THE HUMANS TO MARS REPORT 2018

AN EXPLORE MARS, INC. PUBLICATION


NASA

The Humans To Mars Report 2018

Landing Humans on Mars by 2033

The Humans to Mars Report (H2MR) is an annual publication that presents a snapshot of current progress in mission architectures, science, domestic and international policy, human factors, and public perception regarding human missions to Mars - and highlights progress and challenges from year to year. By doing so, H2MR provides stakeholders and policy makers with an invaluable resource to assist them in making decisions that are based on current facts rather than on the dated information and speculation that sometimes tends to persist in the public arena where Mars is concerned.

H2MR does not advocate any particular approach to getting to Mars, nor will this report address speculation or rumor about future architectures - except when such are impacting public perception and policy decisions.

While recently there has been some shift in emphasis in United States near-term space policy, the goal of human missions to Mars in the 2030s still maintains broad-based bi-partisan support, with unwavering support coming from NASA, Congress, and industry. Public interest in Mars also remains strong, as evidenced by a continuing stream of Mars-related consumer products as well as productions by the entertainment industry.

As always, through the publication of the Humans to Mars Report, Explore Mars is not discounting the prospect of human exploration of other destinations in the solar system. In fact, we embrace them, as long as they do not significantly delay human missions to Mars. We view Mars as a critical destination that will enable the exploration and development of space – and we firmly believe that humanity should set the goal of landing humans on the surface of Mars by 2033.

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Explore Mars was created to advance the goal of sending humans to Mars within the next two decades. To further that goal, Explore Mars conducts programs and technical challenges to stimulate the development and/or improvement of technologies that will make human Mars missions more efficient and feasible. In addition, to embed the idea of Mars as a habitable planet, Explore Mars challenges educators to use Mars in the classroom as a tool to teach standard STEM curricula.

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INTRODUCTION

Our nation has long recognized the immeasurable benefits that our space program brings to our economy, our prosperity, and our national security. This is reflected in the strong support that exists in the political realm, among the general public, and elsewhere for achieving the goal of humans walking on the surface of Mars in the 2030s. The momentum that has been building for many years to send humans to Mars has continued unabated during the past year.

With the enactment and signing into law in March 2017 of the NASA Transition Authorization Act of 2017, the legislative and executive branches of government reaffirmed their bipartisan commitment to expanding human presence beyond low Earth orbit, with the aim of launching a human spaceflight mission to Mars by the year 2033. This is a goal and timeframe that has been advocated by Explore Mars, Inc. for many years. Since our 2017 report was published, the National Space Council was created by Executive Order in June 2017, and the President issued a Memorandum in December 2017 that was designated as Space Policy Directive #1 (SP1), both of which have added a greater short-term emphasis on the utilization of the Moon; however, no changes have been made to United States policy to send humans to Mars.

Over the past year much work has been done to further scheduled robotic missions (such as the 2018 Mars InSight lander and the Mars 2020 rover). Such robotic missions are necessary precursors to future human missions. However, our aging fleet of Mars orbiters will require replacement in the near future, and a Mars Sample Return mission is also considered to be a top priority for the 2020s. These future robotic missions will maximize scientific goals as well as advance human exploration in the 2030s.

Work on architectural concepts and refinements has also continued over the past year within NASA, in academia, and in industry. These concepts have placed particular emphasis on addressing commonalities among the various architectural approaches and concepts, as well as the many “long pole” technologies that must be developed in order to send humans to Mars. One example is the fifth Mars Achievability and Sustainability Workshop (AM V) that was held in Washington, DC in December 2017, which was specifically tasked with the development of architectures to achieve different “end states” of human exploration of the Mars system within the decade of the 2030s.

In addition, exciting work is being performed on the “human factors” associated with deep space missions, in order to mitigate overall risk to astronauts. These include research on the effects of long-term exposure to radiation and microgravity as well as studies on an advanced food technology portfolio that are underway to examine nutrient degradation in foods stored under different environmental conditions.

Finally, the fascination of the general public for human missions to Mars is perhaps best evidenced by the extensive and growing number of Mars exploration themes that continue to appear in the media, in the entertainment industry, and even in consumer products.

The goal of walking on Mars has always held a special place in the collective consciousness of all humanity. We can now achieve that goal in less than two decades. As was once correctly said about the Moon and can now be said about Mars: We only have to make the decision to go there.

Figure 1: Current robotic Mars program "trajectory" in place by NASA and international space agencies that feeds into the era of forthcoming human exploration (H2M).

MARS SCIENCE

Setting the Scene for Human Exploration

The pace of scientific discoveries about Mars with implications for future exploration and human-based activities has continued unabated during the past year (2017-2018). Ongoing observations by the fleet of Mars orbiters (Figure 1) have furthered the case for a "dynamic Mars", including exciting new discoveries about the distribution of shallow but thick reservoirs of ground ice. On the surface, the analysis from both the Curiosity rover and the Opportunity rover point to a Mars with a history of water and possible preservation of the signatures of life. Exploration awaits us on the Red Planet as we plan the Mars Sample Return (MSR) mission in the 2020s and human exploration in the 2030s.

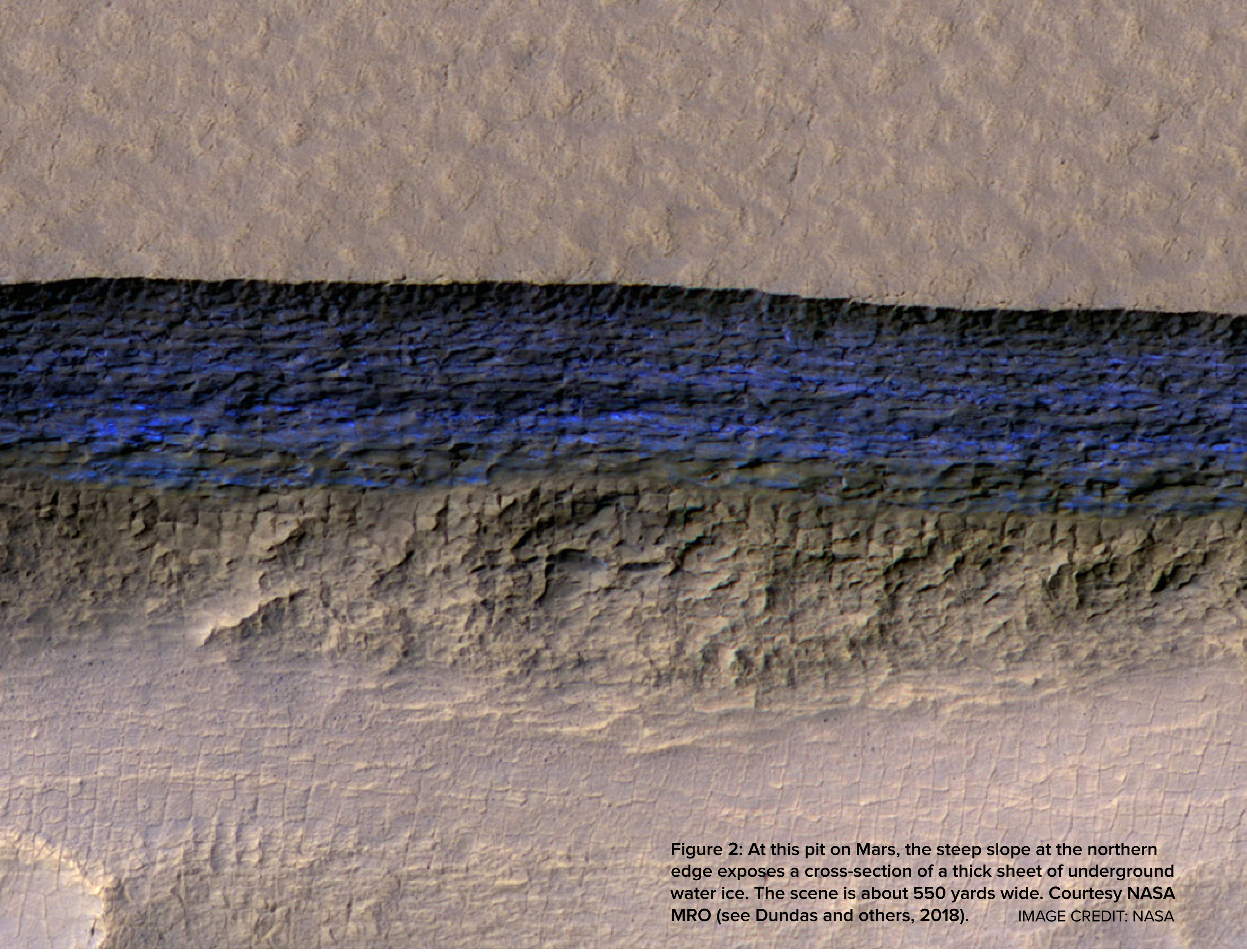


Figure 2: At this pit on Mars, the steep slope at the northern edge exposes a cross-section of a thick sheet of underground water ice. The scene is about 550 yards wide. Courtesy NASA MRO (see Dundas and others, 2018). IMAGE CREDIT: NASA

Thanks to our existing Mars robotic fleet, 2017 saw multiple breakthroughs/milestones in Mars science. Some examples relevant to future human exploration include:

- The discovery of exposed subsurface water-ice deposits on cliffs near the poles. This exciting discovery provides visual confirmation of previous predictions. The water ice on Mars is real, it's accessible, and it's in great quantities in the form of thick, spatially extensive deposits (Figure 2).
- The reaffirmation of the dominant theory that the surface of Mars cannot support liquid water, even briny, on the surface. This is based on the identification of Recurring Slope Lineae (RSLs) as dry granular flows. That being said, scientists have not ruled out that liquid water is somehow involved in this process. Further investigation is clearly called for to resolve this significant issue.
- Research showed that dust devils on Mars have the potential to throw dust particles (sub-micron scale) around the globe. This work has broad implications for planetary protection protocols in that any terrestrial microbes released on Mars have the potential to spread around the globe.
- The discoveries from MAVEN coupled with those from MRO suggest there may have once been an era in which thick deposits of ice were episodically formed, eroded, and released as liquid surface waters, only to freeze again. These subsurface remnant glacial deposits are key areas for the search for life and have the potential to be used by future human explorers.
- The ESA/ROSCOSMOS Trace Gas Orbiter (TGO) completed its aerobraking at Mars and successfully entered its science orbit, armed with a powerful payload for studying the Martian atmosphere.

