# Launch and Transfer Systems Technology and Architecture Considerations for Mars Exploration

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**Abstract:** The development of the mission architectures for future Mars exploration depends very heavily on the availability and capability of certain systems technologies for those missions. A systems technology could be defined as something which requires the integration of multiple subsystems in order to demonstrate their combined functionality and/or integration and operation of a system in a space environment which cannot be fully demonstrated on the ground. This paper discusses some of these considerations for launch and transfer systems and proposes some candidate plans for development of these system technology capabilities.

**Systems Technologies:** The fundamental requirements on the flight and ground elements of these missions depend on the mission concepts and the systems technology that is available to support those concepts. Five of the most basic systems technology considerations for launch and orbit transfer systems are:

1. Autonomous rendezvous and docking.
2. Cryogenic fluid storage, management and transfer.
3. In-situ Resource Utilization (ISRU).
4. Mars Ascent Vehicle System Design.
5. Planetary Ascent Vehicle Inertial Guidance System Initialization.

*Autonomous Rendezvous and Docking.* This technology is crucial in making architecture decisions on whether it is possible to implement rendezvous and docking in Earth orbit for outbound transfer to Mars or in Mars orbit for inbound transfer back to Earth. Both of the current baseline architectures for a robotic sample return mission [1] and a human crewed mission [2] assume the use of this technology. For missions to Mars which begin in Low Earth Orbit the systems which orbit Earth and can assist with orbit and position determination like the GPS, would not likely be available at Mars anytime in the near future. The availability of this technology can significantly change the requirements and costs of launch from Earth to Low Earth Orbit and from Mars to Low Mars Orbit.

*Cryogenic Fluid Storage, Management and Transfer.* Cryogenic propellants provide the highest specific impulse of any propellant combination for launch and transfer vehicles. Due to this significant performance difference, the ability to store and/or transfer cryogenic propellants for use on stages, depots or ascent vehicles has the potential to have a significant effect on the size or architecture of the system. Mars transfer orbits from Low Earth orbits could be accomplished with multiple launches with rendezvous and docking similar to the original architecture of the Constellation Program for Lunar missions.

*In-Situ Resource Utilization.* The ability to utilize planetary resources to produce propellants would have a significant effect on the architecture, requirements and mass of Mars ascent vehicles.

*Mars Ascent Vehicle System Design.* As has been identified in numerous studies, the design of a planetary ascent vehicle will be a challenge due to the velocity change requirements, the storage and operational low temperature environments on Mars and the integration requirements with its carrier spacecraft and sample or human return vehicles.

*Planetary Ascent Vehicle Inertial Guidance System Initialization.* In order to perform its ascent function, the guidance system on the vehicle must be initialized with its' position in a planetary coordinate system. The current capability for position location error on Mars is approximately 10 km. This will show up as a bias error in the ascent vehicle guidance orbit injection solution. It must be corrected by using additional propellant on the space vehicles after they reach orbit and have had an orbit determination accomplished. If this initial position error could be reduced it could reduce the propellant required on-orbit to correct for this bias error.

**Technology Development Needs and Planning:** One of the first technology needs is autonomous rendezvous and docking. This is part of the Low Earth rendezvous architecture for the baseline crewed missions and necessary at Mars for the robotic sample return missions and crewed return missions. Perhaps the first step should be to demonstrate this systems technology with Earth orbiting spacecraft and upper stages before proceeding to more complex and expensive missions at Mars. Some of these missions could also be Lunar missions to develop and demonstrate the systems technologies and operations for ISRU, ascent vehicle design and autonomous guidance system initialization. These missions could also provide valuable Lunar science and sample return from Lunar sites which have not been previously accessed and may be of future interest.

Another technology need is cryogenic propellant fluid storage, management and/or transfer. This technology along with autonomous rendezvous and docking allows the use of cryogenic propulsion stages to rendezvous/dock and perform the transfer orbit to Mars with much greater propulsion efficiency.

ISRU technology could be developed for use at Mars to enable the capability to fuel Mars ascent vehicles and Mars orbit to Earth transfer vehicles with propellant produced locally at Mars. This could significantly reduce the landed mass of the ascent vehicle on Mars and the performance requirements for launch and transfer vehicles which inject them on Mars transfer trajectories from Earth. Dedicated missions to Mars to develop and demonstrate this ISRU technology should be accomplished prior to incorporating it into a mission concept and architecture baseline.

The design of Mars ascent vehicles from a propulsion standpoint is different from both Earth based launch vehicles which have high thrust, high mass fractions because of their scale and high specific impulse. If is also different from current spacecraft propulsion systems which have low thrust, low mass fractions and more modest specific impulse. The propulsion systems for Mars ascent vehicles must meet thrust requirements like Earth launch vehicles in order to attain positive thrust to weight ratios, but must do so on a much smaller scale. They must also be stored and operate in the very cold Mars environment. This has impacts for the electrical power and thermal subsystem design of the ascent vehicles and the landing vehicles which carry the ascent vehicles to the surface. As has been shown by Whitehead [3], the propulsion and system design challenges must be addressed by focused technology development. The technology focus for this area should be appropriate propellant and other subsystem component design, low temperature storable propellants and/or the incorporation of IRSU for on-planet propellant production.

First for robotic sample return missions, there is a need to autonomously initialize the position of the ascent vehicle inertial guidance system. One potential solution is with the use of digital sun sensors coupled with inertial measurement units to make sun position measurements to perform autonomous celestial navigation on the planet for initial position determination. This technology could be tested on Earth first and then on Lunar sample return missions and Mars lander and rover missions before incorporating it into Mars return missions. This is essentially an autonomous surveying technology need rather than a need to develop inertial guidance technology. Other position location technologies might also be examined for development. For future crewed missions, the assistance of the crew could be utilized as a primary or backup method for accurate initial position determination.

NASA should develop an integrated and incremental set of technology development plans and missions in order to support launch and transfer systems technology. This is necessary to support credible architecture definition for future robotic sample and crewed return missions from Mars.

**References:**

[1] The iMARS Working Group (2008) *Report of the International Mars Architecture for the Return of Samples (iMARS) Working Group*

[2] Drake B.G. (editor) (2009) NASA-SP-2009-566 *Human Exploration of Mars Design Reference Architecture 5.0*

[3] Whitehead, J.C. (1997) AIAA -1997-2950 *Mars Ascent Propulsion Options for Small Sample Return Vehicles*