

Human Exploration of Mars Design Reference Architecture 5.0

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ABSTRACT

This paper provides a summary of the Mars Design Reference Architecture 5.0 (DRA 5.0), which is the latest in a series of NASA Mars reference missions. It provides a vision of one potential approach to human Mars exploration. The reference architecture provides a common framework for future planning of systems concepts, technology development, and operational testing as well as Mars robotic missions, research that is conducted on the International Space Station, and future lunar exploration missions. This summary the Mars DRA 5.0 provides an overview of the overall mission approach, surface strategy and exploration goals, as well as the key systems and challenges for the first three human missions to Mars.

Key Words:

Mars exploration
Human exploration
Mars systems
Mars challenges
Mars architecture

1. HISTORICAL BACKGROUND

During the past several years, NASA has either conducted or sponsored numerous studies of human exploration beyond low-Earth Orbit. These studies have been used to understand requirements for human exploration of the Moon and Mars in the context of other space missions and research and development programs. Each of these exploration architectures provides an end-to-end reference against which other mission and technology concepts can be compared. This paper provides a summary of the 2007 Mars Design Reference Architecture 5.0 (DRA 5.0), which is the latest in a series of NASA Mars reference missions (Drake, 2009). It provides a vision of one potential approach to human Mars exploration. The strategy and example implementation concepts that are described here should not be viewed as constituting a formal plan for the human exploration of Mars, but rather provide a common framework for future planning of systems concepts, technology development, and operational testing as well as potential Mars robotic missions, research that is conducted on the International Space Station, and future exploration mission to the Moon or near-Earth objects. This summary of the Mars DRA 5.0 provides an overview of the overall mission approach, surface strategy and exploration goals, as well as the key systems and challenges for the first three concepts for human missions to Mars.

2. DRA 5.0 OVERVIEW

The NASA Design Reference Architecture 5.0 envisions sending six crewmembers to Mars on each of three consecutive opportunities. The rationale for a crew of this size has been judged to be a reasonable compromise between the skill mix and level of effort for missions of this complexity and duration balanced with the magnitude of the systems and infrastructure needed to support the crew. One of the primary objectives for potential future human exploration of Mars would be to understand the global context of the history of Mars, and thus, each mission would visit a different unique location. The science and exploration rationale for visiting three different sites recognizes that a planet as diverse as Mars would not likely be adequately explored and understood from the activities that could take place at a single site. However, this three-site assumption does not preclude returning to any of the sites should there be a compelling need to do so. This approach was endorsed by the Human Exploration of Mars Science Advisory Group, which is an independent science team sponsored by the Mars Exploration Program Analysis Group (MEPAG, 2008).

Each of the three missions would use conjunction class (long-stay) trajectories combined with a “forward deploy” cargo strategy. A portion of each mission’s assets would be sent to Mars one opportunity prior to the crew. This forward deploy strategy would allow for verification and checkout of many of the Mars systems prior to departure of the crew from Earth, thus reducing mission risk. In addition, pre-deployment would allow lower energy trajectories to be used for these pre-deployed assets, which would allow more useful payload mass to be delivered to Mars for the propellant available. The decision to pre-position some of the mission assets also would better accommodate the strategy to make part of the ascent propellant at Mars, using the martian atmosphere as the raw material source for this ascent propellant. This use of in-situ resources and the equipment to process these resources into useful commodities would result in a net decrease in the total mass that would be needed to complete a mission as well as a significant reduction in the size of the landers. A surface nuclear power source would be utilized for producing this ascent propellant as well as for providing power for the surface systems once the crew arrives. Splitting the mission elements between pre-deployed cargo and crew vehicles would allow the crew to fly on faster, higher-energy trajectories, thus minimizing their exposure to the hazards associated with deep-space inter-planetary travel.

