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Author: Mrs. Alice De Oliveira
Politecnico di Milano, Italy

Prof. Michèle Lavagna
Politecnico di Milano, Italy

ASSESSMENT OF REUSABLE LAUNCH VEHICLES RE-ENTRY DYNAMICS CONTROL EFFECTIVENESS WITH ENHANCED AERODYNAMICS MODELLING

Abstract

The controlled atmospheric re-entry associated with the precision soft-landing of Reusable Launch Vehicles (RLV) on Earth is very challenging as it depends on multiple parameters [1]. Over the last decade, the cost-effectiveness of such a technology has been finally demonstrated with the successful landing and reuse of SpaceX's Falcon 9 first-stage rocket [2]. This breakthrough has been made possible by the development of advanced computational methods able to compute in real-time the flight conditions and to command the optimal vehicle's deflections accordingly to achieve a safe pinpoint landing on Earth.

During an atmospheric re-entry, the vehicle is subjected to fast system dynamics changes partly induced by external loads associated with the terrestrial environment, such as aerodynamics, wind, and gust [3]. In that purpose, the Guidance, Navigation & Control (GNC) system must be advanced and robust enough to counteract them. This paper studies the development of a Six-Degree-of-Freedom (6-DoF) RLV re-entry controlled dynamics simulator with a particular focus on the modelling of the aerodynamics and the uncertainties involved. It covers the atmospheric re-entry and vertical landing of a first-stage rocket equipped with a thrust vector control system and planar fins. Then, different guidance and control methods are embedded into the simulator to assess their performance, particularly towards aerodynamics consideration.

An aerodynamics model for reusable rockets with the quantification of the uncertainties involved has been developed and is presented in this study. This model, incorporated into the simulator, allows to obtain the aerodynamic and the pressure coefficients as function of the flight parameters (Mach number, aerodynamic angles), needed to calculate the corresponding forces and moments acting on the vehicle. Then, existing guidance and control methods are integrated in a closed-loop fashion into the simulator, and tested to assess their performance, as well as their robustness towards uncertainties through Monte-Carlo analyses. The results show that advanced guidance methods which consider the aerodynamic drag, as successive convex optimisation, show better performances, especially in terms of propellant savings. Furthermore, outputs of the Monte-Carlo analyses show the relevance of a robust control system able to withstand aerodynamics uncertainties. Finally, this study paves the way towards the design of a 6-DoF RLV re-entry dynamics simulator as a tool to develop and assess of advanced guidance and control techniques.

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