IAF SPACE PROPULSION SYMPOSIUM (C4)
Liquid Propulsion (2) (2)

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LARGE EDDY SIMULATION OF SELF-EXCITED COMBUSTION INSTABILITY IN A CONTINUOUSLY VARIABLE RESONANT COMBUSTOR

Abstract

Self-excited combustion instability is an intrinsically unsteady phenomenon, which can only be captured by time resolved high fidelity simulations. Large eddy simulation (LES) can capture the relevant physics including turbulent mixing, unsteady heat release, acoustic wave propagation and flame-acoustics/geometry interactions leading to combustion instability. LES can simulate self-excited modes but would require excessive computational time for the limit cycle to reach converged state. In this study, large eddy simulation (LES) framework is developed to simulate combustion instabilities in a sub-scale rocket experiment. The model rocket combustor of Purdue University called the continuously variable resonance combustor (CVRC) is used in this study. The experimental set up allows the length of the oxidizer injector to be varied continuously to excite and sustain longitudinal mode instabilities. The test set up provides an opportunity for detailed numerical investigation on coupling between the acoustics and combustion in a typical rocket chamber. The instability modes in the CVRC are tuned by varying the length of the oxidizer post by moving the location of choked inlet in the oxidizer tube. A well-defined acoustic boundary conditions with choked inlet and exit are maintained during the test. The main objective of this study is to develop a reactive flow LES modeling framework to capture self-excited and sustained thermo-acoustic instability as observed in CVRC tests. The non-adiabatic flamelet model is used to represent the hydrocarbon combustion process. GCH4/GOx chemistry is modeled using flamelet generated manifold (FGM) model, which accounts for realistic chemical kinetic effects incorporated into turbulent flames via progress variable definition. Laminar opposed-flow diffusion flamelets are calculated using a detailed chemical mechanism and embedded in a turbulent flame using statistical PDF methods. The key aspect is to simulate and accurately capture the unsteady pressure activity seen during specific operating regime of CVRC. In this work, LES is carried out for specific oxidizer post location which corresponds to maximum power spectrum density of combustor acoustic modes.The LES framework could capture pressure fluctuations originating due to coupling of heat release and acoustic waves, with dominant frequencies (1L and harmonics) in close match with the experimental values.The developed LES methodology could reproduce the limit cycle behavior and typical signatures of self-excited combustion instability.