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From transition to fully developed particulate turbulent flows: the effect of finite size particles

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Abstract

The effect of particles on turbulence is a key phenomenon in many practical industrial flows (slurries, fluidized beds, ...). Depending on the size ratio between the particles and the smallest scale of turbulence, the particle feedback on the flow can either enhance or suppress turbulence. In this communication, we will focus on two generic flow configurations: homogeneous isotropic turbulence seeded with particles and a transitional plane channel flow.

Fully-coupled numerical simulations are used to investigate the interactions between neutrally-buoyant finite-size particles and the fluid flow. The numerical method chosen for this work is the Force-Coupling Method (FCM) (Climent and Maxey, 2009). It is fully-resolved in the sense that the fluid equations are solved at a length-scale smaller than the particle radius. The FCM is based on a low-order, finite multipole expansion of the velocity disturbance induced by the presence of the particles. The presence of the dispersed phase in the fluid is then represented by a body force distribution written as a multipole expansion where the first term is the monopole representing the force that the particle applies on the fluid (due to an external forcing or particle-to-particle contact forces). The second term is the dipole tensor. Its anti-symmetric part is related to external torques applied on the particle. The symmetric part is set through an iterative procedure to ensure that the strain-rate within the fluid volume occupied by the dispersed phase is zero (enforcing solid body response).

Particles in turbulence are experiencing shear flows at different scales. The method has been validated on low Reynolds number shear flows (Abbas et al., 2006) and extension to finite Reynolds will be commented in this communication. Second, the numerical method has been validated in the case of inertia-induced particle migration in a plane Poiseuille flow. In laminar channel flows, neutrally buoyant particles are submitted to a lift force induced by the interaction between the finite-size particle and the parabolic velocity profile when the particle Reynolds number is finite.

Homogeneous isotropic turbulence seeded with finite size neutrally buoyant particles (typically few Kolmogorov length scales) is investigated (Yeo et al., 2010). Results are given on the modulation of the turbulence at volumetric concentrations of 6%. We analyzed the Lagrangian statistics for the velocity and acceleration of the dispersed phase. The turbulent fluctuations are damped at mid-range wavenumbers by the particles while the small scale kinetic energy is significantly enhanced. The pivoting wavenumber characterizing the transition from damped to enhanced energy content is shown to vary with the size of particles.

For neutrally buoyant particles seeded in transitional pipe flows, Matas *et al.* (2003) observed changes in the values of the critical Reynolds numbers depending on both the solid volume fraction and the particle-to-pipe size-ratio. Typically, the transition occurs at lower Reynolds numbers when the flow carries macro-sized particles at dilute to moderate concentrations (up to 25%). On the contrary, the critical Reynolds numbers of the onset of transition is shifted

towards greater values when particles are micro-sized and their concentration is higher. In this communication, we aim at understanding the mechanisms lying behind the shift of the laminar-turbulent transition regime down to lower critical Reynolds numbers in suspension flows of macro-sized particles. Particles are randomly seeded into a fluctuating channel flow at a solid volume fraction of 5%, the size ratio of particle diameter to channel height being 1/16. After a transient regime, particles are homogeneously distributed in most of the channel flow. A larger concentration occurs in the near-wall region mainly due to inertial particle transversal migration (Ségré-Silberberg effect). The wall-normal and spanwise flow velocity fluctuations are significantly changed compared to the single-phase flow case. They are larger in the wall vicinity due to larger particle concentration in this region, and they are slightly larger in the channel core due to energy redistribution from the streamwise towards the transverse directions. Hence in the suspension flow, the particles are responsible for the significant agitation growth (in transverse directions) compared to the single-phase case. In our simulations of suspension flows, values of the wall friction coefficient are larger than in the single-phase case. The fluctuating flow exhibits a nearly constant friction coefficient in the transition regime whereas the friction coefficient increases when the Reynolds number is decreased below 1200. Substituting the Reynolds number by a mixture Reynolds number based on the effective suspension viscosity, the evolution of the friction coefficient almost collapses with the laminar law.

These results tend to show that compared to single-phase flows, even at low concentration, finite Reynolds particulate flows relaminarize at lower Reynolds number, in accordance with previous experimental observations of Matas et al. (2003).

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