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MULTI-VARIABLE OPTIMIZATION OF GASEOUS OXYGEN HYBRID ROCKET MOTORS FOR SMALL SATELLITE PROPULSION

Abstract

Stanford University is currently investigating a small satellite mission concept for near-Earth asteroid exploration and mapping. Because these spacecraft are typically launched as secondary payloads and operated in low Earth orbit, they are subject to very tight mass and volume constraints. As a result, they could greatly benefit from compact and lightweight propulsion systems to further expand the applicability of low-cost missions. The objective of this research is to provide a range of Delta-V capabilities of gaseous oxygen hybrid rocket motors, and to determine mass and volume allocations for the propulsion system. The resulting designs can then be used to identify possible asteroid rendezvous missions.

To answer these needs, a multi-objective, multi-variable optimization program was developed using a Matlab genetic algorithm. The code uses a target Delta-V and payload mass to determine the propellant and structural masses of the motor using an iterative scheme. Three main components of the system are sized: a spherical composite overwrapped pressure vessel for oxygen storage, a single port cylindrical combustion chamber, and a conical nozzle with ablative insulation. Contingency is added for feedline components, electronics, and miscellaneous. The program determines the ranges of five main design variables that lead to the most compact and lightweight motor designs: combustion chamber pressure, nozzle area ratio, oxidizer to fuel (O/F) ratio, burn time, and port dimensions. The resulting Pareto optimal solutions can be used for comparative studies and system trade-offs.

This study proves useful for variable sensitivity analysis, and provides a deeper understanding of individual parameter selection. As an example, the O/F ratio is often chosen to maximize theoretical specific impulse (Isp). However, the mixture ratio has a significant impact on propellant and structural mass allocations, and therefore the optimal Isp design does not necessarily lead to the ideal motor. Furthermore, given minimum material thickness constraints, the structural coefficient variation with scaling can be quantified. The non-linear effect of combustion efficiency is also investigated.

This research identifies the difficulties still encountered in hybrid rocket conceptual design, and highlights the need for further investigation in the areas of fuel regression rate, nozzle erosion, high pressure composite overwrapped vessels, and miniature lightweight piping components. Given the interdependencies of the five main design parameters on the overall system, this research demonstrates the advantages of this type of study to optimize mass and volume, and promotes hybrid rocket propulsion as a potential cost efficient and safe option for small satellite missions.