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ORBIT DESIGN FOR FUTURE SPACECHIP SWARM MISSIONS

Abstract

Recent innovations in spacecraft design exploit advances in miniaturisation to fabricate small satellites with dimensions of a single chip (1cmX1cmX25μm). Current concepts for functional devices have been designed with micro-power sources, sensing, computing and bi-directional communication capabilities. This new technology offers the benefit of low-cost manufacturing of vast numbers of micro-spacecraft (e.g., up to 10,000) for use in swarm applications. The considerably smaller dimensions of satellite-on-a-chip envisage their deployment in orbit from a CubeSat or as piggy-back on a conventional spacecraft, thus allowing significant cost savings.

The deployment of vast numbers of such 'SpaceChips' will enable future missions, such as global sensor networks for Earth observation and communication, distributed space missions for multi-point, real-time sensing for space science (space weather, geomagnetic physics, reflectometry), interplanetary exploration in support of traditional spacecraft, or deployment in the vicinity of a vehicle for diagnostic or environmental detection purposes.

The realisation of these new concepts requires an understanding of orbital dynamics at extremes of spacecraft length-scale. The significantly higher area-to-mass ratio, with respect to conventional spacecraft, allows new insights into orbital dynamics, as perturbations such as solar radiation pressure and aerodynamic drag become dominant with respect to the Earth's gravity.

This paper investigates long-lived Earth centred orbits for swarms of SpaceChip devices under the effect of solar radiation pressure and aerodynamic drag. Given the initial orbital elements of the spacecraft, the shadow geometry is determined as a function of semi-major axis, eccentricity and angular displacement Σ between the Sun-Earth line and the orbit pericentre. The secular change in the in-plane orbital elements over a single orbit revolution, in the presence of Earth shadow, is evaluated analytically. The search for long-lived orbits is performed through a global optimisation approach over a wide range of orbit eccentricities, altitudes of the pericentre and different values of Σ, and local optimisation through non-linear programming.

The paper presents families of long-lived orbits for swarms of SpaceChips where the condition of Sun-synchronous apse-line precession is achieved passively without any propellant mass consumption. The variation of the other in-plane orbital elements is balanced passively by exploiting the effects of asymmetric solar radiation pressure to offset aerodynamic drag. Moreover, in analogy with the orbit evolution of natural dust grains, other families of orbits are shown which exploit solar radiation pressure to achieve a propellant-less escape from the Earth's gravity field or aerodynamic drag for end-of-life re-entry.