

Shock-Driven Multiphase Flows under Extreme Conditions: From Supercritical Fuel Mixing to Hypersonic Aerodynamics

Abstract

Shock-driven multiphase flows play a critical role in high-speed propulsion systems, including fuel injection and combustion in high-pressure, high-temperature environments, multiphase detonation, and the interaction of hypersonic vehicles with atmospheric droplets. These flows involve complex interactions among shock waves, interfacial instabilities, droplet breakup, phase change, and fluid mixing across a wide range of length and time scales, presenting significant challenges for experimental characterization and predictive modeling. This presentation will introduce a multiscale computational framework integrating molecular dynamics (MD) and direct numerical simulations (DNS) to investigate shock-driven droplet dynamics under extreme thermodynamic conditions. The transition from subcritical to supercritical conditions, where changes in interfacial properties, phase behavior, and molecular transport alter droplet breakup, evaporation, and fuel–oxidizer mixing will be shown. The presentation will also examine reacting shock-driven droplet interactions under high-pressure and supercritical conditions, focusing on the coupling among shock dynamics, phase change, chemical reactions, and mixing. These mechanisms will be further explored in multiphase detonation systems, where droplet breakup, evaporation, and combustion interact with propagating detonation waves and influence detonation dynamics. These studies advance our understanding of shock-driven multiphase flows and provide a foundation for improved modeling of next-generation propulsion systems and hypersonic vehicle aerodynamics.

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