Developing Vehicle Sound Packages

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This article discusses the thought process that one needs to go through for developing an appropriate sound package treatment for a vehicle. In the development process, you need to put proper emphasis on understanding the source, path, and the receiver system. You need to have an understanding of how to reduce the noise at each location. You may need to conduct a feasibility study of the benefits of various noise control options. In terms of sound package treatments, you need to understand the fundamentals of acoustical materials, how they work, and why one material performs differently than another, as well as the importance of a well documented specification that every supplier has to meet.

In the 21st century, with the globalization of the automotive industry very much underway, and with two of the world's largest OEMs requiring immense financial support from the government, the quality of an automobile is a major part of the success equation. The question is, what is "quality?" Although this has different interpretations by different people, it generally means how good a product is in relationship to what the manufacturer claims it to be. In the overall scheme of things, the acoustics of a vehicle is an important aspect of overall quality.

The acoustics of a vehicle are affected by power-train noise, road noise, wind noise, ride and handling, and structural response, among other things. In addition, when one noise intermixes with another, it complicates the issue. In other words, there are simple sources and there are complex sources. To address the vehicle noise issue appropriately, all these issues need to be examined thoroughly and carefully. After they are studied thoroughly, options for a feasible solution become clearer.

Although the fundamentals of vehicle noise generation and propagation have changed very little, the expectation of customer comfort has changed significantly. Therefore, there is a substantial need to understand the problem thoroughly prior to coming up with an adequate solution. In developing a quiet vehicle, acoustical engineers examine the problem from different directions (i.e., they look into reducing power train noise, road noise, wind noise). We focus here on sound package treatments to reduce vehicle interior noise. This means developing proper sound package treatments that will reduce the impact of various noises from entering the vehicle as well as reducing the impact of noise that is already inside the vehicle at the ears of the occupants. The successful development of these treatments greatly depends on understanding the path through which sound and vibration propagate from one place to another.

The actual design and engineering work starts way before the launch date of a vehicle. When an OEM decides to design and release a new vehicle, some research is complete including the market segment where the vehicle will be introduced. However, there are still a lot of things that need to be done for a vehicle launch to be successful, including:

- Styling.
- Vehicle attributes.
- Pricing.
- Comfort in ride and handling.
- Acoustics.

In the area of vehicle acoustics, though exterior noise plays a significant role, the major focus is on interior noise. To be successful in achieving proper acoustics, OEM engineers first have to develop a realistic vehicle level target.[1] Then they have to develop realistic procedures (including component and material level targets) to achieve these objectives. The purpose here is to lay out these thoughts in a systematic way so that acoustical engineers can make the best decisions.

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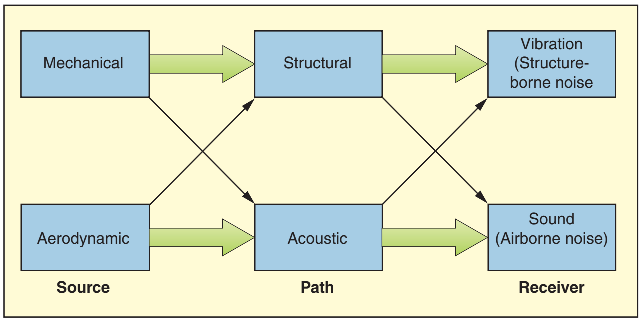

Figure 1. Vehicle noise mechanism.

Noise Issues in Vehicle Design

The fundamentals of automotive design have not changed greatly, although measurement technology has changed significantly. As the design of a vehicle is changed, whether for occupant safety, fuel efficiency, or for some other reason, the change may affect vehicle interior noise.[2] Generally, there is insignificant noise generation inside the vehicle due to operating dynamics. Noise is generated outside the vehicle and is propagated into the vehicle interior. Although holes and pass-throughs on the dashboard are necessary for vehicle operation and comfort of the occupants, the design philosophy behind establishing these intrusions is different from one OEM to another.[3] Therefore, a different degree of effort is spent by OEMs to understand how to fine tune noise control by using products such as grommets, sealers, and seals, while at one time these products were used primarily to address corrosion, dust, moisture, and water intrusion.[4]

