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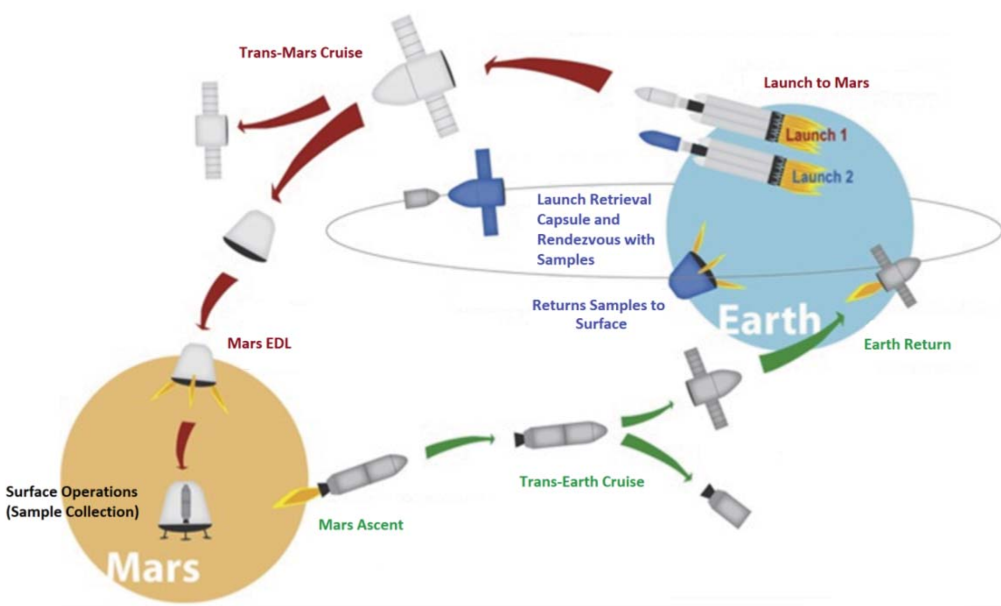
Mars Sample Return Using Commercial Capabilities: Mission Architecture Overview



Mars Sample Return (MSR) is the highest priority science mission for the next decade as recommended by the recent Decadal Survey of Planetary Science. This paper presents an overview of a feasibility study for an MSR mission. The objective of the study was to determine whether emerging commercial capabilities can be used to reduce the number of mission systems and launches required to return the samples, with the goal of reducing mission cost. We report the feasibility of a complete and closed MSR mission design using the following scenario that covers three synodic launch opportunities, beginning with the 2022 opportunity: A Falcon Heavy injects a SpaceX Red Dragon capsule and trunk onto a Trans Mars Injection (TMI) trajectory. The capsule is modified to carry all the hardware needed to return samples collected on Mars including a Mars Ascent Vehicle (MAV), an Earth Return Vehicle (ERV), and hardware to transfer a sample collected in a previously landed rover mission to the ERV. The Red Dragon

descends to land on the surface of Mars using Super Sonic Retro Propulsion (SSRP). After previously collected samples are transferred to the ERV, the single-stage MAV launches the ERV from the surface of Mars. The MAV uses a storable liquid bi-propellant propulsion system to deliver the ERV to a Mars phasing orbit. After a brief phasing period, the ERV, which also uses a storable bi-propellant system, performs a Trans Earth Injection (TEI) burn. Upon arrival at Earth, the ERV performs Earth and lunar swing-bys and is placed into a lunar trailing circular orbit - an Earth orbit, at lunar distance. A later mission, using Dragon and launched by a Falcon Heavy, performs a rendezvous with the ERV in the lunar trailing orbit, retrieves the sample container and breaks the chain of contact with Mars by transferring the sample into a sterile and secure container. With the sample contained, the retrieving spacecraft makes a controlled Earth re-entry preventing any unintended release of pristine martian materials into the Earth's biosphere.

The analysis methods employed standard and specialized aerospace engineering tools. Mission system elements were analyzed with either direct techniques or by using parametric mass estimating relationships (MERs). The architecture was iterated until overall mission convergence was achieved on at least one path. Subsystems analyzed in this study include support structures, power system, nose fairing, thermal insulation, actuation devices, MAV exhaust venting, and GN&C. Best practice application of loads, mass growth contingencies, and resource margins were used. For Falcon Heavy capabilities and Dragon subsystems we utilized publically available data from SpaceX , published analyses from other sources, as well as our own engineering and aerodynamic estimates.

Earth Launch mass is under 11 mt, which is within the estimated capability of a Falcon Heavy, with margin. Total entry masses between 7 and 10 mt were considered with closure occurring between 9 and 10 mt. Propellant mass fractions for each major phase of the EDL - Entry, Terminal Descent, and Hazard Avoidance - have been derived. An assessment of the effect of the entry conditions on the thermal protection system (TPS), currently in use for Dragon missions, shows no significant stressors. A useful payload mass of 2.0 mt is provided and includes mass growth allowances for the MAV, the ERV, and mission unique equipment.

We also report options for the MAV and ERV, including propulsion systems, crewed versus robotic retrieval mission, as well as direct Earth entry.

International planetary protection policies as well as verifiable means of compliance will have a large impact on any MSR mission design. We identify areas within our architecture where such impacts occur. We also describe preliminary compliance measures that will be the subject of future work.

This work shows that emerging commercial capabilities as well as new methodologies can be used to efficiently support an important planetary science objective. The work also has applications for human exploration missions that use propulsive EDL techniques.