Interactions Between Shock Waves and Liquid Droplet Clusters: Interfacial Physics

Mitansh Tripathi[1], Prashant Khare[1*]
[1] Department of Aerospace Engineering, University of Cincinnati, Cincinnati, OH 45221-0070
*Prashant.Khare@uc.edu

Introduction

This study investigates the fundamental mechanisms underlying the interfacial behaviors of liquid droplet clusters exposed to a normal shock wave using high-fidelity direct numerical simulations. Next-generation liquid-fueled high-speed engines such as scramjet and rotating detonation engines (RDE) where the liquid fuel interacts with shock waves and undergoes deformation, atomization [1], and vaporization [2] before mixing with air and subsequently burning motivates this research.

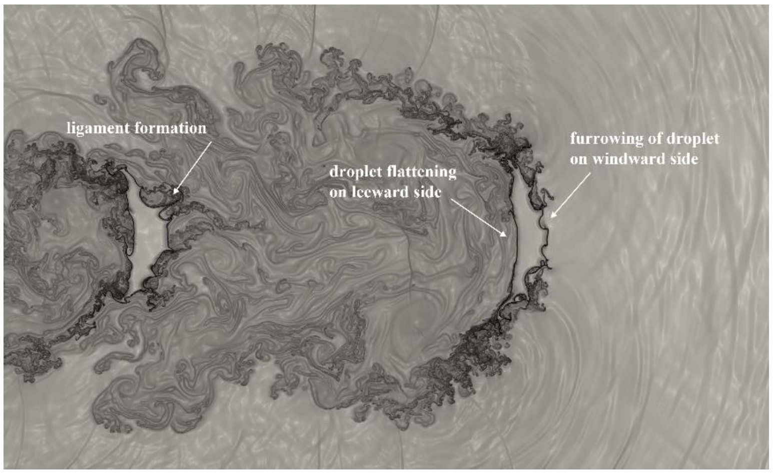

Figure 1. Density gradient highlighting interfacial physics.

Description of the flow visualization method

This multiphase multicomponent turbulent flow problem poses several challenges that include (1) the presence of two phases because of which there is a sudden change in physical and transport properties at the liquid/gas interface and frequent interfacial topology changes due to the presence of surface tension, (2) highly compressible gas phase with discontinuities, and (3) widely disparate length and time scales. Therefore, to investigate the phenomena of interest, a fully compressible Eulerian-Eulerian approach equipped with a volume-of-fluid (VOF) based diffused interface algorithm, with an explicit treatment of viscous and surface tension effects is used. To render calculations manageable and computational efficiency, an adaptive mesh refinement (AMR) methodology is adopted. The configuration consists of two water droplets with diameters of 4.8 mm each, placed 30 mm apart interacting with a shock wave traveling at a Mach number of 1.47. The data generated from this numerical experiment, visualized by contours of the density gradient is used to investigate the interfacial physics, shown in Figure 1.

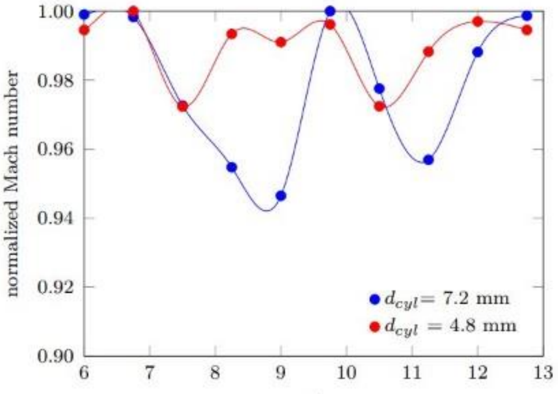

Figure 2. Impact of cylinder size on shock strength.

Physical insight and conclusions

It is found that the interactions between the individual cylinders and the shock wave leads to the flattening of the droplets, followed by the formation of instability waves, which are amplified by the baroclinic torque and the continuous reflections of the waves transmitted inside the liquid interior, causing ligament stripping. The upstream cylinder is also affected by the shock wave reflected from the downstream cylinder, and at times, ligaments at its poles stretched in the direction opposite to the incident shock wave. The effect of the presence of liquid cylinders on the strength of the initial shock wave is also investigated and it is found that the cylinder size determines the temporal evolution of shock strength, as shown in Figure 2.

References

[1] Tripathi, M., Ganti, H. and Khare, P., 2022. Interactions Between Shock Waves and Liquid Droplet Clusters: Interfacial Physics. Journal of Fluids Engineering, 144(10), p.101401.
[2] Redding, J.P. and Khare, P., 2022. A Computational Study on Shock Induced Deformation, Fragmentation and Vaporization of Volatile Liquid Fuel Droplets. International Journal of Heat and Mass Transfer, 184, p.122345.