HOW THE DISPERSION OF A DROPLET CLOUD DEPENDS ON ITS INITIAL SIZE

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Abstract A cloud of droplets evolves under the influence of strong turbulence. The droplets are made from a phosphorescent fluid. From this cloud we select at $t = 0$ a narrow line by exciting the droplets with a UV laser, which causes them to glow for a few milliseconds. The dispersion of this line is followed in time using a fast intensified camera. A large range of droplet sizes (Stokes number St) was measured. It appears that lines with $\mathrm{St} \approx 1$ disperse faster than a line of fluid tracers. Lines of droplets which are narrowest initially, spread fastest.

EXPERIMENT

The turbulence chamber, used in this research and based on the design of [3], is sketched in Fig. 1(a). It is a cubic box with sides of 0.4 m, in which isotropic and near-homogeneous turbulence is generated with help of 8 loudspeaker-driven synthetic jets at its corners. These loudspeakers are driven by colored noise. The turbulence properties are measured using particle-image velocimetry. The turbulent velocity is $u = 2.2$ m/s, the Taylor-scale Reynolds number is $\mathrm{Re}_\lambda = 531$, the Kolmogorov length is $\eta = 83\ \mu\mathrm{m}$, and the Kolmogorov time is $\tau_\eta = 425\ \mu\mathrm{s}$, while a small mean velocity of $\approx 0.1\ \mathrm{m/s}$ remained. Droplets are introduced in the volume using a spinning disk generator, making near-monodisperse droplet

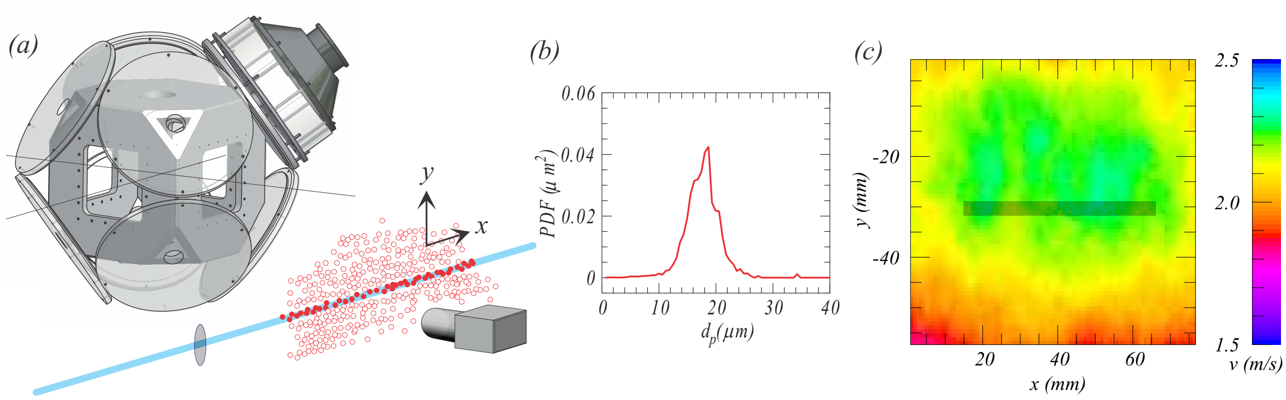

Figure 1. (a) Sketch of the experimental setup which consist of a turbulence chamber with the flow stirred by 8 synthetic jets, driven by 30 cm diameter loudspeakers (for clarity only one is shown). (b) Typical size probability function of the used droplets. The PDF is volume normalized. (c) Distribution of the vertical turbulent velocity v, the line indicates the extent of the initially written line of droplets.

distributions. The droplet sizes are measured using interferometric particle imaging. The sizes are tuned through varying the rotation rate of the spinning disk, and are characterized by the Stokes number $\mathrm{St} = \tau_d/\tau_\eta$, where τ_d is the Stokes particle relaxation time. The droplets are made from a solution containing a phosporescent tracer based on Europium. When excited with a 355 nm UV laser, the droplet will phosphoresce with a half life of $783\ \mu\mathrm{s}$.

The first snapshot of the intensified high-speed camera is taken $5\ \mu s$ after excitation; we define it as $t = 0$. The evolution of this tagged line is followed during 10 snapshots, spaced $100\ \mu s$ apart. The experiment is repeated at the next shot of the exciting UV laser, 100 ms later. The images are phase-averaged over more than 1400 laser cycles. The widening of these phase-averaged lines reflects the *absolute* dispersion of the droplet cloud. This procedure is illustrated in Fig. 2. These images were summed along the $x-$axis, resulting in a time dependent intensity profile $I(y, t)$. The dispersion was quantified by convolving the intial profile $I(y, t = 0)$ with a Gaussian,

$$I_G(y,t) = \frac{1}{\sigma(t)\pi^{1/2}} \int_{-\infty}^{\infty} \mathrm{d}y'\ I(y', t = 0)\ \mathrm{e}^{-\frac{(y-y')^2}{\sigma(t)^2}},$$

where the width $\sigma(t)$ was determined in a least squares fit of $I_G(y, t)$ to the measured time-dependent profile $I(y, t)$.

