AM V

# AM V
# The Fifth Community Workshop on Achievability and Sustainability of Human Exploration of Mars

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Sponsored by Explore Mars, Inc. & the American Astronautical Society

John Connolly (NASA JSC), Harley Thronson (NASA GSFC),
& Chris Carberry (Explore Mars, Inc.)

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*Are there achievable, affordable, and sustainable scenarios for human exploration of Mars by the mid-2030s that will be supported by the broad community? If so, what are the priority technology investments, major architectural elements, and milestones.*

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

# Workshop Background, Motivation and Deliverables

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Over the past few years, NASA and multiple other organizations have produced a large number of plausible scenarios for human exploration of Mars in the 2030s.

The fifth *Achieving Mars* invitation-only workshop (AM V) developed three distinctly different human Mars exploration architectures based on three different "end states." Subject matter experts identified areas of commonality, as well as areas where opinions differ and important decisions need to be made among the three.

## Deliverables:

- **Community-developed common architectures for human exploration of Mars** in the 2030s, along with options and alternatives.
- **A community-based assessment of achievability and sustainability** of different current scenarios for human Mars exploration in the 2030s, especially elements of different Mars architectures that are seen to be divergent among the half-dozen existing scenarios.
- Findings and observations on **viable common elements of different architectures**, priority near-term actions, and investments to ensure achievability of these elements and their importance in a sustainable human exploration program.
- Commentary on elements of the different architectures that are not in common.
- **The role** that a small number of venues could/should play in assuring achievability and sustainability: **ISS, cis-lunar space, the lunar surface**, Mars orbit, Martian moons . . .
- Engagement plans to the general public and stakeholders

# Human Mars Mission Continuum

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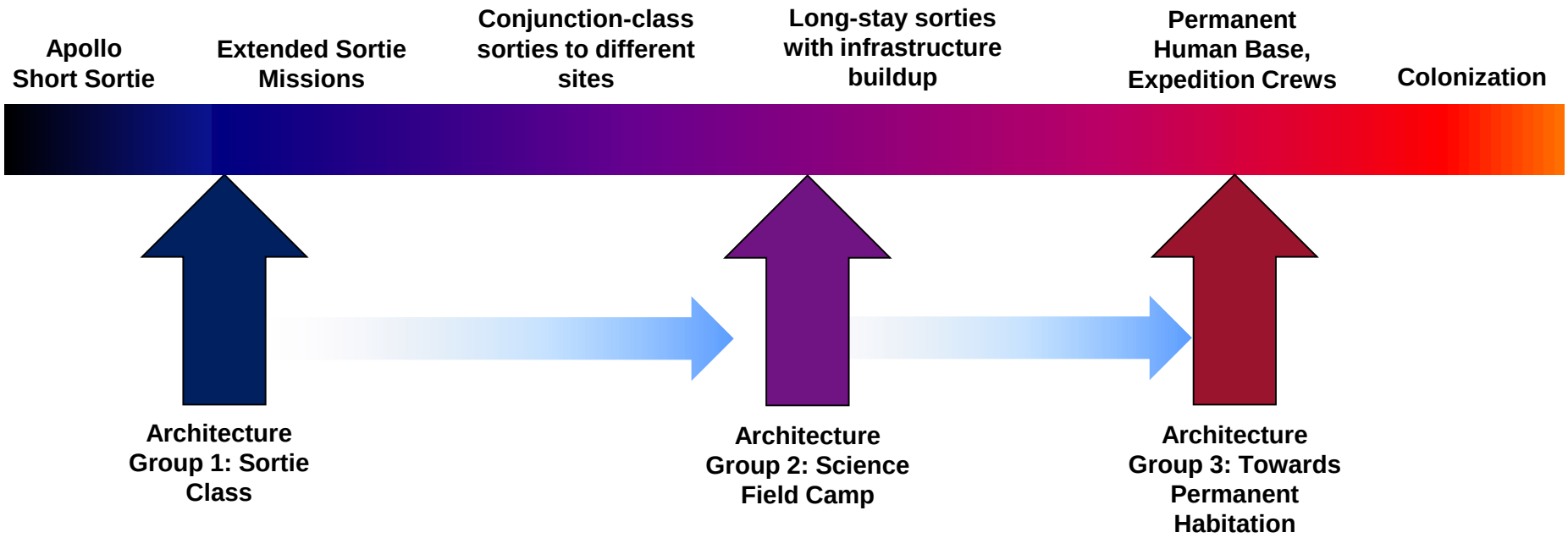
Three different "end states" for human exploration of Mars were adopted as representative of the goals widely identified and an architecture was developed that sought to achieve each of them under common ground rules and constraints.




