Asteroid Missions – Upper Stage Orbiters, Landers, Hoppers and Bases

Thomas Lee Elifritz
The Tsiolkovsky Group, Marshall Space Flight Center, Marshall, Wisconsin USA

This paper is the last of a series of three proposals for the use of hydrogen upper and core stage tankage as basic infrastructure for a sustainable near earth and inner solar system space development program.

In the first proposal I described how geosynchronous orbit and its large inventory of satellites can serve as a resource rich interim step to beyond earth orbit space exploration and resource exploitation, where the individual components of retired telecommunications satellites can be repurposed into a variety of practical deep space uses - fuel storage depots and refueling stations, solar sunshades and reflectors, impact and radiation protection devices, thermal and attitude control systems, solar energy conversion and storage systems, and telecommunications systems, while directly addressing technology necessary for orbital debris removal, and preparing for future lunar surface landings and asteroid rendezvous.

Direct deep space flight of hydrogen powered core and upper stages was then extended to the surface of the moon, where volatile and ice rich cold and dark lunar polar reservoir crater locations are capable of providing continuous sunlight, direct Earth communications, moderate ambient temperatures, ample shielding with regolith, a light surface gravity and easy cryogenic fuel storage in deep reservoir craters. In this paper I will analyze and present the dynamical and environmental parameter space for asteroid missions using the same design philosophy that I have previously presented for near earth orbital space.

Asteroids range in size from sub-meter impact ejecta fragments all the way up to protoplanetary bodies, and in the case of Ceres, full blown planets. Material compositions of these bodies range from the pure metallic cores of disrupted protoplanets all the way to dark volatile depleted carbonaceous chondrites, running through a wide range of primitive and altered minerals to classic stony rubble pile materials. Axial tilts and rotation rates vary widely due to collisional momentum combined with the YORP effect. Surface gravities range from negligible all the way up to a small fraction (up to 3%) of Earth's gravity. Some asteroids are contact binaries, possess moons, or are very closely orbiting disrupted rubble piles. Radar observations have recently become useful in characterizing their sizes, shapes and composition.

Propulsive Hohmann orbital transfers from lunar or Mars space to the asteroids and the planet Ceres are envisioned, with Ceres as the primary base for asteroid resource exploration and materials utilization. Solar electric attitude control and propulsion are envisioned as a continuous backup to the propulsive delivery of the lander, spacecraft and its upper stage to the selected destination and mission scenario. Bodies with near 90 degrees of axial tilt, such as 16 Psyche, offer polar landing opportunities where continuous sunlight and earth communications will be available for durations of six months or more. Long transit times necessitate that the upper stage and its hydrogen orbital transfer engines are simply along for the ride, but cryogenic tankage can serve as a framework for the substantial solar power array which is required on station - to operate the spacecraft for long duration stays in orbit or on the surface.

Detailed high resolution mapping of the surface of Ceres should be available by late 2015 which would enable the advanced planning for any surface landings on Ceres for extensive soil sampling and testing. A solar powered upper stage in polar orbit would provide observational and communications support. Hypergolic fuels may be required to land upper stage systems or a lander spacecraft onto the surfaces of these larger asteroids, and great care will be required to minimize the exhaust blast ejecta on smaller bodies, which can cause hazardous debris clouds to be ejected into space in the vicinity of the asteroid. Elevated peak landings and horizontal takeoffs may be required when leaving these low gravity bodies.

Larger asteroids have enough surface gravity to settle dust quickly so industrial operations can proceed unhindered, but carry an additional propulsive cost of landing and leaving, while smaller asteroids are highly susceptible to material loss, but provide unlimited freedom of movement on and off the body, allowing the operation of a wide variety of orbital observatories and relays, surface bases and cruisers - capable of unlimited hovering, landing, hopping and roving to maximize imagery and science products. Surface gravity and rotation axis orientation are the primary drivers of mission approaches and landing.

The axial tilt of Ceres is very small (3°), so missions may be best served by polar orbiters and landers during the specific orbital periods when the desired pole is oriented towards the sun (Ceres summers!). Preliminary observations do indicate the surface of Ceres is compositionally homogeneous and smooth, due to impact regolith formation, but macroscopically rough at larger scales, indicating that the surface topography and altitude elevations could exhibit wide variations, thus exposing cross sections to view. Definitive ground truth on Ceres will be available in late 2015, but mission planning should begin now.