Initial Results from The Sixth Community Achieving, Affording, and Sustaining Human Exploration of Mars Workshop (AM VI)

Lunar Operations, Technologies, and Activities to Enable Human Exploration of Mars

28-30 August 2018, The Elliott School
The George Washington University
Sponsored by Explore Mars, Inc. & the American Astronautical Society

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Joseph Cassady (Aeroject Rocketdyne), and Stephen Mackwell (USRA)

24 October 2018

Reports available at https://www.exploremars.org/affording-mars

Goal of AM VI workshop . . .

A critical assessment by approximately 70 community representatives from NASA, academia, industry, research institutions, and international organizations of candidate activities on the lunar surface and its vicinity that may feed forward to support affordable and sustainable human missions to the surface of Mars in the 2030s.

Relevant Previous AM Community Workshops

AM VI

AM III (December, 2015 at the Space Policy Institute, GWU)

Integration of priority science goals with increasingly detailed human space flight scenarios: modify science goals and elements of human exploration to improve integration. Included planetary protection.

AM IV (December, 2016, Doubletree Hotel, Pasadena)

Critical comparison of major technological “long poles” necessary for achievable, affordable, and sustainable human exploration of Mars.

AM V (December, 2017, Washington Plaza Hotel, Washington, DC)

Developed in detail three distinctly different scenarios for human exploration of Mars by the end of the 2030s that were required to be affordable.

Workshop Scenario Ground Rules

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- The first human mission to the surface of Mars will take place during the 2030s. [cf., AM I – V]
- Budgets for the space agencies will grow approximately with inflation. Modestly greater budget growth is possible in response to broad public and stakeholder support for lunar exploration and travel to Mars.
- No technological, political, or budget “miracles” are permitted or, if so, they must be clearly identified and justified.
- SLS, Orion, the Gateway, and commercially available medium-lift launch vehicles will be available during the time period considered here, so will not be assessed in depth in this workshop
- The presented Moon and Mars scenarios may not be altered in significant ways.
- Teams are not to advocate for any lunar scenario, but rather accept the scenarios as presented.
- There will be a continuous human presence in low Earth orbit to provide research and development opportunities via the ISS and/or other (e.g., commercial) platforms throughout the timeframe considered in this workshop.
- Partnerships (international, industrial, commercial, academic . . .) will be an essential component of human exploration.

Workshop Process

The Human Exploration of Mars Mission Continuum From AM V

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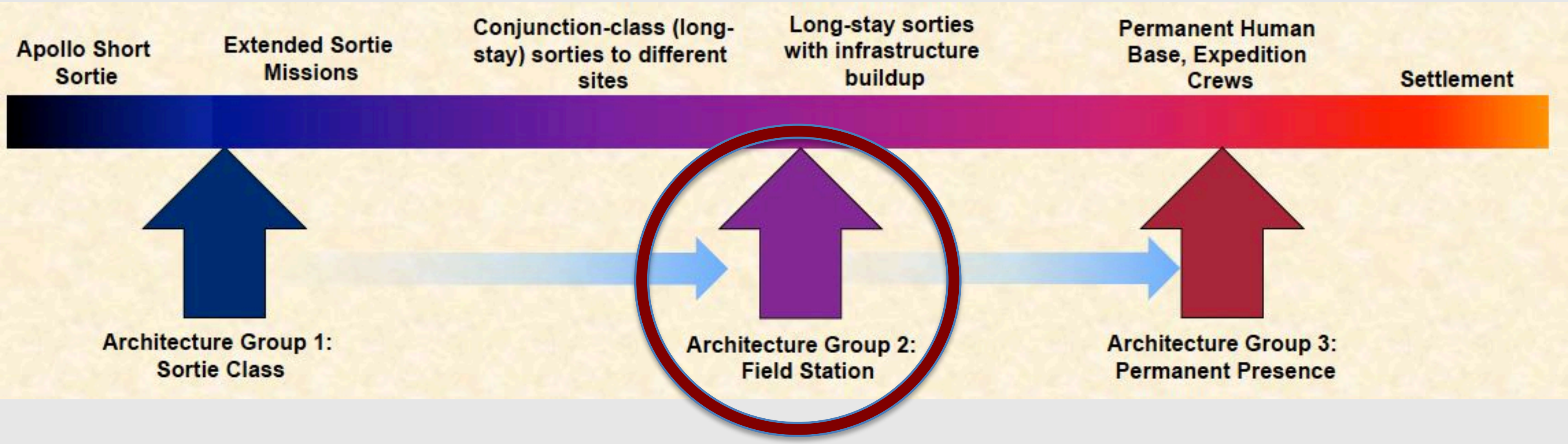
Three different “end states” for human exploration of Mars were adopted in AM V as representative of the goals widely identified and an architecture was developed that sought to achieve each of them under common ground rules and constraints.



