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Experiment of A Cavity-gap Coupling Model for The Safty and Comfort of A Driving Condition

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Abstract : For the purpose of controlling the coupling between the car body panels and passenger compartment, experimental investigation of an acoustic cavity with an air gap is carried out to reveal how the air gap influences the acoustic modal characteristics of the cavity. The acoustic modal characteristics of the cavity is closely related with the booming noise. The experimental results show that a very small air gap can change the acoustic modal characteristics of the cavity and, as a result, the air gap can be an important factor in controlling the booming noise for comfortable and safe passenger compartment.

Key words : air Gap, safety and comfort of passenger compartment, booming noise, acoustic cavity

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1. Introduction

The reduction of severe booming noises is one of important factors in the car NVH study for the safety and comfort of a high-speed driving condition[1-2]. Many researches have studied about various ways of reducing the booming noises such as the reduction of the engine noise, the control of noise-transmitted paths, and the consideration of the coupling of the car body panels and passenger compartment[3-8].

In most passenger cars many kinds of inner material sheets, such as the headliner beneath the roof, the upper sheet on the rear (package) tray and the carpet on the floor, are attached to the boundary panels for various purposes. In particular, the headliner may be separated from the roof by a thin gap, which is partially filled with porous absorbent materials in rare cases. By now, the function of the gap has been not investigated in the booming frequency range. From a common sense standpoint, the compound system composed of the headliner and the gap seems to hardly influence the resonance of lower cavity modes. The reason is that the thickness of the gap is very small compared with the compartment dimensions, and that the boundary panels are much stiffer than the headliner. But in this paper, it is revealed that the compound system has a considerable effect on the modal characteristics of the compartment only if it is well designed. The effect of the compound system on the resonance of the compartment is to suppress the resonant peaks of the compartment in company with the shift of the peaks. The effect is analogous to that of a Helmholtz resonator, which plays a role in absorbing an acoustic energy in a narrow frequency band[1]. It is confirmed that the density of the headliner and the thickness of the gap have deep relation to the inertance and compliance of the Helmholtz, respectively.

In the author's previous research[9], it has also been shown from analytical models that the resonance of enclosed cavities, which is closely connecter with the booming noise, can be effectively suppressed by fairly designing the air gap system. In the paper, it is verified through experimental models that the analytical results agree qualitatively well with experimental ones.

2. Acoustic Responses using Various Partition Sheets

Figure 1 shows a box-shaped cavity for examining the effect of increasing the gap thickness when a partition sheet is separated from the upper boundary of the cavity. In this experiment, four kinds of real headliners are installed for the partition sheet: one of the headliners has been used in a foreign motor company and the others have been used in domestic motor companies. In Table 1 are given the surface density and the first four

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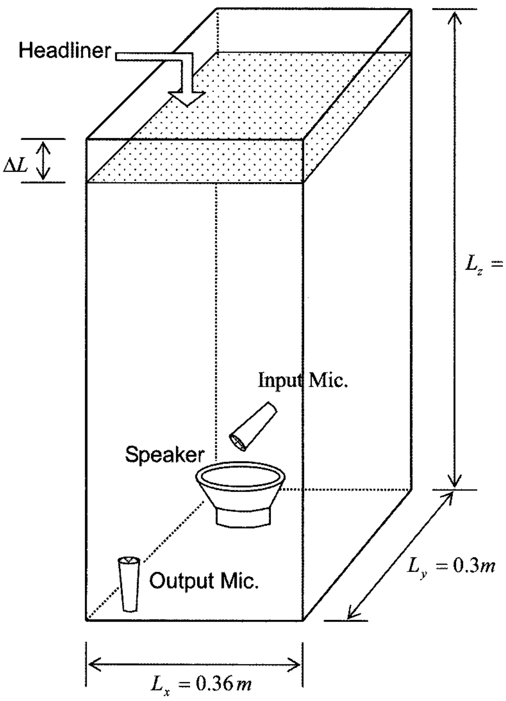


Fig. 1. Experimental set-up of a box-shaped cavity for the airgap effect.

natural frequencies for each of the headliners. In the case of C-headliner, note that the density and natural frequencies are lower than the other headliners.

