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ASTRODYNAMICS ASPECTS OF DESIGNING SMALL SPACECRAFT MISSIONS BEYOND EARTH ORBIT: LAUNCH, TRANSFER, ORBITAL DEPLOYMENT

Sergey Trofimov[(1)], **Maksim Shirobokov**[(2)], **and Mikhail Ovchinnikov**[(3)]
[(1)]*Centre for Mechanical and Aerospace Science and Technologies (C-MAST), University of Beira Interior, Calçada Fonte do Lameiro 6, Covilhã, 6200-358, Portugal, serge.trofimov@ubi.pt*
[(2)] *Keldysh Institute of Applied Mathematics, Miusskaya Pl. 4, Moscow, 125047, Russia, shmaxg@gmail.com*
[(3)]*Keldysh Institute of Applied Mathematics, Miusskaya Pl. 4, Moscow, 125047, Russia, ovchinni@keldysh.ru*

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ABSTRACT

The small spacecraft paradigm is on the verge of heavily transforming interplanetary and deep space exploration, in the same fashion as it has revolutionized many near-Earth applications over the last quarter of the century. As with any such revolution, a number of technological challenges must first be resolved. In this research, we study some of them related to astrodynamics and mission design.

The common challenge of practically any smallsat mission beyond Earth orbit (BEO) is the launch. The most affordable option—a rideshare launch with a primary payload or many other small spacecraft—requires a lot of effort from the flight dynamics team to accommodate for a flexible launch date. Additionally, preliminary negotiations with launch providers should usually start at early stages of mission design when both the spacecraft mass and the available payload slots onboard a launch vehicle are known with considerable uncertainty. We investigate the currently most popular BEO launch scenarios with different small/medium-lift rockets and launch sites all over the world. Depending on the BEO destination and the transfer scheme selected (high-energy or low-energy), the required launch energy C3 and favorable parking orbit geometry are estimated and transformed into a contour map of maximum secondary payload mass for a given rocket and a specified launch site. Such maps allow a mission designer to quickly evaluate whether the primary payload mass and nominal orbit are suitable for a rideshare launch of a planned BEO mission.

Another major challenge a BEO mission designer is faced with is the selection of the propulsion system. Considering smallsat mass, volume, and power limitations, high-thrust propulsion systems would have a small delta-v budget due to their low specific impulse, while low-thrust propulsion is energetically very demanding and not capable of performing fast critical maneuvers. Two possible ways of coping with this problem are proposed: hardware—by utilizing a hybrid propulsion system—and dynamical, by leveraging the Sun's gravity in low-energy lunar transfers and lunar gravity assists in transfers to near-Earth asteroids, Mars, and Venus. The phase of capture and target

orbit insertion is specifically discussed. An efficient strategy of delivering a spacecraft to medium and high lunar orbits is formulated based on the third-body (Earth) gravity perturbation. For the deployment of multiple-plane lunar small satellite constellations, two single-launch schemes are analyzed.