Interplanetary Trajectory and Mission Analysis

Although no date has been chosen for the first potential human mission to Mars, missions with Earth departure dates ranging from 2030 to 2046 were considered. These dates were chosen to assess the variability of mission opportunities across the synodic cycle and not to represent proposed actual mission dates. Mission opportunities occur approximately every 2.1 years in a cycle that repeats every 15 years (the synodic cycle). Along with the crewed missions, one-way cargo delivery trajectories were also generated that would depart during the opportunity preceding each crewed mission. At Mars, the vehicles would be inserted into a 1-sol elliptical orbit (250 km by 33,793 km). An example crew mission in the 2037 opportunity would result in transit times of 174 days outbound and 201 days inbound. The crew's Mars stay time would be 539 days, and the total mission duration would be 914 days. The supporting cargo vehicle would depart Earth a little more than two years before the crewed mission and follows a minimum energy trajectory. The trip time of 202 days would be the quickest cargo flight time that was observed over the dates analyzed.

Getting Ready, Getting to Mars, and Getting Back

Due to the significant amount of mass required for a human mission to Mars, numerous heavy-lift launches would be required. Using the same launch vehicle currently envisioned for lunar missions would greatly improve the overall mission risk due to the improved maturity of the launch vehicle by the time the Mars missions would commence. Current estimates of the mission manifest indicate that at least seven heavy-lift cargo launches would be required, but the number of launches could be higher, depending on the architecture-wide technology options inserted. This large number of launches would necessitate a launch campaign that must begin several months prior to the opening of the Mars departure window. The reference strategy that is adopted would eliminate on-orbit assembly of the mission elements by segmenting the systems into discrete packages and using automated rendezvous and docking of the major elements in Earth orbit. Launches would occur at least 30 days apart and would be completed several months before the opening of the Mars departure window to provide a margin for technical delays and other unforeseen problems. This strategy requires that the in-space transportation systems and payloads loiter in orbit for several months prior to departure for Mars.

The first phase of the mission architecture would begin with the pre-deployment of the first two cargo elements, the descent/ascent vehicle and the surface habitat. These two vehicle sets would be first launched, assembled (via rendezvous and docking), and checked out in Earth orbit. After all of the systems have been verified and are operational, the vehicles loiter in Earth orbit until the Earth-Mars departure window opens, when they would be injected into minimum energy transfers from Earth orbit to Mars just over two years prior to the launch of the crew. Upon arrival at Mars, the vehicles would be captured into a highly elliptical Mars orbit. The surface habitat would remain in Mars orbit in a semi-dormant mode, waiting for arrival of the crew two years later. The descent/ascent vehicle would be captured into a temporary Mars orbit from which it would autonomously perform the entry, descent, and landing on the surface of Mars at the desired landing site. After landing, the vehicle would be checked out and its systems verified to be operational. Dormant upon landing, the surface fission reactor would be deployed from the lander, power generation initiated, and production of the ascent propellant and other commodities that would be needed by the crew would be completed before committing to the crew phase of the mission.

A key feature of the long-stay mission architecture is the autonomous deployment of a portion of the surface infrastructure before the crew arrives, such as the surface power system. This strategy includes the capability for these infrastructure elements to be unloaded, moved significant distances, and operated

for significant periods of time without humans present. In fact, the successful completion of these various activities would be part of the decision criteria for launch of the first crew from Earth.

The second phase of this architecture begins during the next injection opportunity with the launch, assembly, and checkout of the crew Mars transfer vehicle. The transfer vehicle would serve as the interplanetary support vehicle for the crew for a round-trip mission to Mars orbit and back to Earth. Prior to departure of the flight crew, a separate checkout crew might be delivered to the vehicle to perform vital systems verification and any necessary repairs prior to departure of the flight crew. After all vehicles and systems, including the Mars ascent vehicle (on the surface of Mars), surface habitat (in Mars orbit), and the transfer vehicle (in Earth orbit) are verified operational, the flight crew would be injected on the appropriate fast-transit trajectory toward Mars. The length of this outbound transfer to Mars would be dependent on the mission date and would range from 175 to 225 days.

Upon arrival at Mars, the crew members would perform a rendezvous with the surface habitat, which would serve as their transportation leg to the surface of Mars. Current human health and support data indicate that it might take the crew a few weeks to acclimate to the partial gravity of Mars after landing. After the crew has acclimated, the initial surface activities would focus on transitioning from a “lander mode” to a fully functional surface habitat. This would include performing all remaining setup and checkout that could not be performed prior to landing, as well as transfer of hardware and critical items from the pre-deployed descent/ascent vehicle.

