Deformation and breakup of droplets in turbulence

Doctorant·e

ROA ANTUNEZ Ignacio

Direction de thèse

DUMOUCHEL CHRISTOPHE (Directeur·trice de thèse)
BRANDLE DE MOTTA JORGE CESAR (Co-encadrant·e de thèse)

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Rapporteurs de la thèse

BRENN GUNTER Professeur des Universités Université Technique de Graz (AUT)
RISSO FRÉDERIC Directeur de Recherche Inp (Toulouse)

Membres du jury

BRANDLE DE MOTTA JORGE CESAR, Maître de Conférences, Université de Rouen Normandie
BRENN GUNTER, Professeur des Universités, Université Technique de Graz (AUT)
DUMOUCHEL CHRISTOPHE, Directeur de Recherche, Université de Rouen Normandie
HAKANSSON ANDREAS, Professeur des Universités, Université de Lund (SUEDE)
PERRARD STEPHANE, Chargé de Recherche, Sorbonne Université
RENOULT MARIE-CHARLOTTE, Maître de Conférences, INSA de Rouen Normandie
RIMBERT NICOLAS, Professeur des Universités, Université de Lorraine
RISSO FRÉDERIC, Directeur de Recherche, Inp (Toulouse)

Abstract

The atomization process is influenced by the deformation and breakup of droplets, which in turn affects the final distribution of droplet size. Several authors have related the breakup of droplets due to turbulence to their free oscillations and have shown that even, for low turbulence levels, droplets break due to a resonant mechanism. This phenomenon provides the foundation for the present study. As a baseline of this work, the theoretical linear shape oscillations of droplets are first examined from both theoretical and numerical perspectives. The first-order oscillatory motion of an initially deformed droplet, considering the dynamic effects of the surrounding fluid, is described. Subsequently, the oscillations and breakup of a single, initially unperturbed, spherical liquid droplet subjected to a homogeneous and isotropic turbulent medium are investigated. A theoretical framework for droplet oscillations is developed using a spherical harmonic decomposition that tracks the deformation of the surface from its initial state to just before its breakup as an expansion of each mode of deformation. This approach links the small perturbation amplitude deformation of the droplet to the parameters and properties of the turbulent medium, allowing us to observe how turbulence excites the different modes, ultimately leading to breakup. We relate this phenomenon to linear stability theory and analyse how the droplet lifetime is associated with the turbulence statistics for the ensemble of characteristic values. During droplet deformation, perturbations of different origins favour the growth of liquid structures of various sizes and shapes. Notably, regions exhibiting contraction (bottlenecks) and accumulation (swelling) patterns may indicate potential breakup events. To accurately predict breakup events, it is essential to consider the multiscale nature of these systems. The temporal evolution of the scale distribution is used to identify all the dynamics involved in the deformation process at each scale throughout the droplet's lifetime The problem is approached by direct numerical simulation of the two-phase Navier-Stokes equations using the in-house code ARCHER. By combining these three analyses, the lifetime of the droplet is studied in two parts: First, the oscillatory motion and frequency of the different modes present in the deformation through the spherical harmonic framework to shed light on the resonance mechanism. Second, the temporal evolution of the scale distribution through a multiscale analysis at the end of the droplet lifetime.