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CFD ANALYSIS OF COMBUSTION INSTABILITY IN AXIAL-INJECTED HYBRID ROCKET ENGINES DURING THROTTLING TRANSIENT

Abstract

Combustion instabilities in the low frequency spectrum (ILFI) are now a well-known recurring phenomena in axial-injected hybrid rocket motors. The characteristic time period of oscillation of ILFI is typically of the order of a few tenths of a second. This incidentally can lie in a similar scale to the time scale of throttling resulting in a potential for the two processes to couple, leading to changes in regression rate. As throttling is an important feature in hybrids, especially considering that in the future, the upper stages of a rocket may be hybrid-based; it is in our special interest to analyze the features of this instability during throttling.

The numerical model developed consists of:

1. Gas dynamics model using Quasi-1D Euler equations solver which simulates the flowfield inside the combustion chamber.
2. A combustion model modelled after NASA CEA.
3. An analytical model (Karabeyoglu's) to simulate the heat feedback from flame to the solid fuel.
4. Thermal conduction model to simulate the heat flow into the solid fuel.

The regression rate is calculated by solving the unsteady energy balance equation at the fuel regressing surface.

Initially, the efficacy of the numerical model to accurately predict space-time averaged regression rates is ascertained by comparison of results of our steady state solutions against experimental data in literature. As the next step, the presence of instabilities is investigated through a time-dependent simulation. Since in hybrids, the regression rate is coupled to the mass flux, mass flux perturbations are added at different frequencies, to a fixed mean oxidizer inflow and the subsequent effect on the regression rate at a given axial position inside the combustion chamber is monitored. As the next step, further complexity is added to the system by the addition of explicit time delays experienced by the heat flux to the changes in the oxidizer mass flux and regression rate. This essentially results in the capture of boundary layer delays experienced by the system which otherwise would not be captured by our Eulerian flowfield. As the final step, the model is now tested in the same way as described above – by the addition of small mass flux perturbations around the mean value of oxidizer inflow – however with just one difference – the mean value of the oxidizer is also being changed now as per the throttling ratio and throttle time. Changes to the regression rates are monitored and conclusions reached.