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Development of Prediction Method for Aerodynamics Noise Generated Inside Tailgate Gap Sections

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In modern HEV and BEV vehicles, the reduction of powertrain and road noise has increased the relative contribution of aerodynamic noise to interior sound quality, particularly at high vehicle speeds. Among various aerodynamic noise sources, noise generated inside tailgate gap sections often causes distinct tonal components in the vehicle cabin. This phenomenon is known to be related to resonance behavior inside the gap cavity; however, conventional evaluation methods rely on wind tunnel testing using full-scale vehicles at late development stages, which limits early design optimization.

Fig.1 illustrates the aerodynamic noise generation mechanism in a tail gate gap section. Turbulent flow along the rear roof and spoiler region induces random pressure fluctuations, which excite Helmholtz resonance inside the cavity formed by the tailgate gap. The generated acoustic waves then propagate through sealing structures and glass panels into the vehicle cabin, resulting in audible interior noise.

In this paper, a numerical prediction method for aerodynamic noise generated inside tailgate gap sections is proposed, enabling evaluation from the early phase of vehicle development. The proposed method is based on a coupled simulation framework combining unsteady computational fluid dynamics using the Lattice Boltzmann Method (LBM) and Statistical Energy Analysis (SEA), as shown in Fig.2. LBM is employed to simulate unsteady flow structures and surface pressure fluctuations inside the tailgate gap, which is suitable for capturing transient phenomena in complex and narrow geometries. Acoustic components are extracted from the calculated pressure fluctuations using wavenumber filtering, and these components are applied as excitation inputs to an SEA model to predict the transmission of aerodynamic noise into the vehicle cabin.

To evaluate the effectiveness of the proposed method, three tailgate gap configurations with different geometric parameters were investigated. Fig.3 presents representative simulation and experimental results of interior noise spectra. The simulation results captured clear resonance peaks associated with Helmholtz resonance behavior. Raising the roof edge position reduced sound levels without changing the resonance frequency, while extending the cavity neck length shifted the resonance frequency to a lower range. These tendencies were consistent with analytical Helmholtz resonance characteristics.

Wind tunnel experiments using a full-scale vehicle were conducted for validation. The predicated resonance frequencies and interior noise trends showed good agreement with the measured results, confirming the validity of the proposed LBM-SEA coupled approach. The proposed method is suitable for evaluating tailgate aerodynamic noise reduction and interior sound quality improvement.

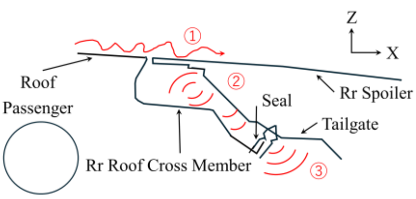

Fig.1 Mechanism of aerodynamic noise generation at tailgate gap section

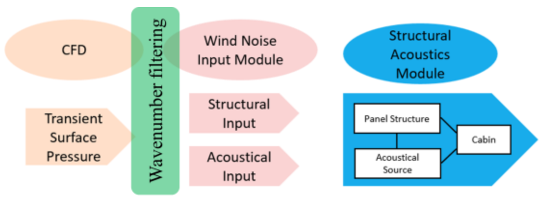

Fig.2 Simulation flow of the proposed LBM-SEA coupled method

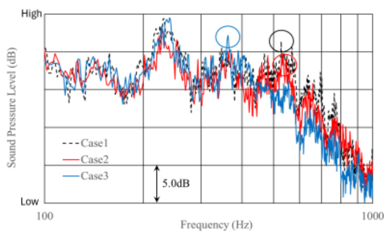

Fig.3 Comparison of measured interior noise spectra

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