Explore Mars, Inc. is pleased to present the 2016 Humans to Mars Report. As stated in our premiere issue in 2015, this annual publication provides a snapshot of current progress in mission architectures, science, policy, international engagement, human factors, and public perception regarding human missions to Mars, and highlights progress and challenges from year to year. By doing so, this report provides stakeholders and policy makers with a resource to help them make decisions based on the most current information rather than on outdated sources, speculation, and occasional misinformation.

The Humans to Mars Report is not advocating any particular approach for sending humans to Mars. To be clear, this report will not include speculation or rumor about future architecture, unless actually impacting public perception and policy decisions. Instead, we report on current official progress and viable approaches, as well as on relevant technologies and capabilities, that are in the public domain and thus are subject to critical review and analysis.

As highlighted in this report, there have been significant developments since the premiere issue was released. Mars has been in the news regularly and the United States has embraced Mars as the goal for human space flight more than ever before. For example, in October 2015 NASA began the process of assessing potential candidate human landing sites on Mars for the first time.

However, much additional progress is needed and greater urgency is required to achieve the goal of landing humans on Mars. The greatest threat to mission success is complacency and delay. More clarity is required about the intermediate steps that will be needed for human landings on Mars. This historic goal has become far more realistic than ever before. We believe that the Humans to Mars Report will help to enable a human presence on Mars beginning in the early 2030s.

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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 or at the email address info@ExploreMars.org

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Mars is a challenging destination, both for robotic science and eventual human missions. Over the past three years, Explore Mars, Inc., in conjunction with the American Astronautical Society, has conducted the Mars Affordability and Sustainability Workshops [http://www.exploremars.org/affording-mars] bringing together unparalleled expertise from NASA, industry, and academia to focus efforts on future exploration of Mars. Our goal has been an integrated effort of both robots and humans working closely together to yield outstanding scientific value, while providing critical data to close knowledge gaps in preparation for human exploration. In our workshops, we brought together scientists and engineers to develop plausible scenarios for human missions that achieve exciting scientific results. By combining the experience, the capabilities, and the imaginations of all of those involved in planning for Mars, we intend to produce a far more sustainable plan for exploration. In addition to these tangible benefits, there are also intangibles, such as closer partnership among scientists and engineers toward an exciting future for both. Whether formally or informally motivated, the outcome for both robotic and human missions is improved.

We expect that much of the progress on which we report this year actually crosses traditional boundaries. Historic firsts occurred in 2015, such as when the science and human mission planning communities came together in October for the first Mars Exploration Zone/Landing Site Workshop during which the two communities discussed issues of importance to both. Future workshops are planned to foster an integrated approach for exploration of Mars. Data returned from the radiation monitor on the Mars Science Laboratory/Curiosity rover continues to help refine the requirements for future human missions. The Mars Oxygen ISRU Experiment (MOXIE) payload, which will demonstrate the ability to make oxygen from the martian atmosphere, is in development and will fly on the Mars 2020 mission. Terrain Relative Navigation (TRN), which is a key element for more precise landings on Mars, will also be demonstrated on Mars 2020. Technology development now underway in NASA’s Space Technology Mission Directorate (STMD) for human missions, such as high-power Solar Electric Propulsion (SEP) and Supersonic Retro-Propulsion (SRP) combined with advanced aerodynamic decelerators, may enable more capable robotic missions as precursors to human missions.

This year, for the first time, we include a section on human biomedical issues as well as research topics that are planned to address them. Much publicity surrounded the “one year” mission of Scott Kelly aboard the International Space Station (ISS), an example of the work that NASA is embarking on to learn more about the human-related issues of long-duration missions in deep space. However, there are many other human research related knowledge gaps that need to be addressed prior to embarking on a human mission to Mars. Another exciting area of progress is in systems and architectures development. Examples include the NASA Jet Propulsion Laboratory’s (JPL) “Minimal Mars” study and NASA’s “Evolvable Mars Campaign”, summarized in this report, which are focused on affordability and sustainability. At this point it is too early to state what will become the final approach, but all of these studies demonstrate that there are many common capabilities regardless of the approach, thus allowing for systems development to proceed. Furthermore the JPL study showed that it is possible to meet the schedule of getting humans to Mars orbit by the 2030’s while staying within a human spaceflight budget assumed to grow only with inflation. This is significant not because it is the ideal plan, but because it responds to the one impediment that most critics have focused on – budget – and demonstrates that human exploration of Mars can be achieved with reasonable and stable budgets.

Finally, this report also summarizes current trends in public policy and public perception, two topics of great importance in this Presidential election year. Transitions in administrations have traditionally been a time of uncertainty for space activities. Our goal in this report is to lay out the many reasons why support for a long-term sustainable approach to a campaign leading to humans on Mars in the 2030’s is an issue that all of our nation’s leaders should embrace.
NASA’s Mars Exploration Program (MEP) continues to advance the exploration of the martian frontier. This program includes the ongoing surface-based scientific exploration by the Mars Exploration Rover Opportunity, and the Mars Science Laboratory rover Curiosity, which is the first-ever mobile analytical laboratory on another planet. MEP also includes the state-of-the-art investigation of the upper atmosphere and surface of Mars by the Mars Atmosphere and Volatile EvolutioN orbiter (MAVEN), the Mars Reconnaissance Orbiter (MRO), and the Mars Odyssey orbiter, as well as plans for in-situ molecular analysis via the Mars Organic Molecule Analyzer (MOMA) on the 2020 European Space Agency’s ExoMars drilling rover. This scientific exploration of Mars has produced a series of “revolutions” in our understanding as well as a realization that the planet we thought we were unveiling during the first era of exploration (circa 1971 to around 1996) is far more intriguing than we first suspected. Unanticipated new discoveries include recognition of ancient habitable environments, the possibility of modern environmental habitats, and evidence of dramatic climate change.

