Sound field evaluation on the acoustical experiment using non-steady state analysis

Akihiro Kudo*
National Institute of Technology, Tomakomai college, Japan

Makoto Sakamoto, Amane Takei
Faculty of Engineering, University of Miyazaki, Japan

**Corresponding author*

Abstract

Identifying acoustic effects of sound waves emitted by a sound source on the listener is important for understanding the localization of sound as perceived by the listener. In this presentation, we will analyze the effect of the presence of a chair on the psychoacoustic effect using a practical model simulating a psychoacoustic experiment consisting of a loudspeaker, a listener, and a chair. Non-steady state analysis is required to analyze changes in acoustic effects over time. To analyze the interference of sound waves in the vicinity of the listener, a short Gaussian pulse-like solitary wave is set up on the loudspeaker's vibrating surface. Since sound waves in the audible band are used for these simulations, a mesh size of less than 25 mm is used. The laboratory is 3m of depth and width, and 2.5m of height, which means that the computational whole target consists of over 15 million elements. This simulation requires a large number of calculations, so a parallel computing method with ADVENTURE_Sound that is an open-source software for sound simulation, is used to run the simulation. From the simulation results of the non-stationary analysis and consider the effect of the presence of the chair on the sound image localization.

Keywords: large-scale simulation, acoustical sound field, non-steady state analysis

1. Introduction

In the experimental environments, there are objects to disturb sound wave propagation: wall, floor, ceil and chair, etc. Since the effects of these objects change the sound waves reaching the listener's ears, the accuracy of sound image localization may also change. Our goal is to clarify the effect of these environments on the sound image localization characteristics. To evaluate the time-related effects of objects around the listener on the sound waves reaching the listener's ears, this paper examines a non-steady state sound field simulation is performed.

2. Adventure Sound

2.1. Brief introduction

ADVENTURE_Sound is an open-source software for sound simulation. This allows us to simulate parallel finite element analysis software for the sound fields in huge space. Analyses are performed by solving the large-scale linear system with parallel computing based on the Mandel’s domain decomposition method (DDM) [1].

2.2. Simulation procedures with ADVENTURE_Sound

The procedure to use ADVENTURE_Sound is as follows; 1) generate the mesh data, 2) add boundary conditions (BCs), 3) subdivide the mesh data into subdomains, 4) simulate the sound field distributions, 5) convert to the results to vtk data for visualization. On the fourth procedure, it needs to calculate Helmholtz equation in the time domain. For this, Newmark β method is adopted to the equation. As the boundary conditions, input wave function and first and second derivatives of that function.

3. Preliminary test to simulate non-steady state analysis

3.1. Test model

Fig.1 shows that test model for simulation. The model is AHLV100 that is known as a reference model in code_Aster. This is also described in the ADVENTURE_sound manual as a sample. This simulation was done to confirm the use of transient analysis in ADVENTURE_Sound.

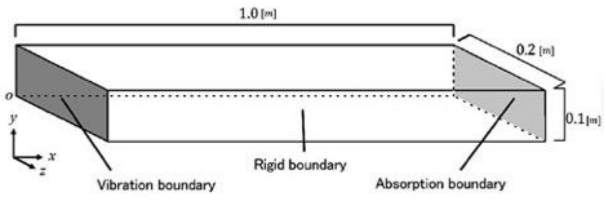

Fig. 1. Test model

3.2. Specs of the parallel computer

Our parallel computer is called as TOMAHAWK.
Table 1 shows that the detailed specs of the parallel computer.

Table 1. Specs of parallel computer

CPU	Intel Xeon E5-2650L,1.8GHz with 16 cores L2 20480[KB]
Main memory/node[GB]	32
Number of nodes	8
Total cores	128
OS	CentOS 6.2
Compiler	gcc-4.4.7 mipch-3.2

3.3. Simulation conditions

Table 2 shows that analysis conditions.

