An Analysis of Exploration Capability Gaps for Future Habitation Systems to Inform Risk Assessment and Development Priorities

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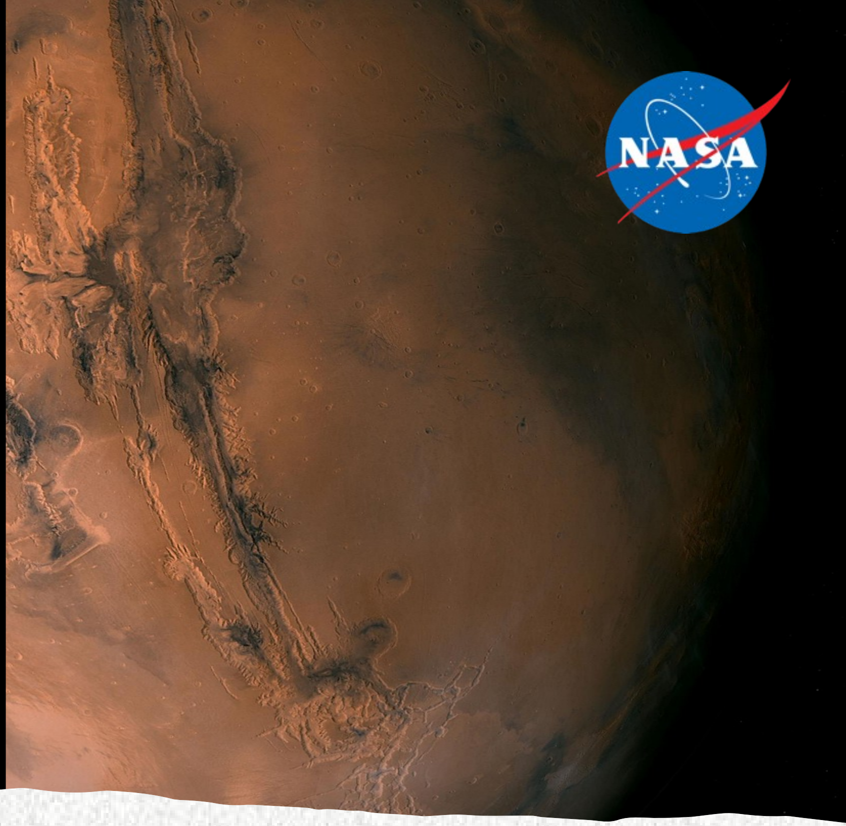
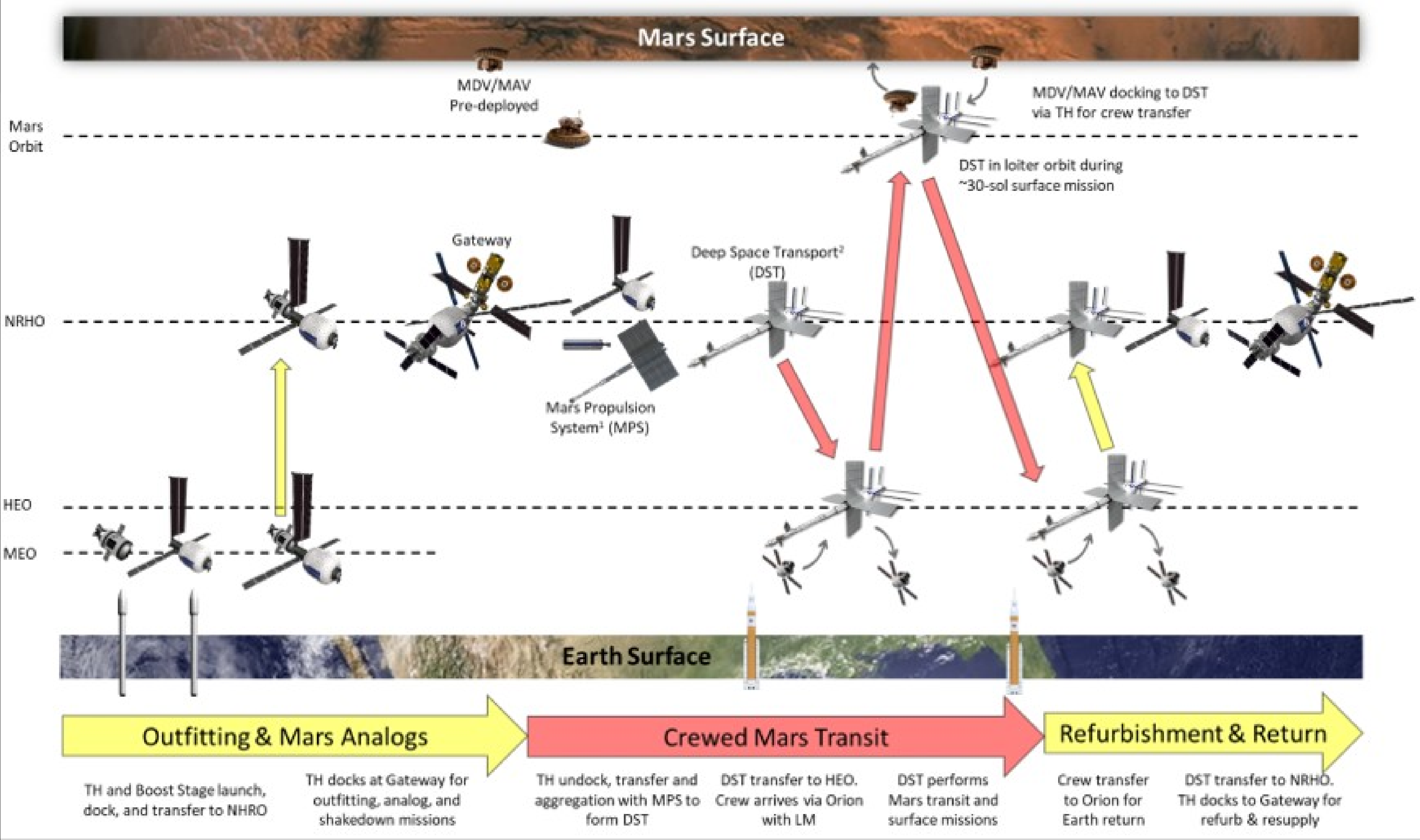


