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VENUS MISSION DESIGN LEVERAGING LOW-ENERGY CAPTURE AND NONLINEAR ORBIT CONTROL

Abstract

Exploration of Venus is recently driven by the interest of the scientific community in understanding the evolution of Earth-size planets, and is leading the implementation of missions that can benefit from new design techniques and technology. In this work, we investigate the possibility to implement a microsatellite exploration mission to Venus, taking advantage of (i) multiple powered swing-by maneuvers, (ii) low-energy capture, and (iii) nonlinear orbit control. Often, microsatellites cannot benefit from dedicated launch opportunities. This research considers the case of a microsatellite, equipped with a high-thrust and a low-thrust propulsion system, and placed in a highly elliptical Earth orbit, not specifically designed for the Earth-Venus mission of interest. In this dynamical context, multiple flybys are designed for Trans-Venus Injection (TVI), for the main purpose of enlarging the launch window, while simultaneously reducing propellant consumption. In particular, to minimize the propellant mass, phase (ii) of the mission was designed to inject the microsatellite into a low-energy capture around Venus, at the end of the interplanetary arc. Because of the small eccentricity of Venus orbit, the low-energy capture can be designed in the dynamical framework of the circular restricted 3-body problem (CR3BP) associated with the Sun-Venus system. Modeling the problem with the use of the Hamiltonian formalism, capture trajectories can be characterized based on their state while transiting in the equilibrium region about the collinear libration point L2. Low-energy capture orbits are identified that require the minimum velocity change to be established. These results are obtained using GMAT, which implements planetary ephemeris. After completing the ballistic capture, phase (iii) of the mission starts, and it is aimed at driving the microsatellite toward the operational orbit about Venus. The transfer maneuver is based on the use of low-thrust propulsion and nonlinear orbit control. Convergence toward the desired operational orbit is investigated and is proven analytically 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 results prove that the mission profile at hand, combining multiple flybys, low-energy capture, and low-thrust nonlinear orbit control, represents a viable and effective strategy for microsatellite missions to Venus.