Other international space programs are also very active in Mars exploration. ESA’s Mars Express is in its thirteenth year of operation. The Indian’s first Mars Mission, Mars Orbiter Mission (MOM) arrived at Mars in 2014 and has continued its science operations through the last year. ESA & Roscosmos also successfully launched the ExoMars mission in March of 2016 and the spacecraft is currently enroute to Mars, and is due to arrive at Mars in October, 2016.

Scientific breakthroughs since 2000 strongly suggest that Mars was once a habitable world with chemistry, sources of energy, liquid water, and related environmental factors that would have been conducive to life as we presently understand it here on Earth. Finding signs of preserved bio-signatures that demonstrate that ancient habitable Mars was indeed inhabited, even if only episodically by microbial life, would be humanity’s first evidence of extraterrestrial life. In addition, the potential determination of the extent and duration of biotic activity on Mars would help answer the question of how biology gains a foothold on a planet ultimately to evolve into global scale system (ecologies) or more complex organisms. Today, the collective efforts of NASA, international space-faring nations, industry, and academia are poised to produce discoveries that could change the longer-term trajectory of exploration of the Red Planet.

Since the establishment of the modern program of exploration of Mars (the MEP), dating back about two decades, one of the four core goals has been Preparation for Human Explorers. As part of this program, many of the implemented robotic missions have included instruments/investigations that were designed to collect the data needed to reduce the risk of eventual human missions. Examples of such enabling investigations include: the Mars Radiation Environment Experiment (MARIE) on the 2001 Mars Odyssey orbiter, the Radiation Assessment Detector (RAD) on the 2011 Mars Science Laboratory rover, the Microscopy, Electrochemistry, and Conductivity Analyzer (MECA) on the 2007 Phoenix lander, and the upcoming MOXIE instrument (oxygen ISRU) on the Mars 2020 rover. In addition, a number of other investigations have had a dual purpose, and have advanced both the science agenda and the preparation for human exploration (for example, high resolution orbital cameras are needed for both scientific purposes and for selection of human landing sites).
Although significant progress has been made, more robotic work is needed to enable safe and affordable human missions. Crucial elements include: resource reconnaissance of the Mars system to prepare for ISRU (water ice and hydrated minerals) and a telecommunications infrastructure upgrade. Additionally, a round trip demonstration which includes Mars Sample Return is important not only for the revolutionary science made possible, but also to assess toxicity and backward contamination issues for the Earth.

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 replace 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.

- When appropriate, robotic missions to Mars should not only advance important science goals (such as whether Mars contains evidence of past or present life) but also advance technologies/capabilities that would help to advance human missions to Mars. Example: A ‘heavy’ Mars Sample Return mission would not only satisfy the sample return objective but also advance EDL and ascent capabilities.

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**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>
</thead>
<tbody>
<tr>
<td><strong>In Development</strong></td>
<td></td>
</tr>
<tr>
<td>ExoMars 2016 (ESA/Roscosmos)</td>
<td>Trace gas atmospheric measurements and distribution as well as hydrogen detection in the upper 1 meter of regolith. Hydrogen detection is key for identifying potential water ice deposits for ISRU.</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><strong>Under Study</strong></td>
<td></td>
</tr>
<tr>
<td>Mars Moon Explorer (JAXA)</td>
<td>Phobos sample return. Critical insight into 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.</td>
</tr>
<tr>
<td>Next Generation Mars Reconnaissance Orbiter</td>
<td>Martian system resource reconnaissance for ISRU of Mars and its moons; SEP demonstration flight; critical telecommunications refresh</td>
</tr>
<tr>
<td>Mars Sample Return</td>
<td>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.</td>
</tr>
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**IMAGE CREDIT:** NASA/JPL-Caltech/University of Arizona
NASA, academia, and industry continue to assess and update Mars architectural designs and system concepts for sending humans to Mars. These activities have set the goal of humans reaching the Martian surface by the 2030s. Having this goal become a reality would require a program architecture that balances multiple constraints, including, most importantly, fiscal affordability, along with technical feasibility, acceptable risk, continuous stakeholder interest, private and international engagement, and political sustainability across multiple administrations. Many previous studies have called into question the actual affordability of human missions to Mars, including the most recent National Research Council (NRC) report called, “Pathways to Exploration”, in which multiple exploration pathways to Mars were assessed for programmatic success. Affordability is a critical aspect for many government programs; however, space exploration is particularly affected by budgetary pressures due to long program lifespans and high technology needs. As such, recent studies have focused on affordability as the key parameter and have yielded insightful and positive results.
To provide focus and to limit the possible alternatives, a set of ground rules and constraints were initially applied:

- Technology investments, research priorities, and mitigation strategies.
- Reference for the EMC. This baseline scenario is then used to evaluate capabilities, schedules, risks, challenges, and tradeoffs described in the EMC. It acts as a point of comparison for future assessments and serves as the baseline to Mars surface scenario. Of these, only one spans all Mars vicinity destinations. The "Mars vicinity and Phobos, followed by mission pathfinders. These capabilities have resulted in several possible scenarios for a human mission to the Martian surface. The Human Exploration and Operations Mission Directorate leads this campaign, with participation from nine NASA centers, and close coordination with other architectural analysis groups, the Science and Space Technology Mission Directorates, and the Offices of the Chief Scientist and the Chief Technologist. The EMC routinely invites input from external organizations as well, including international partners, industry, academia, and NASA advisory groups.

