Unraveling Soret Effects in Trans/Supercritical CH_4/LOx Combustion with Quasi-Direct Numerical Simulation

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The accurate prediction of combustion behavior in liquid rocket engines depends critically on modeling complex transport phenomena under extreme conditions. However, traditional simulation approaches often neglect Soret effects. This study presents quasi-DNS simulations of coaxial CH_4/LO_x combustion under trans/supercritical conditions. In this work, the reactingFoam solver was enhanced to improve numerical stability and convergence while incorporating real fluid effects, differential diffusion, and Soret transport. The research quantifies the impact of these phenomena under engine-relevant high-temperature, high-pressure conditions. Previous studies have established that Soret diffusion significantly impacts hydrogen/air flame propagation but minimally affects hydrocarbon fuels at standard conditions. However, the findings reveal more complex behavior in trans/supercritical regimes. For methane, though direct Soret effects on combustion rate remain modest, they influence overall combustion efficiency by affecting other exergy loss contributions. The simulations demonstrate that accurate prediction of flame characteristics in rocket propulsion systems requires comprehensive transport modeling.

The enhanced computational framework effectively captures complex combustion physics in extreme environments, providing a reliable tool for high-pressure propulsion system optimization. The results emphasize the importance of complete transport phenomena consideration in high-fidelity trans/supercritical combustion simulations.