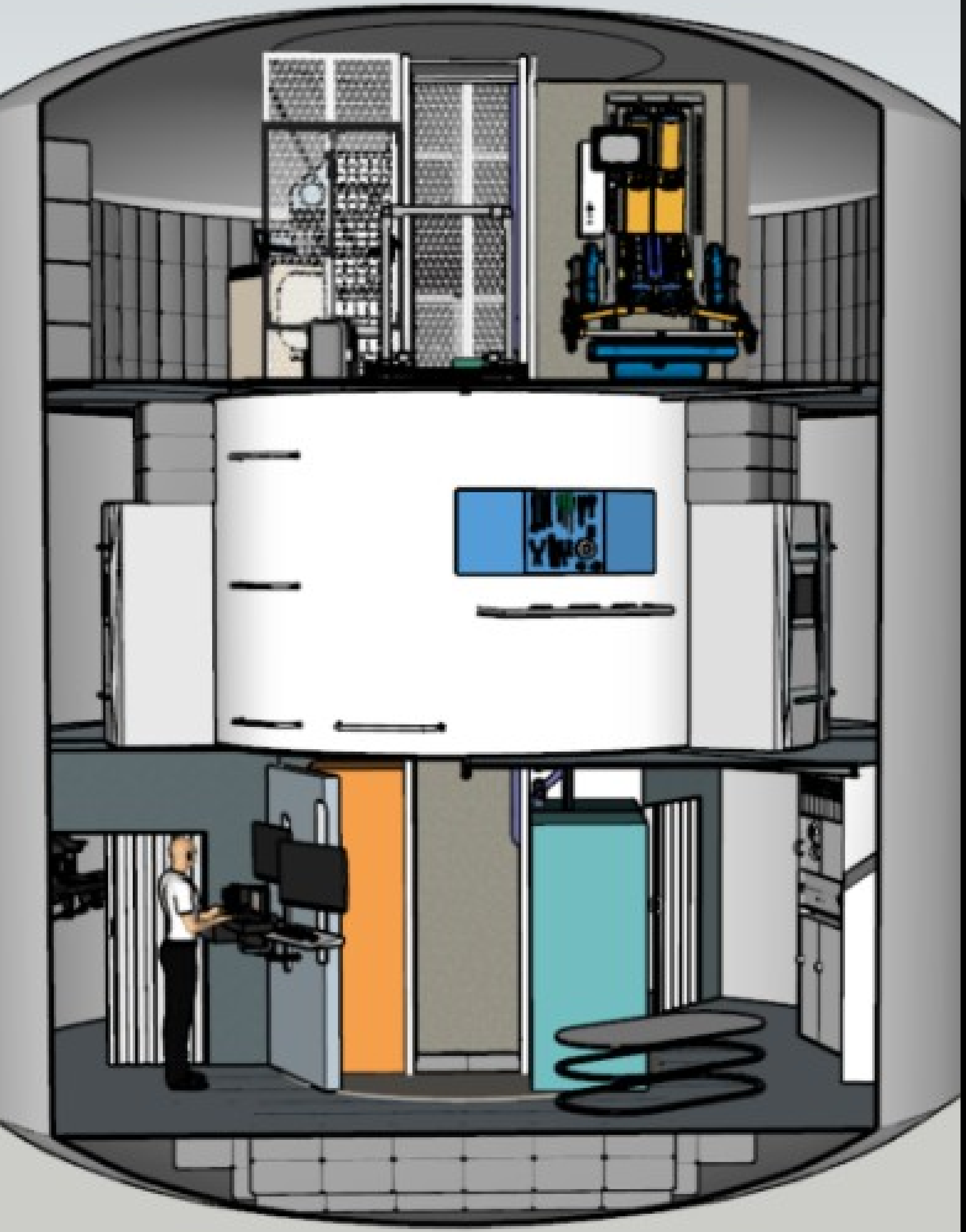
- Enable sustainable exploration of the Lunar surface
- Leverage moon to develop and advance technologies to support eventual Mars exploration

Mars Transit Habitat

- Key element for future Mars missions
- Initially docked at Gateway for outfitting and shakedown/analog missions
- Supports 4 crew for up to 1,200 days

