Simulation numérique de la combustion diphasique dans les écoulements supersoniques

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Abstract

Supersonic and hypersonic flight technologies are strategic for the next generation of atmospheric transport (suborbital aircraft) and defense applications, particularly through the use of scramjets or supersonic combustion engines. These engines require a deep understanding of their operation, and numerical tools, such as simulations of compressible and reactive flows, have become sufficiently advanced to tackle these challenges. In this context, the SiTCom-B code was used to simulate two configurations of supersonic two phase flames fueled by kerosene using Large Eddy Simulations (LES). An Eulerian-Lagrangian approach was employed to couple the gas phase with the dispersed liquid phase. This PhD work begins with a review of kinetic mechanisms applied to kerosene, modeled as n-decane. A new skeletal kinetic mechanism was developed to better predict the ignition delay time, a key factor in flame stabilization. Additionally, the Lagrangian solver was enhanced to model the behavior of small droplets in hot and compressible flows by incorporating correlations for droplet drag and an evaporation model. A semi-implicit method was also developed to reduce computation times associated with kinetic mechanisms. The first configuration studied, in 3D, is inspired by Cheng's supersonic burner, with hydrogen replaced by kerosene, injected in either gaseous or liquid form. The sonic injection of kerosene is surrounded by a supersonic co-flow of vitiated air, ensuring flame stabilization. At a global equivalence ratio of 0.5, three kinetic mechanisms were used : two from the literature and one developed in this thesis. The study analyzed the impact of ignition delay time, droplet size, and combustion regimes on flame stabilization. The results show that, regardless of the kerosene phase, the flame structure is predominantly governed by a diffusion regime, although a locally rich premixed regime was also observed. The second configuration focuses on a cavity in a scramjet engine (L/D = 5.625). Simulations show that the cavity enhances kerosene evaporation and mixing through recirculation. Hydrogen injected upstream is crucial for ignition due to its low ignition temperature. Comparisons with experimental data show good agreement within the cavity and upstream, although discrepancies remain downstream, highlighting the need for improved boundary layer modeling.