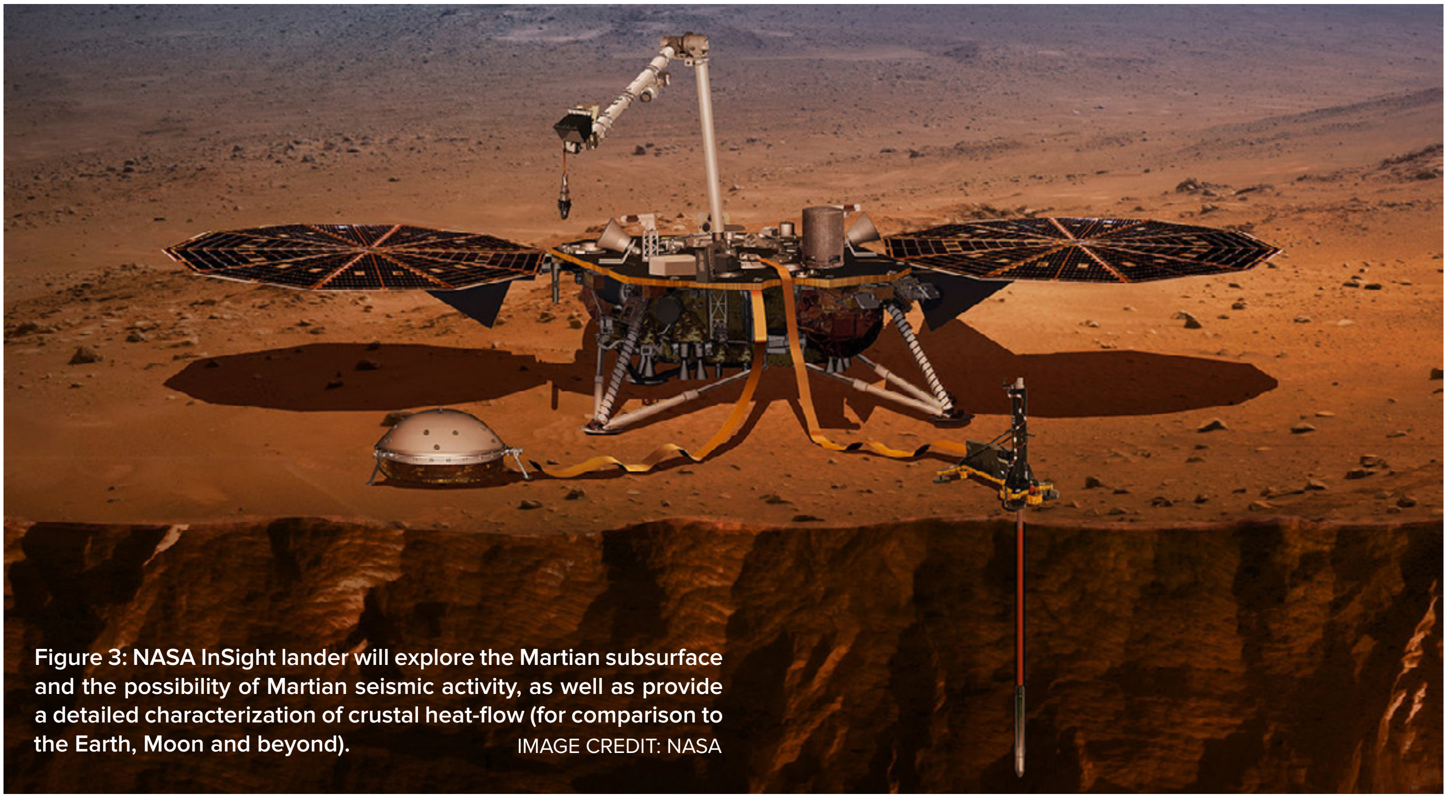


Figure 3: NASA InSight lander will explore the Martian subsurface and the possibility of Martian seismic activity, as well as provide a detailed characterization of crustal heat-flow (for comparison to the Earth, Moon and beyond). IMAGE CREDIT: NASA

Looking ahead, the upcoming landing of the Mars InSight lander will be a key step in characterizing the interior of Mars and comparing it with other rocky planets. TGO will also begin its science mission to provide better atmospheric maps and new observations of critical trace gases later this year.

Mission preparation for the NASA Mars 2020 rover also continues. The primary objective of this mission is to cache carefully-selected Martian samples with the intention of returning them to Earth in later missions. In addition, Mars 2020 will employ a multi-frequency mobile ground penetrating radar contributed by Norway (the Radar Imager for Mars' Subsurface Experiment, or RIMFAX) to sense tens of meters below the surface in search of interfacing layers associated with water ice at extremely fine vertical scales. In other ways, the "vertical mobility" that the ExoMars 2020 rover will demonstrate with its 2m subsurface drill will finally expose materials shielded from the ravages of deep space radiation to sensors such as the Mars Organics Molecule Analyzer (MOMA) instrument developed jointly by NASA and Germany. MOMA is the first instrument that should be capable of detecting complex organic molecules associated uniquely with the preserved record of life as we understand it here on Earth, or if not, untangle what fragments of such complex molecules can be preserved on Mars. The Mars 2020 rover will also carry an ISRU demonstration experiment (Mars OXygen In situ resource utilization Experiment, or MOXIE) to commence engineering evaluation and validation of strategies for "living off the planet" as an enabler of sustained human occupation in the future. Finally, Mars 2020 will demonstrate hazard-awareness and response via its Terrain Relative Navigation (TRN) capabilities which will increase the accessibility of scientifically important sites on Mars.

Furthermore, initial steps are underway to retrieve the Mars 2020 rover cache samples on a future robotic mission, potentially in the late 2020's. Actively-unfolding plans for this subsequent sample return lander will also demonstrate an ascent vehicle and associated Earth return orbiter. This mission would be the first robotic roundtrip demonstration to and from Mars. Surface-based sample return is a major National Academy of Sciences Decadal Survey (Visions and Voyages, 2011) science priority, and has been since the 1980s. Additionally, there is growing evidence that Martian samples are needed to inform future human missions by means of what they will teach us about the mechanical properties of the regolith/dust (abrasiveness, oxidizing potential, particle size, etc.) and potential human health hazards (toxicity, respiratory, extant life, etc.). Science Mission Directorate Associate Administrator Thomas Zurbuchen provided the first public outline of NASA's MSR strategy at a National Academies Space Studies board in August 2017.

There are other international Mars mission plans as well. In 2020 the UAE, ESA, JAXA, and CNSA are all launching orbiters or landers to the Martian system. In 2022 ISRO will be launching a successor to its tremendously successful Mars Orbiter Mission (MOM), and in 2024 JAXA will launch its MMX mission to examine and even sample the Martian moons.

Despite the remarkable successes cited above, NASA's budgetary and political constraints make the launching of necessary robotic missions in the years following the Mars 2020 Rover far from assured. There is no new mission funding beyond 2020.

In addition to Mars Sample Return activities, there are several potential missions that will support global efforts as we prepare for future human exploration. It is essential that we have a plan to replace the aging orbital assets currently at Mars which enable relay of vital science data and situational awareness. These potential missions include:

- A resource reconnaissance orbiter. Necessary to fill key knowledge gaps about potential water resources at Mars. This is critical for the search for life and to understand the potential of this water to support human operations at Mars (e.g., propellant, consumption, agriculture, etc.).
- A special regions drilling mission to verify and characterize the water deposits found with the next generation reconnaissance orbiter.
- Improved orbital and surface weather monitoring. This will help us achieve pinpoint landings of landers delivering human Mars mission surface assets and to understand the potential transport of microbes across the surface of the planet.
- Improved tele-communications capabilities. Given the aging communications assets at Mars and the expected increased data rates required by science and eventual human assets, relay between the Earth and Mars will need to be improved and extended.

Science has always offered the gateway information to promote and expedite human exploration. Most recently, in her review of the Apollo 8 human mission to the Moon, science writer Mary Roach poignantly stated: "It was science that got us to the Moon – not just its mastery but a cultural consensus about its importance and worth." [Washington Post, April 2018]. The science activities on the Red Planet are demonstrating the importance of exploration; they are showing the world that Mars is achievable as our next human frontier beyond cislunar space.

FINDINGS:

- Complete a round trip mission that accomplishes the National Academy's Decadal Survey's highest priority, which is Mars Sample Return. The samples are needed not only for the revolutionary science that will certainly be achieved but also to address significant toxicity and backward contamination concerns for the first human explorers of Mars. Robotic Mars Sample Return is an essential precursor for future surface exploration.
    - Characterize the regolith on Mars through sample return to ascertain its risk to the EVA suits (is it as sharp as the regolith on the Moon that was a danger to the suits on EVAs?). Characterize the Martian "regolith" dust particle size distribution down to 100nm or finer scales.
- Determine how sub-surface ice is distributed so that it can be reached, both for the science and to determine whether there are associated chemical or biological hazards for drinking/use by humans.
    - A next generation reconnaissance orbiter is required to prospect for resources (notably water as subsurface ice) that will reduce the overall cost of missions to Mars while providing significant science gains. Even if ISRU is not needed for initial human missions to Mars, such reconnaissance is essential for selecting human landing sites. Such an orbiter is, moreover, key to replace aging telecommunications infrastructure at Mars, while enhancing and refreshing situational awareness at Mars.
- MRO needs a replacement as it is 14 years old and Mars Odyssey, the other workhorse of communications relay, is 17 years old. We NEED communication relay satellites with downlink capabilities that will extend what the nations of the world can achieve at Mars.
- Embrace stronger collaboration between NASA mission directorates to assure the robotic science missions of the 2020s maximize both scientific goals as well as advance human exploration in the 2030s.

ARCHITECTURES AND SYSTEMS

Current Progress of Elements Required for Mars

IMAGE CREDIT: James Vaughan

Subsequent to the publication of the *Humans to Mars Report* (H2MR) in May 2017, work on architectural concepts and refinements continued within NASA, in academia, and at many industrial partners. With the recent re-establishment of the National Space Council, a policy shift that might influence the direction of Mars planning was widely expected. However, as that policy has unfolded, it now appears that many of the same factors that were previously widely adopted will continue as before: a public-private partnership, the Moon as a candidate proving ground for Mars exploration, and appropriate international participation.

In this section, we discuss both the major elements of current architectures for Mars exploration and recent results from the latest in the series of community workshops known as the *Achievability and Sustainability of Human Exploration of Mars Workshops* (AM V), which are jointly sponsored by Explore Mars, Inc. and the American Astronautical Society (see https://www.exploremars.org/affording-mars).

I. Utilization of Cislunar Space on the Way to Mars

Much of the recent work within industry has focused on a habitat and operations facility in orbit in the vicinity of the Moon, which has gone by multiple names over almost two decades of design development, and recently has been referred to as the Lunar Orbiting Platform-Gateway (or Gateway). Both the European Space Agency (ESA) and NASA have recently hosted workshops on utilization of this facility to achieve major science goals and advance technological preparation for Mars exploration.

In 2002, an architecture based specifically on a facility for extended human occupation and operations in cislunar space was first studied in depth by the Decadal Planning Team (DPT) in response to a request from the NASA Administration and the Office of Management and Budget. A top-level visualization of the proposed architecture is shown in Figure 1, where the Gateway was the central element of a variety of options for human and robotic space exploration, including utilizing it not only to oversee robotic lunar surface operations but also as an aggregation site in preparation for human missions to Mars.

With the recent renewed interest in sustained human operations in cislunar space, the Gateway has now become, after the Space Launch System (SLS) and the Orion crew vehicle, another element in industry architectures proposed by Aerojet Rocketdyne, Boeing, Lockheed Martin, Orbital ATK, and Sierra Nevada Corporation. In current architectures, it serves as a bridge between the experiences gained from research and development on the International Space Station (ISS) and the systems needed to reliably send humans to Mars. Such a facility could also provide a means to demonstrate key technologies required for the Deep Space Habitat and Power and Propulsion elements (discussed in the next section) demonstrating human ability to live and work at increased distance and duration from Earth as well as facilitating science and astrophysics research. In addition, it could serve as the location where the Mars Transfer Vehicle (MTV) is aggregated and supplied, and then refurbished upon its return to the Earth-Moon vicinity. The renewed interest in lunar exploration and the desire to provide an infrastructure that can be utilized by private companies and international partners to perform resource surveys and additional scientific research could also be satisfied by such a Gateway.

