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INTERPLANETARY LOW-THRUST TRAJECTORY USING EARTH GRAVITY ASSIST AND INVARIANT MANIFOLD TECHNIQUE

Abstract

The electric propulsion is attracting a great attention for the application to deep space exploration because of its high specific impulse. This paper presents a new preliminary design scheme of Earth–Mars transfer trajectory combining manifold technique with the Electric Delta-V Earth Gravity Assist (EDV-EGA) scheme. This new trajectory reduces the fuel required for the Earth–Mars transfer compared to the conventional trajectory based on manifold technique.

The EDV-EGA scheme was proposed by Kawaguchi, and demonstrated by the Japanese asteroid explorer MUSES-C. This scheme enables the spacecraft at departure to get the larger velocity relative to Earth than the velocity generated by low-thrust propulsion, and then reduces the fuel consumption for orbital transfer. Meanwhile, to apply this scheme to Earth–Mars transfer, large delta V is required to be put into the orbit around Mars. When the electric propulsion is used to generate delta V around Mars, the larger solar cells are required than running it around Earth. This is because the distance between Sun and Mars is 1.5 times longer than that between Sun and Earth.

In this paper, therefore, we propose the scheme combining the EDV-EGA scheme with ballistic Mars capture utilizing the stable manifold of the halo orbit around Sun–Mars L1 point. This new scheme is implemented by defining special attainable sets. The idea utilizing attainable sets to handle a lot of trajectory candidates at once imitates "manifold technique". The attainable set of Earth escape trajectories is a collection of trajectories propagated with a set of admissible control laws, from Near-Earth. The k-$\omega/\omega_{\mathrm{e}}$ map is utilized to identify the set of admissible control laws, which have high velocity increment during the pre-EGA phase. The attainable set of Mars capture trajectories is a collection of trajectories integrated backward from the halo orbit, states of which are perturbed into the direction of the local stable eigenvector.

The intersections between Earth escape trajectories and Mars capture trajectories are identified by finding suitable surfaces of section. In other words, the attainable sets on the suitable surfaces of section are plotted in a common intersection plane to identify the intersection. Numerical analyzes are carried out to verify the effectiveness of the proposed trajectory design scheme, and then show that the trajectory designed by this scheme can reduce fuel consumption for the Earth–Mars transfer compared with the trajectory designed by conventional manifold technique.