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Author: Dr. Antonio Mazzaracchio
Sapienza Università di Roma, Italy, a_mazzaracchio@hotmail.com

Prof. Mario Marchetti
Associazione Italiana di Aeronautica e Astronautica (AIDAA), Italy, mario.marchetti@uniroma1.it

COUPLED AEROASSISTED ORBITAL PLANE CHANGE MANOEUVRE AND THERMAL PROTECTION SYSTEM OPTIMIZATION

Abstract

The use of the aerodynamic forces acting on a spacecraft in order to perform orbital manoeuvres is a prospective technique aiming to reduce both the propulsion requirements and the travel time of the mission, or rather to increase the allowable payload mass. The aero-gravity assist (AGA) manoeuvres are an extension of those purely gravity-assist (GA), but use a closer approach to the celestial body to exploit the presence of the atmosphere. A GA manoeuvre essentially depends on the size and mass of the planet, and how closely it can be approached. Instead, an AGA manoeuvre depends also on the atmospheric properties and the spacecraft's aerodynamic characteristics. The basic scheme to execute an AGA manoeuvre is to utilize the propulsive phases only in space, combined with a pure aerodynamic segment of flight in the atmosphere. The search to increase the benefit at the level of propellant saving of an aeroassisted manoeuvre requires a deeper and/or longer use of the atmospheric phase of flight. Generally, this fact implies the adoption of a more massive vehicle's thermal protection system (TPS) with its associated greater mass fraction. A natural question that arises is whether the augmented mass of the TPS can cancel the benefits in terms of saving propellant mass. The aim of this paper is to identify the optimal combination between the TPS configuration, namely the localisation of the ablative and reusable zones and their thicknesses, and the trajectory that maximises the allowable payload mass for a spacecraft. The vehicle has a given size, shape, and initial total mass, and it must carry out an assigned variation of the inclination of its orbital plane. In other words, the purpose is to identify the optimal trajectory, subject to heat fluxes and heat load constraints, beyond other types of limitations, which minimizes the sum of the masses of the TPS and the propellant necessary in order to accomplish the manoeuvre. In general, the problem is treated in literature by decoupling the optimization of the trajectory from the sizing of the TPS. The usual procedure is to solve first the trajectory optimization and then to recognise the configuration and the size of the heat shield, which will ensure compliance with the imposed thermal constraints. Moreover, commonly simple "behavioural" models are employed for the ablative analysis. Conversely, in this paper the analysis is conducted considering the coupling of both the trajectory's dynamics and the thermal analysis, and using a highly representative model of TPS. A procedure referring to global optimisation methods, and original related software, were developed and implemented to optimise the manoeuvre together with the evaluation of the optimal TPS configuration. The mass estimation model also takes into account mass variation in the ablative part of the heat shield, due to the loss for ablation and to the material's density change as a result of the pyrolysis phenomena. The analysed mission considers a transfer from two low Earth orbits with an assigned orbital plane change manoeuvre, considering heat constraints as parameters, for a Delta Wing Vehicle equipped with a heat shield consisting of both ablative and reusable materials.