An Overview of Mars Vicinity Transportation Concepts for a Human Mars Mission

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Abstract

To send a piloted mission to Mars, transportation systems must be developed for the Earth to Orbit, trans Mars injection (TMI), capture into Mars orbit, Mars descent, surface stay, Mars ascent, trans Earth injection (TEI), and Earth return phases. This paper presents a brief overview of the transportation systems for the Human Mars Mission (HMM) only in the vicinity of Mars. This includes: capture into Mars orbit, Mars descent, surface stay, and Mars ascent. Development of feasible mission scenarios now is important for identification of critical technology areas that must be developed to support future human missions. Although there is no funded human Mars mission today, architecture studies are focusing on missions traveling to Mars between 2011 and the early 2020's.

Introduction

For several years engineers and scientists at NASA have been developing mission scenarios for sending humans to Mars and returning them safely to Earth. The HMM has evolved as analyses have been completed and updated. The design reference mission (DRM)[1,2] describes the baseline mission architecture at a given time, it is not intended to be a final or recommended mission scenario. As development of the HMM continues, the DRM and various mission architecture options or design reference points (DRPs) are refined and updated. Several locations are included in the DRPs: Mars, the Moon, and asteroids. At this time, only the Mars DRP has been evaluated in any detail.

Overall Mission Description

The baseline mission architecture as currently defined by the Exploration Office at JSC, the Exploration Transportation Office at MSFC, and the offices at the other NASA centers supporting the HMM is based on deploying mission assets on the Mars surface two years before sending the crew. Insuring that the power generation system, in-situ resource utilization (ISRU) plant, and other cargo are safely delivered and operational prior to the crew departure from Earth reduces the risk to the crew. Launch vehicles would be sent to Mars every two years, using rapid transit times (approximately 180 days) for the crewed missions and longer duration, low energy transits for the cargo missions. The crew will spend 18 to 22 months on the surface of Mars before returning to Earth. Table 1 outlines the different propulsion options under consideration for the HMM.

Table 1. HMM Baseline Mission Concepts

	Baseline Mission Concept	Additional Mission Concepts
Earth-to-Orbit	80 mt Magnum Launch Vehicle	
TMI	Nuclear Thermal Propulsion (NTP) [3]	Chemical propulsion, solar electric propulsion (SEP)
Mars Descent/Ascent	LOX/CH_4 RL10 class engines	LOX/LH_2 RL10 class engines
TEI	Chemical propulsion (LOX/CH_4)	Chemical propulsion (LOX/LH_2), NTP

The first cargo launch opportunity is planned for 2011. The first launch series, using two 80 metric tonne (mt) Magnum type launch vehicles, would place the surface habitat stage and descent stage into low earth orbit (LEO). The second launch series would place the ascent stage, the ISRU plant, the surface power plant, and additional surface cargo to LEO. One LEO automatic rendezvous and capture (AR&C) maneuver would be required for each stack prior to beginning the TMI phase of the mission. The surface habitat-descent stage stack would aerocapture into a 1 Sol orbit (250 km x 33,700 km) around Mars and would remain there until the crew arrives to rendezvous prior to landing on Mars. The ascent-ISRU plant-surface cargo stack would also aerocapture into the 1 Sol Mars orbit, would aerobrake out of orbit, and would then descend to the Mars surface. After landing on the Mars surface the surface nuclear power plant would autonomously egress from the descent stage and would deploy. After surface power is established the ISRU plant would begin operation, producing the liquid oxygen (LOX) and liquid methane (CH_4) required by the ascent stage.

Figure 1 presents the crew and cargo launches for the second launch opportunity in January 2014. Two 80 mt launch vehicles would place the transit habitat into LEO. The crew of six would launch in the Space Shuttle and would rendezvous with the stage in LEO. The crew would depart for Mars in the this transit habitat-TEI stage, would rendezvous with the surface hab-descent stage in Mars orbit, aerobrake out of orbit with the surface hab-descent stage only, and would make a parachute and propulsive precision landing on the Mars surface. Four additional Magnum launches would also take place in 2014, deploying the assets for the second piloted mission. These assets would also serve as backup or contingency hardware for the first crew. Following completion of the mission on Mars the crew would use the ascent stage to depart for rendezvous with the TEI stage in orbit around Mars. The crew would live in the transit habitat during the TEI phase of the mission and would return to Earth in an Apollo style small return module. Additional information on the mission transportation scenarios is presented in reference 4.

