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MULTIDISCIPLINARY DESIGN OPTIMIZATION OF CAROLINE, A REUSABLE LUNAR LANDER/ASCENDER FOR ON-ORBIT REFUELING OF HERSCHEL

Abstract

In recent times, we started witnessing a surging interest in the Moon to demonstrate novel technologies and develop a gateway that enables interplanetary logistics. Numerous space agencies and private companies have begun investing heavily in crucial enabling hardware, critical for lunar settlements. In-Situ Resource Utilization (ISRU) plays a leading role in extending and sustaining our presence on the Moon. Successful implementation of ISRU activities on the Moon, such as extraction of propellants, oxygen and other essential materials for life-support, welcomes plenty of new capabilities. The Herschel space telescope was launched in May 2009 as part of the ESA Horizon 2000 program. It consists of a 3.5 m Cassegrain telescope to study the evolution of the Universe. The telescope's cooling system uses superfluid helium (4He) as a consumable coolant to maintain the on-board scientific instruments at absolute zero (0 K). As a result, the quantity of 4He determines the lifetime of Herschel. Assuming that Herschel's design supports external coolant transfer, resupplying it can restore its operation and extend its lifetime. This paper aims to design and optimize Caroline, a stand-alone lunar lander/ascender spacecraft to recursively transport 4He from the Moon to the Herschel, orbiting at Earth-Sun L2 point. The first part of this paper gives an overview of the mission concepts and trade-off studies; a detailed description of the spacecraft trajectory and Caroline's subsystem models follows; the final section presents Multidisciplinary Design Optimization (MDO) of Caroline spacecraft. The modelling and optimization of Caroline's subsystem are carried out in OpenMDAO. The objective of the optimization is to minimize the spacecraft mass subject to constraints such as launch loads, landing loads, operational temperature, allowable coolant boiloff rate etc. The selection of MDO architectures is problem-specific, which requires analysis of multiple architectures. The three monolithic MDO architectures considered in this paper are Individual Discipline Feasible (IDF), Simultaneous Analysis and Design (SAND) and Multidisciplinary Feasible (MDF). In the preliminary analysis, MDF outperformed the other two architectures in terms of optimality, whereas IDF took lesser time than the others. The optimization resulted in Caroline's optimal configuration capable of delivering 3000 litres of 4He to Herschel for every 3.5 years over 10.5 years.