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Comparison of Conventional Methods and Sound Ray Tracing in Automobile Interior Acoustic Space

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With the electrification of vehicles, there is a growing need to evaluate high-frequency sound fields at the early stage of vehicle design. Conventionally, acoustic analysis methods are selected depending on frequency, such as FEM for low frequencies and SEA for high frequencies. SEA efficiently evaluates spatially averaged energy distributions. However, accurately estimating loss factors during model construction remains a key challenge in early-stage design. In contrast, sound ray tracing treats sound as particles and tracks the propagation path of each ray. As a geometrical acoustics method, it can account for the effects of object geometry and spatial configuration.

In this study, sound ray tracing is applied to an automotive interior cavity model and compared with analytical SEA, with a focus on sound pressure prediction and the applicability of ray tracing.

In ray tracing, sound energy emitted from a source is discretized into multiple rays, and each ray loses energy through wall reflections and air absorption. To evaluate steady-state sound pressure under the assumption of a diffuse field, a sound pressure formulation is proposed based on the relationship between energy density and sound pressure. By introducing the arrival time of each ray, denoted as τ_i, the steady state mean-square sound pressure is expressed as

$$\mathrm{p}_{rms}^2 = \frac{\rho_0 c}{t_{max}\frac{4}{3}\pi r^3}\sum_i P_i \times T_{t.i} \times (t_{max} - \tau_i)$$

where P_i is the power carried by each ray at arrival, $\mathrm{T}_{t,i}$ is the residence time within the receiver sphere, $\frac{4}{3}\pi r^3$ is the receiver volume, and t_{max} is the total evaluation time.

A simplified vehicle interior cavity model is used, with two configurations: with and without seats. A point sound source is placed at a representative speaker location, and multiple receiver points are defined in the cabin. Frequency-dependent wall absorption and air absorption are considered. The number of rays, receiver radius, and tracking time are determined based on a convergence study.

The predicted sound pressure is spatially averaged over receiver points and compared with SEA results above 1000 [Hz]. Good agreement is obtained for both configurations, with differences within approximately 1 [dB], indicating that ray tracing provides spatially averaged sound pressure comparable to SEA in the high-frequency range.

However, slight differences in frequency dependence are observed. To investigate this, the damping loss factor (DLF) from ray tracing is compared with that from SEA, as shown in Fig. 2. Good agreement is observed in the unseated model, while significant differences appear in the seated model. In particular, around 300 [Hz], the DLF from ray tracing is approximately twice that from analytical SEA. The cause of this discrepancy is not yet clarified and remains a subject for future investigation.

The computational cost of ray tracing is governed by the number of rays and tracking time. In this study, analysis up to 16,000 [Hz] was completed in approximately 500 [s], demonstrating efficient broadband evaluation. These results confirm that ray tracing is a practical and computationally efficient alternative to SEA for predicting spatially averaged sound pressure in the high-frequency range of automotive interior acoustics.

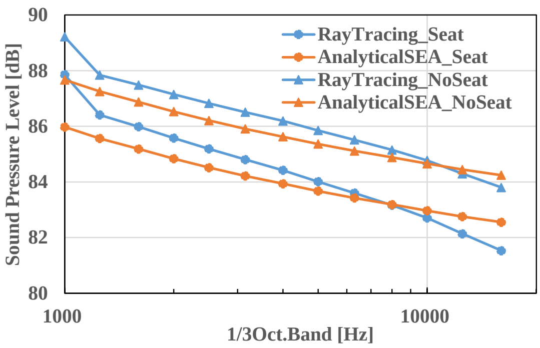

Fig.1 SPL comparison in ray tracing and analytical SEA

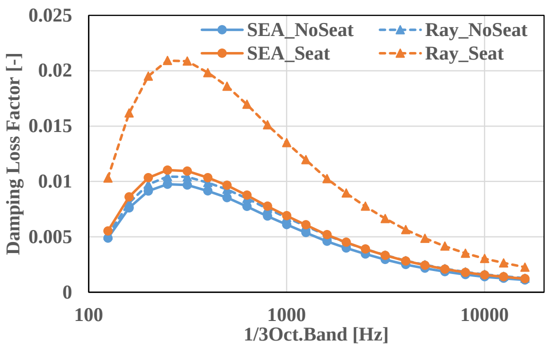

Fig.2 DLF comparison in ray tracing and analytical SEA

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