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NUMERICAL INVESTIGATION OF SUBCRITICAL COMBUSTION IN CRYOGENIC ROCKET ENGINE

Abstract

Low thrust cryogenic engines are used for gimballing of cryogenic stage in flight. The engine operates at a nominal chamber pressure of 40bar, with oxygen injected in subcritical (Tox=84K, Pox=47bar) condition and hydrogen at supercritical (Tf=400K, Pf=45bar) injection state. A multi-element injector head comprising of 36 shear coaxial injector elements is employed in this engine. Due to subcritical injection conditions of oxygen, mixing and combustion in this engine are dominated by atomization as reported in seminal research by Mayer Smith,2004. Sub-critical combustion modeling is complex due to the introduction of droplet dynamics into Eulerian gas phase combustion phenomenon. To understand combustion characteristics at such sub-critical chamber pressure conditions, a combustion model is developed for this engine. A droplet based (Eulerian-Lagrangian) combustion methodology is developed in CFD framework to understand the impact of droplets in gas phase combustion. A discrete particle based methodology (DPM) with non-premixed steady flamelet model for gas phase combustion is developed to capture flow and flame characteristics. The evaporation physics of LOX droplets injected into the engine chamber was captured using DPM model, which solves for droplet movement in a Lagrangian framework. An appropriate droplet size distribution for LOX stream is provided at multiple injector inlets. A flamelet based combustion methodology is used, which accounts for non-equilibrium effects introduced due to flame stretching. A detailed LOX-H2 Chemkin mechanism (8 species 21 reactions) was used to generate non-adiabatic flamelets for pre-processing of mean quantities in probability density function (PDF) table. A computational domain with 36 injection inlets for hydrogen and oxygen droplet entry was used, with combustion chamber modeled till throat section. Simulation results displayed combustion gas temperature evolved in range of 3500K, at a chamber pressure of 40bar. The global evolution of temperature, pressure and droplet spray showed physical trends. The developed methodology could capture the LOX droplet spray, evaporation and gas phase combustion accurately. Further refinement of model in terms of mesh quality, combustion and turbulence closure is being carried out in detail for generation of a stable sub-critical combustion model for cryogenic engine applications.