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Conceptual Design of Single-stage Rocket Using Hybrid Rocket by Means of Genetic Algorithm

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Abstract

In this study, a multi-objective genetic algorithm (MOGA) was applied to the multidisciplinary design optimization (MDO) of a hybrid rocket. A swirling-oxidizer-type hybrid rocket engine (HRE) with a single cylindrical grain port was designed. It was considered that this HRE could temporarily stop combustion via oxidizer throttling; this feature is called multi-combustion. The MOGA was applied to solve the multi-objective problem using real-number coding and the Pareto ranking method. In this study, three design problems were considered. First problem was the maximization of the flight altitude and minimization of the gross weight. Second problem was the minimization of the maximum acceleration and minimization of the gross weight. Third problem was the maximization of the duration time over the target flight altitude and minimization of the gross weight. Each objective function was empirically estimated. In addition, this study compared two types of HREs to investigate the emects of the multi-combustion: one type was able to carry out the multi-combustion, and the other was not. Many non-dominated solutions were obtained using the MOGA, and a trade-off was observed between the two objective functions. To understand the design problem, the MOGA results were visualized using a parallel coordinate plot (PCP).

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Keywords: Hybrid rocket engine; Single-stage launch vehicle; Multi-disciplinary design; Genetic algorithm

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1. Introduction

The hybrid rocket engine (HRE) [1] was successfully put to practical use for SpaceShipOne [2], which completed the first private manned space flight. In Japan, the hybrid rock-et research working group (HRErWG) has been part of the Japan Aerospace Exploration Agency (JAXA),and several studies [3][4][5] have been conducted on the HRE. These stud-ies are characterized by a combination of propellants to lower the environmental impact and to increase the safety level by throttling of the liquid oxidizer. In addition, a HRE can temporarily stop its combustion during engine driving by throttling the oxidizer. This feature, which is called multi-combustion, has the potential to allow efficient engine design by controlling thrust as required.

On the other hand, the HRE has a remarkably different combustion mechanism from a conventional liquid or solid rocket. O/F can be controlled in these conventional rockets before it is ignited, but the mixture of fuel and oxidizer in the HRE is initiated after ignition. Combustion occurs in the boundary layer diffusion flame adjacent to the surface of the solid propellant. Because O=F is decided in this part of combustion process, the solid fuel geometry and the supply control of the oxidizer have to be optimally com-bined to design an efficient HRE rocket.

In an HRE, which supplies the solid fuel to the gas oxi-dized via a single port, O=F is affected by aspects of the solid fuel design, such as the port diameter, fuel length, and mass flow of the oxidizer. As a result, multi-disciplinary optimization (MDO) is desirable in designing HREs, which have to consider the rocket weight, the thrust, and the flight altitude as part of the design. Thus, ref [6] has developed an MDO methodology that includes a technique for an evaluation of the HRE performance. Using the devel-oped methodology, a global design of the launch vehicle (LV) using HRE has been explored the multi-objective genetic algorithm (MOGA) for a small rocket which was same scale as the solid-propellant rocket S-210 used by JAXA.

In this study, three design problems for a single stage launch vehicle (LV) using an HRE are solved using an evaluation method developed in this study. In addition, the effects of multi-combustion are also investigated. The first design problem considers the maximization of the flight altitude the maximization and gross weight minimization. The second design problem considers the minimization of maximum acceleration and the minimization of gross weight. The third design problem considers maximization of the duration time over the target altitude, the minimization of maximum acceleration and minimization of gross weight. For the second and the third problems, the optimization is carried out under the constraint that the LV should reach an altitude of 50.0 km.

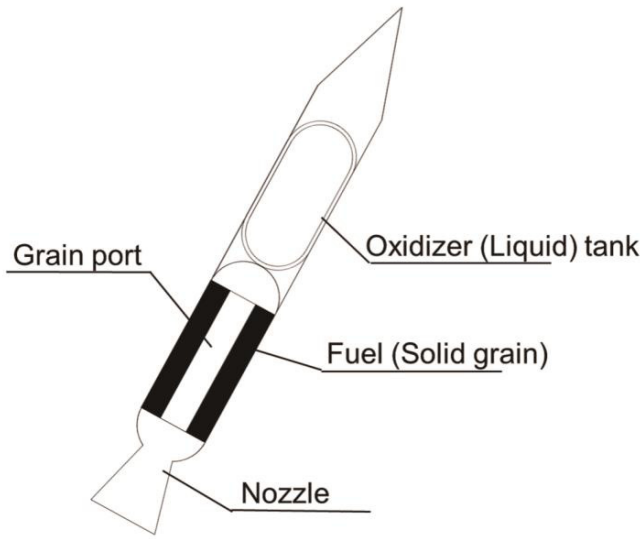

Figure 1. Conceptual illustration of the HRE.