Resulting from the architectural trades, the EMC has identified an integrated set of necessary Mars capabilities which can be developed through science missions, robotic precursors, technology investments and capability pathfinders. These capabilities have resulted in several possible scenarios for a human mission to the Martian surface. Of these, only one spans all Mars vicinity destinations. The "Mars vicinity and Phobos, followed by mission to Mars surface" scenario represents an ambitious campaign that leverages most of the capabilities and potential tradeoffs described in the EMC. It acts as a point of comparison for future assessments and serves as the baseline reference for the EMC. This baseline scenario is then used to evaluate capabilities, schedules, risks, challenges, technology investments, research priorities, and mitigation strategies.

To provide focus and to limit the possible alternatives, a set of ground rules and constraints were initially applied:

**EMC Summary Ground Rules & Constraints:**
- Humans will travel to the Mars system by the mid-2030s
  - Could imply orbital, Phobos/Deimos and/or surface expeditions
- Mars mission launch opportunities throughout the 2030s will be evaluated to ensure that systems have adequate performance for mission availability
- Propulsion technology will utilize solar-electric propulsion systems based on technology in development today.
- SLS Block 2 launch vehicle will be available (4xRS25 Core + Exploration Upper State (EUS) + Advanced Boosters + 8.4 m or 10 m fairing)
- Orion spacecraft will be available
- SLS/Orion launch rate of one per year is sustainable in the Proving Ground
- Vehicle checkout/aggregation will be conducted in the cislunar environment to leverage infrastructure established during "Proving Ground" missions in the 2020s.
- Human missions to the Mars system will be developed for four crew members
- Crew vehicle and propulsion systems will be assessed for reuse with potential cost advantages when reasonable

While the EMC studies are still ongoing, the following early results provide insight into the direction of NASA's human spaceflight planning:

**EMC Major Results to Date:**
- Regardless of Mars vicinity destination, common capability developments are required
- ISS provides a critical Mars mission capability development platform
- Cislunar space is efficient for aggregation and potential refurbishment of exploration systems due to stable environment
- Orion Block 1 is sufficient for Mars architectures with reusable habitats
- Space Launch System (SLS) co-manifested cargo capability increases value of crewed missions and improves cadence
- Deep-space habitation serves as initial starting point regardless of implementation or destination
- Asteroid Redirect Vehicle derived Solar Electric Propulsion (SEP) vehicle can serve as an effective tool for human Mars missions
- Mars Phobos/Deimos as initial Mars vicinity mission spreads out development costs and meets policy objectives of Mars vicinity in 2030's

The EMC study community has included a recent independent study by the Jet Propulsion Laboratory (JPL), discussed in depth below, as a part of the trade space under analysis. The EMC analysis enables a steady cadence of missions and test demonstrations that advance common capability developments across the architecture leading to a sustainable human presence on the surface of Mars.

**JPL Minimal Mars: An Existence Proof**

The Jet Propulsion Laboratory (JPL), building upon prior Mars architecture work, performed an independent study to provide an example of how to meet the most challenging constraints of fiscal affordability while achieving a human Mars landing within the interest horizon of the stakeholders. A key feature of this work is that astronauts would go to the Martian moon, Phobos, first in 2033 and then to the Mars surface six years later in 2039. This could allow NASA and potential partners to share the cost and risk. Completed last year, the effort was then peer reviewed and published in the journal New Space. It can be obtained at: [http://online.liebertpub.com/doi/pdfplus/10.1089/space.2015.0018].

The key guidelines, in priority order, were:
1. Maximize crew safety
2. Maximize affordability and sustainability
3. Conduct in a timeframe of interest for stakeholders
4. Provide adequate science and exploration capabilities
5. Provide a path for building up surface infrastructure and evolving capabilities for a human presence on Mars
Adopting these guidelines drove the architecture to use technologies that are nearly ready today, to utilize systems already in development (e.g. the Space Launch System (SLS) and Orion) or being studied today, and to minimize the number and complexity of new vehicles that would be required. This approach contributes significantly to the overall affordability. Given the complexity and cost of these missions, the architecture was broken up into two segments that could be implemented over time:

1. Getting humans from the Earth to Mars orbit and back safely to Earth
2. Getting humans from Mars orbit to the surface and back safely to Mars orbit

The first segment could be accomplished with a mission to Mars orbit and to Phobos for a crew of four by 2033. The round trip mission would be 2 1/2 years long, of which about 1 year could be spent exploring the Martian moon. This mission could demonstrate the first segment for successfully sending crews to Mars orbit and back and would be a precursor to a Mars human landing campaign.

The first human Mars landing mission in 2039 would be a short surface stay of a few weeks leveraging the same systems for getting to Mars orbit and back as validated in the 2033 Mars Orbital/Phobos mission. Two astronauts would transfer to the lander in Mars orbit and then land on Mars. The surface mission would provide many opportunities for groundbreaking planetary science, potentially with large astrobiological implications. Two astronauts would remain in orbit. After the short surface stay, the crew would return to orbit in the Mars Ascent Vehicle (MAV) and rejoin their other crewmates for the return trip back to Earth.

A one-year surface stay mission with a habitat and additional surface infrastructure would follow in 2043. This mission would send two cargo landers to precede the crew lander with supplies. A new crew of four astronauts would be sent to the surface of Mars every four years with additional infrastructure to build up an expanding Mars base. This could be accomplished on a continuing basis with a SLS cadence of one launch every six months.

