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ORBITAL DYNAMICS OF HIGH AREA-TO-MASS RATIO SPACECRAFT UNDER THE INFLUENCE OF J2 AND SOLAR RADIATION PRESSURE

Abstract

Advances in miniaturisation will enable future use of swarms of 'smart dust' spacecraft, as distributed nodes of a sensor network, for a range of future science missions. Such devices have a significantly higher area-to-mass ratio than conventional spacecraft due to their small length-scale. For these spacecraft, surface perturbations, such as solar radiation pressure (SRP) and atmospheric drag are no longer negligible and rather than been counteracted, they can be exploited to generate new families of highly perturbed non-Keplerian orbits. This paper will investigate the passive orbital dynamics of high area-to-mass ratio spacecraft under the influence of SRP, J2 planetary oblateness, and aerodynamic drag. Through a simplified planar model of the dynamics, where the tilt of the Earth's equator relative to the ecliptic is neglected, it is possible to identify families of equilibrium orbits in the ecliptic plane analytically, where a Sun-synchronous condition is achieved passively such that the orbit apse-line is aligned with the Sun-line, without orbit control and the other in-plane orbital elements are constant or librate around an equilibrium value. We then extend the analysis of these orbits by removing the assumption of planar J2 effect (i.e., zero planet obliquity). Starting from the conditions for the frozen orbits found analytically in the planar case, their long term evolution is studied with a full 3D dynamical model, in terms of the secular variation of the orbital elements through the Gauss equations, and considering also the effect of Earth shadow. When the actual obliquity of the equator relative to the ecliptic is considered, long-term perturbations due to SRP appear in the out-of-plane Keplerian elements (inclination and anomaly of the ascending node). Therefore, the librational orbits identified analytically on the ecliptic plane will present out of plane oscillations, which can be exploited to displace a swarm of small spacecraft on a toroidal region around the Earth's equator. In particular, the paper proposes a new set of quasi-frozen orbits for a swarm of small spacecraft for Earth observation. The effect of SRP and J2 are exploited to maintain the spacecraft on a family of orbits with a Sun-pointing apogee, so that a large fraction of the orbit is spent on the day side for imaging. An additional constraint is imposed on the semi-major axes in order for the spacecraft swarm to passively cluster near apogee to provide a higher density of observations of the day side of the Earth.