GRAVITY EFFECTS ON PARTICLE DYNAMICS IN WALL TURBULENCE

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Abstract Particle dynamics in a vertical channel flow is considered with focus on the slip velocity between the fluid phase and the inertial spherical particles. Five different particle Stokes numbers from 1 to 100 were considered in a $Re_\tau = 395$ flow. Data for the mean slip velocity were mostly in accordance with our expectations, whereas counter-intuitive results for the fluctuating slip velocity were found. These await further interpretations.

BACKGROUND AND MOTIVATION

The role of gravity on particle-laden turbulent flows is an issue of major importance. In experimental studies on particle dynamics in turbulent channel flows [1, 2], the gravitational force is inevitably present although its significance is not clear. In computational studies [3], on the contrary, gravity is neglected in the majority of investigations. If gravity plays a role, it matters whether one consider the particle dynamics near the upper or lower wall in a horizontal channel or whether the particle suspension flows upwards or downwards in a vertical channel. Neglecting gravity makes it therefore difficult to compare results deduced from computer simulations with data from experimental measurements. If at all important, gravity may affect the interactions between individual particles and the coherent near-wall structures, e.g. ejections and sweeps. This may in turn influence the preferential particle concentration, particle entrainment and deposition. We recently [4] hypothesized that the effect of gravity on particle dynamics in wall-bounded shear flows is receding with increasing Reynolds number. The aim of the present study is to systematically address the role of gravity on particle-laden flow in a vertical channel. Results from an upward flow will be compared with results from a downward flow as well as with results for a flow without gravity. A Reynolds number higher than in almost all earlier simulation studies will be considered.

FLOW CONFIGURATION AND COMPUTATIONAL APPROACH

We consider a fully developed turbulent flow in a vertical channel. The flow is driven by an imposed pressure gradient in the streamwise direction either supported or opposed by gravity such that the frictional Reynolds number Re_τ based on the channel half-width h and the wall friction velocity u_τ remains equal to 395. This Reynolds number is substantially higher than the Reynolds numbers 150 and 180 typically considered in earlier simulations [3, 4]. The particular value $Re_\tau = 395$ was chosen here to match the intermediate Reynolds number studied by Moser *et al.* [5]. The simulations are one-way coupled, which means that the turbulent flow field is unaffected by the presence of the particles. The instantaneous flow is obtained in a direct numerical simulation in which the three-dimensional flow field is integrated on a 384^3 computational grid. Five different swarms each of 500 000 inertial spherical particles were tracked in a Lagrangian manner. The five different particle classes correspond to the five different Stokes numbers 1, 5, 15, 30, and 100. We define the Stokes number $St = \tau_p/\tau_f$ where $\tau_p = \rho_p d_p^2/18\mu$ is the particle relaxation time and $\tau_f = \mu/\rho u_\tau^2$ is the viscous time scale of the wall turbulence. We assume that $\rho_p >> \rho$ and the Lagrangian equations of the particle motion therefore include only inertia, Schiller-Naumann corrected Stokes drag, and gravity.

RESULTS AND CONCLUSIONS

In this paper the we focus on the effect of gravity on the slip velocity $\Delta U_i = u_{f,i} - u_{p,i}$ in the x_i-direction. The *slip velocity*, i.e. the relative velocity between the fluid at the particle location $u_{f,i}$ and the particles own velocity $u_{p,i}$ is an essential variable in two-fluid modeling of particulate flows [6]. The slip velocity is also an essential measure of the interactions between the discrete particle phase and the continuous fluid phase and governs the mechanical energy exchange between the phases as well as the particle energy dissipation [4].

Results for the mean slip velocity in the streamwise and wall-normal directions for $St = 100$ are shown in figure 1(a, b), respectively. ΔU is almost uniform across the channel, except in the close vicinity of the walls ($z^+ < 50$). Since the fluid velocity is unaffected by gravity in the computational set-up, the increase of ΔU for the upward flow reflects that the particle velocity is reduced due to gravity, as one would expect. Similarly, ΔU is reduced for the downward flow and $\Delta U < 0$ suggests that the particles are moving faster than the local fluid in this case. Although ΔW in figure 1(b) shows that the slip velocity is fairly small in the wall-normal direction, the accompanying mean drag force tends to drive the particles away from the wall. Outside of $z^+ \approx 100$, however, the particles are dragged towards the walls when the fluid flow is upwards and away from the walls in the case of downward flow. The fluctuating parts of the slip velocity vector shown in figure 1(c, d) are surprisingly large and exceed the corresponding mean values. The remarkable observation that the downward flow is affected by gravity in the core region whereas the upward flow is practically unaffected will hopefully be explained at the time of the conference. The tiny effect on the upward flow is furthermore in the same direction as observed for the downward flow.

