

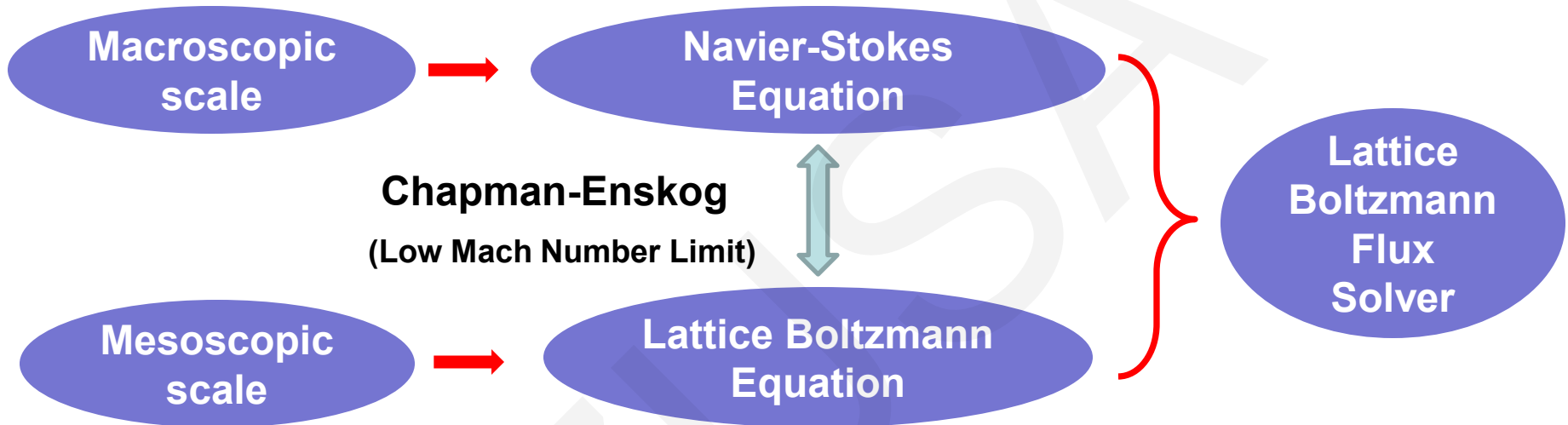
Numerical investigation of flow characteristics around two side-by-side cylinders by immersed boundary-lattice Boltzmann flux solver

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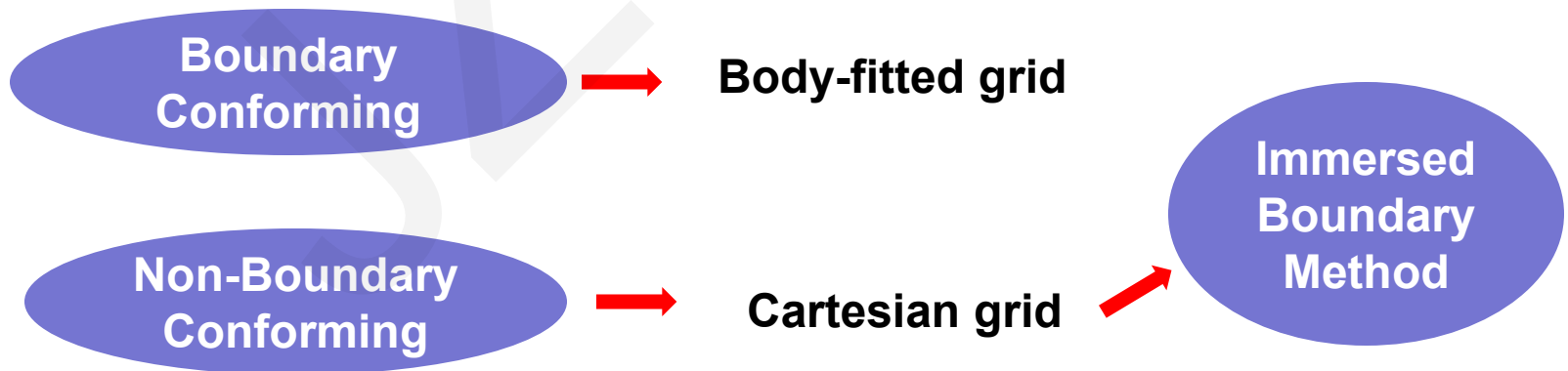
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Numerical Simulation Method

