Acoustic analysis of car cabin space assuming in-vehicle speakers

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Abstract. In order to improve the quietness of the automobile interior, trims such as the ceiling often use a structure with high sound absorption performance. In addition, leather and fabric have different effects on interior noise. The purpose of this research is analyzing the influence of the sound absorption at the time of reflecting in a ceiling, a wall, or a sheet using the FE method and a sound ray method, when the sound emitted from the automobile speaker reaches a crew member's ear. In order to analyze how the sound emitted from a car's speakers changes due to the effects of the ceiling, walls, floor, seats, etc., we created a simple FE model of the interior of the car and performed calculations. We will report the results compared with the experimental results. In addition, in order to perform high-speed calculations up to the high frequency range, we used the acoustic ray method.

1. Introduction

The doors of automobiles are equipped with speakers, and the sound emitted from them is reflected off the walls of the car and enters the passengers' ears. In order to raise the silence of the automobile vehicle interior of a room, the trim of a ceiling etc. uses the structure where sound absorption performance is high. These may affect the music emitted from an in-vehicle speaker. Authors showed clearly how the sound which the thickness hole diameter of a speaker cover and the distance of a cover and a speaker generate from a speaker is influenced [1]. Depending on the vehicle, car seats are made of leather or cloth, and we thought that this might have an effect on the acoustics. In this study, we created a simple FE model of the cabin space that simulates an actual vehicle (NOAH) and calculated the sound pressure level. We will compare the experimental results and calculation results, and present the results of acoustic analysis to see how the sound pressure changes due to the effects of walls and seats at the ear positions of the first, second, and third row seats. When the sound emitted from the speaker of a car reached a crew member's ear, authors analyzed the influence by sound absorption of a trim of a ceiling, a floor, or a sheet using the FE method [2], and checked that it was sufficient analysis accuracy as compared with the experimental result [3]. The sound pressure level in the passenger compartment was calculated using the sound ray method and compared with the calculation results using the finite element method. The sound ray method is a type of geometric acoustic simulation, and is a calculation method that ignores the wave nature of sound (diffraction and interference) and models the energy transfer of sound geometrically. Since there is no need to divide the space, it has the advantage of significantly lower computational load compared to the finite element method. We report on these results.

2. FE MODEL

Figure 1 shows the vehicle (Toyota NOAH) used in this experiment. It is a 2019 model car, and has 3 rows of seats for 8 passengers. Car seats are made of cloth. For the experimental results using an actual vehicle, we used data provided by our co-researchers. In order to create an acoustic space based on an actual vehicle, we used FE models to create the shapes of the glass inner surface, interior trim, car seats, floor, etc., and modeled the air inside using tetra mesh. Figure 2 shows the FE model. The speaker position (yellow dot in Fig. 2) is set at the foot of the driver's seat, and the microphone position (white dot in Fig. 2) is set at the driver's seat, passenger seat, 2nd row right seat, 2nd row left seat, and 3rd row right seat. The earphones were set at six locations in the middle of both ears, including the seat and the left seat in the third row. The mesh pitch is approximately 10mm and there are approximately 14.5 million elements. In this study, the acoustic impedance of the ceiling, floor, seat, and trim was measured by an in-situ measurement method [4] and used as a boundary condition.

Fig.1. Vehicle used in the experiment. This vehicle is a Toyota NOAH, a 2019 model. It has a capacity of 8 people with 3 rows of seats. The seat is made of fabric.

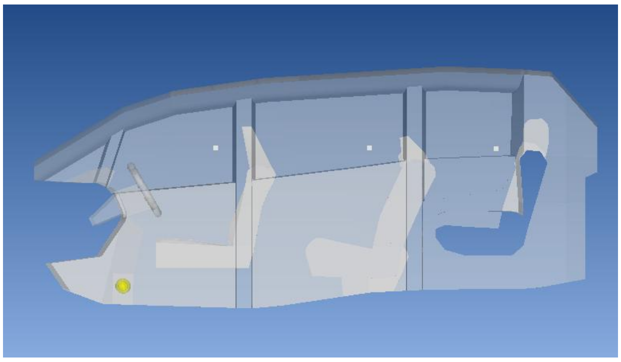
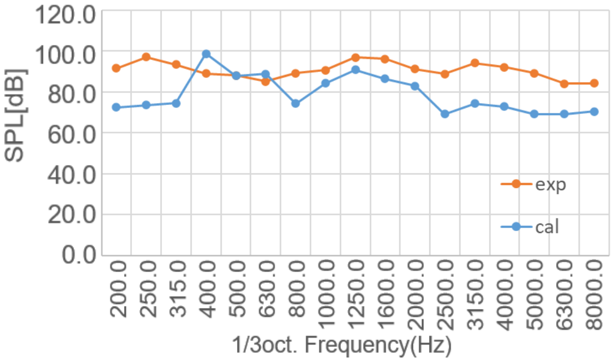


Fig. 2. FE model of automotive acoustic space. The interior space of a car was created using an FE model. The yellow dot at the foot of the driver's seat is the sound source location, and the three white dots in front of the headrest are the sound pressure measurement locations.