Table 2. Analysis conditions for the test model

Mesh size[m]	0.012
Number of elements	140, 604
Absorption boundary [kg/m^{2}s]	445.9
Medium(air) r_0[kg/m^3]	1.3
Speed of sound c_0[m/s]	343
Time resolution Δt [μs]	1.0
Duration time to simulate[μs]	4000
Velocity potential $\{\Phi\}_t$ Full width at half maximum[ms] Cut-off frequency f_c[Hz]	Gaussian pulse 0.264 646

For boundary conditions as input wave, the single wave is useful to analysis the transient sound field, because sound reflections are observed clearly. In this study, a gaussian pulse as velocity potential is adopted as follows,

$$\{\Phi\}_t = e^{-\{\alpha(t-t_0)\}^2} \dots \qquad (1)$$

In the Eq. (1), decay parameter α is set to 3141, delay parameter t_0 is set to 0.001[s].
An input wave for boundary conditions is shown in Fig. 2.

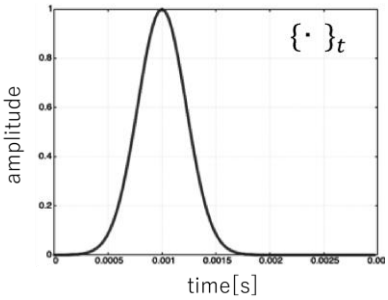

Fig. 2. An input wave for boundary conditions

3.4. Simulation results

Fig.3 shows that the simulation results at some time points. In this figure, bright red color indicates that high intensity of the vector potential that is proportional to the sound pressure.

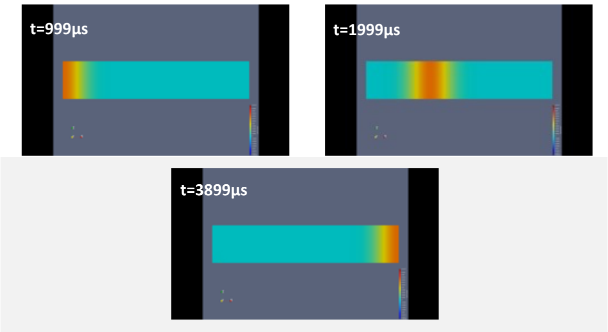

Fig. 3. Simulation results at some time points

3.5. Discussions

From this figure, a single waveform with continuous and positive intensity was observed and the waveform moves from left side to right. Because the sound wave takes 2900μs to reach the right side and length of AHLV100 is 1m, estimated sound speed is 345m/s. This estimate is consistent with the theoretical value. The simulation results show that the use of ADVENTURE_Sound in non-steady state acoustical analysis is appropriate.

4. Simulation of acoustical experimental environment

4.1. Simulation model

Fig. 4 is the dimensions on the side view of simulation model. Table 3 and 4 are dimensions of target and analysis conditions for acoustical experimental environment, respectively.
In this simulation model, there are one loudspeaker and snowman pair that simulates an acoustical experimental arrangement. The snowman simulates a listener's head and torso [2]. In addition, this model also includes a chair to hold the listener in position. These are practical and typical acoustical experimental environment. By

analyzing the sound waves at a position corresponding to the ear of the Snowman model, it is possible to evaluate the effect of sound reflections from the chair as an obstacle on the sound image localization.

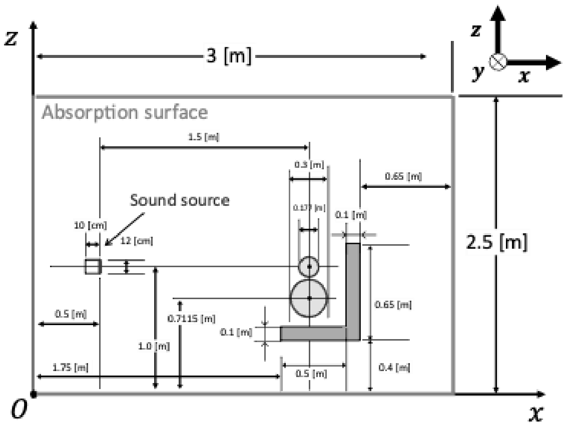

Fig. 4. Dimensions on the side view of simulation model

Table 3. Dimensions of the target

Room, width [m] ×depth[m]×height [m]	3×3×2.5
Room volume [m^3]	22.5
Loudspeaker, width [m] ×depth [m] ×height [m]	0.1×0.12×0.12
Diameter of the listener head, torso [m]	0.177, 0.3 [2]
Distance from loudspeaker to listener [m]	1.5
Backrest, width [m] ×depth [m] ×height [m]	0.5×0.1×0.65
Seat, width [m] ×depth [m] ×height [m]	0.5×0.5×0.1

