

Development of Interior Sound for a Medium Coupe with Sportiness as an Objective Evaluation Index

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ABSTRACT

A new model medium size coupe was developed with consideration of a sporty interior sound. Subjective evaluation of competitor vehicles was correlated with measured objective results to establish a target interior sound index. The target values on this index were determined at the concept stage of development with respect to relative position of competing cars. As a result of subjective evaluation of artificial interior sounds that represented candidate target values, a target sound was established. The air intake system from the base sedan was modified exclusively for the coupe. Adjustments to intake tube diameter, length, and intake inlet position resulted in an exclusive coupe intake sound. This yielded an interior sound with the sportiness and linear feeling that was desired under acceleration.

1. Introduction

Interior sound is one of the major factors that contribute to the product appeal of a vehicle. Each new car concept has different demands for the interior sound: a luxury car requires a quiet interior, while a sports car must allow the driver to hear more sound. In the case of a vehicle where it is desirable to hear more sound, it is important to match the sound with the vehicle and specific driving conditions. In recent years, much has been written about concepts and approaches to

sound design⁽¹⁾. However, because such vehicle development proceeded primarily on the basis of subjective evaluations with certain assumptions about the vehicle and without establishing specific numeric targets, a large number of man-hours were expended in a process of trial and error.

Therefore, as previously reported by one of the authors, a “sportiness” index was developed to quantify target interior sound target values. This paper describes how sportiness was applied in the development of a new medium coupe in order to achieve a sporty sound suited for the new car concept.

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2. Method of Objective Evaluation of Interior Sound

“Sportiness” is an expression by objective parameters, that is, values that can be measured by instruments, of a subjective rating of the degree to which a person feels the interior sound of a vehicle during acceleration as “sporty”. The ratings range from 0 (“not sporty at all”) to 50 (“extremely sporty”), and are calculated by the following formula:

$$\text{Sportiness} = A \cdot (\text{ONR}) + B \cdot (\text{TP}) + C \cdot (\text{ESP}) - D$$

A, B, C, D: Positive constants ONR: Order to noise ratio

TP: Tonality ESP: Engine speed increase rate

The basic concept of sportiness is defined as follows. Sounds of the engine speed order components are regarded as sound components, which work positively to create a sporty feel. Components other than the order components are negative components that are regarded as noise.

The order to noise ratio (ONR) expresses the extent to which the sound components exceed the noise components, weighting each order frequency for each speed, giving some effect to the size of the sound components. Effectively increasing the ONR means increasing the absolute value of the sound components in actual interior sound.

The tonality (TP) is a psychoacoustic parameter that expresses the degree to which a pure sound stands out; in this case, it expresses the degree to which the sound components stand out relative to the noise components. Effectively increasing TP means reducing the noise components in actual interior sound. Unlike ONR, TP is not necessarily affected by the absolute value of the sound components.

Engine speed increase rate (ESP) is expressed as “rpm/sec”. Increasing the ESP means selecting an engine with good pickup.

Accordingly, based on the formula above, in order to increase sportiness it is necessary to effectively increase each parameter (ONR, TP, and ESP).

Although an earlier article reported on the development of this new evaluation index this article describes the incorporation of two objective evaluation methods based on sportiness into the development of a new car.

In order to objectively evaluate the positioning of the interior sound of the development vehicle one of these methods uses a map that shows the positioning of the interior sound by comparing two values, representing sportiness and loudness (volume). The two values are expressed as an average over a range from 2,000 to 6,000 rpm. Figure 1 shows such a map using current major cars; as seen in this figure, the cars can be grouped into four areas: pure sports cars, sporty cars, exclusive sporty cars, and featureless cars. By using this map, the development vehicle positioning can be estimated relative to competitor vehicles. This method is useful when determining the directionality of the target interior sound. It is important to realize, however, that the groupings shown on this map are named for convenience according to the types of cars that fall in those areas; there are no clear-cut boundaries delineated between the areas.

