Numerical modeling of high-pressure liquid propellants injection

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Liquid fuel injection systems are widely used in practical applications, from aerospace to automotive engineering, but their modeling still raises challenging questions. Depending on the operating temperature and pressure conditions, the jet formed during injection may evolve differently. When pressure and temperature are low enough with respect to the critical point conditions, the interfaces can be seen as discontinuities between the liquid and gas phases and the liquid can undergo primary and secondary break-up processes. Balance between inertia forces and surface tension controls the formation of droplets during this atomization process. As pressure or temperature increases toward supercritical conditions, surface tension vanishes and the two-phase sharp interface that is observed at lower pressure smoothens. Yet in supercritical conditions, the jet evolves in the presence of a « thicker » interface between the high-density stream and the surrounding gases. Thermodynamic properties feature strong variations across a diffuse interface. Under such conditions, the fluid injection regime is often referred to as transcritical and the jet mixing is controlled by turbulence and is analogous to that of a variable density jet.

The objective of this research is to develop a numerical methodology to represent such transcritical or two-phase flows in a compressible large-eddy simulation (LES) framework. The main target application is liquid rocket propulsion. The thermodynamical approach to represent transcritical flows relies on the use of real-gas equation of states and associated thermodynamics. Its integration in a LES context will first be presented, with examples of application. The strategy adopted to handle the two-phase regime consists in considering the interface between liquid and gas as a diffuse zone. This approach offers the advantage of being compatible with compressible flows and allows a natural transition between the two-phase regime and the transcritical regime, the latter being by nature a diffuse interface. Two methods have been examined in two-phase region to address phase transition: a liquid / gas equilibrium calculation method and an advanced non-equilibrium thermodynamic method. These methods are presented and discussed. Finally, examples of application of the methods developed in this research are exposed.