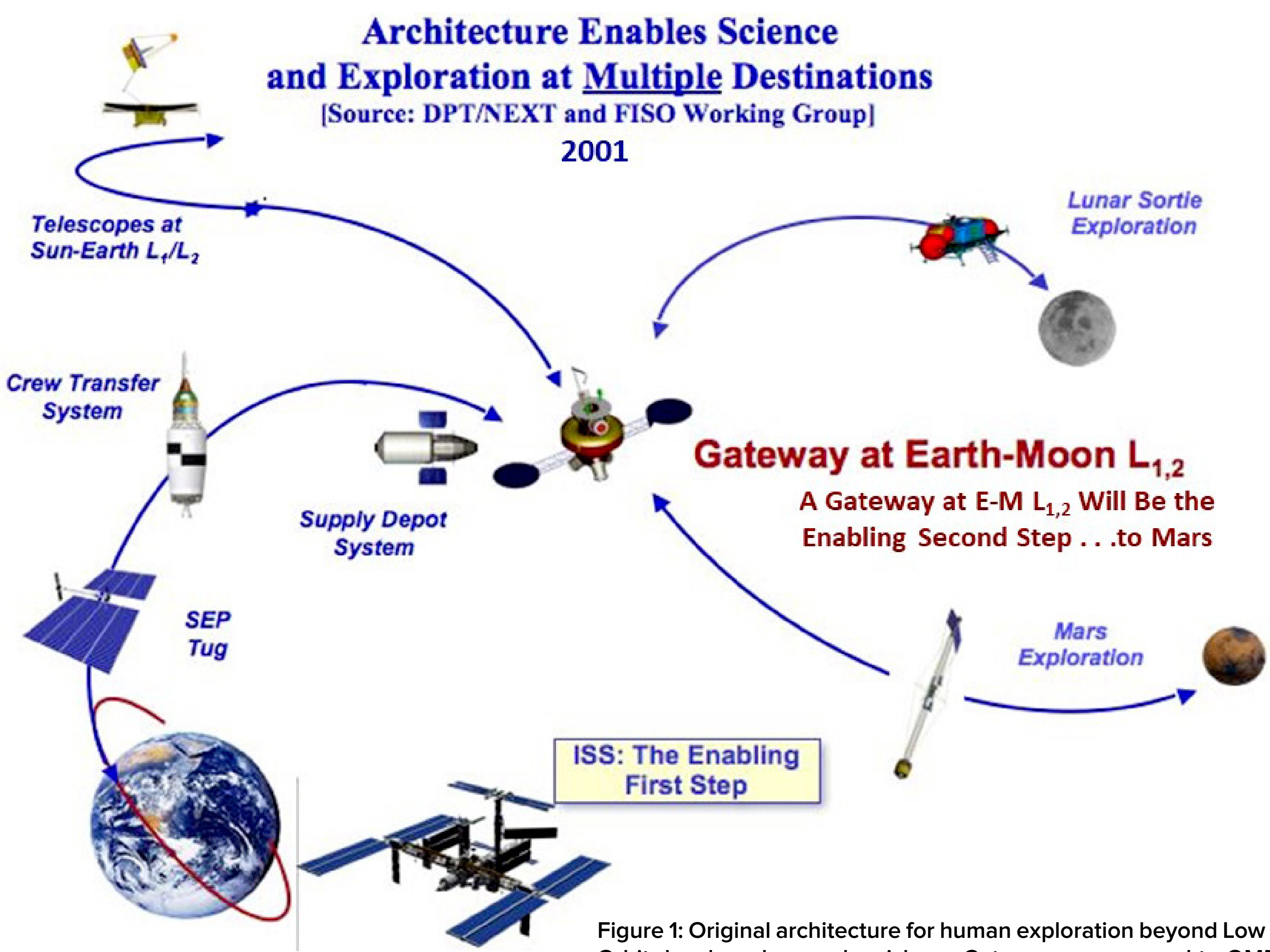


Figure 1: Original architecture for human exploration beyond Low Earth Orbit developed around a cislunar Gateway as proposed to OMB and NASA administration in 2002 by the NASA Decadal Planning Team.

II. Industry Architectures

As described in previous editions of the Humans to Mars Report, most industry architectures for Mars exploration have coalesced into six key elements (Figure 2), to advance capabilities to support human exploration.

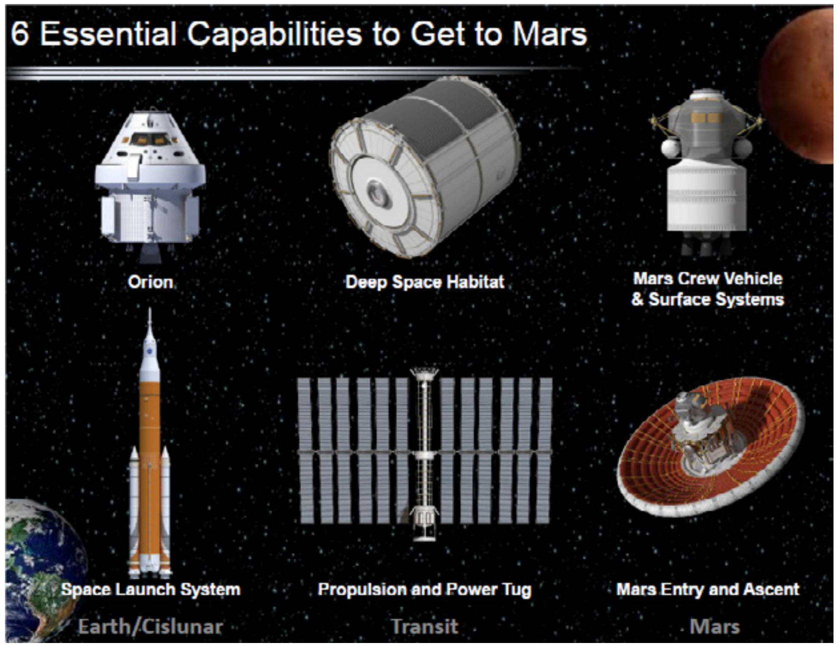


Figure 2: The six elements of a Mars architecture

Work is now beginning on the Power and Propulsion as well as the Habitat requirements for deep space missions. This means that the demonstration of the Transit elements for human missions to Mars– the deep space habitat and the power and propulsion tug – is beginning to take shape.

Other architecture elements that are common to many industry plans include entry, descent, and landing (EDL) for heavy payloads and Mars ascent vehicle designs. Over the past year additional emphasis has been placed on assessing surface systems required for mobility, power, and in-situ resource utilization (ISRU). These can have a large impact because they drive the total landed mass on the martian surface.

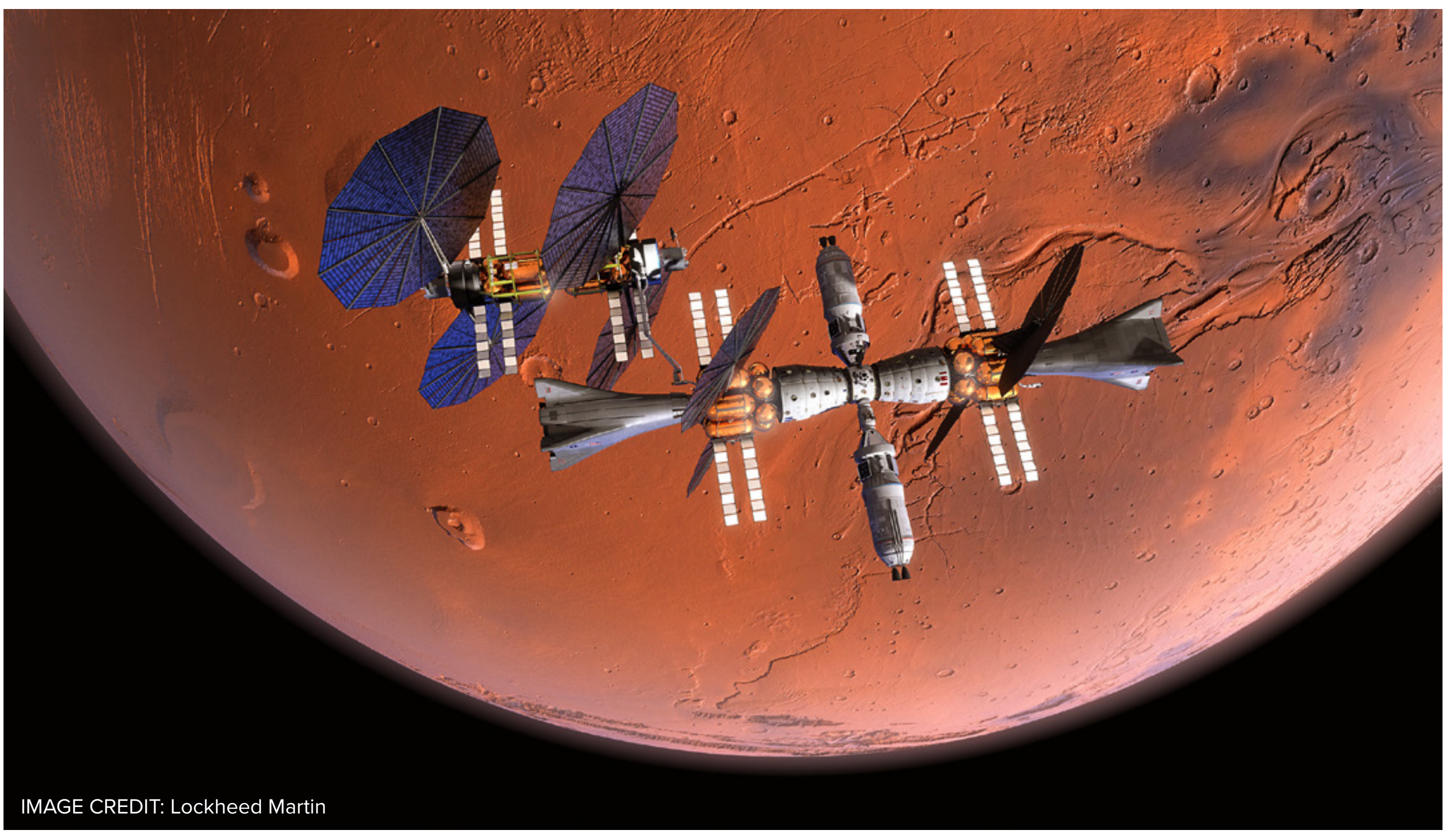


Figure 3: The Lockheed Martin Mars Basecamp with surface sortie vehicles

Lockheed Martin has continued to refine its Mars Base Camp architecture, which aims to enable a human orbital mission to Mars in about a decade. Last year Lockheed Martin added the concept of performing surface sorties using a refuellable and reusable lander/ascent vehicle, as illustrated in Figure 3. The concept to fuel that vehicle involves commercial companies to deliver water to Mars orbit to be converted into propellant. Lockheed Martin is also investigating how to demonstrate these concepts at the Moon.

