• Dr. William Ballhaus, Chair
• Mr. Gordon Eichhorst, Aperios Partners
• Mr. Michael Johns, Southern Research Institute (virtual)
• Dr. Matt Mountain, Association of Universities for Research in Astronomy
• Mr. David Neyland, Consultant
• Mr. Jim Oschmann, Ball Aerospace & Technologies Corp.
• Dr. Mary Ellen Weber, STELLAR Strategies, LLC
• Space Technology Mission Directorate Update
  – Mr. Stephen Jurczyk, Associate Administrator, STMD

• Technology Risk/Challenges Matrix for Humans to Mars and Discussion
  – Mr. Jason Crusan, Director, Advanced Exploration Systems, HEOMD
  – Mr. Jim Reuter, Deputy AA for Programs, STMD
  – Mr. William Gerstenmaier, AA, HEOMD

• Chief Technologist Update
  – Dr. David Miller, NASA Chief Technologist

• Agency Technical Capability Assessment Outcomes
  – Mr. Ralph Roe, NASA Chief Engineer
Elements of the Journey to Mars

2010 2020 2030

**Transition Decade**

**First Human Mars Missions**

**LEGEND**
- Exploration
- Cross-Cutting (Exploration/Technology/Science)
- Science

**Human LEO Transition & Cis-Lunar Habitat**
Long duration human health & habitation build-up including validation for Mars transit distances

**Mars Robotic Precursors**
Identify resources for ISRU, demonstrate round trip surface-to-surface capability

**Asteroid Redirect Mission**
Human operations in deep space

**Orion**
Enabling Crew Operations in Deep Space

**Space Launch System**
Traveling beyond low Earth orbit

**Commercial Cargo and Crew**
US companies provide affordable access to low earth orbit

**International Space Station**
Mastering Long duration stays in space

**Mars Exploration Program**
MRO, Curiosity, MAVEN, InSight, Mars 2020, Observing Mars and Exploring the Surface
Resilient Architectures for Mars Exploration

• There are many different architectures and implementation approaches that can be employed on the Journey to Mars.

• The first step of each Journey to Mars architecture is the same – develop/validate common required Mars mission capabilities in the 2020s.

• The NASA Mission Directorates are collaborating to define a resilient class of architectures for the Journey to Mars in the 2030s.

• Concurrently, they will define missions for the 2020s that reduce the risk for this resilient class of architectures.

Graphic used courtesy of de Weck et al.

Invest in capabilities common to all architectures in near term while refining architecture plans.
Architectural Value

Resiliency is being robust, or adaptable, to change
• J2M will span decades while changes occur yearly
• Narrow to set of architectures between which exploration can cost-effectively switch as conditions change

Candidate Architectures

NRC Pathways
Evolvable Mars Campaign
DRA-5
Inspiration Mars
Mars One
Mars Society
Modular Mars Architecture
Space-X Red Dragon
Explore Mars
Mars Cycler

Proactively planning for change is always better than simply reacting to change as it occurs
Conceptual Integrated Campaign for Mars in the 2020’s

**LEGEND**
- Exploration
- Cross-Cutting (Exploration/Technology/Science)
- Science

**Mars 2020**
- ISRU Prototype
  - EDL Instruments
  - Sample Acquisition
  - In Situ Science
  - Habitable Conditions
  - Ancient Life

**Mars Orbiter**
- Resource Survey
  - Landing Site Selection
  - Optical Comm/Relay
  - High Power SEP
  - Rendezvous
  - Remote Sensing Instruments

**Round-Trip Surface to Surface**
- EDL Evolution/Instruments
  - Mars Ascent
  - Surface Navigation

**Exploration Precursors**
- ISRU Production
  - Surface Power for ISRU
  - Rad/ECLSS Validation
  - Increased EDL Mass & Precision
  - Science Instruments

**Future Launch Opportunities**

2020

2022

# JOURNEY TO MARS
Integrated Vision for a Mars Robotic Precursor Initiative

- **Exploration:**
  - Address key issues to build confidence in round-trip missions to/from Mars
  - Identify and characterize concentrated resources for potential ISRU exploitation