<u>Adopted for AM VI Assessment</u>:
The engineering Long Poles were essentially the same in the medium to long term across all three scenarios examined at the AM V workshop. For this reason, the Field Station was used as the baseline for AM VI.

Adopted Mars Scenario: Surface Field Station
Similar to Evolvable Mars Campaign (EMC)

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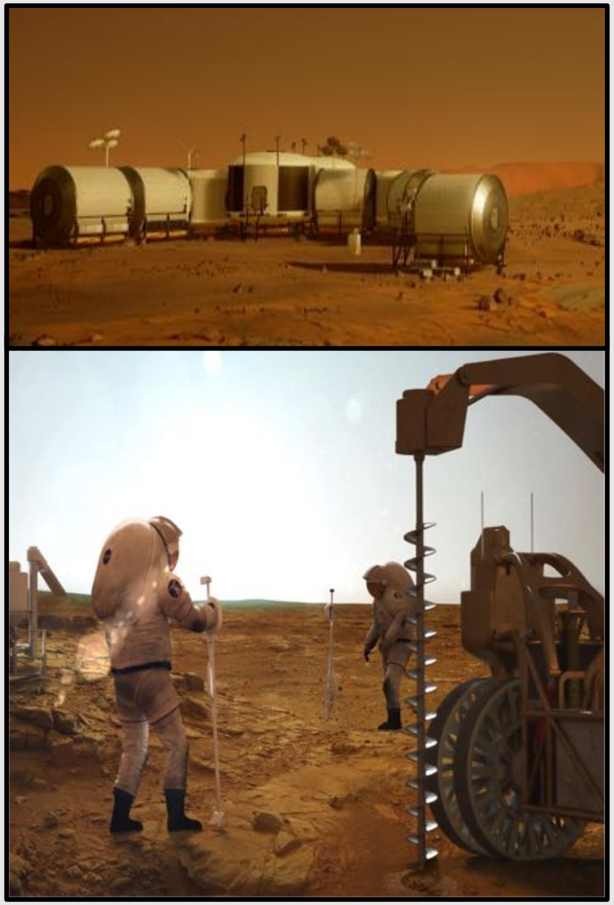
- **Goal of Surface Field Station:** To learn how to live and operate on Mars in preparation for continuous human presence on Mars, via the deployment of a temporary Mars surface field station that is visited by multiple crews over the lifespan of the infrastructure

- **Activities:**
  - **Engineering testing** of surface hardware (e.g., ISRU, in-situ materials, civil engineering, pressurized rovers, etc.)
  - **Environmental monitoring and characterization** (e.g., ground-truthing of orbital recon datasets such as water mapping and surface winds, better informing planetary protection practices)
  - **Understanding long-term human health impacts** of long duration deep space and surface missions and demonstrating appropriate countermeasures
  - **Learn how best to do in-situ science** with human crewmembers as a resource (e.g., to address MEPAG goals)

- **End State:**
  - When sufficient knowledge and operational experience is gained to **decide on the location** and architecture of the **first continuously occupied permanent base on Mars**.
  - Chosen to occur at the same time that Mars surface equipment wears out (thus avoiding the need for system recertification and/or replacement)



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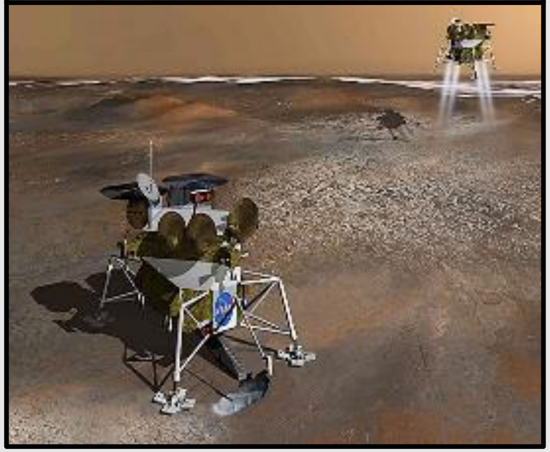
AM V Field Station Key Features