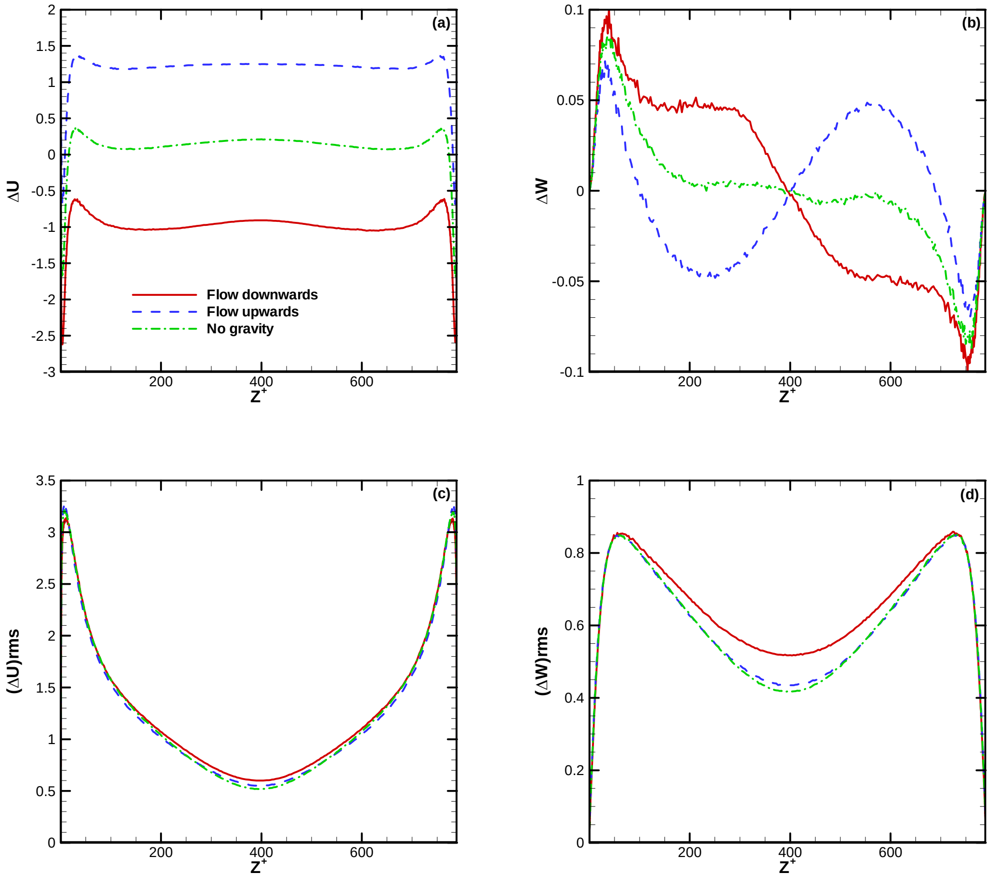

Figure 1. Mean slip velocity for Stokes number *St* = 100 in the streamwise (a) and wall-normal (b) directions together with root-mean-square values of the slip velocity in the streamwise (c) and wall-normal (d) directions. z^+ is the distance from one of the vertical walls measured in inner units.

The one-way coupled simulations enabled us to investigate the effect of gravity on the inertial particles in isolation of any indirect effects from the particles on the turbulence field. No effect of gravity was observed for the fastest particles (*St* = 1) except for the mean streamwise slip ΔU (not shown here). With gradually increasing Stokes numbers, however, more prominent effects of gravity were observed. It is particularly noteworthy that inclusion of gravity affected the slip velocity fluctuations and ΔW only away from the wall, i.e. outside of $z^+ \approx 30$, whereas the buffer layer and the linear viscous layer were unaffected.

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