Droplet breakup in homogeneous and isotropic turbulence

Federico Toschi[1], Prasad Perlekar[1], Luca Biferale[2], and Mauro Sbragaglia[2]
[1] Department of Physics,
Department of Mathematics and Computer Science,
and J.M. Burgerscentrum, Eindhoven University of Technology,
5600 MB Eindhoven, The Netherlands.
[2] Department of Physics and INFN,
University of Tor Vergata,
Via della Ricerca Scientifica 1, 00133 Rome, Italy.
(International Collaboration for Turbulence Research)

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Abstract

This fluid dynamics video shows the breakup of a droplet in a stationary homogeneous and isotropic turbulent flow. We consider droplets with the same density of the transporting fluid. The droplets and the fluid are numerically modelled by means of a multicomponent Lattice-Boltzmann method. The turbulent fluid is maintained through a large scale stirring force and the radius of stable droplets, for the parameters in our simulation, is larger than the Kolmogorov scale. Events of droplet deformation, break-up and aggregation are clearly visible from the movie. With the present database droplet evolution can be studied from both an Eulerian and Lagrangian point of view. The Kolmogorov-Hinze criteria for droplets break-up can be tested also by means of simulations with different viscosity contrast between the two components.

1 Introduction

Droplet emulsions are key to many natural and industrial processes. In presence of an external flow, droplets undergo deformation, breakup, and coagulation. In a turbulent flow, breakup of droplets larger than the Kolmogorov scale is governed by the interplay between surface tension and turbulent

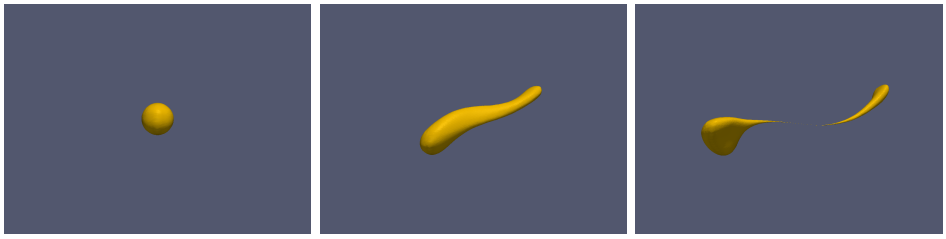

Figure 1: The initially spherical droplet (left panel) get strechted (central panel) by switching on the stirring force and generation of a turbulent flow. The righ panel shows the initial droplet immediately after its first breakup.

pressure fluctuations. Balancing surface tension and pressure fluctuations allows to estimate the minimum unstable droplet diameter that can undergoes breakup [1, 2]. Turbulent pressure-driven and surface-tension stresses across a droplet of typical diameter d and with surface tension σ can be estimated as:

$$\tau_{\rm turb} \propto \rho_c \langle (\delta_d u)^2 \rangle; \qquad \tau_{\rm tens} \propto \sigma/d$$

where with ρ_c we indicate the density of the continous phase and with $\langle (\delta_d u)^2 \rangle$ we indicate a typical velocity fluctuations across the droplet. The ratio between the two gives the Weber number estimated on the droplet diameter:

$$We(d) = \frac{d\rho_c \langle (\delta_d u)^2 \rangle}{\sigma}.$$

The maximum stable *mean* droplet diameter can be estimated by assuming K41 turbulent statistics for velocity increments: $\langle (\delta_d u)^2 \rangle \sim \varepsilon^{2/3} d^{2/3}$ where ε is the energy dissipation. From the condition of Weber number order unity, one obtains:

$$d_c \propto \left(\frac{\sigma}{\rho_c} \right)^{3/5} \varepsilon^{-2/5}. \tag{1}$$

Corrections to finite viscosity of the dispersed phase can also be added [3]. The present simulation allows to study droplets breakup conditions e.g. testing the Kolmogorov-Hinze criteria at changing the Reynolds number and the viscosity ratio between the dispersed and continuos phase. Specifically it is also possible to study the fluctuactions around the mean average stable droplet radius (1) induced by intermittent fluctuations of the velocity field.

In the movie various stages of droplet breakup process are shown. The turbulent flow is homogeneous and isotropic and it is numerically integrated by means of a multi-component Lattice-Boltzmann (MCLB) simulation integrated in order to evolve consistently droplets and the advecting fluid [4].

