# ACCELERATION STATISTICS OF LIGHT PARTICLES IN TURBULENCE

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*Abstract* We report results from the first systematic Lagrangian experimental investigation in the previously unexplored regime of light (air bubbles in water, and rigid hollow spheres) and large particles ($D/\eta >> 1$) in turbulence [1]. Using a traversing camera setup and particle tracking, we study the Lagrangian acceleration statistics of $\sim 3\ mm$ diameter ($D$) bubbles in a water tunnel with nearly homogeneous and isotropic turbulence generated by an active-grid. The Reynolds number ($Re_\lambda$) is varied from 145 to 230, resulting in size ratios, $D/\eta$ in the range of 7.3–12.5, where $\eta$ is the Kolmogorov length scale. The experimental results are closely matched by numerical simulations of finite-size bubbles with the Faxén corrections. We also report preliminary results on light rigid spheres in turbulence.

## MOTIVATION AND EXPERIMENTS

Suspensions of particulate materials, drops or bubbles carried by vigorously turbulent flows occur frequently both in the realm of natural phenomena (e.g. cloud formation) and in industrial applications (e.g. combustion in engines). In order to quantify the statistical properties of such suspensions a prototype problem is often considered: the one of a dilute suspension of spherical particles in incompressible, statistically homogeneous and isotropic turbulence [2, 3]. In this simple form the problem is defined by a set of three dimensionless parameters $[Re_\lambda, \Gamma, \Xi]$, respectively the Reynolds number based on the Taylor scale of the carrying flow, the particle to fluid mass density ratio ($\Gamma \equiv \rho_p/\rho_f$) and the particle to dissipative-length ratio ($\Xi \equiv D/\eta$). Interesting theoretical questions concern how far the particle statistical properties (e.g. moments, probability density functions (PDFs), correlations) of position, velocity and acceleration depart from the Lagrangian properties of the fluid. The goal is to understand how such observables vary as a function of the control parameters.

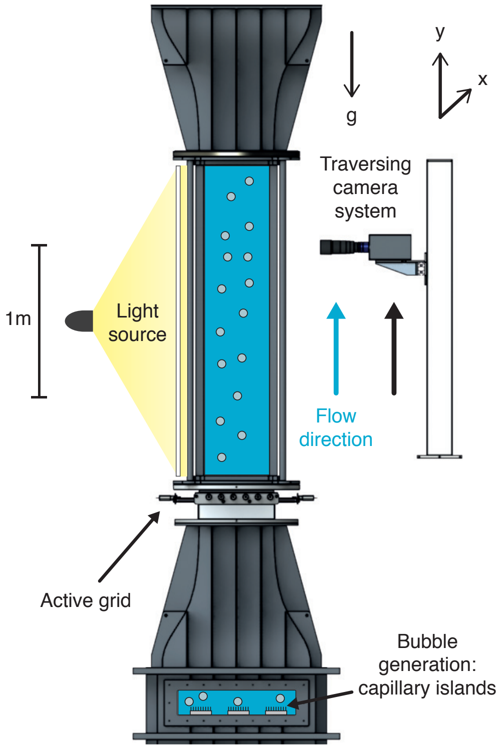

**Figure 1.** The Twente Water Tunnel facility: vertical water tunnel with turbulence generated by an active-grid. Bubbles are dispersed from below through capillary islands and the flow is in the upward direction. The camera moves upward at preset speeds, along with the bubbles, allowing the measurement of long-duration trajectories.

In this work, we present the first systematic experimental investigation in the regime ($\Gamma \ll 1, \Xi > 1$) of the parameter-space, i.e. very light and large particles. For such an investigation we use air bubbles and light rigid spheres, which are dispersed in a turbulent water flow in the two-phase Twente Water Tunnel facility (see Figure 1). We track the particles (bubbles and spheres) using a traversing camera system which can perform 2D recordings of the vertical and one horizontal component of the bubble trajectories. The experiments are compared to numerical simulations based on the particle Lagrangian equations with Faxén corrections [4]. We focus on the effects of finite particle-size on the acceleration statistics. We also experimentally study the effects of gravity, as it could be important at lower $\mathrm{Re}_\lambda$, and very few numerical studies have taken gravity into account.

