Affording Human Exploration of Mars

Workshop Summary

December 3 – 5, 2013

George Washington University

Washington, D.C.

There is a growing consensus that within two decades initial human missions to Mars are affordable under reasonable assumptions and with sustained international political support. In response to this idea, a distinguished group of experts from the Mars exploration stakeholder communities attended the "Affording Mars" workshop at George Washington University. Participants reviewed and discussed scenarios for affordable and compelling human and robotic exploration of Mars, the role of the International Space Station over the coming decade as the essential early step toward humans to Mars, possible "bridge" missions to follow to enable cost-effective human missions, key capabilities required for affordable initial missions, international partnerships, and a first-cut at a usable definition of affordability and sustainability. This document summarizes the findings, observations, and suggested initiatives that emerged from that workshop.

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Achieving a Feasible and Affordable Path to Mars for Human Explorers

Human exploration of Mars has been identified for decades as one of the most compelling goals for human space flight in the post-Apollo era. Over the past several years, significant experience in long-duration human space operation has been gained using the International Space Station (ISS). More recently, concepts building upon this experience to enable "cost-achievable" approaches within current annual budget guidelines in industry, NASA, and international human spaceflight programs have been presented.

At the same time, there is a continuing strong public interest in humans to Mars as one of several keystone destinations. As demonstrated in the recent Mars Generation Survey, Americans overwhelmingly support human and robotic Mars exploration. Among the findings of this scientific national poll were that 71 percent of Americans believe humans will land on Mars by 2033 and 75 percent believe that NASA's budget should be doubled to one percent of the U.S. federal budget to fund initiatives including a human mission to Mars. Complete results of the poll can be found in the **Mars Generation National Opinion Poll** (http://www.exploremars.org/wp-content/uploads/2013/03/Mars-Generation-Survey-full-report-March-7-2013.pdf)

1.0 The Mars Affordability Workshop

In response to this growing interest in human Mars exploration, the Mars Affordability Workshop was planned with the goal of investigating what is necessary to make human Mars missions feasible, sustainable, and affordable. Hosted by Explore Mars, Inc. and the American Astronautical Society, the invitation-only workshop was held on December 3-5, 2013. This three-day workshop began with overviews of current scenarios for human missions to Mars, the status of and future plans for capability development on ISS, the case for science as an element in human exploration of Mars, opportunities for international partnerships, and coordinated robotic exploration. Breakout sessions addressed topics such as "What is affordability?" and how it can be incorporated into mission planning, including prioritization of capabilities and technologies. Other breakout sessions dealt with precursor missions, current scenarios for human Mars exploration, and building on ISS experience in the management of complex programs. Approximately sixty experts representing over twenty organizations participated in this workshop via invitation from the AAS and Explore Mars organizers. The names of participants are at the end of this document.

This workshop was organized to approach the challenge of human exploration of Mars factors, including policies, other than architecture studies. The workshop was designed to address independently many of the key issues that have hindered a sustained human exploration program. These include issues such as current loss of technological capability, shrinking budgets, lack of compelling missions, and the need for sustained political commitment over multiple U.S. administrations. The workshop was not directed, supported, or constrained by government oversight or policy restrictions. Indeed, the working meeting was focused on developing a set of near-term findings that could influence strategies for human

spaceflight beyond low Earth orbit (beyond ISS) in such a way as to lead to humans on Mars in the 2030s.

The workshop was intended to enable initial human missions to Mars by presenting usable findings, observations, and follow-on activities for national space agencies and other policy makers.

2.0 Workshop: Structure, Findings, and Observations

A small number of ground rules and assumptions were agreed to and adopted by the planning team, which allowed the workshop participants to focus on other major issues, *viz.*

- SLS and Orion will be available during the time periods considered by the workshop.
- The International Space Station will play a critical role in preparing to travel beyond LEO.
- Robotic missions will enable human missions to Mars.
- There are emerging scenarios and capabilities that will influence mission architecture and planning over the next two decades

This report summarizes the observations from three topical breakout sessions:

1. The ISS and the path to Mars: The critical coming decade
2. Affordability and sustainability: what does it mean and what are its implications within guidelines established at the start of the workshop?
3. Notional sequence(s) of cost-achievable missions for the 2020s to 2030s, including capability objectives at each stage and opportunities for coordinated robotic partnerships

