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Author: Mr. Kevin Eppenga
Netherlands Aerospace Centre (NLR), The Netherlands, k.l.eppenga@gmail.com

Mr. Niels Bernving
Netherlands Aerospace Centre (NLR), The Netherlands, nielsbernving@hotmail.com

NON-RIGID BODY EFFECTS ON THE CONTROLLABILITY OF SMALL-SAT LAUNCH VEHICLES

Abstract

Over the years, many high-fidelity simulation models for launch vehicles have been developed. These tools allow the launch vehicle control system to take into consideration the effects of propellant slosh as well as a flexible structure. It remains unclear, however, when such models are required since rigid body equations of motion have proven themselves successful in modelling body motion since the early days of rocketry.

This paper presents the equations of motions for coupled rigid-body, slosh and flexible dynamics, built in a MatLab/Simulink environment. This simulator was previously built for simulating small launch vehicles in the (Small Innovative Launcher for Europe) SMILE project and has now been expanded to incorporate non-rigid motions. The non-rigid body effects are simulated using modal analysis and equivalent mechanical models to estimate the flexibility and sloshing motion.

The equations of motion are validated using flight data from the Stratos III rocket, a sounding rocket built by a group of students from Delft Aerospace Rocket Engineering (DARE) to reclaim the European altitude record for amateur rocketry. This vehicle experienced an anomaly during flight and was destroyed. A Root Cause Analysis showed that this anomaly occurred due to inertial roll coupling. This phenomenon was potentially caused by a centre of gravity misalignment, body flexibility or a combination thereof. These non-rigid body effects can be simulated using the proposed model, meaning that the flight data of Stratos III can be used for model validation. According to this validation, for lightweight launch vehicles with small length over diameter ratios, non-rigid body modelling is required for accurate system modelling. Moreover, this paper determines that the proposed roll-control system for the Stratos IV rocket is likely to counteract inertial roll coupling.

This paper concludes with a sensitivity analysis of launch vehicle controllability for several design parameters, showing when non-rigid body dynamics should be implemented. Based on key parameters such as the body material stiffness, diameter and length, recommendations on the necessity of non-rigid body modelling are provided.