Using the same cost model as the recent NRC Pathways study [http://www.nap.edu/catalog/18801/pathways-to-exploration-rationales-and-approaches-for-a-us-program], the program was shown to approximately fit within the current NASA human spaceflight budget, adjusted for inflation. This assessment made several conservative assumptions that are unlikely to actually come to fruition: It assumed that the U.S. would pay for the entire effort, and it also assumed that the International Space Station (ISS) would be fully funded through 2028 even though the current policy authorizes the ISS only to 2024. For the long-term human exploration of Mars, the required budget would be under the current NASA budget plus inflation for the 2040s and beyond and would allow for new technologies to be utilized to improve performance and contribute to sustainability.

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With an eye toward bridging the gap between today’s operations on the ISS and what is needed to send humans to Mars, NASA has been studying conceptual architectures for a “Proving Ground” near the Moon or in high lunar orbit. The Proving Ground could serve as a venue to reduce two overarching risk areas, the first being the mission/technical risk, that is, a problem happening during a mission to Mars, and the second being health risks to crew members both during and after the mission is complete. The Proving Ground phase involves increasingly ambitious test flights with the goal of becoming “Earth independent”, which is necessary for Mars missions. Much like the Mercury and Gemini programs were to Apollo, the lunar Proving Ground would be to Mars. To reduce mission risk, the key system elements of sending astronauts to Mars, such as the Orion crew vehicle, a Deep Space Habitat, the SEP tug, and the propulsion stages, could all be tested in lunar orbit. Extending human presence beyond low-Earth orbit will help improve the foundational research of how humans perform in deep space and provide a better understanding of the biomedical issues.

If humans are to journey to Mars, they will need to be healthy when they arrive, be able to stay healthy as they live and work on the martian surface, and be healthy enough to complete the return trip home. Current reference mission architectures include a high likelihood of survivability, and selecting healthy crewmembers will reduce the risks of a medical emergency event during a Mars mission. However, the journey and destination itself will expose the crew to inherent risks that will need to be ameliorated in addition to unforeseen events that will have to be accommodated.

The space medicine community has identified several human health and performance risks for a Mars mission [https://humanresearchroadmap.nasa.gov/]. They include but are not limited to: radiation, physiologic adaptation to a reduced gravity environment, psychological stressors of extended missions, limitations on medical care, and developing a sustainable life support environment including Mars environment exposure (dust, soil toxicity, etc.). Most experts believe that these and other risks to human health and safety in long-distance spaceflight can be mitigated, given appropriate levels of research, including an increased number of longer duration missions. Such missions, some of which will occur in cislunar space, will serve as a testbed and countermeasure testing environment for a Mars mission.
Space radiation has long been known to be a risk for spacefarers journeying beyond the protective envelope of Earth’s atmosphere and magnetic field. This radiation is made up of galactic cosmic radiation and solar particle events. Space radiation is generally unlike terrestrial radiation, as the former is composed of higher energy particles that have more mass and are capable of producing significantly more damage to biological tissue. Even the International Space Station (ISS) is somewhat protected from space radiation due to its close proximity to Earth. However, once humans venture past Low-Earth Orbit (LEO), the risks of space radiation injury and long-term consequences to astronauts increase.

The risks of deep space radiation for long-duration human spaceflight are poorly known. The major components of space radiation can be replicated in Earth-based laboratories but radiation experiments on unmanned Mars missions have revealed environments the entire spectrum of which we are currently unable to replicate on Earth. Developing a better understanding of space radiation risks will require sending humans and biological tissue experiments beyond LEO. Few studies have been done on the combined effects of both forms of space radiation on human tissue. However, based upon the current body of knowledge, there are a number of health risks that may be associated with space radiation that are identical to terrestrial radiation risks including: cancer, catacaetis, heart disease, dementia, impaired wound healing, infertility, birth defects, and decreased immunity.

Another risk to humans on long-distance spaceflight missions is related to zero-G spaceflight. Spending months to years in a reduced gravity environment causes the human body to adapt to a new “normal”: bones and muscles atrophy causing decreased muscle strength and the potential for skeletal fractures; the heart and blood vessels become deconditioned and blood volume is reduced, resulting in possible dizziness and fainting on landing; and the vestibular system is reoriented with the change in gravity and balance/coordination are altered, which may lead to trouble walking and problems with fine motor skills when the crewmember returns to gravity conditions on Mars or the Earth. Watching media coverage of the recent return of the two participants who spent almost a year in space shows that, while happy and comfortable with the assistance of the ground team waiting for them upon landing, it would have been challenging for them to immediately establish a habitat or deal with any re-entry mishaps that could have occurred (which could be the case on Mars, which has roughly 1/3 the gravity of Earth).

While NASA and the Russian Space Agency are being rightly praised for the recently completed “year-long mission,” two reasonably healthy subjects (only one of which the U.S. space community will have full access to for research purposes) do not constitute a robust research program. Additional extended duration crewmembers will be required to perform year-long missions with comprehensive research programs to develop and test the countermeasures needed to deal with the adaptation to reduced gravity. Furthermore, as a nominal Mars mission length is up to three years, missions longer than one year plus cislunar missions beyond LEO should be planned to further test these risk mitigation strategies.