The sound in a car is integrally related to the source-path-receiver system of the vehicle. To develop the correct acoustics package for a vehicle, one needs to adequately understand this relationship. This relationship might be simple or complex. A simple relationship would be engine noise, propagating through the dash system and eventually reaching the receiver as noise. An example of a complex relationship would be an aerodynamic noise taking a structural path and then emanating as airborne noise. Figure 1 illustrates the integral relationship of the source-path-receiver system that is built into the vehicle noise mechanism.

Interior vehicle noise can be caused by many sources. Primary excitation sources are:

- Engine/driveline.
- Tire/pavement.
- Wind.

In addition, there are secondary sources within the vehicle that cause noise issues, such as motors, pumps, brakes, climate control systems, actuators, and seat belt retractors.

The engine noise includes combustion noise and mechanical noise that can be both airborne and structure borne. Road noise is generated from the vibration of the tire casing due to irregularities of the road surface. These irregularities are due to structural excitation, and unless proper care is taken to address the issue at the beginning, vibration will radiate as structure-borne noise.

Noise Control Solutions

Vehicle noise control solutions are numerous. It can be controlled at the source, along the propagation path from the source to the receiver, and within the receiving environment. Although noise control solutions can be applied at all three places, each OEM has a preference of where to put the most effort. If most of the effort is directed at the source to reduce the noise, then less effort is

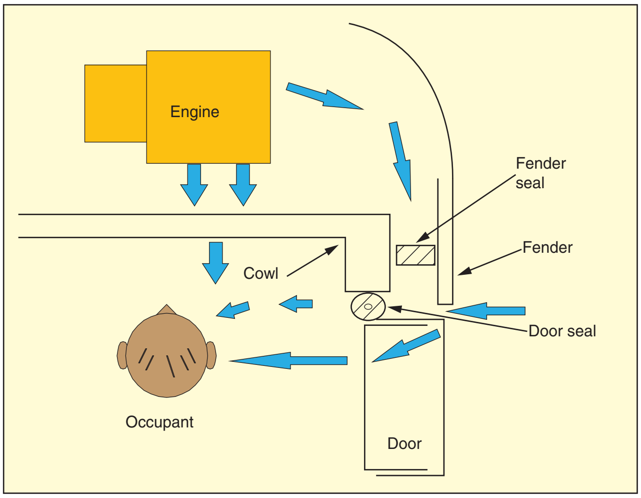

Figure 2. Some paths (arrows) sound can take from engine compartment to inside vehicle.

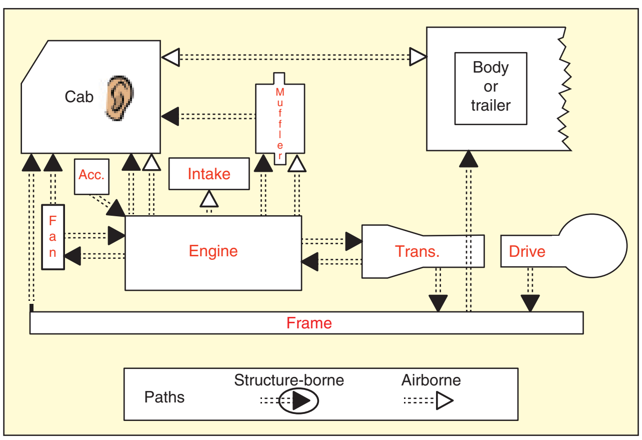

Figure 3. Airborne and structure-borne paths in truck cab.