- Built upon **NASA's Evolvable Mars Campaign (EMC) study** (2014-2016) with additional options considered to increase program sustainability
  - **Conjunction-class missions** with gradually increasing time spent on the Martian surface as more surface capabilities are delivered and more experience is gained
  - **Baseline atmospheric O_2 ISRU** with water-based ISRU considered within the trade space depending on selected landing site and precursors/field station activities
  - **Reuse of Transit Habitat and in-space propulsion** for crew and cargo transit, which are sent back to lunar gateway for refurbishment
  - **Reuse** of **Mars Surface Habitat**
- **Modular build-up** of in-space and Mars surface assets (incl. human habitat and laboratory modules) using **multiple commercial and international providers**
- **Small/mid-size Mars landers derived directly from lunar surface program**
  - Develops experience base and **distributes cost** for Mars program across longer timeline
  - Smaller, modular payloads (~10mT) allows for **increased commercial / international participation** (e.g. launch vehicles, landers, and payloads)
    → increases cost sustainability and political sustainability
  - Allows deployment of **larger science payloads** (than currently considered)
    → increased opportunities for scientific discovery and public engagement
  - Increases **system flexibility and robustness** by allowing individual components to be repaired and/or upgraded as they degrade, or as more experience is gained in their operations





Comparison of Mars Architectural Philosophies

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DRA 5.0 (2009) Minimize risks and exposure of crew/cargo to the deep space environment with short duration transits separated by a long surface stay. Three crewed missions in 10 years with overlapping pre-deployed cargo missions.	Evolvable Mars Campaign (2013 – 2017) Progressive expansion of capabilities through the cis-lunar "Proving Ground" to a sustainable human presence on Mars with reasonable extension of ISS, SLS, Orion and DSG. Emphasis on affordability and sustainability.	AM V Team 2 (2018) Looked for ideas to enable an "enterprise sustainable" architecture for an initial human Mars Field Station. Do not necessarily represent completed trades.
Key Architectural Similarities		
• Conjunction Class – 900-1000d	• Conjunction w/ depart & arrival windows to 1200d	• Conjunction Class
• Pre-deployment of cargo	• Pre-deployment of cargo	• Pre-deployed cargo on a range of lander sizes
• ISRU (O_2 for ascent)	• ISRU (O_2 for ascent)	• ISRU O_2, but also include H_2O as early as possible
• Long surface stay	• Evolve to long surface stay	• Long surface stay
• Round-trip crew vehicle	• Round-trip crew vehicle (hybrid SEP/Chemical option)	• Round-trip crew vehicle
Key Architectural Differences		
• Crew of 6	• Crew of 4	• Examine crew of 6
• Cost profile – high peak	• Cost profile – long medium	• Cost profile – long medium
• In-space prop: fast transit, NTR	• In-space prop: Minimum energy SEP/Chemical, Chemical, NTP	• In-space prop: NTP, Minimum energy SEP/Chemical, Chemical
• All crew to surface	• 1st crew to orbit, 2nd to surface	• No orbital only missions; All crew to surface
• Vehicle assembly in LEO	• Vehicle assembly in cis-lunar, HEO departure and arrival	• Vehicle assembly in cis-lunar, HEO departure and arrival
• Max launch cadence – 6/yr.	• Max launch cadence – 2/yr. (1 crew and 1 cargo)	• Launch cadence depends on commercial landers
• Crew trip to Mars each opportunity	• Crew trip to Mars every other opportunity	• Aim for frequent opportunities
• Minimize crew space exposure	• Crew 1100 days in space ok	• Minimize crew space exposure (surface stays + NTP)
• Redundant surface systems possible	• Single string of elements	• Modular habs and labs likely have redundancy
• Each landing site different for science	• Single site build-up infrastructure	• Single site with broad science exploration
• All systems expended	• Reuse of habitat, transportation, surf. Sys.	• Reuse of habitat, transport, and surface & examine MAV reuse

Key Characteristics of Lunar Activity Categories

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Lunar Attribute	Gateway-Only	Sortie-Class	GER-Class	Field Station
All options assume Gateway staging, heavy lift, and 11 km/s return vehicles				
Human Surface Mission?	No	Yes, Multiple Sites	Yes, Multiple Sites	Yes, Fixed Base Site
Crew to Surface	0	2-4	4	4+
Surface Exploration Duration	n/a	3-5 Days	42 Days	6 Months
Pre-Deployed Surface Assets	No	No	Yes	Yes
Key Attributes	• Earth or Gateway tele-operated robotic science & demonstrations	• Unpressurized rover for local exploration	• Pressurized Rover • Cryogenic lander/ascent • Reusable ascent stage • KiloPower	• Pressurized Rover • Cryogenic lander/ascent • Reusable ascent stage • KiloPower • Habitat • ISRU
Exploration Range	n/a	<10 km per site	100 km per site	100 km from base

A range of lunar missions was considered in order to help drive key capability and technology needs and potential applicability toward future Mars missions

Engineering Long Poles to Enable Mars Exploration

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About a dozen engineering Long Poles required for eventual human missions to the martian surface were identified and assessed in our 2016 AM IV workshop.

