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Subjective experiment on auditory localization for traffic alarm sounds in a heavy truck

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ABSTRACT

When driving a road vehicle, it is often experienced that the judgment of directions of alarm sounds like horn and sirens of ambulance car, fire engine *etc*. becomes difficult. Especially in case of a heavy truck, the misjudgment of auditory localization of sirens is seriously related to traffic safety, because a road can be obstructed by a heavy truck. In this study, therefore, the auditory localization for traffic alarm sounds at driver's position in a heavy truck was examined by laboratory experiments. To perform the auditory tests in an anechoic room, the 6-channel recording/reproduction system as a 3-dimensional sound field simulation technique was applied. By using measured directional impulse responses from outside into a driver's head position in a heavy truck, the source position for localization tests was distributed at every 30 degrees in horizontal plane. Further, to see the influence of a connected loading space on driver's auditory localization, the experimental investigation was performed for two cases, with/without the loading space. In this paper, the results of the localization tests are presented and acoustic problems are discussed.

Keywords: Heavy truck, Traffic alarm, Auditory localization, Sound field simulation
I-INCE Classification of Subjects Number(s): 60

1. INTRODUCTION

In recent years, to improve acoustical comfort in a road vehicle, sound insulation properties of a body of a vehicle have remarkably been changed for the better. As a result of the improvement, when driving a road vehicle, it is often experienced that the direction-of-arrival of such alarm sounds as horn sounds and sirens of ambulance car, fire engine truck, police patrol car *etc*. becomes difficult to judge inside a car. Authors have examined the sound shielding effect of a passenger car on an auditory localization ability of a driver through psycho-acoustical experiments using a horn alarm of a passenger-car [1]. As a result, it has been observed that the sound localization ability in horizontal plane is deteriorated under such driving condition. Especially in case of a heavy truck, it is very serious for traffic safety to fail to get out of the way of an emergency vehicle because of the misjudgment of auditory localization of traffic alarm sounds. Though for a driver who spends many hours in driving a heavy truck, acoustical amenity in a cab is very important, it is necessary to consider the improvement of the auditory sound localization.

In this paper, therefore, the sound localization for traffic alarm in a cab of a heavy truck was examined by subjective test applying a 3-dimensional sound field simulation technique [2, 3] in an anechoic room. For the auditory experiment, the acoustical measurement of transmission characteristics from outside to inside of a cab was performed changing the position of sound source at every 30 degrees in horizontal plane. For the auditory tests, sirens of ambulance car were convolved with each of measured directional impulse responses. In this study, the effect of a loading space on auditory localization was also examined.

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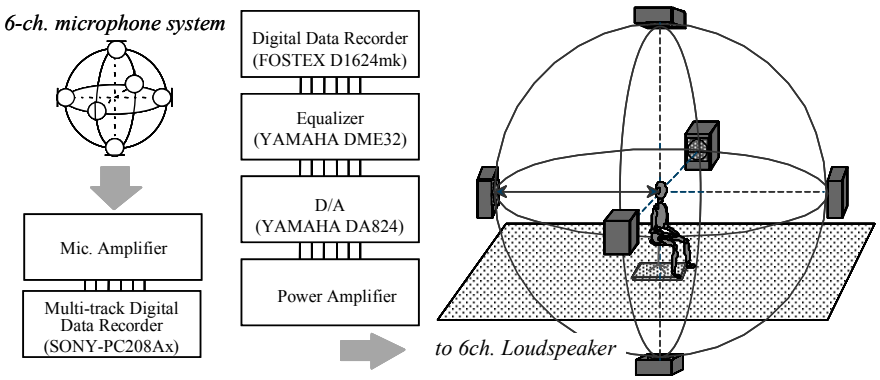
2. EXPERIMENTAL SYSTEM

2.1 6-channel Recording/Reproduction System

Figure 1 shows the block-diagram of the 6-channel recording/reproduction system [2-3] used in this study. In this system, the receiving system (SANKEN, CU-6CH) consisting of six uni-directional microphones combined at every 90 degrees in the horizontal and vertical plane is used. Distance of opposite two microphone units was set at 0.055 m. The respective 6-channel signals recorded through this system are reproduced through six loudspeakers (TANNOY, T-12) set in an anechoic room, which are arranged at every 90 degrees in the same way as for the microphone set. By using this system, not only sound pressure but also particle velocity is accurately simulated at the center point of the reproduced sound field and therefore the sound intensity vector can be simulated at the point. When hearing the sounds at the point, that is a listening position, a natural impression can be realized with 3-dimeinsional information. Applying this technique, any direction of sound source in original sound fields can be simulated at the center position. A listener sitting at the listening position can turn his/her head when judging test sounds [1].

