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INVARIANT-MANIFOLD, LOW-THRUST TRANSFERS TO LOW MARS ORBITS

Abstract

This work concerns the exploitation of the intrinsic dynamics arising from n-body models together with the optimal control techniques related to continuous low-thrust propulsion. The results show that it is possible to obtain accurate high-performance interplanetary trajectories from both the point of view of mass consumption and flight time. A method to systematically design Earth-to-Mars transfers is proposed through the definition of special attainable sets. Low orbits around Mars are reached through a combination of ballistic and low-thrust stages. Moreover, the Earth escape phase, the rendez-vous one and the final descending arc are solved at the same time. Finally, the transfers are optimized within wider dynamical n-body models using a direct method approach and multiple shooting technique.

In details, the complete concentric four-body Sun-Earth-Mars-Spacecraft system is subdivided in two classic three-body problems: the Sun–Earth model and the Sun–Mars one. Within this applicative scenario, the ballistic approach is not suitable: the necessary condition to define low-energy transfers requires that the invariant tubes intersect in a finite time. This happens for the Planet-Moon cases, but not for the Sun-Planet systems of the inner celestial bodies. Only the introduction of the low-thrust perturbation term in the invariant-manifold technique makes possible to obtain interplanetary transfers taking advantage of the invariant structure of the problems. Then, by means of a suitable Poincaré section, the trajectory design is restricted to the selection of the transit point on this surface. Flown backward, this initial condition generates a trajectory close to the middle stable and exterior unstable manifolds of the L2 Lyapunov orbits of the Sun–Earth system; this trajectory represents the ballistic Earth escape stage of the transfer. Integrated forward, first an accelerated low-thrust arc that allows the rendez-vous with Mars and then, a transit, martian capture orbit (through L1 gateway) are achieved.

The spacecraft is assumed to be initially on a circular parking orbit around the Earth; then an impulsive maneuver provided by the launcher, places the spacecraft onto a heliocentric trajectory. Low-energy low-thrust transfers to low Mars orbits are studied: after the launch, the spacecraft can only rely on its low-thrust accelerative propulsion to encounter Mars; then considering a low-thrust deceleration, a spiral descending trajectory to the target Mars orbit, according to the mission requirements, is obtained.