All boundaries of the cavity were made of thick Acril-panels that can be assumed as rigid walls. When no headliner is inserted, the resonant frequencies of the first four vertical modes of the cavity were found to be 173Hz, 358Hz, 556Hz and 741Hz. Particular attention will be given to the suppression of the first resonance peak when the four types of headliners used in the concerned experiment.

2.1 When H1-headliner is used

Figure 2 shows how vary the acoustic responses in the cavity when the gap thickness is increased from 0.0cm to 6.0cm by 0.5cm. When the headliner is directly attached to the boundary of the cavity, only higher resonant peaks are just a little influenced. However, as the thickness is increased, it may be seen that the damped frequency zone is moved in the low frequency region so that lower resonant peaks are suppressed. The key feature (that the damped frequency zone is moved in the low frequency region as the gap thickness is increased) is similar to that predicted in analytical models. When a value of 3.0cm is given for the gap thickness (See Figure 2g), the second resonant peak is split into two peaks with the same levels. From this fact, the thickness of 3.0cm is called the reasonable gap thickness for the second resonant peak. It may be also said from Figure 21 that the gap thickness of 5.5cm is the reasonable gap thickness for the first resonant peak.

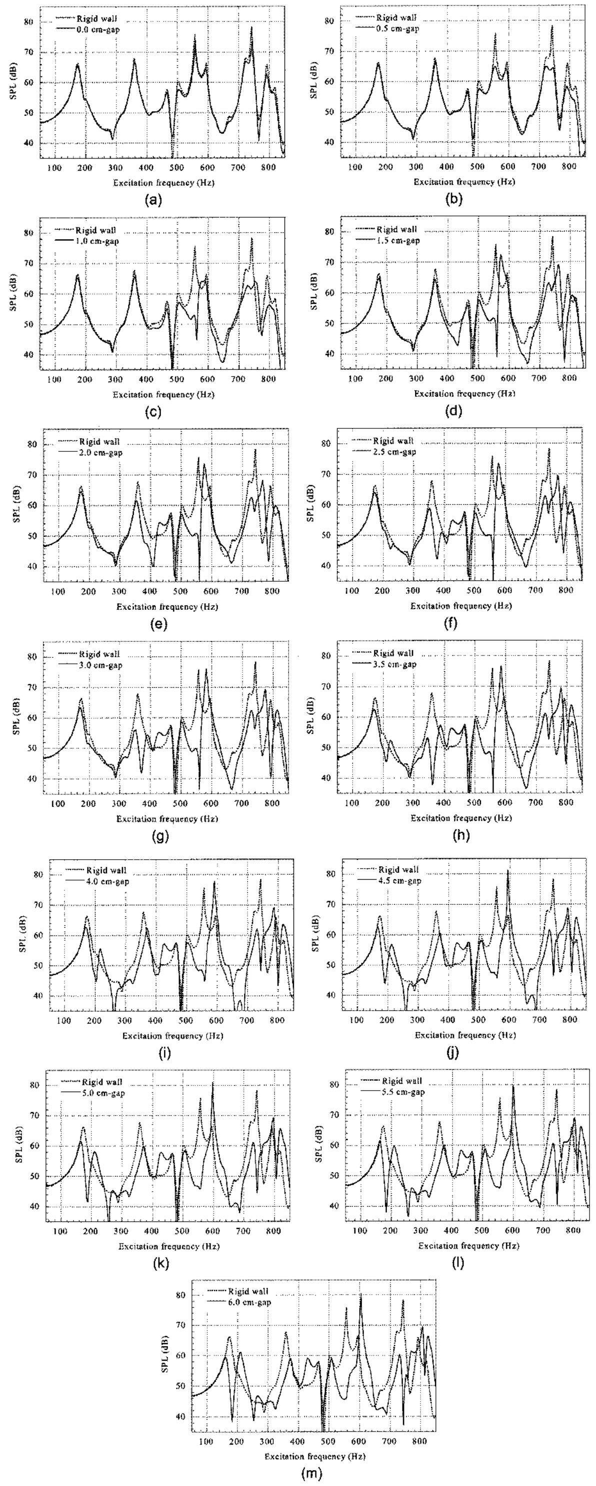
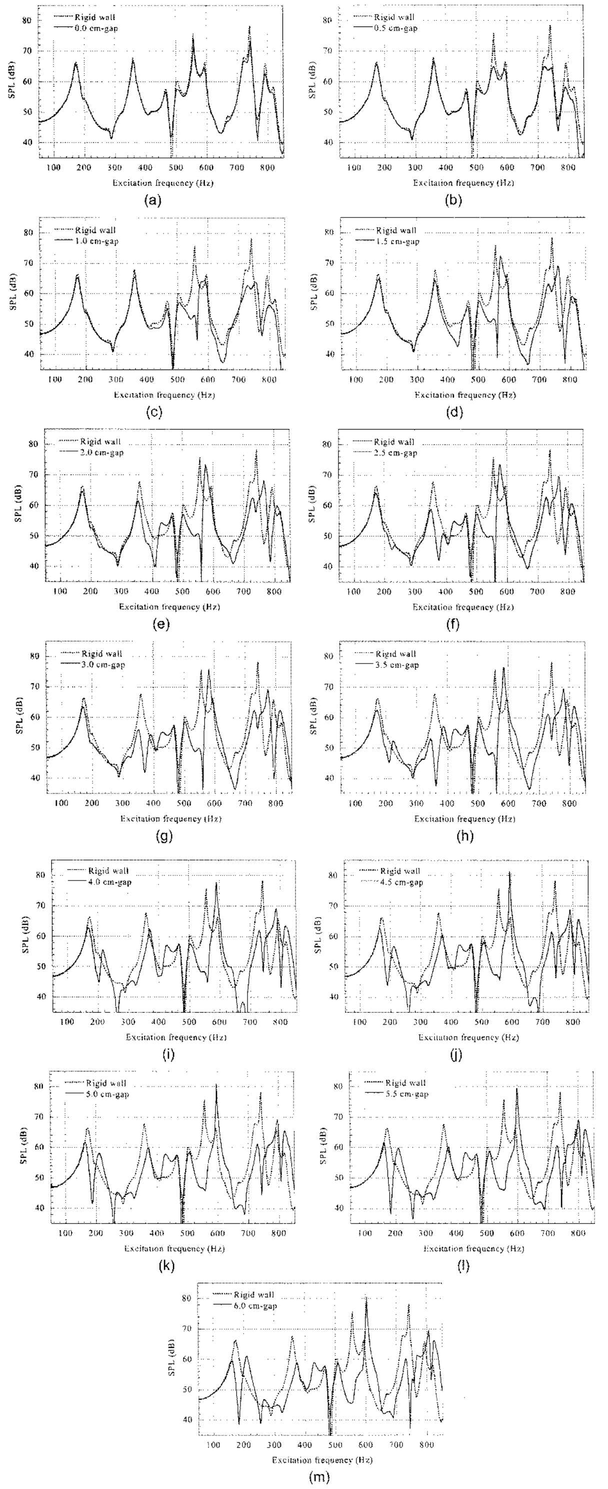
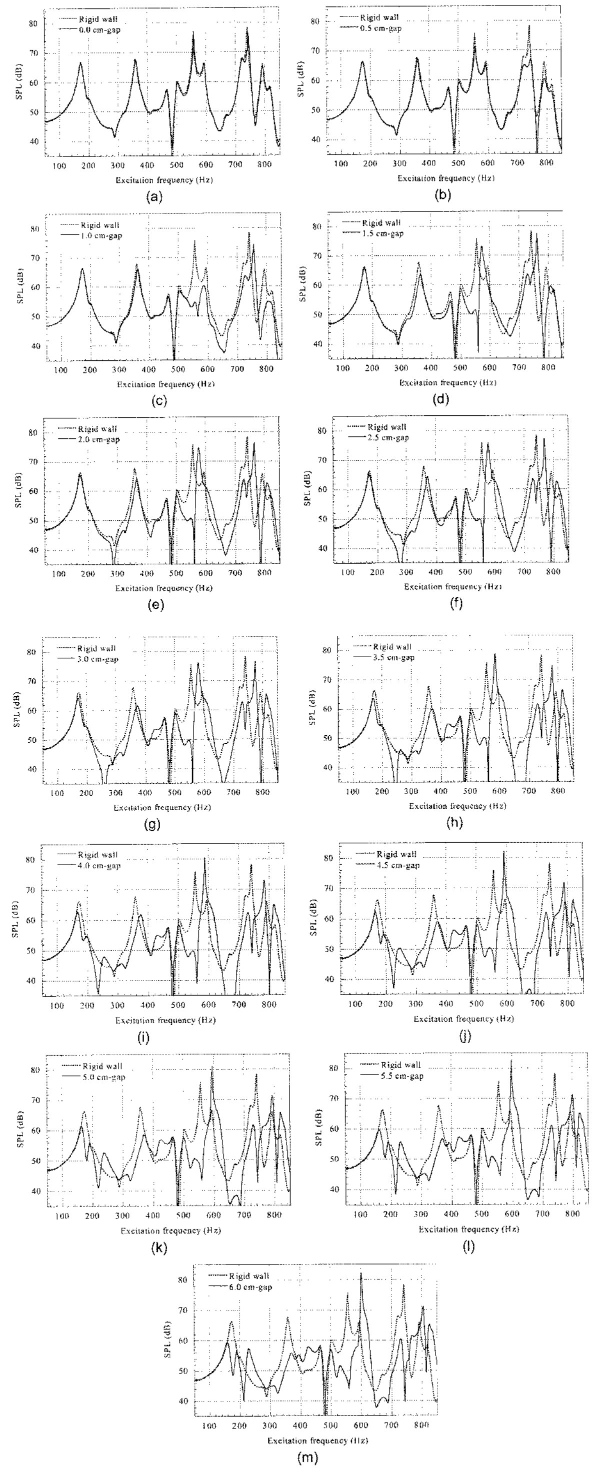