Governing Equation



Moving boundary problem



Governing equations

$$\frac{\partial \rho}{\partial t} + \nabla \cdot \left(\sum_{\alpha=0}^N \mathbf{e}_{\alpha} f_{\alpha}^{\text{eq}} \right) = 0$$

$$\frac{\partial \rho \mathbf{u}}{\partial t} + \nabla \cdot \Pi = \mathbf{f}$$

where

$$\Pi = \sum_{\alpha=0}^N (\mathbf{e}_{\alpha})_{\beta} (\mathbf{e}_{\alpha})_{\gamma} \left[f_{\alpha}^{\text{eq}} + \left(1 - \frac{1}{2\tau} \right) f_{\alpha}^{\text{neq}} \right],$$

$$f_{\alpha}^{\text{neq}} = -\tau \delta_t \left(\frac{\partial}{\partial t} + \mathbf{e}_{\alpha} \cdot \nabla \right) f_{\alpha}^{\text{eq}}.$$

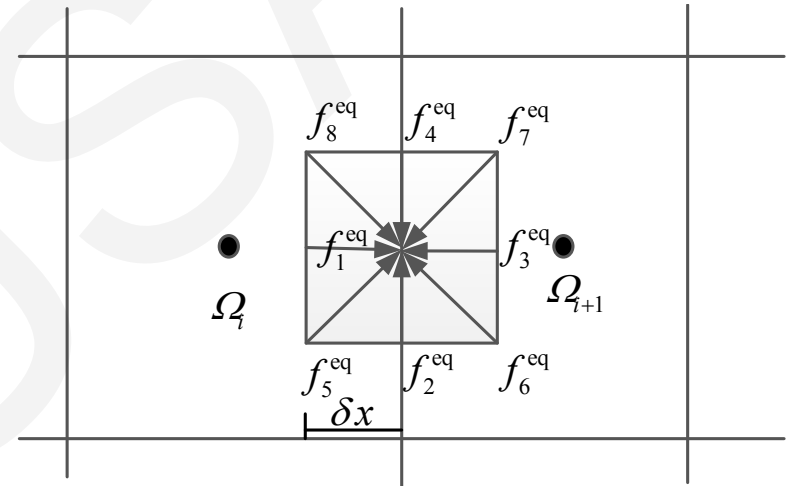


Fig. 1 Local flux reconstruction at cell interface

Numerical results

Computational models

Flow past two stationary side-by-side cylinders

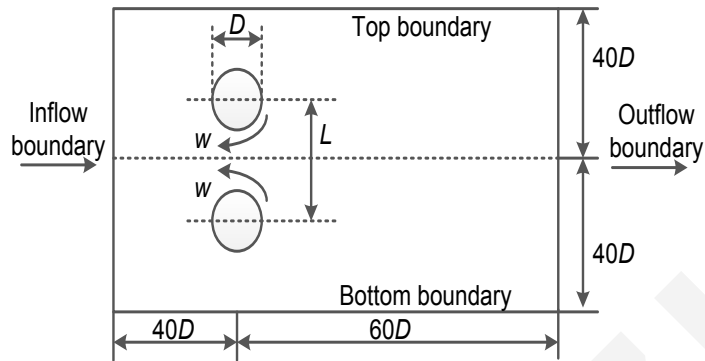


Fig. 2 Computational domain of two side-by-side cylinders

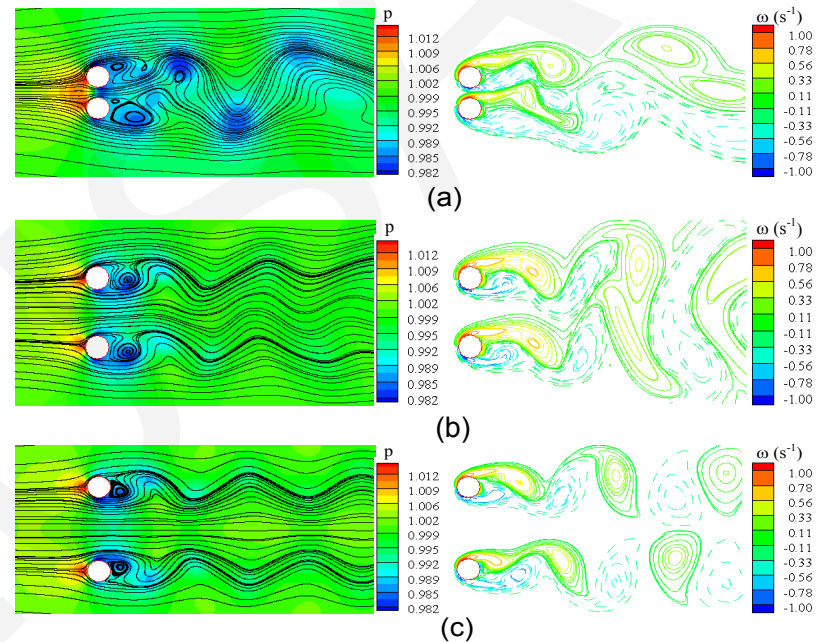


Fig. 3 Flow characteristics for two side-by-side cylinders ($Re=100$) on different gap spacings