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

# Guiding Workshop Assumptions and Ground Rules

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

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

# Architecture Group 1: Sortie-class Mission

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- Mars orbit-only mission in 2033
- Separate robotic sky crane mission would deliver 1 t unpressurized rover with science equipment
  - Could be controlled from Earth for site characterization
  - Could be teleoperated from Mars orbit
  - Would serve as unpressurized rover for the landing crew

- 1ST two-week landing sortie in 2037
- 2ND two-week landing sortie in 2041
- 3RD and following missions could include cargo landers, habitats, and/or pressurized rovers and other equipment
- Flight rate could potentially be increased to a new crew every Mars opportunity
- Program could expand to add more cargo landers, have longer stays, on-ramp new technologies, and build up a base

# Two-Week Mars Surface Sortie Mission Concept

crew of 4; 5 SLS launches; ~5 commercial launches

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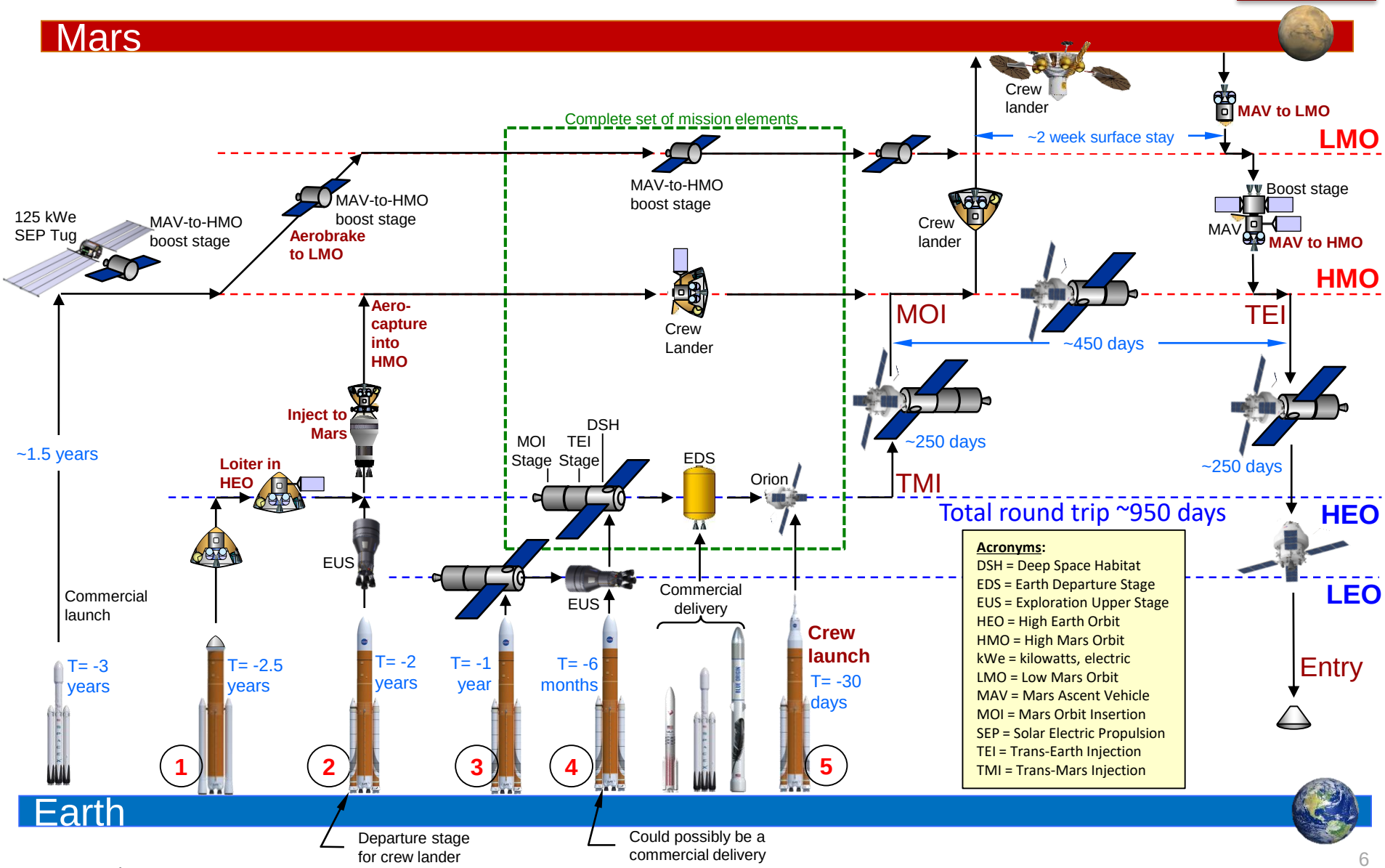