2.1 Top-Level Workshop Findings (Principles of Agreement)

- Mars should be the overarching goal of human space flight over the next two to three decades.
- Identifying and solving key technical gaps over the next several years will be important in making the human exploration of Mars feasible by the 2030s. Between now and 2030, human exploration of deep space must be prioritized in a manner that advances the objective of human exploration of Mars starting in the 2030s.
- Taking advantage of ISS, including international partnerships, is essential for human missions beyond LEO and, especially to Mars.
- Continuation of robotic precursor missions to Mars throughout the 2020s is essential. The robotic Mars exploration science strategies of NASA and ESA should be coordinated with humans-to-Mars efforts while preserving their primary science objectives.
- International and industrial partnerships, efficiency, consistency of purpose, and policy/budget stability are the required elements to allow a two decade-long humans-to-Mars (H2M) effort to succeed. The right combination of these elements will make the H2M campaign affordable.

2.2 Breakout Session Findings and Observations

Breakout Session #1:
The International Space Station (ISS) as a Platform to Advance Exploration

ISS was designed and is being utilized to play a pivotal role in support of future missions beyond LEO. The following is a summary of the numerous roles that ISS can play as a platform for exploration beyond LEO, including H2M. ISS is well-positioned to deliver the following key capabilities relevant in the coming decade:

- Long-duration human exposure to microgravity by a wide range of crew members to develop a statistical database to understand how to reduce risk
- Fundamental physiology research supporting long-duration missions
- Platform for long-duration testing and exposing hardware to a space environment, including life-support systems to demonstrate reliability and reduce the logistics supply chain.
    - *Actionable item*: Review current ISS logistics demands and processes to determine those areas that could be modified to more closely mimic initial Mars missions.
- Demonstration platform for mission operations concepts relevant to Mars missions, such as in-space telerobotic control of robotic systems, contingency and exploration-class EVA suits and capabilities.
- Using ISS as a platform for testing multi-vehicle proximity operations such as rendezvous and docking relevant for assembling very large spacecraft stacks.
- Using ISS to address Mars mission capability gaps.
    - *Actionable item:* Perform an analysis elaborating which tasks are most effectively and efficiently performed on ISS versus a hypothetical cis-lunar facility to provide a basis for comparison.

Reflections on commercial activity in LEO: An affordable human exploration program will be augmented by the transition of government-led activity in low-Earth orbit to non-government organizations. This will include commercial launch and delivery capabilities for crew and cargo in support of ISS operations and expanded utilization and funding support from other U.S. government research organizations as well as academic, commercial, and international research entities. Continuing NASA's efforts to enable a LEO-focused research and utilization constituency/community and an operational framework could eventually free NASA's ISS operational resources to be directly applied to exploration-related missions or activities beyond LEO.

The ISS program and NASA must engage key stakeholders, including Congress, the public, and potential users in defining its role as the initial "stepping stone" to Mars.

- *Actionable item:* ISS program can work with the technology community to analyze how ISS could be used to support the development and demonstration of relevant exploration capabilities.

This breakout session included discussion of an interim step between human spaceflight in LEO (i.e., ISS) and the human exploration of deep space (such as a trip to Mars). One option discussed is a modest, short-lived human-tended facility in cis-lunar space. [Other options for

interim missions (e.g., lunar exploration, asteroids, etc.) were covered in Session 3.] Such a facility could be important during the early 2020s in advance of initial missions to Mars to demonstrate crew operations in a deep-space environment. The workshop group discussed a number of concepts for such a facility. Although no specific concept was favored by the participants, there was consensus agreement on its capabilities.

Such a facility could

- Continue the international partnerships developed on ISS
- Demonstrate both human and untended/autonomous operations in a deep-space environment
- Develop capabilities for deep-space operations, which must be less dependent on Earth, such as a reduced logistics train and slow- or no-abort
- Temporarily sustain a series of missions that demonstrate progress toward missions to Mars
- Provide an opportunity to extend commercial crew and cargo programs beyond LEO to circumlunar space
- Establish a potential assembly site for large Mars-bound spacecraft that cannot be launched on a single SLS flight

➢ *Actionable item:* The ISS program could
- define objectives and conceptual designs for this facility, including the options for using hardware supplied by international partners
- evaluate the objectives that must be satisfied, and determine the most efficient and effective way of achieving them: ISS, cis-lunar facility, or other.