Concept of Operations for Mars Transit Habitat

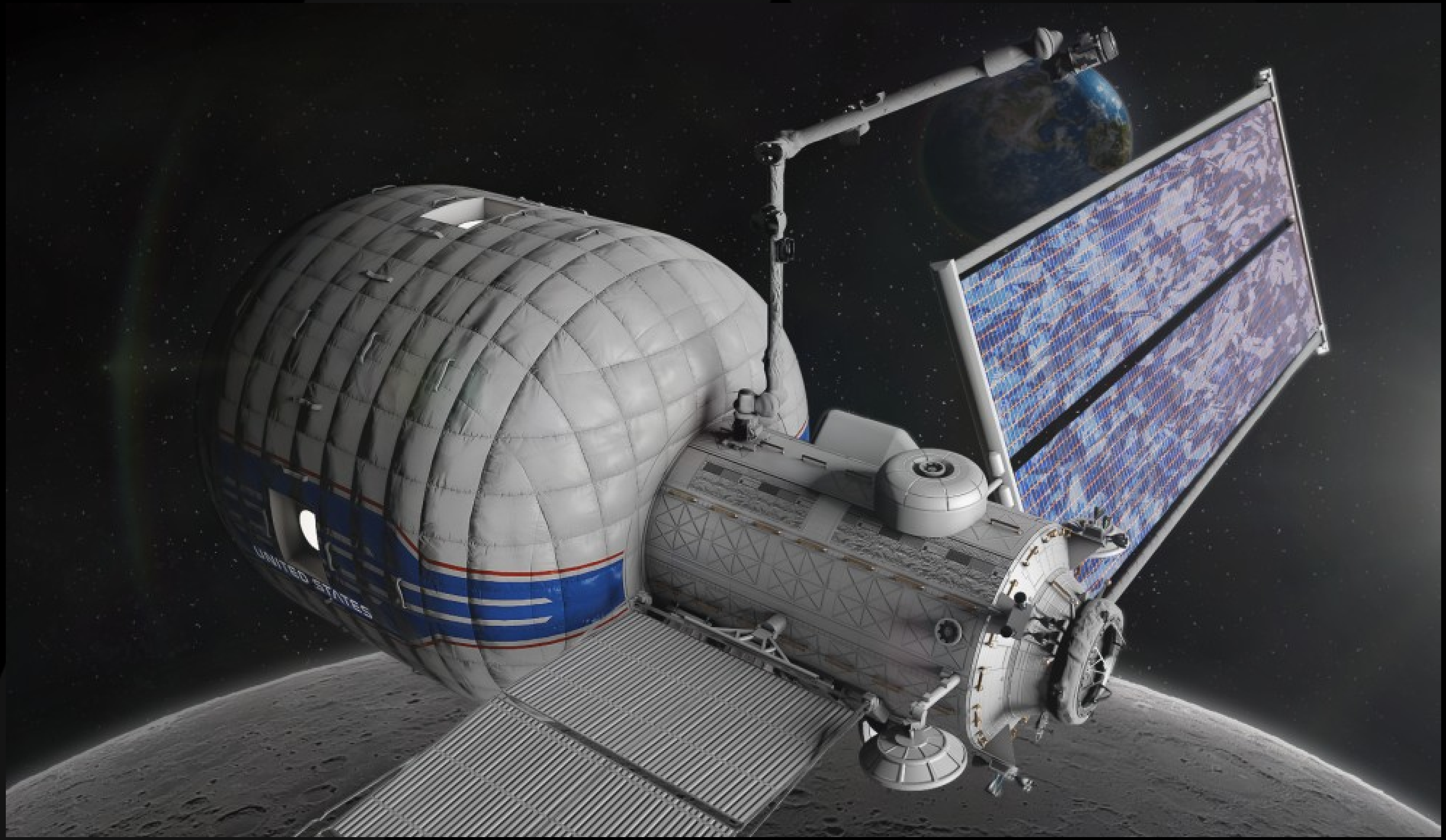




Mars Transit Habitat: A Closer Look

- Inflatable softgoods with central core passageway
- Metallic airlock for contingency Extravehicular Activity (EVA)
- Three story layout
  - Private crew quarters
  - Exercise areas and recreation
  - Research stations/science utilization
  - Galley
  - Command and control
  - Logistics stowage
  - Trash Management

A. Choate, D. Harris, T. Nickens, P. Kessler, M. Simon, "NASA's Moon to Mars (M2M) Transit Habitat Refinement Point of Departure Design," IEEE Aerospace, 2022.



Capability Gaps

- Characterize difference between current state of the art and future needs
- Mars mission challenges
  - Communication delays
  - No abort or resupply opportunities
  - Extended exposure to microgravity and radiation hazards
- Analysis assesses
  - Gaps identified for Mars Transit Habitat
  - Likelihood of near-term closure

Gap Classification

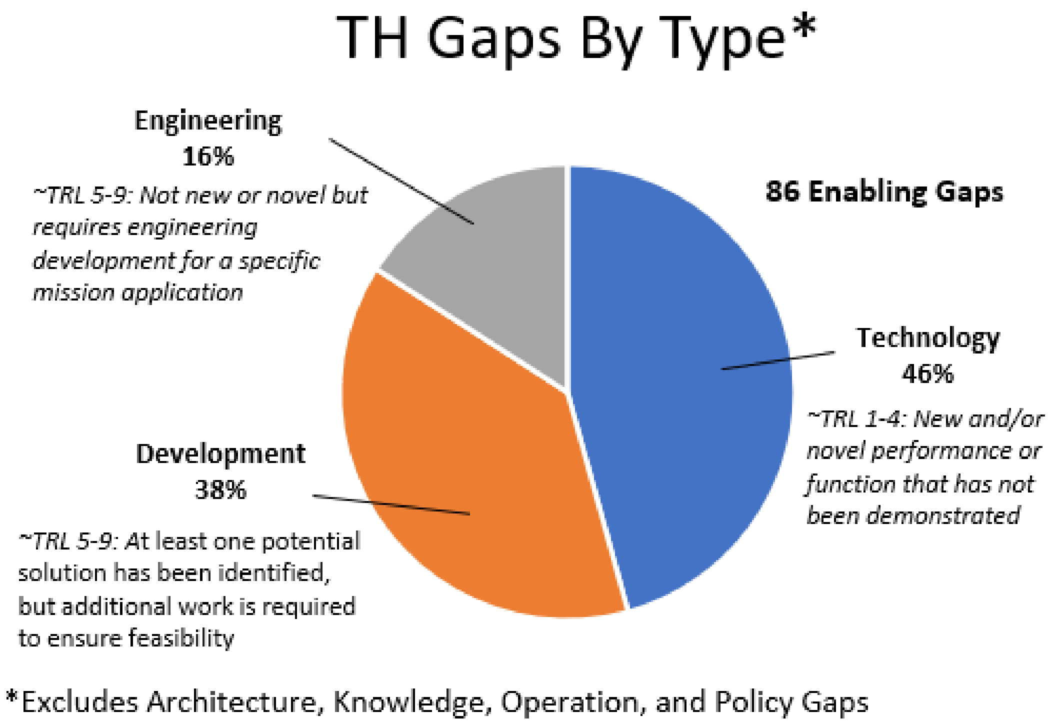
- Importance to architectural element
  - "Need" - Architecture *cannot be executed* without gap closure*
  - "Want" - Architecture *significantly enhanced* by gap closure
  - "Not Required"
- Gaps are further classified into one of the following categories:

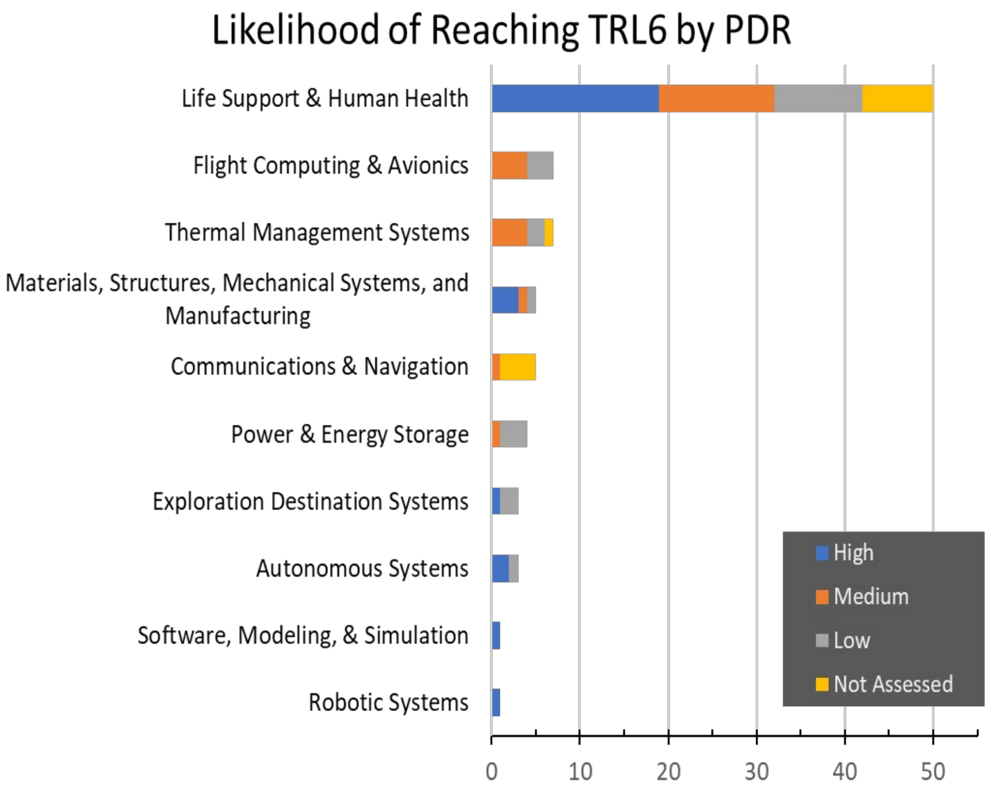
Gap Type	Description
Technology	Requires development of new technology
Development	Additional work needed to assess feasibility of technology
Engineering	Technology requires engineering development for a specific mission
Knowledge	Unknown data that will drive requirements; requires scientific research to close
Architecture	Unknown mission parameters; requires further architecture development and stabilization for gap closure
Operations	Gaps in training and flight operations
Policy	Policy or management issues must be addressed for gap closure

*Analysis here restricted to enabling ("need") gaps

**Analysis for Mars TH does not consider knowledge, architecture, operations, or policy gaps

Breakdown of Transit Habitat Gaps by Type





Technology categories for gaps (bar chart) largely consistent with NASA technology taxonomy

Why are some gaps unlikely to close by PDR?