The second method expresses the change in sportiness versus the engine speed as a characteristic in order to

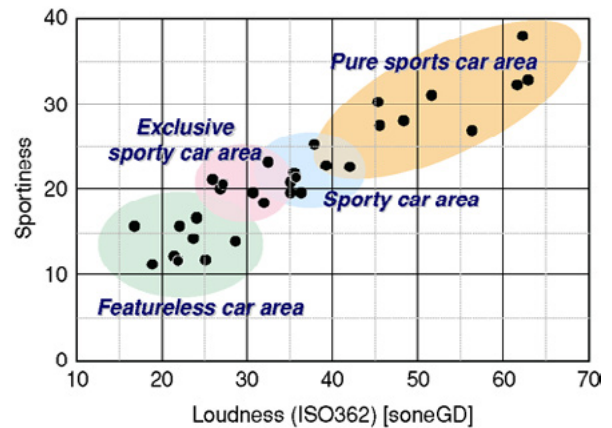


Fig. 1 Sportiness/loudness map

objectively evaluate the sensory expression of linearity during acceleration. This method permits an understanding of the positioning of the development vehicle on the sportiness/loudness map as an even more detailed characteristic. By comparing the results with the target characteristics, it is possible to clearly determine the range of engine speeds that requires improvement, and to what extent.

3. Setting the Target Sound

3.1. Target Setting on the Sportiness/Loudness Map

In setting the target for the interior sound of a new coupe based on the concept, the set target was replaced with information on how the user would drive the car and a sensory expression of the sound when the car was being driven in that manner. The decision was made to emphasize quietness while cruising, with a linear sporty sound that matches the driver sensations during acceleration for merging or passing on the American highway. In other words, while cruising, the quietness of the base sedan would be targeted, but during acceleration, the car would feature a sporty interior sound unique to the coupe.

Next, four vehicles (the base sedan and comparative vehicles A, B, and C) were driven by experts, who provided subjective evaluations of the interior sound. For the comparative vehicles, three medium size sedans/coupes with 6-cylinder/3-liter engines were selected, since they were thought to be likely competitors to the new coupe. First, the interior sound of these vehicles during acceleration was measured and their positioning on the sportiness/loudness map was clearly determined. These objective evaluations were then verified by cross-referencing them with the subjective evaluations that were made during the test drives. The correlation between these objective and subjective evaluations was extremely high. The target area on the map for the objective evaluations was then established, based on the index value for comparative car A, which was closest to the targets for the new car in the subjective evaluations by the expert drivers, as shown in Fig. 2.