Breakout Session #2: Affordability and Sustainability of Human Mars Exploration

Considerable discussion at the workshop was devoted to the definition of "Affordable" in the context of a human mission to Mars. In a breakout session devoted to this topic the following definition was adopted for the purposes of the workshop:

> ***Definition of an Affordable Program:*** A strategy that enables success within a budget and timeframe justified by the importance of mission goals.

Discussion around this definition led to the conclusion that this approach will likely require incremental mission planning and execution; international, governmental, and private sector partnerships; policy/mission consistency; openness to developments that could potentially foster new and efficient program advancement; and political commitment for sustained support for agreed-upon priorities for space exploration. Examples of how this may be achieved include

- Incremental Approach: An incremental approach will be required to achieve human travel to Mars within constrained budgets. The incremental approach allows for modest elements of the overall plan to be assessed and budgeted. These elements can also be offered for bid to private or international partners.

- Avoid Single-Use Hardware: Architectural elements, including point designs that support multiple customers and multiple goals are highly desirable because it spreads fixed cost bases and avoids repeated non-recurring engineering costs.
- Space agency budgets should at least keep pace with a realistic measure of inflation. Currently NASA's budget is inadequate to support its programs. Current flat budgets are not realistic and result in reduced buying power over time. Modest increases will be necessary to achieve adequate support of this and other NASA priorities.
- Alternate Models: Alternate acquisition and development methods should be considered to create efficiency, such as creating a hybrid contracting approach, and employing other innovative management approaches. These could include streamlined government oversight and Skunk Works/Phantom Works-like structures.

Establishing a well-thought-out, widely vetted, and compelling plan for the initial human missions to Mars with a regular cadence of achievements is the highest priority for the national space agencies. Sustainability and affordability of this plan can be achieved. To do so it is also important that the space community and policymakers agree on and construct a strategy that incorporates the following suggested principles:

- Continuity and stability of programs and budgets: Budgetary and policy consistency are essential. As such, the space communities need to design programs/missions that lend themselves to budgetary stability and take an incremental approach to constructing a program. Budgetary increases for inflation must also be included *as a minimum*, so that NASA and our international partners' buying power can be maintained for the duration of this long-term program.
- All human space exploration and related robotic activities must be prioritized and conducted with the requirement that a human landing on Mars is the overarching goal for human space flight. Deviation from this will lead to delays from which it will be difficult to recover.
- Full use should be made of current relevant capabilities such as the ISS, robotic precursor missions to Mars, and the technology development programs of NASA, industry, and international partners. These should be part of the campaign to send humans to Mars.
- Essential robotic and human precursor missions will be necessary and must clearly advance capabilities required for crewed missions to the surface of Mars.
- Provide a clear return for stakeholders by developing missions and capabilities in concert with national and international partners. Development of partnerships among industry, academia, other government agencies, and multiple agency directorates will allow leveraging of resources and talent.
  Establish ambitious dates for compelling near-term milestones to enable efficient use of resources and expedited management, while protecting sufficient flexibility to adjust for developments of capabilities, new discoveries, and changing political environments. Notional example milestones over the coming decade could include:
  - Successful demonstration of SLS and Orion
  - A Mars "free-return" mission using SLS and Orion
  - Sustained robotic science-driven exploration coordinated with human space flight goals

- Regular progress on relevant technology capabilities developed on ISS
- Deployment of a transitional deep-space facility in the early 2020s

Consistent and continuous communication is essential, including

- Assuring that stakeholders (political leaders, policy makers) are fully informed of progress, program goals, and the criticality of stable budgets.
- Developing a coalition of advocates from industry, government, academia, human space flight, and science communities who share a common interest.
- Clearly and regularly communicating to the public the achievements and benefits of the program.

Breakout Session #3: Notional Sequence of Missions Leading to Humans on Mars

The third breakout session of the workshop concentrated on potential "pathways" for achieving a human mission to Mars. In this sense, the term "pathways" refers to the sequence of missions that would be accomplished leading up to and including the human Mars landing. This set of precursor missions along with the first human landing mission can be thought of as an end-to-end campaign, and the different options for achieving that campaign are the potential pathways. The purpose of the third breakout session was to begin the process of assessing potential pathways.

It became clear at the start of the breakout session that a top-level set of requirements were needed. These are often called Level 0 requirements. While it was beyond the scope of a three-day workshop to define top-level requirements of this nature, the following list was used to guide the discussions.