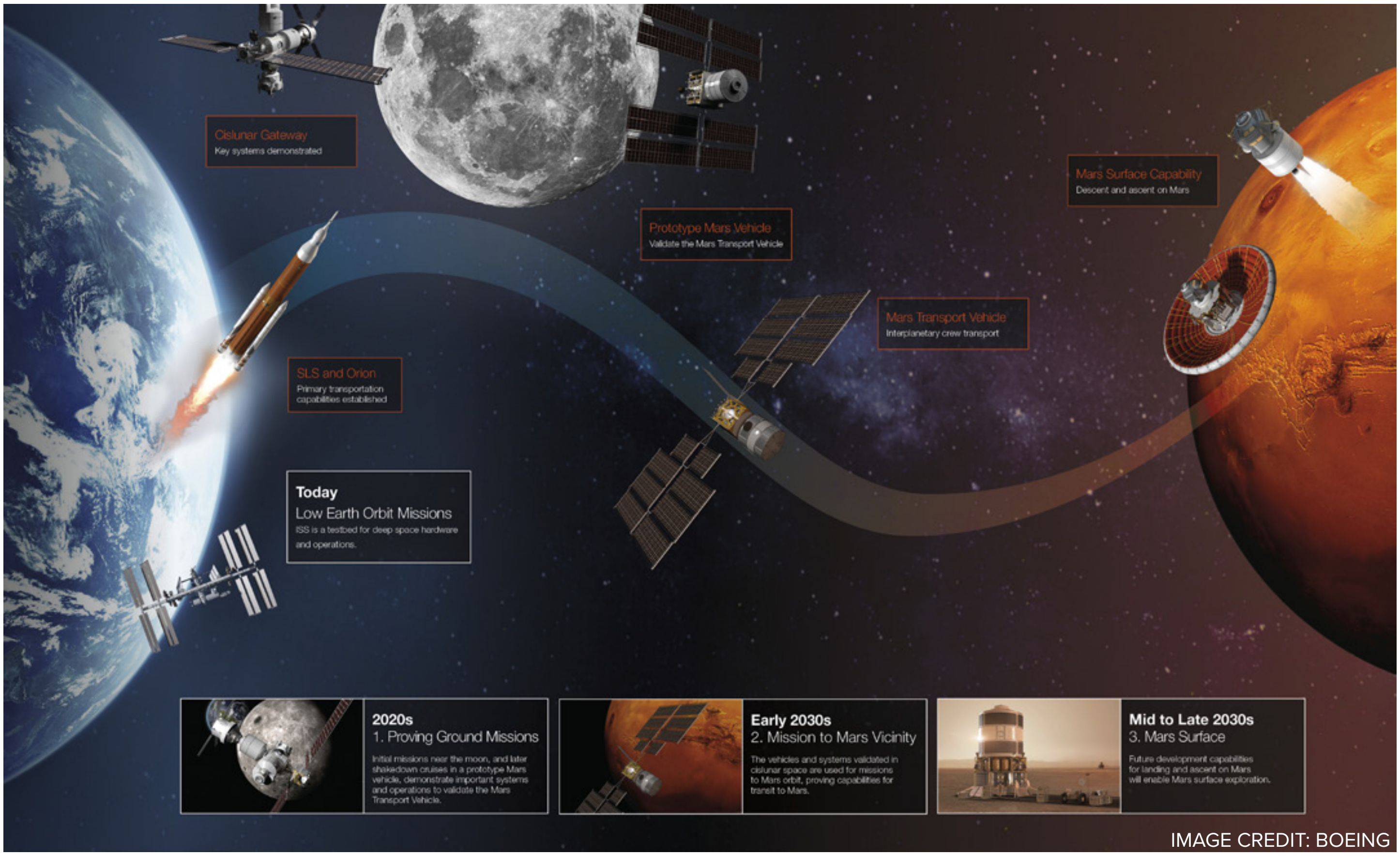


IMAGE CREDIT: BOEING

Figure 4: Overview of the Boeing architecture

Boeing recently revised its architecture to incorporate testing of some additional elements on the Moon or in lunar orbit. These are summarized in the architecture overview shown in Figure 4. As part of cislunar activities, Boeing has examined the development of a human-scale lunar lander that can test descent and ascent propulsion for later use at Mars.

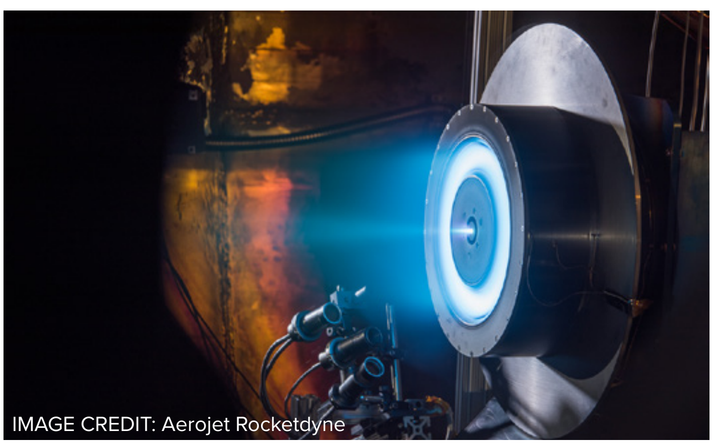


IMAGE CREDIT: Aerojet Rocketdyne

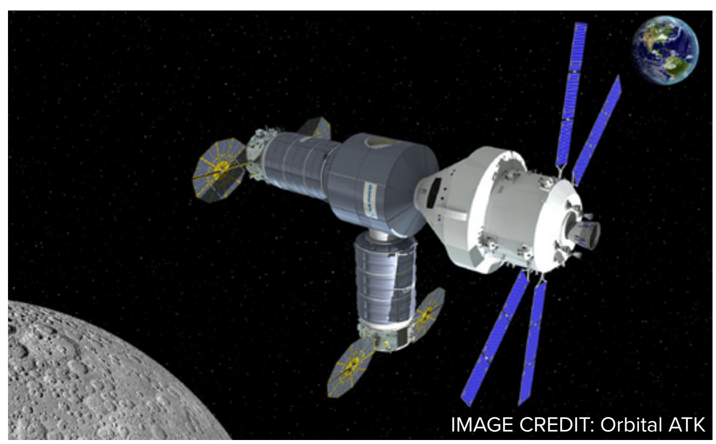


IMAGE CREDIT: Orbital ATK

Aerojet Rocketdyne (AR) continues to mature the design of the Solar Electric Propulsion Module (SEPM) for cargo transportation. The primary goal of the AR effort has been to determine the optimal level of the SEPM to allow large payload blocks (~40 mt – 50 mt) to be delivered to Mars with a transfer time that synchronizes well with launch opportunities and reduces the overall time between cargo launches and crew launch. Since AR's architecture retains a split crew and cargo transfer approach, AR is also studying the impact of a 25,000 lb thrust nuclear thermal rocket engine fueled by low-enriched uranium (LEU) on the crew transfer time.

Orbital ATK continues to refine the elements of its proposed Mars architecture, specifically focusing on leveraging existing investments in spacecraft in Low Earth Orbit (LEO) to extend capabilities to enable long-term human habitation in cislunar space. These enhanced capabilities will be utilized as the basis for the deep-space transportation elements necessary to take humans to the Martian system. The Orbital ATK architecture also attempts to introduce as much commonality as practical to further enhance both the reliability and maintainability of the individual elements as a crucial way to enhance the probability of mission success while building upon the capabilities provided by NASA's Space Launch System.

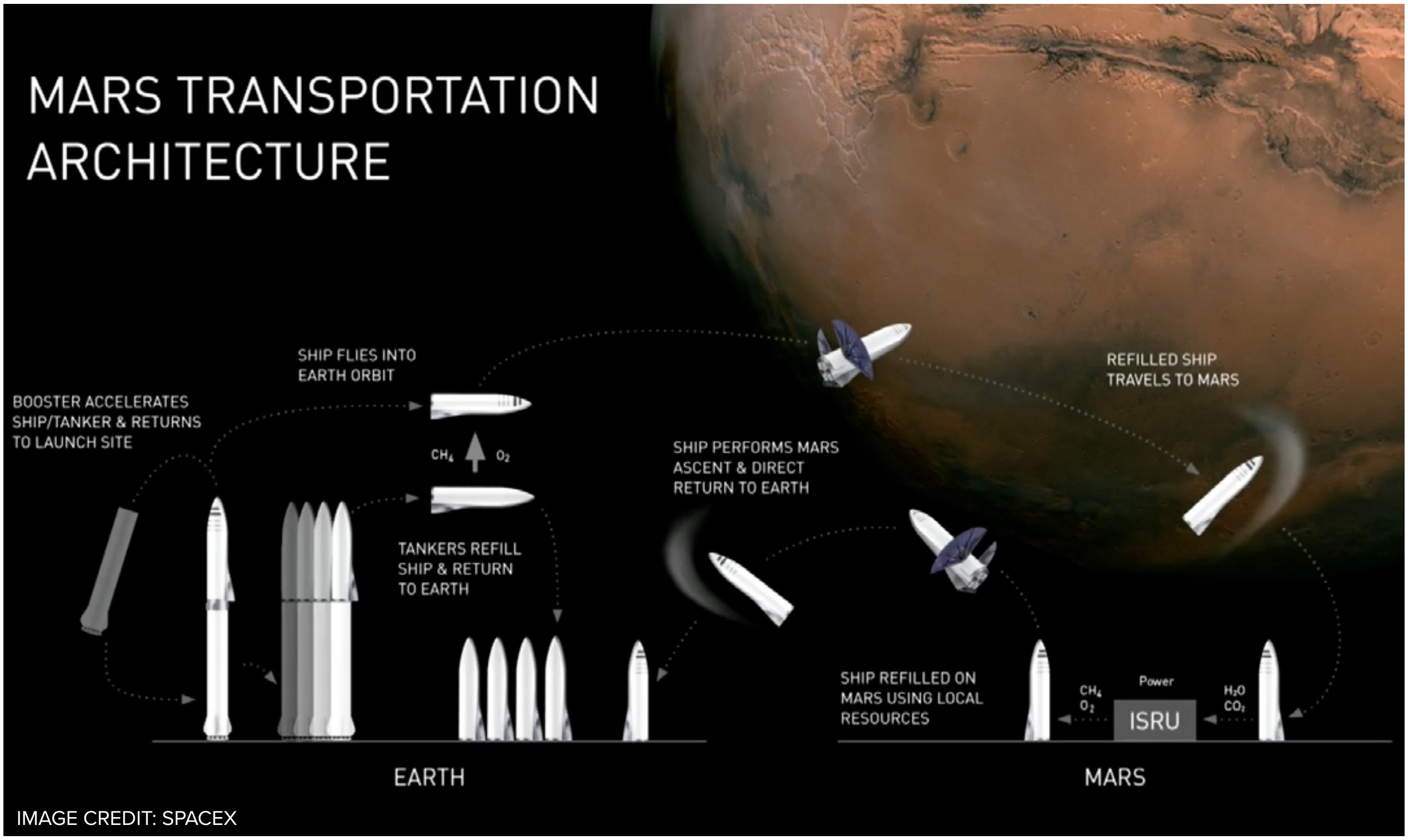


Figure 5: Mars architecture as presented by SpaceX at the 2017 International Astronautical Congress

At the International Astronautical Congress (IAC) that was held in September 2017 in Adelaide, Australia, SpaceX announced that it has reduced the size of its Big Falcon Rocket (BFR) design from the original design laid out the previous year at the IAC held in Guadalajara, Mexico. The basic concept for its Mars architecture, however, remains the same, with a two-stage design. The first stage is a reusable, fly-back booster with 31 Raptor engines, reduced from 42 in the original design. This allows the BFR first stage core diameter to shrink from 12 m to 9 m. The second stage retains the functions of orbital insertion into LEO and later transfer to Mars, as well as descent and ascent to the martian surface, after being fully refueled on-orbit by multiple tanker vehicles, as shown in Figure 5. ISRU would be used to refill the ship prior to Mars ascent. All propulsion is lox-methane. In a recent interview, SpaceX founder Elon Musk stated that testing of some of the elements of the BFR would begin in 2019.

III. NASA Architectures

NASA has refined Mars planning within the agency to respond to different human space flight priorities resulting from the transition from one administration to another. As a result of this transition, the role of international lunar exploration, both by robots and humans, has returned as a priority for the agency. In the meantime, NASA and the aerospace communities continue to evaluate the optimum approach for sustainable exploration of Mars. Details of these lunar plans are still being developed, although, as indicated above, a cislunar human operations and habitation facility, or Gateway, is once again under consideration to provide a place for testing concepts that will apply to future Mars missions.

Among the key design drivers that influence architecture selection for human Mars missions are:

1. The “end state” for human Mars operations: sorties, outpost, or human settlement?
2. Earth-to-orbit transportation
3. In-space transportation
4. Landing site selection
5. In-situ resource utilization

Depending on the assumptions made for each of these design drivers, a variety of potential optimized architecture solutions can ensue, which we discuss in the next subsection.

Architectural elements in the trade space include:

1. The transportation architecture, and transportation habitat functionality: Can there be a common design for both in space and on surface?
2. Entry, descent, and landing (EDL) commonality: Common cargo and human landers?
3. The Mars rendezvous orbit.
4. The Earth aggregation orbit.

In addition, parameters such as launch vehicle cadence can affect the resiliency of the architecture. Choices by the mission planners, such as returning multiple times to a single surface site or visiting multiple dispersed sites, also have significant effects, as do decisions about surface mobility.

As evident from the above discussion, the selection of a Mars architecture for human exploration is a complex, and interconnected, series of design choices. NASA continues to evaluate these choices and update its planning, even as SLS and Orion are brought online. This will provide a basis-of-comparison design against which evolving technologies, constraints, and mission options can be traded and compared. Additional robotic precursor missions to Mars will also help to inform these decisions in the early to mid-2020s.

IV. Affording, Achieving, and Sustaining Mars Exploration Community Architectures

Over the past few years NASA and multiple other organizations have produced a large number of plausible scenarios for human exploration of Mars in the 2030s as described in the previous sections. In general, however, these scenarios have been developed independently of one another. The fifth *Achieving Mars* workshop (AM V https://exploremars.org/affording-mars) held in December 2017, in contrast, brought much of the exploration community together to develop three distinctly different human Mars exploration architectures. Subject matter experts identified areas of commonality, as well as areas where opinions differ, and important decisions need to be made among the three.