- **Science:**
  - Leverage expertise built through five decades of robotic Mars exploration
  - Build upon recent science discoveries
  - Continue to support decadal priorities

- **Technology:**
  - Leverage technology investments
  - Mission Infusion opportunities
  - Enable end-to-end Earth/Mars missions

- **Infrastructure:**
  - Sustain and improve Mars telecommunications and surface reconnaissance infrastructure

---

The 2020’s will be a “transition decade” that leads to Humans to Mars in the 2030’s
A Brief History of Beyond-LEO Spaceflight Architecture Development
Body of Previous Architectures, Design Reference Missions, Emerging Studies and New Discoveries

- Internal NASA and other Government
- International Partners
- Commercial and Industrial
- Academic
- Technology developments
- Science discoveries

Evolvable Mars Campaign

- An ongoing series of architectural trade analyses that we are currently executing to define the capabilities and elements needed for a sustainable human presence on Mars
- Builds off of previous studies and ongoing assessments
- Provides clear linkage of current investments (SLS, Orion, etc.) to future capability needs
STMD Strategic Planning

- Core values, guiding principles, implementation goals flowdown

STMD Strategic Alignment Framework

- Get There, Land There, Live There, Observe There, Invest Here

STMD Strategic Themes

- Stakeholder input: Space Technology Roadmaps, NRC recommendations, STIP, MD roadmaps, Roundtables, etc.

STMD Thrust Areas

- Focused areas of STMD investments

Strategic Guidance

National Science and Technology Priorities

Content Generation

STMD Programs

- Principal Technologists: Technology investment plans

- Crosscutting Investment strategy and content selection

- Implementation instruments

Get There
Improve the ability to efficiently access and travel through space

Land There
Enable the capability of landing more mass, more accurately, in more locations throughout the solar system

Live There
Make it possible to live and work in deep space and on planetary bodies

Observe There
Transform the ability to observe the universe and answer the profound questions in Earth and space sciences

Invest Here
Enhance the nation’s aerospace capabilities and ensure its continued technological leadership

STMD Strategic Themes
HEOMD/STMD Engagement on Technology Needs

• Evolvable Mars Campaign (EMC) has a strategic set of needs for enabling long-range capabilities; Orion and SLS needs are primarily near-term and mission focused.

• Crosscutting needs identified by HEOMD:
  • Radiation monitoring & protection (ISS, Orion, HRP, EMC)
  • EVA suit & PLSS (Orion, ISS, ARM, EMC)
  • Environmental monitoring (Orion, ISS, EMC)
  • Spacecraft fire safety (Orion, ISS, EMC)
  • Exercise equipment (Orion, HRP, EMC)
  • Advanced solar arrays (ARM, ISS, EMC)
  • Automated rendezvous & docking (Orion, ARM, EMC)

• Areas with greatest number of gaps:
  • Human Health, Life Support, & Habitation Systems (Orion, HRP)
  • Communications & Navigation (SCAN)

• Categories of collaboration:
  • Deliveries: STMD matures technology and delivers to AES for system-level evaluation (e.g., RCA, VOR, EVA Gloves, RPM instruments, etc.)
  • Partnerships: STMD and HEOMD/AES co-fund the development of technologies that are of mutual interest (e.g., MOXIE, MEDA, MEDLI-2, SCOR, etc.)
  • Coordination: STMD and HEOMD/AES define specific divisions of responsibility within a technical discipline (e.g., nuclear systems, synthetic biology, advanced manufacturing, etc.)
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## Capabilities for Pioneering Space: Steps on the Journey to Mars

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### STMD focus areas

- EARTH RELIANT
- PROVING GROUND
- EARTH INDEPENDENT
In Situ Resource Utilization & Surface Power

• **Objectives**
  - Reduce logistical support from Earth by utilizing local resources to produce water, oxygen, propellants, and other consumables.
  - Generate abundant power for surface systems.