Example Level 0 requirements include

- Human mission to Mars by the 2030s
- Incremental Approach: Near-Term and Regular Accomplishments
- Realistic Budgets
- International Program
- Public and Stakeholder Engagement
- Sustainable Approach
- Clear Science Objectives

➢ *Actionable item:* Development and vetting of a set of highest-level requirements for initial human Mars missions in the 2030s must be undertaken now to guide investments over the coming decade.

This breakout session focused on developing a list of potential precursor missions that could be used leading up to a human landing mission. The participants purposefully decided to "cast a wide net" so that most relevant mission concepts would be considered. The resulting list of potential missions is long and is naturally tied to particular Mars mission architectures. The discussion emphasized the progressive extension of capabilities along the pathways. For example, the proposed NASA Asteroid Redirect and Retrieval Mission (ARRM) demonstrates

longer crew durations outside the Van Allen belts, tests Orion systems, and uses solar electric propulsion (SEP) to move the large mass of the asteroid into Distant Retrograde Orbit (DRO).

While this work of assessing mission pathways is only just beginning, there were several clear findings from the breakout session:

- Interactions between the NASA Human Exploration and Operations and Science Mission Directorates participants were highly beneficial. Each group brought strengths that complemented the other.
- International cooperation brings program stability, although also includes challenges.
- There appear to be no technical "showstoppers" for a human Mars mission, although several technical challenges remain to be addressed. The most common examples expressed at the workshop were entry, descent, and landing techniques and radiation protection.
- There are also several emerging technology opportunities. A frequently mentioned example was solar electric propulsion

Assessment of the mission pathways will continue in 2014 as a post-workshop activity.

- *Actionable item*: Detailed mission pathway assessment is a priority effort that will require dedicated resources and sufficient analysis time. This activity is proposed to take advantage of the Global Exploration Roadmap (GER) and associated work, although with more detailed engineering analysis.

Conclusion

Affordability and sustainability will require dedicated effort. Careful coordination among stakeholders, NASA, industry/commercial, and potential international partners will be required. The human space flight stakeholders must initiate new and sustainable programs that will clearly advance the goal of landing crews on Mars by the mid 2030s. A logical, affordable architecture with a campaign of mission "stepping stones" and elements must be developed. From the start, such an architecture must incorporate management efficiencies and flexibility based on lessons learned from ISS, commercial programs and other past NASA programs, as well as from DOD and industry. Above all, political and budgetary stability is essential over a two-decade time span. Accomplishing the goal will require a policy and appropriate budget commitment over multiple US Congressional and Presidential elections as has been done for other major undertakings in history. Sending humans to Mars is far less an issue of cost than it is of commitment.

Human and robotic exploration of space is critical to national prosperity, security, scientific and technological progress and leadership, as well as demonstration of cultural leadership. With clearly defined exploration goals, we have a chance to maintain and further our intellectual and technological capabilities and leadership. Our national stakeholders expect U. S. leadership. Furthermore our international partners are awaiting NASA leadership in international space exploration. These expectations and the ability to build on our heritage

and past investments are not timeless and must be exploited before the opportunity slips away. The international space community is widely recognized by the public for filling these needs and this community is prepared to write the next chapter in the exploration of space: Humans to Mars!

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Breakout Session Guiding Questions

The ISS and the path to Mars: The critical coming decade

What are the key capabilities that ISS is well-positioned to deliver between 2014 and mid-2020s?

How should the ISS program engage key stakeholders in its role as "initial stepping stone" to Mars?

What is an actionable "mission statement" for ISS in 2020 in support of initial human missions to Mars?

Is there an obvious affordable follow-on or "bridge" mission to follow ISS on the path to Mars and what would its capabilities be?

What are the key "lessons observed" in the management of ISS, its engagement with stakeholders, and international coordination?

Affordability and sustainability: what does it mean and what are its implications within guidelines established at start of the workshop?

In the current programmatic and budget environment, is an initial human mission to Mars feasible within the 2030s?

What is a usable definition of affordability and sustainability?

What are the dominant characteristics of management of an affordable and sustainable human exploration program?

What are the key characteristics of a successful, affordable international human mission to Mars? What are the programmatic and policy criteria for assigning major program elements among international partners? What are priority substantive "next steps" that agencies can carry out in international coordination (e.g., more closely coordinated technology development, joint engineering design studies)?

How may two (or more) major human space flight programs be carried out simultaneously and affordability? And how?

How should roles and responsibilities be distributed among industry, government, and academia to enhance affordability?

