

Establishment of Performance Design Process for Vehicle Sound-Proof Packages Based on SEA Method

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ABSTRACT

The process for setting the marketability targets and achievement methods for automotive interior quietness (as related to air borne noise above 400Hz, considered the high frequency range) was established. With conventional methods it is difficult to disseminate the relationship between the performance of individual parts and the overall vehicle performance. Without new methods, it is difficult to propose detailed specifications for the optimal sound proof packages.

In order to make it possible to resolve the individual components performance targets, the interior cavity was divided into a number of sections and the acoustic performance of each section is evaluated separately. This is accomplished by evaluating the acoustical energy level of each separate interior panel with the unit power of the exterior speaker excitation.

The applicability of the method was verified by evaluating result against predicted value, using the new method, during actual vehicle operation. The difference between predicted interior cavity sound pressure level (SPL) and that of measured was less than 3dB. In addition, the difference in the level of reduction in interior cavity SPL by countermeasure between predicted and measured was less than 0.5dB. This was judged as acceptable accuracy. This new method is being developed for use within the design process and makes it possible to propose optimized specifications for sound proof package.

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INTRODUCTION

Since quietness is an important item for enhancing product performance appeal, the need for a high degree of quietness in the interior cavity is increasing with each year. However, reducing vehicle body weight is also important from the viewpoint of enhancing fuel economy. To simultaneously fulfill both of these needs in the early stage of vehicle development, it is necessary to derive the complete vehicle quietness target value of the development vehicle. At the same time, deriving the acoustical performance of sound-proof packages that include the panels needed to achieve those targets is necessary. In addition, it is also necessary to add component weights and costs as the performance judgment items for appropriate adjustment of the sound-proof package specifications in the early stage of the development.

For appropriate adjustment of the sound-proof packages, development should follow the flow written below while using the acoustical performance of each area obtained by dividing the interior cavity surface which is defined as system performance. At first, the system performance of a mass-production vehicle is accurately ascertained. At the same time, the development vehicle quietness target in interior cavity is set. Next, by cascading-down from the

target quietness, the system performance target values are set. After that, sound-proof package specifications are investigated, which is capable of achieving the system performance target values with light weight. Finally each sound-proof package specification is reflected to the drawings. Appropriate sound-proof package specifications for achieving the quietness target values can be determined by performance cascade-down from the vehicle quietness via the system performance. This type of development flow is called a performance design process for vehicle sound-proof packages (hereafter, "performance design process").

In this performance design process, a panel contribution analysis method is needed for setting the system performance target value. In this case, the panel is small divided area of the interior cavity surface. When conducting the panel contribution analysis of the mass-production vehicle, the acoustical input powers identified from the tire radiation noise or engine radiation noise and the system performances are needed to be used. Therefore, the contribution analysis which uses the system performances and an evaluation method of that system performance are indispensable.

Table 1. Method comparison

	Masking method	Experimental SEA method	HSEA method	Acoustical performance with speaker excitation	Proposed method with ETL
Power contribution analysis	O	O	O	N/A	O
Energy flow indication	X	O	O	N/A	O
Acoustical system performance	N/A	N/A	N/A	X	O
Analysis period	X	X	O	N/A	O
Proposed method with ETL	X	X	X	O	O
Applicability	X	X	X	X	O

There are multiple contribution analysis methods. The masking method [1.] obtains the acoustical power contribution ratio by covering the interior cavity surfaces with heavy sound-proof materials and then removing the sound-proof materials one surface at a time. In addition, the hybrid SEA (HSEA) method [4., 5., 6.] obtains the acoustical power contribution ratio by accurately synthesizing the interior cavity SPL using a combination of the experimental SEA method [2.] and the analytical SEA method [3.]. This method enables numerical specification study of sound-proof package.

The masking method experimentally identifies the acoustical power from each divided interior cavity surface. And, it enables to identify the influence of each sound-proof package on interior cavity SPL based on the acoustical performance of each test piece and the specification of each sound-proof package, such as layered structure, material, applied area, and thickness.

In this case, since the acoustical power from the interior cavity surface cannot be reliably broken down into the acoustical input power to the vehicle and system performance, making it a challenge to set the system performance target values for the development model. In addition, the HSEA method is able to represent the energy flow from the input sources of the complete vehicle to the interior cavity with the energy coupling loss factor (CLF) and energy damping loss factor (DLF). And it can identify the acoustical power from each divided interior cavity surface. However, it is unable to identify the system performance using CLF and DLF with this method. Table 1 summarizes these issues.

