## ASTRODYNAMICS SYMPOSIUM (C1) Mission Design, Operations & Optimization (2) (2)

Author: Ms. Hongru Chen Kyushu University, Japan

Dr. Yasuhiro Kawakatsu Japan Aerospace Exploration Agency (JAXA), Japan Prof. Toshiya Hanada Kyushu University, Japan

## PHASING PROBLEM FOR SUN-EARTH HALO ORBIT TO LUNAR ENCOUNTER TRANSFERS

## Abstract

Halo orbits are advantageous for various space applications. There will be more utilization of halo orbits in the future. Inspired by the ISEE-3 Sun-Earth halo orbit mission, which applied low-energy transfers to achieve more goals than planned, our work concerns about the extended mission following the completion of a halo orbit mission.

It is interesting to link halo orbits with interplanetary exploration. There have been several studies on this. In a previous study, we proposed the strategy of using the unstable manifolds associated with the Sun-Earth  $L_1/L_2$  halo orbit along with lunar gravity assists to achieve Earth escape, and compared this scenario with the escape along manifolds only. Some remarks are: 1) the manifold-guided lunar gravity assists can achieve much higher characteristic energy ( $C_3$ ) with respect to the Earth than the direct escape along manifolds; 2) if the  $V_{\infty}$  with respect to the Moon at the lunar encounter is not great enough for high energy escape, a second lunar gravity assist can efficiently increase the  $C_3$  to the theoretical maximum level at the expense of another 90 day flight time. For these advantages, the present work investigates the minimum required phasing  $\Delta V$  for the transfer from the halo orbit to a lunar encounter.

The transfer consists of a departure to the unstable manifold at infinitesimal cost, followed by a coast along the manifold, and a corrected trajectory to the Moon led by a phasing  $\Delta V$  paid along the coast manifold trajectory. The lunar phase with respect to the halo orbit (by defining an initial lunar phase  $\theta_0$ when the spacecraft passes a reference point  $\mathbf{x}_0$  in the halo orbit) and the halo orbit size (z-amplitude  $A_z$ ) would be known in practical missions. The paper presents the routine of calculating the minimum phasing  $\Delta V$  for given  $\theta_0$  and  $A_z$ . A concern arises as there are multiple solutions (e.g. the short-way and long-way motions) for the two-point boundary value problem as well as multiple optimization directions. Based on the knowledge and partial derivatives of the two-body Lambert problem, the differential correction sequence we developed can identify the two solutions in the three-body problem. The  $\Delta V$  budget to cover full lunar phases will be revealed. In addition, the paper discusses referencing the lunar phase to consecutive halo revolutions to decide a minimum- $\Delta V$  phasing plan.