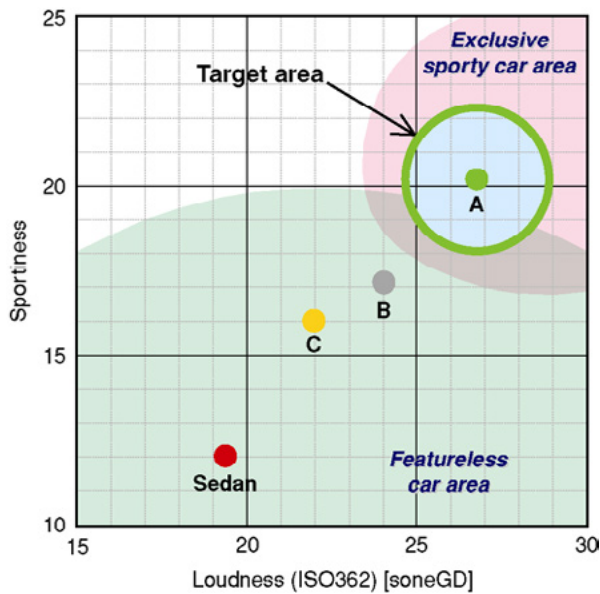


Fig. 2 Target area of sportiness/loudness map

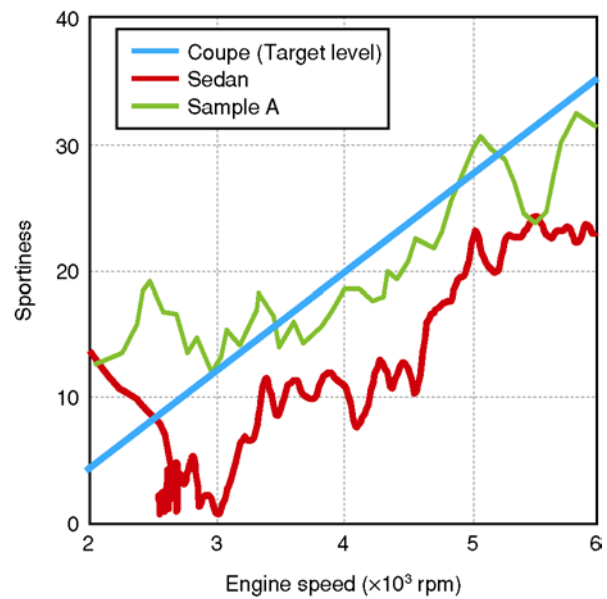


Fig. 3 Target sportiness characteristics

3.2. Setting the Target Sound Based on Subjective Evaluation of Artificial Sounds

Once the target area was established on the sportiness/loudness map, the target sound was studied. First, the sound of the base sedan was measured. A sound editor was then used to process the data and create several types of target sounds that would be positioned in the target area on the map. Next, the expert drivers listened to these candidate target sounds; on the basis of their subjective evaluations, the target sound was selected. Figure 3 shows the characteristics (sportiness versus engine speed) of the target sound that was ultimately selected. The sportiness of the target sound for the coupe was about ten units higher than that of the base sedan, and rose in a linear fashion as the engine speed increased. Figure 4 shows the results of an order tracking analysis accumulated for each engine speed. As shown in Fig. 4, the sound of the third order component of the engine speed was highest. This indicates that this sound component, which contributes positively to creating a sporty sensation, was high.

3.3. User Verification of the Target Sound

Next, the target interior sound selected by the expert drivers was played for typical users to verify how they would react to the sound. 55 test subjects who currently own a car in the same category were selected at random from the region where the car is to be sold. For this subjective evaluation, recordings of the target sound for the new car as well as the interior sound of the four vehicles that were used for the subjective evaluation by expert drivers (as described previously) were prepared. The test subjects were then asked about the following three items in regards to each interior sound:

- (1) Is the sound appealing or not
- (2) Is the sound sporty or not
- (3) Does the sound fit the subject's impression of the car design

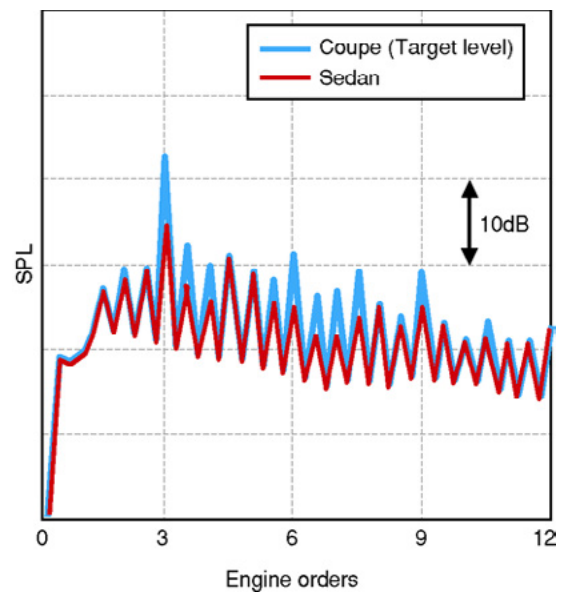


Fig. 4 Target interior sound characteristics

The test subjects were each allowed to view design sketches in order to determine whether the sound fit the design of the car.