The departure and return dates and trajectories are presented in Figure 2 for the 2014 piloted mission opportunity. In this flight profile the outbound trip time is 178 days. After 561 days on the surface of Mars the crew returns to Earth in 156 days.

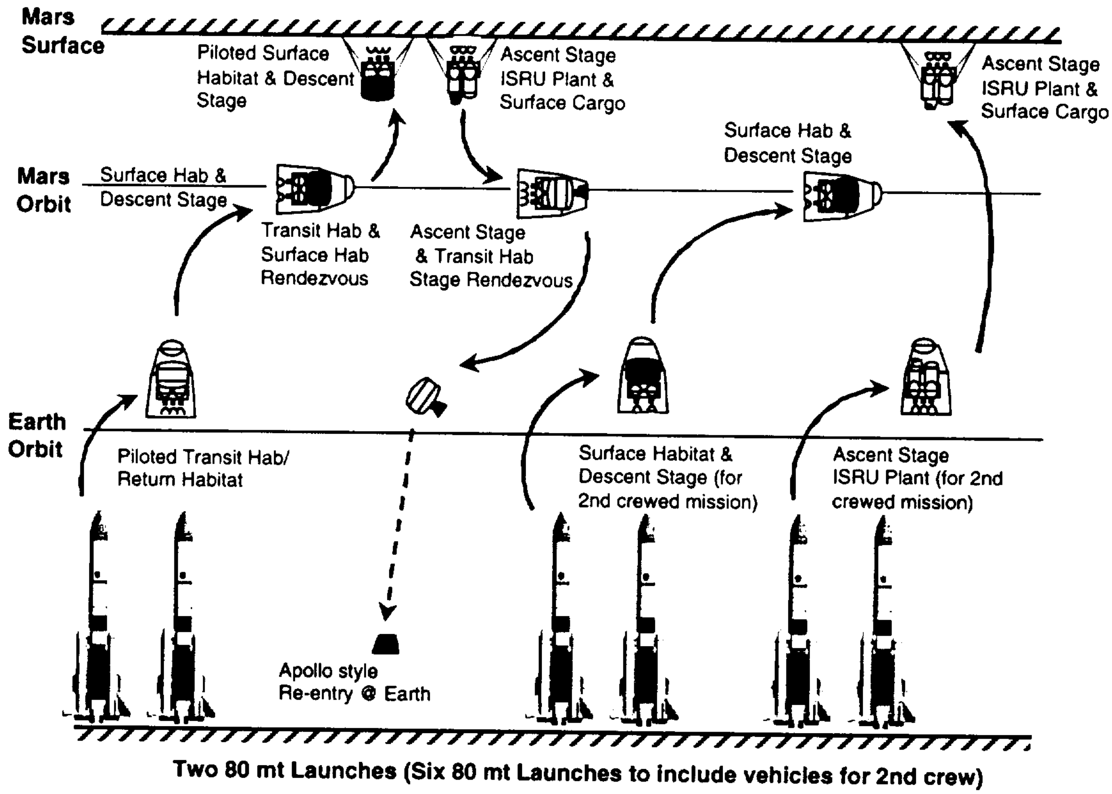

Figure1. HMM Architecture, Design Reference Point: 2014 Opportunity[4]

