Paper ID: 38148
oral
student

20th IAA SYMPOSIUM ON HUMAN EXPLORATION OF THE SOLAR SYSTEM (A5)
Interactive Presentations (IP)

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MISSIONS, ARCHITECTURES AND TECHNOLOGIES FOR A LUNAR SPACE TUG IN SUPPORT OF CISLUNAR INFRASTRUCTURES

Abstract

Curiosity and discovery are vital elements for the future of human space exploration. Starting from past and present experiences in human and robotic exploration, the global community is working on preparing humans to push themselves beyond known boundaries, i.e. the Low Earth Orbit (LEO) environment, to reach, explore and, eventually, colonize the Mars surface. This goal requires capability evolution and technology investments. The pathway to Mars includes multiple destinations. The Moon and its vicinity seem to represent the most promising intermediate step to fill the technology gap. The Lunar Space Tug (LST) represents one of the possible key elements to sustain the growth and the operability of the future Space Station orbiting in Cislunar space, thanks to its reusability and the adoption of electric propulsion. It can transfer unmanned modules from LEO up to the Cislunar Space Station (CSS) and back, to provide the required replenishment. Among all LST mission phases, autonomous rendezvous (RDV) and mating maneuvers represent one of the most critical one from the point of view of the technology involved in the LST design. The strong environmental impact must be considered to define the optimal RDV approach, especially when the maneuver must be performed in different environments as in this case, i.e. LEO and Cislunar. For the RDV maneuver, it is crucial to estimate environmental disturbances that can jeopardize the system as well as the maneuver success. To be compliant with the strict safety requirements that characterize this maneuver, a robust control can guarantee the constraints satisfaction, even when persistent disturbances are acting on the system. In this paper a Linear-Quadratic Model Predictive Control (LQMPC) has been adopted to control the LST during the last phase of the RDV maneuver, showing the robustness behavior of this approach in the presence of reduced persistent disturbances and the compliance of the controller with the real-time application. Once the LST design is defined through a multi-purpose systems engineering tool, the 6 degrees-of-freedom (DoF) LST simulator is used to analyze in deep the RDV maneuver. The optimal maneuver design is obtained according to the Attitude and Orbit Control subsystem (AOCS) architecture and the Thrust Management Function (TMF) adopted for the determination of the proper control actuators selection and command duration, to realize the control action required. Main results on the LST design and related performance during proximity operations in both LEO and Cislunar environments are discussed and main conclusions are drawn.