In AM VI, these were used to assess the content of the lunar scenarios that most enabled exploration of Mars in the 2030s.

Long Pole [1]	Yrs to close [2]	Driving Gaps [3]	Long Term Goal	Enabled Human Missions				
			Mars Surface Long Stay	Cislunar Shakedown Cruise	Mars Fly-By [4]	Mars Orbital	Orbital + Martian Moon Sortie	Mars Surface Short Stay
3. Aggregation and Refueling / Resupply Capability	11	Design of logistics architecture and demonstration in deep space, Autonomous operations at Mars. Xenon & cryogenic transfer.	X	X	X	X	X	X
4. Mars Transfer Vehicle (hab & Propulsion)	HRP roadmap green + ? years	Hab: Space radiation protection for crew,	X	X	X	X	X	X
5. Solar Electric Propulsion Cargo Tug		300-kW Class Solar Array, ARV-derived Power Distribution, 12.5-kW Electric Propulsion Thruster, Low Thrust Navigation	X			X	X	X
6. Martian System Recon for Human Operations	12	Resource Reconnaissance for Landing Site Selection, ground truth of resource mapping Round-trip Demo / Sample Return, extant biology in soil (?), atmospheric recon for EDL,	X				X	X
7. Mars Crew / Cargo Lander(s) [5]	13	Mars EDL system (30 t, <100 m precision), LOX/Methane Propulsion and CFM	X					X
8. Mars ISRU Tech Development	6 (atmos) 8 (water)	Convert CO_2 to O_2, Dust effects on ISRU hw. Oxygen extraction from CO_2. (DRM 5.0) Access H_2O-- subsurface ice/minerals. Resource Acquisition, Liquefaction and CFM	X					
9. Mars Surface Hab / Science Lab	~5 -- 17	Surface Habitation (architecture for livability and usability)	X					X
11a. Mars Surface Power - Solar + RPS	8 - 10	SEP-derived Solar Arrays, lightweight fuel cell/ battery storage, high power/high efficiency RPS	X					X
11b. Mars Surface Power - Nuclear Fission	10 - 12	10s kW Fission Power, Heat pipe thermal transport, high efficiency energy conversion	X					
13. Mars Ascent Vehicle (MAV)	13	LOX/CH_4 Propulsion and CFM, habitability, GN&C, Integrated System, ISRU Convert CO_2 to O_2,	X					X
14. Mars Communication Network for Human Expl and Science		Deep Space, High-Rate Forward Link / Downlink and High Rate Proximity Communication	X			X	X	X

Example: Long Pole Matrix

Mars Ascent Vehicle Assessed by Transportation/Propulsion Team

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Long Poles and Associated Driving Gaps	Minimum Success Criteria and *other information	Gateway Lunar orbit only with surface telerobotics	Lunar Sorties Short duration stays with local crew exploration	GER Class Medium duration with local exploration, relocatable	Field Station Long duration with regional exploration, single site	Key environmental differences that impact Long Pole/driving gap reduction	Other Considerations	Capabilities which can be matured at the ISS now	Capabilities with long lead times which must be developed specifically for Mars
1: Aggregation/Refuel/Resupply (11)									
Design of logistics architecture and demonstration in deep space	Demonstrate the autonomous delivery and transfer of fuel and cargo in deep space	Medium: Aggregation, assembly and refueling/resupplying of the Gateway will inform Mars mission assembly Small quantities and scale	Low: Assuming expendable descent and ascent stage	Medium: Assuming at least a reusable ascent stage. Vehicle Refurbishment at Gateway High: If descent stage (cryo) is fueled at Gateway Medium scale logistics	High: Assuming fully reusable lander. Long duration operations on the surface of the Moon will help refine future Mars logistics strategies. Large scale logistics	N/A	*Note: Focus only on logistics here since fuel is covered below.	ISS analog possible	Yes Cryo Fluid Management needs to start immediately. The Moon should be used to develop the experience base prior to going to Mars
Autonomous operations at Mars	*Operations of systems at Mars distance with limited/no Earth support	Medium: Uncrewed/autonomous operation at Gateway provides an analogue for autonomous operation at Mars Transition from autonomous to crewed operations Demonstration of Comm Ops through Comms relay	Medium: Autonomous mating of lander with Gateway and checkout prior to human arrival Potential autonomous landing operations	High: Repeated/extended autonomous operation of lander at Gateway	High: Assume field station is permanently occupied (less autonomous than previous). Initial operations similar to GER class	Time lag may influence autonomous operations		ISS analog possible (Proposed)	No