Three different "end states" for human exploration of Mars were adopted at AM V and an architecture was developed that sought to achieve each of those end states under common ground rules and constraints. The three end states were:

1. Initial exploration analogous to the Apollo Program or the Lewis and Clark "Corps of Discovery".
2. Semi-permanent base or "field camp" on the Martian surface, analogous to early Antarctic exploration.
3. Building toward sustained, permanent habitation analogous to current Antarctic exploration.

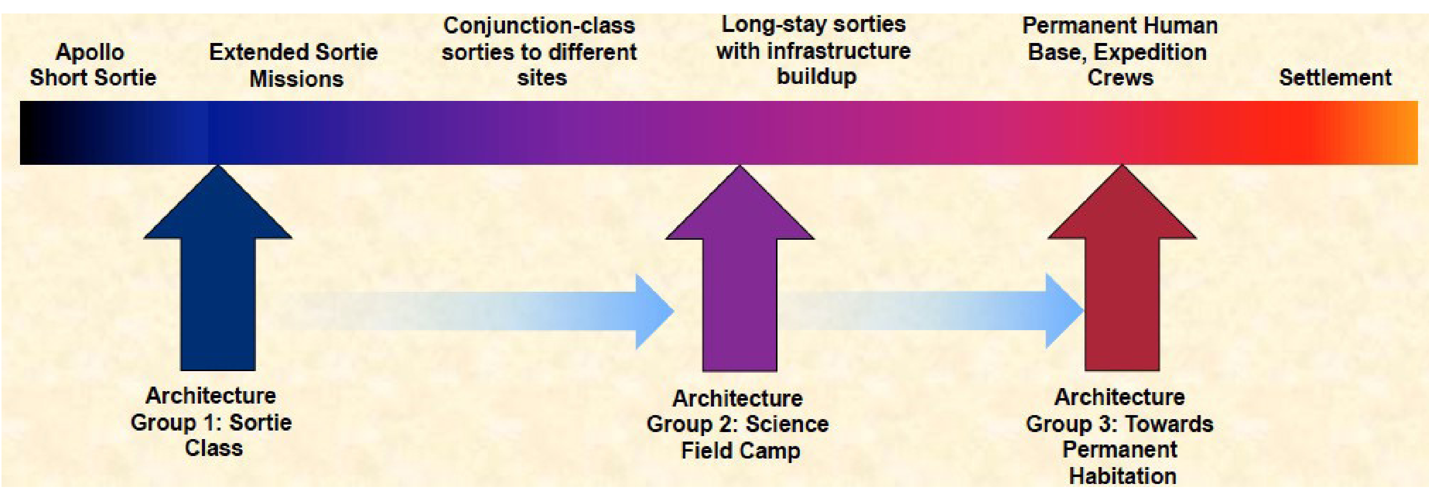


Figure 6: The three architecture "end states" considered by the AM V workshop along a continuum of options for human Mars exploration. The "end states" are depicted here as feeding forward into more ambitious exploration options.

IMAGE CREDIT: JAMES VAUGHAN

Three teams, both during the workshop and over the months that followed, developed and critiqued the three distinct architectures in detail. They were guided by a handful of ground rules and assumptions:

- The initial human mission to the vicinity of Mars will take place by about the mid-2030s.
- SLS and Orion will be available during the time period considered here, so will not be assessed in depth in this workshop.
- Early and focused technology investment will be identified, including precursors and demonstration missions.
- Partnerships (international, industrial, commercial, academic) will be an essential component.
- The role of lunar surface operations with astronauts and robots will be assessed.
- The role of a cislunar habitation and operations facility will be assessed.
- Community engagement will be essential.
- Research and development will continue on ISS at least through the mid-2020s.
- Budgets available for human exploration of Mars will be assumed to grow approximately with inflation. If additional funding appears to be required above that, plausible sources of the funding will be identified.
- No technological “miracles” or, if so, clearly identify and justify them.

In addition to major exploration timelines and milestones, priority technology developments, major elements of the architecture and an annual and total cost for each of the three architectures are presented in the final report noted above.

Common areas of consensus among the three distinct architectures are discussed more fully in the final AM V report, although in summary they include:

- **The destination should be the Martian surface.** Preliminary missions to cislunar space, the lunar surface, Venus, flyby of Mars, or Phobos are considered unnecessary. All teams agreed that the first surface mission should be flown no later than 2037.
- **All missions should be flown using Conjunction Class trajectories.** The long-duration stay in the Martian system was key to the exploration objectives, and even the Apollo-class architecture.

- **Split Missions are desired to deliver cargo ahead of the crew** to the Martian system, and rendezvous/transfer activities should occur in Mars orbit.
- **International and/or commercial launch vehicles could be considered** for Human Expansion missions.
- **Launch vehicles will require a minimum of 8.4 m diameter payload shrouds, with 10 m diameter needed for most Mars landers.**
- All teams favored the use of **aerocapture or aerobraking** for Mars orbit capture.
- A crew should consist of **4 to 6** persons.
- Surface science operations should focus on field work within the **100 km Exploration Zone**.
- A **deep-space habitat** should be designed for missions of 1000 days or more.
- **All types of robotics** should be employed, with science goals an important component.
- A number of workshop input assumptions showed up as common design choices from each of the architecture teams, including the use of **Orion and SLS**, although some specific challenges for both of these programs were common across architectures. These included evolution of the Orion crew complement from 4 to 6, and the need for a 10-meter diameter launch fairing on the cargo version of the SLS to support Mars EDL systems.

Significant points of departure and disagreements among the three architectures included:

- **The potential dates for** conducting an initial mission are inversely proportional to the mission's scope: For example, the more simple Apollo-class mission targets 2033 for a crewed mission to Mars orbit and a two-week sortie mission to the Martian surface in 2037.
- **The "build-up" of mission capabilities** corresponds to the scope of the mission endpoints:
  - The Apollo-style architecture goes directly to a short surface stay,
  - The Research Base architecture favors an evolutionary buildup from short to longer-duration surface missions, and
  - The Human Expansion architecture advocates long-duration missions from the start.
- Other **mission architecture decisions** that scaled with the scope of the three architectures included:
  - Launch vehicle flight rate.
  - Landed payload mass.
  - Power sources.
  - Length of surface mission.
  - Total number of crew members to the surface.
  - Returned payload mass.
  - Choice of landing sites.
- The **cost distribution** of each of the architectures varied significantly.

ARCHITECTURE & SYSTEMS FINDINGS

- Architectures/systems for deep space missions should be designed in a manner that advances the goal of human missions to Mars in the 2030s.
- As plans develop for returning humans to the vicinity of the Moon, including a lunar Gateway, special emphasis should be placed on those that have significant value for both lunar missions and the exploration of Mars, such as utlitizing cislunar space not only to oversee robotic lunar surface operations but also as an aggregation site in preparation for human missions to Mars.
- Work should begin immediately on tackling the most difficult technological challenges including (landers, reconnaissance, surface hab/lab etc.,.) that are critical for both the Moon and Mars.
- NASA, industrial/commercial, and international stakeholders should focus their efforts on greater collaboration and agree on a unified, achievable, and sustainable approach for human missions to Mars.

HUMAN HEALTH & PERFORMANCE

Human System Risk for a Mission to Mars

Introduction

The first human mission to Mars is one that will be both exciting and risky, with many unknowns. The "human system" will undoubtedly make up a significant portion of the overall mission risk which, if unnecessarily high, will put the success of a Mars mission in jeopardy. There is a strong need to mitigate and reduce this overall mission risk to acceptable levels in order to achieve mission objectives and protect the health and safety of astronauts before, during, and after a mission. This has been an area of focus for NASA and its international partners for many years now. At NASA, the Human Research Program (HRP) is tasked with supporting applied research that specifically addresses the risks of the human system, as identified in the Human Research Roadmap (HRR). To accomplish this goal, HRP is composed of a number of Elements, whose ongoing work is mapped to each of these individual risks, any number of which could put an exploration spaceflight crew in danger and threaten the success of their mission.

Human Health Countermeasures Element (HHC)

The Human Health Countermeasures (HHC) Element focuses on developing a scientifically-based, integrated approach to understanding and mitigating the physiological health risks associated with human spaceflight. HHC is responsible for conducting research within 15 defined risks and gaps of knowledge, such as: development of advanced food technology; understanding of optimal nutritional status (including the prevention of oxidative stress and damage); sensorimotor dysfunction; Spaceflight Associated Neuro-Ocular Syndrome (SANS), which causes vision disturbances in some astronauts; bone loss; degradation of muscle strength; immune dysfunction; etc.

Recent Progress: While all of the risks and concerns under HHC's purview are of importance, there are two risks that are of particular concern, due to a greater likelihood of occurrence and/or higher potential for negative consequences. These are the advanced food technology risk and the SANS risk. Over the past year, the research plans of these two risks have been accelerated in an attempt to identify and validate countermeasures before the end of International Space Station (ISS) operations in 2024. For both risks, multiple studies are occurring concurrently, using a variety of platforms and study designs, including studies using flight-like analogs or studies on the ISS. New and exciting data have recently been collected regarding the SANS risk in studies aboard the ISS, as well as in studies using parabolic flights, a head-down tilt bedrest human model, and a hind-limb unloaded rat model. These data indicate that the mechanisms for the fluid shift induced changes in vision may be more complex than previously anticipated.

Figure 1. NASA Image: ISS051E051923 - NASA astronaut Peggy Whitson harvested another crop of Tokyo Bekana cabbage on the International Space Station.

The advanced food technology portfolio of studies underway examine nutrient degradation in foods stored under different environmental conditions. Food for a Mars mission may have to be prepositioned on the Martian surface prior to the crew's arrival, and therefore may be several years old by the time the astronauts actually consume it. HHC is examining whether nutrient enrichment, various packaging types, and/or different food matrices, may be used as countermeasures that would prolong the food's nutritional content. They are also studying human acceptability factors such as taste, color, and texture.

Currently, HHC is evaluating the potential for fresh food to be grown and consumed during a mission (*see Figure 1*). This would be a significant change from the current process of launching prepared food. HHC is studying what required infrastructure would be needed, the nutritional content of potential food crops, and microbial safety of fresh grown food in a space environment. In addition, HHC is studying the psychological benefits of tending to growing plants in collaboration with the Human Factors and Behavioral Performance Element.

Human Factors and Behavioral Performance Element (HFBP)

The scientists and managers of the Human Factors and Behavioral Performance (HFBP) Element provide scientific oversight and manage research activities related to nine identified risks related to spaceflight hazards for long-duration missions. These risks include: human factors in the areas of habitability, mission processes, and tasks; human and automation/robotic interactions; dynamic loads and occupant protection; training processes; as well as health and performance risks in the areas of behavioral medicine, sleep/fatigue, and team performance. To this end, HFBP scientists plan and conduct research in spaceflight analogs around the world, using these experimental research settings to replicate, with high fidelity, many of the expected spaceflight hazards (e.g., isolation, confinement, stress, sleep schedules, workload demands, and others). These scientific contributions are intended to help NASA achieve its goals associated with exploration spaceflight that will involve long-duration and long-distance missions (e.g., a mission to Mars).

Recent Progress: Recent HFBP work includes deliverables related to long-duration spaceflight, such as the Spaceflight Habitability Assessment Questionnaire (SHAQ), which will be used to assess the behavioral health and performance impacts of volume, layout, and other design features of vehicles and habitats for long-duration exploration spaceflight and other operational environments. HFBP has sponsored the development of precise methods to measure attention/vigilance and cognitive processing using the newly updated Cognition neurocognitive screening software. This work is being undertaken to effectively monitor operationally-relevant changes to the brain performance pathways of the central nervous system that may be altered by one or more of the many spaceflight hazards. HFBP also supports research around the world, including in the Antarctic (Concordia), the :envihab research facility at the DLR Institute in Cologne, and the development of a long-duration isolation project (SIRIUS) at the Institute of Biomedical Problems (IBMP) NEK facility in Moscow.