Table 4. Analysis conditions for the acoustical experimental environment

Mesh size [m]	0.025
Number of elements	14,497,814
Room wall, floor, ceiling [kg/m^{2}s] Loudspeaker, snowman, chair [kg/m^{2}s]	445.9 4.56× 10^9
Medium(air) r_0 [kg/m^3]	1.3
Speed of sound c_0 [m/s]	343
Time resolution Δt [µs]	1.0
Duration time to simulate [µs]	8000
Velocity potential $\{\Phi\}_t$ Full width at half maximum [ms] Cut-off frequency f_c [Hz]	Gaussian pulse 0.264 646

4.2. Simulation results

Fig. 5 is the simulation results on the xy-plane at y=1.5m. Since gaussian pulse is given to the surface of the loudspeaker, the sound waves are spread over. As sound wave travels from the loudspeaker, the sound directivity can be observed on x-axis.

Fig. 6 is the simulation results on the xy-plane at z=1.0m. The distance from the loudspeaker to the listener is 1.5m, so it takes 4.4ms for the sound wave to reach the listener. From these results, the sound wave reaches to the listener at approx. 5ms and the time for gaussian pulse to show its maximum value is 1ms, because it takes for approx. 4ms, the simulation corresponds to the theoretical value.

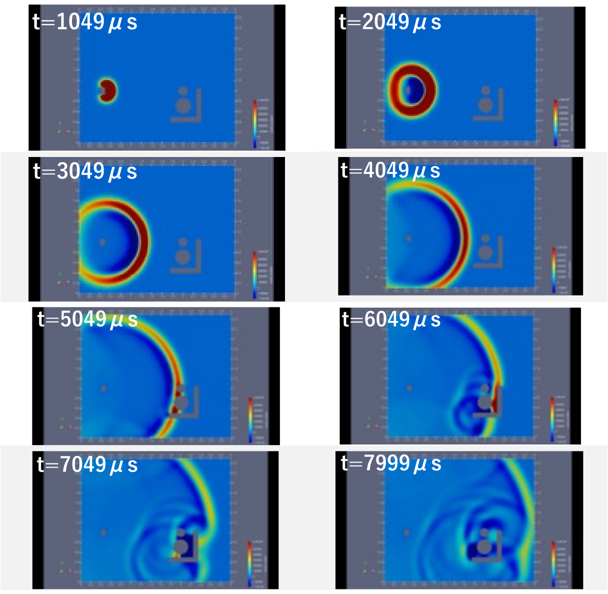

Fig. 5. Simulation results on the xz-plane at y=1.5m

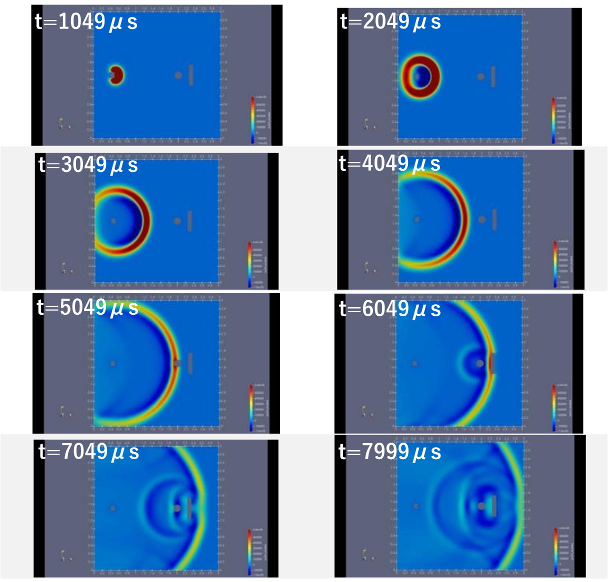

Fig. 6. Simulation results on the xy-plane at z=1.0m

4.3. Discussions

Fig. 7 is the snapshots on the xz-plane at y=1.5m.

