VORTEX SHEDDING PATTERNS IN FLOW PAST INLINE OSCILLATING ELLIPTICAL CYLINDERS

by

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Vortex shedding patterns in flow past inline oscillating elliptical cylinder are simulated by lattice Boltzmann and direct forcing/fictitious domain method which is validated by finite volume method when this cylinder is fixed. The modes of vortex shedding are analyzed in detail by changing the amplitude and the frequency of oscillation by using the first method in this paper.

Key words: *lattice Boltzmann method, finite volume method, vortex shedding patterns*

Introduction

In order to predict the loading on offshore structures and understand flow patterns in its wake of underwater bodies, vortex shedding after bluff bodies is widely studied. It is well known that Karman vortex street which is happened when uniform flow past a fixed circular cylinder is antisymmetric. But vortex shedding patterns in flow past inline oscillating cylinder can be antisymmetric, symmetric which are depended on the frequency and the amplitude of oscillation. Vortex shedding after an inline oscillating circular cylinder in a uniform flow is studied by numerical simulation and experiment [1-8]. Besides antisymmetric mode, symmetric mode named S-I and S-II are found. It is also simulated when circular cylinder is substituted by square cylinder and rectangular cylinder [9], a new mode named S-III is discovered. To our knowledge, there are no previous studies on vortex shedding in uniform flow past inline oscillating elliptical cylinder.

Besides finite volume method (FVM), application of lattice Boltzmann method (LBM) to simulate particles suspended in a viscous fluid was first proposed by Ladd [10]. In his model, the non-slip condition on the particle-fluid interface is treated by the bounce-back rule and the particle surface is represented by the boundary nodes, which are essentially a set of mid-points of the links between two fixed grids. It was proved robust and efficient for particulate flows, especially in the case of large number of particles [11-15]. Recently, the LB-DF/FD method [16], which combines LBM and DF/FD (direct forcing/fictitious domain)

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method, has been proposed for the 2-D particle-fluid interaction problems. In fictitious domain method, the interior domains of the particles are filled with the same fluids as the surroundings and a pseudo body force λ is introduced to enforce the interior (fictitious) fluids to satisfy the constraint of rigid body motion. Furthermore, a certain number of Lagrangian nodes are distributed to represent the particle while an Eulerian mesh is used for the fluids.

Problem description

The main purpose of this paper is to study vortex shedding patterns in flow past inline oscillating ellipse cylinder by changing the frequency and amplitude of oscillation. The schematic diagram of geometry is shown in fig. 1. As shown in this figure that a = 16, b = 8, lx = 1200, ly = 1000 and the elliptical cylinder is placed at 0.3 lx far away from inlet. The size of element is uniform with unit length which means there are 1.2 millions grid points in this fluid domain and the arrangements of Lagrangian points in the ellipse is shown in fig. 2. The boundary conditions are u_x = U = 0.1 m/s, u_y = 0 at inlet, upside and downside of solution domain with $\partial u_x/\partial x = 0$, $\partial u_y/\partial x = 0$ at outlet. The cylinder is oscillated in horizontal direction which velocity is $u_x = A\Omega \sin(\Omega t)$, where $A = 2aw_e$ is the amplitude and $\Omega = 2\pi f_e$ is the frequency of oscillation. The characteristic length in this paper is taken to be the major axis 2a of the ellipse, and the characteristic velocity is U. So the Reynolds number is defined as Re = 2aU/ν and the Strouhal number as St = $2af_0$/U, where ν is the viscosity of fluid and f_0 is the shedding frequency of the vortices. All simulations in this paper will be carried out at Re = 100.