The test subjects were asked to respond to each question on a scale from 0 (negative response) to 50 (positive response). The results were then subjected to a cluster analysis. Figure 5 shows the average ratings for the largest clusters. The target sound for the new car attained high ratings in response to each question. The highest mark was attained in regards to the question of whether the sound was sporty or not. The car that received the next highest rating was the car that had the interior sound that was established as the target for the new car from among the four vehicles for which the experts gave their subjective evaluations.

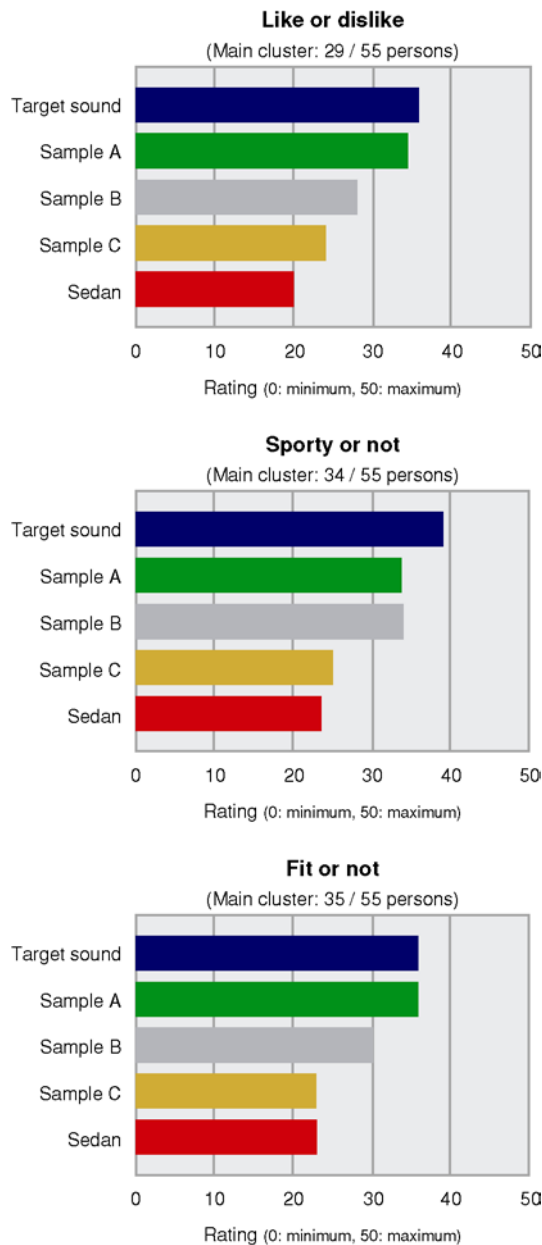


Fig. 5 Results of subjective evaluations

4. Study of Measures to Achieve the Target Sound

Once the target sound was determined, it was necessary to study the means for attaining that target sound. It was decided that the goal would be to maintain a quiet sound equivalent to that of the base sedan while cruising, but to obtain a sporty, linear sound during acceleration. From that standpoint, it would be necessary to emphasize the third order component of the engine speed order frequency in the interior sound of the coupe during acceleration compared to the sedan. Therefore, the decision was made to control the sound during acceleration by using the intake noise that is generated according to how far the throttle is opened.

4.1. Air Intake Location

When using the intake noise to control the interior sound, the intake noise characteristics and the air-borne transfer characteristics of the car body become very important factors.

Because the air-borne transfer characteristics are determined by the location of the air intake, the location of the air intake was studied first. As shown in Fig. 6, a comparison was made between two locations: at the front left side of the engine bay (the same location as in the base sedan), and in the left fender panel at a location that allows space for air intake system tubing. Figure 7 shows the transfer functions for both locations. The transfer coefficient for the location in the fender panel is greater than that of the location in the engine bay (the same location as the sedan). In other words, this location demonstrates characteristics that make the intake noise mode audible in the interior of the car. Therefore, in order to make the intake noise during acceleration stand out, the decision was made to locate the air intake inside the fender.