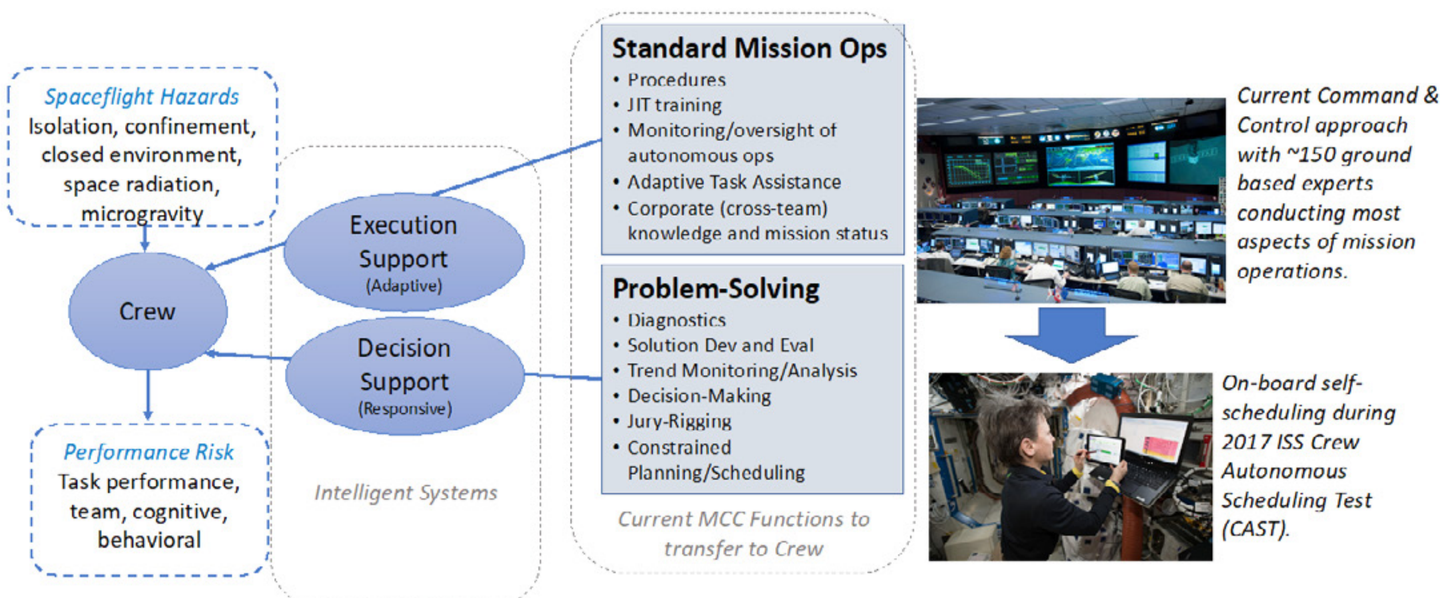


Figure 2. A Mars mission will require a shift from the current ground-based command control model to an on-board, autonomous approach.

One primary goal of HFBP is to help ensure that there is synergy between human factors design knowledge/research and what engineers see as requirements for long-duration spaceflight, in order to find the right balance between human capabilities and spacecraft design features needed to reduce the risks posed by the spaceflight hazards. For example, a mission to Mars will shift the current command and control model from ground-based systems to on-board, autonomous systems for both problem-solving and standard mission operations (*see Figure 2*). The autonomous crew of the future will need an intelligent system that provides both decision-making and execution support to help mitigate performance risks related to standard mission operations and problem-solving.

Space Radiation Element (SR)

The goal of the Space Radiation Element is to ensure that crewmembers can live and work safely in space with acceptable health risks from radiation, with a focus on the characterization and mitigation of these risks along with understanding how they interact with other biological stressors found in the space environment. Outside of the Earth's protective magnetosphere, interplanetary crews will be at higher risk for radiation exposure from both intermittent solar particle events as well as from higher levels of chronic high-energy protons and galactic cosmic rays (GCR). This galactic cosmic radiation consists of high mass and energy (HZE) ions, secondary protons, neutrons, and fragments produced as a result of interacting with spacecraft shielding and human tissues. These heavy ions differ from terrestrial forms of radiation, such as x-rays or gamma-rays, and impart unique biological damage as they traverse through tissue and cells (*see Figure 3*). Understanding the quantitative as well as qualitative differences in biological responses produced by galactic cosmic radiation compared to Earth-based radiation is a major focus of space radiation research and is required for accurate risk assessment and development of effective mitigation strategies for long-duration space missions.

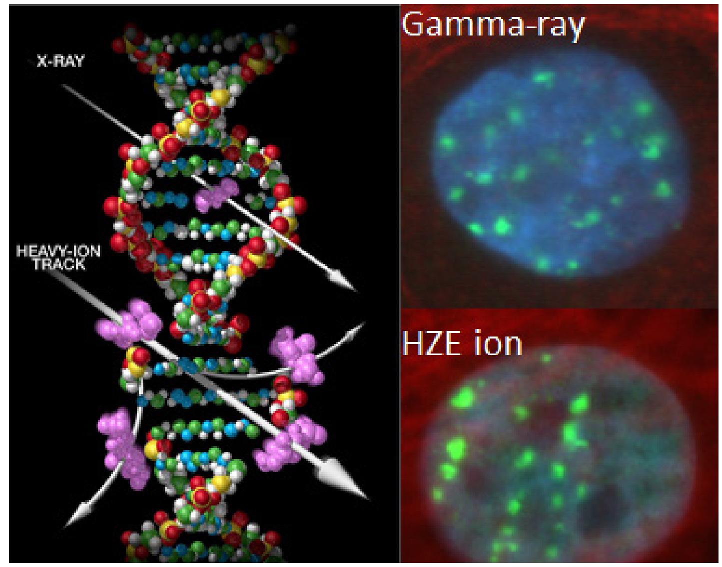


Figure 3 :Galactic cosmic rays are qualitatively different from x-rays or gamma-rays
Image credits: Cucinotta and Saganti, National Geographic, 2001 (left); Huff and Patel, unpublished (right).

The major space radiation health issues of concern that may occur during exploration missions are central nervous system effects that could result in cognitive or behavioral impairments and degenerative tissue effects including cardiovascular disease, accelerated aging, and chronic immune dysfunction. The risk of acute radiation syndromes in the event of an unshielded exposure to a large solar particle event during flight is also of concern to space radiation experts. Lastly, epithelial carcinogenesis (particularly cancers of the lung, breast, stomach, colon, and bladder) and leukemia are long term health concerns that result from radiation exposure.

Recent Progress: Given the technical challenges of studying radiation in the true space environment, ground-based research is performed at the NASA Space Radiation Laboratory (NSRL), which is located at the Brookhaven National Laboratory and is where NASA has a beamline dedicated to the study of the radiobiology of heavy ions (see Figure 4). One major effort that is ongoing this year is the Galactic Cosmic Ray Simulator Project, which is focused on the development of the facility, hardware, and software tools needed for delivery of a GCR primary and secondary environment with a mixed field, high-energy capability that accurately simulates the radiation environment astronauts will experience during interplanetary travel to Mars. This research capability is essential to address high priority research areas required for risk modeling and medical countermeasure testing and validation, for both deep space and Mars.

Figure 4: Beamline at NASA Space Radiation Laboratory

Exploration Medical Capability Element (ExMC)

The Exploration Medical Capability (ExMC) Element is tasked with decreasing medical risks in human spaceflight. To accomplish this goal, ExMC charters research projects, funds goal-directed technology development, and interfaces with intra- and extra-agency resources. Within the Element, engineering and medical specialists work to reduce the risk of adverse health outcomes and decrements in performance due to inflight medical conditions that could occur in future deep space missions. Essential to completing this task is the advancement in techniques that identify, prevent, and treat many health threats that may occur during space missions. ExMC is establishing evidenced-based methods of monitoring and maintaining astronaut health and developing capabilities to provide long-term preventive and crew-autonomous healthcare during spaceflight.

As human spaceflight ventures further from the Earth, crews will be increasingly isolated. In the event of a medical emergency during one of these missions, the possibility of returning to Earth for timely, definitive medical care may be challenging, impractical, or impossible. However, many factors associated with long-duration space missions make the provision of autonomous medical care difficult, including limitations on available medical equipment and supplies due to mass and volume constraints, a lack of comprehensively trained medical personnel amongst the mission crew, and the potential for encountering unfamiliar medical conditions and hazards particular to the space environment. Solutions proposed to address these problems include advanced diagnostic technologies, medical record-keeping systems, and guided treatment methodologies. These solutions are one focus of current ExMC research activities.

Recent Progress: The ultimate goal of ExMC is to develop and demonstrate a pathway for full medical system integration into vehicle and mission design. Elements of this effort for 2018 include: an evidence-based medical and data handling system appropriate for long-duration, exploration-class missions; a clear concept of exploration operations; quantitative risk assessment capabilities; and the ability to perform engineering trade space analyses to recommend an appropriately scoped system to meet mission needs. Combining ExMC's medical efforts with a systems-engineering approach allows for the development of a completely vehicle-integrated medical system that will better meet exploration mission needs (see Figure 5). These integrated and technologically oriented goals define the ExMC approach to enable an appropriately scoped medical capability to support human space exploration.

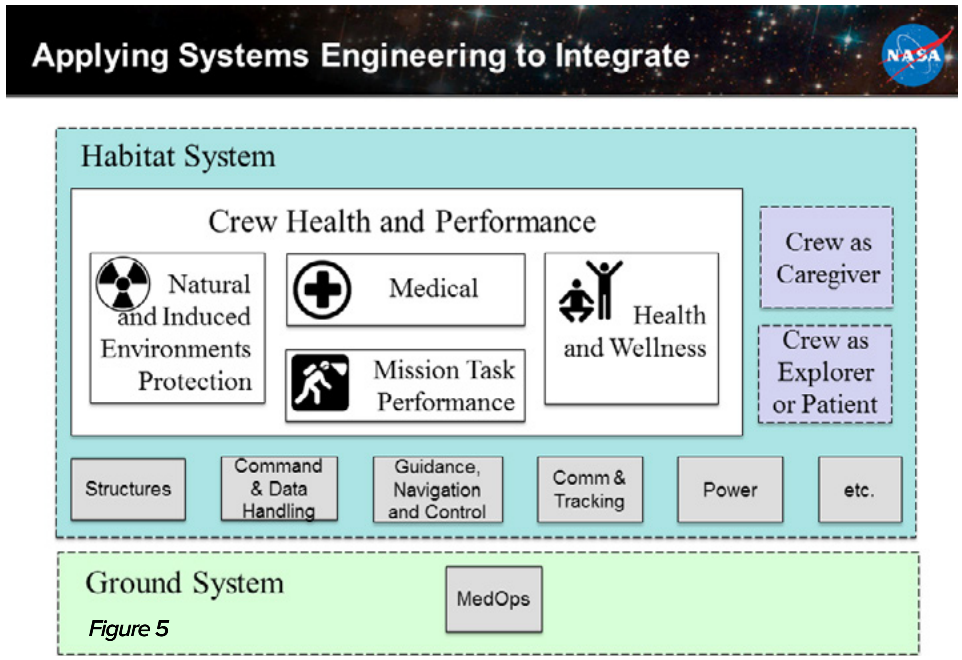


Figure 5

Summary

In a 2001 report by the U.S. National Academy of Sciences entitled *Safe Passage*, it states "Human exploration of this scope requires optimum functioning of both spacecraft and astronauts—of both the engineering and the human components. Failure of either could result in mission failure." In order to accomplish this optimum functioning and decrease overall mission risk to acceptable levels, the human system will need to be fully integrated in the spacecraft. This will require early involvement of human systems experts in every step along the way, from planning to design and through implementation. These experts will bring forward the latest advances in knowledge and research that will help to mitigate and reduce the risks to human health and performance in exploration spaceflight.