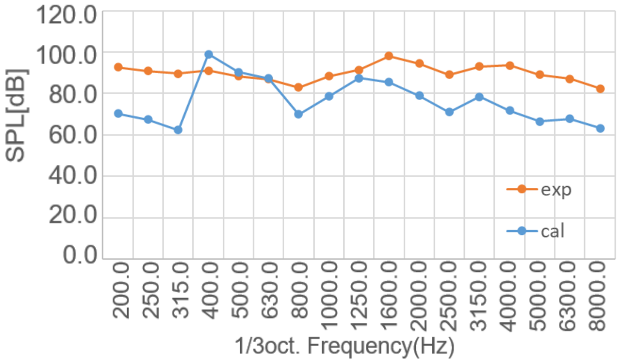
3. Calculation results

3.1 Comparison of calculation results and experimental results

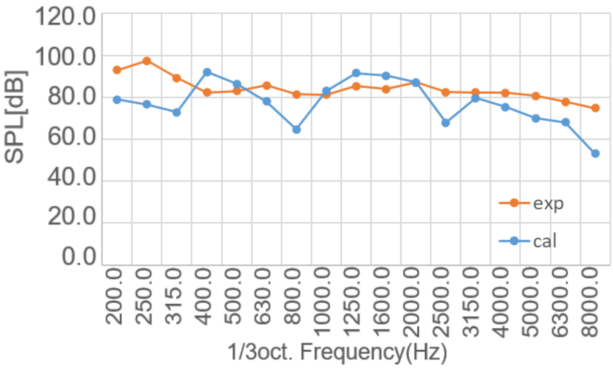
Figure 3 shows a graph comparing the calculation results and experimental results when setting the boundary condition using acoustic impedance. Calculations were performed at 1/3 octave band frequencies from 200Hz to 8000Hz at six locations. Figure 4 shows a graph of the calculation results (light blue line: initial calculation results below) and experimental results (orange line) when all boundary conditions are set. Calculations were performed from 200Hz to 8000Hz. In the first column, the trend is consistent with the experimental results, but the calculated sound pressure level is lower in the high frequency range. For the second row right seat, the calculated sound pressure level was lower at 800Hz, 2500Hz, and 8000Hz. In the second row left seat, the calculated sound pressure level is lower at 630Hz, but overall. For the third row right seat, the calculated and experimental results are relatively consistent. For the third row left seat, peaks appear at 400Hz and 1600Hz, but the same trend appears as the frequency increases.



