DNS of the Generation and Propagation of Sound

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Computational study of sound is called “Computational AeroAcoustics” (CAA) and is rapidly developing, exciting research field. Works in the field of CAA can be categorized into three groups depending on the method to use [1]: hybrid method, acoustic/viscous splitting method and direct numerical simulation (DNS) method.

The first group (hybrid method) makes use of an acoustic analogy, under the assumption of compact sources, to predict the far-field sound. The source terms are evaluated using the near-field flow quantities, which are obtained by solving the incompressible Navier-Stokes equations for low-Mach-number flows. This method saves computational time as well as memory storage compared with DNS, because the flow in the far field is assumed to be stationary or uniform and thus not solved numerically.

The second group (acoustic/viscous splitting method) assumes that flow quantities are represented, under the assumption of low Mach number, by an incompressible mean flow and a perturbation about the mean. In the far field, the perturbation quantities are equivalent to acoustic quantities. This method may possibly be a convenient method of predicting sound field resulting from low-Mach-number, non-compact source region. So far the results obtained by this method are qualitative, and detailed descriptions of sound fields have not yet been given.

The third group makes use of DNS, where both the fluid motion and the sound which it generates are directly computed. Recent development of a high-performance supercomputer and highly-accurate numerical schemes makes it possible to simulate a sound field by directly solving the compressible Navier-Stokes equations over the entire region from near to far fields. This method does not suffer from restrictions such as low Mach number and compactness of the source region, but requires a large amount of computer resources; the studies using DNS are very few.

Aeolian tone is sound generated by an obstacle in a flow, and one of the most interesting topics in CAA. In this paper, DNS results of aeolian tones generated by a two-dimensional (2D) obstacle in a uniform flow are presented and the generation and propagation mechanisms of the sound are discussed. The 2D, unsteady, compressible Navier--Stokes equations are solved by a finite difference method. For spatial derivatives, a sixth-order-accurate compact Pade scheme is adopted [2]. The fourth-order Runge--Kutta scheme is used for time-integration. Non-reflecting boundary conditions are used for the outer boundary of the computational domain [3]. The Mach number, M, of the uniform flow is prescribed to be $M = 0.05$ to 0.3. The Reynolds number Re is prescribed to be $Re = 150$ to 10,000. For more details about the numerical method, readers are referred to Inoue and Hatakeyama [1] for a circular cylinder case.

A typical example of computational results is presented in Fig. 1, where an instantaneous fluctuation pressure field superimposed on a vorticity field is shown for the case of a circular cylinder. The Mach number is $M = 0.2$ and the Reynolds number is $Re = 150$. In the figure, positive fluctuation pressures and vortices with anticlockwise rotation are shown by red; negative fluctuation pressures and vortices with clockwise rotation are shown by blue. We can see from the figure that sound pressure pulses are generated in response to vortex shedding and that the generated sound has a dipolar nature. When a vortex is shed from the leading edge, a negative pressure pulse is generated on the upper side of the airfoil whereas a positive pressure pulse is generated on the lower side. On the other hand, when a vortex is shed from the trailing

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edge, a negative pressure pulse is generated on the lower side whereas a positive pressure pulse is generated on the upper side. Therefore, alternate vortex shedding from the upper and lower sides of the cylinder produces negative and positive pressure pulses alternately from both sides of the cylinder, resulting in the generation of fluctuating lift force. The generated pressure pulses propagate upstream under the Doppler effect.

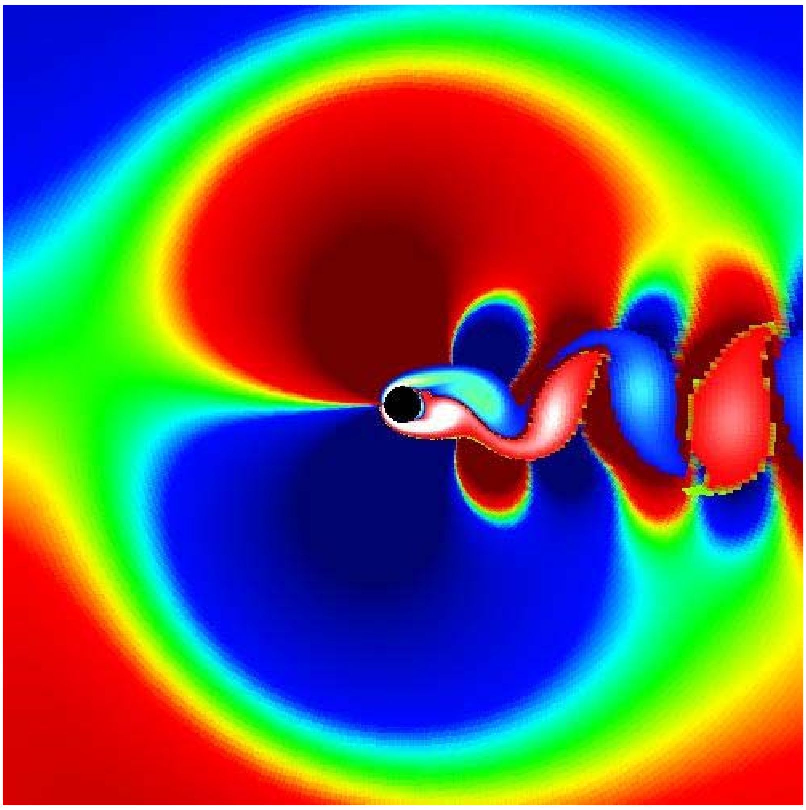

Fig. 1. Fluctuation pressure superimposed on vorticity. Circular cylinder. $M = 0.2$, $Re = 150$.

References

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