High-Fidelity Modeling and Simulation of Multiphase Flows

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Abstract

Liquid sprays and droplets play an important role in numerous applications of practical interest including, liquid-fueled combustion devices such as diesel, gas-turbine and rocket engines, cooling of turbine blades and microchips, and industrial processes such as spray painting and inkjet printing. However, even after decades of research, because of the lack of appropriate diagnostic and simulation tools, the understanding of the atomization process remains limited. Additionally, no attempts were made in the past to conduct fundamental studies that led to the development of universal theories and models to predict statistics, such as, droplet/particles sizes and distributions, resulting from the breakup of liquid jets and droplets. Fortunately, recent progress in high-performance computational (HPC) capabilities, both hardware and software, has greatly enhanced the tools that can now be brought to investigate the dynamics of liquid atomization. This talk focuses on: (1) investigation of fundamental physics underlying the behaviors of impinging liquid jets and liquid jet in crossflow configurations, and (2) dynamics of droplet deformation and fragmentation and the development of generalized models to predict the resulting statistics over a wide range of operating pressures and Weber numbers. The theoretical and mathematical formulation to study these multiphase problems is based on incompressible Navier-Stokes equations with surface tension. A critical issue is the treatment of multi-scale liquid-liquid and gas-liquid interfaces. Therefore, a state-of-the-art, high resolution, volume-of-fluid (VOF) interface capturing method is adopted to resolve the large-scale interfacial evolution. Surface tension is accommodated as a Dirac delta distribution function on the interface. The theoretical formulation outlined above is solved numerically using a finite volume method augmented by an adaptive mesh refinement (AMR) technique to improve the solution accuracy and efficiency. Underlying mechanisms and general theories that explain the dynamics of liquid jet atomization and droplet breakup over a wide range of pressures, and Weber numbers are established. These theories are used to develop universal models that can predict the droplet behaviors, including size-distributions and drag coefficients taking into account the effects of deformation and fragmentation. The ultimate goal of the effort is to enhance the fundamental understanding of multiphase flows, and to develop theories and algorithms for active and passive control using multiphysics processes.

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