The long-stay mission architecture would lend itself to a very robust surface exploration strategy. The crew would have approximately 18 months in which to perform the necessary surface exploration. Ample time would be provided to plan and re-plan the surface activities, respond to problems, and readdress the scientific questions posed throughout the mission. The focus during this phase of the mission would be on the primary science and exploration activities that would change over time to accommodate early discoveries. A general outline of crew activities would be established before the launch, but would be updated throughout the mission. This outline would contain detailed activities to ensure initial crew safety, make basic assumptions as to initial science activities, schedule periodic vehicle and system checkouts, and plan for a certain number of sorties.

Much of the detailed activity planning while on the surface would be based on initial findings and, therefore, could not be accomplished before landing on Mars. The crew would play a vital role in planning specific activities as derived from more general objectives defined by colleagues on Earth. Alternative approaches for exploring the surface are still under discussion and are expected to be examined further, including maximizing commonality with lunar systems.

Before committing the crew to Mars ascent and return to Earth, full systems checkout of the ascent vehicle and the transfer vehicle would be required. Because both vehicles are critical to crew survival, sufficient time must be provided prior to ascent to verify systems and troubleshoot any anomalies prior to crew use. In addition, the surface systems would be placed in a dormant mode for potential reuse by future crews by stowing any nonessential hardware, powering down critical systems and their backups, and performing general housekeeping duties. Lastly, some surface elements would be placed in an automated operations mode for Earth-based control so that scientific observations could be continued after the crew has departed. The crew would then ascend in the ascent vehicle and perform a rendezvous with the waiting transfer vehicle. This vehicle would be used to return the crew from Mars, ending with a direct entry at Earth in a modified Orion crew vehicle. The potential nuclear thermal rocket version of the DRA, also known as a “bat chart,” is shown in figure 1. **[Insert Figure 1 here]**

