HAT DRMs 2013

September 30, 2013
Background

NASA uses a set of Design Reference Missions (DRMs) to help focus capability development activities across the agency.

The DRMs are intended to show capability needs and represent a set of various implementations.

The “mission class” context is used to establish temporal priorities and a LIMITED set of DRMs is used to capture driving mission capabilities.

The DRMs represent a snapshot in time of current thinking, and do not represent all potential future missions.

The DRMs are generic in nature, with stated assumptions for some supporting capabilities and elements - they do not represent firm requirements.

SLS/Orion DRMs are being developed and refined as part of the development program for SLS & Orion and are not included in this package.
Capability Driven Framework

Incremental steps to steadily build, test, refine, and qualify capabilities that lead to affordable flight elements and a deep space capability.
### Human Exploration Design Reference Missions

#### Initial Exploration Missions
- ★ SLS/Orion (EM-1: Exploration Mission 1, Uncrewed Lunar Flyby Mission)
- ★ SLS/Orion (EM-2: Exploration Mission 2, Lunar Orbit Crewed Mission)
- ★ SLS/Orion (EM-X: Exploration Mission X, Crewed Mission)
- ★ Translunar missions

#### Extending Reach Beyond LEO
- ★ Crewed Visit to a Redirected Asteroid
  - ★ Crew to NEA Mission
  - ★ Crew to Lunar Surface (ISECG GER)
  - ★ Crew to Lunar Surface (Minimal)
  - ★ Mars Test on Moon
  - ★ Crewed Mars Moons Mission
    - Crewed Mars Orbital Mission
    - Crewed Mars Surface Mission (DRA 5.0)
    - Crewed Mars Surface Mission (Minimal)

#### Into The Solar System
- Gold – Mission under development
- White – Primary Design Reference Mission
- Green – Secondary Design Reference Mission
- Blue – Internationally Led Design Reference Mission

#### Exploring Other Worlds

#### Planetary Exploration

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**Notes:**

Design Reference Missions serve to define bounding cases of capabilities required to conduct missions. They are intended to serve as a framework for understanding the capabilities and technologies that may be needed, but are not specific actual missions to be conducted.

Design Reference Missions updated periodically.
## Evolution of Key Assumptions that Drive Transportation System Performance

### 2011 HEFT
- **10% Architecture Reserve**
  - on wet cargo stack (+ adapter) mass
- **2.5% launch vehicle adapter mass**
  - on wet cargo stack mass
- **1% Flight Performance Reserve on ΔVs**
- **Elements Margins**
  - Orion: data provided
  - Other elements: 30% MGA
- **Insertion orbit:** 55.56 x 240.76 km
- **Crew of 3 on Lunar & NEA missions**
- **25 meter SLS shroud barrel**

### 2012 Cycle-A
- **5% Level I Customer Reserve**
  - on wet cargo stack (+ adapter) mass
- **2.5% launch vehicle adapter mass**
  - on wet cargo stack mass
- **5% Flight Performance Reserve on ΔVs**
- **Elements Margins**
  - Orion: data provided
  - CPS BLK1: 15%
  - Other elements: 30% MGA
- **Insertion orbit:** 55.56 x 240.76 km
- **Crew of 3 on Lunar & NEA missions**
- **25 meter SLS shroud barrel**

### 2012 Cycle-B
- **5% Level I Customer Reserve**
  - on wet cargo stack (+ adapter) mass
- **2.5% launch vehicle adapter mass**
  - on wet cargo stack mass
- **5% Flight Performance Reserve on ΔVs**
  - **Except for Orion burns**
- **Elements Margins**
  - Orion: data provided
  - CPS BLK1: 18.8%
  - CPS BLK2: 21.2%
  - Lander: Margin remains on lunar surface
  - Other elements: 30% MGA
- **Insertion orbit:** -87 km X 241 km
- **Crew of 4 on Lunar & NEA missions**
- **18 meter SLS shroud barrel**

### 2012 Cycle-C+
- **5% Level I Customer Reserve**
  - on wet cargo stack (+ adapter) mass
- **2.5% launch vehicle adapter mass**
  - on wet cargo stack mass
- **5% Flight Performance Reserve on ΔVs**
  - **Except for Orion burns**
- **Elements Margins**
  - Orion: data provided
  - CPS BLK1: 18.8%
  - CPS BLK2: 21.2%
  - Lander: Margin remains on lunar surface
  - Other elements: 30% MGA
- **Insertion orbit:** 55.56 x 240.76 km
- **Crew of 3 on Lunar & NEA missions**
- **25 meter SLS shroud barrel**

