EXPERIMENTAL STUDY OF RELATIVE VELOCITY STATISTICS AND COLLISIONS OF INERTIAL PARTICLES IN TURBULENCE.

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Summary Current work suggests that the collision rate of particles in turbulence can be computed from their relative velocity statistics and from the degree to which they cluster (measured by the radial distribution function). Existing experimental data are often difficult to interpret because of the simultaneous presence of particles of many different sizes. Here we present experimental data taken in isotropic turbulence in air at Reynolds numbers up to 210 (based on the Taylor scale), and for particle Stokes numbers between 0.1 and 0.9. The particles were liquid water droplets about 25 microns in diameter. Shadow-based Lagrangian particle tracking provided the droplet sizes, positions, velocities and accelerations along their trajectories. For particle separations within dissipative scales, the moments of the relative velocity were power laws of the separation distance for all Stokes numbers, but the exponents of the power laws differed from those for fluid tracers. The exponents decreased with increasing particle Stokes number. In the same regime, in contrast to an existing theory, we found that the tails of the probability distribution functions (PDF) of the particle relative velocities exhibited stretched exponential forms, just as they do for fluid tracers. Specifically, the stretching exponent was independent of Stokes number, and was the same as the one for fluid tracers, to within the experimental uncertainty.

Turbulence causes heavy inertial particles suspended in a fluid to collide. This is of considerable interest for its implications on the theory of rain formation in atmospheric clouds [1]. Recent theoretical and numerical studies suggest that the collision rate of the particles is related to the velocity differences between pairs of particles and to the extent to which the particles cluster in the flow [2]. Yet, there is little experimental data with which to test such theories.

We report on measurements of relative particle velocities, and examine how the statistical properties of the relative velocities depended on the Stokes number, St, which characterizes the importance of particle inertia compared to the advective forces of the turbulence. We are interested in how relative particle statistics scale with the separation distance between particles in the dissipation range, and in quantifing the droplet collision and coalescence rate in turbulent flows in order to compare to theoretical predictions.

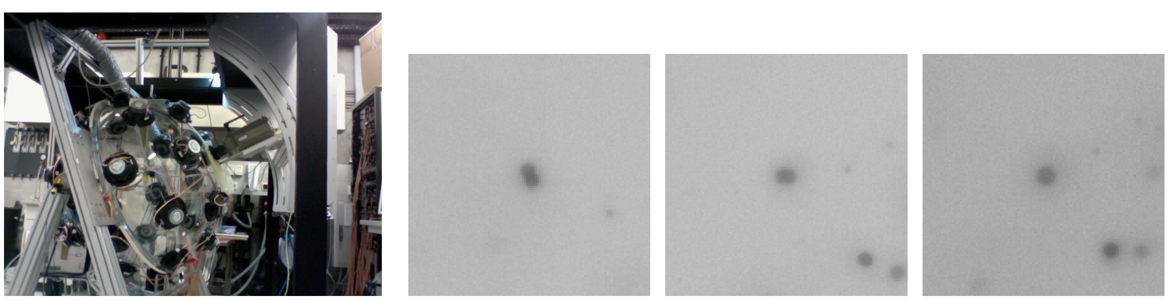

Figure 1. Left: Picture of the experimental setup. The soccer ball is the sphere to the left side of the image. It is about 1 m in diameter and has one it loudspeakers that are 17 cm in diameter. The soccer ball is surrounded by structures that support cameras, a light source, and the spinning disc droplet generator. **Right**: Snapshots of droplets at three successive instances from left to right. Each frame shows a region in space 0.26 mm wide and about 1 mm thick that is moving in the plane of the image at the same speed as the particles in the center of the image. The interval between first two frames is 300 μs, and between the last two frames it is 133 μs. From such a sequence, we obtain particle sizes, positions and velocities. At some time between the last two frames, the two droplets at the center of the first image coalesced, forming a single larger droplet.

