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Author: Mr. ARUN KUMAR P
Liquid Propulsion System centre, India

Mr. RAJEEV SENAN C
Liquid Propulsion System centre, India
Mr. AJITH B
Liquid Propulsion System centre, India
Mr. PONNUSWAMY M
Liquid Propulsion System centre, India
Dr. NARAYANAN V
Liquid Propulsion System centre, India
Dr. BALACHANDRAN P
Liquid Propulsion System centre, India

INVESTIGATIONS ON THE EFFECT OF VARIATIONS IN CHARACTERISTIC LENGTH(L*) AND CONTRACTION RATIO OF THE COMBUSTION CHAMBER ON THE PERFORMANCE OF A LIQUID HYPERGOLIC BIPROPELLANT THRUSTER

Abstract

Hypergolic bipropellant radiation cooled thrusters utilizing Monomethyl Hydrazine (MMH) and Nitrogen Tetroxide (NTO) are commonly used in spacecraft missions for attitude and orbit control. The performance index of a rocket engine is the specific impulse (Isp) which is a function of combustion efficiency known as C* efficiency (C*eff) and nozzle efficiency. An investigation is carried out using an analytical model validated with experiments to evaluate the effect of combustion chamber design parameters at different injection pressures on C*eff .Design variables considered are characteristic length, L* and the contraction ratio (CR). The injection pressure was varied by 5 bar. This paper presents the details of the study. Analytical model developed by Priem et.al based on propellant vaporization as rate controlling combustion process is used for performance prediction. Model quantifies the combustor length required to vaporize 90 percent of the spray mass injected in the combustor by describing it as a function of design and operating conditions. For the individual propellants, actual chamber length(Lc), length of nozzle convergent section, CR, nozzle shape, chamber pressure(Pc), injection velocity, mass median drop size(MMD) and initial propellant temperature are used to predict effective combustion length(Leff) . Fraction of the propellant vaporized/ effective utilization factor (Fp), defined as the ratio Leff / Lc is then computed and mixture ratio(MR) vaporized and C*eff evaluated. Cold flow evaluation of coaxial swirl injector using simulant water was done to evaluate the MMD and injection velocity, which is normalised to the propellant flow conditions. Hot test for 10s using the stainless steel chamber was done at sea level with instrumentation for chamber pressure, mass flow rate of propellants and throat temperature. Injector which was subjected to the cold flow evaluation was used in all hot tests with a flanged joint combustion chamber. Combustion chamber length was varied using spacers. In total, 63 tests (3 CR's ,7 steps of L* and 3 injection pressure conditions) were carried out. Comparison of C*eff experiment (exp) with C*eff predicted (pred) indicates disparity. This is due to the error in MMD value considered as the injector spray formation is in the onion stage. Model is validated by using a correction factor of 0.89 for MMD of fuel which narrowed down the differences. Inferences and conclusion: Dependence of C*eff on L*, injection pressure CR were studied by varying one parameter at a time. The results are as follows.

For an increase in L*, C*eff (calc) has an optimum range up to a point beyond which it decreases, whereas variations in C*eff (exp) is marginal and within the measurement accuracy. For a decrease in injection pressure, average C*eff (calc) varies marginally up to a point beyond which increase is noted. This is due to the variations in MMD and in the injection velocity of fuel. C*eff (exp) shows that the variations are marginal. For an increase in CR, C*eff (calc) increases up to 17 followed by marginal variation. This is due to the variations in the effective vaporization length, affecting Fp. C*eff (exp) indicates good agreement in trend except for lower L* of 62cm. This could be due to shorter combustor length affecting droplet stay time resulting in C*eff change for lower L*. C*eff depends on the MR vaporized which is influenced by Fp of the chamber for the decisive propellant which is MMH for this study, as full vaporization of oxidizer(NTO) takes place for the range of combustion chamber length considered. Throat temperature trend is also identical to C*eff (exp). For a given injection and operating conditions, there exists a range of L* and CR where C*eff will be optimum and less sensitive.