Past experience has shown that humans have some difficulty in long-term relative isolation environments, as our species is quite social in nature. Long-duration isolation missions (historical polar missions and current studies in Antarctica, Mars500, Mir/ISS, Biosphere, etc.) have provided very useful insights into how humans react to remoteness, loneliness, and seclusion; motivation decreases; interpersonal conflicts arise more easily; feelings of depression become more likely; and dangerous behavior may occur. The success of any human space mission is dependent upon the crew working together in a highly effective manner, which may be at risk if their psychological responses to isolation are not taken into account. Thus, further research on assessing psychological issues in long-duration and long-distance spaceflight will be vital to mission success.

“Even if the previously mentioned risks are addressed and missions are executed with a rigorously selected, medically pre-screened crew, a variety of medical issues could still arise. These must be considered for effective contingency planning and would consist of both traumatic and medical emergencies. The current protocol for the ISS is to evacuate a crewmember to Earth for treatment for anything more significant than a minor medical issue as soon as safety allows. This would not be an option for a Mars mission and, as such, the crew must be prepared to be substantially more autonomous and ready to respond to a wide variety of in-flight human health emergencies.

A medical treatment facility in the deep space and/or martian environment would have several limitations when compared with a similar facility here on Earth. First and foremost, the mass and volume available for medical equipment (such as instruments, intravenous fluids, and medications) in the design of spacecraft are limited. In addition, the resupply capability is essentially non-existent other than instruments and supplies that could be produced in the spacecraft itself (e.g. using 3-D printers, bioreactors, or environmental reclamation). Optimal spaceflight medical equipment should be multi-purpose, reusable, reliable, repairable, and easily storable. Many of these requirements are similar to those encountered when providing medical care in remote or austere environments here on Earth. Applying the lessons learned in these extreme environments will allow for the development of more robust medical and surgical capabilities in space, and, in the reverse direction, the research and development of space technologies can benefit those on Earth.

Finally, another consideration for optimizing human health in space must be creating a sustainable life support environment. Living and working in space for years at a time will be arduous for future astronauts and creating a spacecraft that will keep its occupants safe and sound will help to optimize their performance. This requires close attention to myriad factors that are needed for optimal human function, including but not limited to: improving closed-loop environmental control and life support systems; reducing and mitigating noise and vibration issues; meeting the nutritional needs of the astronauts; preventing toxic exposures; and minimizing circadian rhythm and sleep disturbances. These human factors have the potential to dramatically impact the chances of mission success, which are obviously increased when the crew remains healthy.

“Even if the previously mentioned risks are addressed and missions are executed with a rigorously selected, medically pre-screened crew, a variety of medical issues could still arise. These must be considered for effective contingency planning and would consist of both traumatic and medical emergencies.”

**SUMMARY & RECOMMENDATIONS of BIO-MEDICAL Considerations**

While NASA and its research partners continue to make progress on resolving the issues identified for a human mission to Mars ranging from radiation protection, food storage and bone and muscle loss, it was stated last year that, “There are no crew health risks at this time that are considered “mission-stoppers” for a human mission to Mars”. See the report at [http://www.nasa.gov/sites/default/files/files/NACRADS.pdf](http://www.nasa.gov/sites/default/files/files/NACRADS.pdf). In order to ensure that human crewmembers of a Mars exploration mission are as healthy as possible during the mission, are able to complete mission-critical tasks, and can return to Earth in a good state of health, it is recommended that the current knowledge base regarding human health and performance in space be expanded through the following means:

- Multiple additional long duration missions in LEO should be executed.
- Cislunar missions beyond LEO should be performed to study issues specific to long distance spaceflight which can only be properly addressed farther away from Earth within a deep space radiation environment.

**Developing a better understanding of space radiation risks will require sending humans and biological tissue experiments beyond LEO.** Few studies have been done on the combined effects of both forms of space radiation on human tissue.
Interim Cryogenic Propulsion Stage (ICPS) is in production in Decatur, Alabama. A cold-condition booster test in summer 2016 will pave the way for qualification, while hardware is being processed for the first flight. At Stennis Space Center in Mississippi, the first RS-25 test series was completed in August 2015, and a second test series has begun.

There is much progress to report on SEP development for Mars missions. In January 2016, four contracts were awarded to industry—The Boeing Company, Lockheed Martin, Orbital ATK, and Space Systems Loral—to study the design of a high-power solar electric propulsion (SEP) vehicle for NASA’s Asteroid Redirect Robotic Mission (ARM). The SEP system on this vehicle will provide twenty times more thrust than the SEP system used on NASA’s highly successful Dawn mission. The use of SEP is also being seriously considered for the proposed Mars 2022 orbiter. Scaling the 50 kW SEP system up by another factor of three or four will result in an operational vehicle capable of paying for human missions to Mars. The high-power electric thrusters for these missions are under development at NASA Glenn Research Center (GRC) and JPL. A contract for the development and delivery of the flight electric thrusters and corresponding power processing units for ARM was awarded to Aerojet Rocketdyne in April 2016.

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Recent analysis by Lockheed Martin confirms that Orion is also a Mars-capable spacecraft. Although Orion was originally designed for lunar missions, the vehicle can operate for 1000-day mission durations and withstand the even faster reentry conditions of Mars return trajectories, while keeping q-values high enough for astronauts after long stays in space. Initial operational missions in the early 2020s will see Orion astronauts operating near the Moon to develop capabilities and technologies needed for long duration missions in deep space. The next Orion spacecraft is being built and tested by Lockheed Martin and NASA for Exploration Mission 1, which will use the first launch of SLS to send an uncrowed Orion to cislunar space in 2018.

