Lunar Injection, Circumnavigation, Flyby and Gravity Assist Trajectories For Direct Lunar Polar Surface Landings, Lagrange Point Deliveries, Mars and Asteroid Transfer Orbits, and Core Stage Recovery

Thomas Lee Elifritz, The Tsiolkovsky Group, Madison, Wisconsin USA

I have recently outlined a parallel staged and clustered approach to reusable heavy lift launch vehicles, which, with appropriately efficient reusable hydrocarbon boosters and hydrogen powered core stages, provides an ideal method of performing efficient trans-lunar-injection burns to the vicinity of the moon. I have also extended that concept to the direct lunar landings of large uncrewed Space Launch System (SLS) core stages directly onto the surface of the poles of the moon - as functional initial lunar bases. In this paper I will describe the extension of these techniques to the entirety of the lunar surface, and to lunar circumnavigation orbits back to the vicinity of the Earth, either to geosynchronous or aerobraking orbits, to any of the solar and lunar Lagrange points, and indeed, to any Mars or asteroid transfer orbits. The goal of this effort is to allow more efficient crew deliveries and recoveries from the lunar surface, by separating the lunar payload and landing stage from the core booster - which allows for its recovery and reuse in simultaneous cis-lunar, near Earth space and deep space industrial development programs. This allows for much lighter weight and more fuel efficient crewed reusable lunar landers to be fielded.

The orbital recovery of large hydrogen powered Space Launch System core stages is dependent upon more sophisticated space rated, low boil off, cryogenic insulation and boil off management techniques. Cryogenic insulation systems for core stages immediately landed upon the moon are less problematic as a result of the absence, due to lunar gravity, of orbital debris problems related to insulation shedding. On the other hand, insulation methods for large cryogenic tankage in orbital recovery schemes must be totally impervious to debris shedding even after their residual fuel is fully expended or converted, if the vehicle is to remain in deep space for reuse or repurposing as fundamental space based infrastructure.

There are many trajectory choices for powerful hydrogen powered core stages on the way to the moon. If the core stage and payload are unable to develop enough delta V to reach the lunar surface, then the core stage or payload can be delivered to geosynchronous or lunar orbit with subsequent circularization burns, or directly returned to low Earth orbit for aerobraking and the payload can make up the shortfall. Alternatively, if the core stage is able to accelerate to full escape velocity, either the core stage or the payload can perform maneuvering burns to redirect to the lunar poles, and either the core stage or the payload can remain in roughly equatorial orbit and fly lunar circumnavigation for free return, or lunar flyby orbits or lunar gravity assist trajectories to any number of destinations lying in the plane of the ecliptic. These destinations may include geosynchronous orbit, lunar and solar Lagrange points, or even Mars and asteroid Hohmann transfer orbits, depending upon lunar position and mission timing. Lunar circumnavigation also allows for return of the core stage or payload to Earth aerobraking orbits using a retrograde free return and subsequent prograde Earth circumnavigation, flyby or gravity assist in the same way a lunar cycler would operate, opening up many more core stage recovery and reuse options. Equatorial to polar and retrograde to prograde maneuvers after the trans-lunar-injection burns may also be augmented by continuous fuel settling micro thrusting using cryogenic boil off gases, enabling both cryogenic boil off abatement and cryogenic restarts for lunar orbit insertion and parabolic arc landings.

In conclusion, multiple clustered and parallel staged reusable hydrocarbon boosters, in association with the higher impulse of hydrogen fueled core stages such as the Space Launch System, enable a diverse phase space of accessible Earth-Moon system trajectories, which in turn provides for a richer variety of stage recovery techniques and destinations, such that a fully reusable lunar landing system is possible.