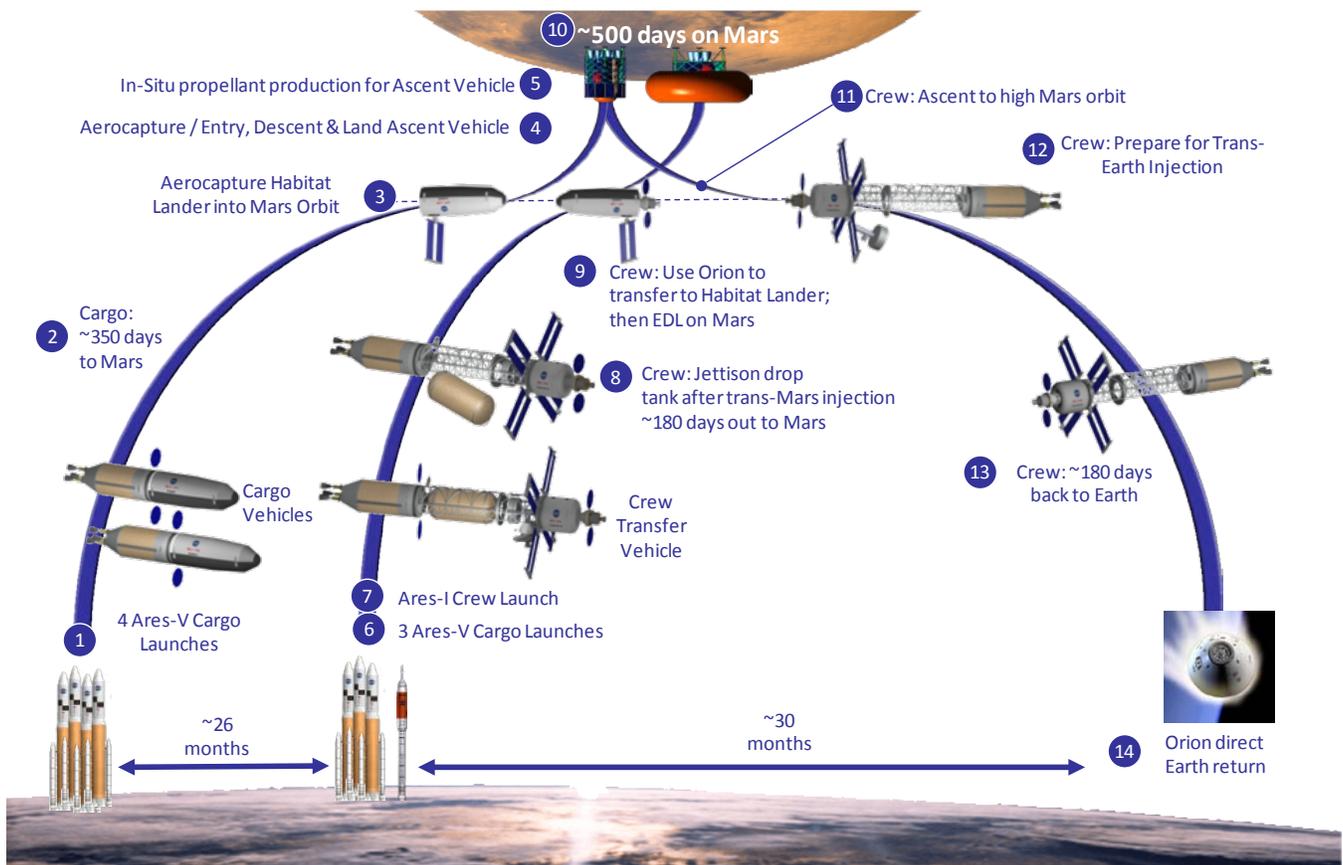


Figure 1 - Mars Design Reference Architecture 5.0 Mission Profile

Exploring the Surface

Candidate surface sites would be chosen based on the best possible data available at the time of the selection, the operational difficulties associated with that site, and the collective merit of the science and exploration questions that could be addressed at the site. Information available for site selection would include remotely gathered data sets plus data from any landed mission(s) in the vicinity plus interpretive analyses based on these data.

Several different surface architectures were assessed during the formulation of the Mars DRA 5.0, each of which emphasized different exploration strategies that were embodied in the combination of duration of in-the-field, range of exploration reach, and depth of subsurface access. The nominal surface mission scenario adopted for DRA 5.0 is the so-called “Commuter” reference architecture, which would have a centrally located, monolithic habitat, two small pressurized rovers, and two unpressurized rovers (roughly equivalent to the lunar rover vehicle that was used in the Apollo missions to the moon). This combination of habitation and surface mobility capability would allow the mission assets to land in relatively flat and safe locations, yet would provide the exploration range that would be necessary to reach nearby regions of greater scientific diversity. In this scenario, power for these systems would be potentially supplied by a nuclear power plant that was previously deployed with the descent/ascent vehicle and used to make a portion of the ascent propellant. Traverses would be a significant feature of the exploration strategy that would be used in this scenario, but these traverses would be constrained by the capability of the small pressurized rover. In this scenario, these rovers have been assumed to have a

modest capability, notionally a crew of two with a minimum of 100 km total distance before being resupplied and one- to two-week duration. Thus, on-board habitation capabilities would be minimal in these rovers. However, these rovers are assumed to be nimble enough to place the crew in close proximity to features of interest (i.e., close enough to view from inside the rover or within easy extravehicular activity walking distance of the rover). Not all crew members would deploy on a traverse, so there would always be some portion of the crew in residence at the habitat. The pressurized rovers would carry (or tow) equipment that would be capable of drilling to moderate depths – from tens to hundreds of meters – at the terminal end of several traverses.

Figure 2 illustrates a notional series of traverses to features of interest at the junction of the Isidis Planatia and Syrtis Major regions. No particular preference is being given to this site; it is included here to illustrate some general features of a human exploration mission and the resulting implications for operations at such a site. [Insert Figure 2 here]