(a) Streamlines and pressure contour (left) and vorticity contour (right) at $L/D=1.5$; (b) Streamlines and pressure contour (left) and vorticity contour (right) at $L/D=3.0$; (c) Streamlines and pressure contour (left) and vorticity contour (right) at $L/D=4.0$

Numerical results

Flow past two rotating side-by-side cylinders

Table 1 Time-averaged values of the drag and lift coefficients for the upper cylinder ($L/D=2.0$)

Re	Force coefficients	Reference	Time-averaged value					
			$\alpha=0.5$	$\alpha=1.0$	$\alpha=1.5$	$\alpha=2.0$	$\alpha=2.5$	$\alpha=3.0$
100	C_d	Chen et al. (2011)	1.153	0.836	0.496	0.224	-0.008	-0.005
		Present	1.154	0.809	0.525	0.258	0.033	0.016
	C_l	Chen et al. (2011)	1.370	2.533	3.771	5.127	6.585	6.127
		Present	1.371	2.508	3.666	4.952	6.416	6.925
150	C_d	Chen et al. (2011)	1.151	0.780	0.459	0.168	-0.024	0.003
		Present	1.225	0.833	0.508	0.200	0.005	0.016
	C_l	Chen et al. (2011)	1.311	2.441	3.673	5.023	6.520	6.078
		Present	1.381	2.448	3.514	4.862	6.411	6.804
200	C_d	Chen et al. (2011)	1.150	0.766	0.417	0.133	-0.038	-0.002
		Present	1.347	0.897	0.438	0.166	-0.007	0.012
	C_l	Chen et al. (2011)	1.335	2.434	3.740	4.986	6.615	6.070
		Present	1.339	2.428	3.467	4.790	6.402	6.851