Most Relevant Systems and Technologies (aka, "Long Poles") to Test/Demonstrate on the Moon to Feed Forward to Mars

AM VI

Prioritized Space Transportation and Propulsion Systems, Technologies, and Operations

1. **Long-term cryogenic fluid management**
   Long-term storage of cryogenic propellants (LOX, LCH_4, LH_2), passive/active reduced boiloff tanking, liquid acquisition, tank mass gauging

2. **Lander development** (e.g., propulsion, precision & autonomous landing, hazard avoidance)
   Cryogenic engines in the 40 - 100 kN range, deep-throttling engines, cryogenic reaction control system (RCS), precision landing, hazard avoidance

3. **Vehicle aggregation** (e.g., refueling, refurbishing, checkout)
   Vehicle servicing, cryogenic refueling, refurbishment, repair, cleaning, re-certification for flight readiness

4. **Human health and biomedicine** (e.g., radiation, psychosocial)
   Deep-space behavioral health monitoring, deep-space radiation

Most Relevant Systems and Technologies (aka, "Long Poles") to Test/Demonstrate on the Moon to Feed Forward to Mars

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Surface Systems/Technologies/Operations

Highest priority (Alphabetical Order)

- **Human health and biomedicine** (e.g., psychosocial, food & medicine)
- **Power systems** (e.g., fission for primary power, radioisotope power for mobility)
- **Rovers for human exploration** (e.g., operations, energy storage, airlocks, suitlocks)
- **Surface suits** (e.g., pressure garment, environmental protection layer, maintenance)

Next highest priority (Alphabetical Order)

- **Communication systems** (e.g., orbital assets, local communication)
- **In-situ resource utilization** [See *Notable Topic* below]
- **Surface habitats and laboratories** (e.g., systems availability, operations)

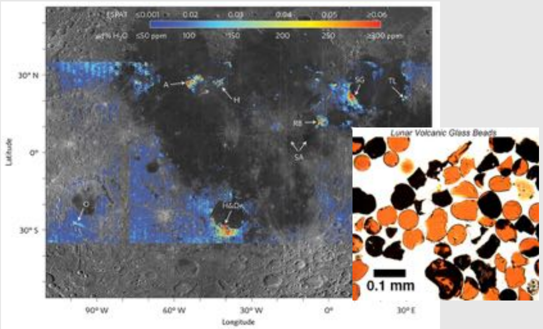
Notable Topic: In-Situ Resource Utilization

In-situ resource utilization (ISRU), especially of lunar and Martian near-surface extractable water and the Martian atmosphere, has the potential to enable affordable and sustained human occupation of the Moon and/or Mars. However, critical information about these resources is not yet available. Therefore

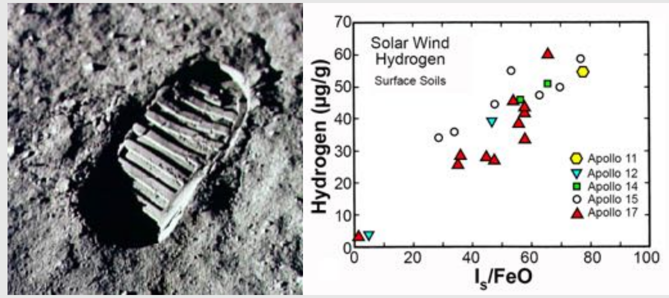
- *ISRU surface and orbital reconnaissance of potential lunar and martian resources must continue to verify their potential, especially whether or not lunar water ice feeds forward to Mars exploration*
- *Verify the potential for lunar ISRU technologies, processes, and operations (e.g., excavation/drilling, water cleaning and electrolysis, liquefaction/storage) to feed forward to human Mars exploration.*

