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STABILISATION OF THE HYPERBOLIC EQUILIBRIUM OF HIGH AREA-TO-MASS SPACECRAFT

Abstract

The orbital evolution of high area-to-mass spacecraft, such as large thin solar sails or centimetre scaled 'smart-dust' spacecraft, shows a peculiar behaviour under the coupled effect of solar radiation pressure and the perturbation due to the Earth's oblateness. This dynamical system at low inclinations can be described through a Hamiltonian written in two variables, the osculating orbit eccentricity and the solar angle ϕ between the orbit pericentre and the Sun-line. At specific values of the orbit energy, the system allows the existence of five stationary points, of which two stable points at ϕ=0 and ϕ=π correspond respectively to families of heliotropic and anti-heliotropic orbits. The other three stationary points correspond to saddle solutions.

In this paper we focus attention on the hyperbolic equilibrium point in the phase space existing at high eccentricities and ϕ=π, for a semi-major axis above a certain value there are potential applications for missions such as GEOSAIL. This unstable equilibrium has two dimensional stable and unstable manifolds of topological type 'saddle x saddle' in the phase space of eccentricity-ϕ. Therefore, the eccentricity cannot be maintained near this interesting equilibrium point unless a controller preserving the Hamiltonian structure is constructed to change its topological type from hyperbolic to elliptic. In this way, any initial eccentricity close to equilibrium conditions will lead to a bound trajectory around the controlled elliptic equilibrium. The controller works well because the invariant manifolds are employed in a feedback to remove unstable dynamics. Moreover, the relationship between any pair of semi-major axis and area-to-mass ratio and the critical stable gain of the controller will be analysed through an ergodic representation.

The control for the hyperbolic point can be exploited as gateway from the low-eccentricity region where librational motion around the stable equilibria is possible, to the high-eccentricity region, where the spacecraft naturally decay due to atmospheric drag. A GEOSAIL-type mission for the study of the Earth's geomagnetic tail is designed, where a swarm of micro-spacecraft equipped with small solar sails is initially deployed on a circular orbit. The controller allows the stabilisation of the swarm on anti-heliotropic elliptical orbits in correspondence to the hyperbolic equilibrium. At the end of life, the swarm is forced to orbit decay through the unstable manifold leading to high eccentricities. The control requirements are quantified for different mission durations and feasible control systems are proposed for stabilisation, relying on solar sail, low-thrust propulsion, or electrochromic control.