automatic so that we do not have to calculate the acceleration for each case; when one simulation finishes, the next launches," explains Bogdanski. "This ensures that the whole process is easy and error-free; we simply let the scripts run."

The team also optimized the frequency-dependent absorption coefficients necessary to achieve a strong correlation between the measured and simulated sound pressures. The analysis then provided the sound pressure levels emanating from each microphone array (see Figure 5).

VIRTUAL TUNING TAKES A NEW TURN

AS A RESULT of their validated simulations, HARMAN is able to start developing a sound system even as a vehicle is still being designed. Only when the car is ready for test-driving does an acoustics engineer need to get into the car to fine-tune the audio. They're now setting up a playback system that will, "based on simulation results and signal processing, allow the user to listen, evaluate, and compare any optimized audio system including subwoofers, midranges, and tweeters," says Malbos. "Design modifications are done much quicker in the virtual domain than rebuilding a real prototype." Listening tests demonstrate that this scientific approach can successfully replace in situ listening.

The ability to assess an audio system based purely on simulation is increasing the quality and speed of the product development process at HARMAN, improving customer responsiveness, and lowering the cost of design amendments, thus creating more sense of design freedom for the engineers.

"The beauty of simulation is that a systems engineer can sit at a desk, put headphones on and begin to tune a system without the car. Using simulation we can assess, optimize and predict the performance of a proposed sound system, even though it does not actually exist yet," says Strauss. ◎

The HARMAN VPD team consists of François Malbos, Michael Strauss, and Michał Bogdański.