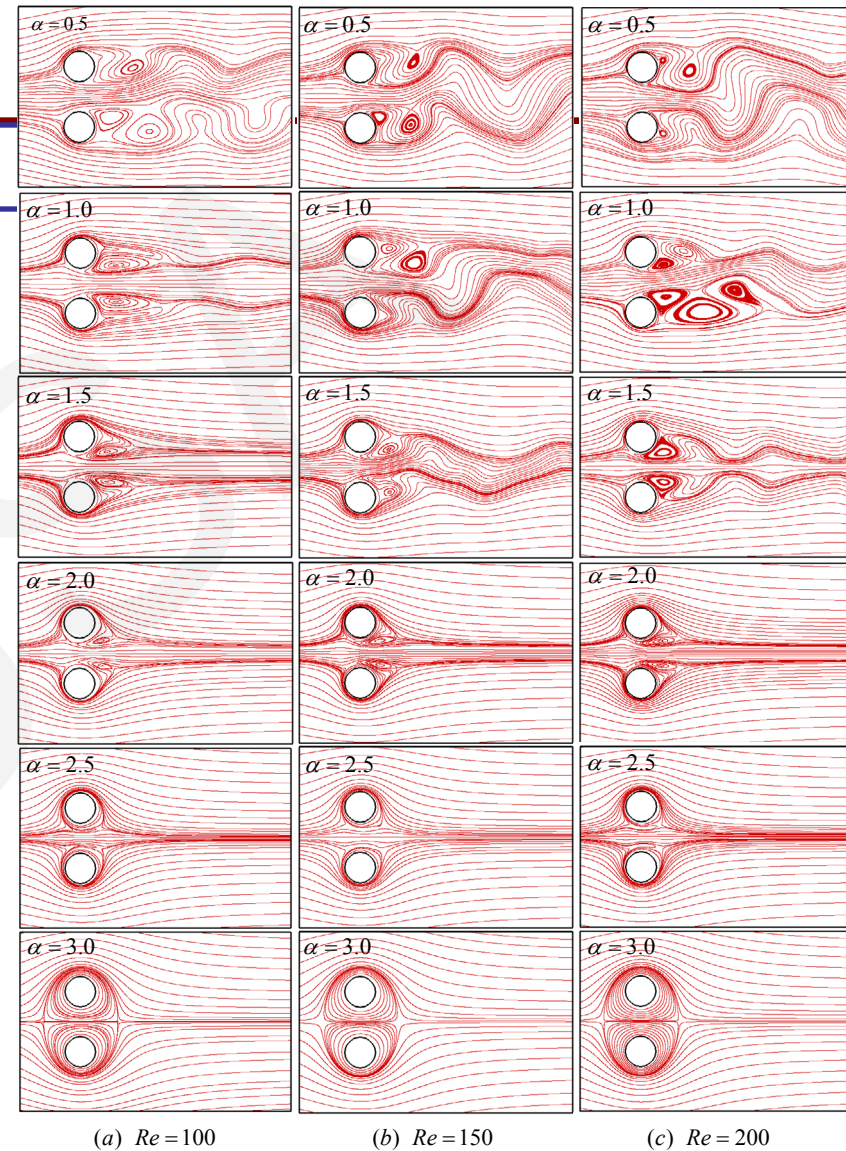


Fig. 4 Streamlines for flow past two side-by-side rotating cylinders at $L/D=2.0$ at different

Conclusions

- ◆ Immersed Boundary-Lattice Boltzmann Flux Solver is validated as an available alternative for simulating the flow past multiple bluff bodies.
- ◆ For flow past two stationary side-by-side cylinders at a low Reynolds number, the simulation results show that the wake is irregular at a small gap spacing. As the gap increases, the biased flow vanishes and there is less wake interactions until the in-phase or anti-phase flow is observed. The Reynolds number also effects the value of the force coefficients.
- ◆ For flow past two rotating side-by-side cylinders, the simulation results illustrate that a low Reynolds number has little effect on the force coefficients. The rotational speed, as the main important parameter, effects flow characteristics. As the numerical results illustrate, with increasing rotational speed the unsteady wakes can be suppressed and the flow becomes steady. Furthermore, the wake structure is effected by the gap spacing. At a small gap spacing, the flow is unsteady and intermittently deflected to each of the two cylinders. As the gap spacing increases, two separate vortex streets behind each cylinder are formed with a definite phase relationship and a single shedding frequency.