# Six Vehicles to Enable Crewed Missions to Mars

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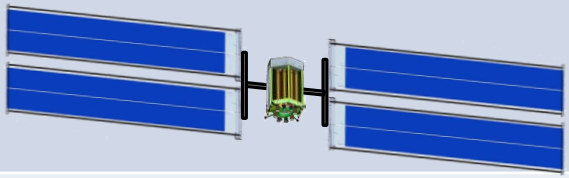
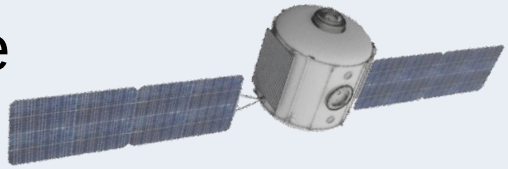
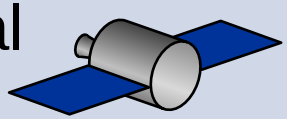
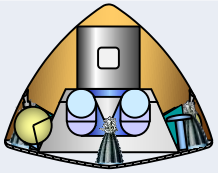
| Vehicles | # Vehicles per Mission | Production Rate | |
|---|---|---|---|
| Orion | 1 | 1 every 4 years | In development |
| SLS | 5 | 1.25 per year | In development |
| SEP Tug ~125 kWe  | 1 | 1 every 4 years | Studies are on contract |
| Deep Space Habitat  | 1 | 1 every 4 years | Studies are on contract |
| In-Space Chemical Propulsion Stage  | 4 | 1 per year | Could be an international contribution |
| Mars Lander  | 1 | 1 every 4 years | Development would need to start |

# Architecture Group 2: Mars Field Station Architecture

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Breakout Group 2 developed a mission architecture to deploy a **temporary field station** on the surface of Mars from which the crew would conduct scientific research. This work **builds on designs developed as part of NASA's Evolvable Mars Campaign (EMC).** The AM V team re-examined this architecture to **incorporate more commercial/international participation** and consider integrating technology demonstration and operations development in cis-lunar space.

An essential characteristic of this architecture is the **demonstration of the feasibility of human occupation of Mars, beginning with a series of missions starting with robotic precursors and technology development in LEO and at the Moon.**

**After the necessary robotic recon and support infrastructure have been deployed, equipment and eventually crews of up to six people will journey to the surface.** These first missions to the surface of Mars will be carried out over the course of a decade and will help demonstrate both the strengths and limitations of our equipment, con-ops, and even our landing site.

The architecture is defined by the flexibility of the approach. For example, to reduce long-term expenses, the architecture phases in more efficient technologies as they are developed as funding is available. One example is nuclear thermal propulsion, a technology not implementable in the near term, although necessary for sustainable human occupation.

