Seamless Immersed Boundary Lattice Boltzmann Method for Incompressible Flow Simulation

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Abstract: In this paper, the seamless immersed boundary lattice Boltzmann method is proposed, in order to simulate the complicated incompressible flows on the Cartesian grid. In the present method, the external forced density term which satisfies the velocity condition on virtual boundary is added not only to the grid points near the boundary but also to the grid points inside the boundary. The present method is validated for the flow around a circular cylinder. Then, it is concluded that the seamless immersed boundary lattice Boltzmann method is very versatile for simulating the complicated incompressible flows.

Keywords: Lattice Boltzmann Method, Seamless Immersed Boundary Method, Incompressible Flow Simulation.

1 Introduction

In the incompressible flow simulation, the lattice Boltzmann method is highlighted as an alternative computational approach for solving the Navier-Stokes equations. However, the lattice Boltzmann method originally assumes that the latices move on the rectangular grid. For applying to the curved boundary, the suitable curved boundary condition and immersed boundary approach are proposed. In this paper, we try to combine the seamless immersed boundary method [1] with the lattice Boltzmann method. A new seamless immersed boundary lattice Boltzmann method is validated for the flow around a circular cylinder.

2 Seamless Immersed Boundary Lattice Boltzmann Method

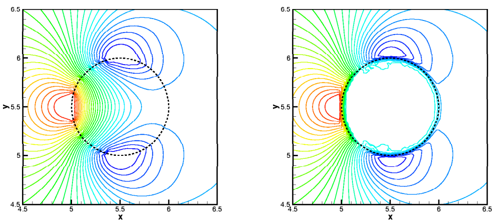
The immersed boundary lattice Boltzmann equation [2] can be written by

$$f_\alpha(\mathbf{x}+\mathbf{e}_\alpha\Delta t, t+\Delta t) - f_\alpha(\mathbf{x},t) = -\frac{1}{\tau}\left[f_\alpha(\mathbf{x},t) - f_\alpha^{(eq)}(\mathbf{x},t)\right] + \Delta t\frac{w_\alpha \rho}{c_s^2}\mathbf{e}_\alpha \cdot \mathbf{g}(\mathbf{x},t)\ , \qquad (1)$$

where $\mathbf{g}(\mathbf{x},t)$ is the external forcing function defined by $\mathbf{g}(\mathbf{x},t) = \left(\overline{\mathbf{U}} - \mathbf{u}\right)/\Delta t$, where $\overline{\mathbf{U}}$ is the specified velocity and $\mathbf{u}$ denotes the tentative velocity at next time step. This forcing term is added to the grid points not only near the boundary but also inside the boundary. On the grid points near the boundary, the specified velocity, $\overline{\mathbf{U}}$, is computed by linear interpolation between velocities on the virtual boundary and on the neighbouring grid point. On the grid points inside the boundary, the specified velocity is set as $\mathbf{U}_{vb}$, e.g., $\mathbf{U}_{vb} = 0$ for stationary solid media.

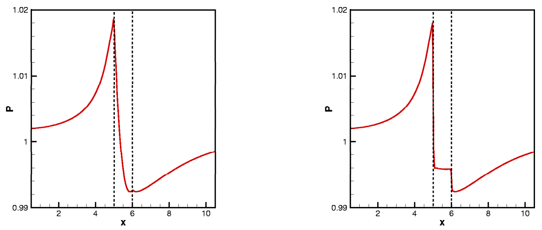
3 Computational Results

The flow around a circular cylinder is considered. The number of grid points is 841×441, which is the resolution of 40 grid points per a diameter of circular cylinder. The condition on the virtual boundary and inside the boundary is specified as the non-slip condition, $\mathbf{u} = 0.0$. Figures 1 and 2 show the steady state pressure field and pressure on the centerline with $Re = 40$. In the unsteady flow with $Re = 200$, the snapshot of pressure is shown in Figs. 3 and 4. It is found that the pressure obtained by the immersed boundary lattice Boltzmann method, in Figs. 1(b) and 3(b), distributes along the boundary. These pressure distributions arise from the pressure jump near the boundary shown in Figs. 2(b) and 4(b). On the other hand, the present method gives the very smooth pressure profile without pressure jump near the boundary, as shown in Figs. 1(a)∼4(a).



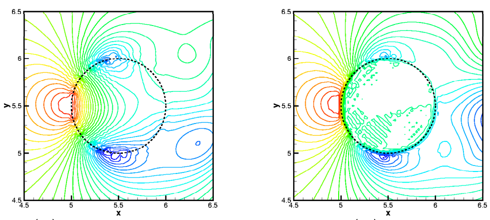
(a) Seamless IB. (b) IB.

Figure 1: Pressure field ($Re = 40$).



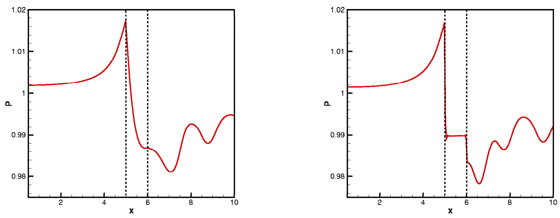
(a) Seamless IB. (b) IB.

Figure 2: Pressure on the centerline ($Re = 40$).



(a) Seamless IB. (b) IB.

Figure 3: Pressure field ($Re = 200$).



(a) Seamless IB. (b) IB.

Figure 4: Pressure on the centerline ($Re = 200$).

4 Conclusions

In this paper, the seamless immersed boundary lattice Boltzmann method is proposed and validated. In the present method, the external forced density term which satisfies the velocity condition on virtual boundary is added not only to the grid points near the boundary but also to the grid points inside the boundary, so that the pressure profile near the boundary becomes smoothly, because the presure jump near the boundary is removed. Then, it is concluded that the seamless immersed boundary lattice Boltzmann method is very versatile for simulating the complicated incompressible flows.

References

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