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Multi-objective Particle Swarm Optimization Design an Optimal Liqui-Rocket Engine

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Abstract: A liquid rocket engine has an open gas generator cycle that uses LOX/RP-1 (kerosene). The engine is designed to com-pute the size of the combustion chamber pressure, nozzle expansion ratio, and mixture ratio O/F. Therefore, this study proposes particle swarm optimization to determine the values of these three variables for an optimal engine. In this work, the engine's design was obtained through multi-objective optimization. Multiple targets presented the energy balance condition. The first function was the setting of the specific impulse (I_sp), and the second function was the thrust-to-weight ratio (T/W). The physical properties of the combustion chamber were modeled on the basis of typical parameter val-ues. The simulation results demonstrated that the algorithm gave a specific thrust increase of more than 3.5%, and the T/W increased by up to 20%. Furthermore, Pareto frontier lines were obtained for various thrust.

Keywords*: Liquid Rocket Engine, Multi-objective Optimization Design, Particle Swarm Optimization*

1. Introduction

Liquid rocket engines in gas generation are related to projectile works [1]. A liquid rocket engine is a system com-posed of a combination of various parts, such as a combus-tion chamber, a turbine, and a turbo pump [2]. The design of each of these parts has complex variables interacting with one another. The performance of a liquid rocket engine is impulsive, and it can be expressed as a specific impulse (I_sp) and a thrust-to-weight ratio (T/W). The mixture ratio O/F, mass flow rate, and combustion chamber pressure significantly influence the particular thrust of a liquid rocket engine. Meanwhile, the combustion chamber pressure and nozzle expansion ratio affect the thrust-to-weight balance, thus considerably influencing the machine's weight. In liquid rocket engines, many design variables affect one another; as such, finding optimal design variables is challenging because each part can use various analysis methods [3]. Therefore, a technique for modularizing and analyzing each component, which is expressed as an input/output variable, is used. In the first stage of the liquid rocket engine design, appropriate de-sign parameters that meet the system requirements must be determined [4]. In the past, design variables were set by predicting performance on the basis of experimental data [5]. However, since the 1980s, various system design techniques and optimization techniques have been used. Then, since the 2000s, much research on program development using multidisciplinary optimization has been con-ducted. To identify the optimized design for the initial stages, several aerospace institutes in the United States or China, Korea, and Russia have been developing specific software programs that can provide parameters that produce the best performance, launch the vehicle of the upper sys-tem, conduct a reliability analysis, and predict the cost of production [6]. In general, although the ANSYS or SOLD-WORK programs have a simple entry that can design the variables of the fuel, cycle, propellant, required thrust, and design altitude, finding the optimal performance for each component of the engine is challenging [7].

Hargus et al. estimated the weight of a liquid rocket engine by presenting the weight of the components as a function of the combustion chamber pressure on the basis of the data of the actual liquid rocket engine [8]. In their study, Hargus's weight evaluation method was applied. The weight of the thrust chamber was estimated using the response plane method from the graph expressed as a function of nozzle expansion ratio, thrust, and combustion chamber pressure. Meanwhile, Gradl and Peter [9] demon-strated that the weight of the entire engine can be determined as a function of the nozzle expansion ratio, combustion pressure in the main thrust chamber, and required thrust. Recently, engineers have developed many projects and found the optimal design for gas generator cycles us-ing genetic algorithms using the MATLAB program. The engineering can quickly obtain the desired performance design variables [10]. Evolutionary techniques, genetic algorithms, and particle swarm optimization can find solutions only with function values suitable for system optimization programs composed of module programs [11]. In this study, each module was composed of a simple analysis program using particle swarm optimization. The program was configured for later application in module analysis programs. This study aimed to determine the optimal de-sign parameters with specific thrust and thrust-to-weight ratio as the multi-objective function for the gas generator cycle using particle swarm optimization.

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2. Liquid Rocket Engine

2.1 Combustion