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An efficient numerical method for studying noise generation in vortex-induced vibration of bluff bodies

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Abstract: The vortex-induced vibration or VIV is a natural phenomenon of fluid-structure interaction, where excited vibrations in bluff solid structures synchronize with the unsteady vortex shedding in the wake. These structural vibrations are vigorous with large amplitude, generate acoustic noise, and can sustain for a long time. Having a comprehensive understanding of VIV is essential to test different control techniques to suppress vibrations that can causes structural damage or fatigue failures. Studying VIV experimentally or numerically is challenging due to the complex nature of fluid-structure acoustic interactions. Consequently, many aspects of VIV are yet to be discovered, especially noise generation in VIV. In this study, an efficient and stable numerical method is developed to examine the vibration response of 2-dimensional and 3-dimensional rigid bodies and the noise generation and propagation during VIV.

The computationally efficient lattice Boltzmann method (LBM) is used to model the fluid flow, while a widely used diffusive immersed boundary method is utilized to tackle the fluid-solid interface. In addition, the popular perfectly matched layer boundary condition and the multi-block grid refinement are used. The former is to avoid non-physical sound wave reflection into the domain from the outer boundaries and the latter is to reduce the computational cost. As the lattice Boltzmann method describes the evolution of mesoscale distribution functions based on the free-streaming and collision processes, it is intrinsically suitable for acoustic simulations. There are several ways to model the collision process, and BGK (Bhatnagar-Gross-Krook) collision operator is the simplest and most used. Numerical stability is important in aero-acoustic simulations, therefore the more stable yet computationally efficient recursive and regularized BGK collision operator is used here. The immersed boundary methods are non-confirming grid methods, thus, they are computationally efficient.

The vortex-induced vibration response of a 2D circular cylinder is studied at the Reynolds number of 200, with a mass ratio 10 at the Mach number of 0.17 for a range of reduced velocities ($3.0 \leq U^* \leq 7.2$). The cylinder's vibration synchronizes with the periodic counter-rotating vortex shedding behind it, for $4.3 \leq U^* \leq 6.4$, as reported in the literature. As U* increases, the vibration amplitude first increases rapidly until $U^* = 4.8$ and beyond that it decreases gradually. A dipole-type acoustic response is observed. The intensity of the acoustic field is enhanced by approximately four times as the cylinder vibrates at $U^* = 4.8$ compared to the stationary case. As U* increases beyond 4.8, the acoustic intensity decreases as the cylinder vibration amplitude and fluctuating lift force coefficient decrease.

The VIV response of a sphere is studied at Reynolds number of 300 with a mass ratio 3, at the Mach number of 0.17, at $U^* = 6$, 8 (synchronization region) and 11 (non-synchronization region). The sphere shows synchronized vibrations only at $U^* = 6$ and 8, as reported in the literature. The acoustic field generated by the sphere is less intense than that of a cylinder. This is due to the difference in the vortex-shedding mechanism. Nevertheless, the intensity of the acoustic field is still enhanced by ~4 times as the sphere vibrates compared to the stationary case.

The effect of passive controllers on VIV response and acoustic generation will be examined in a future study.

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