Dynamics and Control of Modular and Extended Space Structures in Cislunar Environment

Andrea Colagrossi[1*] and Michèle Lavagna[1]
[1]*Politecnico di Milano, Aerospace Science & Technology Dept., Milan, Italy*
andrea.colagrossi@polimi.it

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Future space exploration missions will be less and less confined to Low-Earth orbits. In fact, the attention of the international space community is evolving towards cislunar and interplanetary space [1]. The modern vision about this broad exploration program is based on the sustainability of the entire network of systems and operations to accomplish the established ambitious goals, which would not be achievable without a solid support of preliminary missions, intermediate steps and new technologies development. Planned human and robotic exploration of the Solar System will rely on a complex infrastructure of automated transfer vehicles, space stations and logistics operations that will be progressively ideated and developed. The feasibility of the whole project is strongly dependent from the improvements in new trajectory design and GNC techniques that have to leverage Three-Body problem dynamics, coupled orbit-attitude equations of motion, appropriate structural models and efficient control techniques.

These enhanced methods are especially needed when dealing with a large and flexible space structure, such as a space station in the vicinity of the Moon: key point for the successful realization of the aforementioned exploration program. The analysis of this system is in a preliminary phase, and the architecture still have to be defined, but it is already clear that the cislunar station will be assembled in-orbit by means of many automated operations. They will be carried out in a non-Keplerian environment, being one of the Earth-Moon libration points the ideal location for a space system of this kind [2].

The dynamics of the extended space structure is founded on the well-known Circular Restricted Three-Body Problem and expressed through a coupled orbit-attitude model that includes the effects due to the structure flexibility and the most relevant perturbing phenomena, such as the second order deviations in the main gravitational attraction due to the finite extension of the spacecraft, the Solar Radiation Pressure and the fourth-body (Sun) gravity [3]. A multi-body approach has been preferred to represent the modular and extended cislunar infrastructure: interconnected simple structural elements - such as beams, rods or lumped masses linked by springs and dampers - build up the space segment. In this way, it is easy to represent varying inertia properties of the space structure, in order to simulate docking operations, when independent modules are attached and detached from the main structure. A sensitivity analyses is performed on the possible families of non-Keplerian orbit with respect to the various structural configurations. The full space of solutions is studied to highlight possible stable conditions that may be exploited to host the cislunar station with minimum control effort. Preliminary results exploiting efficient control methods are presented. Simple and dual spin stabilization are compared and the results are carefully analyzed to highlight a control strategy that is less resource consuming.

The outcomes of the research presented in this paper are intended to highlight drivers for the lunar outpost design and station-keeping cost minimization. Furthermore, a case study for a large and flexible space structure in selected non-Keplerian orbits around the Earth-Moon collinear Lagrangian points is discussed to point out some relevant conclusions for the potential implementation of such a mission.

References

[1] International Space Exploration Group (ISECG), The Global Exploration Roadmap, 2013.
[2] R. Whitley and R. Martinez, Options for Staging Orbits in Cislunar Space, *NASA Technical Report*, 2015.
[3] A. Colagrossi and M. Lavagna, Preliminary Results on the Dynamics of Large and Flexible Space Structures in Halo Orbits, *67th International Astronautical Congress*, 2016.