Spring 2016 will see Orion further hardened for the even faster reentry conditions of Mars return trajectories, while keeping q-values high enough for astronauts after long stays in space. Initial operational missions in the early 2020s will see Orion astronauts operating near the Moon to develop capabilities and technologies needed for long duration missions in deep space. The next Orion spacecraft is being built and tested by Lockheed Martin and NASA for Exploration Mission 1, which will use the first launch of SLS to send an uncrowed Orion to cislunar space in 2018.

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POLICY: OPPORTUNITIES and CHALLENGES

The Path Forward

Domestic Policy

As indicated in the 2015 Humans to Mars Report (H2MR), there has been steady progress over the past few years in building consensus for human spaceflight beyond Low Earth Orbit (LEO), particularly regarding human missions to Mars. Momentum for such missions has, in fact, been apparent in the policy arena for over a decade, with the enactment of NASA Authorization Acts in 2005, 2008, and then in 2010. Most recently, the U.S. House of Representatives passed its version of a NASA Authorization Act of 2015 that states, in Section 204(a), that “Human exploration deeper into the Solar System shall be a core mission of the Administration. It is the policy of the United States that the goal of the Administration’s exploration program shall be to successfully conduct a crewed mission to the surface of Mars to begin human exploration of that planet…” In Section 202 of the same bill, the U.S. House called on NASA to develop a Human Exploration Roadmap to achieve that goal. In addition, support by the Administration for human missions to Mars is reflected in the President’s proposed budgets for both FY 2016 and FY 2017 that were entitled, in part, “Journey to Mars.” The National Academies report, Pathways to Exploration, also endorsed Mars as the horizon goal for NASA’s human spaceflight program.

Unfortunately, this policy-level support in both the executive and legislative branches has not been accompanied with budgets sufficient to achieve those goals. As a result, NASA has been forced to delay programs, or parts of programs, which in many cases has resulted in higher overall program costs. The 2016 Omnibus Appropriations Act [https://appropriations.house.gov/uploadedfiles/12.15.15_fy_2016_omnibus___cjs___summary.pdf], however, began to rectify the funding shortfalls of previous years. By increasing NASA’s budget by $1.3 billion over the previous year, Congress took a substantial step away from the sequestration cuts of the previous three years and brought NASA closer to the budget levels that are actually necessary to achieve the diverse portfolio of missions that have been assigned to NASA by the Administration and Congress. This budget increase, however, cannot be a one-time occurrence if NASA is to be successful, as NASA’s overall set of missions remains severely underfunded. While the proposed FY 2017 budget contains the largest NASA budget proposed by the current Administration, it is still $260 million below the 2016 Omnibus budget level for NASA.

In addition to support in achieving more sufficient funding levels for NASA, progress has been made recently in reaching consensus about the development of a deep space habitat, which found support in both the 2016 Omnibus and in the President’s FY 2017 Budget Request. Such a deep space habitat was also recommended by the current Administration, it is still $260 million below the 2016 Omnibus budget level for NASA.

Representative Lamar Smith (R-TX-21st) – September 2015 “...we must remain committed to American space leadership and Mars exploration.”

Nevertheless, through various hearings in early 2016, Congress has also 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 administration.

Indeed, demonstrated progress toward a consensus goal was deemed to be critically important in the Report of the Third Mars Affordable and Sustainability Workshop, which identified various accomplishments that would be unambiguous milestones on the path toward humans on the Martian surface in the 2030s [http://www.exploremars.org/affording-mars].

Reaching beyond the traditional Congressional support base continues to be an imperative for space advocates. As stated in the 2015 H2MR, advocates need to speak to members of Congress (1) who are not viewed as necessarily supportive of space exploration, (2) who are not from states that are traditionally regarded as “space states”, and/or (3) whose opinions are not generally known. Progress has been made toward achieving this goal. Grassroots “visits to Congress” by space advocates in 2015 and the beginning of 2016 (such as in the Space Exploration Alliance’s February 2016 “Legislative Blitz”, in which over 170 congressional offices were visited) found a strong level of support for space exploration in these “non-traditional” offices. In fact, many of these offices expressed a willingness to either sign “Dear Colleague” letters or to express their support by other means. These efforts need to be aggressively followed-up and expanded.

Campaign 2016: Not surprisingly, space exploration has not risen as a major issue in the 2016 presidential campaign season. Early in the campaign, several candidates did express general support for space exploration, but these statements were, for the most part, responses that were superficial or extremely general in nature.

Recommendations:

- Congress and the Administration should continue to support budget levels that enable NASA to carry out its missions, including an increase for FY 2017 of at least $1 billion over the FY 2016 enacted level.
- Space advocates should expand efforts to reach out to potential supporters of space exploration who are not necessarily viewed as part of the natural constituencies for space.

International Policy

The United States continues to lead the world in space exploration achievements, contributing knowledge and inspiration to people around the world. American expertise and resources in both human and robotic space exploration position NASA to lead a sustainable international effort extending human presence into the solar system, with future Mars missions as the driving goal. 2015 brought positive momentum as global interest in human spaceflight proved to be strong. The growing support and interest in human space exploration can be attributed to activities funded by international governments, such as the International Space Station (ISS), and private industry. Both public and private initiatives, whether focused on Low Earth Orbit (LEO) or beyond LEO, are supporting each other and realizing the benefits sought by international space agencies investing in human space exploration. Recent robotic activity at Mars, including the successful launch of the ExoMars 2016 mission of the European Space Agency (ESA) and Russia, as well as India’s Mars Orbiter Mission (MOM), provide important scientific knowledge while serving as necessary precursors for future human explorers.