In contrast, the acoustical frequency response function is one another acoustical vehicle body performance, which can be identified with interior cavity SPL by exterior speaker excitation. In this case, the voltage applied to the speaker is used as the reference signal (Figure 1). However, the performance identified by this method cannot be used to identify the acoustical power contribution from the interior cavity surface relative to the interior cavity SPL (Table 1). Thus, it is a challenge to investigate sound-proof package specifications in accordance with the performance design process by using conventional methods.

A method was therefore proposed that divides the interior cavity surface, which includes panels and sound-proof packages, into multiple areas and evaluates the acoustical performance of those

areas using a system performance based on the SEA approach. By using a performance design process that incorporates this method, the efficient specifications in weight and acoustical performance of each component can be investigated in the early stages of vehicle development. As a result, this leads to more accurate confirmation of product performance using prototype vehicles in the verification stage. This realized a V-model development process that combines both experimental and theoretical (CAE) investigation of vehicle sound-proof packages as shown in Figure 2. This paper describes the features of the newly set system performance and its usefulness in vehicle development.

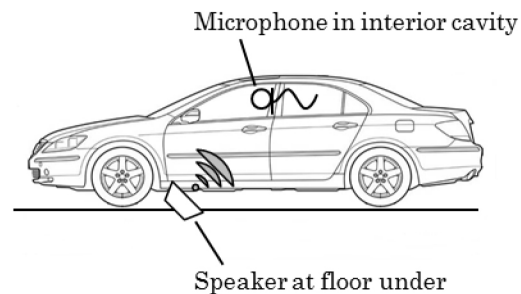


Figure 1. Conventional evaluation method for acoustical performance

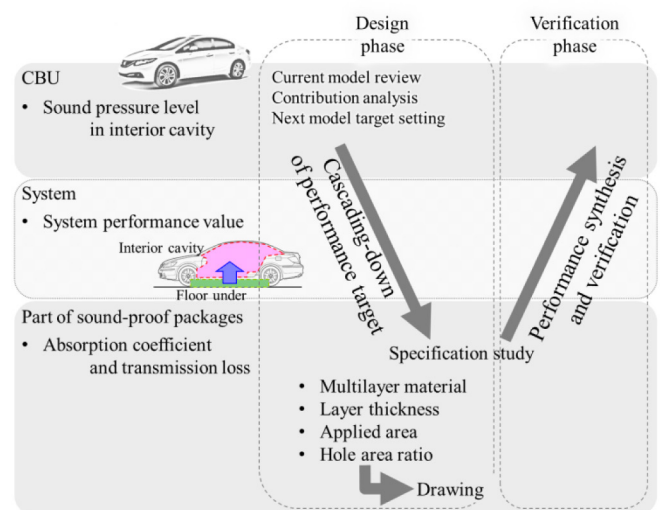


Figure 2. V-model development process for vehicle sound-proof-packages with experimental and CAE method based on SEA

PERFORMANCE SETTING GOALS

The following three points were set as goals when establishing the method of dividing the interior cavity surface, which includes panels and sound-proof packages, into multiple areas and evaluating the acoustical performance of those areas using a system performance based on the SEA approach.

1. Enable to use a new system performance to associate the complete vehicle performance and the acoustical performance of each sound-proof package.
2. Enable to theoretically assign a performance from the complete vehicle quietness target to the system performance.
3. Enable to use the system performance to evaluate the amount of change in component performance.

FEATURES OF SYSTEM PERFORMANCE

Approach toward Systems and Components

In order to systematically assign performance from the complete vehicle quietness to a component performance using the SEA method, the vehicle body is divided into multiple component groups including interior and exterior cavity sound fields. Here, a single divided element is called a system. These systems are further divided in accordance with the applied surface of major sound-proof packages such as the floor carpet, dashboard insulator, roof lining, and glass. In addition, a system includes panels and multiple sound-proof packages, and that sound-proof package group is called a component. Figure 3 shows the approach toward systems and components using as an example the engine room, interior cavity and dashboard panel component.

The systems for an entire vehicle are set in accordance with the seat arrangement and shape of the vehicle. For example, Figure 4 shows a mid-size sedan divided into 13 systems. (Only the left side is shown for left/right symmetrical locations.)