# Architecture Group 2: Mars Field Station Architecture

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**Primary objectives of this mission architecture included**

- Learning how to live and work sustainably on the surface of Mars
- Developing and testing the technologies required for future longer-duration habitation on the surface
- Defining the desirable characteristics of an exploration zone in preparation for future human activities
- Evaluating the viability of biology (human, agricultural, or extant microbes) on the surface, and
- Performing priority science to understand the martian environment and the effects of long-term habitation in space and on the surface on human health

# Architecture Group 3 : "Towards Permanent Habitation"

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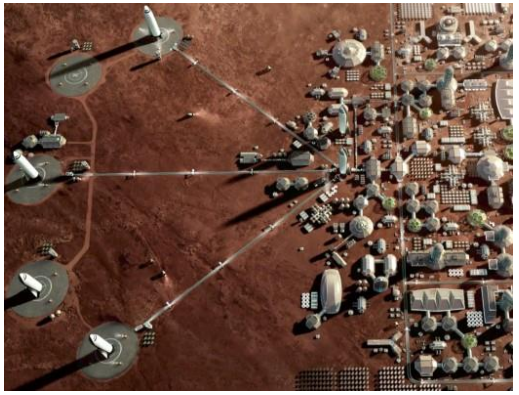
- **Utilizes a set of Guiding Principles which result in permanent presence**
  - **Architecture is really a plan for how to proceed with developments and missions to enable permanent presence at some point in the future, within reasonable NASA, international, and commercial crewed exploration budgets**
  - **Flexibility is designed in to accommodate incorporating what has been learned with each mission, funding changes, and a fluid set of commercial and international partners**
  - **Intended to be a permanent long-term campaign of exploration, with timelines that adjust based on many factors**
- **The goal of permanent human presence results in a number of key architecture differences, as compared to the other AM V architecture groups. Some key differences include:**
  - **Flexible mission objectives**
  - **Heavy emphasis on utilizing local resources**
  - **Protection against failure modes to ensure mission success**
  - **Martian surface treated as dangerous until mastered**
    - **MTV is treated as the safe haven**
    - **Mission sequence builds from orbital missions through short stays to permanent presence**
  - **Six person crews with three person landers/MAVs**



