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SURVEY OF THREE-DIMENSIONAL BALLISTIC CAPTURE TRAJECTORIES USING PERIODIC ORBITS ABOUT MARS

Abstract

Low-energy transfers, of which ballistic capture is an important mechanism, have gained central importance in space mission analysis and design. These orbits provide improved mission versatility when compared to Keplerian solutions. In fact, ballistic capture is used in astrodynamics to reduce fuel consumption, mitigate the risks associated to single-point burn failures, and accommodate wider launch windows. These advantages are achieved at the cost of generally longer transfer times. Ballistic captures are generally computed with direct numerical simulation due to the lack of analytical solutions, and the global picture behind the ballistic capture mechanism is yet to be thoroughly understood. As dynamical models become more involved, the lack of invariant structures, such as periodic orbits and fixed points, translates into the frustrating need to explore the whole extent of a six-dimensional space, hoping to stumble upon the desired solutions. Direct methodologies, extensive grid searches, and use of brute computational power make the task rather demanding. The resulting solutions are not scalable and do not provide a deeper understanding of the complex chaotic dynamics at hand. These issues, coupled with the very high sensitivity to initial conditions, have limited the use of ballistic captures in applied mission designs.

In this work, a systematic approach is devised to find ballistic captures in the spatial elliptic restricted three-body problem. In the planar circular problem, periodic orbits and their manifolds provide sufficient dynamical diversity to span most of its phase space, and are used as generators for ballistic captures in the elliptic problem. Periodic solutions represent a resource to describe and quantify the dynamics in the neighborhood of the secondary; in terms of orbit size, period, energy, altitude profiles, and stability properties. The phase space of the CRTBP has been demonstrated to be the backbone for several mechanisms in more involved models. Accordingly, evidence is mounting that the ballistic capture mechanism is intimately related to CRTBP periodic solutions. A grid search and differential correction are used to find simple planar periodic solutions around the secondary. The solutions are mapped to the planar elliptic problem by means of a single-parametric transformation. Small out-of-plane deviations are then applied to find suitable initial conditions, both state and true anomaly, that propagated backward/forward within the spatial elliptic restricted three-body problem generate weakly captured trajectories at P_2. Results in the Sun–Mars system are shown and thousands potential ballistic captures are evaluated and classified for potential use.