THE HUMANS TO MARS REPORT 2017
AN EXPLORE MARS, INC. PUBLICATION
Explore Mars, Inc. is gratified to present the 2017 Humans to Mars Report (H2MR), the third H2MR to date. Explore Mars believes Mars is the most scientifically important destination for human space exploration that can be achieved in the foreseeable future and that setting 2033 as the goal for the first landing of humans on the surface of Mars is vitally important. The 2033 date is reasonable from a technology development standpoint and a fixed date will help to minimize total program costs. Moreover, the 2033 date is close enough to maintain public and political support for Mars exploration, particularly when coupled with appropriate pre-cursor missions. H2MR is an annual publication that presents a snapshot of current progress in mission architectures, science, policy, international, 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 help them make decisions based on current facts rather than on the dated information, speculation, and sometimes even misinformation that tends to persist in the public arena where Mars is concerned.

H2MR is not advocating any particular approach to getting to Mars. To be clear, this report will not address speculation or rumor about future architectures - except when such are impacting public perception and policy decisions. Instead, it reports on current official progress and viable approaches that are in the public domain and thus are subject to critical review and analysis, and reports on relevant technologies and capabilities.

Over the past year, broad-based bi-partisan support has continued to build, with strong support coming from NASA, Congress, and industry. Likewise, there has been clear public interest in Mars as shown by polling and Mars related productions coming from the entertainment industry.

However, we have also seen challenges over the past year. Recently, there have been attempts in some quarters to shift away from this mandate for Mars and focus on other goals in human spaceflight. We intend that H2MR can help offset these intentions and demonstrate that Mars is clearly the most logical goal for human exploration.

To be clear, 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 delay human missions to Mars. Explore Mars views Mars as a critical destination that will enable exploration and development of space – and we believe we should set the goal of landing humans on the surface of Mars by 2033.
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.

Explore Mars, Inc. is a 501(c)(3) non-profit corporation organized in the Commonwealth of Massachusetts. Donations to Explore Mars are tax-deductible. You can contact us using our website https://exploremars.org or at the email address info@ExploreMars.org.

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Momentum toward sending humans to Mars continued to build during the past year with significant developments on multiple fronts. Political support in the United States for such missions was reaffirmed in March 2017 with the enactment of the NASA Transition Authorization Act of 2017, which contains the most comprehensive language supporting human missions to Mars ever to appear in legislation. International support for precursor missions in the lunar vicinity is strong and specific roles will expand and solidify over the next few years. As these precursor missions will set the framework and reduce risk for later missions to Mars, agreements on international participation are critical and potential participants are working hard to define them.

Public support for Mars has always been strong and, within the United States, Mars is broadly viewed as the next natural step for human space exploration. One gauge for the popularity of Mars is the large number of recent television and movie offerings that focus on the Red Planet. Even Netflix has weighed in with its documentary The Mars Generation.

Robotic exploration of Mars continues to advance and lay the foundation for future human explorers. Currently orbiting spacecraft along with the surface rovers have increased our understanding of the complexities of the planet. Unanticipated new discoveries include recognition of ancient habitable environments, the possibility of modern habitats (such as possible brine flows producing recurring slope lineae), and evidence of dramatic, possibly episodic climate change.

Mars will become a busier place over the next few years. In addition to the current operating spacecraft, NASA is on track to launch the InSight lander in 2018 (understanding of the interior), then follow that with a rover in 2020 (sample cache for later return and in-situ resource generation). Numerous other spacecraft are planned to leave for Mars in the early 2020s including the SpaceX commercial lander demonstration, European ExoMars rover (drill), United Arab Emirates orbiter Hope (global weather mapping), Chinese lander (penetrating radar), Japan’s proposed mission to the Moon of Mars (Phobos sample return), and NASA’s Mars surface sample return mission. These missions, and others to come, advance our scientific knowledge about Mars and also prepare for future human exploration.

Refinement architectures proposed for human exploration that began in 2016 will continue into 2017. In May 2016, Lockheed Martin rolled out its Mars Base Camp concept. This was followed by The Boeing Company releasing an updated version of its Mars architecture plan during the summer of 2016. Then, in September 2016 in Guadalajara, Mexico, SpaceX announced its plan to send settlers to Mars. In addition, companies such as Aerojet Rocketdyne and Orbital ATK have also produced concepts for sending humans to Mars and/or precursor destinations. Finally, in early 2017, NASA released details on its cislunar Deep-Space Gateway based strategy that will be used to demonstrate the technologies, systems, and operational concepts necessary to send humans to Mars. Although each of these architectures differ in detail, the ongoing development of systems for deep space exploration is valuable, with each idea contributing new perspectives and possibilities.

These architectures also contribute to other activities such as the fourth community Mars Achievability and Sustainability Workshop (AM IV) [http://www.exploremars.org/affording-mars], which was held in early December 2016. Approximately 60 invited professionals from the industrial and commercial sectors, academia, and NASA, along with international colleagues, assembled to assess the achievability and sustainability of critical capabilities (or “long poles”) necessary for human exploration of Mars. The AM IV workshop participants concluded that the estimated length of time to retire these long poles strongly suggests that a human mission to the surface of Mars could be accomplished in the early to mid-2030s with sufficient funding. Although major decisions are required in the near future about the exploration architecture, engineering and technology are not the factors limiting initial human missions to Mars.
The current robotic fleet at Mars, which includes spacecraft not only from the United States but now also from the European Space Agency (ESA), continues to teach us about this amazing planet.

