IAF SPACE PROPULSION SYMPOSIUM (C4)
Liquid Propulsion (1) (1)

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EXPERIMENTAL CHARACTERIZATION AND ANALYSIS OF PASSIVE FLOW SEPARATION CONTROL OF UPPER STAGE ROCKET NOZZLE DURING SEA-LEVEL TESTING

Abstract

An upper stage rocket engine is configured with higher area ratio nozzle designed for sub ambient exit pressures to achieve maximum specific impulse. When such engines are tested at sea level conditions, an undesirable phenomenon called flow separation takes place due to adverse pressure gradient. Flow separation leads to severe problems namely side loads; high heat fluxes through the inner shell at the point of flow separation; transition of separation patterns between FSS RSS; secondary combustion due to air entry into annular zone. The ideal scenario for testing of upper stage rocket engine is under high altitude test condition in order to avoid flow separation. However, operating high altitude test-bed is cumbersome due to complex in nature, leading to the high operating cost and longer lead time. Alternatively, testing in sea-level condition is less complex and time consuming. However, protection of nozzle from the adverse effect due to flow separation is a formidable task during sea-level testing. The simplest and efficient method is to deploy a passive control of flow separation using a secondary injection of inert coolant at the nozzle exit for minimizing the effects due to flow separation. In this paper, experimental characterization and analysis of passive flow separation control are studied in detail. Scale down parabolic contour nozzle with area ratio of 100 has been configured with reference to upper stage cryogenic rocket engine. To simulate the kinematic similarities, a thermal simulation rocket motor is considered in which mach number gamma are matched with upper stage cryogenic engine condition. Passive flow separation control module i.e. water injection module at nozzle exit perpendicular to the nozzle plume is designed. Cold flow calibration of passive flow separation control module is carried out to ascertain the pressure drop. CFD analysis was carried out to predict the flow separation location. Based on the results of CFD analysis, discrete locations for heat flux and wall pressure measurements are finalized along the nozzle wall. Hot firing test is carried out with chamber pressure of 5.3 MPa with and without water injection through passive control module. Large reduction in vibration and heat flux on the nozzle wall were observed due to water injection perpendicular to the nozzle plume. An axisymmetric flow separation was observed during higher area ratio nozzle operation with passive water injection module. Parameters for passive control module for the sea-level testing of upper stage rocket engine are derived.