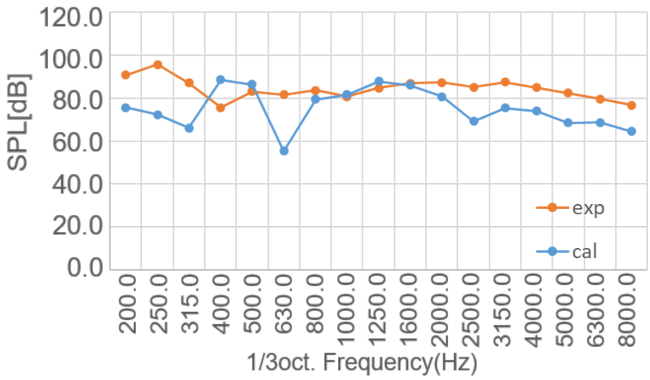
(a) drivers seat



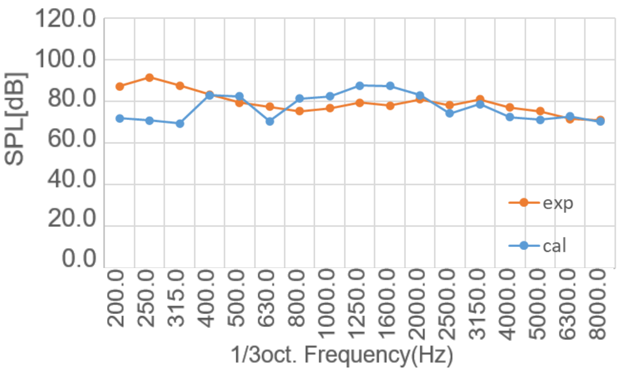
(b) passengers seat



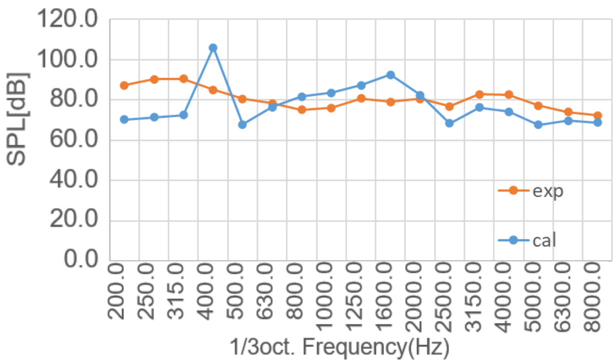
(c) 2nd row right side seat



(d) 2nd row left side seat



(e) 3rd row right side seat



(f) 3rd row left side seat

Fig.3. Calculated and experimental results of SPL.

3.2 Comparison of sound absorption of walls and sheets

We confirmed the effects of whether or not the walls and sheets had sound absorption. Figure 4 shows the initial calculation results (orange line) and the calculation results for total internal reflection (sound absorption coefficient = 0) regarding the sound pressure level at the driver's seat (blue line).

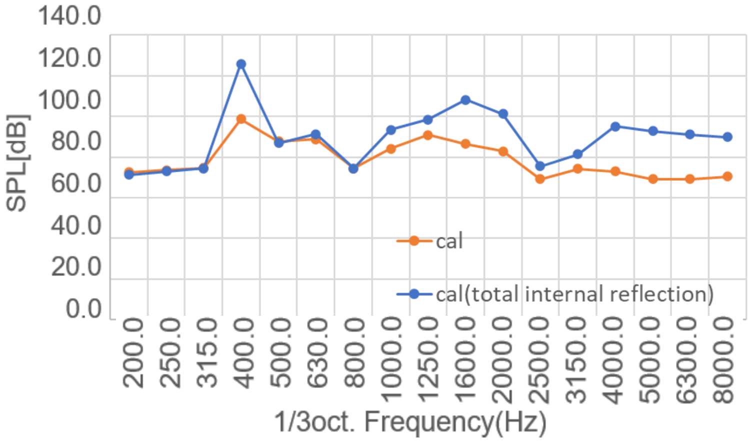


Fig.4. Initial and full reflection calculation result of SPL.

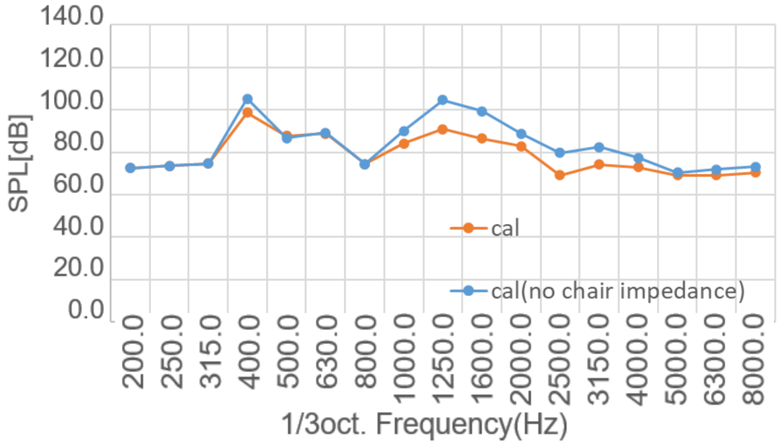


Fig. 5. Initial calculation result and calculation result when the whole sheet is totally reflected.

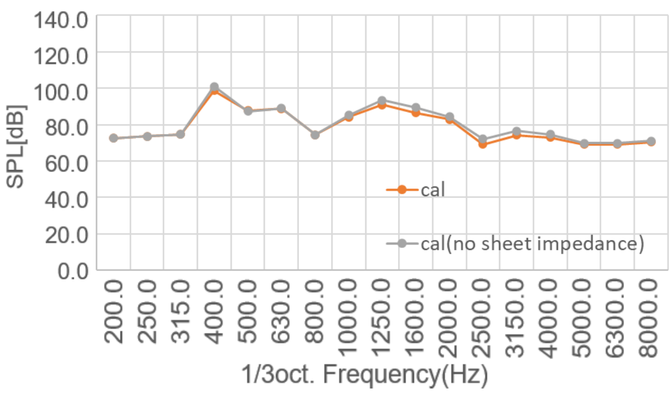


Fig. 6. Initial calculation result and calculation result with total reflection on the bearing surface.