Lunar ISRU Strategy That Feeds Forward Moon-to-Mars

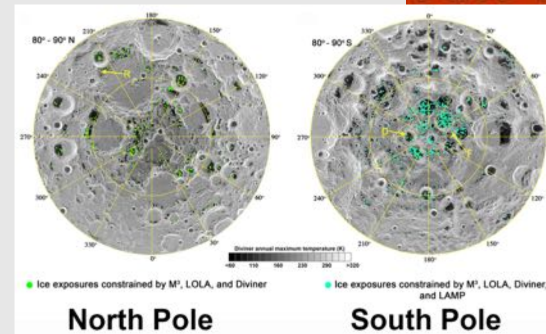
Water Resources on the Moon



Volcanic glasses: ≥0.3 wt.% H_2O

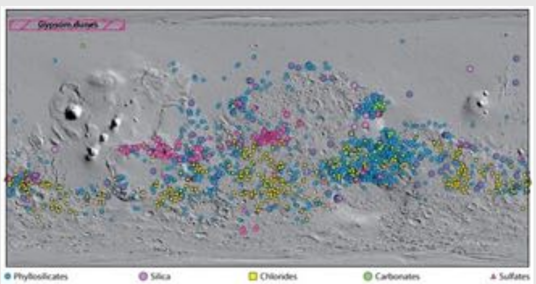


Regolith: solar wind implanted H

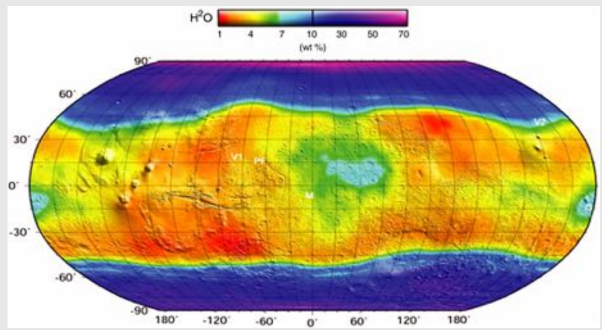


Polar water ice: up to 30 wt.% water ice at the surface

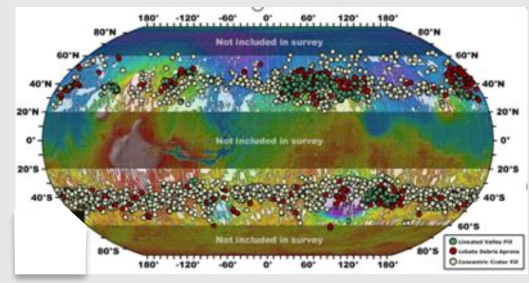
Water Resources on Mars



Mid-latitudes: Hydrated Minerals



Massive ice <1m depth at poles



Potential near-surface ice >1m depth

Mars Forward Lunar ISRU Role and Focus

- **Identify, characterize, and quantify resources/volatiles for future applications**
- **Important Demonstrations:**
  - Demonstrate ISRU concepts, technologies, & hardware that reduce the mass/cost/risk of human Mars missions:
    - ISRU for propellant production; Cryogenic storage & transfer to refuel ascent vehicle
    - Site engineering and infrastructure emplacement for repeated landing/ascent at same location
  - Use Moon for operational experience and mission validation for Mars, such as:
    - Pre-deployment & remote activation and operation of ISRU assets without crew
    - Landing crew with 'empty' tanks with ISRU propellants already made and waiting
  - Long-duration surface operations
    - Increase duration and autonomy; possibly polar location due to more benign solar/thermal environment
    - Build-up of power, communication, and mission support infrastructure after initial surface evaluation
    - Demonstrate Mars Forward human mission surface exploration operations and infrastructure

Selected Workshop Observations

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- Early Mars missions do not necessarily require lunar surface activities. However, an important number of possible human and robotic operations, technology developments, and demonstrations on the surface of the Moon and its vicinity were identified that would contribute to the Mars scenario adopted here (Field Station) by the end of the 2030s.

- **A successful and sustainable Moon-to-Mars human space flight program requires a single "integrating" NASA Headquarters office** with budget authority to apply the results of technology, operations, and science trade studies:
    - *Lunar and martian priorities should not be assessed independently of one another*.
    - *Future priorities for Mars exploration may levy requirements on lunar exploration.*

- The profound environmental differences between the Moon and Mars must be fully incorporated into scenarios that intend for the former to enable the latter.

- The Gateway could be an important test-bed for Mars transportation architectures.