In 2016, the ESA/Roscosmos ExoMars Trace Gas orbiter successfully entered orbit around Mars and, as of this writing, it is in the process of making orbit adjustments to enter its science mapping orbit. Once there, it will study the presence of trace gases like methane, which may have significant implications for the existence of life on the Red Planet.

There are a number of new missions getting ready to head to Mars. NASA’s InSight mission will launch in 2018. With this mission, we will have the first quantitative understanding of the planetary interior of Mars, past and present, including its role in generating an ancient global magnetic field, widespread volcanic activity and in producing warm, wet habitable environments where life could have gotten a start.

Looking even further ahead, 2020 is shaping up to be a very busy year for missions to Mars. The U.S. Mars 2020 rover is due to launch that year. This mission is a critical leg in achieving Mars sample return—a long-standing Decadal Survey priority. The U.S. private company SpaceX is currently projecting that it will be able to launch its first ever Red Dragon to Mars in 2020; this mission is largely a technology demonstration mission, but it will have some payload capacity. ESA is launching their ExoMars 2020 rover; this rover will have, among other capabilities, a drill capable of accessing two meters below the surface—this is considered a critical region to investigate for signs of life.

In addition, in 2020 the United Arab Emirates plans to launch its Hope orbiter, with an objective to better understand martian climate dynamics and atmospheric escape while performing global weather mapping.

The Chinese have also scheduled a launch for both an orbiter and rover to Mars in 2020. The China National Space Administration’s first mission to Mars will reportedly explore both the martian atmosphere and terrain with a major objective of this mission being to search for signs of present and past life.

Beyond that, in 2024, the Japanese will be launching their Martian Moons Exploration (MMX) mission, which will perform the first-ever round trip demonstration from Earth to Mars and return samples from Phobos.

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RECOMMENDATIONS

- Implement a next generation orbiter as soon as possible to prospect for resources (notably water) that will reduce the overall cost of missions to Mars while providing significant science gains. Even if ISRU is not needed for the initial missions to Mars, this reconnaissance is needed to select the human landing site. Such an orbiter is also key to replacing aging telecommunications infrastructure at Mars.

- Complete a round trip demo to the martian system, which also accomplishes the decadal survey’s highest priority, Mars Sample Return. The samples are needed not only for the revolutionary science that would be achieved but also to address significant toxicity and backward contamination concerns for human beings, including the first human explorers of Mars.

### Future Mars Science Missions Can Provide Key Answers for Human Exploration

<table>
<thead>
<tr>
<th>Mission</th>
<th>Benefits / Key Knowledge Gaps Addressed</th>
</tr>
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<tbody>
<tr>
<td>InDevelopment</td>
<td></td>
</tr>
<tr>
<td>InSight (2018)</td>
<td>Subsurface geothermal gradient/seismology and internal structure of the planet. Instruments will identify any local areas of seismic risk. And a weather station on the lander will contribute to the understanding of weather on Mars.</td>
</tr>
<tr>
<td>ExoMars 2016 (ESA/Roscosmos)</td>
<td>Landed platform science and rover with a ~1.5 m drill and ground penetrating radar, searching for biosignatures, surface hydrated materials and very shallow subsurface ice.</td>
</tr>
<tr>
<td>Mars 2020</td>
<td>MOXIE ISRU demo, caching for sample return. Samples are not only top Decadal Survey priority but allow us to perform due diligence on toxicity and backward contamination concerns for human beings.</td>
</tr>
<tr>
<td>Hope 2020</td>
<td>UAE mission to near-aerostationary orbit providing synoptic weather views moving through all times of day, filling several strategic knowledge gaps.</td>
</tr>
<tr>
<td>Red Dragon (SpaceX)</td>
<td>First use of supersonic retro-propulsion in a Mars lander. TBD Experiments</td>
</tr>
</tbody>
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| Under Study |
| Martian Moons Exploration (JAXA) | Phobos sample return. Critical insight into the potential for martian moons to support ISRU. Also provides an understanding of the gravity and mechanical properties of the moons, which are key for potential human landings on the moons. |
| Next Generation Mars Reconnaissance Orbiter | Martian system resource reconnaissance for ISRU of Mars and its moons; SEP demonstration flight; critical telecommunications refresh, addressing SKGs |
| Mars Sample Return | More detailed biological analysis, due diligence to address toxicity and potential biological risks; round trip demo including advancement of Entry, Descent, and Landing (EDL) as well as ascent techniques. |
Efforts by NASA and industry continue to produce exciting designs for human exploration of Mars. Proposals have expanded from purely technical concepts to also address many of the fundamental realities of executing a space exploration program. Multiple non-technical constraints must be addressed and balanced: affordability, feasibility, engagement and interest. Recent work shows that Mars exploration in the near term is increasingly possible within current constraints and technology with multiple pathways to success. The basic transportation systems—the Space Launch System and Orion—are well into production and rapidly approaching first flight. Technology development and testing continues to improve the safety and reliability of spacecraft systems needed for Mars with new systems headed towards the International Space Station for testing. New architectures are evolving into increasingly credible plans that address all factors needed to achieve Mars program success. The human exploration of Mars is coming closer every day due to the positive results of ongoing architecture and space systems efforts.