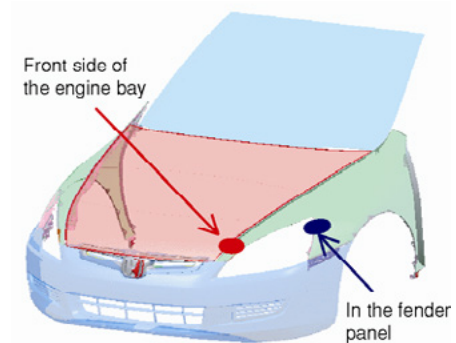


Fig. 6 Location of the intake orifice

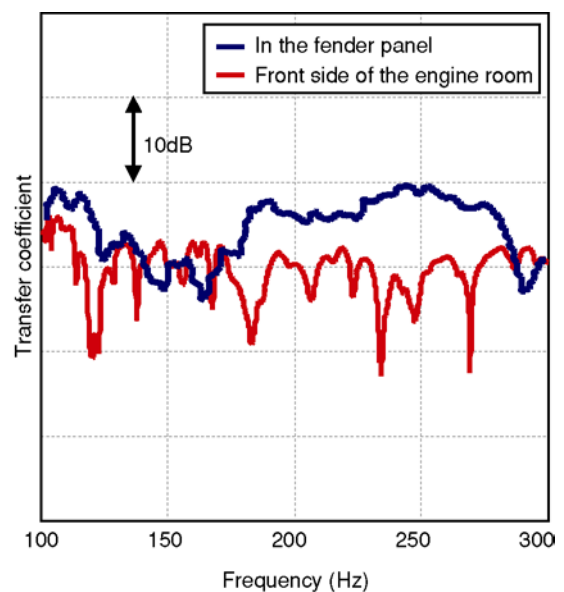


Fig. 7 Air-borne transfer characteristics

4.2. Intake Noise Characteristics

By setting the air intake inside the fender, it was possible to use the intake noise to control the interior sound. First, the target intake noise was calculated on the basis of the target interior sound and the air-borne transfer characteristics against the air intake. Figure 8 shows the difference between the target intake noise for the coupe and the intake noise of the base sedan. These results indicate that the third order component of the intake noise at high speeds needs to be increased by approximately 20 dB.

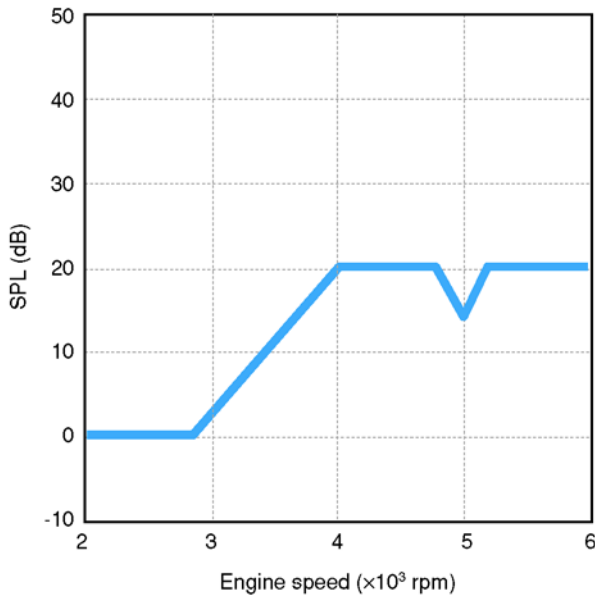


Fig. 8 Difference of intake noise target (3rd order)

In studying the specifications for the intake system, it was assumed that the base engine and the same intake system air cleaner and air flow tubes from the sedan would also be used in the new coupe. Therefore, careful attention was given to the intake tube. The inner diameter of the intake tube in the sedan is 80 mm, the length is 1,000 mm, and it has a 7 L resonator and multiple side-branches, resulting in high noise reduction performance. The study of the intake tube specifications for the coupe was performed by calculating the intake system attenuation, and setting the target value so that the intake system attenuation would be reduced by 20 dB in the range of the third order component compared to sedan's intake system attenuation. The calculations indicated that an intake tube that would satisfy the coupe's target value for the attenuation would have an inner diameter of 90 mm, a length of 700 mm, and 195 Hz branch tubes. Figure 9 shows the

