Computational Simulation Method of Evaluating Aerodynamic Sound Sources

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Noise generated aerodynamically has become the dominant noise generated by today's high-speed trains, which run at a maximum speed of 300 km/h (190 mile/h) in Japan. The aerodynamic noise is produced mainly by projecting devices, such as pantographs and cable heads on the roof, gaps between cars, and cavities at the bogie sections. This noise is proportional to the 6th-8th power of the wind (vehicle) speed, and at high speeds it exceeds other noises, such as the rolling noise from wheels and rails, which is normally proportional to the 3rd power of the vehicle speed. Since the Environmental Quality Standards established by the Japanese government stipulate that the peak noise level shall not exceed 75 dB(A) at trackside, it is crucial to reduce the aerodynamic noise produced by trains.

Although experiments in a low-noise wind tunnel are an effective way of examining preventative measures against aeroacoustic problems, it is difficult to determine experimentally the detailed relationship between an unsteady flow motion and sources of aerodynamic noise. Many previous numerical simulations calculated the pressure fluctuations at the body surface and then estimated the acoustic pressure fluctuations in the far field using Curle's equation. However, they could not directly identify the structure of sound sources in the flow, and the relationship between flow and radiated sound was unclear.

Then we developed a numerical method based on the theory of vortex sound, which suggests that the unsteady motion of vortices produces aerodynamic sound. We combined the calculation of unsteady flow and the evaluation of acoustical performance numerically. First, the unsteady flow around the body is obtained using the large eddy simulation (LES) technique, which solves the spatially filtered equations of continuity and momentum for incompressible flow. Second, the acoustical performance by the presence of the body is estimated by solving a Green's function adapted to the body shape. Finally, by coupling the instantaneous flow properties with the Green's function, the distribution of aerodynamic sound sources around the body is obtained. We also proposed a new idea that avoids the sudden termination of vortices at the outer boundary of a finite computational domain and extracts the net contribution from so-called dipole sound sources.

Fig. 1 shows a numerical result of the distribution of aerodynamic noise sources around the pantograph horn, which are installed at both side-ends of a pantograph head in order to ensure movement onto the contact strip of out-of-running wires. Periodic holes in the cylindrical horns were already known to reduce the noise level, but the detailed mechanism of noise reduction was not clear. The result proves that intermittent flow through holes suppresses the strength of dipole sound sources at the shear layer and collapses the large two-dimensional structure of sound sources in the spanwise direction.

Fig. 2 shows another result around a pantograph head. Strong vortices are shed from each corner periodically, and these create an unsteady force that acts on the pantograph head. Strong noise sources are formed in regions where the variation of flow over time is great. Such findings will set important guidelines for improving shapes for noise reduction and adequate contact force.

The new method proposed here is capable of estimating the acoustic pressure fluctuation in the far field using detailed information about the structure of sound sources in the flow, and is applicable to other aerodynamic noise generated by various parts of the train. Using this method, the process of developing a new generation of high-speed trains is expected to be shortened.

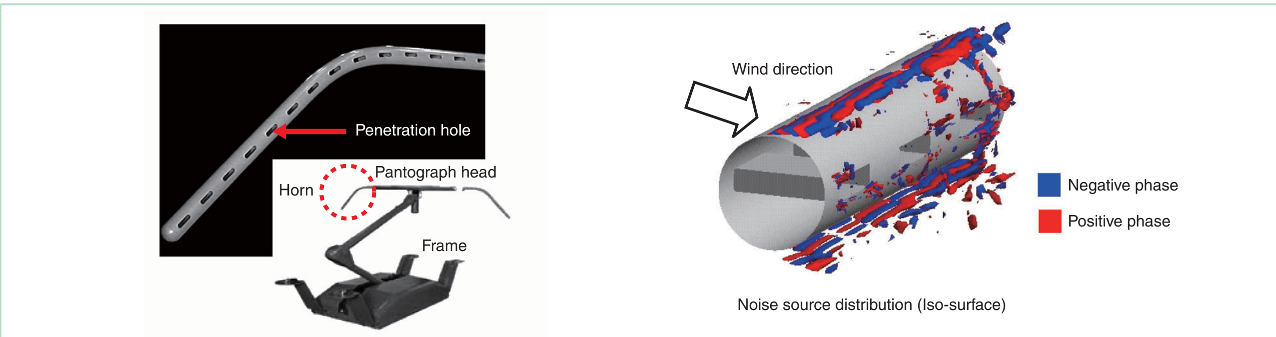

Fig. 1 Distribution of aerodynamic noise sources around the pantograph horn

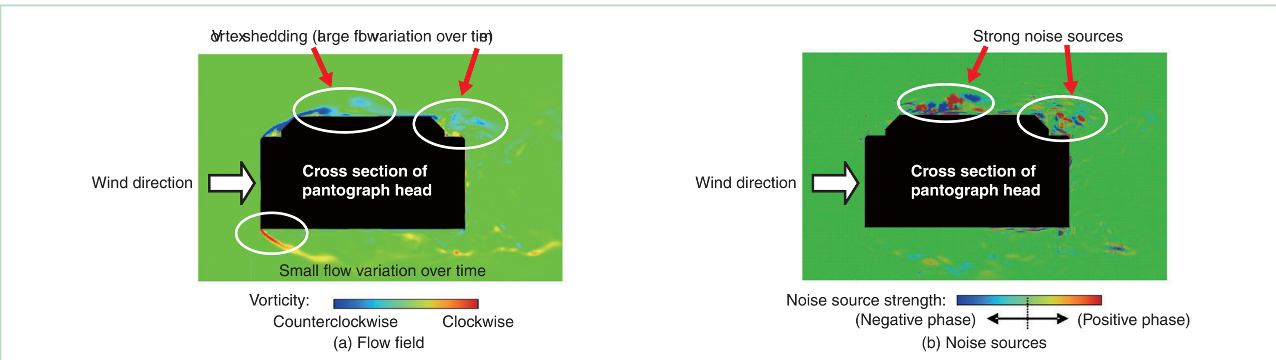

Fig. 2 Flow field and aerodynamic noise sources around the pantograph head