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EARTH-MARS MICROSATELLITE MISSIONS USING BALLISTIC CAPTURE AND LOW-THRUST PROPULSION

Abstract

Growing interest in the deep-space exploration using microsatellites is leading the development of novel trajectory design techniques compatible with the constraints of this class of spacecraft. This work proposes a strategy to inject a microsatellite into a desired orbit around Mars. Two departure strategies are considered: (i) traditional Earth-Mars transfers and (ii) escape trajectories with lunar flyby. The latter option allows relevant propellant savings for the first leg of the mission, which concludes with the spacecraft gravitational capture in the proximity of Mars. With regard to this, the microsatellite is assumed to be equipped with a low-thrust propulsion system, which is unable to provide the necessary velocity variation that allows a traditional capture maneuver, during the first pass of the spacecraft at the Mars periapse. Nevertheless, ballistic capture around Mars can be achieved by injecting the microsatellite into a low-energy trajectory, in the dynamical framework of the elliptic restricted 3-body problem (ER3BP) associated with the Sun-Mars system. These trajectories can be classified in terms of a quasi-integral (J), changing in time as Mars orbits the Sun. The quasi-integral characterizes the shape of the zero velocity surfaces, which are time-varying as well. A critical value of J can be identified, corresponding to the minimum energy level at which the zero velocity surfaces surrounding the Sun and Mars always merge. This condition is necessary to allow low-energy transfers from the Sun to Mars and it also extends to transfers from the Earth to Mars. Previous works by the authors on the circular restricted 3-body problem led to a topological characterization of low-energy ballistic captures. Using the Hamiltonian formalism and canonic transformations, these results are here extended to the ER3BP. Once ballistic capture is achieved, low-thrust propulsion is ignited, with the intent of driving the microsatellite toward two operational orbits: (a) the ESA 4-SOL orbit and (b) a low Mars orbit. To do this, nonlinear orbit control is employed. Convergence toward the desired operational orbits is investigated, and can be guaranteed – using the Lyapunov stability theory, in conjunction with the LaSalle invariance principle – under certain conditions related to the orbit perturbing accelerations and the low-thrust magnitude. The numerical simulations prove that the combination of ballistic capture (simulated also with real ephemeris, with the use of GMAT) and low-thrust nonlinear orbit control represents a viable and effective strategy for microsatellite missions to Mars.