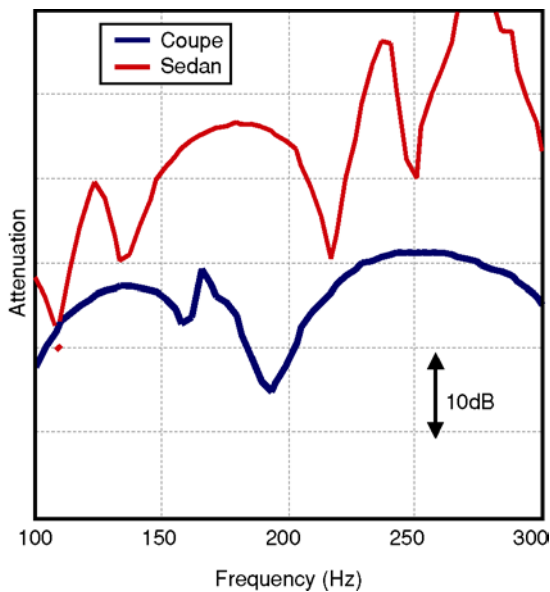


Fig. 9 Intake attenuation characteristics

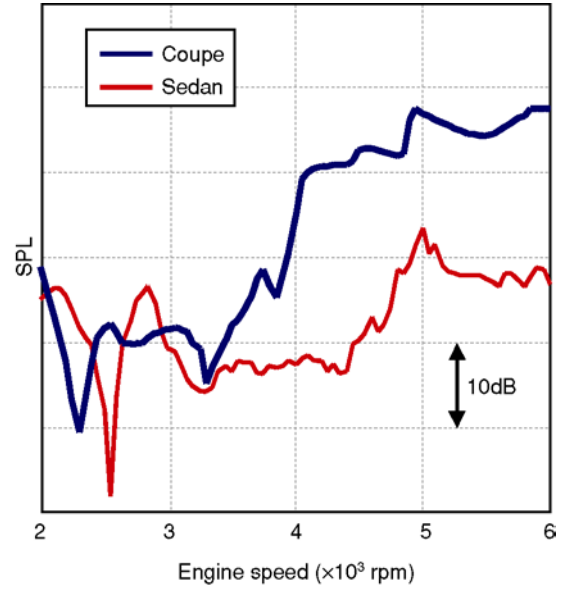


Fig. 10 Result of intake noise (3rd order)

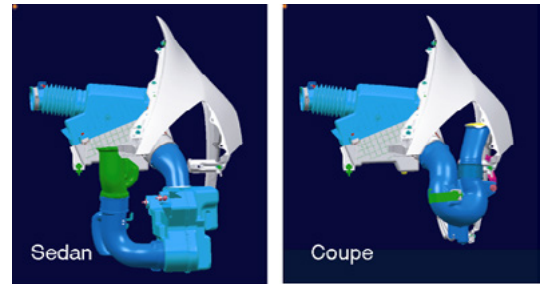


Fig. 11 Intake system layout

results of the calculated attenuation with these specifications. In addition, a prototype of the coupe with an intake tube that met these specifications was produced, and the intake noise was measured. As shown in Fig. 10, the measured results satisfied the target intake noise characteristics with a 20 dB increase in the third order component at high speeds over the sedan.

Based on these results, the intake system for the new coupe was specially adapted, and differed from the intake system of the base sedan as shown in Fig. 11.

5. Confirmation of Results in an Actual Car

An intake system meeting the specifications that resulted from the preceding study of the intake system was installed in a prototype of the new coupe, and the interior sound was measured. Figure 12 shows the positioning of the measured results and the target interior sound as sportiness versus engine speed. This graph indicates that the results produced by the current proposed specifications are very close to the target interior sound. In addition, as shown in Fig. 13, these results fall in the target area on the sportiness/loudness map.

