EQUULEUS Mission Analysis: Design of the Transfer Phase

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Scheduled in 2018, Exploration Mission-1 will launch the Orion Multi-Purpose Crew Vehicle with 13 CubeSats via the NASA's new SLS rocket. EQUULEUS (EQUilibriUm Lunar-Earth point 6U Spacecraft) [1] is one of the selected CubeSats, proposed by JAXA and The University of Tokyo. One of its main goals is to reach a lunar libration point orbit around the Lagrange point L_2 to observe the far side of the Moon.

As a CubeSat, EQUULEUS faces several challenges. The nominal $\triangle v$ budget is only 80 m/s, which will be shared among navigation, stationkeeping, and unloading maneuvers. Therefore, the deterministic $\triangle v$ for the transfer is tightly restricted, including the critical maneuver $\triangle v_1$ shortly after the separation. For $\triangle v_1$, some gravity losses are expected due to the limited thrust level (0.3 mm/s^2). On the other hand, the transfer requires precise control in the Sun-Earth-Moon dynamics, and the traditional patched-conic method does not work well in such a multi-body system.

The purpose of this paper is to present the result of designing transfer trajectories from the separation from SSL to the insertion into the libration point orbit under such difficulties. Fig. 1 shows the flowchart of the toolbox that we have developed to find feasible solutions flexibly and robustly; Halo_Generation module computes quasi-periodic halo orbits in the full-ephemeris model using the optimization software jTOP [2]; Forw_Prop module searches lunar flyby states forward in time by applying $\triangle v_1$; Back_Prop module searches lunar flyby states by propagating backward in time from the quasi-halo orbits; Selection module extracts forward and backward legs with small gaps between them; Processing module produces first guess solutions by matching lunar flyby states; Optimization module optimizes total $\triangle v$ by using jTOP.

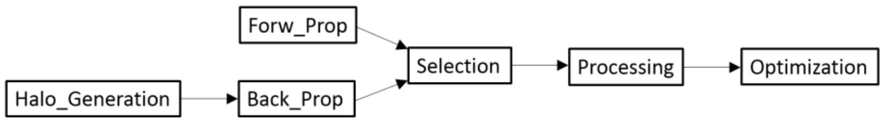

Fig. 1. Flowchart of the transfer trajectory design toolbox.

So far, NASA has provided initial conditions twice (old and current ICs). For both ICs, the toolbox could find feasible solutions in terms of $\triangle v$. Table 1 summarizes optimal solutions of small total $\triangle v$. Fig. 2 shows the trajectory of the case 4003 of the current IC, which exploits solar perturbation to reduce the Moon relative velocity $|v_\infty|$ and lunar flybys to reach the L_2 quasi-halo orbit. The full paper will present transfer trajectories for the upcoming initial condition.

Table 1. Optimal solutions of relatively small total $\triangle v$.

jTOP case	Total $\triangle v$[m/s]	$\triangle v_1$[m/s]	TOF[days]
5004, old	16.4	8.23	353
5001, old	20.7	9.95	250
1006, old	24.7	10.7	315
4003, current	14.1	6.99	326
1004, current	14.4	5.29	358
2003, current	16.3	6.94	382
1001, current	20.8	7.63	283
50002, current	21.8	4.65	355

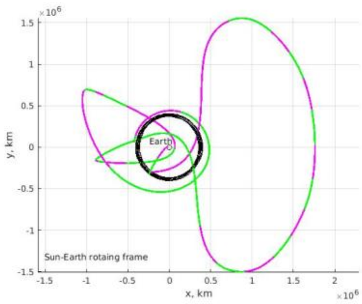

Fig. 2. The trajectory of the case 4003 of the current IC.

References
[1] S. Campagnola *et al.*, Mission Analysis for EQUULEUS, JAXA's Earth-Moon Libration Orbit Cubesat, 67th International Astronautical Congress (2016).
[2] S. Campagnola *et al.*, Low-Thrust Trajectory Design and Operations of PROCYON, the First Deep-Space Micro-Spacecraft, 24th International Symposium on Space Flight Dynamics (2015).