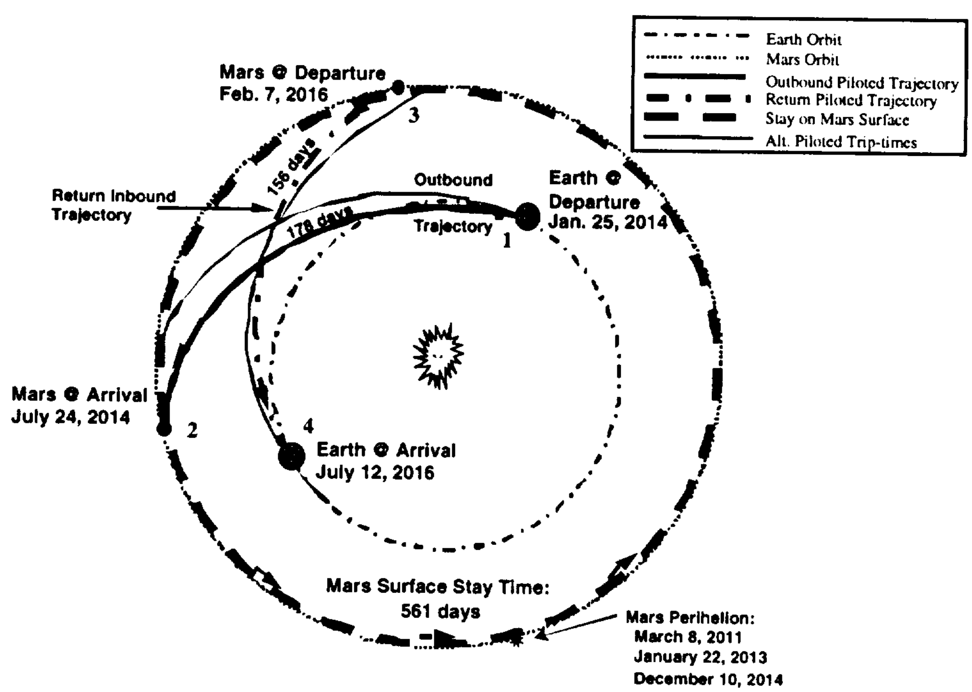

Figure 2. HMM Design Reference Point: 2014 Piloted Trajectory[4]

Mars Vicinity Transportation Description

Development of Mars vicinity transportation capability is focused on several technical areas. The first is aerocapture, or the use of the Mars atmosphere to decelerate and capture the space vehicles into orbit around Mars. Descent to the surface of Mars using both parachutes and propulsive systems is the second area to be discussed. Resources from the Martian atmosphere will be used to provide not only oxygen and water for the crew life support, but propellants for the return to Earth. In-situ propellant production (ISPP), a subset of ISRU, utilizes carbon dioxide (CO_2) from the atmosphere and hydrogen brought from Earth to make both gaseous oxygen and methane. The processes by which these gases are converted into useable liquid propellants is encompassed in cryogenic fluid management (CFM). The final transportation area to be addressed is ascent of the crew from the Mars surface.

Mars Aerocapture

Several options exist for decelerating the TMI stage as it approaches Mars. The vehicle could use the atmospheric forces of Mars to decelerate and land directly on the Mars surface. This aerobrake maneuver would be similar to the direct entry return to Earth used during the Apollo program. Propulsive systems carried on board the TMI stage could be used to slow the vehicle sufficiently to be captured into orbit around Mars. The third option would be to use the atmospheric forces to decelerate and be captured into orbit. The vehicle would enter the atmosphere of Mars and would exit again after the vehicle had slowed to a velocity to place it into the 1 Sol Mars orbit. There are several advantages to the aerocapture maneuver. Some sort of aeroshell would be required, regardless of the deceleration method chosen, due to the high heating rates generated during passage through the Mars atmosphere. Stopping in Mars orbit prior to descent provides more control over the location and time of landing. Aerocapture meets the mission requirement to land both cargo and piloted vehicles in a safe location on Mars and in close proximity to each other. In addition, Mars aerocapture has been estimated to reduce the mission mass over the all-propulsive option.[2,5]

Several operational factors drive the design of the aerobrake shell: vehicle entry speeds (estimated to be less than 7.6 km/sec), atmospheric heating constraints, maneuverability requirements, and the crew deceleration limit (5 Earth g's). As a baseline, a triconic aerobrake shape was chosen for analysis.[2] This design met the mission and vehicle packaging requirements. A sketch of the triconic aerobrake is presented in Figure 3.

