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A FRAMEWORK FOR DERIVING AND VALIDATING THE MULTIBODY EQUATIONS OF MOTION OF MICRO-LAUNCHERS

Abstract

In recent years, a pressure build-up has been observed in the space launch market to reduce the cost to orbit and promote access to space, kindled partly by the increasing demand from the small satellite market. Fierce competition at global level is observed between rideshare (medium to heavy) launch systems which have been successful in reducing launch costs per payload mass, and also providing greater launch flexibility to the micro-launch industry. In this context, reducing design and development costs is essential for emerging launch system companies. This requirement impacts directly to all the subsystems, including the Guidance, Navigation and Control (GNC). In particular, modularity and scalability have become key drivers for the development of launch vehicle simulation tools, which form the basis for the entire design and validation cycle of the GNC solution.

Modelling the dynamic behaviour of a launch vehicle poses numerous challenges, particularly in the early design stages. While the rigid body response can be completely characterised by the aerodynamic, mass-inertia properties, and actuator constraints, a controller synthesised solely based on the rigid model is unlikely to lead to a rocket that is capable of performing the given mission. This is because the “multibody effects” of the vehicle are not only difficult to estimate during the preliminary design, but also heavily intercoupled. Amongst such effects flexibility, sloshing, and tail-wags-dog disturbances are the most significant. Even though there is a general agreement in the literature regarding the modelling approach for the first two effects, the tail-wags-dog effect is often introduced in a simplified form without a rigorous derivation or justification for its simplifications.

In this paper, we propose a multibody dynamics framework for cross-validating the complete analytical launch vehicle dynamics for both nonlinear and linearized scenarios not only through conventional Newton-Euler method, but also Lagrange, Hamiltonian, and Kane’s method, where applicable. This results in a unified and reproducible description of the vehicle that can provide valuable insights into the complete vehicle behaviour, even under the influence of severe parametric uncertainty. The advantages of each modelling approach are compared, and the resulting robustness to design changes is assessed. The extent to which each method facilitates control synthesis and subsequent GNC design is discussed. The implementation aspects and real-time behaviour are ranked. Finally, all the models are compared against the results produced by a numerical simulation environment such as Simscape. The future work will explore the impacts on GNC design stemming from the higher-fidelity of the resulting model.