Human missions to Mars are our challenge as a species. Many potential space agency partners still see missions to the surface of the Moon as an important step to Mars. However, this is creating a false dichotomy between “Moon as opposed to Mars” in some circles. While stimulating such a debate is not the intention of ESA, space agencies need to work to ensure that the debate is not perceived as that of “Moon vs. Mars”, but rather a question of the degree to which missions to the lunar surface support or enable the path to Mars.

Space agencies participating in the International Space Exploration Coordination Group (ISECG) continue to advance their common roadmap by providing more detail on plans for missions early in the next decade. An updated version of the Global Exploration Roadmap is scheduled to be released in mid-2017, keeping Mars as the driving goal. This update is expected to provide more definition on human missions in cis-lunar space as the common next step of space agencies in preparation for missions to Mars.
RECOMMENDATION:
The ISS continues to serve as a showcase of the benefits that arise from mutual cooperation and the integration of efforts by the U.S. and its partner nations. However, interest in space exploration now goes beyond our traditional partnership base, as demonstrated by plans for future robotic missions to Mars by such nations as India, China, and the United Arab Emirates. Success in these latter endeavors can help to build support for a truly global international effort to send humans to Mars. Such a global enterprise should be pursued and encouraged, as it would entail each nation contributing its own unique expertise, strengths, and resources, thus maximizing efficiencies while avoiding duplication of efforts and resulting in synergies and overall cost savings.

POLICY RECOMMENDATIONS FROM 2015:

- A concentrated effort should be made to help Congressional members and staff better understand the historical evidence of the return on investment from space-related expenditures, the breadth and depth of the long-term value to the economy, the effect on STEM education, and to improving the human condition. Particular effort should be made to identify and engage non-traditional Congressional supporters of space exploration.

- Candidate outreach: Coordinated efforts must be made to educate candidates for President (and their staff) of the value not only of human missions to Mars, but also of maintaining a consistent and sustainable program. The next President can make a significant positive over the past few years.

- Science and Policy Exchange: A program or partnership similar to the Science and Entertainment Exchange [http://www.scienceandentertainmentexchange.org/] should be established to help educate staffers, members, and other policy makers about key science and engineering issues.

- International collaboration for Mars is the stated policy in current U.S. law and NASA should be encouraged to continue its efforts through the International Space Exploration Coordination Group (ISECG) and other programmatic forums to work with International Partners on potential roles and contributions.

- Campaign 2016: Not surprisingly, space exploration has not risen as a major issue in the 2016 presidential campaign season. Early in the campaign, several candidates did express general support for space exploration, but these statements were, for the most part, responses that were superficial or extremely general in nature.

THE HUMAN ELEMENT

Public Perception of Mars Exploration

Introduction: Public interest in Mars exploration, which has always been strong, became pervasive during the past year. This is clearly related to the consistent publicity generated during that time frame by various Mars-related events, such as the announcement by NASA of the discovery of liquid water on the surface of Mars (in the form of Recurring Slope Lineae, or RSLs) and the excitement that accompanied the release of the motion picture, The Martian. More specifically, public perception of Mars exploration has been shaped by the following factors:

NASA and Government Agencies

NASA continues to have the greatest influence on public perception with regards to Mars exploration, and in 2015 the space agency became far more vocal than ever before about its commitment to human missions to Mars. Mars has been the ‘horizon’ goal for many years, but with the release of the Journey to Mars diagram [http://www.nasa.gov/content/nasas-journey-to-mars] at the end of 2014 and with other strong Mars messaging in 2015, NASA demonstrated that Mars continues to garner strong support in the space community as well as elsewhere. NASA has also begun to provide more details about the pathway to Mars. There was strong press coverage of the late September 2015 announcement about liquid water on the surface of Mars, and that was followed several weeks later, in late October 2015, with the convening by NASA in Houston of the First Landing Site/Exploration Zone Workshop for Human Missions to the Surface of Mars. This workshop marked the first time that NASA officially began soliciting and reviewing proposals for human landing sites on Mars. With announcements and activities of this nature, NASA is able to keep Mars in the news cycles on a regular basis.

ENTERTAINMENT and Publishing

The hype and excitement generated by motion pictures is not sufficient in and of itself to lead to humanity on the surface of Mars, but it would be short-sighted to ignore the great impact that the film adaptation of The Martian had in 2015 - and continues to have. This film resulted in countless news stories that not only analyzed the film as a piece of fiction, but it also stimulated worldwide mainstream discussions regarding the viability of human missions to Mars. In addition, the release of the movie was accompanied by special viewing events along with programs around the world that dealt with the facts of Mars, which effectively helped to shed new light on how popular Mars exploration is to the general public. More recently a special ‘Mars Day’ was held at Fox Studios that was attended by representatives from The Martian, the White House, and the greater space community. Furthermore, The Martian helped to stimulate other Mars exploration film projects:

- The Space Between Us – This film, directed by Peter Chelsom and scheduled for release in July 2016, tells the story of a child born in a Mars city. It will feature such actors as Gary Oldman, Asa Butterfield, and B.D. Wong.

- Red Planet: In the fall of 2016, Producer/Director Ron Howard in partnership with National Geographic will be releasing a multi-part series called Red Planet.


An increased volume of Mars film projects does not necessarily mean that the general public is more supportive of actual human missions to Mars. Trends in film genres change frequently, and it would be naïve to conclude that these films are evidence that Americans want to explore Mars. However, what these films do represent are opportunities for the space exploration community to better engage with the entertainment community and to better communicate with the general public. If space professionals can effectively highlight how popular films are based on realism, and on a realistic future, such will go a long way towards building passion and support.
The Humans to Mars Report 2016

Public interest levels tend to wane over time, and elevated levels of interest are usually short-lived, however, therefore it is critical that the space community employs a long-term strategy, with new activities that tie the general public to space on a frequent basis.