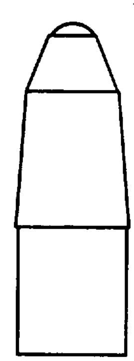

Figure 3. HMM Triconic Aerobrake

Mars Descent

The cargo stage which descends to the Mars surface serves as the ascent vehicle for the crew. This stage would include: parachutes for the initial descent phase and four 25,000 lbf (110,100 N) LOX/CH_4 RL10 class engines for post-aerocapture orbit circularization, de-orbit burn, and final descent maneuvering and landing. During mission analyses earlier this year[2] the parachute system was identified as a cluster of large (about 50 meter diameter) Viking-type parachutes. The parachutes would be deployed at an altitude of approximately 8 km above the Martian surface while the descent vehicle was traveling at 700 m/sec. At an altitude of roughly 5 km the engines would be ignited. The use of a combined parachute/propulsive landing system is estimated to result in mass savings on the order of 10,000 kg over an all-propulsive descent stage.

The modified RL10 class engine characteristics include: a specific impulse of 377 seconds, mixture ratio of 3.5, chamber pressure of 600 psi (4.1 MPa), and a nozzle area ratio on the order of 300 to 400. The engine must also be capable of throttling and gimbaling. Perhaps the most significant requirement for the engine is the need to survive in the Mars environment for several years without an impact to performance or operation.

To minimize the number of engine development programs, the piloted stage would use a similar parachute/propulsive system to land on the surface of Mars. This stage would not however be used as an ascent stage.

Recent analyses have evaluated the use of liquid hydrogen (LH_2) as the fuel rather than liquid methane for the four descent engines. For these analyses the RL10B-2 class engine characteristics included: thrust of approximately 25,000 lbf (110,100 N), specific impulse of 466 seconds, mixture ratio of 6, chamber pressure of 644 psi (4.44 MPa), and a nozzle area ratio of 285. For a valid mission scenario using LH_2 the assumption must be made that no hydrogen boils off during the long-term storage in orbit and on Mars. This will be discussed further in the next section.

In-situ Propellant Production (ISPP)/Cryogenic Fluid Management (CFM)

The atmosphere on Mars is made up almost entirely of CO_2, with some nitrogen and argon. With the addition of hydrogen brought from Earth, the Mars atmosphere provides an abundant supply of materials for the production of liquid rocket engine propellants and crew life support consumables. Several ISPP process options are available, including: the Sabatier reaction, water electrolysis, carbon dioxide electrolysis, methane pyrolysis, and reverse water gas shift process. Power requirements, plant masses, system reliability, and development issues are being evaluated for the process options.

The current baseline plant makes use of the Sabatier, water electrolysis, and carbon dioxide electrolysis (using Zirconia cells) processes. Carbon dioxide from the atmosphere enters the Sabatier plant where it reacts with hydrogen to produce methane and water. Oxygen for the crew life support and for propellant can be produced from this water using the water electrolysis process. Hydrogen from both of these processes can be recycled back into the Sabatier reaction to produce additional methane. The water can also be stored for the crew life support system. The Sabatier plant and Zirconia cells can be operated independently. A simplified sketch of the Sabatier/Water Electrolysis/Zirconia Cell ISPP plant is presented in Figure 4.

The cryogenic fluid management (CFM) system is responsible for converting and storing the gases produced by the ISPP plant as cryogenic liquids. A hybrid system using both insulation and cryo coolers is envisioned for the LOX, methane, and hydrogen. The major advantage of a hybrid cooling system is the feasibility of achieving zero boiloff of the propellants. For long term storage times, in space and on the surface of Mars, zero boiloff results in mass savings not only in the amount of propellant which must be stored or transported, but in smaller tank sizes.

