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ADAPTIVE AUGMENTED CONTROL FOR A LAUNCH VEHICLE WITH FUEL-SLOSH

Abstract

This paper investigates the use of an adaptive control system to improve the stability characteristics of launch vehicles (LV) during the atmospheric phase of flight by mitigating the destabilizing effects arising from fuel-sloshing that, together with model uncertainties and wind disturbances, may undermine the performance of a classical attitude controller.

LVs are complex dynamical systems, subject to a number of factors, such as aerodynamic disturbances, variations of inertial properties due to rapid propellant consumption, and high aerodynamic loads, that may significantly impact their stability and control. Attitude control authority is generally limited to small variations of the thrust direction realized by the TVC, as the use of aerodynamic control surfaces is not effective in case of large and heavy LVs.

Furthermore, the sloshing dynamics is to be dealt with when liquid rocket engines are featured by the LV, because the actions generated by the liquid motion within the tanks can induce significant structural damage or even interfere with rigid body dynamics, leading to the onset of undesirable instabilities. The approaches usually adopted to mitigate sloshing dynamics include tank compartmentalization or suppression devices, and may effectively improve damping but, conversely, cause a reduction of the LV payload due to the increased tank weight.

The development and application of an Adaptive Augmenting Control (AAC) to a LV model with liquid rocket engines is the subject of this study, where a model consisting of a mass-spring-damping system is devised to represent the propellant motion. The AAC algorithm, developed at NASA Marshall Space Flight Center for the Space Launch System (SLS) has demonstrated its effectiveness in enhancing the robustness of the LV classical controller without adversely impacting performance when the vehicle is operating within its design envelope. In particular, the AAC can augment a traditional control system (such as, but not necessarily, a PID) with a multiplicative gain, tuned *on-line* during the flight to minimize deviations from a reference model, adjusting control action and enhancing robustness in off-nominal conditions.

Results will be presented and discussed based on classical linear methods, such as Nichols diagrams, to assess the robust performance and stability of the flight control system (FCS) for a prototypical LV, whose model takes into account rigid-body, tail-wags-dog, and fuel-sloshing dynamics. The results of time-domain flight simulations will be also used to evaluate the overall performance of the proposed FCS, with particular emphasis placed on the attenuation of instabilities related to sloshing dynamics.