Technology

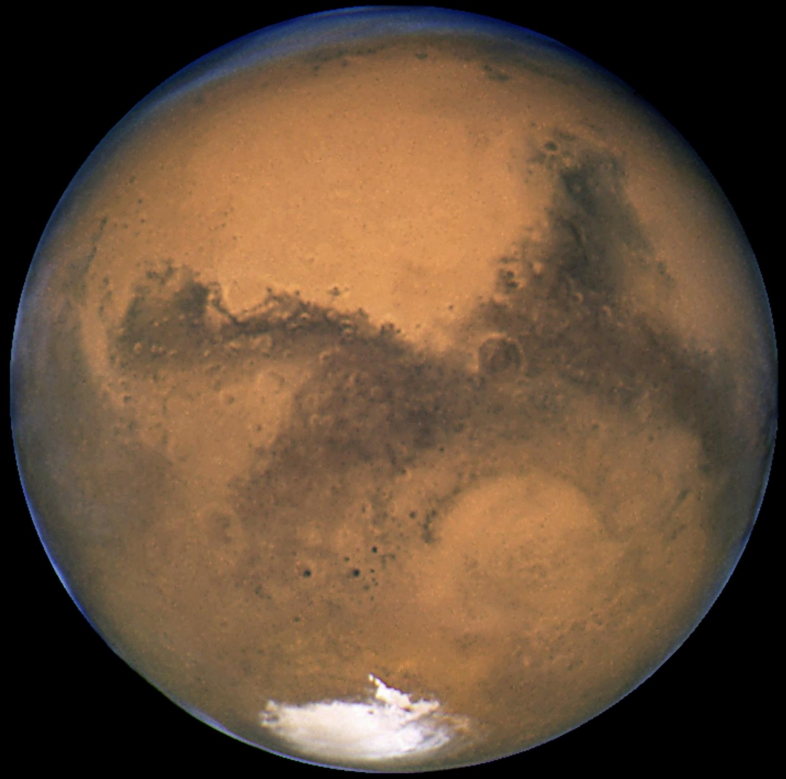
- No current technology options exist

Development

- Technology options <u>need significant improvement and specific testing/characterization</u>
  - Unlikely to meet schedule with current funding and activities
- Flight demonstrations planned, but too late to meet TH timeline or technology development lagging

Engineering

- Gaps in requirements/use case for Mars TH (i.e. gap linked to architecture/knowledge gap)
- Funded work and demonstrations do not align with Mars TH-specific needs



High priority gaps with low likelihood of closure

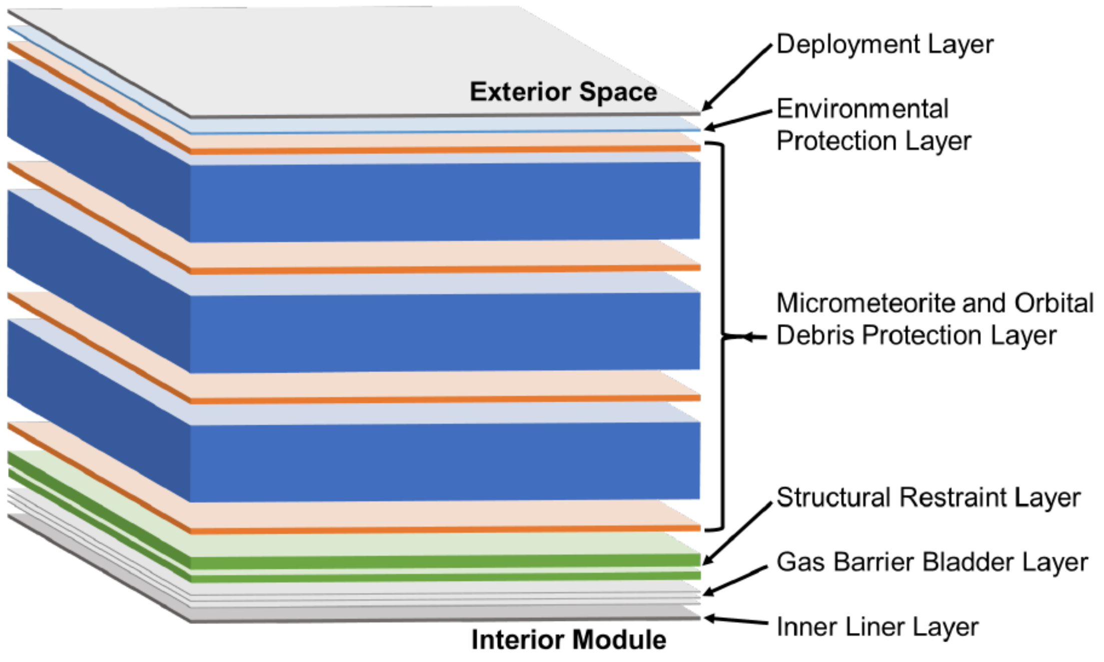
Gap category	Gap list
Avionics	Autonomy High speed networks Enhanced graphics processing systems High speed networks Verification and validation of autonomous systems
Life support and human health	Integrated system for management of crew health and performance data Food system (includes food storage and preservation) Prevention of microbial growth Radiation monitoring and shielding for deep space environments Reliability testing Design for maintainability (and repairability) Enhanced Oxygen and water recovery and food hydration reduction Operations during and following quiescence Design and testing for lower pressure environments In-flight water quality monitors Waste jettison technologies

High priority gaps with low likelihood of closure

Gap category	Gap list
Exploration Destination Systems	Extravehicular tools and mobility aids Outfitting of inflatables
Power	Power management systems with high reliability and radiation tolerance Development of maintainable power management systems built from common components and common modular building blocks for energy storage
Thermal	In situ analysis of coolant fluids Location of coolant leaks
Materials and structures	Hard and soft structure integration

