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Liquid Atomization:
Vorticity Dynamics and Real-fluid Thermodynamics

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Abstract
The presentation is an overview of multi-dimensional, unsteady solutions of the Navier-Stokes equations (NS) for liquid jets moving through a gas with the description of liquid deformation through a cascade involving sequential formation of smaller and smaller liquid structures. We analyze round and slot jets for the temporal mode and the spatially developing round jet. Interface tracking and curvature determination occur simultaneously with the NS solutions while the vorticity field is determined by post processing using λ_2 and λ_ρ methodologies. Vorticity dynamics explains the physical behaviors for both ideal fluids and real fluids.

A wide range is considered for the density ratio of the two fluids. In the study of incompressible gas and liquid without phase change [1, 2], three different physical behaviors can occur depending on the values of Reynolds number (*Re*) based on liquid properties and the Weber number (*We*) based on gas properties. Lobes form at the wave crests. Ligament stretching occurs at low *We* and low *Re* in an orderly formation; less order in ligament formation occurs at higher *Re*; and holes and bridges occur for higher *We*, eventually leading to ligaments. Ligaments break into droplets.

For real fluids at higher pressures, coupling of NS with the energy and species-continuity equations is essential; change of phase, molecular mixing in both phases, liquid compressibility, and heat transfer become important [3,4]. The behavior is very different from the ideal-fluid behavior in the lower-pressure case because of reduced surface tension, liquid compressibility, and phase change. The wrong belief of many that two phases are not present and a diffusion process is dominant is clearly contradicted. When gas species and liquid species differ chemically, two distinct phases with an interface discontinuity for density and other properties may exist at pressures higher than the critical value for any of the species. For a situation where heat conducts from gas into liquid, vaporization occurs at lower pressure but condensation may occur at higher pressure. At transition values of pressure, vaporization and condensation may occur simultaneously at different positions on the interface. Here, the enthalpy jump and internal-energy jump across the interface can be of opposite signs.

At high pressure, the lobes at the wave crests stretch into thin sheets because of the reduced surface tension and then fold (overlap) due to the vorticity. Essentially, there is a more gas-like kinematic behavior but still with two distinct phases. The increase in interface area with time is dominated by this stretching and folding; the spray formation is more modest.

Keywords
Liquid atomization, real-fluid behavior, direct numerical simulation

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