Finally, subjective evaluation by expert drivers also yielded positive results for the sound during acceleration as being sporty and linear, in accordance with the concept for the new coupe.

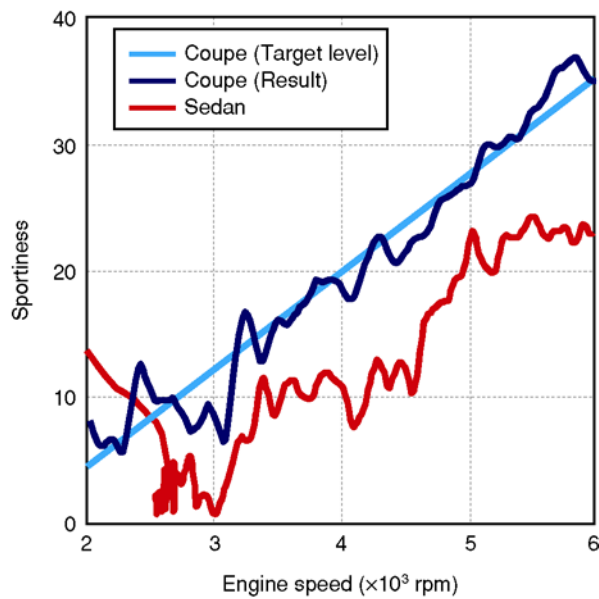


Fig. 12 Result of sportiness characteristics

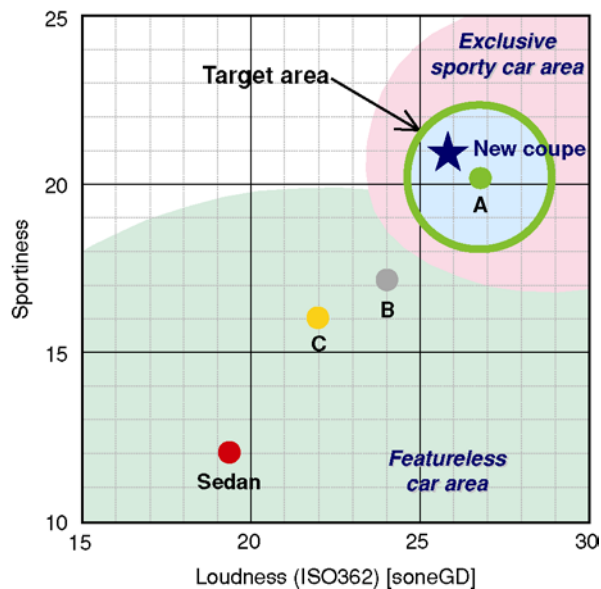


Fig. 13 Result of sportiness/loudness map

6. Conclusions

The development of interior sound for the new medium coupe yielded the following results:

- (1) Using subjective analysis based on comparative vehicles along with the “sportiness” method of objective analysis, it was possible at the beginning of the development process to clarify the positioning of the sound and quantitatively express the target values for the new vehicle that were being aimed at in development.
- (2) By using artificial sounds positioned in the target area on the sportiness/loudness map to create candidates for the target sound and then conducting subjective evaluations through listening tests, it was possible to narrow in on the desired target sound at the beginning of development.

- (3) By considering the sound sources to be controlled and the air-borne transfer characteristics of the car body in relation to the target interior sound, it was possible to quantitatively determine the target values for the sound source and efficiently develop a design suited to those sound source characteristics.

By introducing an interior sound index as described above, it was possible to achieve the aim for the new car, an interior sound that was linear and sporty during acceleration, while simultaneously achieving a major reduction in development man-hours.

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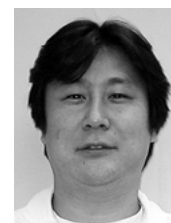
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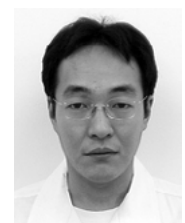
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