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Author: Dr. Kohei Ozawa
Kyushu Institute of Technology, Japan, ozawa.kohei582@mail.kyutech.jp

Dr. Toru Shimada
Institute of Space and Astronautical Science (ISAS), Japan Aerospace Exploration Agency, Japan, shimada.toru@jaxa.jp

A THEORETICAL STUDY ON THROTTLE RANGES OF O/F CONTROLLABLE HYBRID ROCKET PROPULSION SYSTEMS

Abstract

In order to efficiently acquire enough ΔV to put satellites on orbits using hybrid rocket propulsion, it is necessary to control O/F ratio and minimize residuals of propellants. O/F controllability also strongly affects orbit injection accuracy. From these aspects, O/F uncontrollability of conventional hybrid rocket propulsion due to dependence of regression rates on oxidizer flows and their relatively large uncertainties are problems to be solved. In our research, it was found that possible throttle ranges maintaining a constant O/F ratio of several types of hybrid rocket engines can be easily discussed using simple geometric expressions in two-dimensional spaces of fuel and oxidizer mass flow rates. Possible operational areas in the two-dimensional space are calculated from fuel regression behaviors of hybrid rockets. Possible throttle ranges are determined by lines of constant O/F ratios passing the possible operational areas. In this paper,throttlabilities are compared among several types of O/F controllable hybrid rockets: Altering-intensity Swirling Oxidizer Flow Type (A-SOFT) hybrid rocket engine, Aft-end Oxidizer Addition (AOA), and Aft-end Oxidizer Addition using SOFTs (AOA-S). A-SOFTs refer to the method to change swirl strength of Swirling Oxidizer Flow Type (SOFT) hybrid rocket engines. AOAs refer to the method to adjust O/F ratio of burnt gas of axially injected hybrid rocket engines from the main chamber by adding oxidizer in the aft-end combustion chamber. AOA-Ss refer to AOAs using swirling oxidizer injection for fuel regression. Our results revealed that A-SOFTs can operate at any operational points where AOAs cannot do, and AOAs can operate at those where A-SOFTs cannot. Though the former two methods have limitations on operational points, AOA-Ss can theoretically operate at any operational points. Though AOA-S conceptually can operate any operational points, it may not be recommended due to relatively large volumetric and mass penalties of aft-combustion chambers especially in small scale motors. This is because the volume of aft-combustion chamber normalized by total length of the rocket depends on diffusion timescale of the burnt gases and the added oxidizer. Required regression rates also depend on scales of rockets and chemical species of propellants because optimal O/F ratios are unique to combinations of fuels and oxidizers. In addition to the above discussion about theoretical operational areas, suitable types of O/F controllable systems to various scales and propellants of hybrid rockets are also discussed.