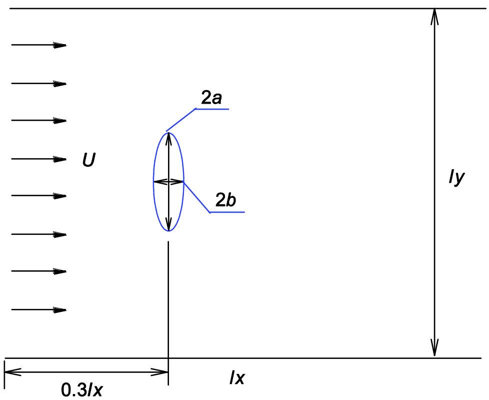

Figure 1. Schematic diagram of geometry

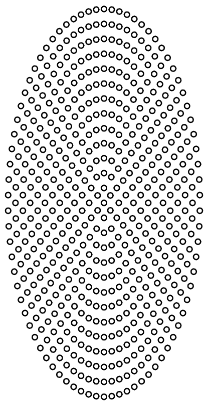

Figure 2. Arrangements of Lagrangian points

Simulation method and results

The numerical approach of LB-DF/FD and FVM are validated by the simulation result of flow past fixed elliptical cylinder. The drag coefficient and lift coefficient for the static elliptical cylinder by LB-DF/FD method is shown in fig. 3. It can be seen that the curve shape is very similar to circular cylinder. Comparison of the drag coefficient, lift coefficient and Strouhal numbers for LB-DF/FD and FVM is listed in tab. 1. The difference between these two methods is very small which means these codes are correct. LB-DF/FD is more easy to program and it is no need to iterate in each time step which will be saving time a lot. So when the elliptical cylinder is oscillating in flow direction, LB-DF/FD method is adopted to simulate vortex shedding.

It can be seen from fig. 4(a), when the oscillation amplitude and frequency are all small, the flow is not too different from that past a fixed elliptical cylinder. When double the frequency which is shown in fig. 4(b) and quadruple the frequency which is shown in fig. 4(c), the vortex is shifting toward the centerline in horizontal direction but is still antisymmetry. For w_e = 0.3, f_e/f_0 = 1, at first the mode of vertex is symmetry. But when t = 41000, the vortex is becoming antisymmetry at some distance downstream. The feature of antisymmetry is more and more visually when iterate time increases which can be easily seen in fig. 5(a)-(e). Finally mode of vortex shedding is antisymmetry which is shown in fig. 4(d). When the amplitude increases to w_e = 0.45, the mode of vortex shedding is stably to symmetry named S-II mode which is shown in fig. 4(e). In this mode, two binary vortices are shed during each time period.

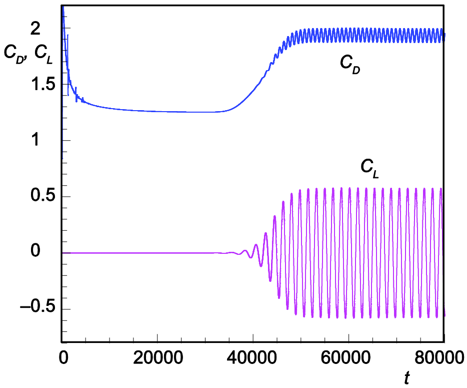

Figure 3. Drag coefficient and lift coefficient for the static elliptical cylinder by LB-DF/FD

Table 1. Comparison of the drag, lift coefficients and Strouhal numbers for LB-DF/FD and FVM

	C_D	C_L	St
LB-DF/FD	1.932 ± 0.063	± 0.576	0.368
FVM	1.863 ± 0.058	± 0.550	0.374

Conclusions

Vortex shedding patterns in flow past inline oscillating elliptical cylinder is simulated by LB-DF/FD method. The modes of vortex shedding are analyzed in detail by changing the amplitude and the frequency of oscillation. Symmetry mode of vortex shedding is more easy to realize by change the amplitude of oscillation. But it is needed to simulate more by changing the amplitude and the frequency of oscillation to get general conclusion.