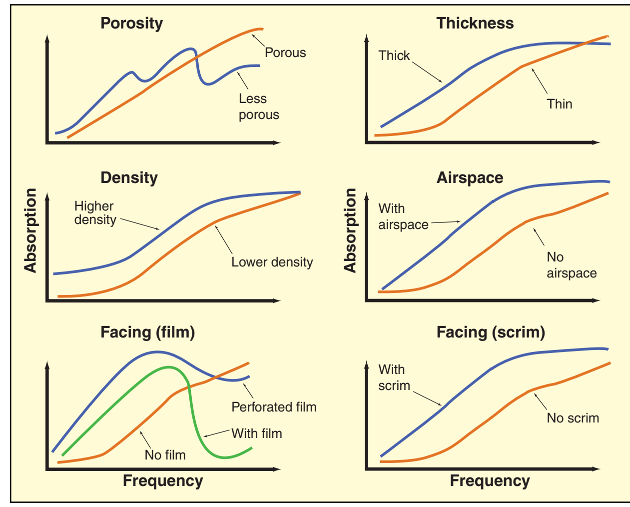

Figure 4. Quantitative effect of various factors on sound absorption.

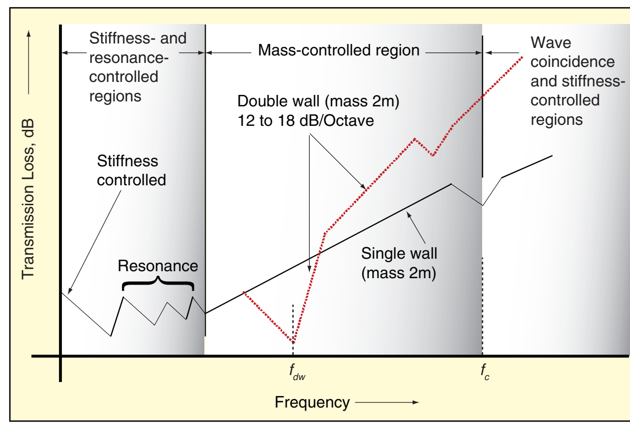

Figure 5. Qualitative STL performance of single- and double-wall constructions.

necessary to reduce the noise along the path or in the receiving environment.

To effectively utilize sound package treatments it is important that the acoustics engineer have a good understanding of:
- Importance of paths where sound package materials are used.
- How acoustical materials work.
- Standards for evaluating acoustical performance of materials.
- How to develop acoustic targets for sound package treatments.
- How to judge whether performance makes sense.

Importance of Paths

Keeping the source-path-receiver system in mind is key to identifying the importance of various paths through which noise and vibration can propagate from the source to the receiver. Figure 2 shows some of the paths that engine noise can take while propagating from the engine compartment to inside the vehicle. The paths are shown using arrows. Proper measurements need to be made along all these paths to understand what kind of sound package treatments need to be used for controlling the noise.

While testing, one may have to make both sound and vibration measurements to ensure that airborne and structure-borne noise paths are properly identified. In today's high-powered vehicles, noise may get transformed from one form to another (i.e., from airborne to structure-borne or vice versa). Figure 3 shows typical airborne and structure-borne noise paths into a truck cab; it also shows that in many cases these two paths are interconnected.

How Acoustical Materials Work

There are essentially four different treatments for solving noise and vibration problems. Absorbers and barriers are used for airborne noise problems, and dampers and isolators are used for structure-borne noise problems.[5] These materials are commonly considered the sound package treatments of choice.

An **absorber** is a product that reduces sound wave reflections from hard surfaces and thereby minimizes sound build-up or reverberation within an enclosed space. Typically, an absorber is either a fibrous or cellular material that is both porous and elastic. Sound waves enter the material and dissipate to thermal energy via viscous dissipation and/or internal friction. The sound wave interaction between the solid constituent of the material and the air within the material influences the performance of the absorber. A critical physical characteristic that affects the performance of an absorber is flow resistance. The performance of a poro-elastic material can be enhanced using flow-resistive facings.[6] Factors impacting performance are: bulk density; solid density; flow resistivity; Young's modulus; shear modulus; thermal length; viscous length; tortuosity; and porosity.

Depending on the type of facing and its flow resistance characteristics, the performance of an absorption material could be affected dramatically. Therefore, if you know the benefits and limitations of the facing material, you can use this information to your benefit. Various factors that affect performance of an absorption material are shown qualitatively in Figure 4.