• **Current Activities**
  - **Resource Prospector**: Formulating robotic mission to prospect for ice and other volatiles in polar regions of the Moon. (AES)
  - **Mars Oxygen ISRU Experiment (MOXIE)**: Demonstration of oxygen production from the Mars atmosphere on the Mars 2020 mission. (AES/STMD)
  - **Fission Surface Power**: Ground demonstration of Stirling power conversion technology and small nuclear reactors for 1-10 kW modular surface power systems. (STMD)
Entry, Descent, and Landing (EDL)

- **Objectives**
  - Develop the capability to land heavy payloads (> 18 mt) on Mars for human missions.

- **Current Activities**
  - **Low Density Supersonic Decelerator (LDSD):** Flight test of supersonic aerodynamic decelerator and supersonic ring sail parachute for future robotic missions to Mars. (STMD)
  - **Hypersonic Inflatable Aerodynamic Decelerator (HIAD):** Conducted sounding rocket flight tests of subscale HIAD. (STMD)
  - **Adaptable Deployable Entry & Placement Technology (ADEPT):** Deployable, semi-rigid aeroshell. (STMD)
  - **Supersonic Retro Propulsion:** Learning from SpaceX flyback booster tests. (STMD)
  - **Advanced Thermal Protection System (TPS) materials:** Developing woven and high heat flux TPS materials. (STMD)
  - **Entry Systems Modeling:** Updating and improving computational fluid dynamics codes to reduce design uncertainties for future missions. (STMD)
  - **Autonomous Landing & Hazard Avoidance Technology (ALHAT):** Flight test of ALHAT system on Morpheus lander. (AES)
  - **Mars Entry, Descent, & Landing Instrumentation (MEDLI-2):** Measuring temperatures and pressures on Mars 2020 heat shield to validate aerothermal models. (AES/STMD)
  - **EDL Pathfinder:** Studying EDL Pathfinder mission to Mars in 2026 to test subscale EDL system for human missions. (EMC)
Environmental Control & Life Support

• Objectives
  – Develop highly-reliable life support systems that recycle air, water, and waste to reduce consumables.
  – Demonstrate next generation life support systems with integrated ground-based testing and ISS flight experiments.

• Current Activities
  – **Spacecraft Oxygen Recovery**: Developing technologies to recover at least 75% of the oxygen from a spacecraft atmosphere revitalization system. (STMD)
  – **Sorbents for CO₂ Removal**: Developing new sorbents that do not generate dust. (AES)
  – **High Pressure Oxygen Generation**: Providing oxygen supply for replenishing space suits. (AES)
  – **Waste Water Processing**: Developing green pre-treatments, Cascade Distillation System, and Biological Water Processor. (AES/STMD)
  – **Spacecraft Atmosphere Monitor**: Instrument for detecting trace gas contaminants in ISS air. (AES)
  – **PCM Heat Exchanger**: Developing a large-scale Phase Change Material heat exchanger to maintain the crew cabin within safe/comfortable temperatures throughout exploration missions. (STMD)
  – **Spacecraft Fire Safety**: Saffire experiments will investigate the spread of fires in microgravity. Also developing technologies for fire suppression, combustion products monitoring, and post fire clean-up. (AES)
  – **Next Space Technology Exploration Partnerships (NextSTEP)**: Developing advanced CO₂ removal technologies, modular ECLSS, and hybrid biological and chemical life support systems. (AES)
## Capability Development Risk Reduction

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<th>Source of Funding</th>
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**EARTH RELIANT**

