Drop Impact in Propulsion

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Drop impacting either another drop or a dry/wet surface is ubiquitous in propulsion systems. Take the aircraft engine as an example; the liquid fuel is injected into the combustor in the form of sprays, within which droplets collide with each other, leading to merging, bouncing, or shattering outcomes, which changes the drop number and size distribution. These drop-drop collisions will therefore substantially affect the gasification process of the liquid fuel, homogeneity of the fuel/air mixture and eventually the engine combustion characteristics. The outcome of drop collision assumes an additional complexity for rocket engines fueled by low-volatility hypergolic propellants, for which the fuel-oxidizer reaction occurs in the liquid phase. Consequently the occurrence of merging and rapid liquid-phase mixing of the fuel and oxidizer jets and drops must be correspondingly maximized. For drop impacting either dry or wet surface, it is also evident that the subsequent outcome, whether bouncing or wetting, would fundamentally affect the microstructure, strength, and effectiveness of the thermal barrier coating used to protect the engine hardware (turbine blades, combustor walls) from high temperature combustion gases. These critical thermal coatings are prepared by impinging high speed precursor drops on substrates. Overall, fundamental knowledge of the dynamics of drop impact necessarily bears critical importance in advancements in propulsion.

In this talk, I shall present our recent investigations on the dynamics of drop-drop collision and drop impact on liquid surfaces. For the former, we have found that there exists a nonmonotonic transition of the outcomes between merging and bouncing with increasing impact speed, characterized by the Weber number which is the ratio of the impact inertia to the liquid surface tension. Specifically, at low impact speed, the drops merge with each other forming a single larger drop. However, with increasing speed, the drops bounce off each other instead of merging as the pressure buildup within the thin interfacial gas layer preventing physical contact of the interfaces. Interestingly, if the impact speed is further increased, merging occurs again. The mixing front also assumes different shapes with increasing Weber number which changes the mixing efficiency. For drop impacting a liquid surface, if the impact speed is high, the drop always merges with the liquid film irrespective of the film thickness. However for low impact speed, if the film thickness is increased, the collision outcome transitions nonmonotonically from merging to bouncing to merging and to bouncing again. Regime diagrams for these drop-drop and drop-film impacts are derived and the controlling physics of these transitions are identified. These results can be used to optimize the operating conditions, as well as sub-grid models in the simulations of propulsion systems.