Paper ID: 51431
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IAF SPACE TRANSPORTATION SOLUTIONS AND INNOVATIONS SYMPOSIUM (D2)
Upper Stages, Space Transfer, Entry and Landing Systems (3)

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EARTH AEROBRAKING ARCHITECTURES FOR A REUSABLE UPPER STAGE

Abstract

Aeroassist maneuvers such as aerocapture and aerobraking offer significant propellant savings when needing to shed velocity to enter a particular orbit. Historically, these concepts have been left to exploratory missions as a way to enable planetary capture or for more on-board science. Today, United Launch Alliance (ULA) is developing a refuelable, long duration LH2/LOx upper-stage. After delivering its primary payload, this spacecraft is intended to serve a second life as a Cis-lunar orbital transfer vehicle. In 2016, ULA's advanced projects group teamed up with CU Boulder to investigate using the Advanced Cryogenic Evolved Stage (ACES) for propellant-saving aeroassist transfers.

This work builds on over two years of research regarding the multi-physics modeling of thin-walled pressure vessels, undergoing aeroassist maneuvers in the Earth's atmosphere. In this paper, we use aerobraking trajectory databases generated from coupled material response, atmospheric flight simulations in order to study and build up full, multi-orbit maneuver architectures. The former trajectory simulations had used high fidelity aerothermodynamic results generated from a series of DSMC simulations along with mixed-mode heat transfer through the spacecraft walls. In the current work, transfer from the EML1 to a 500 km orbit in LEO is analyzed under a broad sweep of scenarios.

As a baseline configuration, the ACES geometry is considered with minor protective materials. Additionally, various performance enhancements are estimated including use of boil-off to cool sections of the spacecraft, as well as additions of both physical and virtual drag multipliers. Using eight such cases, full maneuver architectures were calculated based on a set of constraints and a particular targeting strategy. The two targeting strategies considered were a minimum propellant scheme, referred to as Hohmann Aerobraking (HA) and a minimal duration scheme called Direct Aerobraking (DA). Each scenario (case, constraints, targeting scheme) were run from 0% aerobraking (meaning a fully propulsive transfer) to 100% aerobraking.

Under many scenarios, HA failed to reach the target orbit before using more propellant then the fully propulsive transfer. Most often, DA succeeded at providing propellant savings. However, for the scenarios achieving the largest savings, HA outperformed DA.

The results reveal that propellant usage during targeting compounded with any amount of boil-off greatly restricts the maximum duration of a desirable transfer. Overall this work has however reinforced the benefits of aeroassist maneuvers by showing that even for the conservative scenarios considered, over 50% propellant savings can be achieved.

This research was supported by United Launch Alliance.