- **Employs a 3-phase campaign to establish a Permanent Surface Base**

# Architecture Group 3: Campaign Phases

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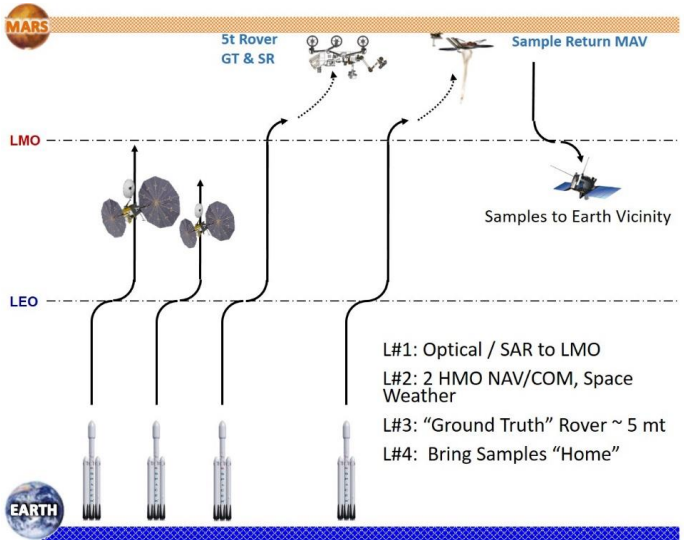
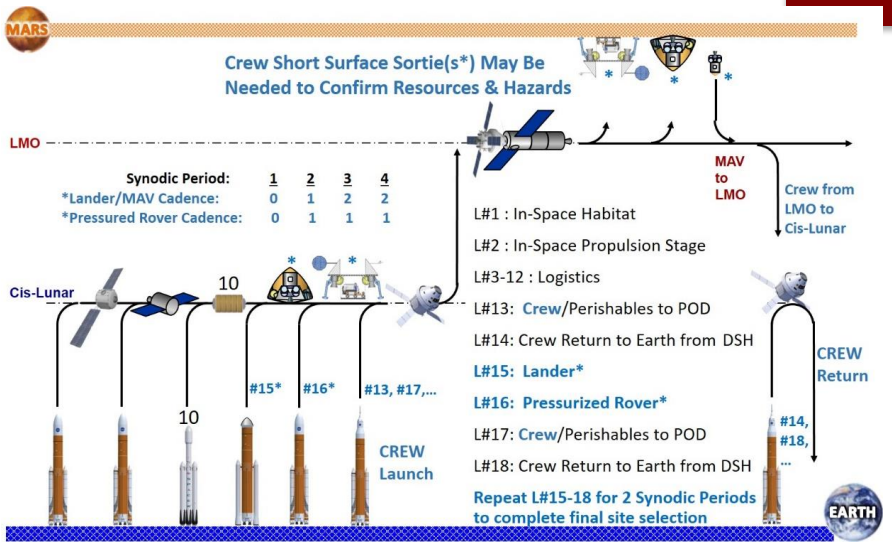
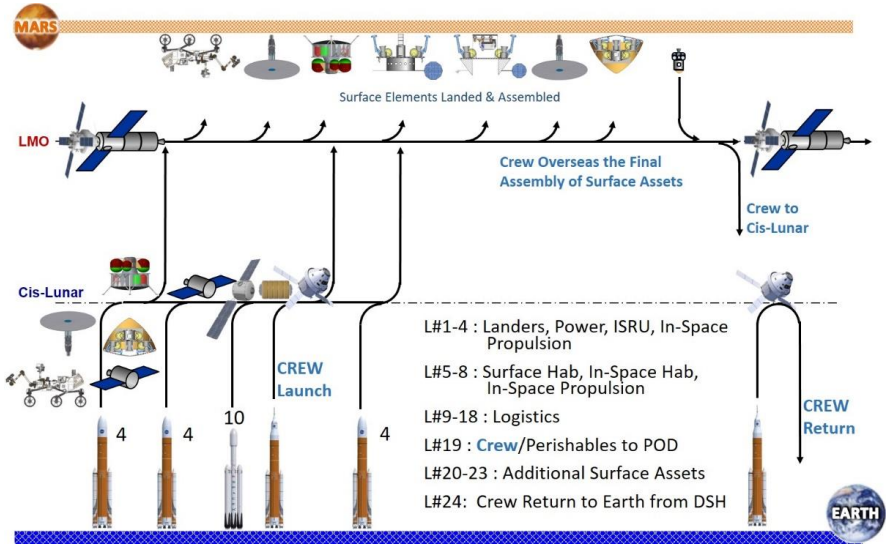



(1) Reconnaissance Missions




(2) Initial Human Presence in Orbit & Site Selection Sorties




(3) Surface Infrastructure Emplacement

# Human Mars Architecture Points of Agreement/ Points of Departure

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| Mission Architecture / End State | | | | | | Transportation | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | | | | Earth-to-Orbit | | | | | |
| Primary Program Focus | Mission Class | Level of Human Activity | Earth Based Mission Support | Cost Emphasis | Reusability | Crew Launch Vehicle | Propellant and/or Logistics Launch Vehicle | Element Launch Vehicle | Launch Vehicle Shroud Size / SLS 2B Fairing | Earth-to-Orbit Flights per Expedition | Launch Vehicle Rate |
| Apollo-Class | Op Sh | | | | | | | | | | |
| Research Base / Antarctic Field Analog | Cl | | | | | | | | | | |
| Primary Activity: Science & Research | | | | | | | | | | | |
| Primary Activity: Resource Utilization | | | | | | | | | | | |
| Primary Activity: Human Expansion | | | | | | | | | | | |

| Transportation | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Cis-Earth Infrastructure | | | | | | | Deep Space | | | | | |
| Initial Orbit | Long-Term Staging | Supporting Space Infrastructure Mass | Orion | In-Space Refueling | Earth Return Mode | Cis-Lunar Propulsion | Mars Orbit Propulsion | Chemical Propellant | In-Space Habitation | In-Space Habitat Duration | No. of Crew to Orbit | Pathway |
| DRO | Cis-Lunar Hab | < 50 mt | Take Orion to Mars | Yes | Direct Entry | All Chemical / Cryogenic | All Chemical / Cryogenic | NTO / Hydrazine | Monolithic Transit Hab | 600 days | 2 | DSG > 2-year Flyby > Long Stay Surface |
| Near Rectilinear Halo Orbit (NRHO) | No Infra | | | | | | | | | | | |
| LEO | | | | | | | | | | | | |
| HEO | | | | | | | | | | | | |
| Cis-Lunar Space | | | | | | | | | | | | |