Notional sequence(s) of cost-achievable missions (or steps) for the 2030s, including capability objectives at each stage and opportunities for robotic partnerships

Based on workshop presentations, are there affordable and sustainable architectures or scenarios for initial human missions to Mars? Why and what are their notable features? What makes these architectures affordable and sustainable?

What are the priority capabilities necessary to develop on the path to a human landing on Mars and their approximate date of IOC?

What are key capabilities or information that robotic missions can contribute in support of human exploration beyond LEO?

Is there an obvious follow-on or "bridge" mission to follow ISS on the path to Mars? Why? What are its desirable capabilities?

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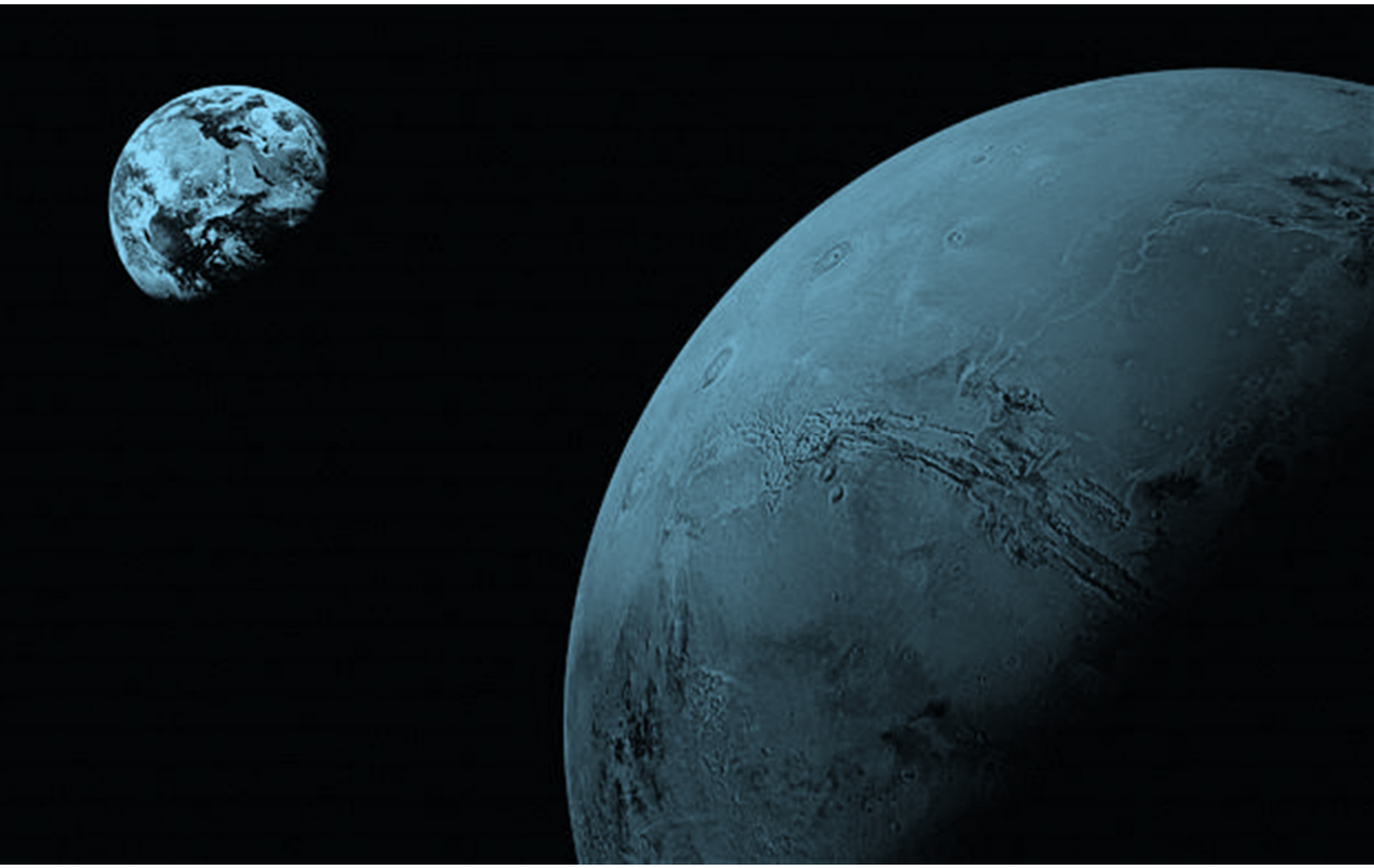

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