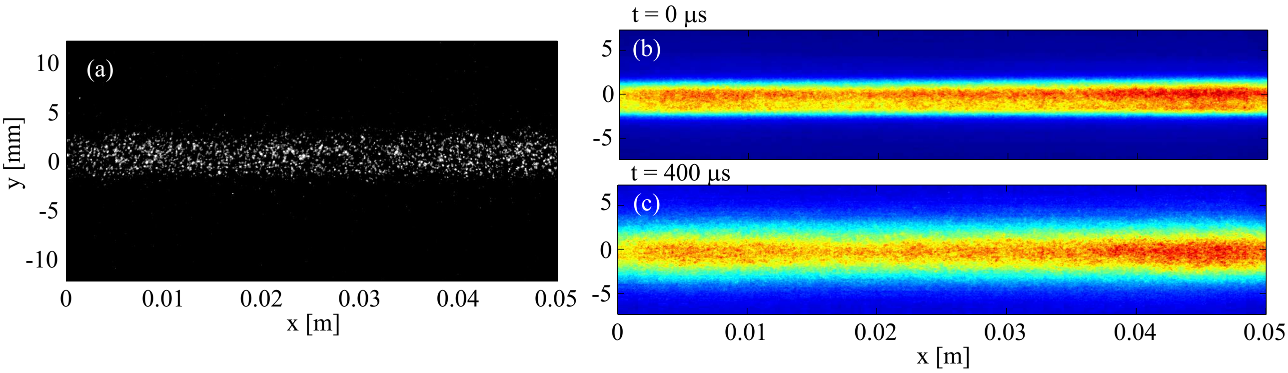

Figure 2. (a) Snapshot image of glowing droplets, $5\ \mu$s after laser excitation. (b,c) Phase-averaged lines of tagged droplets, at $t = 0$ and at $t = 400\ \mu$s.

RESULTS

The width σ_0, of the initial profile was controlled through focusing the laser beam using a lens with a large focal length (1.5 m). For fluid tracers, and times much shorter than the correlation time of the tracer velocity, $\sigma^2(t) = 2\ u^2\ t^2$, with u the turbulent velocity. The behavior of $\sigma^2(t)$ for droplets is shown in Fig. 3(a), demonstrating that $\sigma^2(t) = 2\ v^2\ t^2$. In Fig. 3(b) we show that for Stokes numbers smaller than approximately 15, the spreading velocity v of droplets which are tagged in lines with $\sigma_0 = 10\,\eta$ exceeds that of true fluid tracers u. The increase is significantly smaller when $\sigma_0 = 20\eta$.

The faster *relative* dispersion of inertial particles has been observed before, both in numerical simulations [1] and in experiments [2]. The numerical simulations show that the enhanced dispersion is strongly dependent on the initial separation. It was explained by the influence of *caustics*: singularities of the droplet velocity field. The surprise of the present experiments is that a similar phenomenon can be observed in *absolute* dispersion.

Finally, we show in Fig. 3(c) a measurement of the second order structure function. It was measured using particle-image velocimetry (PIV) using fluid tracers, and using inertial droplets. At all length scales measured, the velocity increments of the inertial particles are larger than those of the fluid tracers.

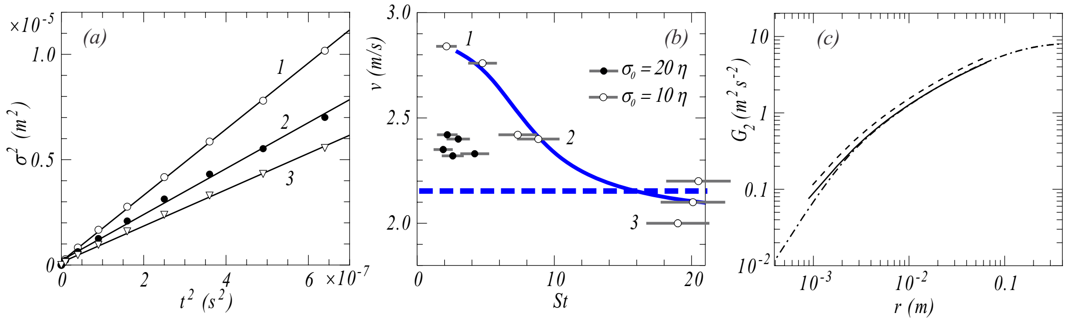

Figure 3. (a, b) Dispersion of a line of droplets for various Stokes numbers. Dots and lines in (a) show σ^2 as a function of t^2, lines are fits $\sigma^2(t) = 2\,v^2\,t^2$ from which v is derived. Open circles in (b) show v as a function of the Stokes number for intial width $\sigma_0 = 10\,\eta$, closed dots are for $\sigma_0 = 20\,\eta$. The numbers correspond to the fits shown in (a). (c) Second-order structure function $G_2(r)$ measured with particle-image velocimetry, full line is measured using fluid tracers (smoke particles), dashed lines are measured using droplets (St = 1.1). The dash-dotted line is $G_2(r)$ computed using the measured dissipation rate ϵ, and taking into account the averaging of the velocity field over PIV interrogation windows.

References

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