| Transportation | | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Deep Space | | | | | | | | | | | | | Earth Return | |
| Destination | Mars Parking Orbit | Mars Orbit Insertion - Cargo | Mars Orbit Insertion - Crew | Mars Orbit Operations | Mars Descent Propellant | Ascent Vehicle Propellant - From Earth | Ascent Vehicle Propellant - From ISRU | MAV Payload Up | Earth Capture Orbit | Earth Return Scheme | Mars Pre-Deployment | Descent to Earth's Surface | Earth Entry Vehicle |
| Mars Orbit | 1-s | | | | | | | | Direct Entry | Direct | | | |
| Phobos | 5-s | | | | | | | | | | | | |
| Mars' Surface | 500 km | | | | | | | | | | | | |
| Combination | Areosync | | | | | | | | | | | | |
| Lunar First | | | | | | | | | | | | | |
| Areosynchronous | | | | | | | | | | | | | |
| Mars Flyby | | | | | | | | | | | | | |
| Backflip | | | | | | | | | | | | | |
| Grand Tour | | | | | | | | | | | | | |
| Fast | | | | | | | | | | | | | |

| Human Health | | | Surface | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| Radiation | Countermeasures | Design Considerations | First Surface Mission Date | Crew Surface Stay Time | No. of Crew to Surface | Lander Payload Size (Metric Tons) | Landed Mass per Crewmember (Metric Tons) | Lander Entry Type | Landing Location | Lander Altitude | Landing Accuracy |
| Passive | Zero-G w | | | | | | | | | | |
| Active | Artificial | | | | | | | | | | |
| | Artificial | | | | | | | | | | |

| Surface | | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| ISRU | Power | Habitat Type | Life Support | Planetary Outpost | Excursion Radius/ Exploration Zone | Length of Surface Stay | Planetary Sciences | Laboratory Sciences | ECLSS | Trash | Robotics | Landing Zone Surveys | Cargo Handling | Surface Communication |
| None | Solar | Monolithic | Open | Different for Each Expedition | < 10 km | 7 sols | Teleoperation of Instrument/ Networks | None | Open | Containers | Low Latency Telerobotics | Orbital | Crane/ Hoist | Line of Sight |
| Demonstration Only | Nuclear | Modular | Closed | Single Outpost | 10 - 100 km | 14 sols | Recon Geology / Geophysiology | Basic Analysis / No Lab | 50 - 75% Closed | Recycle | Autonomous | Robotic | Ramp | Relay Satellite |
| Atmospheric Oxygen | RTG | Inflatable | | Multiple Outposts | > 100 km | 30 sols | Field Work | Moderate Geochemical + Life Science | 75 - 90% Closed | Combination | Crew Partnered | | ATHLETE | |
| Water from Regolith | Combination | Rigid | | | Walk Back | 90 sols | Drilling/ Geophysical Tests | Full-Scale Life Science | > 90% Closed | | All | | Other | |
| Water from from Subsurface Ice | Fuel Generator | Local Features and Resources | | | | 300 - 500 sols | | | | | | | Humans | |
| Fabrication / Manufacturing | | Ascent Stage | | | | 500 - 1000 sols | | | | | | | TBD | |
| Combination | | | | | | > 1000 sols, overlapping crews | | | | | | | | |
| Export | | | | | | | | | | | | | | |

