IAF SPACE TRANSPORTATION SOLUTIONS AND INNOVATIONS SYMPOSIUM (D2)
Interactive Presentations - IAF SPACE TRANSPORTATION SOLUTIONS AND INNOVATIONS SYMPOSIUM (IP)

Author: Dr. Christie Maddock
University of Strathclyde, United Kingdom, christie.maddock@strath.ac.uk

Mr. Lorenzo Angelo Ricciardi
University of Strathclyde, United Kingdom, lorenzo.ricciardi@strath.ac.uk
Mr. Federico Toso
University of Strathclyde, Glasgow, United Kingdom, federico.toso@strath.ac.uk
Prof. Massimiliano Vasile
University of Strathclyde, United Kingdom, massimiliano.vasile@strath.ac.uk

MULTIDISCIPLINARY DESIGN ANALYSIS OF A SEMI-REUSABLE TWO-STAGE-TO-ORBIT SMALL PAYLOAD LAUNCH SYSTEM

Abstract

This paper contains an analysis of the design trade-offs for a semi-reusable two-stage to orbit, rocket-powered launch system for small payloads. The system is to be air-launched off a modified commercial aircraft with a full reusable, flight capable return vehicle. This allows the system to be operational from any suitable space or airport; a increasingly common aim of new, agile launch concepts for small payloads.

The system was modelled with a multidisciplinary design optimisation (MDO) framework using two different optimal control solvers: MODHOC, a multi-objective optimiser that combined an evolutionary-based global optimisation together with a collocation-based optimal control solver; and TROPICO, a single-objective optimiser using a direct multi-shooting approach.

The vehicle design trade-offs were analysed for a feasibility design stage, specifically gross take-off and dry masses, aerodynamic design including wing loading limits and wing sizing for the return vehicle, and propulsion system design optimising engine thrust capabilities and on-board fuel mass, for each stage. The MDO simultaneously optimised variables for the design of the launch vehicle and operation of a full mission, comprising the 3DOF trajectory controlling the angle of attack, bank angle and thrust level, for release and ascent, stage separation, second stage ascent, injection to orbit for the payload, and re-entry and approach for the first stage.

The trade-off looks at sets of Pareto-optimal solutions for minimising the system gross mass (at release from the carrier aircraft), fuel consumption, thrust-to-weight ratio of each stage, averaged/peak accelerations, dynamic pressure and heat loads, and re-entry performance of maximum achievable down range vs cross-range.

This approach to the analysis was chosen to understand the relative influence and impact of the various design and performance variables on each other and on the overall system. For example, by using multiple optimisation objectives, it was found that a significant reduction in the peak acceleration can be achieved by accepting a reasonable penalty in terms of propellant mass and choosing slightly different engine and wing parameters than the optimal solution from the single objective, minimum gross takeoff mass case. The goal is not to find a single ‘perfect’ solution but to understand and better quantify the trade-offs.

Various test cases have and will be run to analyse the same launch system configuration for equatorial and polar based drop sites and orbits in-line with the aims of many commercial launch companies.