Clustering of inertial particles in shear flows

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Abstract. *Particles with finite inertia present anomalous transport properties such as small scale clustering, a feature usually addressed in homogeneous and isotropic conditions. Here the effect of the mean shear on the particle clustering is analyzed by using DNS in several configurations of shear flows: homogeneous shear, pipe flow, and free jet. Data evidence that the segregation process is essentially anisotropic, even in the range of scales where isotropization of velocity statistics already occurred. Spatial inhomogeneity adds additional features associated with the migration of particles towards specific regions of the flow*

Keywords: Inertial particles, Clustering, Preferential Accumulation.

Transport of particles is a classical problem in fluid mechanics since the pioneering contributions of Richardson and Taylor. In many cases the inertia of the particles plays a crucial role in their dynamics. An essential phenomenology induced by inertia is clustering, thoroughly analyzed for statistically homogeneous and isotropic flows[1]. In such conditions the most striking result concerns the singular behavior exhibited by the radial distribution function showing that, under proper conditions, clustering may occur at small scales, below the Kolmogorov length. Actual flows are neither isotropic nor homogeneous. Purpose of this work is to describe recent contributions addressing the effects of shear and inhomogeneity on particle dynamics. The effects of shear are evident in the instantaneous configuration of particles shown in the top panel of figure 1, taken from homogeneous turbulent shear flow [2]. The presence of clusters is apparent, as it is their orientation induced by the velocity field anisotropy. Technically clustering amounts to an increased probability to find particles at a given distance r and it is quantified by the radial distribution function (RDF), bottom-left panel of figure 1. The main parameter controlling the dynamics for small, diluted, heavy particles is the Stokes number, $St_\eta = \tau_p/\tau_\eta$, where $\tau_p = \rho_p d_p^2/(18\mu)$ is the particle relaxation time and τ_η is the Kolmogorov time. Clustering is maximum when $St_\eta \simeq 1$, see the slope of the RDF at small scales. The anisotropy of the advecting field results in a strong directionality of the probability to find particles at small separation, bottom-right panel of figure 2. The data provide evidence of the substantial anisotropy of the particle

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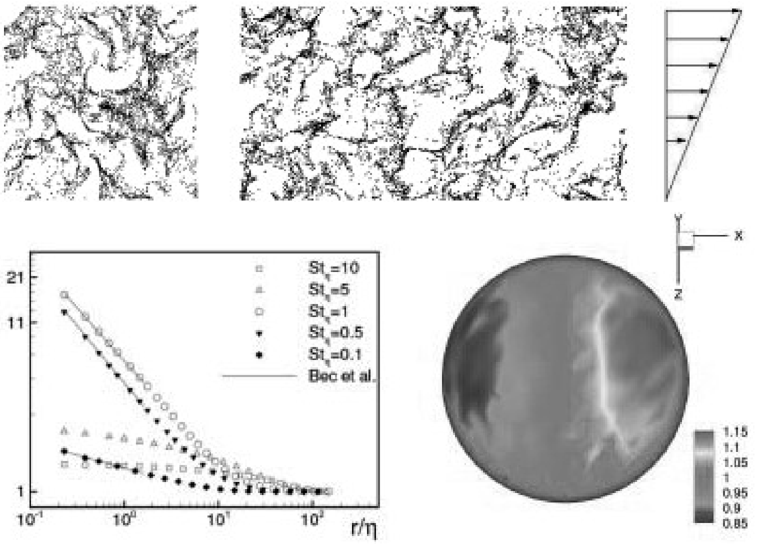

Figure 1: Top panel: instantaneous slice of particle distribution at $St_\eta = 1$ in homogeneous shear flow at $Re_\lambda = 100$. Left-bottom panel: radial distribution function for different Stokes numbers; right-bottom panel angular distribution function for $St_\eta = 1$ and $r = 4\eta$. See [2] for more details.

distribution which, under appropriate conditions, may easily reach the small scales of the flow where isotropization of velocity statistics already occurred.

Anisotropic clustering is a generic property of particle-laden turbulent shear flows, see e.g. figure 2 providing the instantaneous particle distribution in a free turbulent jet at $Re_D = 4000$. Inhomogeneity adds new features, inducing the migration of particles towards specific regions of the flow. The effect is striking in wall bounded flows [4], where particles of suitable mass $St^+ \simeq 10 \div 50$

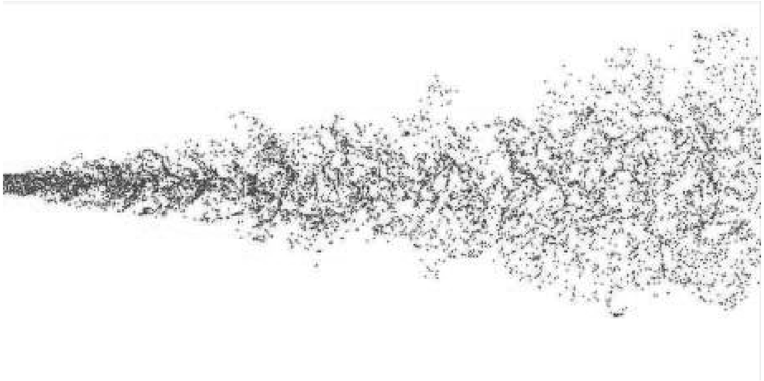

Figure 2: Snapshot of particles with $St_D = \tau_p U_0/D = 4$ in a turbulent jet at $Re_D = 4000$

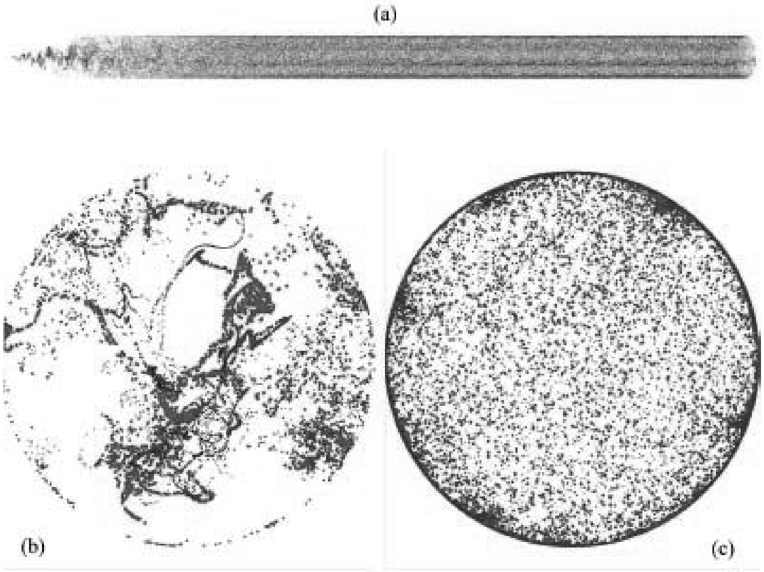

Figure 3: Snapshots of particle distributions in a spatial developing pipe flow at $Re_\tau = 200$. Colors correspond to different Stokes numbers $St^+ = 0.1$ green, $St^+ = 10$ blue, $St^+ = 100$ red. Panel (a) whole domain with length $L_z = 200R$ (not to scale). Panels (b) and (c): cross sections at $z/R = 25$ (developing region) and at $z/R = 200$ (far field), respectively. region. See [3] for more details.

drift towards the wall reaching concentration up to thousands times the value in the bulk. Accumulation at the wall, figure 3, occurs together with spatial localization of the particles in elongated patterns, which, as discussed in [3], are necessary features of the equilibrium distribution.

References

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