AN IMMERSED BOUNDARY METHOD FOR SIMULATING AN OSCILLATING AIRFOIL

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EXTENDED ABSTRACT

Aerodynamic, inertial and elastic forces acting on the airfoil, which can cause airfoil vibration, lead to structural fatigue failures. An understanding of the physics of the mutual interaction between flow and oscillating airfoil is essential for improved overall efficiency, durability and reliability. The iterative coupled method is the most popular coupled method in the past ten years. It involves the solution of the fluid and structural equations separately, but the information is exchanged at each time step. Most studies use body-fitted grid and re-grid to accommodate changes in the structure deformation or displacement in the fluid domain. It is known that this approach will not only cost time, but also make the grid quality near the moving structure hard to control. In addition, there is a time-delay when the information transmits between fluid domain and structure domain. Actually, we have attempted to develop an efficient, robust and fully coupled numerical simulation method to fluid-structure interaction and based on this method we found some new phenomena.

The vibrating forms of the oscillating airfoil consist of forced vibration and self-excited vibration. Forced vibration is the motion in which an object is under a continuous and periodic external force. If the force changes according to a simple harmonic vibration, the steady state of forced vibration is a simple harmonic oscillation. Self-excited vibration is the motion in which the periodic external force is due to the system itself. In the present study, both forced vibration and self-excited vibration in the mutual interaction between fluid and oscillating airfoil are found and the results are presented with emphasis on physical understanding of fluid-airfoil interaction.

Based on the immersed boundary method[1], a fast simulation for solving unsteady, incompressible, viscous flow associated with the oscillating airfoil is established on a quasi-three-dimensional coordinate system[2-3]. Using this method, the coupling processes are simulated on simple Cartesian meshes. The interfacial force is calculated using Virtual Boundary Formulation, as presented by Goldstein[4]. The main advantage of this method is that it enables the calculation of this force field, even if the interface is moving or deforming. Zhong[5] combined the immersed boundary method with the operator splitting technique to investigate the two-dimensional fluid-structure interaction problems.

In order to validate the method, two simulate cases: oscillating circular at low K-C number and two degrees of freedom oscillating cylinder are carried out and the results agree well with the precious research [6-7] (Fig. 1- Fig. 2).

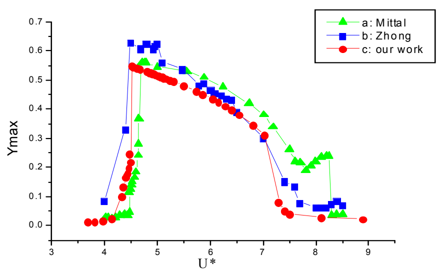

Fig. 1 Variation of the maximum transverse displace-

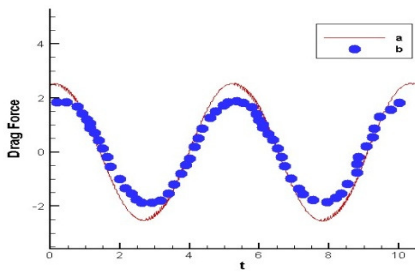

Fig. 2 Drag force comparison of an oscillating

ment of the cylinder with reduced velocity circular cylinder in water at rest

Based on these benchmark cases, a numerical simulation for an oscillating airfoil is then established and the relevant analysis to the behavior of the airfoil at different reduced velocity U^* is presented with emphasis on the physical understanding of fluid-airfoil interaction.

It is found that the reduced velocity U^* is a very sensitive factor. In the present example, When $m = 0.5$, the frequency is almost the same in the lower range of U^*, this frequency is just the vortex-shedding frequency, but when U^* has an increase close to 2.6, the frequency jump phenomena is observed, and then the frequency is reduced when U^* increases. Also, the amplitude of transverse oscillation is almost zero when U^* is less than 2.6. But When U^* is greater than 2.6, the amplitude of transverse oscillation increases rapidly. From the result, it is found that the trend of the curve are very close except the frequency jumping point and the amplitude jumping point are different at different mass. It is also shown that in the jumping section, the frequency is "lock-in" to the natural frequency just like the oscillating cylinder.

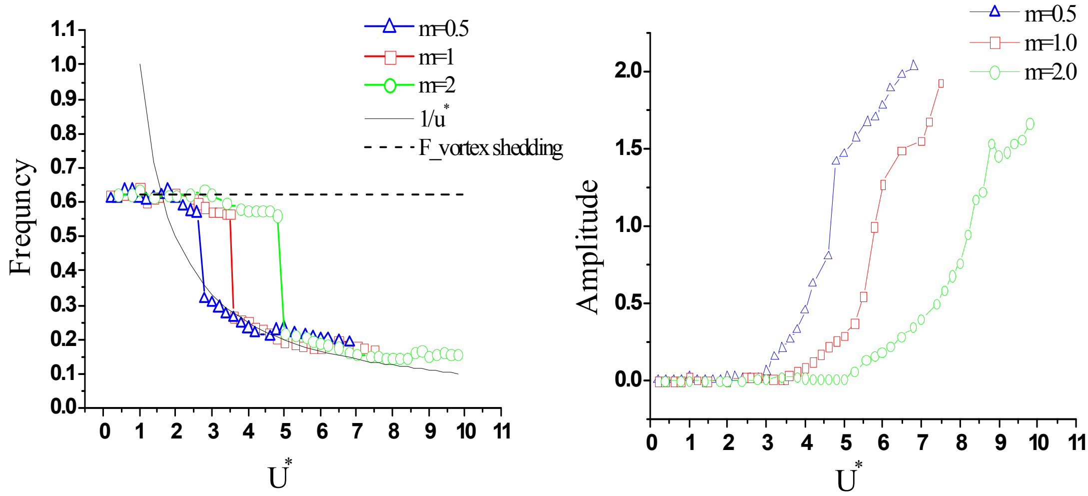

Fig. 3 Variation of the frequency and the amplitude of transverse oscillation with U^* at different mass ratio

It is worth noting that the coupling process is not necessary to be generating any body-fitting grid, which makes it much faster in computational process for such a complicated fluid-structure interaction problem.

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