EXPERIMENTAL STUDY OF LARGE SUSPENDED ANISOTROPIC PARTICLES IN TURBULENCE

G. Bellani[1,2] and E. A. Variano[1]
[1] *Department of Civil and Environmental Engineering, University of California, Berkeley, CA 94720, USA*
[2] *Department of Industrial Engineering, University of Bologna, I-47100 Forlí, Italy*

BACKGROUND

The majority of attention in the field of turbulent suspensions has been focused on spherical particles [3] and particle having high aspect-ratio as long-chain polymers or elongated fibers (*e.g.* [4]). However, many objects found in environmental flows, such as organisms, sediment, droplets, or aggregates of these are in between these two extremes, and have aspect ratio between 1 and 10. Herein we examine an idealized model of such particles.

In particular, in this work we focus on the effect that such particles have on the background turbulent flow. A turbulent flow can be changed by adding suspended particles; this process is called “turbulence modulation” and has been investigated for decades [1, 2].

Two critical factors in determining turbulence modulation are the density ratio $\rho_{particle}/\rho_{fluid}$ and the volume fraction Φ. Herein, we focus on the specific case of $\rho_{particle} = 1.002\rho_{fluid}$, which describes a large number of aquatic organisms and aquatic sediment aggregates. Such particles can exert a significant influence on the flow in natural water bodies, especially when they reach high concentrations due to settling. To understand their impact, we vary the volume fraction Φ systematically and measure the turbulence modulation that they cause. We focus on the dilute regime of Φ in which particle collisions are unlikely and the presence of suspended of particles does not appreciably alter the rheology or density of the ambient fluid.

We are interested in particle sizes that allow for 2-way interaction with the fluid. This excludes very small particles, which follow the ambient flow without influencing it appreciably, and very large particles, which fall through the fluid without being significantly influenced by it. To do this, we work with particles having length, time, and velocity scales that are on the same order as those of the ambient turbulence.

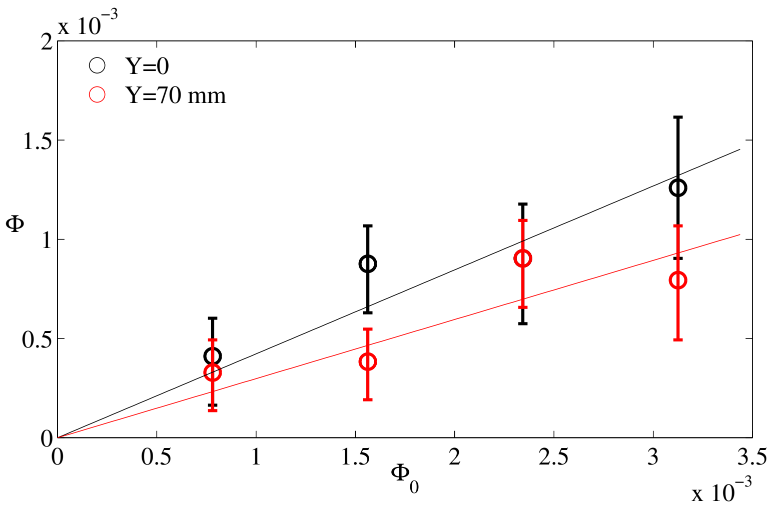

Figure 1. Relationship between local volume fraction Φ and the volume fraction averaged over the entire stirred tank Φ_0. Comparison of the two shows the effect of gravitational settling.

EXPERIMENTS

We use laboratory measurements to study ellipsoidal and spherical particles suspended in homogenous isotropic turbulence (HIT). We study how particles affect the velocity statistics of the turbulent flow, as well as statistics of particle’s linear and angular motions. The particles have size, time, and velocity scales corresponding to the inertial subrange of the turbulence, and are nearly neutrally buoyant. These characteristics make them likely candidates for two-way interactions with the fluid (i.e. they influence the flow and are influenced by it). We vary the volume fraction of suspended particles and observe the effects on one– and two–point velocity statistics in the fluid phase. Measurements at two different heights indicate that particle buoyancy (0.5% denser than the ambient fluid) significantly changes volume fraction (see figure 1).

We see that particles' effect on turbulent kinetic energy is a non–monotonic function of the volume fraction. We also find that particles' presence causes a redistribution of velocity variance from large scales to small scales within the inertial subrange, and that this effect is concentration-dependent (see figure 2). These results will be discussed in detail in the final paper, focusing in particular on the comparison between a suspension of spherical ellipsoidal (aspect ratio particles of aspect ratio 2.

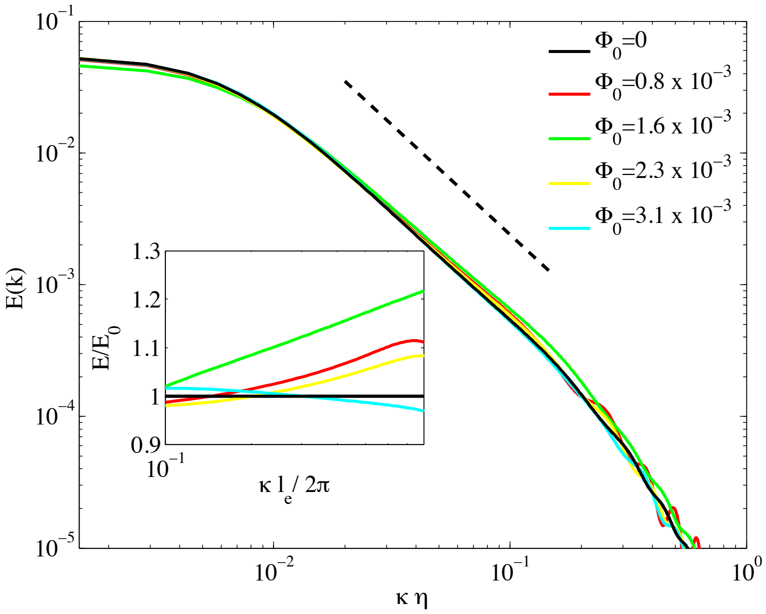

Figure 2. Power spectrum for increasing particle concentration showing spectral tilting (Black: $\Phi_0 = 0$, Red: $\Phi_0 = 0.8 \times 10^{-3}$, Green: $\Phi_0 = 1.6 \times 10^{-3}$, Yellow: $\Phi_0 = 2.3 \times 10^{-3}$, Cyan: $\Phi_0 = 3.1 \times 10^{-3}$). The inset shows the relative change of the spectra (compared to single-phase) on a scale relative to the particle size l_e. The blue line shows the 'reverse pivot'.

References

[1] S Balachandar and John K Eaton. Turbulent Dispersed Multiphase Flow. *Annu. Rev. Fluid Mech.*, **42**:111–133, 2010.

[2] E Guazzelli and Jeffrey F Morris. *A Physical Introduction to Suspension Dynamics*. Cambridge University Press, 2011.

[3] F. Lucci, A. Ferrante, and S. Elghobashi. Modulation of isotropic turbulence by particles of Taylor length-scale size. *J Fluid Mech*, **650**:5–55, 2010.

[4] S. Parsa, E. Calzavarini, F. Toschi, and G. Voth. Rotation Rate of Rods in Turbulent Fluid Flow. *Phys Rev Lett*, **109**:134501, 2012.