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Multi-scale analysis of drops in turbulence

I. Roa, C. Dumouchel, M. C. Renoult, J. C. Brändle de Motta*

Droplet deformation and breakup play a critical role in the atomization process. For many applications, such as spray-painting, coating or fuel injection, it is desirable to achieve appropriate fragmentation sizes. Turbulence is one of the most important mechanisms by which breakup can be achieved. Many authors have related the breakup of droplets due to turbulence to their free oscillations and have shown that droplets break due to a resonant mechanism, but the prediction of droplet lifetime remains with certain unknowns to be found. In particular, when analyzing the complex geometries near pinch-off, the classical shape parameters, such as averaged curvature and aspect ratio, are not sufficient to define a critically deformed state¹². Throughout the droplet deformation, perturbations of different origin favor the growth of liquid structures of different sizes and shapes. Notably, regions exhibiting contraction (bottle necks) and accumulation (swelling) patterns may indicate potential breakup events. The multi-scale nature of these systems must be considered when describing mechanisms to accurately predict breakup events.

The present study uses a previously developed multi-scale description tool³⁴ to investigate the behavior of simulated drops in a turbulent environment from a database of droplets generated as a part of a previous study²⁵. The multi-scale framework considers the liquid system as well as all systems parallel to it in the liquid phase. These parallel systems refer to those that are obtained through successive erosion operations. This consists of removing the liquid system region covered by a sphere of diameter d dragged along the liquid-gas interface keeping the center of the sphere on the interface surface, providing a description of the droplet deformation at all the levels (See Fig. 1 left). The system is described using the cumulative scale distribution $E_3(d)$, which corresponds to the liquid volume lost after the scale d erosion operation, and its successive derivatives. At small scales these quantities are equivalent to the Minkowski Functionals.

The scale distribution and successive derivatives report valuable information on the shape of the system. For instance, they inform on the presence of bottle-necks, flattening or swelling. They also introduce specific characteristics such as the minimum and maximum length scales whose temporal evolution is accessible (see Fig. 1 right). The objective of this work is to investigate the breakup of drops submitted to a turbulent environment with the help of these indicators.

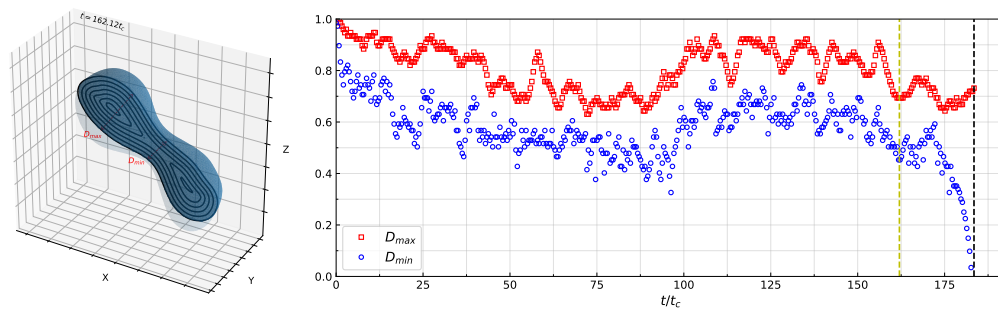


Figure 1: On the left: Visualization of the droplet scales. On the right, time evolution of the reach D_{min} and maximum erosion scale D_{max} of the drop. The yellow line shows the time of the droplet and the black dashed line represents the breakup.

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¹Håkansson et al., *Colloids Surf. A Physicochem. Eng. Asp.* **648** (2022)

²Deberne et al., *Int. J. Multiph. Flow* **173** (2024).

³Dumouchel et al., *Int. J. Multiph. Flow* **92** (2017)

⁴Dumouchel et al., *Int. J. Multiph. Flow* **152** (2022)

⁵Roa et al., *Front. Phys.* **11** (2023).