HUMAN HEALTH & PERFORMANCE FINDINGS

The following will guide the work necessary to enable the first successful human mission to Mars:

- Develop and validate comprehensive, integrated, multi-system countermeasures that will support optimal health and performance of astronauts when they embark on deep space missions to Mars and beyond.
- Sponsor human research around the world that uses short-term, long-term, and high-fidelity spaceflight analogs to conduct realistic research that will help us to characterize and mitigate the risks posed by the hazards of the space environment.
- Develop and validate the GCR reference environment in terms of NSRL operational and delivery parameters for use in addressing fundamental radiobiology questions related to mixed field and dose-rate for the chronic exposures astronauts will experience on the journey to Mars.
- Utilize a thorough and disciplined systems engineering approach, with capabilities to assess trade spaces, as the cornerstone of future medical system development and vehicle integration for space exploration missions.

POLICY: OPPORTUNITY & CHALLENGES
The Path Forward

Particpants in the Space Exploration Alliance (S.E.A.) Legislative Blitz, February 2018, Image Courteousy of Art Harman

United States Space Exploration Policy: Adjusting to New Directives

It has been an extremely active year in United States space exploration policy. The overall long-term goal remains the human exploration of Mars, but the Administration has proposed policy changes that call for greater emphasis on lunar exploration in advance of human missions to Mars, including a greater emphasis on commercial and international partnerships to enable a return to the Moon. It remains to be seen how these changes will impact plans to land humans on Mars in the 2030s.

Some of the most significant policy-related developments over the past year include:

The National Space Council: In June 2017, President Trump signed an Executive Order that reinstated the National Space Council to advise the President on space-related issues. Vice President Mike Pence was selected to chair the Space Council and Scott Pace was named Executive Secretary. Membership in the Space Council consists of cabinet members and other high-ranking government officials including the NASA Administrator, the Secretary of State, the Secretary of Defense, the Secretary of Commerce, the Director of the Office of Management and Budget, the National Security Adviser, and representatives of other agencies that also have a stake in space.

The first meeting of the Space Council was called, "Leading the Next Frontier: An Event with the National Space Council," and was held at the Smithsonian National Air and Space Museum's Steven F. Udvar-Hazy Center on October 5, 2017. At this meeting, Vice President Pence stated that, "We will return American astronauts to the Moon. Not only to leave behind footprints and flags, but to build the foundation we need to send Americans to Mars and beyond."

Space Policy Directive #1: On December 11, 2017, President Trump signed a Memorandum designated as Space Policy Directive #1 (SP1). This policy directive did not reconstruct the United States space program, but instead modified that program, while remaining consistent with the policy direction provided by Congress in current law. It replaced the Obama Administration's focus on missions to Mars with the following paragraph that includes the Moon as a central element of U.S. space policy on the path to Mars: "Lead an innovative and sustainable program of exploration with commercial and international partners to enable human expansion across the solar system and to bring back to Earth new knowledge and opportunities. Beginning with missions beyond low-Earth orbit, the United States will lead the return of humans to the Moon for long-term exploration and utilization, followed by human missions to Mars and other destinations…".

Vice President Pence also addressed SP1 at the second meeting of the Space Council, which took place at the Kennedy Space Center in Florida on February 21, 2018 and was entitled, “Moon, Mars and Worlds Beyond: Winning the Next Frontier”. During his speech, the Vice President stated that SP1 “makes it a national policy of the United States to return to the Moon, put Americans on Mars and bring renewed focus to human exploration in space.” Vice President Pence also announced the names of those individuals who had been selected to serve on the Space Council’s User’s Advisory Group, which is comprised of high ranking industry representatives, several astronauts, and other influential individuals in the space industry. The Vice President stated that this is “an extraordinary group of Americans that’s bringing together some of the brightest minds in this country to accelerate innovation across our nation’s space enterprise.” It should be borne in mind that SP1 is an executive document and provides guidance and policy emphasis for the executive agencies. Any actual change in policy that is inconsistent with current law must be proposed to, and adopted by, Congress before it can be effectively authorized. Then, of course, it must run the gauntlet of the appropriations process before any required new funds can be made available.

Nomination of Congressman Jim Bridenstine (R-OK-1st) to be NASA Administrator: In late 2017, President Trump nominated Congressman Jim Bridenstine from Oklahoma for the position of NASA Administrator. Congressman Bridenstine was confirmed by the Senate on April 19, 2018.

FY 2019 NASA Budget: The President submitted his FY 2019 budget in mid-February 2018. This budget proposed an increase in 2019 to $19.9 billion (from $19.6 billion), and thereafter planned a reduced, and flat budget, of $19.6 billion each year after that until at least 2023.

However, due to the broad bi-partisan support in Congress for our nation’s civil space program, NASA subsequently received a larger increase in its FY 2018 budget. In the Consolidated Appropriations Act of 2018 that was enacted by Congress and then signed into law by the President in late March, NASA’s FY 2018 budget was increased to $20.7 billion.

Status of a new (2018) NASA Authorization Act: The United States House of Representatives in early 2018 started work on a 2018 *NASA Authorization Act*. This bill is intended to follow-up on the *NASA Transition Authorization Act* of 2017 that strongly supported human exploration of Mars. As of the time that this Report went to print, the United States Senate had not yet taken up work on its own version of a 2018 *NASA Authorization Act*, but because of strong bi-partisan support, it is likely that this bill will retain its current goal of Mars explorations.

Legislative Outreach: Grassroots visits to Capitol Hill by space advocacy groups continued in 2017 and 2018. This included the 2018 Legislative Blitz conducted by the Space Exploration Alliance that in late February 2018 met with approximately 180 Congressional offices over two days. In such visits, people from around the country come to Washington, DC to impart to our elected representatives the importance that the general public attaches to our space program, and to convey the message that NASA must be provided with adequate and sustained funding in order to accomplish all that it has been tasked with by Congress and the Administration. Indeed, such advocacy groups as well as certain industry groups called for an increase in NASA’s budget, such as a 5% per year increase for the next five (5) years. Groups such as the Citizens for Space Exploration and the Students for the Exploration and Development of Space (SEDS) also had successful events on the Hill in 2017 and numerous professional and industry groups, including the AIAA and the SLS/Orion Suppliers’ Conference, also staged large visits to Capitol Hill.

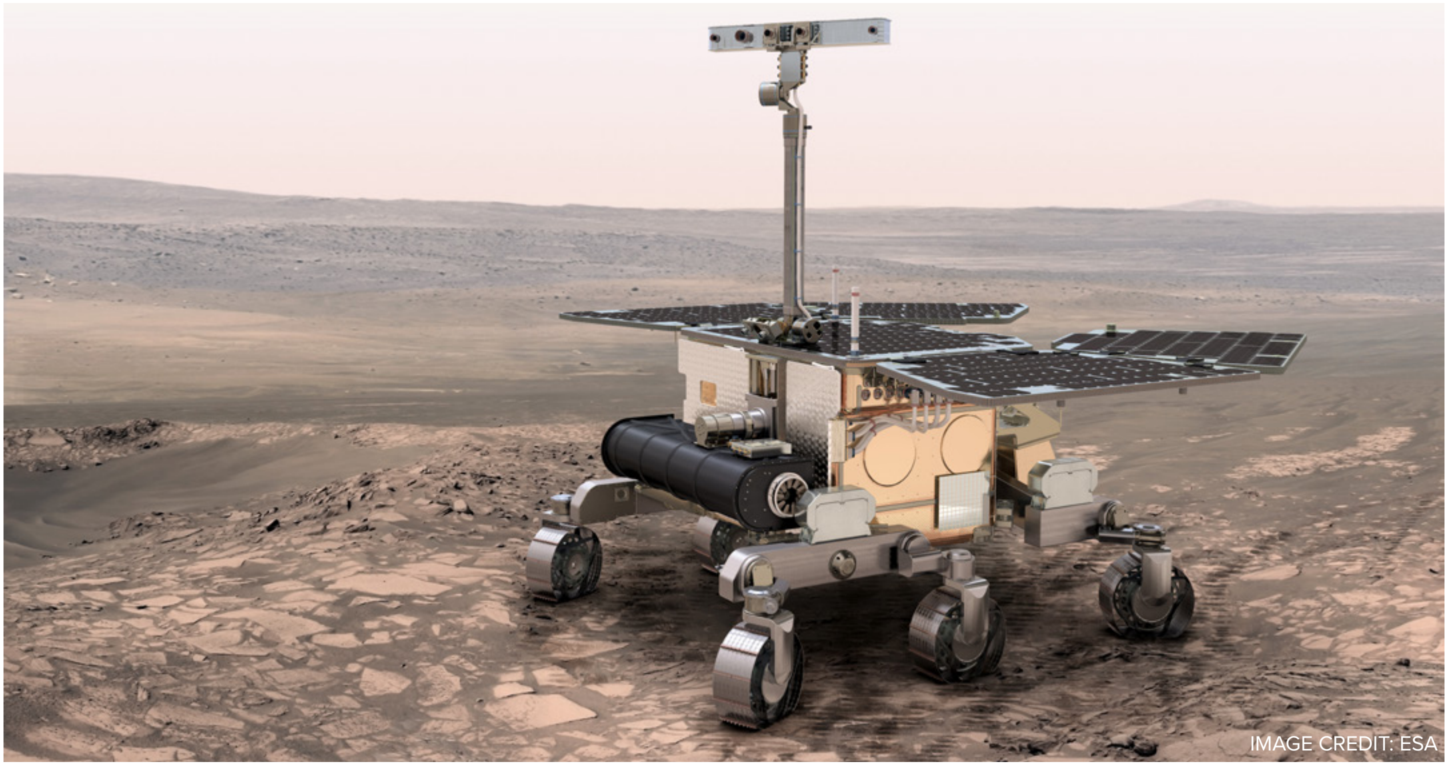
EXPLORATION POLICY FINDINGS:

Our review of the current status of policy guidance for Space Exploration led to a consensus on some areas where it was believed providing specific findings to policy makers in the Congress and the Administration might be helpful:

- Foster synergies and collaboration between government and private entities to create policies and programs that effectively utilize the Moon on the path to Mars.
- NASA and its international and industrial partners should advance the development of “long pole” technologies [such as Entry, Descent, and Landing (EDL) technology, reliable and self-sustaining Environmental and Climate Control Systems (ECCLS), and in-space and surface power systems] that are critical for human missions both to the Moon and to Mars.
- As lunar activities are developed, these plans should be constructed in a manner that will advance the goal of human missions to Mars in the 2030s and should not hinder achieving that goal.

International Policy

An affordable and sustainable program of robotic and human exploration of the Martian surface will require a multi-national effort. While there is no unified international consensus on the respective contributions to be made by various nations or even on a timeline for sending humans to Mars, there is substantial international interest in the exploration of Mars.



Current missions or programs include:

I. Europe

- **Mars Sample Return:** There is a growing interest in conducting a Mars Sample Return mission; in fact, it remains as the top recommendation in the Planetary Sciences Decadal Survey conducted by the National Academies of Sciences, Engineering and Medicine. As an example, a Mars sample return mission was the focus of the 2nd *International Mars Sample Return Conference,* which was held in Berlin, Germany from April 25-27, 2018. Mars 2020, a robotic mission planned by NASA in conjunction with international partners, has as part of its current mission profile the collection and preservation of soil samples from Mars for retrieval during a later sample return mission.
- **ExoMars:** The ExoMars program consists of two missions: One is the Trace Gas Orbiter, which included an Entry, Descent and landing demonstrator Module (EDM) known as Schiaparelli, launched on March 14, 2016; and the other features a rover with a scheduled launch date in 2020. Both missions are carried out in cooperation between the European Space Agency and the Russian Space Agency, Roscosmos. The main objective of ExoMars is the search for evidence of life on Mars.
- **AMADEE-18:** In February 2018, the Austrian Space Forum in partnership with the Sultanate of Oman conducted a Mars analog field simulation in the Dhofar desert region of Oman.
- **European Mars Workshop:** A European workshop hosted by Explore Mars, Inc., and tentatively scheduled for late September 2018, will be conducted. The workshop will bring together space exploration experts and stakeholders from Europe, the United States, and elsewhere to discuss areas of agreement in Mars science, Mars precursor robotic and human missions, and eventual human surface missions on Mars.