2.2 Accuracy of Reproducibility

To examine the reproduction accuracy of the 6-channel recording/reproduction system from psycho-acoustical viewpoint, the auditory localization test was performed. For the investigation, directional impulse responses changing a position of a sound source at every 30 degrees around the receiving system in the horizontal plane were measured in an anechoic room using the swept-sine method. In this measurement, a loudspeaker sound source was located at a distance of 7 m from the receiving system. The measured 6-channel directional impulse responses were convolved with sirens of Japanese ambulance car repeated three cycles (1^{st} signal: 960 Hz, 2^{nd} signal: 770 Hz, one cycle: 1.3 s), severally. Time pattern and spectrum of the siren sounds used in the sound localization test are shown in Figs. 2 and 3, respectively. The convolved test sounds were reproduced from the six loudspeakers set in the anechoic room as shown in Fig. 4. The presentation level of the test sound under the condition that the direction of sound source was set in front of a test subject, that is 0 degree, was adjusted to 70 dB in terms of A-weighted sound pressure level. In the judgment test, each test condition of twelve designed directions in the horizontal plane was reproduced four times in random order. When judging the direction, the subject sitting at the center position of the reproduced sound field was allowed to turn his/her head. As the test subjects, ten Japanese university and graduate students (nine males and a female in their twenties) with normal hearing ability participated in this experiment. The judgment results by all of the subjects are shown in Fig. 5, in which the diameter of each circle indicates the relative number of the response. In these results, it can be seen that the direction of the sound source was judged with a considerably high accuracy, though a few responses of the front-back confusion was seen. From the result, under the condition there is no sound shielding effect of a body on sound localization, the direction-of-arrival of such sirens as including strong tonal components can be judged accurately.



(a) Recording system (b) Reproduction system

Figure 1 – Diagram of 6-channel recording/reproduction system

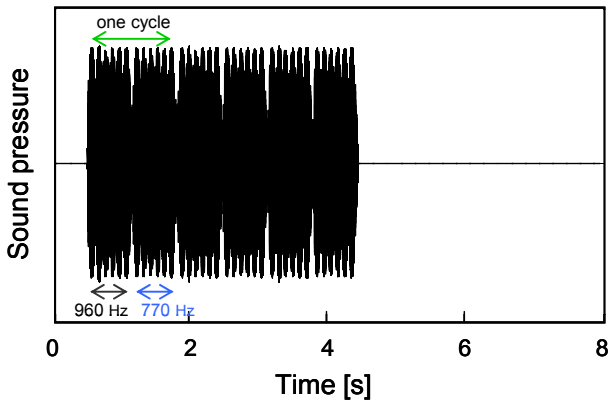


Figure 2 – Time pattern of siren sounds of Japanese ambulance car used in localization tests.

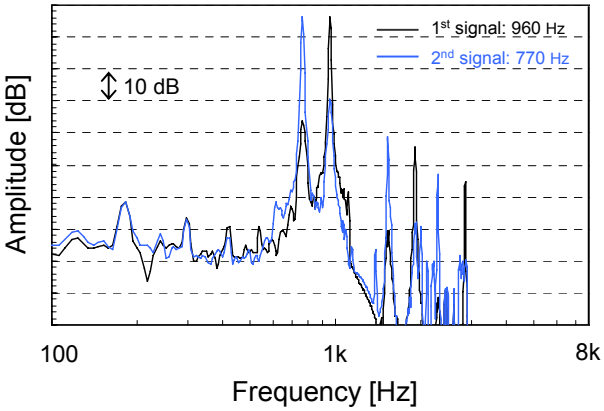


Figure 3 – Spectrum of siren sounds of Japanese ambulance car used in localization tests.