Our experimental apparatus is the 'soccer ball' turbulence chamber shown in figure 1. It is an acrylic sphere that is 1 m in diameter. 32 pulsating jets, each formed independently by a 90 W loudspeaker, generate turbulence in the ball. The jets are positioned uniformly around the surface of the sphere and point toward its center. When a randomized pumping scheme is applied to the speakers, they generate homogenous isotropic turbulence in a region about 10 cm in diameter at the center of the sphere. Care was taken to ensure that the pumping caused negligible exchange of air between the chamber and the surroundings. Taylor micro-scale Reynolds numbers, R_λ, of up to 400 and Kolmogorov micro-scales in the range of 150 to 500 microns were possible by adjusting the amplitude of the speaker oscillations. The energy injection scale was about 10 cm.

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Droplets in our experiments were produced with a spinning disc droplet generator [3]. Liquid was fed to a disc spinning at up to 60,000 rotations per minute, and at the disc edge the centripetal acceleration caused monodisperse drops with diameters in range of 10 to 50 microns in diameter to be ejected together with smaller satellite drops that were about 3 times smaller.

To record the droplet positions, we imaged their shadows projected by a white light source into a camera (we use a Phantom V640) fitted with a macro lens. In the focal volume of the camera, the particles appeared as round black dots on a white background, as can be seen, for example, in figure 1, on the right side. The camera captured images at more than 10,000 frames per second, to fully resolve the velocities and acceleration of the particles. We measured the three-dimensional positions of the droplets with stereoscopic Lagrangian particle tracking [4].

The right panel of figure 1 shows a sequence of images of particles in a turbulent flow. We draw attention to two particles that move together and merge. This is an instance of a collision with coalescence between droplets. The coalescence rate can be determined by counting such occurrences. From the same images, we measure particle relative velocities and the radial distribution functions.

Results presented here pertain to the dissipative scales of turbulent flow. In figure 2, on the left side, the second moment of the particle relative velocities exhibits power-law scaling with respect to the particle separation distance. The exponents of these power laws decreases with increasing particle Stokes number (defined with respect to Kolmogorov timescale). This finding confirms that the velocity fields of inertial particles form "caustics," or singularities in space (see e.g. [5]). The results also corroborate recent computational findings [6]. The right panel of figure 2 shows that the tails of the PDF of the particle relative velocity exhibit stretched exponential forms. The stretching exponents is independent of Stokes number to within experimental errors (not shown here).

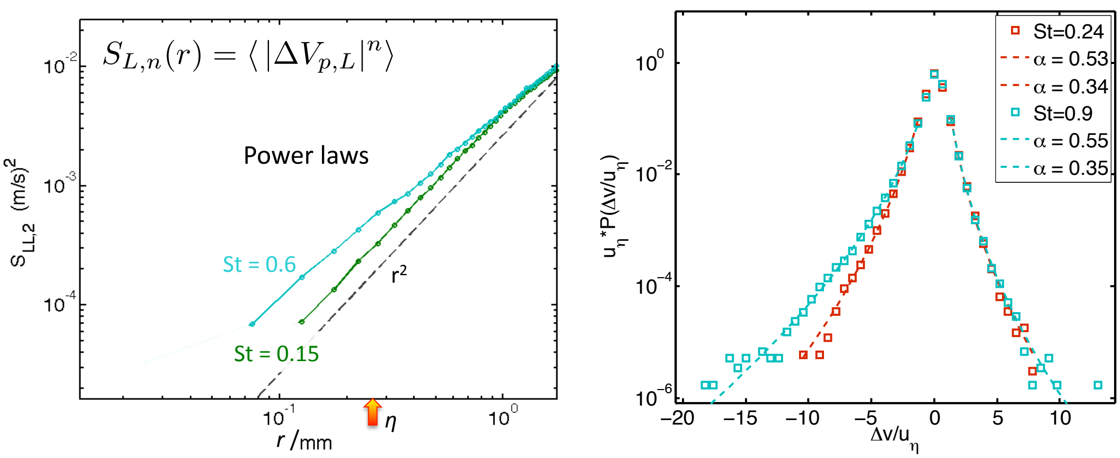

Figure 2. Left: The second moment of the particle relative velocity shows power-law scaling in the dissipative scales. The Kolmogorov scale, η, is marked with an arrow. **Right**: In the dissipative scales (of the order of η), the tails of the PDF of particle relative velocities exhibit stretched exponential forms.

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