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ANALYSIS OF TRANSFER TRAJECTORIES IN CISLUNAR SPACE USING SEQUENCES OF LOBE DYNAMICS

Abstract

Space exploration to the Moon and beyond has been attracting great attention for the development of science and engineering. However, trajectory design in cislunar space is challenging because spacecraft dynamics is chaotic and highly nonlinear. For lowering fuel consumption, invariant manifolds are among the essential dynamical structure of its natural dynamics. There are two ways of leveraging invariant manifolds: tube dynamics and lobe dynamics. Tube dynamics utilizes stable and unstable manifolds of periodic orbits and indicates the global transport structure for spacecraft. Lobe dynamics, on the other hand, focuses on the "lobe", the region determined by stable and unstable manifolds of a resonant orbit, and can reveal phase space transport of chaotic trajectories. Lobe dynamics has not been in the light as tube dynamics because of its complex structures even though it enables involving chaotic motions in trajectory design. Thus, trajectory design based on lobe dynamics should be developed for fully exploiting natural dynamics and saving fuel consumption.

This study analyzes transfer trajectories in cislunar space based on lobe dynamics. In general, lobe dynamics of one resonant orbit can transfer a spacecraft only around the resonant orbit in concern. To fully understand lobe dynamics in cislunar space, this study focuses on lobe dynamics of various resonant orbits in the Earth-Moon circular restricted three-body problem (CR3BP). We develop an algorithm to identify the lobes surrounded by stable and unstable manifolds of the resonant orbits in the periapsis Poincare map. Once a spacecraft is injected into one of the lobes, it transfers to the next lobe based on lobe dynamics describing the map of the lobes, i.e., a lobe sequence can be obtained. It is also demonstrated that the sequences of lobe dynamics of the resonant orbits are connected by appropriate impulsive thrust inputs.

As a preliminary analysis, lobe dynamics in the standard map is examined because the standard map is a simple Hamiltonian system exhibiting chaos. The proposed algorithm estimates how to connect the sequences of lobe dynamics by small fuel consumption. Subsequently, the transfer trajectories based on lobe dynamics in the CR3BP are analyzed based on the developed algorithm. Numerical examples of the transfer trajectories give us insights into the dynamical structure based on lobe dynamics in the Earth-Moon CR3BP.