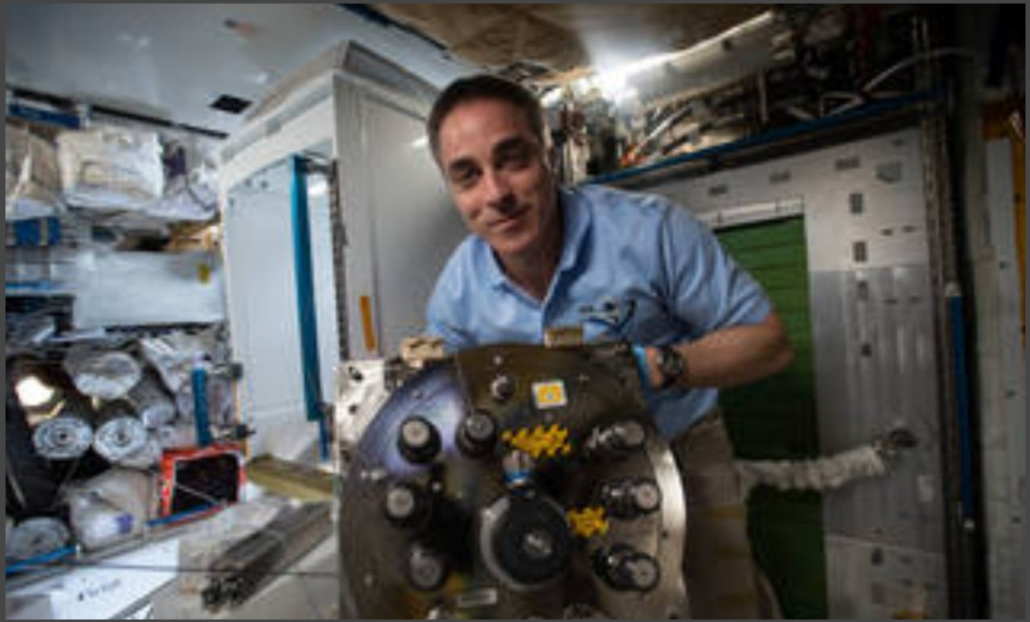
Engineering Gap: Inflatable Softgoods Maturation

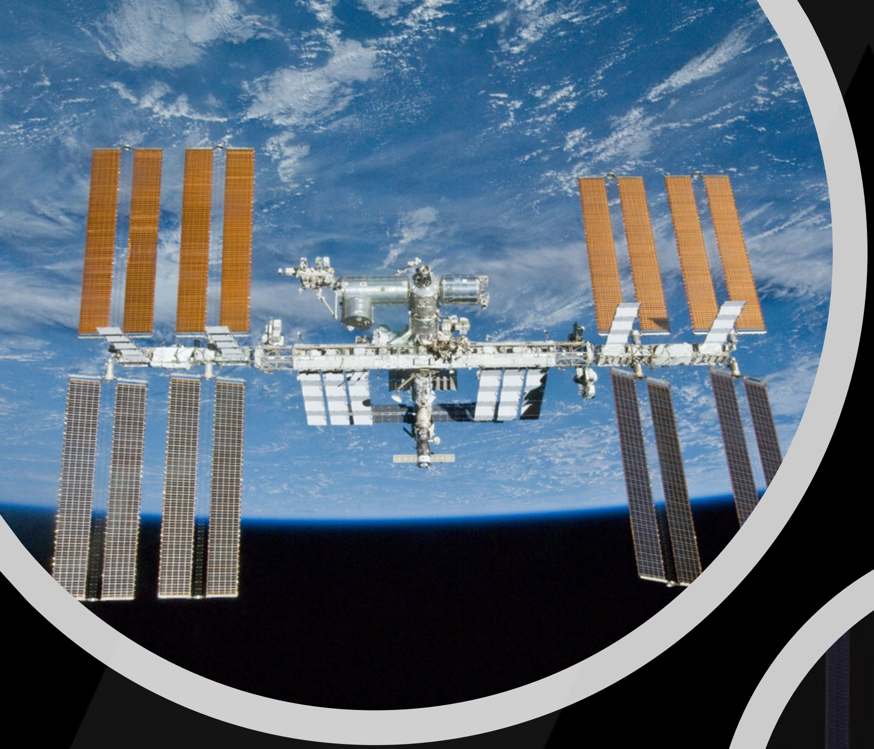
- Baselined for both Mars Transit Habitat and Lunar Surface Habitat to meet habitable volume
- Requires stepwise progression of testing to close engineering gaps
- Testing outlined in recently released document "Certification Guidelines for Crewed Inflatable Softgoods Structures" (JSC-67221)



Environmental Control and Life Support Systems (ECLSS) Options and Testing

- ECLSS suite and loop closure is currently being traded
- Regenerative ECLSS reduces consumables delivery with higher initial mass and associated spares mass
- Need more reliable and less complex systems for Mars missions
- Systems assessed as highly likely to meet Mars TH implementation:
  - Enhanced Oxygen Generation Assembly
    - Electrolyzes water to supply Oxygen
  - Water Processing Assembly
    - Purifies grey water into potable water
  - 4-Bed Carbon Dioxide Removal Assembly
    - Removes CO_2 from the atmosphere via passive sorbent beds
  - Urine Processing Assembly
  - Brine Processing Assembly
  - Plasma Pyrolysis Assembly
  - Environmental monitoring





Maturation Platforms

International Space Station (ISS) (Operational)

- Regenerative ECLSS maturation and validation
- Assessing countermeasures for crew health
- Advancing exploration medical capabilities

Gateway (In Development)

- Will test power management and distribution, quiescent operations, environmental monitoring, exploration medical