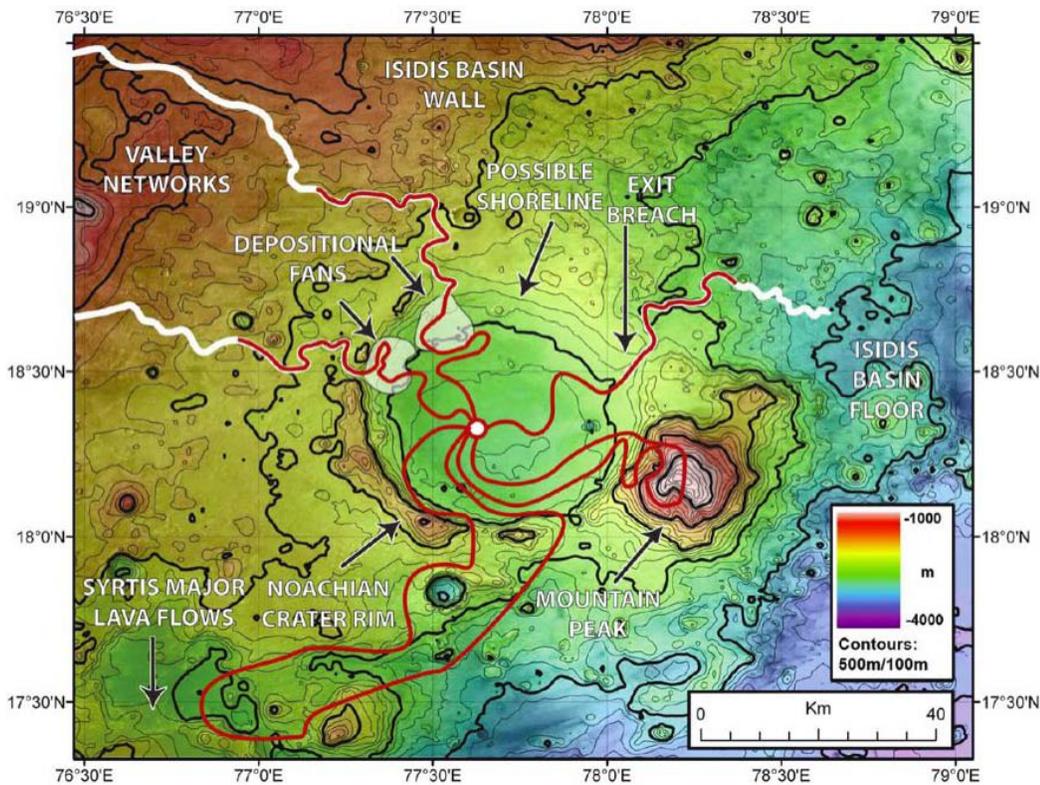


Figure 2 – Example Surface Mobility and Exploration Range

From an operational perspective, this location has a relatively broad, relatively flat, centrally located area where cargo elements could land in relative safety. However, this would place these systems and the crew at large distances from features that are of interest to the crew and the science teams. The scale at the lower right of figure 2 indicates that these features of interest are beyond what is currently considered a reasonable walking range for the crew (determined by the distance a crew member could walk during one charge of power and breathing gases in his/her Portable Life Support System roughly 20 km total). Although sites with much more closely spaced features of interest certainly exist, they are usually found at the expense of a relatively safe landing site.

One feature of interest is not illustrated here: the subsurface. Understanding the vertical structure of the site would also be of interest, indicating that a drilling capability would need to be included for each mission and site. The ability to move a drill from location to location would also be desirable. The primary habitat would have space and resources allocated for on-board science experiments. The pressurized rovers would carry only the minimal scientific equipment deemed essential for field work (in addition to the previously mentioned drill). Samples would be returned to the primary habitat and its on-board laboratory for any extensive analysis.

4. VEHICLE AND SYSTEMS OVERVIEW

Successfully accomplishing the goals and missions set for DRA 5.0 would require a variety of launch, in-space, and planetary surface vehicles as well as specific operational procedures to use them. The technical assessments conducted for the DRA 5.0 focused primarily on launch vehicle, interplanetary transportation, and entry, descent and landing systems. Assessments of the applicability of the Orion crew exploration vehicle as well as the Mars descent/ascent vehicle and the interplanetary transit habitat were also conducted, but not to the same level of detail. Assessments of using the Constellation Program's heavy-lift launch vehicle, the Ares V launch vehicle, for a human mission to Mars were examined both in the context of the required performance (e.g., initial mass in low-Earth orbit, and number of launches, etc.). For the in-space transportation system for crew and cargo, the design team assessed both nuclear thermal and advanced chemical propulsion options. In previous design reference missions, a small capsule was envisioned for the Earth return vehicle, but with the design of the Orion there is now a block-upgrade path that would seek to augment the capsule that is currently being designed to go to the moon for use on a potential round-trip Mars mission. This would primarily involve upgrading the Thermal Protection System on the current Orion design to account for the higher Earth entry speeds and certifying the vehicle for extended dormant times in a space environment.