A **barrier** is a material that blocks sound propagating from one area to another; for example, from the engine compartment to inside the vehicle. A barrier is a nonporous, massive, and limp material. If there are holes in the barrier, the sound energy, depending on the wavelength of sound and the size of the hole, has the potential to pass to the other side without attenuation. Therefore, a barrier with a hole cannot effectively block sound with one-quarter wavelength equal to or shorter than the size of the hole. The more massive the barrier, the better its ability to block sound. As sound waves strike the barrier material, the mass of the barrier does not allow it to vibrate. Therefore. the air on the other side of the barrier does not get excited, and the sound energy does not propagate easily. A barrier needs to be limp to prevent resonance effects, so it does

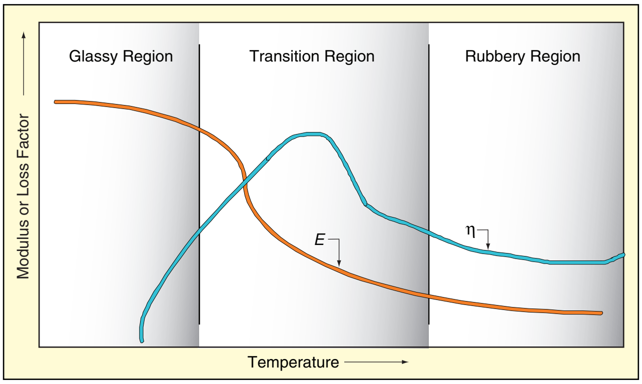

Figure 6. Qualitative picture of vibration damping.

not re-radiate sound easily.

Dashboard material by itself is a good material for noise control. Unfortunately, that alone is insufficient to control noise propagation from the engine compartment to inside the cabin. Therefore, additional acoustical materials such as dash mats are used to enhance performance. Unfortunately, there are holes and cutouts on the dashboard and dash mat for different accessories to pass through between the engine compartment and cabin. These accessories have the potential to introduce noise leakage paths. Because of this and in the effort to reduce weight, many vehicles use lightweight dash mat constructions.[7-9] The dash mats in this case are essentially two different absorption materials with different resistive characteristics that have the potential to enhance the net acoustical performance of the treatment.[10] But for luxury and very high-quality vehicles, barriers are one of the few ways to obtain the acoustical requirements that consumers desire. Therefore, in all world-class vehicles, regardless of manufacturer, a lot of barrier materials are used to achieve the target acoustics.[11]

While using barriers to reduce noise, one needs to be familiar with the performance benefits and limitations of single-wall and multiwall (also known as double wall) constructions.[4] The sound transmission loss of a double-wall construction system depends on various factors:[12]

- Surface density and stiffness of the individual walls.
- Space and material (decoupler material) used between the two walls.
- Stiffness of the decoupler material.

A qualitative performance diagram for barriers is shown in Figure 5.

A **damper** is used to dissipate structure-borne excitation of body panels. When a structure vibrates at resonance, a damper reduces the amplitude of vibration and reduces sound radiation. A damper generally works by transferring the vibration energy into heat.[13] In that sense, a vibration damper works like a sound absorber. A combination of molecular structure and free volume affects damping performance. In addition to frequency, performance also depends on temperature. The molecular structure and the visco-elastic characteristics of a material changes with temperature; therefore damping properties also vary with temperature. A qualitative performance diagram for dampers is shown in Figure 6.

Evaluating the Acoustical Performance of Materials

Proper evaluation of the acoustical performance of a material is critical in the sound package selection process. Standards are developed by various committees within different professional organizations. The purpose of a standard is to provide:

- Information on conducting measurements according to a specific test procedure.
- Guidance on how to understand whether measurements are correct.
- Precautions and limitations of a test method.
- A methodology so that the user can compare test results provided by different suppliers, tested at different laboratories.