- Using the ISS or a similar platform, where crews are continuously present using systems intended for Mars, is key for understanding how these systems will perform and potentially need to be maintained for a three-year Mars mission. In addition, permanent presence by crews in a zero-g and relatively isolated and stressful environment is critical for reducing human health and biomedicine risks for long-duration missions.

- Two martian engineering Long Poles – Crew and Cargo Landers and Martian System Reconnaissance – have very long development times. If development of these Long Poles is delayed, the goal of landing humans on the surface of Mars will be likewise delayed.

Proposed Assessments of the Extent to which the Moon may be used to Further Mars Exploration (I)

AM VI

Priority Follow-on Activity to AM VI

We found significant value in the Moon and Mars communities working together to understand how lunar operations and capabilities can feed forward to Mars. We recommend a more extensive assessment with increased participation by these communities. This collaboration, under NASA leadership, should commence **as soon as possible** and use the ongoing NASA *Engineering Long Poles for Getting Humans to the Surface of Mars* effort as the basis for the activity.

Trade Studies (Not in Priority Order)

1. Comparison of end-to-end costs of resources extracted from the Moon with those supplied from terrestrial sources

2. Lunar ascent vehicle/lander extensibility to Mars ascent vehicle/lander

3. Pros/cons of different cryogenic propellant combinations (i.e., LOX/CH_4 versus LOX/H_2) for lunar and Mars scenarios

4. Value of remotely operated robot versus on-site astronaut operations on the lunar surface to feed forward to human missions to Mars

5. Airlock versus suitlock, including planetary protection, habitat access, and cognizance of different environment

6. Common development paths for Mars and Moon surface suit thermal systems

7. Long-lived pressurized rover energy production and storage (e.g., Kilopower versus radioisotope power system (RPS), fuel cells versus batteries)

8. Rover needs on the two worlds (e.g., duration of trips, what rovers are used for (science, construction, maintenance, transportation), day-night cycle, and crew size)

9. Study on ISRU-based site preparation and construction for landing, lift-off, and surface transportation operations on lunar and martian terrain.

Proposed Assessments of the Extent to which the Moon may be used to Further Mars Exploration (II)

AM VI

National Academies Studies

- In-situ resource utilization (ISRU), especially of surface/shallow geological deposits containing extractable water, has the potential to enable affordable and sustained human occupation of both the Moon and Mars. However, certain critical information about these resources is not yet available and, consequently, how and when such resources might be exploited. Therefore,
  - *What are the priority surface and orbital reconnaissance programs of potential lunar and martian resources to assess their potential?*
  - *What is the degree to which lunar resource exploration, production, beneficiation, and commodity storage processes feed forward to Mars?*
  - *What are the effects of declining launch costs and development of lunar resource extraction capabilities?*

- Mitigation of environmental damage to human health (e.g., radiation, psychosocial, zero g, partial g) for lunar and Mars missions:
  - *What needs to be carried out at ISS and Gateway, and what can be learned on the Earth?*

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AM VI

Questions?

Opening talk by Dr. Jim Green (NASA Chief Scientist)
Closing talk by Dr. Ellen Stofan (Director, NASM)

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Back Up

AM VI

AM V Architectures


The Fifth Community Workshop on Achieving and Sustaining Human Exploration of Mars:
Three Scenarios for the 2030s (AM V)

5 – 7 December 2017
Washington Plaza Hotel
Washington DC

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Three Architectures

1. Sorties
2. Research station
3. Permanent habitation

AM IV Long-Poles


Continuing to Build a Community Consensus on the Future of Human Space Flight

The Fourth Community Workshop on Achievability and Sustainability of Human Exploration of Mars (AM IV)

Organized by Explore Mars, Inc.
and
the American Astronautical Society

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https://ExploreMars.org — http://Astronautical.org

Ten key technology long-poles

Map criticality of each long pole to one of AM V architectures

Pre-workshop Mapping

Notional Lunar Architectures

1. Gateway only
2. Sortie-Class
3. GER-Class
4. Field Station

For each long pole from the selected Mars architecture, rate the degree to which it can be advanced by each lunar architecture

