MISSION DESIGN ASPECTS OF EUROPEAN ELEMENTS IN THE INTERNATIONAL SPACE EXPLORATION FRAMEWORK

Markus Landgraf[(1)], Marcel Düring[(2)], and Florian Renk[(3)]

[(1) (3)]*ESA/ESOC, Robert-Bosch-Str. 5, 64291 Darmstadt, Germany, +49-6151-903627, Markus.Landgraf@esa.int*

[(2)]*University of Stathclyde, 75 Montrose Street, G1 1XJ Glasgow, United Kingdom, Marcel.Duering@strath.ac.uk*

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ABSTRACT

In the context of the international space exploration coordination group (ISECG) ESA defines the framework for its possible future contribution to an infrastructure that will enable us to explore the solar system in situ in a much more direct way than today [e.g. 1,2].

From a mission system design point of view the exploration scenario relies heavily on the exploitation of the dynamical properties of the Earth-Moon system. Here we look into the mission system aspect of a reference scenario that comprises the elements of a captured mini-asteroid on a distant retrograde orbit (DRO) around the Moon, as well as visiting vehicles from the Earth, and excursions to the lunar surface. The motivation for the analysis of the associated transfers in the Earth-Moon system is the requirement for ESA to provide propulsive elements for the initial missions of the most likely visiting vehicle (Multi Purpose Crew Vehicle, MPCV), based on hardware from the Autonomous Transfer Vehicle (ATV).

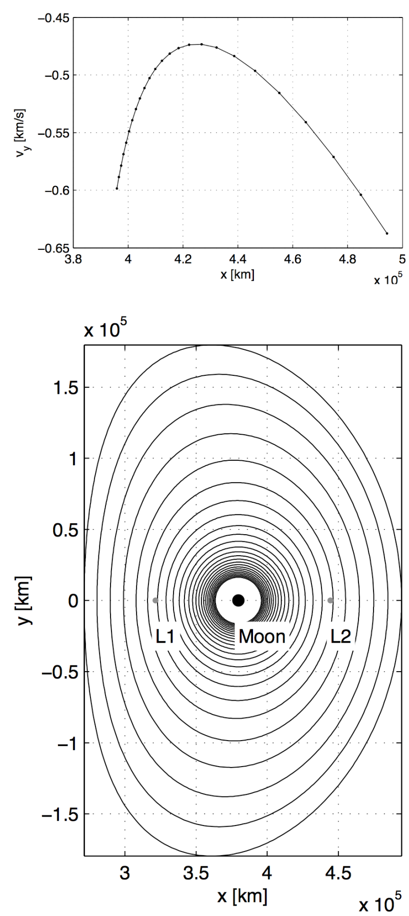

Figure 1: Family of distant retrograde orbits (DRO) in the synodic frame

A DRO is a solution of the idealized circular restricted three-body problem (CR3BP), which has been investigated deeply in literature [3, 4]. A spacecraft on a DRO follows a path around the Earth that seems elliptic around the Moon due to the 1:1 resonant interaction with the Moon. DROs possess invariant manifolds and other dynamical system properties similar to the Libration point orbits. Those can be exploited for the design of transfers. A multiple shooting algorithm also produces these orbits in the full ephemeris model. In the lunar orbital plane periodic DROs can be found at various sizes. We refer to the size of the orbit as “amplitude”, because the motion in the CR3BP is more analogous to a two-dimension oscillation than to Keplerian orbital motion. Usually, the amplitude is in the order of the distance from L_1 to the Moon [5]. However, small DROs have a smooth transition to in-plane retrograde Keplerian lunar orbits.

Interestingly, the orbital velocity on a DRO increases with amplitude, while of course the orbital velocity on a Keplerian orbit decreases with circular radius (see Figure 1).

DROs are sufficiently high up in the gravitational well of the Earth-Moon system that a transfer of a 100-tonne class near Earth mini-asteroid. On the other hand do they provide the mission system design benefits of an orbit in the Earth-Moon system, e.g. a libration orbit around the far side Earth-Moon Libration point (EML_2), which are:

- Low orbit maintenance cost ($<10\ ms^{-1}y^{-1}$)
- Low-energy connection to orbits in the Sun-Earth system
- Low-energy connection to near-Earth interplanetary space
- Free transfer from low lunar orbit
- Direct injection transfer from lunar surface
- Low transfer times from Earth (~5d)
- Small insertion manoeuvre from Earth (~ 600 ms^{-1})

In particular the final point has some bearing on the system design. Large elements of an exploration infrastructure need to be launched from Earth using highly efficient cryogenic chemical propulsion, which is known to have a system mass penalty on the transfer time due to off boiling. The accessibility of the DROs from the lunar surface allows considering a supply infrastructure between the two destinations.

Thus, from the dynamical properties of the transfers and orbits in the Earth Moon system the picture of a mission system arises that is analysed in the full paper: capture of a near-Earth asteroid into an Earth-Moon DRO, transfer of crew and equipment to DRO and rendezvous with the target asteroid followed by the set-up and maintenance of a gateway station in formation with the asteroid, providing a hub for exploration missions to the asteroid, the lunar surface, near Earth interplanetary space, and destinations in the Solar System. The analysis comprises target orbit construction, orbit maintenance cost, as well as transfer times and cost.

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