ARCHITECTURES AND SYSTEMS
Elements Required for Mars and Current Progress

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ARCHITECTURES
Interested organizations within government and industry continue to examine various aspects of putting humans on Mars and add detail to plans to accomplish that goal.

NASA Mars Study

NASA’s Mars Study seeks to define the basic capabilities and elements needed for sustainable Mars exploration.

Strategic Principles for Sustainable Exploration

NASA’s approach to pioneering is embodied in a set of guiding principles that will increase our successes and benefits over the coming decades. These key principles are the basis for a sustainable, affordable space program and provide overarching guidance to ensure NASA’s investments efficiently and effectively enable the journey to Mars. These principles are:

- Implementable in the near-term with the buying power of current budgets and in the longer term with budgets commensurate with economic growth;
- Exploration enables science and science enables exploration, leveraging robotic expertise for human exploration of the solar system;
- Application of High Technology Readiness Level (TRL) technologies for near term missions, while focusing sustained investments on technologies and capabilities to address challenges of future missions;
- Near-term mission opportunities with a defined cadence of compelling and integrated human and robotic missions providing for an incremental buildup of capabilities for more complex missions over time;
- Opportunities for U.S. commercial business to further enhance the experience and business base;
- Resilient architecture featuring multi-use, evolvable space infrastructure, minimizing unique major developments, with each mission leaving something behind to support subsequent missions; and
- Substantial new international and commercial partnerships, leveraging the current International Space Station partnership while building new cooperative ventures.

JPL Minimal Mars

The Jet Propulsion Laboratory (JPL) performed an independent study to examine the affordability of an example plan to place astronauts in Mars orbit in 2033 and on the surface of Mars by 2037. The example program plan was scoped to fit within NASA’s current human space flight budget, adjusted for inflation.

The architecture leverages existing capabilities to minimize development risk and avoids unnecessary complexity to minimize mission risk. Complex and costly technologies such as in-situ propellant production and cryogenic propellants would be integrated into later missions after retiring the initial risks of travel to Mars. 100 kW class solar electric propulsion (SEP) tugs would be used to place assets in Mars orbit prior to crew arrival.

Emphasis is placed on crew safety, providing abort capability wherever feasible, even during entry, descent, and landing (EDL), and having the return stage for the next mission arrive in time to serve as a backup for the previous mission. The example program plan features Mars vehicle testing at the Moon, including a crewed landing, to qualify the designs before committing a launch to Mars. The low gravity environment of the Moon could provide for high-fidelity flight verification of the terminal landing phase, surface system operations, EVA and science operations, dust mitigation, and ascent vehicle operations. The lunar missions would be dress rehearsals for the Mars missions, just as Apollo 10 was a dress rehearsal for Apollo 11.
The Mars Base Camp concept is a bold and achievable plan to transport scientist-astronauts from Earth to Mars to answer fundamental science questions and prepare for a human landing.

Using two Orion crew modules as the cornerstone, the initial mission crew would explore the moons of Mars and tele-robotically operate assets on the surface of Mars, including the return of Mars samples to the orbiting base camp. Follow-on missions would include a reusable, single stage, crewed, descent and ascent vehicle to perform sortie missions to the Mars surface.

Before going to Mars, the base camp elements would be assembled and tested in the cislunar proving ground, evolving from Lockheed Martin’s designs for NASA’s Deep-Space Gateway in orbit around the Moon. Mars Base Camp would build upon existing deep space technologies in development today and provide a blueprint for NASA’s Journey to Mars. This plan prioritizes significant scientific discovery, evolution of specific mission objectives, and astronaut safety.

AFFORDABILITY
Affordability is the ability to bear cost and return value commensurate with that cost. Affordability is a critical evaluation point for any Mars architecture. The architecture, whether it is publicly or privately funded, must be affordable to the funding entity. Affordability must be considered at all stages of architecture development and leads to sustainable human space exploration. Consideration of human space flight scenarios that are believably affordable and sustainable will result in the strongest plan for exploration. Investments in technologies, systems, and capabilities that provide savings through low cost operation and evolvable reuse and formation of strong cost-sharing partnerships offer the best opportunity for a sustainable Mars exploration program.

LOCKHEED MARTIN Mars Base Camp

The Mars Base Camp concept is a bold and achievable plan to transport scientist-astronauts from Earth to Mars to answer fundamental science questions and prepare for a human landing.

The company aims to begin emplacing Mars surface infrastructure by the mid-2020’s, and has minimized the number and complexity of unique systems and technologies across the architecture, minimizing propulsion systems that must be developed and maintained.

SpaceX has begun key developments for this architecture, including testing of their Raptor methane-oxygen engine and large, advanced carbon-fiber propellant tanks. The company aims to begin emplacing Mars surface infrastructure by the mid-2020’s, and has minimized the number and complexity of unique systems and technologies required to achieve this.

SPACEX Mars Architecture

The SpaceX Mars architecture is intended to provide an affordable, near-term means of delivering large quantities of cargo and people to Mars, in order to enable humanity becoming a multi-planetary species. The system delivers at least 100 tons to the surface of Mars per flight and supports multiple flights per Mars mission opportunity.

