Luni-solar perturbations for missions design in highly elliptical orbits

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Highly Elliptical Orbits (HEOs) about the Earth are often selected for astronomy missions, such as INTEGRAL and XMM-Newton, as well as for Earth missions, such as Molniya or Tundra orbits, as they offer vantage point for the observation of the Earth. In 2018 the Proba-3 satellites will be injected into a HEO to demonstrate formation flying in the context of a large-scale science mission. HEOs guarantees spending most of the time at an altitude outside the Earth's radiation belt; therefore, long periods of uninterrupted scientific observation are possible. Geo-synchronicity is often opted to meet coverage requirements, enhanced at the apogee, and optimise the ground station down-link. If the inclination is properly selected, HEO can minimise the duration of the motion inside the eclipses.

This paper analyses the long-term evolution of spacecraft in HEOs. The dynamics of HEOs with high apogee altitude is mainly influenced by the effect of third body perturbations due to the Moon and the Sun, which induces long-term variations in the eccentricity and the inclination, corresponding to large fluctuations of the orbit perigee. The single and double averaged disturbing potential due to luni-solar perturbations and zonal harmonics of the Earth gravity field are used to study their interaction. The long-term evolution of HEOs is characterised in the phase space of eccentricity, inclination and anomaly of the perigee with respect to the Earth-Moon plane. A method is proposed to compute the optimal manoeuvre to perform end-of-life re-entry or transfer into a stable elliptical orbit. The Δv manoeuvre is computed in the eccentricity-inclination-anomaly-of-perigee map, first introduced by Kozai. Given the available delta-v on-board, the reachable space of orbital elements can also be identified. Through these maps, conditions for quasi-frozen, or long-lived libration orbits are identified.

In addition, to allow meeting specific mission constraints, stable conditions for quasi-frozen orbits can be selected as graveyard orbits for the end-of-life of HEO missions, such as the XMM-Newton mission. On the opposite side, unstable conditions can be exploited to target an Earth re-entry at the end-of-mission, such as the INTEGRAL mission.

Keywords: highly-elliptical orbits, luni-solar perturbation, long-term propagation.