Statistics and preferential distribution of micro-particles in turbulent boundary layer: implications for resuspension mechanisms

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Abstract

The distribution of inertial particles dispersed in turbulent flows is highly non-homogeneous and may exhibit a complex pattern which is driven by the structures of the turbulent flow field. Fluid motions in turbulent flows are intermittent and have a strongly organized and coherent nature represented by the large scale coherent motions.

In this work, we simulate a turbulent channel flow of air laden with a dilute dispersion of inertial micro-particles for different values of their inertial parameter (the relaxation time). We study a turbulent channel, calculated for a shear Reynolds number based on the half-width equal to 150, using a pseudo-spectral Direct Numerical Simulation. The domain is $1885 \times 942 \times 300$ in the streamwise (x), spanwise (y), and wall-normal (z) directions, respectively, and is discretized into $128{\times}128{\times}129$ Fourier/Chebichev modes. The dispersion dynamics is simulated using Lagrangian tracking of swarms of $O(10^5)$ particles characterized by different values of their inertia parameter (Stokes numbers equal to 0.2, 1, 5). We run simulations considering different sets of forces acting on particles (Drag, inertia, gravity and lift) and different modelling approaches: one-way and two-way coupling.

The object of the paper is to examine in detail the influence of the inertia on particle transfer mechanisms and specifically on reentrainment mechanisms. In particular, we focus on the unbalance between transfer fluxes toward and away from the wall which causes the well known phenomenon of *turbophoresis* (Caporaloni, et al., 1975, and Reeks, 1983).

In our previous works (Marchioli and Soldati, 2002, and Marchioli et al., 2003), we concluded that particle transfer fluxes away from the wall are limited by the time and space causal relationships among the different events characterizing turbulence regeneration cycle in the wall region *i.e.* the causal relationship between strongly coherent sweeps and ejections, quasi-streamwise vortices and low speed streaks. Specifically, we observed that particles which are driven to the wall by a sweep and are not re-entrained to the outer flow by the corresponding ejection on the opposite side of the quasi-streamwise vortex are bound to remain in the viscous wall layer for long times and slowly diffuse to the wall (Narayanan et al., 2003).

We examine first the role of quasi-streamwise structures on reentraining particles from the viscous sublayer. In Figure 1, we show the probability density function of the time spent by the swept-and-reentrained particle in the viscous sublayer (*i.e.* the wall region between $z^+ = 0$ and $z^+ = 5$). We calculated the pdf by recording the time spent by each particle which enters the viscous sublayer (threshold level $z^+ = 5$) coming from the outer region ($z^+ > 5$) before the same particle crosses next the same threshold coming from the inner region ($z^+ < 5$). We observe that the pdfs have a maximum in the range $7 < t^+ < 12$ for the different time scales of the particles investigated. If we consider that the inverse of the streamwise vorticity (*i.e.* the average time scale of the vortical structures) peaks sharply at $z^+ = 5$ where it has a value of $t^+_{\omega_x} = 14$, we can infer the following: i) first, we can confirm that the quasi-streamwise vortical structures dominate particle transfer toward and away from the wall; ii) second, the particles with the highest probability of being reentrained are those which enter and exit the viscous sublayer riding the same quasi-streamwise vortical structure.

A relevant issue in boundary layer turbulence is the modulation of turbulence structures by the presence of dispersed particles. We examine how the particle wall transfer fluxes are modified due to the action of particles themselves in modulating turbulence. In Figure 2, we compare the time evolution of the $\tau_p^+ = 5$

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particles number distribution profiles as a function of the wall normal direction. We can observe that if particles have a feedback on the flow field (two-way coupling), the concentration peak is reduced thus decreasing the importance of turbophoresis. Apparently, particles modulate turbulence at the wall such to reduce selectively the action of the quasi-streamwise structures.

In the full paper, we will present complete results describing thoroughly the interactions among particles and turbulence structures in the wall region.

References

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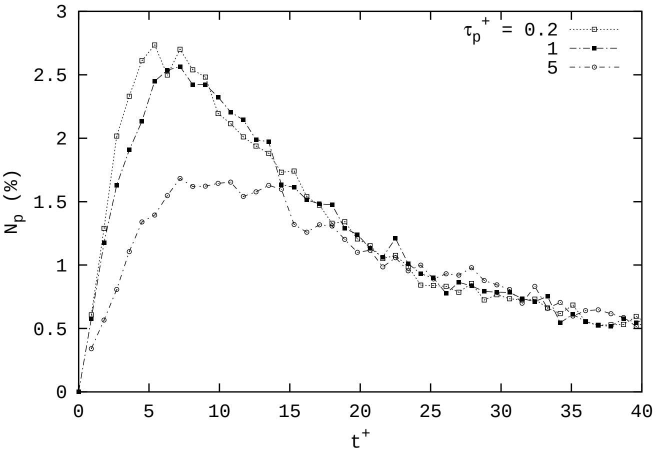

Figure 1: PDF of the time spent by the swept-and-reentrained particle in the viscous sublayer ($z^+ < 5$).

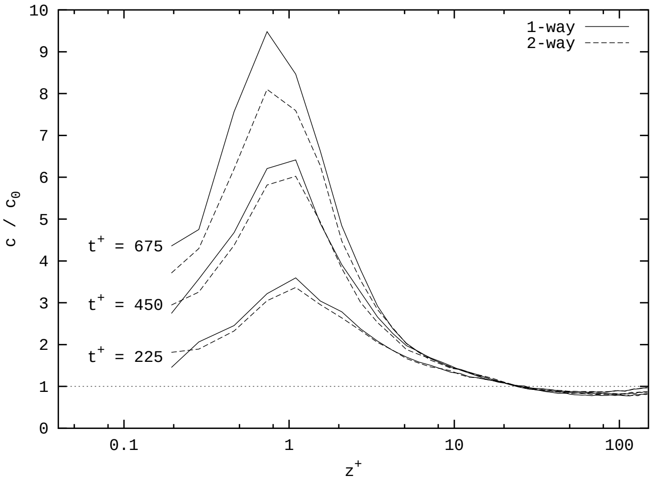

Figure 2: Time evolution of the $\tau_p^+ = 5$ particles number distribution profiles as a function of the wall normal direction.