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# OPTIMAL ESCAPE MANIFOLDS FOR CIS-LUNAR HALO ORBITS

**Abstract**

Different families of three-body orbits are being proposed as location for a human-tended lunar orbiting station, and as operational orbit for communication relay and navigation satellites. In particular, Space Agencies are currently considering the Near Rectilinear Halo Orbits (NRHO) family as a staging location for a lunar exploration infrastructure. Due to the increased interest, a close investigation of the NRHO dynamics, at insertion and departure respectively, is worth to consolidate transfer capabilities, back and forth the Earth and other destinations. The paper investigates the trajectory sensitivity to the incoming and outgoing manoeuvres direction; different models (Circular Restricted Three-Body Problem, Bi-Circular Restricted Four-Body Problem, full ephemeris model) are exploited, to gradually increase fidelity of the dynamical model and to classify the transfer shape. For any manoeuvre direction, several manifolds for NRHO departure/arrival exist, differing in manoeuvre magnitude and time of flight. Generally, a single family of trajectories directly leaves the NRHO towards the Weak Stability Boundary (WSB). The other manifolds describe additional orbits around the Moon before connecting to the WSB, either going towards heliocentric escape, or colliding with the Moon or the Earth. Notably, the correlation between time of flight and manoeuvre magnitude is highly irregular; Finite Time Lyapunov Exponent (FTLE) are here used to correlate the two quantities to identify transitions between dynamical regimes, in order to derive the manoeuvres bounds that describe similar dynamical behaviours. To deepen the knowledge of the dynamical regime, the paper analyses the manoeuvre direction effect, mapping the results in Azimuth-Elevation plane with respect to the Earth-Moon rotating frame. Optimal $\Delta$V directions are identified, as circular structures in such phase space, whose bounds are defined through a local FTLE analysis; this offers the analyst a further degree of freedom in manoeuvre planning, e.g. to satisfy pointing constraints. As operational example, WSB transfers from/to Earth are identified, first constraining the arrival manoeuvres on the $X$ direction of the Earth-Moon rotating frame, and then showing how a proper exploitation of the manifold structures and geometry can reduce the magnitude of said manoeuvres. The performed analyses give rise to general guidelines for manoeuvres design; indeed, transfers to and from any Halo orbit - optimal in terms of manoeuvre magnitude and time of flight – can be easily assessed.