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DESIGN OF LOW ENERGY ESCAPE TRAJECTORY AND DELTA V REDUCTION

Abstract

In the trajectory design for deep space missions, when one uses chemical propulsion, it requires much fuel and large rockets, which inevitably causes to increase launch costs as well as spacecraft's weights. On the other hand, it has been focus on the sampling return missions such as JAXA's Martian Moons eXploration (MMX) and it needs sufficient fuel in order to escape from gravity of a target planet as well as to obtain energy to transfer to the Earth. So far, as a conventional method, the Grid Search method and the V-Infinity Leveraging Maneuver method have been proposed. The former method searches escape trajectories by numerically propagating various initial conditions, while the latter method makes use of proper swing-by. This raises the trade-off problem; namely, ΔV may be lower for escape but the time of flight (TOF) longer.

In this context, we propose a new method to design escape trajectories with low ΔV as well as relatively short TOF, where we consider the mission design of MMX, in particular, from Phobos to the vicinity of halo orbit. This is a method to realize low energy transit trajectory, and we take reference points on a halo orbit as a hub and we consider local invariant manifolds at each reference point with perturbations. Propagating the reference point with perturbations in backward/forward time enables a spacecraft to escape from the vicinity of a planet. We illustrate our theory by the example of designing escape trajectories from the Martian moon "Phobos" in the context of the three-dimensional Sun-Mars-Spacecraft circular restricted three-body problem (CR3BP). In addition, the FTA method, which modifies an orbit of a spacecraft having deviation from the planned orbit in real space, is applied to the designed trajectory by numerical computations for reducing ΔV of escape for practical use.

As a result of this design method, we show that Mars escape trajectory can be realized whose ΔV is equivalent with that of Grid Search method, and also that TOF is shorter than that of V-Infinity Leveraging Maneuver method; namely, the lowest ΔV escape trajectory concludes that ΔV=0.8718[km/s] and TOF=282[day]. On the other hand, ΔV reduction method is shown to apply to several designed trajectories, namely, the trajectory originally with ΔV=0.9075[km/s] and TOF=310[day] is reduced to that with ΔV=0.8857[km/s] and TOF=126[day].

In conclusion, we can construct a systematic design method of escape trajectory so that ΔV reduction is realized for several individual trajectories.