Fig. 2. Acoustic response as increasing the gap thickness when H1-headliner is used: the thicknss is increased from 0.0cm to 6.0cm by 0.5cm.



(a) (b) (c) (d) (e) (f) (g) (h) (i) (j) (k) (l) (m)

Fig. 3. Acoustic response as increasing the gap thickness when H2-headliner is used: the thickness is increased from 0.0cm to 6.0cm by 0.5cm.

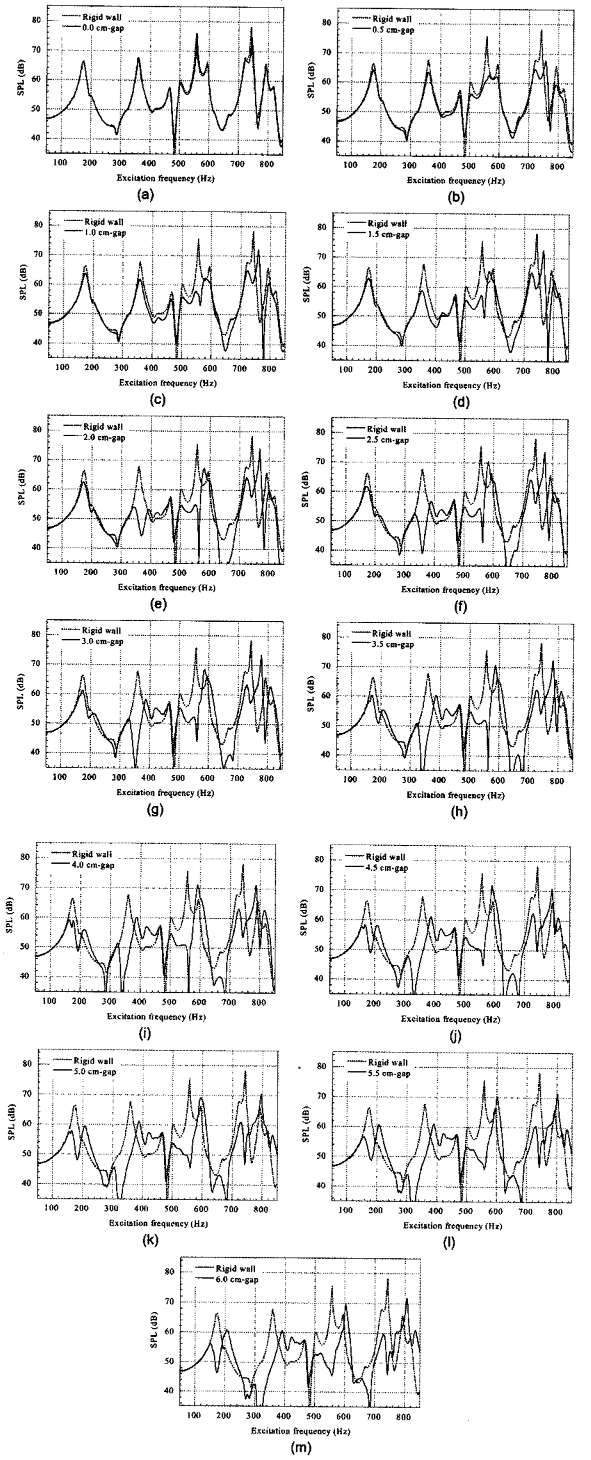


(a) (b) (c) (d) (e) (f) (g) (h) (i) (j) (k) (l) (m)

Fig. 4. Acoustic response as increasing the gap thickness when D-headliner is used: the thickness is increased from 0.0scm to 6.0cm by 0.5cm.

2.2 When H2-headliner is used

Figure 3 shows acoustic responses measured when H2-headliner has been used. As shown in Figure 3l, the gap thickness of 5.5 cm may be determined as the reasonable gap thickness for both the first and the second resonant peak. In this thickness, each of the two peaks is split into the resonant peaks whose levels are decreased to minimum values.



(a) (b) (c) (d) (e) (f) (g) (h) (i) (j) (k) (l) (m)

Fig. 5. Acoustic response as increasing the gap thickness when T-headliner is used: the thickness is increased from 0.0cm to 6.0cm by 0.5cm.

2.3 When D-headliner is used

As shown in Figure 4k, when values of 5.0cm are given for the gap thickness, the second resonant peak is reasonably suppressed. In order to reasonably suppress the first resonant peak, a value of the gap thickness above 6.0cm is required, as shown in Figure 4m. In the case of D-headliner, it may be said that the reasonable gap thickness for the first resonant peak exists above 6.0cm and that for the second one exists near 5.0cm.

Table 1. Modal characteristics of the headliners used in experiment: T- headliner has been used in a foreign motor company.

HEADLINER TYPES	H1	H2	D	T
SURFACE DENSITY (kg/m^2)	1.9	1.7	2.1	1.5
1st (Hz)	72	78	90	58s
2nd (Hz)	148	158	152	128
3rd (Hz)	170	174	206	142
4th (Hz)	240	248	272	198

Table 2. Natural frequencies of the compartment cavity and the headliner (unit: Hz).

Modes	1st	2nd	3rd	4th	5th	6th
Cavity	182	266	306	318	326	406
Headliner	28	58	66	92	108	116