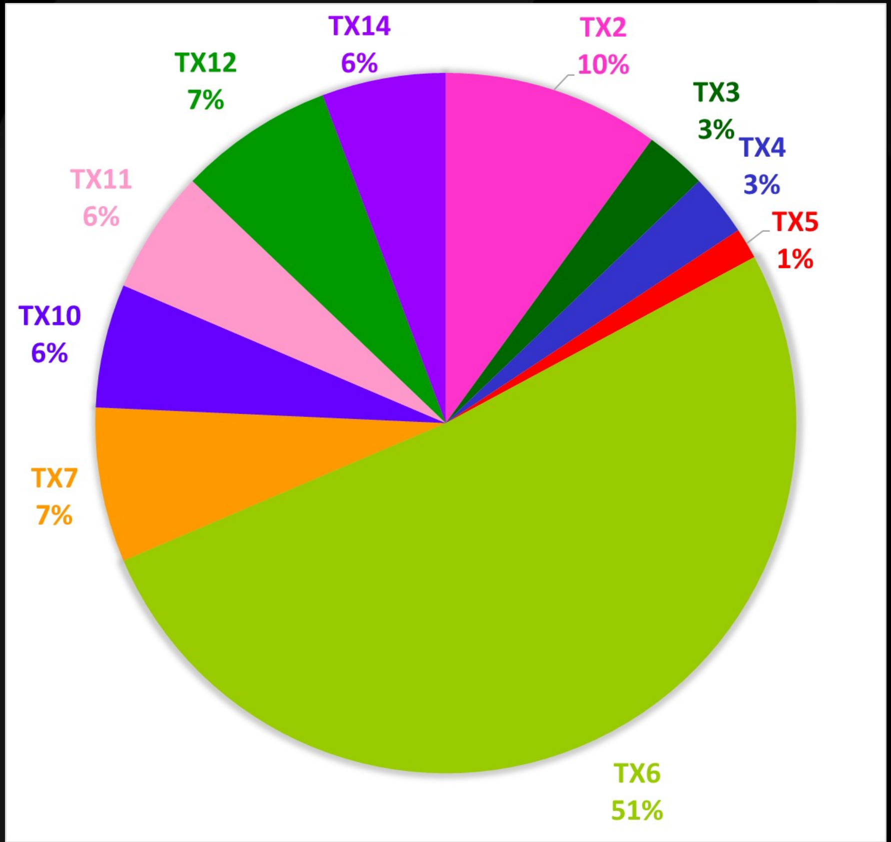
Commercial Low Earth Orbit Platforms (Early Concept)

- In early concept development through NASA’s Commercial LEO Destinations Program

Lunar Surface Habitat (Early Concept)

- Strong linkage to closure of many gaps

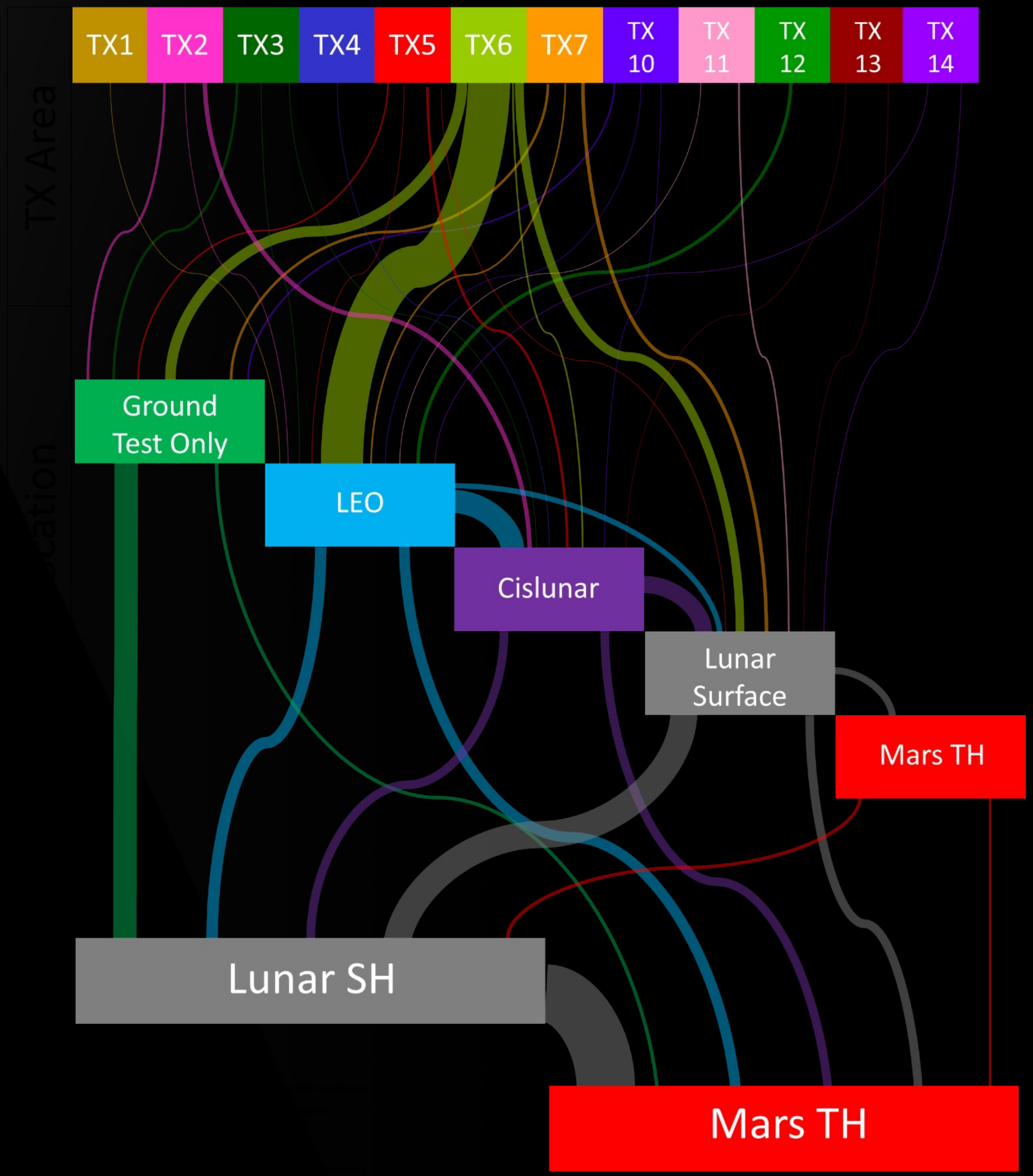
Link between Lunar Surface Habitat and Mars Transit Habitat Capability Gaps



