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LARGE EDDY SIMULATIONS FOR COMBUSTION DYNAMICS IN LIQUID ROCKET ENGINES

Abstract

An understanding of combustion dynamics is important for a liquid rocket engine programme. The unsteady combustion dynamics in a rocket engine can lead to damage of hardware and can hamper the design and realization cycle of the rocket engine. An important facet of combustion dynamics is the interaction of pressure oscillations with unsteady heat release in the chamber. It is imperative to study such combustion related aspects to refine the design process and for safe working of a high pressure rocket engine system. Large eddy simulation (LES) is capable of reliably capturing large scale unsteady phenomenon even in turbulent reactive flows. Recently, LES has acquired considerable importance in capturing combustion dynamics in rocket engine due to availability of extra computational resources. The capability of LES to capture complex unsteady flow, heat release and acoustic wave propagation make it a suitable candidate for combustion dynamic simulations. In this study, LES is performed on sub-scale and full scale rocket engine chambers with a view to capture the stability charactertics of combustion at typical operating pressures. Multi-element three dimensional models are developed to analyse unsteady flow and flame features. The accuracy of dynamic simulation of combustion is directly dependent upon mesh resolution and numerical methodology used for the simulation. In this study, the large scale eddies are resolved in LES framework, with sub-grid scales modeled using dynamic Smagorinsky-Lilly model. Sufficient mesh resolution required to capture eddies and unsteady pressure fluctuations are provided. The flamelet based combustion closures are used for gas turbine combustion instability simulations. The capability of chemistry tabulation methods to capture unsteady heat release and acoustic interaction in LES is well established. In this study, non-adiabatic steady flamelet based non-premixed tabulation method is used consistently. The probability density function (PDF) table is generated with detailed chemical kinetic mechanisms to incorporate the effect of multiple species. LES is carried out for sub-scale and full scale combustion chambers to determine peak-to-peak pressure amplitude and power spectrum density in different frequency modes. Appropriate time resolution is provided to clearly retrieve the unsteady acoustic phenomenon without significant numerical dissipation. LES is performed for sufficient number of acoustic cycles to collect unsteady features after the limit cycle. LES accurately captures dominant resonant modes and corresponding high frequency harmonics in both sub-scale and full scale combustors. Initial spectral analysis of pressure statistics indicated similar frequency features in chamber and injector section. The possibility of unsteady heat release and acoustic wave coupling will be further assessed to evaluate the stability margins.The LES based methodology developed in this work, can be adapted to simulate and predict the combustion dynamic features in liquid rocket engines.