Often, OEMs develop their own test methods, especially if a standard does not exist. Some basic strategies need to be followed in the development of a standard:[14]

- Rationalize the need for a standard.
- Define the scope of the standard.
- Conduct a survey to know current practices.
- Ensure proper representation in the committee – user, manufacturer, test lab, consultants.

These steps are necessary so one can share and understand the test methodology and results and can eventually recommend proper solutions. Procedures need to be verified by conducting round-robin tests at different laboratories. Once a study is conducted, all test facility participants need to discuss the test results together to understand what may cause variations in test results and how these variations could be minimized. Everybody has to be ready to address these issues together and be ready to solve the problem. Otherwise, despite laboratory accreditation, certification, and/or registration, test results may not be able to do justice to the vehicle in the quest to achieve target acoustics.[15]

Developing Acoustic Targets

Developing acoustic targets is a critical part of the entire sound package development process. The purpose of developing a target is to make sure that the OEM is getting the correct material for the vehicle. In doing so, the OEMs conduct extensive benchmarking studies of competitive vehicles under different operating conditions. They identify acoustical parameters of competitive vehicles and opportunities for competitive target levels for the new vehicle.

Computer-aided engineering, numerical acoustics, and acoustic measurements participate in developing and optimizing an effective sound package treatment. Computer-aided analysis provides guidance very early in the program. Sound package treatments can be developed using statistical energy analysis (SEA) tools before prototype vehicles are available, reducing development time and cost.[16] This is an effective way of understanding the type of treatments that may be necessary to meet vehicle level acoustic targets. It also allows the developer to work with different variables to see how different treatments affect the vehicle sound level.[17] The model is used for noise path analyses and developing system and component level targets from vehicle level targets.

In developing targets, it must be understood that, depending on need, there may be three targets – material level, component level, or vehicle level. Once the purpose of each target level is understood, the challenge becomes target setting. If the targets are based on SEA analysis, the targets depend on the input data necessary to build the model. Eventually, a prediction needs to be validated through measurements. Regardless of whether the targets are based on SEA analysis or measured data, there are other variables that come into play. These include but are not limited to whether the target should be based on:

- One set of measurements.
- Maximum performance.
- Minimum performance.
- Average of several measurements with proper representation of test to test and operator variations, some factor of safety, and a minimum acceptable level for that application.
- Allowances for production tolerances as well as design clearances (e.g., a predetermined gap between the perimeter of a grommet and the sound package component).

Judging If Performance Makes Sense

Once the measurements are made and results distributed, one of the key concerns of the OEMs is to make sure the results make sense. OEMs may not make the actual measurements but are likely to use the data and make decisions on further development of the sound package treatments. Therefore, the user needs to have the proper training and background to judge whether the results are correct. This requires an understanding of:

- How materials work (e.g., an absorber versus a barrier).
- How and why materials are placed in a particular way in an application (e.g., body panel, absorber, acoustical scrim, interior trim panel versus body panel, absorber, interior trim panel).

- How tests should be conducted (e.g., the results of tests of an absorber with an impervious backing would be different if the tests were conducted with no air gap versus an air gap that may simulate the application).

Implementation

Perhaps the most challenging task of all is ensuring that the best sound package has been developed in terms of its value. The value (not just monetary) in today's global automotive market consists of: cost; weight; durability; functionality, recyclability; packaging space; environmental impact; performance; and ergonomics.

One needs to understand in developing the sound package treatment, that significant effort is needed beyond individual material performance to achieve optimum balance of performance for various noise source and operating condition combinations.

The performance of a given treatment component may also depend somewhat on the presence of other components. In other words, there may be situations where increasing the performance of a sound package treatment may not have any overall impact on vehicle acoustics. Therefore, it not only becomes difficult to determine the true importance of certain materials, in some cases the acoustical requirements of certain parts may become very minimal. Unfortunately, this would not be known unless a thorough study is done on the source-path-receiver analysis. In addition, the user also needs to make every effort to minimize flanking paths.

Summary

We have emphasized the basic elements that the automotive acoustics engineer needs to know to develop an optimal sound package treatment for a vehicle.

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