DYNAMICS OF FINITE-SIZED LIGHT SPHERES IN TURBULENCE

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Abstract We report experimental results on the Lagrangian dynamics of finite-size light particles in turbulence. Using an orthogonal camera setup and 3D particle tracking, we study the velocity and acceleration statistics of rigid light spheres in a water tunnel with nearly homogeneous and isotropic turbulence. The Reynolds number (Re_λ) is varied from 180 to 300, and the study covers a range of size ratios ($4 < \Xi < 16$) for marginally light spheres. We find that the normalized acceleration PDF decreases in intermittency with increasing size ratio - in qualitative agreement with the predictions of the Faxén corrected model [1]. We also present preliminary results on the rotational dynamics of large light spheres in turbulence.

INTRODUCTION, MOTIVATION AND EXPERIMENTS

Particles dispersions in turbulent flows exist in many natural situations - typical examples include pollutants dispersed in the atmosphere, droplet suspensions in clouds, and air bubbles and plankton in the oceans. Particle suspensions occur in industrial settings as well, for example, sprays in the combustion chambers of engines, and air-bubbles in bubble column reacters. An accurate representation of the behavior of these particles requires a fundamental understanding of the physics of the problem. Major research efforts are directed to this end, particularly on the statistical properties (mainly the velocity and acceleration) of such particle suspensions in turbulent flows.

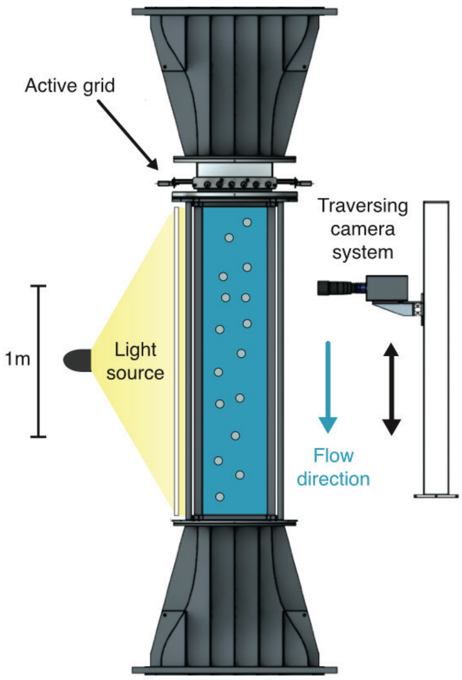

Figure 1. The Twente Water Tunnel facility: A vertical water tunnel with turbulence generated by an active-grid. Light rigid spheres ($4 < \Xi < 16$) are dispersed in the tunnel, with the flow in the downward direction.

The complex problem of particles in turbulence is often simplified to one that involves a dilute suspension of spherical particles in incompressible, statistically homogeneous and isotropic turbulence [2, 3]. These mostly base the particle's description on the Maxey-Riley equation [4], which performs only a temporal filtering of the fluctuating forces. This has led to the introduction of the Faxén corrections [5, 6] for finte size, showing reasonable agreement with experimental results in the limit of vanishing particle Reynolds numbers [1]. The model however is of limited applicability in the case of light particles. In most practical situations involving light particles [7], such as air bubbles or plankton dispersions in the oceans, finite-size particles fall into the regime of finite particle Reynolds number. In this regime, a full and exact description of the particle's equation of motion is unavailable. This is the primary motivating factor for our present study.

In this work, we present an experimental investigation in the regime ($4 < \Xi < 16$, $\rho/\rho_f \approx 0.92$) of the parameter-space, i.e. large, marginally light particles in turbulence. We use rigid light spheres, which are dispersed in a turbulent water flow in the two-phase Twente Water Tunnel facility (see Figure 1). We track the particles in 3D using a two-camera setup. The experiments are compared with numerical simulations based on the particle Lagrangian equations with Faxén corrections [1]. We focus on the effects of finite particle-size on the acceleration statistics. We also present preliminary results on the rotational statistics of large light spheres in turbulence.

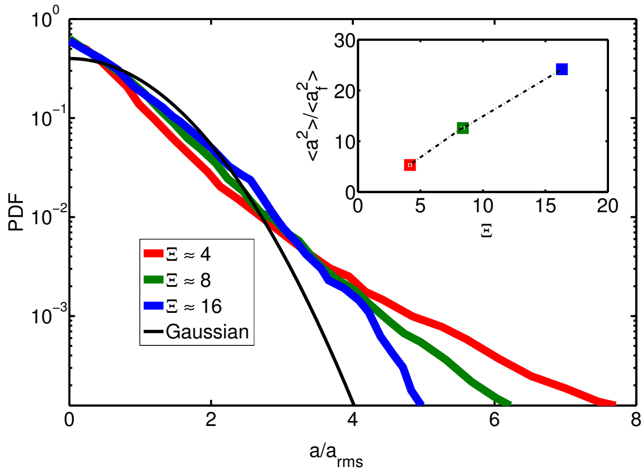

Figure 2. Normalised acceleration PDF for marginally light finite-size particles at $Re_\lambda \approx 180$. Here, $\Xi \equiv D/\eta$, the particle to dissipative-length ratio. Inset: Acceleration variance of particles normalized by that of the fluid versus size-ratio (Ξ). Colors match with the cases presented in the main figure.

RESULTS

The normalized acceleration PDF for marginally light particles (See figure 2) shows a trend of decreasing intermittency with growing size ratio, Ξ. At the smallest size ratio explored ($\Xi \approx 4$), the PDF has wide tails, while at larger size-ratios, the PDF progressively approaches a Gaussian distribution. These results are in qualitative agreement with the predictions of Faxén corrected DNS [1]. The inset shows clearly the trend of increasing acceleration variance with size for light particles.

SUMMARY

Buoyancy causes light particles to have finite rise velocities, resulting in finite particle Reynolds numbers. In this regime, the effects of drag, lift and history forces become dominant, and these effects are manifested in the particle's acceleration variance shown in the inset to figure 2. The increase in acceleration variance with size is in contrast to the -2/3 scaling found for neutrally buoyant particles [8]. These findings are of relevance to a wide range of natural and industrial environments which encounter finite-sized light particles.

References

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