A preliminary numerical study on tsunami-borne submerged debris motion

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INTRODUCTION

Tsunamis can generate a large amount of debris that causes damage to buildings and infrastructure (Chock et al., 2013). The motion of tsunami-borne debris poses great challenges to post-disaster rescue and reconstruction, making it a research hotspot (Nistor et al., 2017). However, existing numerical studies (Ardianti et al., 2018; Hasanpour et al., 2021) have limitations in simulating high Reynolds number turbulent flow and have low computational efficiency. Recently, the lattice Boltzmann method (LBM), a new numerical method, has been developed that has high parallel scalability and computational efficiency (Krüger et al., 2017). By combining the LBM with the immersed boundary method, the numerical model can simulate the motion of debris in turbulent flows. This study uses the cumulant lattice Boltzmann method (Geier et al., 2015) to develop a three-dimensional high Reynolds-number debris motion model that accurately simulates the motion of debris driven by tsunami. The model provides a new research method for further studying the transport of tsunami debris, with high scalability and computational efficiency. Using the established numerical model, the settling process of different underwater objects was simulated, and the results were in good agreement with experimental data (Parnaudeau et al. 2008 and Yu et al., 2022). In summary, the three-dimensional lattice Boltzmann model developed in this study can overcome the limitations of previous numerical models and has high computational efficiency and scalability, making it a promising tool for studying debris motion.

METHODOLOGY

The cumulant lattice Boltzmann method solves a discretized lattice Boltzmann equation with multi-relaxation rates collision term in frequency space,

$$f_{ijk}\left(\mathbf{x}+\mathbf{e}_{ijk}\delta_t, t+\delta_t\right)-f_{ijk}\left(\mathbf{x},t\right)=\Omega_{ijk}\left(\mathbf{u},\mathbf{f}\right) \tag{1}$$

where $f_{ijk}\left(\mathbf{x},t\right)$ denotes the discrete momentum distribution function at space $\mathbf{x}$, time t with momentum $\rho\mathbf{e}_{ijk}$; δ_t being the time step; $\mathbf{e}_{ijk} = (ic, jc, kc)$ is the microscopic velocities with $c = \delta_x/\delta_t$ being the velocity quantum and i, j, k are integers; ρ is the fluid density; δ_x being the lattice constant; $\mathbf{u}$ is the fluid velocity vector and $\mathbf{f}$ is the momentum distribution function vector; Ω_{ijk} denotes the cumulant collision operator. The implementation of the cumulant collision operator can be separated into five steps: forward central moment transformation, forward cumulant moment transformation, collision, backward cumulant moment transformation, backward central moment transformation.

The motion of debris is solved as a rigid body motion:

$$\frac{d\mathbf{M}(t)}{dt}=\mathbf{F}(t) \tag{2}$$

$$\frac{d\mathbf{L}(t)}{dt}=\mathbf{T}(t) \tag{3}$$

where **M** is the momentum of debris, **F** is the force, **L** is the angular momentum of debris and **T** is the torque. The first-order forward difference scheme is adopted to solve the two equations.

The fluid-debris interaction is calculated using the immersed boundary method with diffusive algorithm as illustrated in the Figure 1.

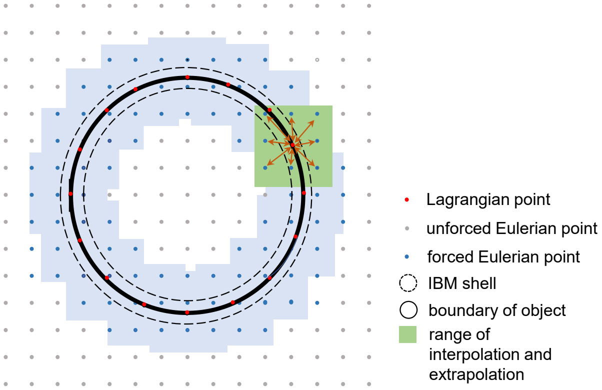

Figure 1 - Illustration of the immersed boundary around the surface of a solid circle.

DISCUSSION AND RESULTS

Figure 2 depicts streamwise velocity in the wake centerline of a circular cylinder in open channel flow. As seen, the velocity distribution simulated by the present model is well fitted to the experimental data, the reverse region of the wake simulated by the present model is the most accurate compared to other numerical models.

Figure 3 depicts settling velocities of objects with different sizes in static water. As seen, the settling velocity calculated by the present model is well fitted to the formulation proposed by (Yu et al., 2022), which proved to be the most accurate settling velocity formula for objects with lower density.

More details about the tsunami-borne debris settling velocities under static water and dynamic water conditions will bring in further ongoing research by using the present accurate numerical model for fluid-debris interaction under high Reynolds number turbulent flow condition.

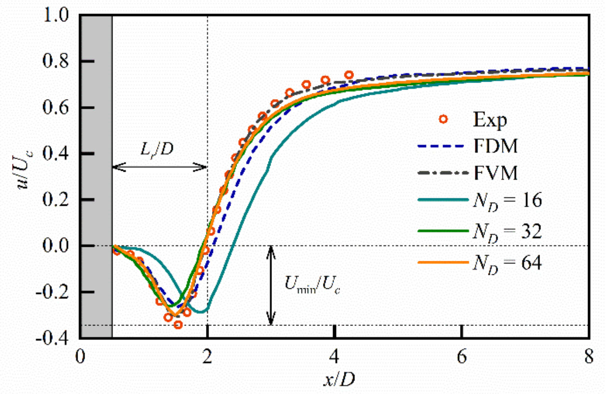

Figure 2 - Streamwise velocity in the wake centerline of the circular cylinder. Experimental data from the PIV result of (Parnaudeau et al. 2008); FDM data from the HR LES result of (Parnaudeau et al. 2008); FVM data from the L64-1 result of (Tian and Xiao 2020); N_D = 16, 32, 64 represent the present simulation results.

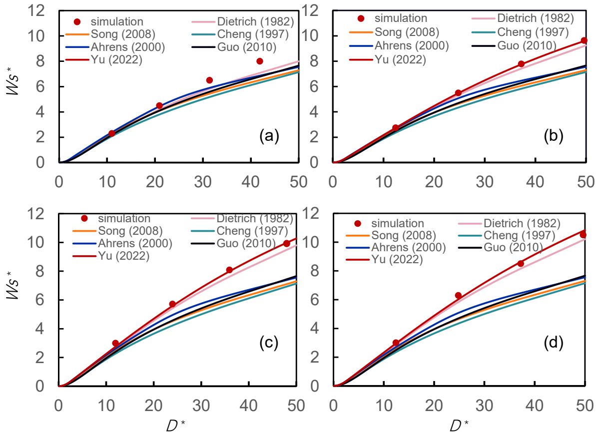

Figure 3 - Settling velocities of objects (ρ = 1130 kg/m^3) calculated by the present model and empirical formulas.

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