THREE-DIMENSIONAL MEASUREMENTS OF HEAVY AND LIGHT PARTICLE DISPERSION IN SHEAR TURBULENCE

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Abstract We present new experimental data concerning the statistics of heavy and light particles dispersed at low concentrations in a homogeneous turbulent shear flow. Information on both the spatial distribution and on the relative velocity of the dispersed phases is obtained by accurate three-dimensional optical measurements, and will allow to comparatively discuss the issues of turbulent clustering and small scale anisotropy by analyzing the scale- and angular dependence of suitable particle observables computed in the two cases.

Turbulent multiphase flows are of fundamental relevance for many technological systems and natural phenomena, see e.g. Ref. [1]. In many such instances, quantitative prediction of key quantities such as the local concentration of the dispersed phase or the residence time of particles within the system is required. For small particles (i.e., with size comparable with the Kolmogorov scale of the flow) these aspects have been the subject of numerous analytical and experimental studies, as well as of recent numerical simulations using the point-particle approximation [8]. The common understanding is that, due to the different inertia between carrier and dispersed phases, particles sample the fluid domain in a preferential way: small heavy particles are centrifuged out from high-vorticity zones and accumulate in regions of high strain, while lighter-than-fluid particles migrate towards high-vorticity regions in virtue of pressure forces. This phenomenon of preferential accumulation or turbulent clustering clearly affects the characteristics of the concentration field - since it leads to strong non-uniformities of the particle distribution - but has also a strong influence on other important quantities such as the settling velocity of the dispersed phase. While most of previous studies have been conducted in the idealized context of homogeneous isotropic conditions, the motion of heavy particles or microbubbles advected by a liquid flow is expected to be greatly affected by the characteristics of the background turbulence. Isolating the main features of practical flow configurations and assess their influence on the characteristics of the dispersed phase represents then a natural approach for advancing the understanding of complex multiphase problems.

In the present work we focus our attention on the effects associated with a mean velocity gradient $S = \partial U_x/\partial y$. We do so from an experimental point of view by setting-up in a water channel a homogeneously sheared turbulent flow, i.e. a turbulent environment characterized by uniform values of both the mean shear S and of the turbulent velocity fluctuation u' (see the left panel of Fig.1). The flow is defined by two main quantities, namely, the Reynolds number Re_λ based on the Taylor microscale base (here $Re_\lambda \approx 600$) and the shear parameter S^* representative of the extent of turbulent scales affected by the shearing forcing ($S^* = Su'^2/\epsilon \approx 5$, ϵ being the energy dissipation rate). The dispersion of two different classes of inertial particles at low bulk concentrations will be investigated: spherical glass beads with density ratio $\rho_p/\rho_f \approx 3$ and undeformable vapor microbubbles generated by means of a cavitation device with $\rho_p/\rho_f \approx 10^{-3}$. In both cases, the particle diameters are comparable with the Kolmogorov scale η of the unladen flow (here $\eta \approx 0.2$ mm). In a previous work [4], we have already employed two-dimensional measurements to characterize from a geometrical and a statistical point of view how the anisotropy associated with the mean shear is reflected on the dispersion of heavy particles. The most salient feature of the instantaneous particle field consisted in the presence of thin elongated clusters of particles preferentially aligned in the direction of the maximum mean strain, as indicated in right panel in Fig.1 by the characteristic shape of the two-point particle correlation function computed in the longitudinal plane. In the same plot, the phenomenon of preferential accumulation commonly observed in isotropic turbulence is revealed instead by the divergence of the correlation function as the separation r between two particles vanishes.

The aim of the present work is to get a more complete picture of the dispersion process of heavy particles by means of three-dimensional measurements of the features of the dispersed phase. Moreover, we aim at comparing results concerning heavy particles with the corresponding statistics gathered for the case of microbubbles, where much less predictions are available and where substantial modifications of the carrier flow are known to occur even at extremely low bulk void fractions (see e.g. [3]). Three-dimensional information on the dispersed phases is obtained by means of an optical technique known as Defocusing Particle Image Velocimetry [6]. Particles within a measurement domain (roughly $150 \times 150 \times 100$ mm^3 in size) are illuminated with a pulsed laser light (see Fig.2, left panel) and their position in space is obtained with great accuracy at each pulse instant by using the out-of-focus projections on the image plane of three cameras placed at different angles with respect to the flow. The velocity vector of each particle can also be obtained, provided the field is sampled at sufficiently high pulse rates. Use of this rich information can allow to fully describe the fluctuations in both the spatial distribution and in the relative velocity of the dispersed particles. Firstly, the concentration field will be systematically characterized at changing observation scale by employing a number of consolidated techniques. Instrumental to this purpose is e.g. the so-called Angular Distribution Function used in Ref. [5] and [2], which gauges the probability of finding two particles along a fixed direction at given separation r, and hence provides details on both clustering effects and on the scale-by-scale anisotropy of the concentration field (as illustrated in the right panel of Fig. 2

