Cross-correlation analysis of aeroacoustic sound and flow field using time-resolved PIV

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The noise from a high-speed train such as the Shinkansen is mainly consists of rolling noise and the aeroacoustic noise originated from the turbulence of air flow around the train. It is particularly known that the power of the aeroacoustic sound is proportional to the sixth power of the velocity of the train, and hence, reduction of the aeroacoustic noise is increasingly required. In case of the mechanism of the generation of sound waves, Howe (1975) expressed the source term in Lighthill’s equation using vorticity in the flow field and clarified that aeroacoustic sound is generated by the unsteady behavior of vorticity.

In this study, the temporal evolution of the flow field around a cylinder is determined using a time-resolved PIV technique; these data are then applied to Howe’s vortex theory subject to the dipole sound in order to estimate the aeroacoustic sound at the far field. For this purpose, we developed an apparatus for the simultaneous dual-plane measurement of two cross-sections, and extracted a coherent structure that was dominant to the aeroacoustic sound.

1. Experimental apparatus

Fig.1 shows a schematic of the experimental apparatus. The test section of the wind tunnel is of the open type and the wind velocity is 15 m/s. A glass cylinder with a diameter of 6.0 mm is used as the specimen; this cylinder is bounded on both sides by end plates made of acrylic. The radiated sound is measured using an omnidirectional microphone placed 300 mm above the cylinder. The main objective of using this microphone is to compare the actual radiated sound with the sound predicted using the time-resolved PIV.

2. Results

Fig.2(a) shows a comparison between the spectral analysis results of the sound pressure predicted using PIV and that measured by the microphone. A Strouhal number $St$ is a dimensionless number representing frequency; $St = 0.2$ corresponds with the peak frequency of the Aeolian tone of a cylinder. The peak $St$ agrees well with the result of the microphone. Both the coherence and phase difference between the sound pressure predicted by PIV and the actual one are shown in Fig.2(b). The phase difference at $St = 0.2$ becomes almost $0°$. Fig.3(a) shows the color map and isoline of the power spectra of sound sources, whereas Fig.3(b) shows the coherence distribution between the actual sound pressure and the PIV-predicted one. These two figures indicate that the sound sources around the immediate vicinity of the cylinder and the Kármán vortex region contribute to the aeroacoustic sound observed at the far field.

4. Conclusion

We constructed a system for the simultaneous measurement of a flow field by time-resolved PIV and sound pressure with a microphone in a small-scale wind tunnel: further we investigated the cross-correlation between the two. In the case of the PIV measurement, a dual-plane PIV system is realized to measure two cross-sections simultaneously and evaluate the coherence and phase structure of sound sources. First, the analysis of a single cross-section PIV measurement showed a strong cross-correlation between the PIV-predicted sound pressure and the actual sound pressure at $St = 0.2$. We also experimentally demonstrated the cancellation of sound waves and the doubling as a dipole sound around the two separation points. Second, through the newly developed dual-plane PIV measurement, we carried out the volume integration, considering the obtained phase difference.

References


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