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IDENTIFICATION OF NEW ORBITS TO ENABLE FUTURE MISSION OPPORTUNITIES FOR THE HUMAN EXPLORATION OF THE MARTIAN MOON PHOBOS

Abstract

One of the paramount stepping stones towards NASA's long-term goal of undertaking human missions to Mars is the exploration of the Martian moons. Since a mission to Phobos would be an easier precursor to a mission to land on Mars itself, NASA is targeting this moon for future exploration, and ESA has also announced Phootprint as a candidate Phobos sample-and-return mission. In this paper, a showcase of various classes of non-keplerian orbits is identified and a number of potential mission applications in the Mars-Phobos system are proposed. Firstly, the dynamics are derived for this unique system, and the numerical tools used to study it are presented. Orbital dynamics around small planetary satellites is particularly complex because many strong perturbations are involved, and the classical circular restricted three-body problem (R3BP) does not provide an accurate approximation to describe the system's dynamics. The case of Phobos is extreme, since the combination of a small mass-ratio and length-scale means that the sphere-of-influence of the moon moves very close to its surface. Thus, an accurate model must consider the additional perturbations due to the complete gravity field of Phobos, which is far from a spherical-shaped body. The proposed nonlinear model of a spacecraft's motion in the vicinity of Phobos incorporates the highly-inhomogeneous gravity field into a R3BP using a spherical-harmonics series-expansion, which is shown to be suitable for this case thanks to Phobos' physical and orbital peculiarities. Finally, state-of-the-art analytical and numerical methodologies from dynamical systems theory, such as differential-correction continuation schemes, are applied to this improved model to identify new periodic and quasi-periodic orbits, that could provide unique low-cost opportunities for space missions in the proximity of Phobos. These results could be exploited in upcoming unmanned missions targeting the exploration of this Martian moon. These applications include: the dynamical substitutes of Libration Point Orbits for close-range observations around Phobos; their manifold structure for high-performance landing/take-off maneuvers to and from Phobos' surface; low-thrust orbits about Phobos; Quasi-Satellite Orbits for long-period station-keeping and maintenance. In particular, these latter orbits could exploit Phobos' shadowing wake as a passive radiation shield in future manned flights to Mars, for undertaking real-time robotic investigations of Phobos and Mars while reducing human exposure to radiation.