Advancing the State-of-the-Practice for Liquid Rocket Engine Injector Design

Current shortcomings in both the overall injector design process and its underlying combustion stability assessment methodology are rooted in the use of empirically based or low fidelity representations of complex physical phenomena and geometry details that have first order effects on performance, thermal environments and combustion stability. The result is a design and analysis capability that is often inadequate to reliably arrive at a suitable injector design in an efficient manner. Specifically, combustion instability has been particularly difficult to predict and mitigate. Large hydrocarbon-fueled booster engines have been especially problematic in this regard. Where combustion instability has been a problem, costly and time-consuming redesign efforts have often been an unfortunate consequence.

This paper presents an overview of a recently completed effort at NASA Marshall Space Flight Center to advance the state-of-the-practice for liquid rocket engine injector design. Multiple perturbations of a gas-centered swirl coaxial (GCSC) element that burned gaseous oxygen and RP-1 were designed, assessed for combustion stability, and tested. Three designs, one stable, one marginally unstable and one unstable, were used to demonstrate both an enhanced overall injector design process and an improved combustion stability assessment process.

High-fidelity results from state-of-the-art computational fluid dynamics CFD simulations were used to substantially augment and improve the injector design methodology. The CFD results were used to inform and guide the overall injector design process. They were also used to upgrade selected empirical or low-dimensional quantities in the ROCket Combustor Interactive Design (ROCCID) stability assessment tool. Hot fire single element injector testing was used to verify both the overall injector designs and the stability assessments. Testing was conducted at the Air Force Research Laboratory and at Purdue University.

Companion papers provide details of the overall injector design process, full- and sub-scale testing, ROCCID-based stability assessments and the CFD simulations.