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AUTONOMOUS UPPER STAGE GUIDANCE WITH ROBUST SPLASH-DOWN CONSTRAINT

Abstract

This paper presents an efficient and reliable approach for the optimal guidance of a launch vehicle upper stage. In general, the launch vehicle performance is subject to several sources of dispersion and uncertainty, related mainly to the propulsion system and the aerodynamic coefficients. Thus, the design of robust guidance algorithms that ensure the rocket in-flight capability to accurately target the desired orbit even in presence of significant uncertainties is key to the success of a mission. Besides safety-related considerations, guidance must also be aimed at maximizing the vehicle efficiency, e.g., in terms of propellant consumption. Model predictive control (MPC) is one of the few control synthesis methods that can concurrently meet these conflicting demands since both robustness and optimality are achieved by recursively solving an optimal control problem (OCP) updated with real-time measurements.

In this paper, the third stage of a VEGA-like launch vehicle is considered as case study due to the unique challenges it poses. For instance, the stage burns out at an extremely high velocity, falling very distant from the launch site; thus, the splash-down point must be actively constrained to an uninhabited area. To obtain a valuable estimate of the splash-down location, a complete simulation of the return trajectory must be included in the OCP, greatly increasing its complexity. Also, the uncertainties on the solid rocket motor performance result in a footprint of possible impact points that needs to be bounded while minimizing its effect on the launch vehicle performance. Thus, we also constrain the sensitivity of the splash-down to perturbations on the burnout position and velocity. This guarantees that the actual splash-down location is sufficiently close to the predicted one, despite model uncertainties.

The complete (nonconvex) OCP is transcribed as a convex optimization problem through state-of-the-art convexification methods, thus allowing for routinely solving it via polynomial-time algorithms. The resulting optimization procedure is highly efficient and converges to the optimal solution of the original problem even under significant deviations from the nominal trajectory. By embedding the convex optimization into the MPC framework, high update frequencies can be achieved and the closed-loop guidance effectively compensates for disturbances. Numerical results assess the robustness and performance of the proposed algorithm via extensive Monte Carlo campaigns. Particular focus is posed on the analysis of the splash-down footprint, to investigate how it can be minimized in the optimization process.