SPACE TRANSPORTATION SOLUTIONS AND INNOVATIONS SYMPOSIUM (D2)
Small Launchers: Concepts and Operations (7)

Author: Mr. Federico Toso
University of Strathclyde, Glasgow, United Kingdom, federico.toso@strath.ac.uk

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

DEPLOYED PAYLOAD ANALYSIS FOR A SINGLE STAGE TO ORBIT SPACEPLANE

Abstract

The capacity of a launch vehicle, how much mass can be delivered into which orbit, is one of the key metrics defining the commercial viability of a launch vehicle. Generally, assessments for vertical rocket launches are done using heuristics, trading-off deployed mass with orbital altitude, optionally at different orbital inclinations. These heuristics do not hold true however for the different, more complex flightpath options of spaceplanes.

This paper will analyse the operational capabilities of a horizontal take-off and landing spaceplane. The novelty of this work lies in the way the data is obtained. Instead of using empirical relationships, each mission is optimised individually.

This study uses an in-house multi-phase optimal control software developed specifically for spaceplanes that employs both evolutionary and gradient-based optimisation with multiple-shooting transcription method. The approach is needed to evaluate the performance of a complex system such a spaceplane, characterised by different mission phases, with multiple engine operating modes and flight regimes. The objective is the maximisation of the payload mass, equivalent to minimising the fuel mass assuming a fixed GTOW. Path constraints will minimise the dynamic loads of the vehicle, with boundary constraints on the orbital insertion requirements (position and velocity vectors).

The analysis is performed on a generic SSTO vehicle, using a variable point-mass 3DOF dynamic model with open loop control on the engine throttle, angle of attack and bank angles. The aerodynamic characteristics during flight are obtained from surrogate models over the different regimes, while the propulsive system is a rocket based combined cycle. Take-off and landing operations are from a single UK-based spaceport to deliver up to 1000 kg payloads into LEO.

The performance metrics are the specific kinetic energy, a function of the orbital velocity per unit mass, and the specific potential energy, which accounts for the orbital altitude per unit mass. The two values will be compared against the maximum achievable payload mass. The maximised payload mass at the orbital insertion point will vary according to the propellant mass required for the flight path.

The study will highlight the importance of a specific, tailored analysis and can provide a comparison against the accuracy of existing heuristic-based approaches. The tool presented will be a valuable asset to vehicle operators to predict the performance at given launch sites, and to spaceport operators and investors to determine the commercial market for their site.