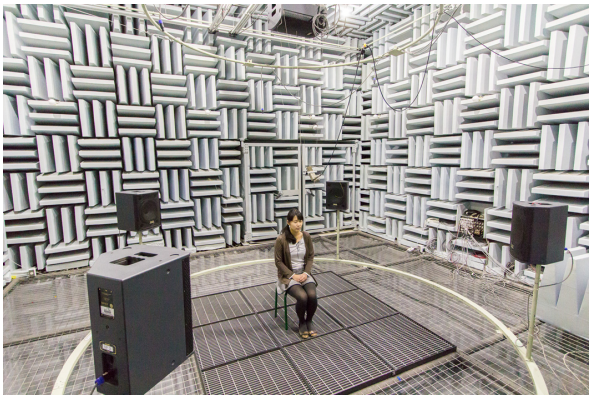


Figure 4 – Localization test performed applying the 6-channel reproduction system in an anechoic room. (x-arrangement; each of four loudspeakers was set at a angle of 45/135/225/315 degree in the horizontal plane)

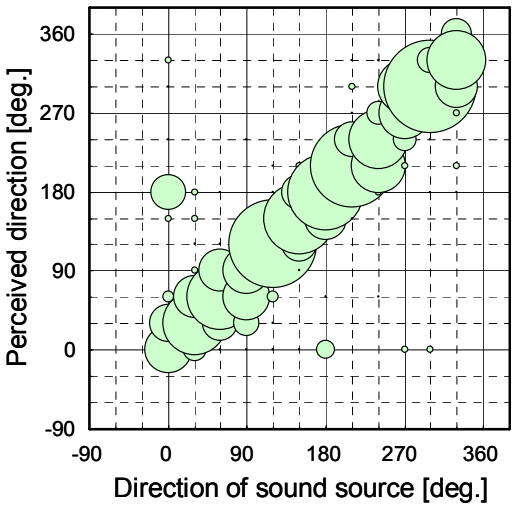


Figure 5 – Accuracy of sound localization in the simulated sound field.

3. LOCALIZATION TESTS

3.1 Measurement of the Transmission Characteristics

To simulate the situation of listening to the alarm sounds transmitted into a cab of a heavy truck, the directional impulse responses from outside to inside of a cab were measured in a hemi-anechoic room changing a position of sound source at every 30 degrees around the center position of a driver's head in the cab. Arrangement of sound source and receiving position in a horizontal plane are shown in Fig.6. In this measurement, a swept-sine signal was generated from a dodecahedral loudspeaker set at a height of 1.5 m from the floor outside of the cab and the 6-channel microphone system was located at the center of driver's head at a height of 0.7 m from the seat in the cab as shown in Fig. 7. The loudspeaker sound source was located at a distance of 5 m from the receiving position in the cab. In this study, to investigate the effect of a connected loading space on auditory localization of a driver, two conditions with/without a loading space (w:2.5m, h:3.5m, l:9.6m) were examined as shown in Fig. 8. In case of experimental condition with the loading space, eleven direction of sound source except 180 degree were examined as shown in Fig.6.

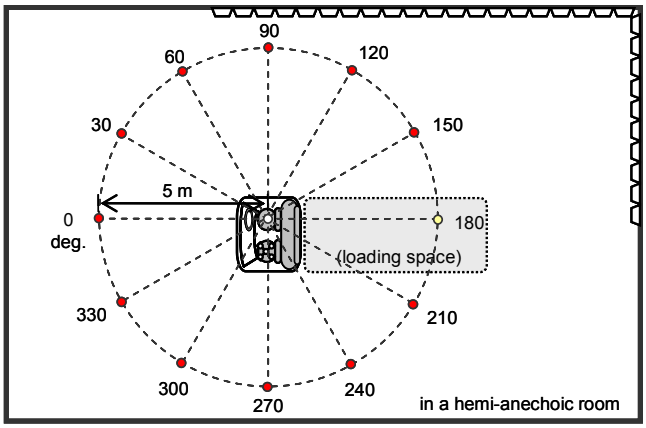


Figure 6 – Arrangement of sound source and receiving position in a hemi-anechoic room.

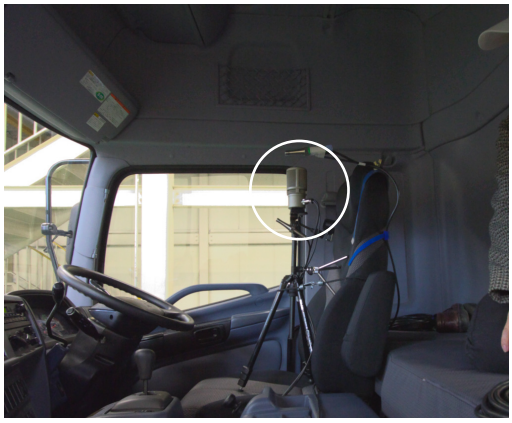


Figure 7 – Recording system set in a cab of a heavy truck.

