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PROPELLANT AND CAPITAL EFFICIENT TRANS-MARS INJECTIONS USING LUNAR PROPELLANT

Abstract

The authors draw on their published work to formulate and quantify Concepts of Operations (CONOPs) supporting trans Mars-injections using lunar propellant. Leveraging the astrodynamics of the Earth-Moon system, the oxygen to hydrogen ratio of water versus hydrolox, the likely Mars-bound vehicles, and the concentration of vehicle use in cislunar space archives Propellant and capital efficiency.

As the Moon passes through the Earth's equatorial plane, a trans-Earth injection performed from a lunar polar orbit can freely select an Earth orbit inclination to match a Mars marshalling orbit. The vehicle can be inserted into Earth orbits between lunar distant and low Earth (LEO), with lower orbits being more propellant or aerobraking mass expensive. Precession effects that drive sun-synchronous orbits can be harnessed by tuning the apogee to trade propellant against time and align lunar vehicles orbits for a rendezvous with elements marshalling for Mars.

Transportation modelling shows that the mass of oxygen by-product from water-based lunar hydrolox production is approximately the mass that the hydrolox can deliver into geosynchronous transfer orbits (GTO). Thus, the most efficiently deliverable lunar propellant in GTOs is oxygen, and the SpaceX Mars project will require around 450,000 t/y of oxygen in LEO.

Since the efficiency of lunar propellant delivery increases with the apogee of the delivery orbit, the authors propose incremental oxygen delivery and boost cycles to pump Starships marshalling for Mars into successively higher orbits, which also reduces CH_4 required since less LOX needs to be lifted. A near GTO apogee is a compromise between low propellant cost from the Moon and a short orbital period for convenience of rendezvous. However, one might go as high as the lunar distant high Earth orbits used in some recent NASA proposals (with different motivations).

One can also improve capital efficiency. A full Starship in a GTO can land 3x its nominal cargo mass on Mars (ignoring entry descent and landing constraints). This CONOPs reduces the number of Starships making the Mars transit by a factor of three. Frequently reused cislunar vehicles provide the residual impulse between transfer windows; this requires few Earth and cis-lunar tankers. Using cis-lunar tankers also reduces Earth infrastructure requirements and other terrestrial dependencies.

Relative to the baseline SpaceX Mars Project and the canonical "deliver lunar propellant in LEO" scenario, the proposed CONOPs reduce Mars vehicle and transit operations costs and increase lunar propellant efficiency. One can apply these CONOPs to other interplanetary transfers.