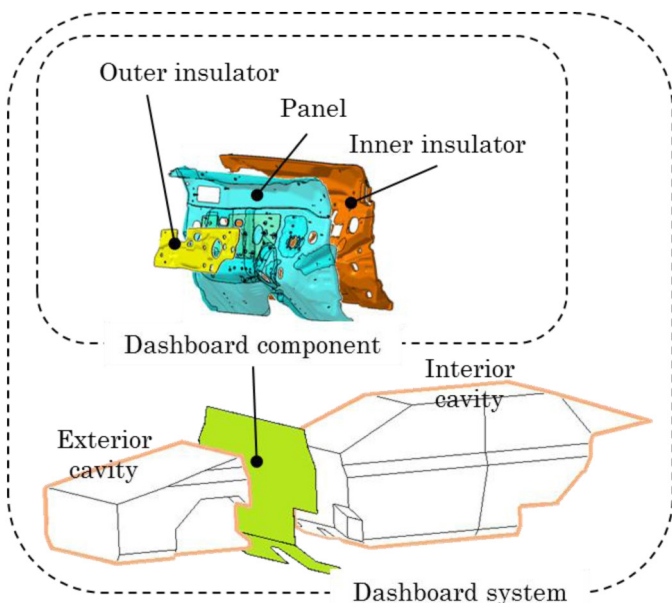


Figure 3. Definition of system and component

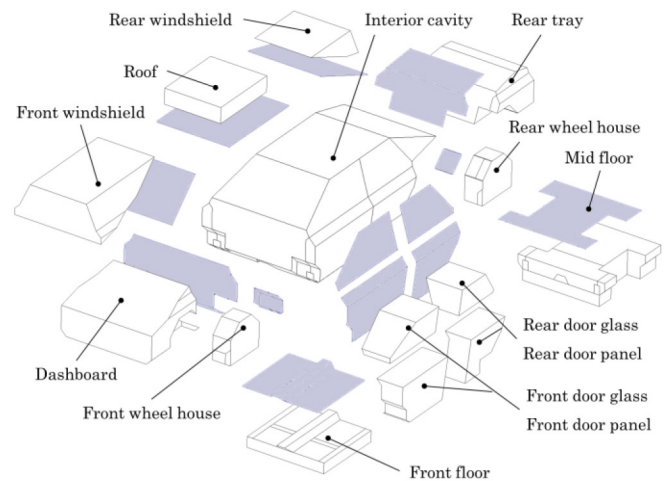


Figure 4. Interior cavity and all systems for mid-size sedan

Definition of System Performance

In order to set the system performance, the concept when evaluating a system by acoustical excitation using a speaker was compared experimentally and theoretically. Figure 5 shows schematic diagrams of the acoustical input, SPL and energy level [Z.], using as an example a system with the engine room as an exterior cavity sound field. Both the experimental and theoretical cases show that the system can be evaluated by the response energy $E_{IC-1,1W}$ of the interior cavity sound field when acoustical unit power of 1 W is input to the exterior cavity sound field. Here, $E_{IC-1,1W}$ is defined as shown in Equation (1), and the subscript notation rule is first character = response sound field and second character = excitation sound field.

$$E_{IC-1,1W} = \frac{V_{IC}}{\rho_{air} c^2} \overline{p_{IC-1}^2} / P_1 \quad (1)$$

Where, V_{IC} is the volume of the interior cavity sound field, ρ_{air} is the air density, c is the speed of sound, p_{IC-1} is the average SPL on the interior cavity side, and P_1 is the speaker acoustical power.

$E_{IC-1,1W}$ is defined as a new system performance as shown in Equation (2) so that it can be treated as transmission loss, and is called the energy transmission loss (ETL) ETL_{1-IC} .

$$ETL_{1-IC} = 10 \log \left(\frac{1}{E_{IC-1,1W}} \right) \quad (2)$$

The subscript notation rule here is from the sound field indicated by the first character to the sound field indicated by the second character. In this example, this is the ETL from the engine room to the interior cavity sound field.

In the theoretical case, the energy of the interior cavity sound field can be obtained using a commercially available sound field and sound pressure prediction application based on the SEA method, by inputting acoustical power of 1 W to the exterior cavity sound field of