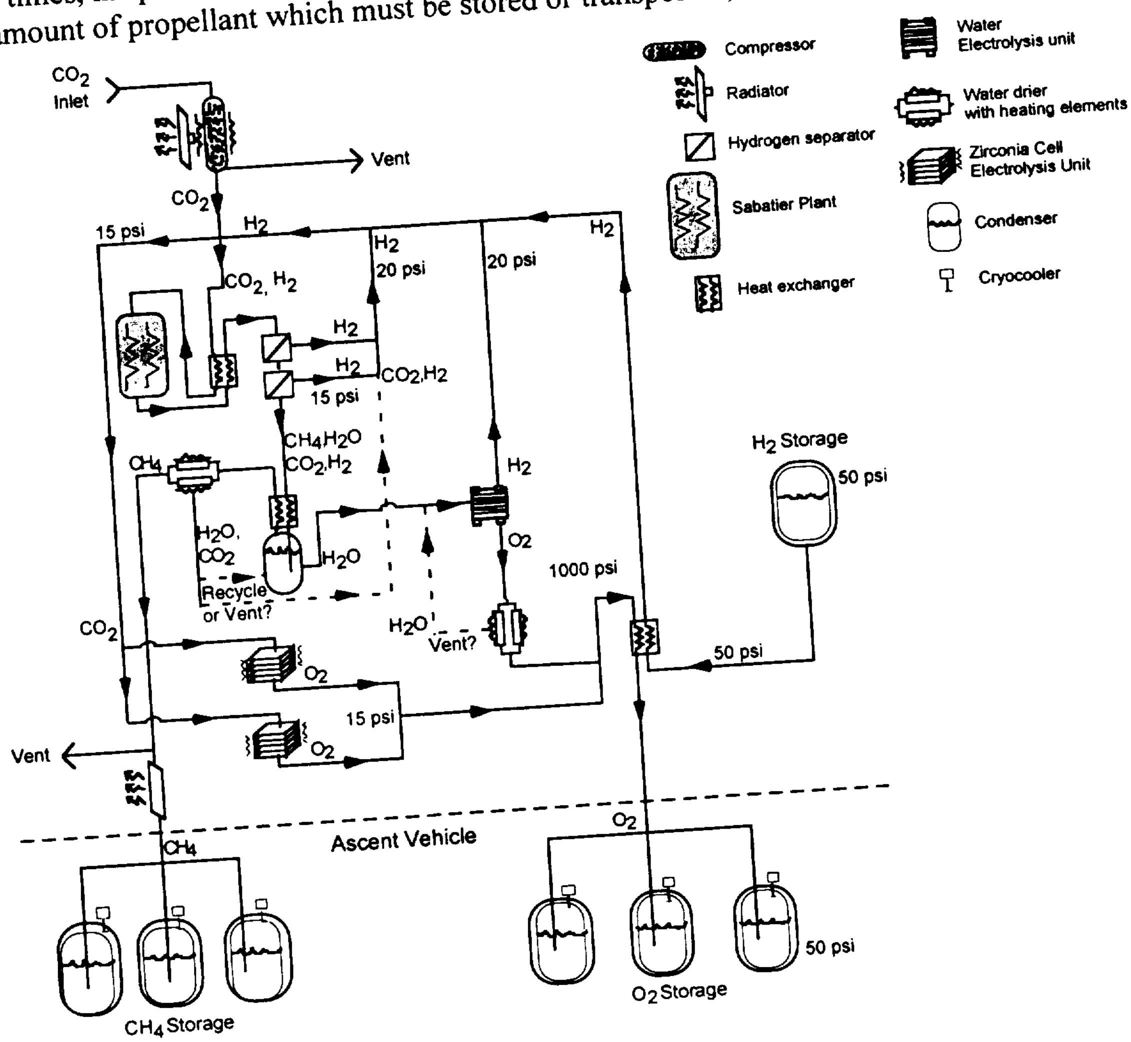

Figure 4. Baseline ISPP Plant[6]

Mars Ascent

After nearly two years on the surface of Mars the crew will begin their long journey back to Earth. The ascent vehicle, which landed on Mars nearly four years ago, would have been previously loaded with both LOX and methane. Although four engines were used during descent of the ascent vehicle to Mars it is anticipated that only two engines will be required during the ascent phase. These engines will have been fired previously during orbital maneuvers and during descent, therefore it is critical that they have high reliability and be capable of surviving on the Mars surface for extended duration with minimal or no maintenance. The ascent vehicle will rendezvous in the Mars 1 Sol orbit with the TEI stage and will then begin the trip home.

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