3.3 Effect of sheet sound absorption

We calculated the effect of sound absorption on the seat. Figure 5 shows the initial calculation results (orange line) regarding the sound pressure level at the driver's seat, and when the seat (both seat and backrest) is set to total reflection. Fig. 7 shows the sound pressure level when the seat is set to total reflection. Fig. 8 shows the calculation results when the backrest part (back surface) is subjected to total reflection. From Fig. 5, it was found that the sound pressure level increases from 1000Hz to 4000Hz. Figure 6 and 7 show that the effect of total reflection on the seat and back surface is small.

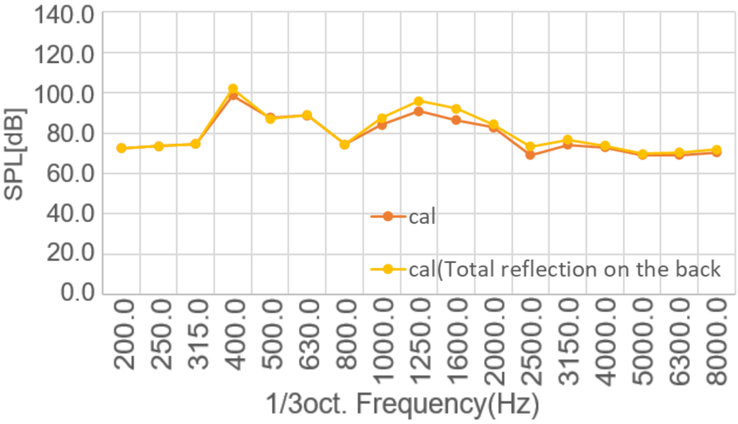


Fig. 7. Initial calculation result and calculation result with total reflection on the backrest.

3.4 Comparison of calculation results between FE model and sound ray method

Figure 8 shows a comparison of the sound pressure level in the driver's seat between the calculation results using the FE model (light blue line) and the calculation results using the sound ray method (yellow line). Although they show similar trends overall, the results obtained using the acoustic ray method are smaller in the low frequency range, and the results calculated using the FE model are smaller in the high frequency range. Regarding the low frequency range, we believe that this is due to the fact that diffraction was not taken into account when calculating using the sound ray method. I think that by adding the effect of diffraction, the calculation results of the sound ray method will become closer to the calculation results of the FE model.

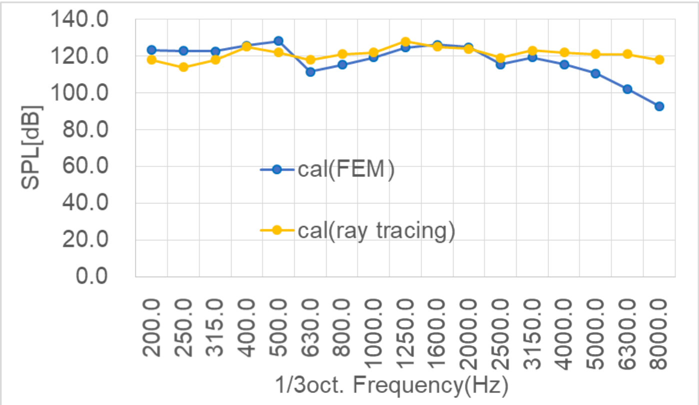


Fig. 8. Calculation result of initial and calculation result by sound ray tracing method.

4. Conclusion

Comparison of experimental results and calculation results using the FE model, assuming the sound coming from a car speaker. If the ceiling, door trim, seat, and floor are set to have total reflection (sound absorption coefficient = 0), only the seat will have total reflection (sound absorption coefficient = 0). We compared the effect on the acoustics when setting the rate = 0) and the calculation results using the sound ray method. Regarding the calculation results of the FE model, values roughly close to the experimental results were obtained, but the calculation results from 200Hz to 315Hz were lower than the sound pressure level of the experimental results at all six calculation positions. In addition, there was a deviation in the values at the peak frequency, so in the future we will review the model to improve the accuracy of calculations. It was found that when walls and sheets were used for total reflection, the sound pressure level increased above 400Hz and 1000Hz. In addition, the effect of sound absorption by the seat was significant when all of it was made into total reflection, but it was found that only the seat surface and only the back surface had no significant effect of sound absorption. Regarding the sound ray method, we obtained values that were roughly similar to the finite element method calculation results, but differences appeared in the high frequency range. We will study how to get the calculation results closer to the FE model calculation results.

It was confirmed that the sound absorption of the ceiling and seats affected the sound emitted from the speakers. In automotive design, it is important to select trim materials that can both reduce noise in the vehicle and affect music. The results of this study make it possible to consider the position of the sound-absorbing trim that does not affect the music coming out of the speakers and can reduce the noise in the car.

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