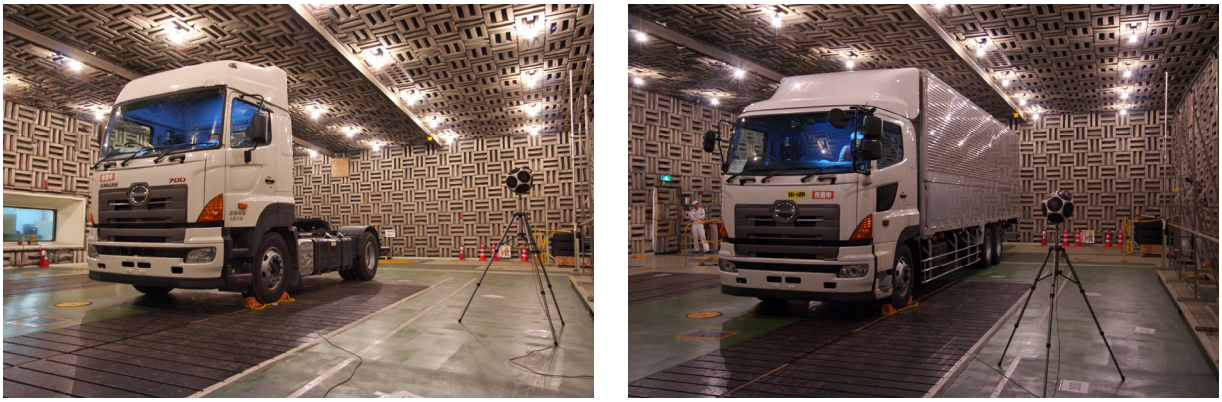
3.2 Procedure of Auditory Test

In this localization test, same procedure as former auditory experiment was followed. For test sounds, the 6-channel directional impulse responses measured in the cab mentioned above were convolved with the sirens of Japanese ambulance car (see Figs. 2 and 3). The presentation level of the reproduced test sound under the condition where the direction of sound source was set in front of a subject, that is 0 degree, was adjusted to 70 dB in terms of A-weighted sound pressure level. In the judgment test on the direction of the sound source, each direction was reproduced four times in random order. The subject was asked to judge the direction-of-arrival of the siren sounds. During the judgment, the subject was allowed to turn his/her head to detect the direction of the test sound. Each experimental condition with/without a loading space was performed separately. In this experiment, same ten Japanese students as those in former experiment participated.

3.3 Results of Auditory Test

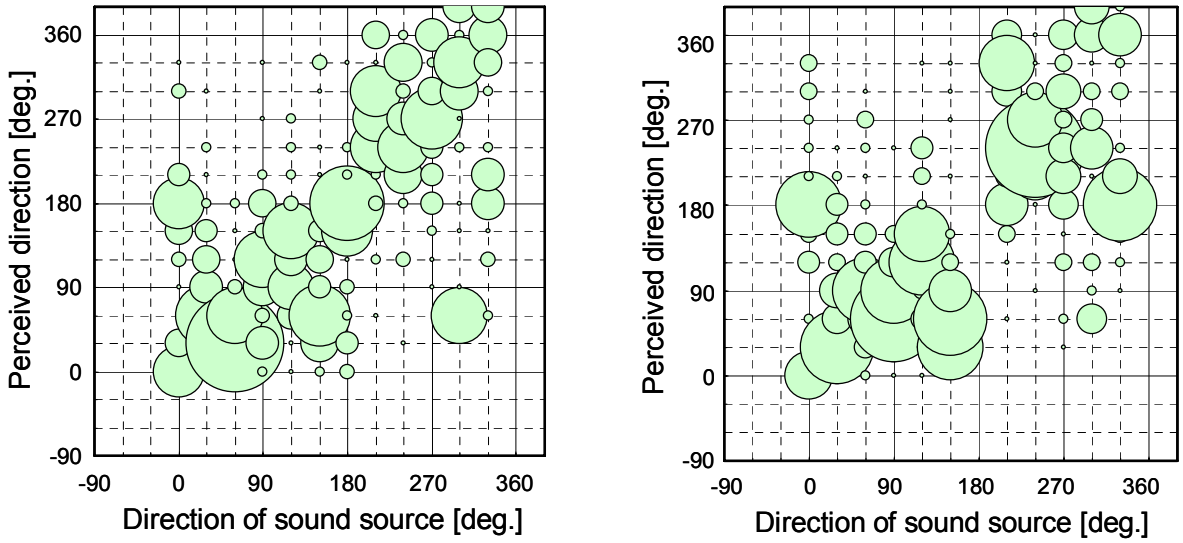
The results of judgment by all of the subjects are shown in Fig. 9, in which the diameter of each circle indicates the relative number of the response. In both conditions, the tendency is seen that the accuracy of the judgment of the perceived direction at the driver's seat is deteriorated by sound shielding effect of the cab with/without the loading space. On the whole, it is seen that the judgment in right/left direction is fairly good, whereas that in front/rear direction is in confusion. Especially, the tendency is seen that the designed front direction expressed "0 degree" in Fig.9 is confused with a back direction, that is "180 degree" and the designed direction on the right in the back is misjudged on the right in the front. In the condition without the loading space, the accuracy of direction judgment is slightly improved. The mean localization errors were also calculated as shown in Fig. 10. The localization error defined as the absolute difference between the perceived and designed horizontal angles averaged over the number of repetitions. In both conditions, the similar tendency is seen. In the condition with the loading space, under the condition of 0, 150, 330 degree, error was over 90 degree.