A two-stage vehicle provides transportation, with a first-stage booster for Earth launch and a ship that completes the ascent to Earth orbit and performs all in-space and planetary vicinity operations. Following launch from Earth, the ship makes use of propellant delivered by tankers prior to traveling to Mars. After delivering its Mars surface payload, the ship once again refills by making use of locally produced propellant before returning to Earth. Methane-oxygen propellant is exclusively used across the architecture, minimizing propulsion systems that must be developed and maintained.

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BOEING Cislunar and Mars

Boeing has proposed a cislunar proving ground and Mars architecture that is based upon the heavy lift capability of the Space Launch System (SLS) and the integrated capability to co-manifest a 10 ton element with Orion on a single launch to cislunar space. The architecture takes maximum advantage of available capabilities to maintain a consistent human cislunar presence while developing Mars mission readiness. Key technology and operations demonstrations include deep-space environment mitigations, advanced closed-loop life support systems, electric propulsion, automated rendezvous & docking, operating with significant communications lag, and tele-robotic operations.

After testing the prototype Mars vehicles, the cislunar Gateway would then be used to launch a series of missions to Mars that start with exploration of Mars’ moons and the remote operations of robotic elements on the surface of Mars. The plan would culminate in the landing of the first humans.

The elements in this architecture take advantage of existing systems and technology whenever possible to lower costs and increase reliability. Starting with the very first launches of the Space Launch System, this plan would make steady progress towards Mars with every human mission to deep space.

FINDINGS

- The wide range of architectures for the exploration of Mars and the credibility of the institutions and companies producing them demonstrate both the wide interest in Mars exploration and the positive opinions of the viability of current technology to achieve it.
- Mars exploration architectures must consider and address affordability, including how the architecture will return appropriate value to its stakeholders, as a fundamental requirement for credibility.
- Sustainability is also a fundamental requirement and will be driven by, besides affordability, international and commercial partnerships. To effectively engage these partners, clear consideration of their contributions and objectives must be made.
- A well-defined set of accepted scientific objectives will anchor coordination between the human spaceflight and science communities and ensure the widest possible support for human exploration of Mars.
- Timely identification of strategic knowledge gaps and a robust technology demonstration program is needed to mature systems for Mars explorations. Testing systems at the International Space Station and in cislunar space would provide valuable operations experience for Mars systems.
- Robotic reconnaissance of Mars from orbit and on the surface is needed to finalize selection of landing sites and inform technology development and system design.
- The ongoing discussion and development of systems and architectures for deep space exploration is valuable with each idea contributing new perspectives and possibilities. Architecture choices must be rational and transparent to maximize participation. Open and wide-ranging discussion will produce the strongest possible Mars architecture.
- Mars is achievable.
NEXT STEPS

Lunar Proving Ground: Advantages and Goals

Many of these architectures share the common element of an initial phase in cis-lunar space. Within the constraints of these architectures, cis-lunar space provides a valuable location for systems maturation and risk reduction while addressing affordability concerns by proving a steady cadence of infrastructure-building missions within defined budgets.

Testing in cis-lunar space allows increased confidence in systems through operations directly in the deep space environment that will be experienced by all Mars systems.

Operations in cis-lunar space will provide valuable knowledge for later Mars missions. Lunar exploration is not incompatible with Mars exploration and instead offers a wide range of synergies that would strengthen both goals.

Lunar Exploration

NASA has continued to focus on placing a small outpost orbiting near the Moon as the right first step to mature technologies and demonstrate operations for deep space explorations. Discussion around this goal is ongoing and a consensus has been achieved. The Affording/Achieving Mars workshops [http://www.exploremars.org/affording-mars] organized by Explore Mars, Inc. and the American Astronautical Society have continued to bring together space experts to build a community consensus on the future of space exploration, including cis-lunar efforts as a stepping stone on the path to Mars. Efforts in cis-lunar space can help enable NASA’s Mars effort but NASA should not lead or fund exploration of the lunar surface.

Lunar exploration does not detract from the goal of putting humans on the surface of Mars. The key to remaining on the path to Mars is to design systems for the mission to Mars, and then demonstrate those systems during lunar exploration. The reverse is not true; systems designed only for the Moon are not compatible with the exploration of Mars. In addition, commercial efforts, possibly cargo delivery or communications, in low Earth orbit and cis-lunar space could likely bring valuable new participants and technologies. International partners with the goal of human lunar landings can take advantage of the capabilities developed by the U.S. to operate in cis-lunar space. Private endeavors such as the Google Lunar XPRIZE, which offers a prize to the first team to land a spacecraft on the Moon’s surface, travel 500 meters and transmit video back to Earth, are stimulating public support and engagement for deep space exploration in general. With so much existing focus on lunar surface exploration, NASA should remain focused on Mars and not fund crewed lunar surface exploration activities. There is value in all space exploration and every effort can help contribute to the goal of humans on the surface of Mars in the 2030s.

RADIATION

Space radiation (galactic cosmic radiation and solar particle events) is a known risk of space travel and travel beyond low Earth orbit increases this risk to astronauts. Numerous health impacts due to radiation are documented but the combined, long-term impact of space radiation is not yet well characterized. Mars missions durations are well beyond current experience and careful study will be required to properly protect the astronauts. However, the risks from radiation are not considered insoluble and will be addressed through a combination of hardware, operational and health mitigations.

