Paper ID: 70116
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IAF ASTRODYNAMICS SYMPOSIUM (C1)
Mission Design, Operations & Optimization (2) (7)

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MARS ORBIT INJECTION VIA AEROCAPTURE AND LOW-THRUST NONLINEAR ORBIT CONTROL

Abstract

Several types of orbit injection maneuvers were used in past missions to Mars, including long-duration, multiple aerobraking passes, aimed at selecting the desired operational orbit. This research proposes a new strategy for Mars orbit injection, based on aerocapture and low-thrust nonlinear orbit control. The range of altitudes that allow aerocapture are identified as a function of the hyperbolic excess velocity at Mars arrival, with reference to a large variety of atmospheric density profiles, associated with different seasons and dust storm conditions. This preliminary analysis regards different spacecraft, with distinct ballistic coefficients, and demonstrates that a safe periares altitudinal range leading to aerocapture in all atmospheric conditions does not exist. This result is further confirmed through Monte Carlo simulations, assuming stochastic – yet realistic – atmospheric density profiles. This circumstance implies the need of designing suitable correction maneuvers, aimed at avoiding both impact and escape. Four such types of maneuvers are identified, by minimizing the velocity changes required to achieve aerocapture. At the end of this first, crucial phase, the spacecraft orbit exhibits large dispersions in terms of orbit elements. Therefore, the identification of an effective autonomous guidance strategy, capable of driving the spacecraft toward the desired operational orbit, is mandatory. To do this, low-thrust nonlinear orbit control is proposed as an effective option. A feedback law for the low-thrust direction and magnitude, with saturation on the thrust magnitude, is defined, and is proven to enjoy global stability properties, using the Lyapunov direct method and the LaSalle invariance principle. As a result, the spacecraft travels toward the operational orbit of interest, i.e. either (a) a quasi-synchronous inclined orbit, (b) an areostationary orbit, or (c) a low-altitude, sunsynchronous orbit. Monte Carlo simulations, with stochastic density profiles, point out that the overall propellant budget is considerably reduced, in comparison to direct orbit injection based on chemical propulsion. The overall time of flight typically ranges from 70 to 100 days, and therefore it is much shorter than that required with the use of aerobraking. Furthermore, low-thrust nonlinear orbit control allows achieving a variety of operational orbits, with great accuracy. Propellant consumption, time of flight, and reachable orbits represent unequivocal advantages with respect to alternative options, and make the strategy based on aerocapture and low-thrust nonlinear orbit control particularly attractive and convenient for Mars orbit injection.