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High Pressure LOx/H_2 Rocket Engine Combustion

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Abstract

Increasing liquid rocket engine performance margins for re-usability and escalating payload demands requires a detailed understanding of injection and reaction of transcritical and super-critical propellants. Full scale static firing of modern day liquid rocket engines for research and development purposes is prohibitively expensive. A sub-scale combustor has been developed for fundamental liquid rocket engine research. The combustor is fitted with quartz glass windows for optical accessibility and is capable of multiple re-starts for extended periods with representative propellant temperatures, injector flow rates and combustion pressures.

A parametric study based on propellant injection conditions has been performed with a single shear coaxially injected liquid rocket engine combustor. Steady state operation has been closely examined with the thrust chamber operating at sub critical, near critical, and supercritical pressure levels with respect the thermodynamic critical pressure of oxygen. High speed optical diagnostics have been applied to the near injector field including spontaneous OH chemiluminescence to visualise the combustion zone and shadowgraph imaging to observe the propellant flowfield.

The propellant injection velocity ratio (R_v) and reduced pressure (P_r) have been identified to have a significant effect on thrust chamber operation. Interchanging injector geometries and

regulating propellant flow-rates at constant ocidiser to fuel ratio (R_{OF}) has enabled examination of the local and global influence of R_v and P_r on combustion over a range of conditions. Two hydrogen injection temperature ranges have been successfully investigated at a constant liquid oxygen injection temperature.

Analysis of measurement system data indicates a significant difference exists between thrust chamber operation at pressures below, near and above the thermodynamic critical pressure of oxygen. The combustion efficiency (η) and the peak-to-peak dynamic pressure data analysis ($P_{p\text{-}p}$) consistently highlight dissimilarities between sub- and supercritical pressure regimes. An inherent unsteadiness at reduced pressure levels less than unity is frequently observed through examination of the near injector flow-field and combustion zone images. The liquid oxygen core typically exhibits an increase in local surface perturbations and flow oscillations at reduced pressure levels less than unity ($P_r < 1$) which coincides with observations construed from the measurement data.

A range of combustor start-up transients have also been analysed. The point of ignition has been captured using high speed diagnostics with different injection conditions. The start-up process is characterised and described in detail for each of the conditions examined.

Low frequency (LF) combustion instability has been witnessed at subcritical pressure levels. Investigations indicate that unstable combustion triggered at $P_r < 1$ could not be replicated at a P_r equal to, or greater than unity under near identical injection conditions. In fact, unstable combustion could not be triggered whatsoever with LOx/H_2 propellants at near or supercritical pressure irrespective of operating conditions. Such findings illustrate that operating near or above the critical pressure of propellants (oxygen) results in inherently stable combustion process over a broad range of operating conditions.

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