**PROVING GROUND**

**EARTH INDEPENDENT**
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<th>Capabilities</th>
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<td>In Situ Resource Utilization &amp; Surface Power</td>
<td>Resource Prospector and MOXIE are small-scale demonstrations of ISRU on planetary bodies. These would need to be significantly scaled up to support human exploration needs.</td>
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<td>Habitation &amp; Mobility</td>
<td>ISS is demonstrating long-duration habitation in LEO, but duration depends on resupply. Conceptual studies are underway for short duration cis-lunar habitats.</td>
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<td>Human/Robotic &amp; Autonomous Ops</td>
<td>Human/Robotic &amp; Autonomous Ops are being demonstrated on ISS. Substantial additional work is needed to enable maintenance of human exploration systems.</td>
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<td>Exploration EVA</td>
<td>Uncertain if next generation spacesuit will be ready before 2024 for demonstration on ISS.</td>
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<td>Crew Health</td>
<td>Human Research Program is investigating crew health risks on ISS, and developing medical diagnostics and countermeasures. Some health risks may not be controlled by 2024.</td>
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<td>Environmental Control &amp; Life Support</td>
<td>ISS life support systems require frequent maintenance. New ECLSS technologies are being demonstrated on ISS. Long duration, closed-loop, system-level ECLSS demonstration is being planned.</td>
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<td>Radiation Safety</td>
<td>Characterizing LEO, cis-lunar, and Mars surface radiation environments. Improving forecast models for solar particle events. Reducing uncertainly in radiation effects on humans. Effective shielding has not been developed.</td>
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<td>Ascent from Planetary Surfaces</td>
<td>Little work is being done in this area except for MAV concept studies and small LOX-methane propulsion efforts.</td>
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<td>There are multiple EDL technology development activities for Mars robotic missions but analogous projects for human missions are in early stages of progress.</td>
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<td>In-space Power &amp; Propulsion</td>
<td>Developing 40 kW SEP system for ARM. Initiating ground testing of 100 kW electric thrusters. Developing small fission reactors for surface power (low funding level).</td>
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<td>Beyond LEO: SLS &amp; Orion</td>
<td>Working towards first flight of SLS and Orion in 2018.</td>
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<td>Communication &amp; Navigation</td>
<td>Demonstrating high bandwidth optical communications for cis-lunar and Mars. Deep space optical comm is a candidate for demonstration on SMD missions.</td>
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By the mid-2030s, I believe we can send humans to orbit Mars and return them safely to Earth. And a landing on Mars will follow.

-President Barack Obama, April 15, 2010
HEOMD and STMD working together have identified a range of critical technologies and further capabilities required to support human missions to Mars.

- NASA has a broad range of architectural landscape options and is working to narrow them.
- NASA is defining a common set of technology investment requirements across these architectures.
- They have identified gaps in the areas of: power & in-space propulsion, ECLSS, habitation, ISRU, communications & navigation.
TI&E Committee Finding

In order to assess the technology investment matrix, the TI&E committee would need the following:

– A mission definition
– A plan that includes technology risk burn down lead times and tech demo completion dates
– Budget commitments and authority to proceed dates
– An assessment of technologies that could be effectively evaluated on extant ISS environment

In the absence of these items, the committee offers the following:

– The committee has been told that NASA budget limitations and uncertainties are a significant impediment to a human exploration mission to Mars in the 2030s with SLS, Orion, and other system developments as the current near term pacing items in human exploration.
– NASA has defined what budget it needs in STMD, but the discretionary portion has diminished over time, and has forced many of the planned technology investments and demo risk reduction missions to be significantly delayed, de-scoped, or eliminated.
To effectively advocate to correct this situation, in the absence of a defined mission plan to go to Mars, this committee believes the preferred approach is to develop the technology pull from the proving ground missions

– The committee believes the current HEOMD efforts must demonstrate measurable progress in most of the essential areas enabling future HE missions

– At a cadence that maintains US human space leadership and US public support

– Must address major technology gaps (power & in-space propulsion, ECLSS, habitation, ISRU, communications & navigation) with timeline for need dates and appropriate investment
## Current Technical Capability Area Leadership

### Discipline-level Technical Capability — OCE Leadership with NASA Technical Fellows

| 1. Aerosciences          | 11. NDE                      |
| 3. Electrical Power      | 13. Propulsion               |
| 5. GN&C                  | 15. Structures               |
| 7. Life Support/Active Thermal | 17. Space Environments (new)|
| 8. Loads and Dynamics    | 18. Cryogenics (new)         |
| 10. Mechanical Systems   |                             |

Note: (new) signifies that a Capability assessment has not been conducted or reviewed by the EMB

### System-level Technical Capability — OCE Interim Leadership

1. Entry, Descent, and Landing
2. In-Situ Resource Utilization
3. Rendezvous and Capture
4. Autonomous Systems (new)