KEY ELEMENTS AND SYSTEMS

ORION

The first successful Orion mission, Exploration Flight Test 1, was completed in 2014. For the second uncrewed test flight, Exploration Mission 1 (EM-1), Orion will travel into Distant Retrograde Orbit, more than 40,000 miles beyond the Moon, and farther than the most distant Apollo mission. Lockheed Martin and its partners on the Orion program are currently finalizing crew system designs, building primary structures and flight components, running mission simulation tests and assembling the EM-1 crew module at Kennedy Space Center. The EM-1 European Service Module is being assembled in Bremen, Germany by Airbus Defense and Space. The service module structural test article has completed acoustic testing and solar array deployment at NASA’s Plum Brook Station. The team is also performing integration testing for NASA’s Space Launch System and the European Service Module. This is currently scheduled to be Orion’s final test flight before a crewed mission, but NASA is also assessing the feasibility of adding a crew to EM-1.

SPACE LAUNCH SYSTEM (SLS)

All major components for the first flight of the Space Launch System – Exploration Mission-1 – are now in production or test, heading toward integration at NASA space centers around the country. Flight hardware for the core and upper stages of the rocket is ongoing at the Michoud Assembly Facility (MAF) in New Orleans, Louisiana, the Marshall Space Flight Center (MSFC) in Huntsville, Alabama, the Kennedy Space Center in Florida and at other locations. The Interim Cryogenic Propulsion System (ICPS), structural test article and flight hardware for EM-1 was delivered ahead of schedule.

The second and final qualification solid rocket motor was successfully tested last summer and EM-1 flight motors are being filled with propellant. Test firings of the RS-25 main engines ensure that the re-purposed space shuttle main engines will meet the demanding SLS performance requirements. Looking forward to subsequent missions, the Exploration Upper Stage (EUS) for EM-2, a more capable replacement for the ICPS, completed Preliminary Design Review (PDR) in January. Across the country, the manufacturing and testing of SLS is progressing at an aggressive pace.

TESTING

Testing of systems and operations techniques in cis-lunar space and on the surface of the Moon will provide valuable insight and knowledge on the path to Mars. Testing in a relevant environment offers the best insights into system behavior and helps planning for future missions through a perceptive understanding of system operation.

In addition to the testing of hardware in the deep space environment, sending humans further and further from Earth will also present increasing operations challenges due to increased communication lag, lowered operational comfort by flight controllers and increased isolation of the flight crew. Long duration missions in cis-lunar space will alleviate these concerns by providing valuable data and allowing practice for a gradual transition to long distance operations.

Human space flight has a strong history of testing and flying, where systems are tested rigorously under flight conditions and the understanding gained is then used to improve the design. The journey to Mars will benefit from this same step-wise approach.
Current exploration scenarios envision missions that deliver cargo payloads via low thrust, highly efficient solar electric propulsion (SEP) and missions that deliver crew via higher-thrust, faster transportation systems. Nuclear thermal propulsion (NTP), with similar thrust but up to twice as efficient as the best cryogenic chemical system today, is being studied again to provide faster access to Mars. Scientists and industry engineers are looking at new technologies that permit the use of low-enriched uranium (LEU) similar to that in commercial power plants. SEP is even more efficient than NTP but at a low thrust requiring much longer mission times, making it ideal for cargo missions. Shorter mission times improve astronaut safety and health by limiting exposure to weightlessness and space radiation. Reduced mass through improved efficiency improves affordability, payload mass, abort options, and mission flexibility. Aerojet Rocketdyne was awarded contracts in 2016 for maturing the LEU NTP design and developing the 12.5 kW Hall thruster system that will form the basis of a SEP vehicle. Other contractors are studying the incorporation of SEP into electric propulsion vehicles for deep space cargo and exploration missions.

Development of concepts for deep space habitats has accelerated in the past year, matching the increased pace of propulsion development and firmly anchoring the deep space transportation leg of the path to Mars. A small outpost orbiting near the Moon offers unique advantages to test technologies and prepare for deep-space explorations. Under NASA’s Next Space Technologies for Exploration Partnerships (NextSTEP) project, Bigelow Aerospace, Boeing, Lockheed Martin, and Orbital ATK generated designs for a cis lunar habitat, while Dynetics Inc., Hamilton Sundstrand, and Orbital Technologies (OrbitTek) developed habitat life support subsystems. NASA announced a second phase of the habitat effort to continue development and awarded new habitat work to the four incumbents plus Sierra Nevada and Ixion. Life support systems will be a critical component of human vehicles for Mars exploration due to the long trip times with no possibility of aborts back to Earth. Integrating these new and efficient technologies into deep space habitats will help enable safe and affordable Mars vehicles.

Surface systems needed for Mars include habitats, power, surface transportation, and surface Extra-Vehicular Activity (EVA) and must support a crew for up to 500 days on the surface. Some habitation systems will be common with deep space versions but the martian surface also presents unique challenges that will require new or modified hardware. NASA continues to facilitate landing site discussion on landing site selection, landing site usage for a wide variety of objectives, and the need for robust surface reconnaissance. As with nuclear thermal propulsion, nuclear surface power is also increasingly interesting to the community for the unique advantages it can provide, particularly for a Mars surface outpost (see Affording/Achieving Mars workshops reports at http://www.exploremars.org/affording-mars). A combination of pressurized rovers and EVA suits will provide both a large exploration range and detailed surface interaction.