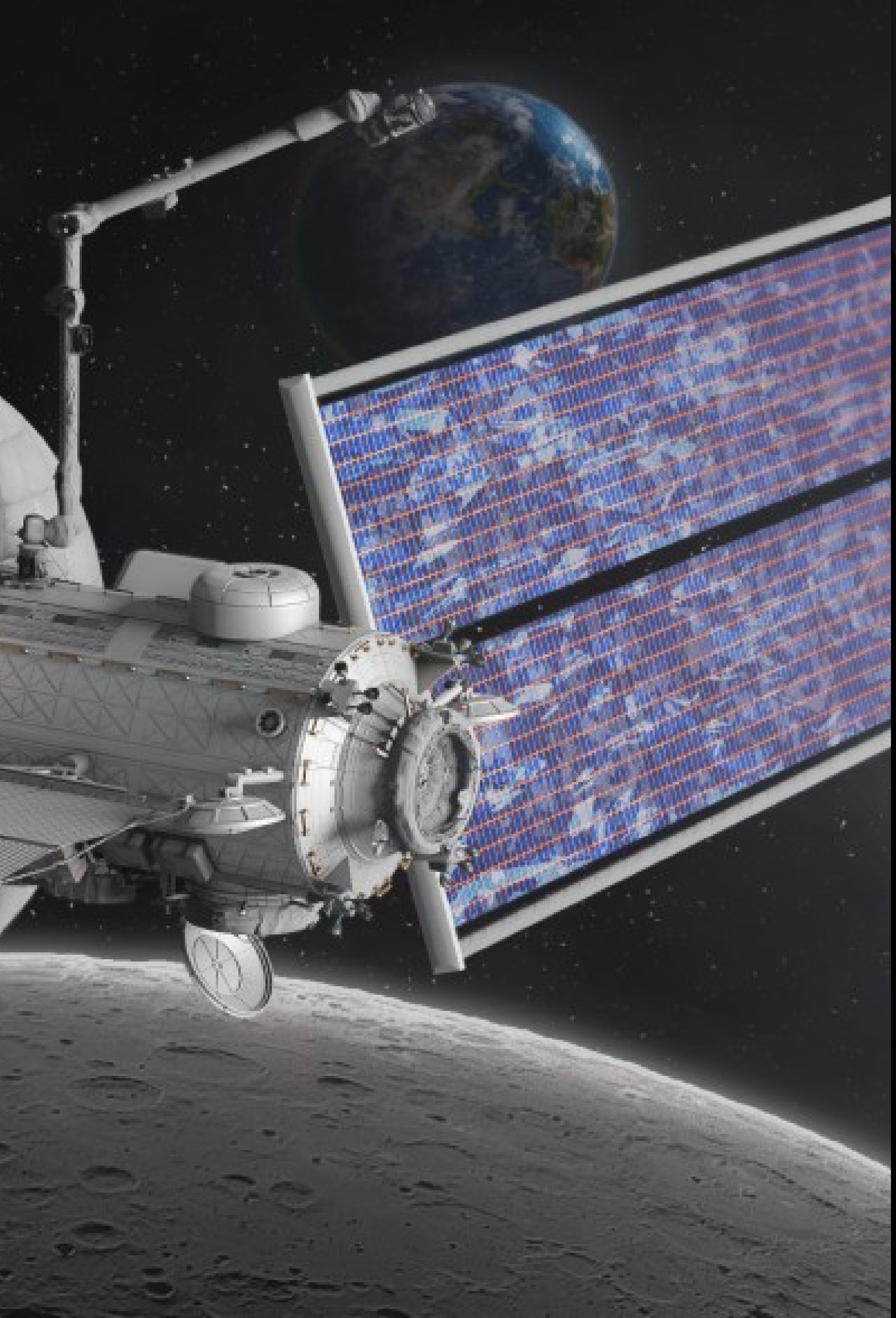
TX2- Flight computing/avionics
TX3- Power and energy storage
TX4- Robotic systems
TX5- Communications and navigation
TX6- **Human health, life support, and habitation systems**
TX7- Exploration Destination Systems
TX10- Autonomous systems
TX11- Software, modeling, and simulation
TX12- Materials/structures/mechanical systems/manufacturing
TX14- Thermal systems

Overlapping Gaps Needed to Close Between Lunar Surface Habitat and Mars Transit Habitat by Taxonomy Classification. In terms of gaps that are solely needed by both elements, approximately 61% of the gaps applicable to Mars TH have closure pathways that may be addressed earlier by closing gaps with the Lunar SH.

Sankey diagram demonstrating capability gaps by TX, testing locations, and elements enabled



The size of the flow lines correspond with how many gaps are tested, demonstrated, or validated at the various gap closure platform locations in the middle section.



Summary

- Mars Transit Habitat presents new and unprecedented challenges due to the duration of the anticipated missions it will support and the operational environment
- Technology assessment and maturation plan in development for Mars TH
  - identify critical technologies needed to close gaps, assess the maturity of these technologies, and maturation activities required for Mars TH implementation within currently envisioned timeline
- This analysis has identified high priority gaps for Mars TH, with a focus on those evaluated as having a low likelihood of closure by PDR
- Testing on ISS, potential CLD platforms, Gateway, and lunar surface habitat can “feed forward” into Mars TH technology development

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