A Study on Highly-Functional Hybrid Rockets Using Axial and Tangential Oxidizer Injections

論 文 の 内 容 の 要 旨

論文題目　A Study on Highly-Functional Hybrid Rockets Using Axial and Tangential Oxidizer Injections
(酸化剤の軸/周方向噴射を用いたハイブリッドロケットの高機能化に関する研究)

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Hybrid rocket propulsion is a promising candidate as a chemical propulsion system for future space transportation because of its inherent safety and low lifecycle costs. In this thesis, a series of efforts revealed the impacts of an intrinsic problem called O/F shifts on flight performances and experimentally demonstrated the concept of a technique to eliminate O/F shifts. In order to evaluate the impact of O/F shifts, vertically launched single stage sounding rocket flight simulations were carried out, and the flight performances were compared between O/F controlled and uncontrolled hybrid rockets. The engine model in the flight simulation includes the several sources of O/F shifts and the phenomena affected by O/F shifts such as gaseous total enthalpy shift, c* efficiency and nozzle throat erosion. The sources of O/F shifts are the nominal nonlinear dependence of fuel regression rates on oxidizer mass flow rates and the uncertainty of fuel regression rates, and the systematic and random error were modeled from the previous experimental results. The individual sources of O/F shifts yielded considerable loss of flight performances, and the results also revealed the interesting facts that the most dominant phenomena on flight performances are the residual mass of propellants and enthalpy shifts caused by O/F shifts. After comparing advantages and disadvantages of the O/F shifts elimination technologies, Altering-intensity Oxidizer Flow Type (A-SOFT) hybrid rocket engine was selected as the object to study. A-SOFT applies the dependence of regression rates on swirl strength of the oxidizer flow in the fuel port to control regression rates, O/F ratio, and thrust. The comparison of the elimination technologies revealed that A-SOFT practically does not have limitation on throttle

range, and has favorable characteristics rather than other representative candidates. The static firing experiments were carried out as the conceptual demonstration of A-SOFTs. This set of experiments showed monotonous and stable dependence of regression rate and O/F ratio on oxidizer mass flux and swirl strength. Thrust was also subject to the system of a continuous function predicted by performance calculation program. These results indicate favorable characteristics of A-SOFTs in practical use.

Apart from the main topic, the mechanism of regression rates enhancement using swirling injection were also analytically investigated. This approach is useful for fuel grain designs, regression rate prediction and heat designs of swirling hybrids including A-SOFTs. The classical and analytical evaluation of heat transfer to the fuel wall in flat plate boundary layer was extended for in axi-symmetric flows. From the heat flux to the wall, static regression rates in swirling hybrid rocket engines were evaluated. Our evaluation predicted that the boundary layer thickness in swirling hybrids reaches port radius in the middle of the fuel port, and starts to transit to the developed turbulent pipe flow. The predicted results agreed with the previous experimental results of the swirling hybrids. The axial distributions of regression rates in A-SOFTs were compared between the prediction and the experiments. The predicted curves agreed well with the experimental results though the transitions to the developed turbulent pipe flow in large swirl strengths were not observed due to the existence of the nozzle.