Trajectory analysis for the Phobos proximity phase of the MMX mission

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It is well known that the design of trajectories for the exploration of the Martian moon Phobos poses several interesting problems to the mission analysts. The mass-ratio and the length-scale of the Mars-Phobos couple make this planetary satellite an almost unique case in the Solar System. To start with, the sphere of influence of the moon is too close to the surface for the Keplerian motion of the S/C around Phobos to be possible. Therefore, dynamical models used for Phobos exploration always need to include Mars gravitational attraction. When using a restricted three body model, the libration points L1 and L2 are found only a few km above the surface of the moon (roughly 2 or 3 km). At such distances, the non-uniformities of Phobos gravitational field cannot be neglected. Consequently, dynamical substitutes for the libration points and the libration point orbits have to be computed in models which include spherical harmonics of Phobos gravitational field, in addition to Phobos orbital eccentricity [1]. It is possible, however, to orbit Phobos in a kind of orbits called Quasi Satellite Orbits that are found beyond the libration point regions. These relative motions of the S/C with respect to Phobos are retrograde orbits, similar to the quasi-synchronous relative motion of two satellites in formation flying (chief and deputy) orbiting a central body [2]. The fact that the mass of the chief satellite (Phobos) is not negligible, especially at distances of the order of 10 to 50 km, results in a variety of apparent motions of the S/C of different relative periods, that tend to the quasi-synchronous formation flying epicycle when the distances between the space probe and Phobos are sufficiently large (of the order of 100 km).

The work performed at CNES concerning the trajectory design and operations for the exploration of Phobos in the frame of a potential contribution to JAXA's MMX mission will be presented in this paper. Firstly, we will introduce the methodology that we have implemented for designing QSO orbits (for both the planar and 3-dimensional cases). Furthermore, a preliminary assessment of the feasibility of using libration point orbits and their associated manifolds for the descent and touchdown to the surface of Phobos, in contrast with ballistic descent arcs, will be outlined. We will focus both on mission analysis parameters for orbit selection (illumination, visibility of Phobos surface, relative orbital velocity) and on operational aspects, such as injection strategies and robustness to navigation and manoeuvring errors. Finally, we should bear in mind that the knowledge of Phobos' gravitational field is bound to improve during the Martian phase of the mission. At CNES we plan to transform this enhanced knowledge of Phobos gravity into usable gravitational models, thanks to one of our research partners (GRGS). We design the tools for the analysis of QSO and LPO accordingly, making them flexible enough to allow for the exploitation of the updated models and the recalculation of possible operational orbits at each stage of the mission.

References

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