The ascent vehicle is perhaps the most important vehicle in any Mars scenario. Mars landers and ascent vehicles face significant mission challenges, including long periods of dormancy, storage of propellants, large delta velocity requirements, exposure to widely varying environments and the need to keep the crew alive and healthy with a minimum of resources. Discussion at the Affording/Achieving Mars workshops [http://www.exploremars.org/affording-mars] organized by Explore Mars, Inc. and the American Astronautical Society has highlighted these issues. The large payload masses involved for a Mars ascent vehicle or surface habitat add to the challenge. While there is relatively more development time available for landers than for in-space systems, work on key technologies is continuing to yield good results. Though these are challenges to future Mars missions, the challenges can be mitigated with proper timely decision making, planning, and funding. SpaceX has demonstrated supersonic retro propulsion, an important technology for bringing large payloads to the surface, in Earth’s atmosphere at altitudes that simulate Mars conditions and announced the intention of testing it at Mars. Efforts on rigid aeroshells and inflatable structure, which would use the atmosphere of Mars for deceleration, also continue.
2016 saw progress on several fronts in the world of Human Factors:

Preliminary results from NASA's Twins Study demonstrate that, in long-duration spaceflight, inflammation may be increased, bone formation may decline over time, and chromosomal changes may occur.

- An exploration-class mission exercise device (Advanced Twin Lifting and Aerobic System = ATLAS) is being developed that can be used for aerobic exercise while also providing up to 600 lbs. of resistive force. Testing for the ATLAS is planned to happen on ISS.
- A study by the DLR institute of Aerospace Medicine is researching the visual impairment and intracranial pressure syndrome using bedrest subjects who will be kept in a head down tilt for 30 days in an elevated carbon dioxide environment that is similar to the ISS.
- Work is ongoing to develop a global research strategy to develop/examine simulated or artificial gravity technologies, which can be used as a countermeasure for physiological deconditioning.

Human Factors & Behavioral Performance Integration: Deep Space Vehicle/Habitat

The human-vehicle interface for a deep space exploration/habitat vehicle offers an excellent conceptual model for how the system architecture must retain critical technical capability while maintaining and sustaining crew health and operational readiness. This end-state is only achievable with carefully thought out principles that allow for the seamless and effective integration of key requirements (in order of priority):

- Maximization of crew safety
- Maximization of affordability and sustainability
- Timeframe of interest (i.e., duration of mission)
- Adequate science and exploration capabilities
- Plan for developing Mars surface infrastructure for prolonged human presence
The Deep-Space Exploration Vehicle/Habitat will serve as the “micro-world” for the crew’s interplanetary transit. The Human System Interaction Design helps pull the various systems and requirements together to ensure human factors and behavioral performance capabilities are maintained and sustained. As depicted in Figure 1 below, this process incorporates four key elements: monitoring systems, environmental design options and solutions, human system standards and requirements, and human health countermeasures/protocols.

Integration of Multi-System Processes for Deep-Space Exploration Vehicle/Habitat

Human habitats on the surface of Mars will represent a new paradigm for NASA designers, necessitating solutions that will focus on living in partial gravity. These designs will be used in a very harsh environment that humans must inhabit after a long-duration spaceflight journey that will likely result in a deconditioned state. The human factors design must also address performance issues that are impacted by the deconditioned status of crew and how they may be at increased risk of injury due to the anticipated dynamic loads transferred to the crew via the vehicle during landing, aborts or launches for return voyages. Habitats must also accommodate the day-to-day tasks of astronauts on a planetary surface, including both work-related tasks such as science experiments, extra-vehicular activities, and habitat maintenance, as well as living tasks such as eating, sleeping, and personal hygiene. The habitat must cater to the needs of a high-functioning team as well as the needs of those individuals on the team, all with minimal resupply opportunities. Habitation systems must accomodate the needs for food, waste management, and exercise while adhering to minimal standards for up-mass, volume, and mass. Designers today will have to anticipate these needs and incorporate them into a human-centric system focused on providing the hardware and habitat layout that the future inhabitants of Mars will need to effectively perform their expected tasks. NASA continues to modify these requirements based on findings from ISS-based research as well as ground studies in analog environments, such as the Human Exploration Research Analog and Antarctic research stations.

All of the above considerations need to be addressed in order to increase the chances of mission success. However, these considerations alone are not sufficient; they must be added to those biomedical challenges identified in the 2016 Achievability and Sustainability of Human Exploration of Mars Report (AM IV), which include but are not limited to:

- Minimizing the negative impacts of space radiation
- Optimizing human health in a partial gravity environment
- Developing exploration medical capabilities and technologies
- Creating sustainable life support systems for long-duration, long-distance spaceflight

The incorporation of human factors and behavioral performance expertise with the necessary solutions for space biomedical challenges are the key elements to a human-centric Mars mission design. These efforts will be essential to ensure mission success and to optimize astronaut performance in what will be the most challenging human exploration effort ever undertaken.