Acknowledgment

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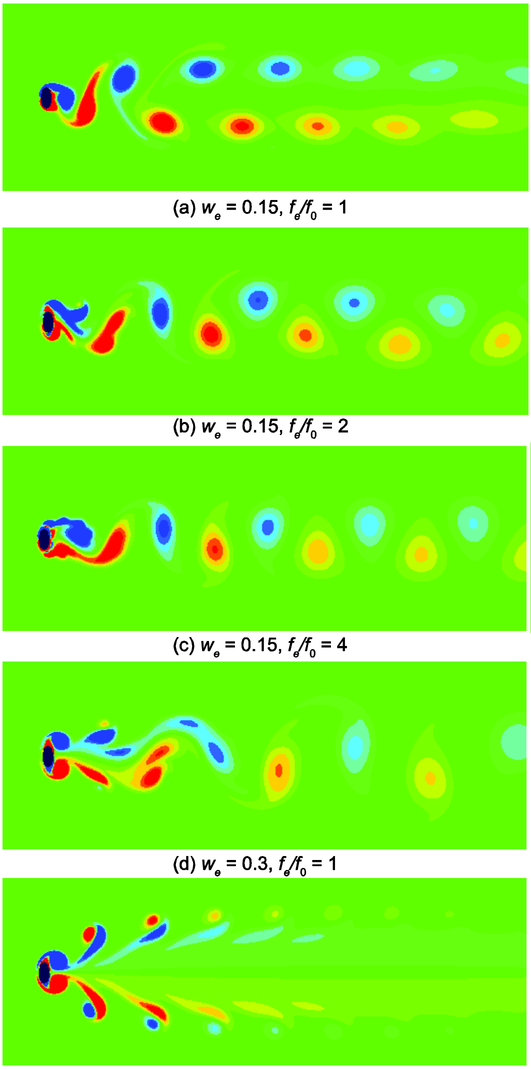

Figure 4. Vortex shedding patterns at different amplitude and frequency

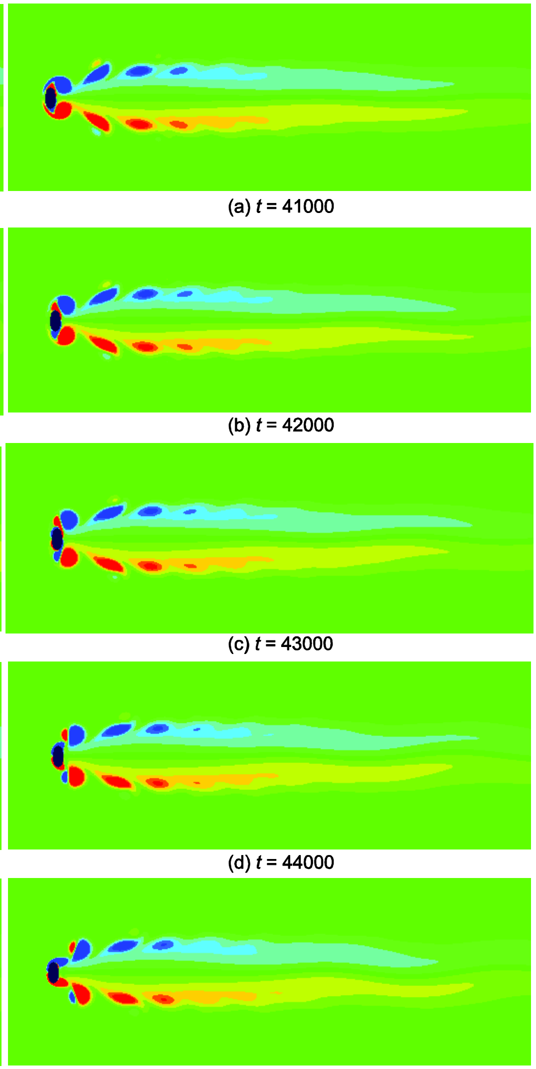

Figure 5. Vortex shedding patterns at different time when w_e=0.3, f_e/f_0=1

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