From 6.7ms to 7.3ms, an increased sound pressure was observed bottom of the listener's torso due to the sound waves reflecting off the seat of the chair.

The sound wave reaches the listener at approx. 5.2ms and the sound wave reflected by the chair returns to the listener at approx. 6.4ms, so this duration time is 1.2ms. This might affect the spaciousness of sound image although not directional accuracy of the sound image localization, because this time interval exceeds the maximum time difference 0.6ms that humans use to localize a sound image [3].

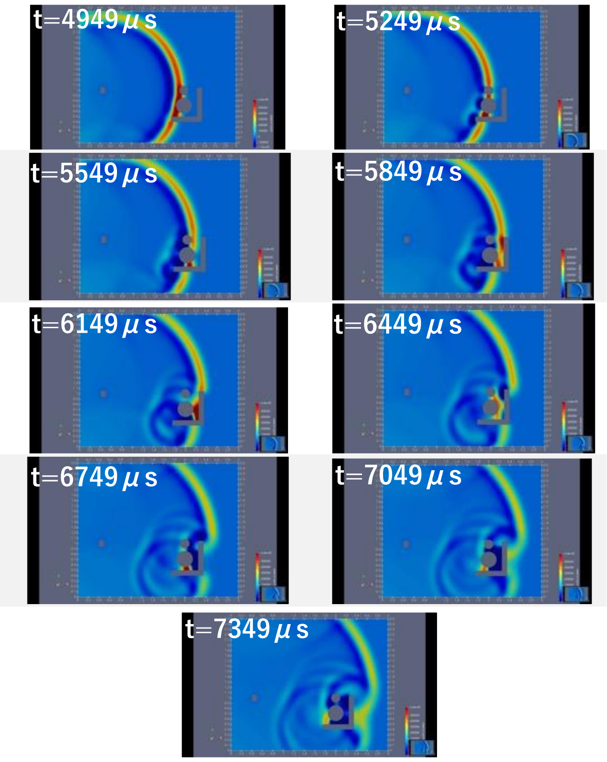

Fig. 7. Snapshots on the xz-plane at y=1.5m

5. Conclusion

Purpose of this paper is to clarify the effect of these environments on the human auditory characteristics, especially sound image localization ability. The simulation target is loudspeaker and snowman model with chair, was adopted as a typical acoustical experimental environment. The simulation results showed that 1) An increased sound pressure was observed bottom of the listener's torso due to the sound waves reflecting off the seat of the chair, 2) The time taken for sound wave reaching the listener to reflect off the chair and return to the listener, was 1.2ms.

Since the time required for sound image localization is up to 0.6ms and the sound wave delay caused by chair reflection is shorter than this time, the reflection on chair may affect the spread of the sound image more than the directional accuracy of sound image localization.

Acknowledgements

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Authors Introduction

Prof. Akihiro Kudo

He received Ph.D. degree from Nagaoka University of Technology He is a professor in the Department of engineering for innovation, National Institute of Technology, Tomakomai college. He is a member of Acoustical society of Japan, Information and Communication Engineers (IEICE).

Prof. Makoto Sakamoto

He is presently a professor in the Faculty of Engineering, University of Miyazaki. His first interests lay in hydrodynamics and time series analysis, especially the directional wave spectrum. He is a theoretical computer scientist, and his current main research interests are automata theory, languages and computation. He is also interested in digital geometry, digital image processing, computer vision, etc.

Prof. Amane Takei

He is working as Associate Professor for Department of Electrical and systems Engineering, University of Miyazaki, Japan. His research interest includes high performance computing for computational electromagnetism, iterative methods for the solution of sparse linear systems, domain decomposition methods for large-scale problems. Prof. Takei is a member of IEEE, an expert advisor of IEICE, a delegate of the Kyushu branch of IEEJ, a director of JSST.