Hollywood passion: Profitability is certainly the primary driver for producing films. Nevertheless, there are dozens of high-profile public figures, astronomers, and others who are well-known advocates for space exploration and who use motion pictures as a profitable method of advocating for a future in space. The space community needs to better acknowledge and harness this passion by working with the entertainment industry to inspire new projects that are not only profitable for studios and artists but at the same time provide realistic and inspiring stories about space exploration.

Increased Realism: The balance between entertainment and real science has improved dramatically since the founding of the Science and Entertainment Exchange through the National Academy of Sciences. This organization “connects entertainment industry professionals with top scientists and engineers to create synergy by accurate science and engaging storytelling...” This group’s work makes it far easier for the space community to secure the connection between fiction and reality. NASA has recognized the value of such connections, and has engaged filmmakers over the past few years to assure that films have more scientific and engineering accuracy.

BUDGETARY CONTEXT and Technical Reality

As mentioned in the 2015 Humans to Mars Report, inflated perceptions by the public and by policymakers of the realities of Mars exploration and NASA budgets continue to hinder the prospects of mission success. If the public continues to believe that the NASA budget is multiple times higher than it actually is - or, for example, that NASA rivals the Defense Department or Social Security budgets in funding levels - then NASA will always be unsupported. However, as previous polling suggests (see the 2013 Mars Generation National Opinion Poll [http://www.exploremars.org/wp-content/uploads/2013/03/Mars-Generation-Survey-full-report-March-7-2013.pdf] if budgetary reality is articulated and communicated clearly to the public, then Americans will overwhelmingly support Mars exploration.

NEW COMMERCIAL/ Private Exploration Ventures

The prospect of private Mars missions fascinates the public. While MarsOne, a proposed one-way journey to the Red Planet, has faded from the public consciousness, SpaceX continues to hint about its own Mars exploration plans. In April 2016 SpaceX announced plans to privately fund a mission to land an unmanned Dragon spacecraft on Mars as soon as 2018. The mission would be conducted in cooperation with NASA pursuant to an unfunded Space Act agreement. Further, Elon Musk has stated that he hopes to announce details of SpaceX’s Mars architecture in September 2016 at the International Astronautical Congress in Guadalajara, Mexico.

ACCURACY AND IMPACT of Public Polling

As can be seen in the examples below, favorable polling numbers are significantly higher in the 2013 Mars Generation National Opinion Poll than in the 2015 Monmouth poll. In contrast, according to a poll by the Program for Public Consultation at the University of Maryland’s School of Public Policy, as part of an exercise to help balance the budget through cuts in the discretionary budget, participants on average would reduce NASA’s budget. The different results of these polls show that the answers that are garnered by polling can be swayed both by preconceived, and very often inaccurate, notions about the cost of space exploration, as well as by the manner in which the questions are phrased. The Mars Generation Poll provided actual budgetary context to the participants, dispelling the notion at the very beginning of the poll that the NASA budget was, for example, as large as the defense budget - something that the Monmouth Poll did not do. The Monmouth Poll, on the other hand, implied that Mars exploration is expensive – without any additional explanation. When participants in the Mars Generation Survey were provided with the current NASA budget level, over seventy percent of poll participants supported Mars exploration and over half of them even chose to double the NASA budget, provided that a human mission to Mars would be part of NASA’s program. With respect to the University of Maryland exercise, participants were asked to hypothetically reduce the overall federal budget through cuts to the discretionary budget alone (including the NASA budget). As such, the University of Maryland poll is in an entirely different category and should not be used to gauge actual public support for NASA.

Below are some of the public polling that has been conducted over the past few years:

Program for Public Consultation at the University of Maryland’s School of Public Policy [http://www.govexec.com/management/2016/02/americans-would-cut-fy17-funding-these-agencies/125786/?oref=govexec_today_nl] This exercise provided data that implied that Americans would be willing to cut NASA’s budget by $2-3 billion to help balance the budget.

PREVIOUS POLLS CITED:

a. Monmouth University Poll 2015 - [http://www.monmouth.edu/polling/MUp79_7.pdf] - 51 percent feel that spending should be increased on the space program • 42 percent believe funds should be spent on sending crews to places like asteroids, the Moon, and Mars.


RECOMMENDATIONS

Providing current and accurate information, especially about the overall NASA budget compared to the overall federal budget, with the NASA budget currently being less than one-half of one percent of the total federal budget, is the best ally for building strong and consistent public support for Mars exploration. Works of fiction that provide more realistic presentations of space travel and exploration can help, but the space community needs to do a better job at translating excitement about movies into support for actual missions to Mars. The public’s perception of humans missions to Mars can be improved by better addressing the following issues:

- The question Why Mars? needs to be better articulated by the space community.
- After NASA, the media/press provide the primary influence to public perception. Better relationships must be built with 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.

CONTINUING RECOMMENDATIONS FROM 2015

- Dispel the $1 trillion myth: Human missions to Mars will only cost a fraction of this amount.
- Better story telling: NASA and the space community need to better explain 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. When a major film is released, the space community, Hollywood, and other players need to find ways to harness public interest in the film to build support and passion about actual missions to Mars. Assets are innumerable prominent members of the entertainment industry who are passionate about space exploration, they need to be engaged in the NASA planning. Venues must be created to highlight that their ardor for space is a primary motivator in making space films.

THE HUMANS TO MARS REPORT 2016