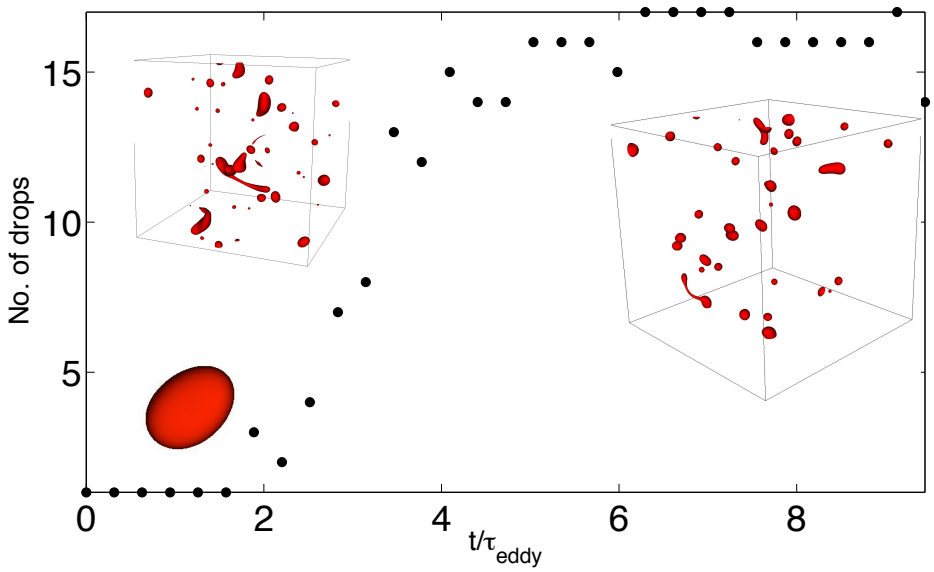

Figure 2: Different phases in the time evolution of a large droplet in a turbulent flow (•). Initially the droplet deforms until it is broken it two droplets. This event is rapidly followed by several other multiple fragmentation events until a stationary droplet dispersion is attained. In the final stages the droplets continuously undergo deformation, break-up, and coagulation. Here the time is non dimensionalized by the large eddy turnover time τ_{eddy}.

The multicomponent flow is simulated using a standard Shan-Chen model [5], the turbulence is generated by applying a large scale forcing, and periodic boundary conditions are used. The parameter used in our simulation are given in table 1.

We start the simulation with the fluid at rest and all the droplet volume fraction residing into a large, single spherical droplet. From the beginning of simulation, the large scale stirring start to be applied and the turbulence level grows continuosly during roughly one large scale eddy turnover time. In the initial phase the large drop gets mildly deformed, then stretched, and finally broken into smaller droplets (see Figure 1). At this point the fragmentations process continues for about another $1 \div 2$ eddy turn over times. After this period the distribution of droplets is almost stationary and is characterized by continuos coagulation, deformation and breakups events due to the continuous presence of underlying turbulent fluctuactions.

N	σ	ν	$u_{\rm rms}$	R_λ	d_0	d_c	d_c^{lbm}
512	1.6×10^{-3}	5×10^{-3}	8.5×10^{-3}	29	50	24.16	25 ± 2

Table 1: Parameters of the numerical simulation from which the movie was produced. N is the number of grid points along each direction, σ is the surface tension, $R_\lambda \equiv u_{\rm rms}\lambda/\nu$ is the Taylor-microscale Reynolds number, $\lambda \equiv \sqrt{E/\Omega}$ is the Taylor-microscale, E is the average fluid kinetic energy and Ω is the average enstrophy. d_0 is the initial droplet diameter, d_c is the critical droplet diameter obtained from the theoretical estimate (see text) and d_c^{LBM} is the critical droplet diameter as measured from our simulation. The Reynolds number was kept low on purpose in order to keep the dissipative scale relatively large: this allow us to have an interface thickness smaller than the viscous scale.

For very long simulation one may experience some droplets evaporation. The different phases in the time evolution of droplets are schematically illustrated in Fig. 2.

Interesting questions concern the rate of collision and the nature of deformation and breakup events. It is also of interest to quantify the evolution of the statistical properties of droplets diameter and the correlations between stresses on the droplet and break-up dynamics. These results will be reported in a forthcoming article [6].

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