II. Asia:

United Arab Emirates (UAE):

- **Emirates Mars Mission a/k/a Hope Mars Mission:** Scheduled to arrive at Mars in 2021 to coincide with the 50th anniversary of the founding of the UAE, the unmanned Hope orbiter will study the Martian atmosphere and climate.
- **Mars Science City:** Scheduled to be completed by 2020, this simulated, prototype Mars city/analog will stimulate international collaboration to advance Mars exploration and will inspire STEM education throughout the Middle East and around the world.
- **Mars 2117:** In 2017, the UAE announced plans to establish a city on the surface of Mars within the next 100 years – by the year 2117.
- **Space Settlement Forum:** This took place at the World Government Summit in Dubai in February 2018. This program highlighted how Mars/space exploration benefits all humanity. Specific topics included how future explorers can "live off the land" on the Moon and Mars, including Mars agriculture and surface power.

India:

- **Mars Exploration Mission 2:** The Indian Space Research Organisation (ISRO) is planning a follow-up mission to its successful Mars Orbiter Mission (MOM) spacecraft of 2016. Scheduled to launch in 2021, MOM-2 may also include India's first Mars lander.

Japan:

- **The "Martian Moons eXploration" (MMX)** mission is designed to clarify the origin of the Martian moons and the process of evolution for the Mars region. It is scheduled to launch in the early 2020s.

China:

- China plans to send an orbiter, lander, and rover to Mars, with a target launch date of 2020. China has also recently revealed its desire to ultimately establish human settlements on Mars.

FINDINGS FOR ENHANCEMENT OF INTERNATIONAL COLLABORATION AND PARTICIPATION

Findings for enhancement of international collaboration and participation surfaced in the examination of current international activities. These findings are offered for consideration as Exploration Program architectures become more refined and their implementation proceeds:

- While most of these missions/programs promote international collaboration, there is need for far greater coordination of efforts in order to truly advance international science and human missions to Mars. This coordination among the respective agencies, organizations, and/or partnerships could start with data sharing agreements so that science/robotic missions to Mars can build on one another to maximize readiness for future human missions.
- As long as valid security concerns by the United States and its international partners are sufficiently addressed, the role of China in future international efforts to reach Mars should be considered by Congressional and Administration policy makers.
- International Space Station (ISS): The ISS is being used today to test equipment, to develop operations concepts, and to better understand the physiological and psychological impacts of being in space for extended durations. It is also an important model of a successful international partnership in space exploration, as well as a model of a sustainable program. This partnership should be extended by the current ISS partners as well as new partners to form an international cooperative effort aimed at moving humanity beyond low Earth orbit and on to Mars.

THE PERCEPTION ELEMENT

How Public Interest Impacts & Drives Mars Exploration

Mars exploration themes continue to resonate in television, movies, games, virtual reality experiences, consumer products, and even the alcoholic beverages industry.

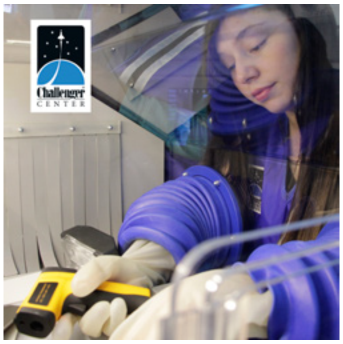
While some uncertainty about committing to Mars has arisen as the Administration and Congress make adjustments to U.S. space policy, public interest nevertheless remains strong. Over the remaining months of 2018, many details of the Administration's plans should come into focus, which may impact overall public perception, but Mars (and space in general) continues to excite the public.

I. Films and Television

The entertainment industry continues to see value in producing Mars related projects. Mars references also continue to be commonplace in popular television shows and elsewhere.

There are well over a dozen Mars-related television and film projects in production that clearly evidence the continued enthusiasm for Mars exploration in the general public. Some of these projects include:

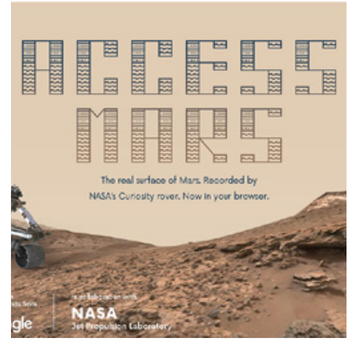
- ***Seat 25***: This independent film tells the story of Faye Banks, a woman who secretly enters a competition for a seat on a one-way trip to Mars. When she discovers that she has won, Faye's life is turned upside down, forcing her to decide whether to leave her husband, family, friends, and everything else she knows for the kind of purpose and fulfilling life of which she has always dreamed.
- **National Geographic *Mars*: Season 2**: National Geographic will be releasing Season 2 of their television drama, *Mars*, in the Fall of 2018. This series is a hybrid between documentary and drama. The drama depicts the struggles and successes of the first explorers and settlers on Mars. During the documentary portion of the series, some of the top personalities in space exploration discuss the real-life prospects of Mars missions.
- ***The First***: With Beau Willimon (writer, House of Cards) as its Executive Producer and starring award-winning actor Sean Penn, *The First* is a television series that explores the challenges of taking the first steps toward interplanetary colonization in the near future.
- ***Life on Mars***: John Krasinsky (creator of A Quiet Place) and his production company Sunday Night Productions will be producing a film version of a short story by Cecil Castellucci called *We Have Always Lived On Mars* that tells the story of a woman, who is a descendent of colonist who were abandoned by Earth years earlier, who finds one day that she can breathe the Martian atmosphere.



II. Projects

There are numerous impressive and well-funded non-government Mars projects underway around the world:

- **Challenger Center**: Challenger Center, a leading nonprofit STEM education organization, ignites the potential in students using simulation-based programs, including two programs specifically about Mars. Whether participating in *Expeditions Mars* at a Challenger Learning Center or *Earth to Mars* in a classroom, students are challenged to work together and solve problems while learning about Mars and what it will take to live on the Red Planet. Challenger Center programs deepen student engagement in STEM and introduce them to relevant careers. Today's students are future STEM leaders and innovators. Challenger Center programs inspire these students to be a part of our country's incredible mission to send humans to Mars.
- **Mars 2117**: In 2017, the United Arab Emirates (UAE)/Mohammed bin Rashid Space Center announced their aspirational plans to build a city on Mars by the year 2117. While this is a government program, it highlights world-wide excitement and desire for humanity to expand beyond Earth.
- **Mars Science City**: In 2017, the UAE announced the Mars Science City project. This research city will cost $140 million and will serve as a "viable and realistic model" to simulate a city on the Martian surface. This facility will also help stimulate international cooperation toward the goal of sending humans to Mars.
- **Mars World Enterprise (MWE)s**: MWE is planning to build one or more theme parks depicting life in a Martian colony in 2088 (http://marsworld.com/). Mars World in Las Vegas will be a $1.9 billion mixed-use immersive attraction, resort and casino destination built inside a huge dome. Additional Mars Worlds are planned for Orlando, China, Japan, India, and other locations.
- **AMADEE-18**: The Austrian Space Forum (OeWF) in partnership with international partners carried out their latest Mars analog field simulation in the Dhofar region of Oman for four weeks in February 2018, directed by their Mission Support Center in Austria. The Oman desert was selected due to its resemblance to Mars surface features. With its team of 7 analog astronauts chosen through an extensive selection process, and specifically trained for the OeWF Mars spacesuit simulator "Aouda." OeWF analog astronauts are assigned "in analogy to" future human (Mars) expeditions for preparatory research and development projects.
- **HI-SEAS**: (Hawai'I Space Exploration Analog and Simulation) is a habitat on an isolated Mars-like site on the northern slope of Mauna Loa on the Big Island of Hawaii at approximately 8200 feet above sea level. The HI-SEAS site has Mars-like geology which allows crews to perform high-fidelity geological field work and add to the realism of the mission simulation.



III. Products

Mars-related consumer products also are more popular than ever. Numerous toys, games, and other products have appeared over the past couple of years including:

- **HP Mars Home Planet**: Established to simulate everything imaginable about the physical reality of a built environment on a Mars populated by 1 million humans, HP Mars Home Planet supposes that colonists might even be comprised of families at some point after 2030, and that these families would by necessity be involved in understanding and working on solutions to various engineering problems.
- **Surviving Mars**: Surviving Mars is a sci-fi settlement builder about colonizing Mars and surviving the process. A player chooses a space agency for resources and financial support before determining a location for his/her colony, and then build domes and infrastructure, research new possibilities and utilize drones to unlock more elaborate ways to shape and expand his/her settlements.
- **Terraforming Mars**: In Terraforming Mars, players control a corporation with a certain profile, utilizing project cards, building up production, establishing cities and green areas on the map, and competing for milestones and awards. When the three global parameters (temperature, oxygen, ocean) have all reached their goal, the terraforming is complete, and the game ends after that generation.
- **Access Mars**: Access Mars is a free immersive experience created using data collected by NASA/JPL and permits anyone with an internet connection to take a guided tour of how scientists investigate; visit four sites that have been critical to NASA's Mars Science Laboratory mission; and zero in on objects of scientific interest. Additionally, the rover's latest location will be periodically updated to reflect the mission's ongoing progress. Access Mars offers a visceral impression of what it would be like to walk alongside the Curiosity rover on the surface of Mars.
- **Luciana Vega**: The American Girl Doll 2018 "Girl of the Year", Luciana Vega, whose aspirations are to become the first woman on Mars, has been dubbed a role model for girls and a champion for STEM. A three-book series about her character follows Luciana's story as she wins a scholarship to attend Space Camp in Huntsville, Alabama. The 18-inch doll, featuring brown eyes and dark hair, and full product line including "STEM-inspired outfits and accessories", launched in stores, online and through American Girl's catalog on Jan. 1, 2018.
- **Oculus - The Martian VR Experience**: This product is a Virtual Reality (VR) experience based on the film and book, *The Martian*, in which participants navigate Mars from the perspective of astronaut Mark Whatney. This product is produced by Ridley Scott and directed by Robert Stromberg.

- **Mission to Mars**: Together with Sprayground, a New York-based accessories label, retired NASA astronaut Buzz Aldrin has created his “first and only fashion collaboration”: a “Mission to Mars”-themed capsule line featuring a parka, a solar-panel backpack, a duffel bag, a baseball cap and gloves all detailed with a colorful assortment of patches, including one featuring Aldrin’s face and the words “Moon, Mars, and Beyond.” The spartan color palette of black, white and gray is enlivened by pops of orange that recall NASA’s launch and entry spacesuits.
- **Budweiser Mars**: In 2017, Budweiser announced its intention to become the first beer manufacturer on Mars. To advance this goal, Budweiser arranged for 20 barley seeds to be launched to the International Space Station to study how seeds germinate in microgravity.


IMAGE CREDIT: SPACEX

Falcon Heavy side cores touching down in tandem at SpaceX’s Landing Zones 1 and 2 on Feb. 6, 2018

IV. Capturing the Imagination of the General Public

On February 6, 2018, SpaceX launched the Falcon Heavy for the first time. While Falcon Heavy is not part of SpaceX’s Mars mission plans, the successful launch of that vehicle garnered much attention. The twin, and virtually simultaneous, landings of its two booster stages as well as the launch of SpaceX CEO Elon Musk’s red Tesla Roadster toward Mars generated a great deal of media coverage and a huge amount of public interest.

PUBLIC PERCEPTION OF MARS FINDINGS:

- Bipartisan and public support for Mars exploration remains strong. Mars advocates need to harness this support to assure Mars remains the central goal of U.S. space exploration policy.
- Mars Products: Mars related consumer products and toys continue to appear in greater numbers. The space community needs to highlight these when possible and partner with companies producing Mars related products.
- While collaboration between the space community and entertainment industry remains robust, this relationship should be strengthened and expanded over the next couple of years.


EXPLORE MARS
https://ExploreMars.Org