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THE VERTICAL LANDING VEHICLES LIBRARY (VLVLIB): A MODELICA-BASED APPROACH TO HIGH-FIDELITY SIMULATION AND VERIFICATION OF GNC SYSTEMS FOR REUSABLE ROCKETS

Abstract

Vertical Take-off Vertical Landing (VTVL) vehicles, such as reusable rockets, are nowadays required to meet increasingly stringent performance levels and reliability requirements. Consequently, GNC algorithms are demanded to be appropriately verified in closed-loop high-fidelity simulators. Considering the growing presence of advanced modeling tools, new frameworks able to capture more complex nonlinear dynamics must be researched and implemented. Similarly important is the need for a responsive modeling methodology, which can quickly adapt to vehicle design changes during the development process in order to speed up the projects timeline, thus reducing the associated costs. So far, comprehensive simulation tools able to accurately capture these dynamics together have not been sufficiently investigated. We try therefore to answer the following question: how is it possible to embed very high-fidelity physical models in a simulation setup meant to verify and consolidate the whole GNC system within Vertical Landing (VL) reusable launch vehicle scenarios?

This paper aims at introducing a flexible framework where cyber-physical models are obtained by means of the DLR's Vertical Landing Vehicles Library (VLVLib). This is written using the object-oriented Modelica modeling language, whose advantages are explored throughout the paper. Given that control synthesis, analyses and simulation campaigns are usually performed in the Matlab/Simulink environment, a core point of the proposed solution is to let the Modelica plant model be easily embedded within any well consolidated Simulink-based framework. As such, the strategies to achieve good integration are illustrated.

As of current status, the VLVLib comprises the main following features and advantages: (1) it is architecture-based, meaning that different models with different fidelity levels can be easily exchanged for each critical vehicle subcomponent; (2) includes propellant slosh dynamics with no limitation on tank assembly structure, number of sloshing modes, acceleration profiles or damping factors; (3) includes the Thrust Vector Control (TVC) dynamics together with different types of nonlinearities affecting the actuator maneuvering the gimballed engine, such as backlash or thermally-caused biases; (4) includes landing legs deployment dynamics, with customizable, impulsive release mechanism and/or interaction with aerodynamics; (5) includes ground contact simulation, which allows to consider those adverse dynamics affecting vehicle stability after touchdown; (6) it is built so to not replicate otherwise verified functions, like frame conversions, environment or sensor modeling, and so on. All these points are detailly analyzed; finally, the potential of the framework is shown as applied to CALLISTO reusable rocket demonstrative mission.