Workshop Consensus Building

Example Long Pole Matrices

AM VI

Transportation Team - Crew/Cargo Lander

Long Poles and Associated Driving Gaps	Minimum Success Criteria and *other information	Gateway	Lunar Sorties	GER Class	Field Station	Key environmental differences that impact Long Pole/driving gap reduction	Other considerations	Capabilities which can be matured at the ISS now	Capabilities with long lead times which must be developed specifically for Mars
		Lunar orbit only with surface telerobotics	Short duration stays with local crew exploration	Medium duration with local exploration, relocatable	Long duration with regional exploration, single site				
5: Crew/Cargo Lander: Entry, Descent, and Landing (EDL) (13)	Perform a precursor mission to demonstrate EDL, prior to delivery of mission-critical cargo								
Human-scale Mars EDL system)	30 t, <100 m precision	Medium: Aeromaneuvering of Commercial Logistics/Earth Return	High: Precision landing and hazard avoidance Medium: Abort scenarios	High: Critical infrastructure near landing zone	High: Abort to surface. Humans present near landing site		*Consider lunar propulsion landing and Mars terminal landing phases	Commercial Resupply for atmospheric entry	Yes
Cryo Propulsion and Cryofluid Management	*Demonstrate a relevant Cryo propulsion system and long-term cryogenic storage in Mars –like surface environmental conditions	N/A Gateway does not use Cryogens Medium: If commercial logistics vehicles use cryo propulsion	N/A	High: Strong similarity between lunar descent and Mars lander propulsion Medium: Potential storage of Cryo at Gateway (lander/tanker)	High: Strong similarity between lunar and Mars lander propulsion Surface production, storage and transfer to landers of cryofluids		*Assume hypergolics for lunar sortie missions	No	Yes Cryo Fluid Management needs to start immediately
Footnotes	GER class missions may have some abort to surface capability								

Surface Team – Mars Communications

Long Poles and Associated Driving Gaps	Minimum Success Criteria and *other information	Gateway	Lunar Sorties	GER Class	Field Station	Key environmental differences that impact Long Pole/driving gap reduction	Other considerations
		Lunar orbit only with surface telerobotics	Short duration stays with local crew exploration	Medium duration with local exploration, relocatable	Long duration with regional exploration, single site		
12: Surface EVA Suit **PRIMARY							How do we operate EVAs on the two surfaces? That can drive differences (relevant for all categories).
Pressure Garment Suit	Addresses abrasiveness and mobility to meet desired maintenance cadence and operations.	Low – elements of next gen Space Suit will provide learning for Surface Suit.	High *We would like it to be high. Depends on design decisions made for the suit. If suit is designed for longer duration mission, then High. Risk posture is different due to different levels of infrastructure available nearby.	High – Moon is a more extreme environment in terms of dust environment; the operations and methodology will be somewhat different but overall similar knowledge gain.	High – Moon is a more extreme environment in terms of dust environment; the operations and methodology will be somewhat different but overall similar knowledge gain.	Best practices of being dust tolerant are very common; some details may be different. Can get a lot of benefit by making Mars and Moon pressure garment same/very similar.	Assuming that this is just pressure garment and does not include the environmental protection layer. Want to be tolerant to suit damage – astronauts will kneel. For short duration missions (Sorties) astronauts can deal with more load and discomfort, so may be a different suit. In Apollo suit there was an environmental protection garment over the pressure garment.
EVA system mobility, durability, and environmental protection layer (e.g., dust management)	Needs to include being able to accomplish science objectives.	n/a	Med – Depends on suit requirements and thus design decisions.	High – design suit to have mobility to accomplish science goals; not need maintenance for 40 days (limited by space, spare parts, etc).	High – design suit for repeated (about daily) use over 6mo, and to have mobility required to accomplish science and other field goals; maintenance possible on the station.	Sortie requirements on the suit are much less, due to ability to maintain it after just ~5 EVAs, back on Gateway or Earth, so meeting requirements will result in a different suit; could be designed for long duration use and the community recommends that a long surface duration suit is designed from the beginning. Do science and field operations have similar mobility needs?	This specifically addresses the durability of joints and other mobility-related components.

Mars Field Station Technology Impacts

AM VI

- Include **Nuclear Thermal Propulsion** (NTP) **in the propulsion trade space**, along with SEP-chemical and hybrid architectures, to understand potential performance improvements, such as:
  - Additional mass margin, potentially providing payload capability for additional commercial/international providers
  - Lower transit times
  - Expanded mission abort options
  - Enabling both conjunction and opposition class missions, thereby providing additional architectural flexibility
- Explore **reusable Mars ascent vehicle**, which
  - Requires exploration of **crew size** (4 - 6), number of crew transported per vehicle (2 - 6) and whether or not they are transported at the same time
    - As population size increases, crews will likely not all arrive and depart in the same vehicle at the same time
  - Exploits element reusability where feasible to reduce cost
  - Leverage/encourage development of reusable lunar surface lander and ascent vehicle technology