Selected HRP Risks Related to Human Factors and Behavioral Performance

- Human-Computer Interaction (HCI): Providing computer interfaces that allow crew to effectively perform work
- Inadequate Mission, Process, and Task Design (MPTASK): Considering human capabilities and limitations in design of missions, processes, tasks, schedules, and procedures
- Inadequate Human and Automation/Robotics Integration (HARI): Designing integrated human-systems for automation & robotics that allow crew to more effectively perform work tasks
- Training Deficiencies (TRAIN): Providing a wide-range of training that will result in crew effectively performing work (e.g., hundreds of hours of lunar module (LM) simulation flights by Neil Armstrong prepared him for unexpected events during actual piloting of LM for first Moon landing)
- Vehicle/Habitat Design (HAB): Designing vehicles and habitats that optimize crew performance in the space environment
- Cognitive/Behavioral Conditions and/or Psychiatric Disorders: Maximizing healthy adaptations and minimizing vulnerabilities to the psychological, interpersonal, and stress-provoking circumstances related to long-duration spaceflight
- Performance and Behavioral Health Decrements Due to Team Issues: Maximize cooperation, coordination, communication, and psychosocial adaptation within a team
- Performance Decrements and Adverse Health Outcomes Resulting from Sleep Loss, Circadian Desynchronization, and Work Overload: Maintaining high performance levels while minimizing fatigue for extended periods of time.
POLICY: OPPORTUNITY & CHALLENGES
The Path Forward

UNITED STATES Space Exploration Policy

Congress: Support in Congress for human missions to Mars remains strong and bipartisan, continuing the momentum that has been building for over a decade with the NASA Authorization Acts of 2005, 2008, and 2010. As noted in the 2016 Humans to Mars Report (H2MR), however, Congress has expressed concerns that (1) NASA has not defined a clear path of how it will achieve the Mars goal, and (2) steps must be taken to assure programmatic stability moving into the next (current) administration. These concerns have been the focus of recent legislative activity:

- Congress held numerous hearings and briefings over the past year that focused on human space flight efforts on achieving human surface missions to Mars within the next two decades. Advocates remain, however, for preparing to achieve those missions by first undertaking human landings on the Moon. In February 2017, the Trump Administration released its first 2018 federal budget blueprint, indicating that more details would be released sometime in May. It calls for a $19.1 billion budget for NASA in FY2018, which is approximately $400 million less than the amount authorized by Congress for fiscal year 2017 in the NASA Transition Authorization Act of 2017 and represents a 0.8 percent decrease from fiscal year 2016 funding levels. The budget blueprint (though lacking details) focuses on deep space exploration, both human and robotic, and on support for public-private partnerships to lower costs and encourage private sector innovation. At the same time, it called for a cancellation of NASA’s Asteroid Redirect Mission, four Earth-science projects, and the agency’s Education Directorate.

- In February 2017, the Senate passed S.442, the NASA Transition Authorization Act of 2017, and the House followed suit in early March 2017. The President signed this legislation into law as P.L. 115-10 on March 21, 2017. This Act contains the most comprehensive language supporting human missions to Mars ever to appear in a piece of legislation. Among other things, it calls for expanding human missions to Mars by 2030, with an aim toward successfully launching and carrying out such a Mars human space flight mission by 2033, a date advocated by independent organizations such as Explore Mars, Inc., as well as by various internal NASA studies, for the past few years. Indeed, Congress acknowledged in the Act the contribution to achieving this goal by Explore Mars, Inc.’s Humans to Mars Report. In Sec. 431 of the Act, Congress specifically referenced “several independently developed reports or concepts that describe potential architectures or concepts and identify Mars as the long-term goal for human space exploration, including…Explore Mars’ ‘The Humans to Mars Report 2016’.

- The Humans to Mars Report 2016, focused on various aspects of Mars mission architecture as well as science, and also on the need to inspire students to pursue careers in STEM fields.

- The Obama Administration: Less than one month before the November 2016 election, and only a little more than three months before he left office, President Barack Obama, in an Op-Ed for CNN, spoke about America’s leading scientists, engineers, and students. He indicated that the next step in space is to reach beyond the bounds of Earth orbit, and that the next chapter of America’s story in space is to send humans to Mars by the 2030s and return them safely to Earth, with the ultimate ambition to one day remain there for an extended time.

- The Trump Administration: Inauguration: While President Trump did not specifically mention Mars during his inaugural address, he did indicate that we stand at the birth of a new millennium, ready “to unlock the mysteries of space…”.

- Human rating Exploration Mission 1 (EM-1): In February 2017, NASA announced that it would investigate the possibility of launching astronauts on the first flight of the Orion crew capsule with the Space Launch System, otherwise known as Exploration Mission 1 (EM-1). This mission was originally planned to launch without a crew with a target launch date in late 2018. However, the proposed crewed EM-1 would send humans into lunar orbit sometime in 2019.

2016 Presidential Statements:

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- Trump Administration Proposed NASA Budget: In mid-March, the Trump Administration released its first 2018 federal budget blueprint, indicating that more details would be released sometime in May. It calls for a $191 billion budget for NASA in FY2018, which is approximately $400 million less than the amount authorized by Congress for fiscal year 2017 in the NASA Transition Authorization Act of 2017 and represents a 0.8 percent decrease from fiscal year 2016 funding levels. The budget blueprint (though lacking details) focuses on deep space exploration, both human and robotic, and on support for public-private partnerships to lower costs and encourage private sector innovation. At the same time, it called for a cancellation of NASA’s Asteroid Redirect Mission, four Earth-science projects, and the agency’s Education Directorate.
The international commitment to robotic exploration of Mars is substantial and growing. Currently, NASA, the European Space Agency (ESA), Russia, and India have operational missions at Mars. In the early 2020s, Japan, the United Arab Emirates (UAE), and China will also launch missions to Mars. The UAE’s motivations for exploring Mars are insightful: “We chose the epic challenge of reaching Mars because epic challenges inspire us and motivate us. The moment we stop taking such challenges is the moment we stop moving forward.”