# Points of Agreement: Architectural Design Decisions Common to All Architectures

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- **The destination should be the Martian surface** – preliminary missions to cislunar space, lunar surface, Venus, flyby of Mars, or Phobos missions were considered unnecessary. All teams agreed that the first surface mission should be flown no later than 2037.
- **All missions should be flown using Conjunction Class trajectories**. The long-duration stay in the martian system was key to the exploration objectives, and even the Apollo-class architecture that only planned to stay on the surface for 14 sols supported conjunction class missions, using the remaining time in the Mars sphere of influence for orbital activities.
- **Split Missions are desired to deliver cargo ahead of the crew** to the martian system, and rendezvous/transfer activities should occur in Mars orbit. For each expedition, at least four Earth-to-Orbit flights are required, at a rate of 2 or more per year. There was no expectation of a high-cost/fast buildup program.
  - All landers should be predeployed to Mars orbit, but Earth-return propellant should be delivered with the crew and should not be separately pre-deployed.
- **International and/or commercial launch vehicles could be considered** for Human Expansion missions. Propellant, logistics, and elements could be launched on any combination of SLS, international, and commercial vehicles.
- **Launch vehicles will require a minimum of 8.4 m diameter payload shrouds, with 10 m diameter needed for most Mars landers**
- All teams favored the use of aerocapture or aerobraking for Mars orbit capture.
- **A crew should consist of 4-6 crewmembers, and at least 4 should go to the surface.**
- **Landers need <100 m landing accuracy**
  - Landing zone surveys should be conducted both from orbit and robotically
- **Earth-Based mission support (mission control) should be used differently than it is today**, with only moderate oversight of crew activities and monitoring of the mission. Continual Earth-based mission support is not required, but a minimum to moderate amount of support is desired.
- **Relay satellites should be used for surface communication**
- **Surface science operations should focus on field work within the 100 km Exploration Zone.**
- A deep-space habitat should be designed for missions of 1000 days or more, and was seen as requiring no more than 50 mt of supporting deep space infrastructure.
- Radiation issues should be handled passively
- Crew health should be maintained using zero-g exercise countermeasures (as on ISS)
- Modular surface habitats were seen as adequate, with large monolithic habitats or those constructed from local resources or features is not required
- All types of robotics should be employed, with science goals an important component

- A number of workshop “input” assumptions showed up as common design choices from each of the architecture teams, including the use of Orion and SLS, although some specific challenges for both of these programs were common across architectures. This included evolution of the Orion crew complement from 4 to 6, and the need for a 10-meter diameter launch fairing on the cargo version of the SLS to support Mars EDL systems.

# Points of Departure: Architectural Design Decisions Vary Across Architectures

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- **The potential dates for conducting an initial mission are inversely proportional to the mission's scope**:
  - The simpler Apollo-class mission targets 2033 for a crewed mission to Mars orbit and a two-week sortie mission to the martian surface in 2037;
  - The Research Base prefers 2035 or 2037 missions, but is realistically targeting the 2040s, dependent on NASA's lunar mission timeline and the available budget; and
  - The Human Expansion architecture did not target a specific date, but instead states that the timeline would scale with its budget.
- **The "build-up" of mission capabilities corresponds to the scope of the mission endpoints as well**. The Apollo-style architecture goes directly to a short surface stay, the Research Base architecture favors an evolutionary buildup from short to longer-duration surface missions, and the Human Expansion architecture advocates long duration missions from the start.
- **Other mission architecture decisions that scaled with the scope of the three architectures**:
  - Launch vehicle flight rate
  - Landed payload mass
  - Power sources
  - Length of surface mission
  - Returned payload mass
- **Use of ISRU for propellant varies among the architectures** – the more limited scope Apollo-style missions do not utilize ISRU, the Research Base architecture prefers LOX-based ISRU, evolving to propellants, and the Human Expansion architecture embraces the full suite of ISRU products.
- **The cost distribution of each of the architectures varied**, with the Human Expansion architecture requiring the highest cost, and the Research Base architecture (not the Apollo-class mission) indicating the lowest cost/buildup option.
- **Landing sites** - The location of the landing site is not considered to be a major decision point for the Apollo-style scenario, since they propose simple science sorties targeting different sites for each mission. The Research Base architecture would seek a mid-latitude site, but the Human Expansion activity considers the location of the landing site to be primary to its mission, desiring a single landing site with the availability of multiple resources, including water, carbon dioxide, radiation protection, construction and additive manufacturing raw materials, and power availability.

# Next update: Future In-Space Operations Seminar (April 18) Complete Details to Be Presented at Humans 2 Mars Summit

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