IAF ASTRODYNAMICS SYMPOSIUM (C1)
Interactive Presentations - IAF ASTRODYNAMICS SYMPOSIUM (IPB)

Author: Dr. Shanshan Pan
Kyushu University, Japan

Dr. Mai Bando
Kyushu University, Japan

LOW-THRUST ASSISTED PERIODIC ORBITS AROUND SMALL BODIES VIA INDIRECT OPTIMAL CONTROL

Abstract

Nowadays, there is a cornucopia of well-motivated scientific and exploration activities focused on small bodies like asteroids and comets. These small bodies inhabit some of the most disturbed and extreme orbital environments within our solar system. Typically, uncontrolled trajectories near small bodies exhibit high instability and may either impact or escape in timespans of hours to days. Two strategies have been employed in asteroid proximity missions: 1) hovering operation and 2) periodic orbit. Hovering operations usually require a large amount of fuel. In contrast, periodic orbits, theoretically fuel-free, come with inherent limitations such as low flexibility and coverage. Strategies like impulsive delta-V or continuous low-thrust assisted periodic orbits have been developed to address these challenges. Specifically, delta-V-assisted teardrop hovering orbits have been studied. However, fewer methodologies are available to identify the low-thrust assisted periodic orbits in perturbed environments due to their inherent complexities.

This research studies the minimum-fuel problem in the Hill Three-Body Problem (Hill3BP), focusing on low-thrust assisted periodic orbits (LTAPOs) around small bodies under some perturbations. LTAPOs are characterized by periodic motion achieved through the implementation of a bang-bang control strategy. First, the minimum-fuel problem is formulated with an initial state given by adding a perturbation to the natural periodic motion. Subsequently, the indirect method is adopted to transform the problem into a two-point boundary-value problem (TPBVP). Then, the intractable minimum-fuel problem caused by a discontinuous control law is solved through the homotopic process from the minimum-energy problem to the minimum-fuel problem. Finally, the study systematically explores the dynamical structures of LTAPOs, delving into aspects such as the solution space and orbital stability.

Numerical findings indicate the feasibility of achieving periodic motion near small bodies by following the minimum-fuel low-thrust trajectory, effectively circumventing challenges associated with operations in such environments. The analysis of low-thrust on the dynamical structure reveals that LTAPOs exhibit different but rather interesting topological properties than natural motion, which can be profitably leveraged in preliminary mission analysis. Moreover, a proposed stability analysis method for LTAPOs enables an understanding of the stability of LTAPOs and aids in selecting suitable orbits for practical missions. Additionally, the required fuel consumption is notably lower than that of alternative operations, especially when disturbances are considered. These properties can enhance our comprehension of dynamic phenomena near small bodies and contribute to missions of greater scientific significance.