



Supercritical Phase Transition Effects on Liquid-Fueled Detonation Structures

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The structure and propagation dynamics of liquid-fueled detonations are critically influenced by the transient thermophysical behavior of dispersed droplets interacting with extreme temperature and pressure gradients. In this study, we apply the Lagrangian droplet approach to elucidate the complex physics governing droplet breakup and phase transition within a detonation wave structure. The model uniquely incorporates preferential supercritical transitions occurring predominantly at the droplet's leading edge, driven by severe thermodynamic conditions induced by shock compression and rapid temperature rise [1].

Our simulation framework tracks individual droplet trajectories, accounting explicitly for spatial variations in local thermodynamic states. Results indicate that droplet deformation, driven by aerodynamic and thermal stresses, significantly enhances localized mass and energy transfer rates. Critically, the preferential supercritical transition at the leading edge dramatically accelerates droplet mass reduction and fuel vapor generation, thereby ensuring fast reaction kinetics and the coupling of the reaction zone with the shock wave within 5mm, as observed in the experimental work of Brown et al. [2].

Parametric studies reveal that droplet size, initial temperature, and surrounding pressure substantially impact the supercritical transition onset and droplet lifetime. Furthermore, the heuristic model predicts distinct morphological droplet transformation patterns, consisting of a flattening of 8-10 times of the original surface area, consistent with experimental visualizations from recent laser diagnostic investigations [3]. This novel approach provides deeper insights into the microscale interactions within detonations, suggesting new avenues for optimizing droplet size distributions and initial conditions to enhance detonability and combustion efficiency in practical liquid-fueled propulsion systems.

References

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