Additional technical studies associated with surface systems for DRA 5.0 focused primarily on understanding the relationship between the functional capabilities necessary to accomplish the exploration goals and objectives and establishment of the top-level definition of the systems that are necessary for those functions. In most cases, detailed designs for surface systems were not developed, but rather, top-level performance estimates and trades were conducted. More in-depth detailed definition of the various surface systems should be conducted in future efforts, including commonality with lunar surface systems.

Perhaps the most important advancement in knowledge since the last Mars reference mission study involves the landing systems that are to be employed at Mars to land payloads on the order of 30 to 50 tons (t). Previous estimates of human-class Mars landing system mass were determined to be optimistic given the great unknowns that are still associated with landing robotic payloads greater than one ton on Mars. Additional knowledge and insights that were gained with the successful Mars robotic mission designs of the last decade (Mars Pathfinder, the Mars exploration rovers Spirit and Opportunity, and the Mars Phoenix lander) have also resulted in more realistic estimates for system masses required for robust lander system designs. The new assessment details a more conservative estimate of entry and landing system mass, which has substantially increased, in spite of the advantage gained from the presumed use of a common Ares V launch shroud/aeroshell payload entry shield. Mass increases in this subsystem are a prime contributor to the overall increase in the initial mass estimates given in this DRA as compared to previous approaches. A summary of the transportation and surface systems envisioned for Mars DRA 5.0 is provided in figure 3. **[Insert Figure 3 here]**



Figure 3 – Transportation and Surface Systems Concepts

5. KEY CHALLENGES

Missions to Mars represent the next plateau in human exploration of space. Just as Mercury, Gemini, and Apollo grew out of the technology and experience base of the aircraft and missile industry, Mars missions would be an outgrowth of our technology and experience base of Apollo, Shuttle, and ISS in combination with other technologies recognized as necessary to reach this plateau. There are significant challenges that must be overcome to successfully complete a potential human Mars exploration mission, but NASA has historically used the creative talents of its workforce to find the ways and means to successfully carry out its assigned missions that more than satisfy the stakeholders; this same workforce would apply this same creativity to the new objectives of returning to the Moon and sending people, for the first time, to Mars. Some of the key challenges facing future explorers to Mars are provided in Table 1 and summarized below. **[Insert Table 1 here]**

Table 1 - Comparison of Lunar and Mars Mission Challenges

	Moon	Mars
Distance from Earth	384,000 km	58,000,000 – 400,000,000 km
Two-Way Communication Time	2.6 seconds	6 – 44 minutes
One-way Trip Time	4 days	180-210 days
Stay Time	7 days (sortie mission)	495 – 540 days
Total Mission Duration	18 days (sortie mission)	895 – 950 days
Aborts	Anytime return	Limited to early in the mission or multi-year
Logistics Delivery	Daily	Every 26 months
Total Mission Mass (Note: ISS ~ 400 t)	~200 t	~800 – 1,200 t
Total Delta-V (LEO to surface and back)	9.5 km/s	12 – 14 km/s

Human Health and Performance

As humans extend their reach beyond Earth orbit to the surface of Mars, they would be exposed to the hazardous environment of deep space for lengthy periods; consequently, protective measures must be devised to ensure crew health and maximize mission success.

