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CONTROL SYSTEM DESIGN FOR THE ALINA LUNAR LANDER

Abstract

Moon exploration and lunar permanent settlement are currently core goals for most space actors. The consequent need of efficient and reliable means to precisely land payloads on the lunar surface has generated an increasing interest in related missions and technologies. In this context, Planetary Transportation Systems (PTS) developed 'ALINA' Moon lander, a spacecraft able to semi-autonomously perform a complete Earth-to-Moon mission and deliver up to 100 kg of payload on its surface. This paper presents the control system developed by the German Aerospace Center (DLR) for this mission as part of the complete GNC software. This design confirmed as viable at project's PDR for the orbital, translunar injection, powered descent and landing phases; furthermore, it proved to flexibly adapt to different other lunar mission studies.

We introduce the vehicle, the mission phases and objectives, the control requirements and the adopted solutions. Of major importance is the spacecraft's propulsion configuration, which comprises several tanks for propellant storage to be used by several non-throttable thruster clusters. Therefore, specific challenges arise, such as control allocation and propellant sloshing. The synthesis of the controllers employs optimal control techniques to design the control laws for the different operation modes, i.e. detumbling, single axis pointing, three-axis control, ΔV maneuvers, and powered descent and landing. Attention has been given to translational and rotational dynamics couplings due to the special placement of the thrusting units.

The control allocation problem is tackled by minimizing a set of cost functions taking into account the desired forces and torques, as well as the fuel consumption; the online solution is found by transcribing the problem into a linear programming form and solving it using the SIMPLEX method. Secondly, propellant sloshing can disturb thrust pointing and potentially generate critical deviations from the nominal trajectory or instabilities. Therefore, as initially more than 75% of the craft mass consists of fuel, our plant model includes an accurate representation of propellant slosh dynamics using mechanical analogies. This goal has been achieved using the multi-physics object-oriented modeling language Modelica, better suited for large multibody representations; the resulting implementation is consequently embedded within the designed framework.

For the verification process, the control system has been included in a high-fidelity simulator. Extensive representative Monte-Carlo campaigns were conducted, with a dedicated focus on the powered descent and landing. The analysis of the control performance throughout each mission phase shows satisfactory overall performance.