Dynamics modelling of satellites orbiting oblate bodies

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Abstract. This work discusses the location of Laplace plane and some effects of the ground-track resonances in the context of a perturbed two body problem, in which the keplerian motion of the small object (the satellite) is perturbed by the oblateness of the central body (the asteroid) and the attraction of a third body (the Sun).

Keywords: Dynamics · Oblate asteroid · Perturbation theory · Harmonics · Resonances.

1 Introduction

Many past missions have "flown by" and investigated asteroids and comets from a considerable and safe distance, providing the first images of these objects, and playing a key role in the estimation of their masses, shapes, densities. Recently, the "in situ" exploration became a reality and some missions are sample return mission (i. e. Hayabusa mission, OSIRIS-REx).

Such robotic missions, venturing towards minor bodies, in their endeavor to reveal new secrets of the Solar System, have to face the unknown natural environment around those explored celestial bodies. One particular element that defines this environment is the presence of particles orbiting or lofted from asteroids and comets. Such objects are deeply affected by various perturbations, for example the oblateness of the primary, which usually has an irregular shape, and can contribute to pose serious threats to the space assets. Given the fact that the explored object's environment is usually unknown at the beginning of the mission ([4]), a first possible evaluation of the environment can be inferred from dynamics modelling and global dynamics analysis, knowing or assuming some bounds for the object physical parameters.

Post mission stability analysis is also relevant. Once the environment of the explored object and its physical parameters are well determined, the study of long-term dynamics of the possible satellites accompanying the primary object can provide valuable information on the history and evolution of the system.

2 Dynamics modelling

The keplerian motion of an object orbiting an asteroid or a comet is perturbed by oblateness of the primary, the attraction of the Sun and planets. If the asteroid (or comet) has a close encounter with a planet, then the attraction of that planet becomes dominant. The majority of asteroids possesses an uniformly rotating state, but there exist also asteroids with a chaotic rotation, for example, the asteroid 4179 Toutatis ([4]). The various shapes of these small celestial bodies, which are determined through diverse methods, for example, light curve analysis, radar imagery or high-resolution radar, play a crucial role in assessing the perturbing effects of asteroid oblateness.

Modelling the asteroid's perturbation is challenging due to the irregular shape of asteroids. A versatile shape model for deriving the asteroid's potential is specified as a general polyhedra with triangular facets at the surface. Another approach is based on the mascons model ([2]). These two methods are adequate for computing accurate orbits in the vicinity of the asteroid's surface. For orbits at larger and larger altitudes, namely in the exterior of the Brillouin sphere, the spherical harmonics approach proves to be sufficiently accurate and can be used on long time scales.

Roughly speaking, the dynamical modelling of satellites orbiting irregularly-shaped bodies can be performed at three levels. The first approach is based on the restricted three (or four) body problem, involving the asteroid and the Sun (possibly a planet) as primaries, and an infinitesimal particle. The second model implies the study of a perturbed two body problem, in which the keplerian motion of the satellite is perturbed by the spherical harmonics of the asteroid potential as well as the attraction of the Sun (and possibly a planet). This model, appropriate for long time scales, can be studied either by using the Cartesian approach, or by following the Hamiltonian formalism. Finally, a third level involves the use of polyedra or mascons models for deriving the asteroid's potential and it is appropriate for studying the evolution of orbits on short time scales (several revolutions of the satellite) and usually at low distances from the primary (are suitable for rendezvous missions).

This work focuses on the second level mentioned above, characterizing the long-term dynamics of a satellite orbiting an oblate body (an asteroid or a comet), in the exterior of the Brillouin sphere. We assume the oblate body is uniformly rotating around a fixed axis and revolves around the Sun on an elliptical orbit. In consequence, the satellite orbit is influenced by the perturbations coming from the rotation of the oblate body, its non-sphericity and the gravitational attraction of the Sun. The study is intended to be done on a long time interval, using mathematical methods based on the Cartesian equations and the Hamiltonian approach.

3 Results

The first application discusses the Laplace's plane for the dynamical problem described above. This plane, also called the invariable plane, has its normal vector located between the normal vector of the equatorial plane and the normal vector of the Sun's orbital plane. We discuss the location of the Laplace plane as a function of several parameters, such as the magnitude of the forces involved, the distance from the oblate body, the obliquity of the Sun's orbit ([1], [5]).

Finally, the second application provides a characterization of the ground-track resonances, which occur whenever there is a commensurability between the orbital period of the satellite and the period of the oblate body rotation ([3], [6]).

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