Further, for reference, the result of localization test performed by using transmission characteristics from outside to inside of a passenger car is shown in Fig.11. In these results, it can be seen that the accuracy of direction judgment at the driver's seat is also deteriorated by sound shielding effect of the car. Compared with the case of the cab of the heavy truck, the direction of the sound source was judged with a high accuracy. After the experiment, especially under the condition of the cab of the heavy truck with/without the loading space, some comments such as that it is very difficult to judge the direction of sound source were reported by the test subjects.



(1) without a loading space (2) with a loading space (*w*:2.5m, *h*:3.5m, *l*:9.6m)

Figure 8 – Experimental condition for 6-channel directional impulse responses measurement at the driver's seat in the cab of the heavy truck.



(1) without a loading space (2) with a loading space

Figure 9 – Experimental results of localization tests; in the cab of the heavy truck.

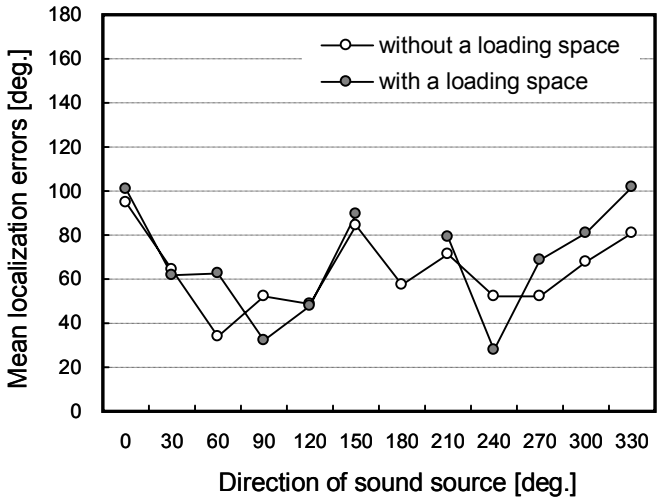


Figure 10 – Experimental results of mean localization errors; in the cab of the heavy truck.

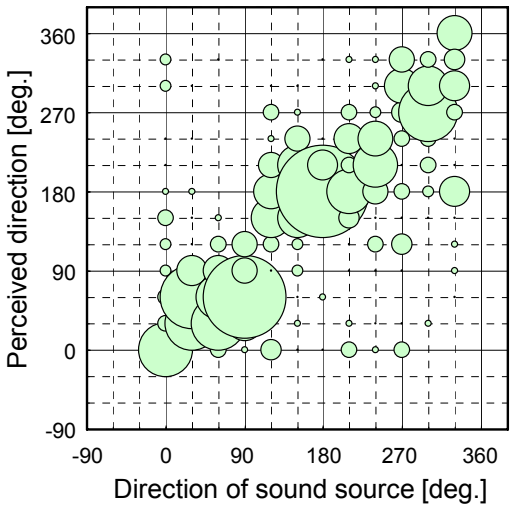


Figure 11 – Experimental results of localization tests; in the passenger car.

4. CONCLUSIONS

In this study, the sound shielding effect of a cab of heavy truck on the auditory localization ability of the driver was examined through psycho-acoustical experiments using the 6-channel recording/reproduction technique. As a result, it has been observed that the auditory localization ability is deteriorated under such driving conditions. This fact should be further examined from a view point of driving safety and the improvement techniques should be investigated from an acoustical view point.

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