- Radiation protection from both galactic cosmic radiation as well as solar proton events. The solution might be a combination of uncertainty reduction, shielding, mission design, and crew selection with effective biological countermeasures
- Countermeasures to ameliorate bone mineral loss and muscle atrophy in reduced-gravity environments for both the transits to and from Mars, as well as the long-duration stay on the surface
- Medical care to ensure crew health and performance with limited mass, volume, power, and crew training
- Improved behavioral understanding in order to measure, monitor, and predict mood and psychiatric conditions prior to and during long-duration remote space missions

Landing Large Payloads on Mars

Our current ability to land robotic payloads on the surface of Mars is largely reliant on the landing technology set that was developed during the Mars Viking Program in the late 1960s and early 1970s. NASA's flagship 2011 Mars mission, the Mars Science Laboratory, has reached the landed payload mass limit capability (approximately one metric ton). The very low atmospheric density at Mars prevents the use of traditional terrestrial aerodynamic decelerators as a means by which to attain subsonic velocities for landing as is done on Earth. Development of a human-rated high mass (40 t useful payload) Mars entry system remains a challenge. NASA has identified several approaches that would overcome this challenge that involve a combination of basic research in hypersonic aerodynamics, materials science, and propulsion technology to deliver these larger payloads.

Heavy Lift

Even with the incorporation of numerous advanced technologies, human missions to Mars would require total mission mass on the order of 800-1,200 t for each mission. (Note that at assembly complete, the International Space Station would have a combined mass on the order of 400 t.) The ability to launch large payloads, both in terms of mass and volumes, would be required in order to minimize the number of launches as well as complexity of assembly operations.

Using Local Resources

The use of resources found at Mars would provide substantial benefits by dramatically reducing the amount of material that must be transported from Earth to a planetary surface. In-situ resource utilization would be a critical component of long-term, largely self-sufficient operations. By extracting and processing local resources to obtain or make O₂, H₂O, CH₄, and buffer gas consumables for life support, extra-vehicular activity, and ascent propulsion, significant mass reductions or increased payload to the Mars surface would be possible.

Advanced Propulsion

Although human expeditions to Mars could be conducted using cryogenic propulsion and aerocapture, nuclear propulsion presents a compelling prospect for tremendously reducing the mass or travel time required. Advanced propulsion concepts, including space storable propellants (oxygen, methane, and hydrogen), nuclear thermal propulsion, and the ability to store and manage cryogenic fluids for long durations, would be required. Development and demonstration of advanced, long-duration transportation concepts to understand their performance and reliability would be a key element in future human exploration missions.

Robust Power

Providing robust continuous surface power, on the order of 40 kWe continuously, would be critical for future exploration of the martian surface. Due to the distance from the Sun as well as environmental conditions on the surface of Mars (atmosphere, dust, winds, etc.) football-field-size arrays would be required for a solar power approach sufficient to provide the power requirements of a nominal human Mars mission. On the other hand, fission surface power approaches are a very promising approach to providing a compact and robust continuous power source for future human exploration. An added benefit to this approach is that a single system development could be used, with minor modifications for the local environment, on the Moon, on Mars and in deep space. Radioisotope power generation

systems also have shown promise as mobile power systems as well as back-up power sources for the crew habitat in emergency systems.

Reliability and Supportability

Resupply capability (from Earth) for human Mars missions would be essentially nonexistent. All resources that would be required to support the mission must be pre-positioned or carried with the crew, with the exception of resources that would be generated in-situ. These missions would also face mass and volume limits that would restrict sparing options and strategies. These two constraints highlight the need for, and challenge of, high reliability and a self-sufficient supportability approach. It would be necessary for the crews of these missions to have at hand all of the resources that are necessary to sustain critical spacecraft systems and support equipment for the duration of their time away from Earth. This capability must be provided while minimizing associated mass and volume requirements. This self-reliance would be achieved, in part, by increasing emphasis on maintenance by repair rather than replacement. A repair-centered maintenance approach would only be effective, however, when strategically coupled with hardware design specifically structured as part of the supportability concept.

REFERENCES

- Drake, Bret G., editor, (2009), "Human Exploration of Mars Design Reference Architecture 5.0," NASA-SP-2009-566, July 2009.
- MEPAG HEM-SAG (2008). "Planning for the Scientific Exploration of Mars by Humans", Unpublished white paper, posted March 2008 by the Mars Exploration Program Analysis Group (MEPAG) at <http://mepag.jpl.nasa.gov/reports/index.html>.