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Author: Mr. Alberto Fossà
Institut Supérieur de l'Aéronautique et de l'Espace (ISAE), France, Alberto.FOSSA@isae-supaero.fr

Mrs. Giuliana Elena Miceli
ISAE - Institut Supérieur de l'Aéronautique et de l'Espace, France, gem.giuliana.miceli@gmail.com
Mr. Laurent Beauregard
ISAE-Supaero University of Toulouse, France, laurent.beauregard@isae-supaero.fr
Prof. Stéphanie Lizy-Destrez
Institut Supérieur de l'Aéronautique et de l'Espace (ISAE), France,
Stephanie.LIZY-DESTREZ@isae-supaero.fr
Dr. Joseph Morlier
ISAE - Institut Supérieur de l'Aéronautique et de l'Espace, France, joseph.morlier@isae-supaero.fr
Mr. Paolo Guardabasso
ISAE-Supaero University of Toulouse, France, paolo.guardabasso@isae-supaero.fr

OPTIMAL CONTROL OF TRAJECTORY OF A REUSABLE LAUNCHER IN OPENMDAO/DYMOS

Abstract

Following the renewed interest in Moon exploration and in-situ resources exploitation, this study analyses new optimal ascent and descent trajectories from the Moon surface to Low Lunar Orbits (LLO) and Near Rectilinear Halo Orbits (NRHO).

The planar, restricted two-body dynamics is employed to describe the motion of a unitary-mass spacecraft subject to the gravitational pull of the Moon and its own thrust, assumed continuous with a specific impulse $Isp = 450\ s$ and an initial thrust over weight ratio of 2.1. The transfer is formulated as a continuous-time optimal control problem and then transcribed into a Non-Linear Programming Problem (NLP) using the open-source Python libraries OpenMDAO and dymos. The resulting NLP is then solved with gradient-based optimizers such as IPOPT and SNOPT. The objective is to minimize the propellant consumption while boundary constraints are enforced to guarantee the spacecraft departs and injects in the target orbits.

A first solution is computed for constant thrust ascent trajectories from the Moon surface to a 100 km altitude LLO. This solution is then improved allowing the thrust magnitude to vary from zero to its maximum, thus obtaining an optimal trajectory characterized by a bang-bang control scheme and a lower fuel consumption. The same algorithms are then adapted to solve for the corresponding descent paths. Safety concerns due to rocks and geographical features are overcome with path constraints to assure vertical take-offs and landings. The three-dimensional, restricted two-body dynamics is also implemented to compute three-dimensional ascent trajectories at constant thrust, computing both in-plane and out-of plane solutions.

These results underline a step forward with respect to the already existing literature. Studies on departure and landing trajectories from the Moon surface hark back to the Apollo program and have been partially renewed in the last few years. Previous approaches impose a predetermined transfer profile split into ballistic arcs and powered phases with fixed transition events, thus obtaining only sub-optimal and highly specific solutions. In contrast, this work proposes a more flexible approach with the control scheme treated as design variable to fully explore the range of feasible solutions while looking for the true global optima.

Optimal transfer trajectories from a circular LLO to a Moon-centered Highly Elliptical Orbit (HEO) are then simulated as first planar approximations of LLO to NRHO transfers. The three-body dynamics in the Earth-Moon system is finally exploited to simulate continuous-thrust transfers from the lunar surface to a given NRHO.