RAPID GROWTH OF COALESCING DROPLETS AND OBSERVATION OF FINE STRUCTURES IN TURBULENT FLOW

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Abstract I will present our results on size-growth dynamics of coalescing droplets in simulation of isotropic turbulent flow. In the short time limit, we observe very fast growth due to correlations of these droplets which can be related to the interaction between their inertia to turbulent advection (this work is done with colleagues at affiliations 1 & 2). In a later part, I will describe our attempt to experimentally observe the intermittent fine structures of turbulence flow using high resolution Particle Image Velocimetry (PIV) technique (this work is done with colleagues at affiliation 3).

PART 1: COALESCENCE DYNAMICS OF COAGULATING DROPLETS IN TURBULENT CLOUDS

In liquid clouds such as in the atmosphere or inside combustion engines, air-turbulence enhances the collision rate of the droplets. It thus influences the evolution of droplet sizes and the timescale for rain formation or burning efficiency in the case of engines. The time evolution of a population undergoing coalescence, aggregation, or flocculation is classically addressed in the statistical physics framework of the Smoluchowski coagulation equation. This mean-field approach relies on the assumption that successive mergers are uncorrelated from one another. It is clear that this breaks in situations where monomers are not distributed in a homogeneous manner but form spatial clusters, as for instance in the case of liquid droplets suspended in an unsteady flow.
We simulate a population of dilute discrete droplets initially containing only of similar size monomers. We let the population evolve under the advection of homogenous isotropic turbulent by direct numerical simulation. The droplets coalesce upon each collisions and produce large droplets (with efficiency of 100 %). Typically as a first attempt, such system are modelled in terms of a Smoluchowski coagulation kinetics equation:

$$\dot{N}_i = \frac{1}{2}\sum_{j=1}^{i-1} \mathcal{K}_{j,i-j}\, N_{i-j}\, N_j - \sum_{j=1}^{\infty} \mathcal{K}_{i,j}\, N_i\, N_j, \qquad (1)$$

where the dot stands for time derivative. $\mathcal{K}_{i,j}$ denotes the average rate at which a collision between size-i and size-j occurs. Hypothesis: the rates are stationary, obtained for instance from ghost-collision approach (more specifically from the stationary statistics of particles dynamics, see, e.g. [1]).

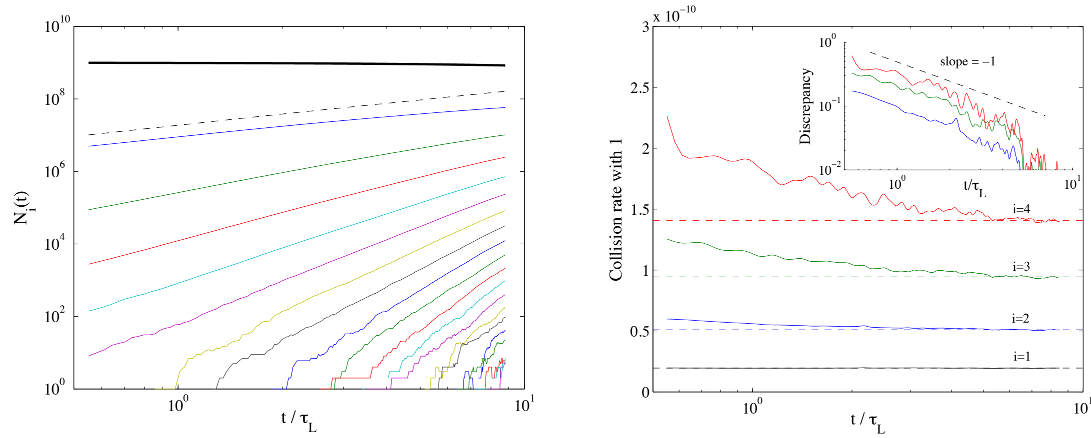

Figure 1. Left) Time evolution of the number of particles. Top curve: number $N_1(t)$ of monomers; Dashed curve: number of monomers that have collided $N_1(0) - N_1(t)$; Then, from top to bottom: $N_2(t)$, $N_3(t)$, $N_4(t)$. Right) Time evolution of the measured collision rate $K_{1,i}$ (in units of τ_L^{-1}) for $i = 1, 2, 3$, and 4. Inset: Normalized discrepancy $(K_{1,i}(t) - K_{1,i}^{\infty})/K_{1,i}^{\infty}$; One observes that larger is i, more significant is the deviation.

We begin by considering the evolution of the system at the early time or in the short time limit. In this limit it is reasonable to assume that the sink terms are negligible and the number N_1 of monomers is almost constant, with this we obtain:

$$\dot{N}_2 \approx \frac{1}{2}\mathcal{K}_{1,1}\, N_1^2$$

and for $i > 2$

$$\dot{N}_i \approx \frac{1}{2}\sum_{j=1}^{i-1}\mathcal{K}_{j,i-j}\, N_{i-j}\, N_j.$$

This should leads to the short-time behavior $N_i \propto t^{i-1}$.
However in our simulation result, we found that $N_i \propto t^{\alpha\, i^{2/3}}$ for large i's. Figs. 1 exemplify our findings. Such growth trend at small times is much faster than what we expect from (1). We shall attempt to expose the detail mechanism of such explosive growth and relate them to the correlation in the dynamics of inertial particles in turbulent flows.

PART 2: EXPERIMENTAL OBSERVATION OF FINE SCALE COHERENT STRUCTURE OF TURBULENCE

Small scale structure of turbulence is strongly spatially intermittent, with isolated and sometimes very localised regions of intense rotation and energy dissipation scattered flow. Understanding intermittency is crucial for with wide ranging practical applications such as turbulent mixing of pollutant. Intermittency is also responsible for the observed departures from the universality of KolmogorovÕs small-scale theories. We will develop a high resolution Particle Image Velocimetry techniques and apply it to a von Karman swirling flow experiment in order to investigate the intermittent nature of small scales dissipative structures in turbulence. I will discuss the challenges, our proposed methodology of realising this study and presents highlights of our preliminary results.

References

[1] G. Falkovich, A. Fouxon, and M.G. Stepanov. Acceleration of rain initiation by cloud turbulence. *Nature*, **419**:151–154, 2002.