for the two-dimensional situation). Complementary information can also be obtained by computing the probability density function of the so-called Voronoi volumes [7], which allows to identify the typical scales involved in the clustering process for the different classes of particles, as well as to to provide a global comparative measure of the intensity of the process. Secondly, the information concerning the particle velocities will be exploited to gain quantitative insight into the scale- and angular dependence of the particle structure functions (i.e., of the moments of the relative velocity of particle pairs at a given distance **r**). Information on the small-scale behavior of this quantity is indeed essential for the correct estimate of the particle collision rate needed in many applications.

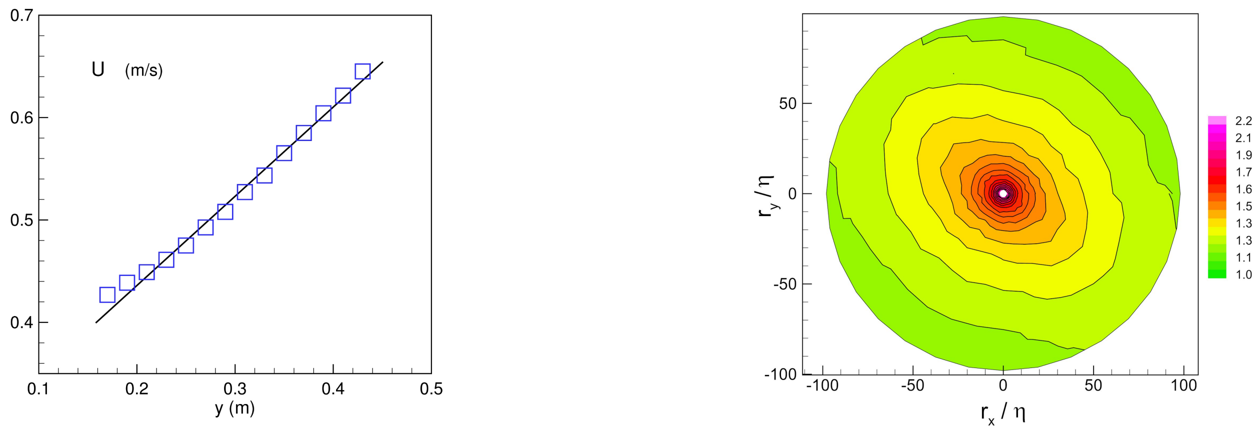

Figure 1. Left panel: the almost linear variation of the mean streamwise velocity U against transverse coordinate y. Right panel: contour levels of the two-dimensional correlation of the instantaneous particle concentration field, the separation **r** lying in the longitudinal plane(sketch extracted from [4]).

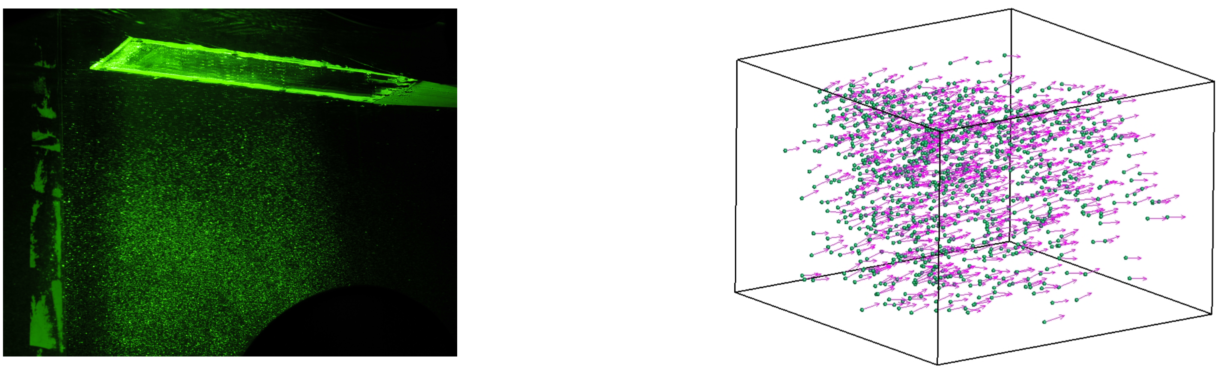

Figure 2. Left panel: a close-up of the three-dimensional measurement volume illuminated by a pulsed laser. Right panel: the instantaneous particle positions with the corresponding velocities.

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