Oral presentation | Multi-phase flow

Multi-phase flow-III

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[3-D-04] Settling of prolate spheroids in a quiescent fluid at different volume fractions

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Settling of prolate spheroids in a quiescent fluid at different volume fractions

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1 Introduction

Particle sedimentation in the fluid flows is commonly encountered in nature and industry. Several studies have been performed in past decades on the settling of spherical particles, and found the enhanced particle settling rate in dilute suspensions [1]. In the present work, to better understand the effect of particle shape, we study the settling motion of prolate particles in a quiescent fluid with different particle volume fraction by using the particle-resolved direct numerical simulation (PR-DNS).

2 Flow configuration and numerical method

We explore the gravitational sedimentation of prolate particles in a tri-periodic domain filled with an initially quiescent fluid. The prolate particle with an aspect ratio $\lambda = a/b = 3$ and a density ratio $\alpha = \rho_p/\rho_f = 2$ (ρ_p and ρ_f represent the density of the particle and fluid, respectively) is considered here. The Galileo number Ga, which measures the ratio between the buoyancy force and viscous force acting on the particle, is set as $Ga = \sqrt{(\alpha-1)|\boldsymbol{g}|D_{eq}^3}/\nu = 80$. Here, $D_{eq} = 2(ab^2)^{1/3}$ is the equivalent diameter of a sphere with the same volume of the prolate spheroid, and ν denotes the kinematic viscosity of the fluid. The particle volume fraction ϕ is defined as $\phi = (\pi N_p D_{eq}^3)/(6L_xL_yL_z)$, in which N_p denotes the number of particles, and L_x, L_y and L_z represent the length of computational domain in the x, y and z directions, respectively. Six simulation cases with $\phi = 0.1\%$, 0.5%, 1%, 2%, 5% and 10% are considered. A second-order finite difference fluid solver is employed to solve the fluid flow governed by the incompressible Navier-Stokes equations. Moreover, we employ the direct-forcing IBM [2] to resolve the interaction between the fluid flow and particle motion. The motion of dispersed particles is solved by the Lagrangian tracking method, in which the soft-sphere collision model together with the lubrication correction [3] is used to take account for particle-particle collisions.

3 Results and discussion

First, we observe that the flow field is disturbed due to the presence of particles, which are non-uniformly distributed (see figure 1). The variation of the mean settling velocity ($\langle V_s \rangle$) of dispersed particles with different particle volume fraction is shown in figure 2. We observe an non-monotonic variation of $\langle V_s \rangle$ with the increase of ϕ, which is larger than the settling velocity of an isolated prolate spheroid at $\phi \leq 2\%$ and is reduced to smaller than V_t when $\phi \geq 5\%$. We find that the tendency of particles to form clusters plays a predominant role in particle mean settling velocities. In the very dilute suspension, although the attraction of particle wakes results in the vertically aligned particle structures, the too long distance between particles inhibits the growth of particle clusters. In another limit of high particle volume fraction, the too close particle-particle distance disrupts the wake of settling particles and weakens the hydrodynamic interactions among particles. The hindrance effect in this regime reduces the mean settling velocity of dispersed particles. More detailed results will be present in the conference.

References

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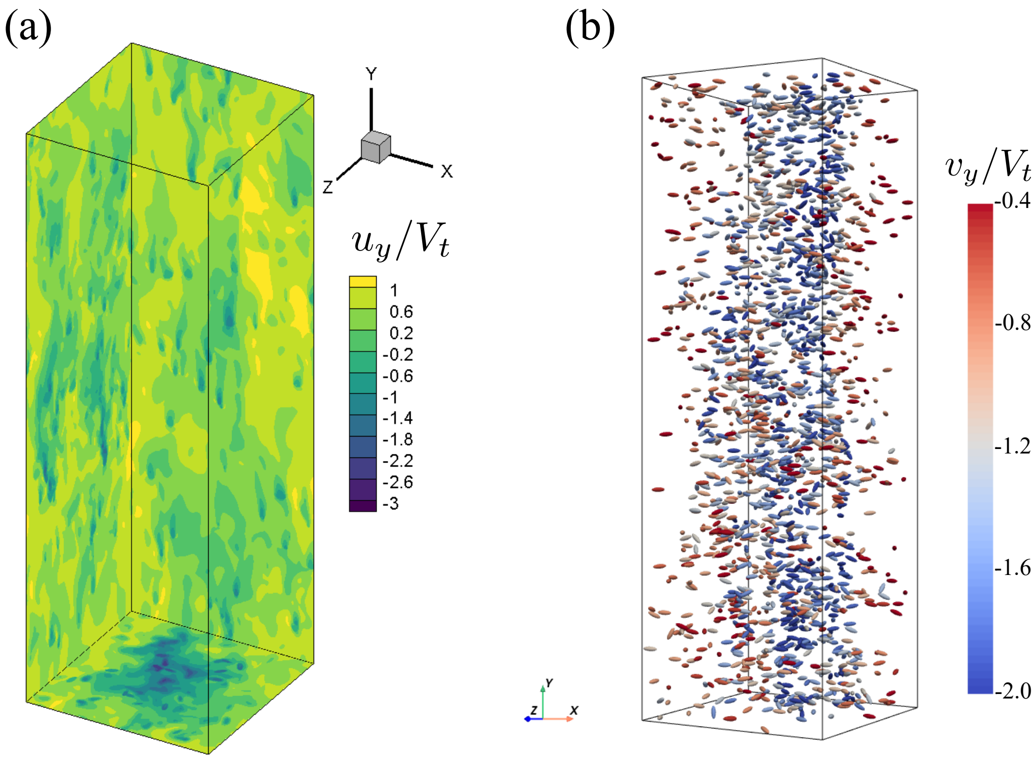

Figure 1: Snapshot of the (a) three-dimensional flow field and (b) the dispersed particles in the suspension of $\phi = 1\%$.

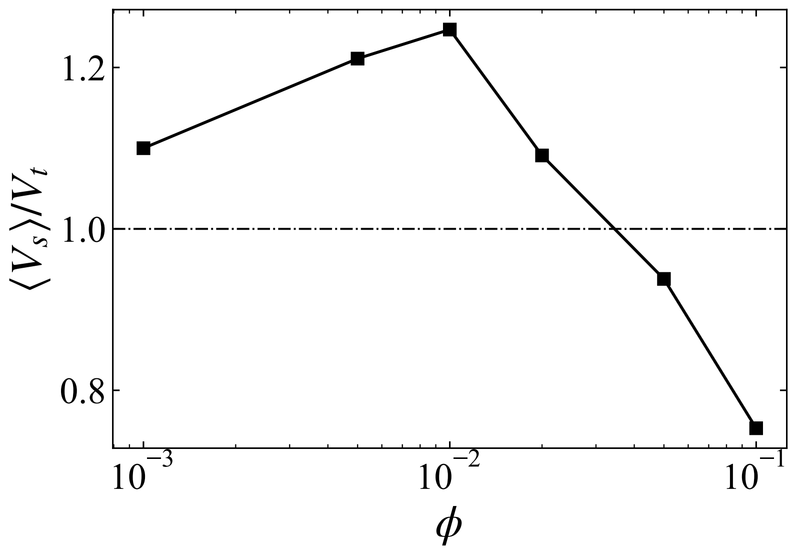

Figure 2: Mean settling velocity dispersed particles as the function of particle volume fraction. The velocity V_t to normalize $\langle V_s \rangle$ is the settling velocity of the isolated prolate spheroid.