Even though a single country (or space agency) may act as the primary sponsor of such missions, virtually all are multinational efforts, with collaborations from one or more countries on the instruments and/or science investigations. Through human missions in cislunar space and robotic missions at Mars, space agencies are taking steps to prepare for human exploration of Mars. With these exciting missions, the human race is beginning to realize that the challenge of human exploration of Mars, while epic, is fundamentally achievable.

**International Policy**

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**RECOMMENDATIONS:**

- **NASA is on a course to send humans to Mars. Congress and the new Administration should work together to maintain this focus and enable human exploration of Mars in the 2030s. Policy goals and objectives must be matched by appropriate, necessary, and sustained funding levels that would enable NASA to carry out such missions. Multiple organizations, including Explore Mars, Inc., the Planetary Society, and the Aerospace Industries Association, have recommended modest increases in NASA’s budget to provide proper resources for deep space exploration and science.**
- **The entire space community, including industry, academia, and government, as well as space advocates from the general population, must continue to reach out to non-traditional audiences and constituencies.**
Public enthusiasm for Mars exploration remained strong throughout 2016. A seemingly endless stream of Mars-related news emanating from NASA, the entertainment industry, American industry, Congress, and elsewhere has kept Mars continuously in the public consciousness.

This momentum, however, was tempered somewhat by election year politics. Detractors of Mars exploration and/or advocates for alternate space exploration goals mounted campaigns calling on the new Administration to change the course of human space flight. While it is unclear how much impact these efforts have had in the public’s perception of human space exploration, it is clear that support for Mars still remains at historically high levels.

Evidence of this public support and perception is reflected in the following categories:

**Entertainment and Publishing:** As stated in the 2016 *Humans to Mars Report* (H2MR), the hype and excitement generated by motion pictures is not sufficient in and of itself to lead to humanity on the surface of Mars. Nevertheless, trends in the entertainment industry (not only in film but also in television and in print) cannot be ignored, especially when these projects take great pains to strive for realism as opposed to science fiction. As such they can be harbingers of the near future:

- **Mars (television):** This National Geographic television series, produced by Ron Howard and Brian Grazer, was released in the Fall of 2016. The 6-part series depicted the struggles of an initial human Mars mission in the year 2033. Viewership was such that National Geographic has approved production of Season 2 of Mars.

- **Mars: Our Future on the Red Planet (book):** National Geographic also released a companion book to its Mars television series, written by Leonard David.

- **The Space Between Us (movie):** This film, directed by Peter Chelsom, was released in February 2017. It tells the heartfelt story of a child born on Mars and his longing to visit humanity’s home world. It features such actors as Gary Oldman, Asa Butterfield, and D.B. Wong.

- **Mission Control (television):** This CBS television pilot, written by author Andy Weir (*The Martian*) and directed by Ridley Scott, follows NASA mission control as it attempts to elevate a next-generation space station from low Earth orbit to a higher orbit, where it will eventually fly to Mars.

- **Passage to Mars (movie):** This documentary tells the incredible true story about a NASA expedition across 2000 miles of treacherous arctic terrain, designed to prepare astronauts for journeys on the surface of Mars. This journey was supposed to take only a period of weeks, but ends up becoming an epic two-year tale of adventure and survival.

- **Life (movie):** This horror/thriller film was released in March 2017 and tells the story of a crew aboard the International Space Station who discover life in a Mars sample return mission. Unfortunately, the lifeform, although being intelligent, also ends up being dangerous. This film features Ryan Reynolds, Rebecca Ferguson, and Jake Gyllenhaal.

- **The Wanderers (book):** This literary fiction novel by Meg Howrey was released in March 2017 and tells the story of a crew preparing for a privately-funded, first human mission to Mars.

- **The Mars Generation (movie):** Produced for Netflix and directed by Michael Barnett, this story follows aspiring teenage astronauts at Space Camp who hope to one day walk on the surface of Mars. This film will be released in early May 2017.
RECOMMENDATIONS:

- The question ‘Why Mars?’ needs to be better articulated by the space community.
- After NASA, the media/press provide the primary influence on public perception. Better relationships must be built with the national and international press, and press briefings should be scheduled more regularly, to ensure that the public is furnished with the facts about Mars exploration.
- Dispel the $1 trillion myth: Recent studies have shown that human missions to Mars will only cost a fraction of this amount.
- Better storytelling: NASA and the space community need to explain better the path to Mars and how current programs will advance that path.
- Strengthen Hollywood partnerships: NASA and the space community regularly collaborate with the entertainment industry, but these ties need to be strengthened to amplify the messaging for human missions to Mars.

CONTINUING RECOMMENDATIONS FROM 2016:

- Early research indicates that the level of press coverage for Mars has increased over the past eight years and that positive press coverage now greatly exceeds negative press coverage. Comprehensive press analysis should be conducted to verify and quantify this trend.
- Special emphasis should be made to inform the public that landing humans on Mars by 2033 is an achievable goal.
- While international and private lunar surface missions should be applauded, increased education needs to be undertaken to articulate why lunar surface operations are not the best path to Mars.
Explore #WhyMars is our Mission at
https://ExploreMars.Org