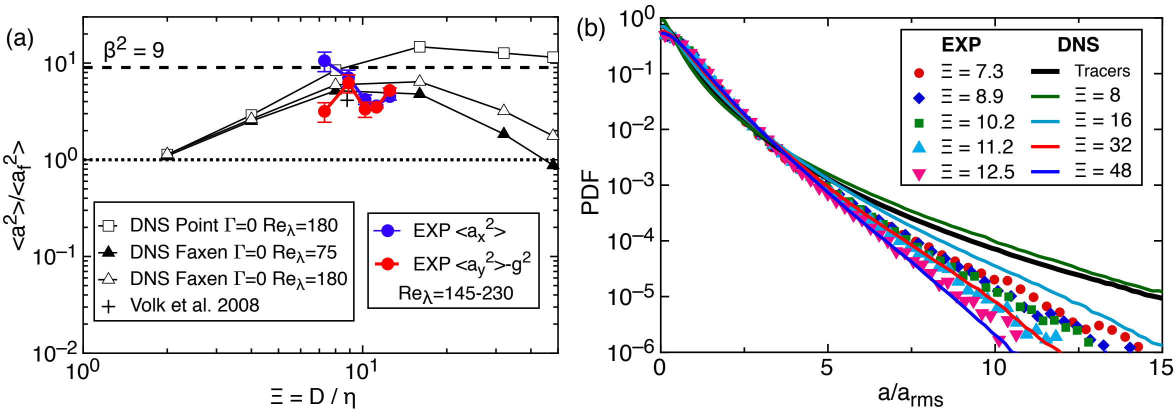

**Figure 2.** (a) The acceleration variance normalized with the variance of fluid tracers, versus the size ratio $\Xi$. $\Gamma$ is the density ratio between the particle and fluid ($\rho_p/\rho_f$), and $\Gamma = 0$ for bubbles, $\Gamma = 1$ for neutrally buoyant particles. (b) The normalized acceleration PDFs of the horizontal component $|a_x|$, from the present bubble experiments (EXP), and numerical simulations (DNS) with the Faxén model at $\mathrm{Re}_\lambda$ = 180.

## RESULTS

The acceleration variances and intermittency indicate that both the effects of finite-size and gravity are important in the case of bubbles. We find that gravity has a surprising correction on the vertical component acceleration. The experiments reveal that gravity does not affect the mean value of the vertical acceleration component but has a $g^2$ offset on its variance. Once this gravity offset is subtracted the variances of both the horizontal and vertical acceleration components are about $5 \pm 2$ times larger than the one measured in the same flow for fluid tracers (see Fig. 2(a)), but still below the estimated upper bound derived from the added-mass effect alone (which is 9 times the tracer value). This is a mark of the finite-sized nature of the bubble. The present experimental acceleration variance measurements are closely matched by numerical simulations of finite-size bubbles [4] (Fig. 2(a)) where no gravity and just the Faxén correction to the added-mass force has been taken into account.

In Fig. 2(b) we plot the PDF of the normalized horizontal (x) acceleration component along with the PDF from the DNS simulations with Faxén corrections, to further study the finite-size effects on the bubbles. The finite-sized bubbles do not respond to the smallest-scale fluctuations, and as a consequence, we find a decrease in the intermittency of the probability distribution function (PDF) of the bubbles, compared to tracers. It is the first time that such a substantial change in intermittency at growing particle size is experimentally observed. The DNS appears to underestimate its functional behavior by a factor ~2-3 in the size ratio $\Xi$. The reason for this discrepancy between numerics and experiments deserves further study. The experiments and numerical simulations indicate a complex interplay between gravity and inertia, and this will be explored further by the experiments on light rigid spheres.

## References

[1] V. N. Prakash, Y. Tagawa, E. Calzavarini, J. M. Mercado, F. Toschi, D. Lohse, and C. Sun, *How gravity and size affect the acceleration statistics of bubbles in turbulence*, New J. Phys, **14**, 105017, (2012).

[2] F. Toschi and E. Bodenschatz, *Lagrangian properties of particles in turbulence*, Annu. Rev. Fluid Mech. **41**, 375 (2009).

[3] D. Lohse, *Particles go with the flow*, Physics, **1**, 18 (2008).

[4] E. Calzavarini, R. Volk, M. Bourgoin, E. Leveque, J.-F. Pinton, and F. Toschi, *Acceleration statistics of finite-sized particles in turbulent flow: the role of Faxèn forces*, J. Fluid Mech. **630**, 179 (2009).