2.4 When T-headliner is used

As shown in Figure 5, it may be concluded that T-headliner has more positive effect on the acoustic response than the other headliners, in that lower resonant peaks are largely suppressed even when a small value of the gap thickness is given. Besides, no higher resonant peak grows up larger than the peaks in the case that the headliner is not attached, when the damped frequency zone has been moved in the low frequency zone. In the case of T-headliner, the values of the reasonable gap thickness for the first and the second resonant peak may be said to be 4.5 cm (See Figure 5j) and 2.0 cm (See Figure 5e), respectively. Among the four headliners, it may be said that T-headliner shows the most excellent performance in that the smallest value of the gap thickness is required to reasonably suppress the first resonant peak. This fact is shown in Figure 6, which offers the comparison of the effects of the four headliners on the first resonant peak when the gap thickness of 4.5cm is given equally for the headliners. The excellent performance is associated with the modal characteristics such as the natural frequencies and the surface density. In Table 1 it is noted that the first natural frequency of T-headliner is considerably low compared with those of the other headliners, and that the surfaces densities make only a little difference.

3. Conclusions

The experiments clearly show that the air gap has a significant effect on the acoustic response. As was predicted in the previous paper [9], the damped frequency zone has been moved in the direction of the low frequency by increasing the gap thickness and, as a result, the peak split phenomenon has occurred. Our experimental results agree well qualitatively with those obtained from one-dimensional and three-dimensional models [8, 9]. In addition, it has been confirmed that the modal characteristics of the headliner as well as the gap thickness can significantly influence the performance.

Acknowledgement

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