SPACE TRANSPORTATION SOLUTIONS AND INNOVATIONS (D2)
Future Space Transportation Systems Verification and In-Flight Experimentation (6)

Author: Mr. Rodrigo Haya Ramos
Deimos Space S.L., Spain, rodrigo.haya@deimos-space.com

Mr. Juan-Carlos Bastante
Deimos Space S.L., Spain, juan-carlos.bastante@deimos-space.com
Mr. Jorge Serna Ferrer
Deimos Space S.L., Spain, jorge.serna@deimos-space.com

END TO END OPTIMISATION OF IXV TRAJECTORY VIA MULTIPLE-SUBARC SEQUENTIAL GRADIENT RESTORATION ALGORITHM

Abstract

The problem treated in this paper is the end to end trajectory optimisation for the IXV vehicle, covering ascent with VEGA launcher (starting at launch pad), injection in suborbital arc, propagation in exo-atmospheric conditions and further re-entry for landing in a specified longitude.

Simplified “direct” optimal control methods solve this problem by converting the mathematical Multiple Point Boundary Value Problem (MPBVP) into a Non-Linear Programming Problem (NLP) or constrained parameter optimisation. However, real optimum performances are only obtained by using “indirect” optimal control methods which really solve the MPBVP without simplifications (i.e., solving the differential equations of motion).

The selected indirect optimal control method is the Sequential Gradient Restoration Algorithm (SGRA), originally conceived by Professor Miele from Rice University, Texas, in the late sixties and beginning seventies, and successfully developed and applied since then to several different scenarios by his team. The Gradient-Restoration algorithm may be directly applied to our problem in the most complex formulation: potential.

Three types of optimal control sub-problems are concatenated to form the complete end to end trajectory: atmospheric thrust of VEGA first stages; exo-atmospheric thrust of VEGA upper stage; and IXV atmospheric re-entry. Each one of these problems has its own set of state and control variables, subject of the optimisation; on the other hand, a global set of parameters (also subject of optimisation) is used to connect the sub-arcs between them through the boundary conditions.

After presenting the general formulation of the problem, results focus on two different types of problems:

In the first one, IXV vehicle mass is considered fixed, the objective is then to compute the trajectory providing providing the minimum heat fluxes to explore the bottom limit of the entry corridor

In the second case, IXV vehicle mass is free, the objective is to find the maximum mass that, still respecting all boundary conditions, also respect the re-entry constraints, in particular that of maximum heat flux peak value and passive to active oxidation constraint.

In all cases, boundary conditions include not only launch pad and IXV landing coordinates, but also 3rd VEGA stage splash down conditions, free molecular heat rate condition at fairing release and detailed modelling of kick manoeuvre after VEGA vertical ascent in the first seconds of ascent profile. The generation of the mission profile is a single optimisation process provides a consolidated input for design, avoiding split of the optimisation objectives in separate loops.