### 2013 Cycle-A
- **5% Level I Customer Reserve**
  - on wet cargo stack (+ adapter) mass
- **5% launch vehicle adapter mass**
  - on wet cargo stack mass
- **1% Flight Performance Reserve on Main ΔVs**
  - **Except for Orion burns**
  - 5% on RCS ΔV’s
  - 0% on Terminal Descent/Landing
  - 0% on Mars Ascent
- **Elements Margins**
  - Orion: data provided
  - CPS BLK1: 18.8%
  - CPS BLK2: 21.2%
  - Lander: Margin remains on lunar surface
  - Other elements: 30% MGA
- **Insertion orbit:** -93 km X 370 km
- **Crew of 2~4 on Lunar & NEA missions**
- **25 meter SLS shroud barrel**
- **DRM-9: 6 crew**
  - DRM-9a: 4 crew
- **25 meter SLS shroud barrel**
## Primary Design Reference Missions

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<tr>
<th>DRM Title</th>
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<th>Mission Class</th>
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<td>Translunar</td>
<td>Extending Reach Beyond LEO</td>
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<td>EM-2: Exploration Mission 2 <em>(not currently in package)</em></td>
<td>Translunar</td>
<td>Extending Reach Beyond LEO</td>
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<td>EM-X: Exploration Mission X <em>(not currently in package)</em></td>
<td>Translunar</td>
<td>Extending Reach Beyond LEO</td>
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<td><strong>Primary DRMs</strong></td>
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<td>DRM - 8a: Crewed Mars Orbital Mission</td>
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<td>DRM - 9: Crewed Mars Surface Mission (DRA 5.0)</td>
<td>Mars Surface</td>
<td>Planetary Exploration</td>
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<tr>
<td>DRM - 9a: Crewed Mars Surface Mission (Minimal)</td>
<td>Mars Surface</td>
<td>Planetary Exploration</td>
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<td><strong>NASA Support of Internationally Led Design Reference Mission</strong></td>
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<td>DRM - 7: Crew to Lunar Surface (ISECG GER)</td>
<td>Moon</td>
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<td><strong>Secondary DRMs</strong></td>
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<td>Translunar Missions <em>(not currently in package)</em></td>
<td>Translunar</td>
<td>Extending Reach Beyond LEO</td>
</tr>
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<td>DRM - 6: 3-Launch SLS-Class Crewed NEA Mission <em>(not currently in package)</em></td>
<td>NEA</td>
<td>Exploring Other Worlds</td>
</tr>
<tr>
<td>DRM - 7a: Crew to Lunar Surface (Minimal) <em>(not currently in package)</em></td>
<td>Moon</td>
<td>Exploring Other Worlds</td>
</tr>
<tr>
<td>DRM - 7b: Mars Test on Moon <em>(not currently in package)</em></td>
<td>Moon</td>
<td>Exploring Other Worlds</td>
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</table>
Crewed Visit to a Redirected Asteroid
Crewed Visit to a Redirected Asteroid

Achievements
• Demonstration of core capabilities for deep space missions
• Demonstration of ability to work and interact with a small zero g planetary body
• Enable initial understanding of planetary defense challenges and asteroid resource utilization potential
• Establishment of a platform for possible exploration test beds, science missions, international and commercial partnership opportunities

Mission Operations
• Total mission duration of 24-30 days and 2 crew members
• Crew and Orion rendezvous with ARV in lunar DRO
• Lunar gravity assists used on both outbound and return
• Asteroid stay time ~6 days, no option to abort during this period
• Two EVAs to recover samples and limited exploration of asteroid

Assumed Element Capabilities

Cross-Cutting Capabilities (Mission Kits)
• EVA Mission Kit
• Orion Grapple Arm / Docking System
• Relative Navigation
Two crew members visit a redirected asteroid that is located at a lunar distant retrograde orbit (DRO). The crew will translate via EVA to sites of interest on the asteroid, take measurements and extract samples to be returned back to Earth.

**Mission Summary**

- Crew performs EVA
- Crew gains access to asteroid
- Samples collected

**Mission Benefits**

- Reduces risk for future human and robotic exploration missions
- Enhances space science, asteroid resource potential, and planetary defense
- Demonstrates capabilities required for future exploration missions
- Demonstrates ability to work and interact with a small planetary body
After docking, final EVA and cabin preparations
• Orion RCS thrusters are used to slew the stack to a +15° yaw
• EVA 1 Prep
  – Suit donning; perform suit pressure integrity and system checks; pre-breathe period; and cabin depressurization and opening of hatch
• EVA 1
  – Sample retrieval, contextual and detailed photographic observations, EVA tool and translation aid deployment
• Orion RCS thrusters are used to return the stack to its nominal solar inertial attitude
• Suit refurbishment
• EVA 2 Prep
  – Suit donning; perform suit pressure integrity and system checks; pre-breathe period; and cabin depressurization and opening of hatch
• EVA 2
  – Sample retrieval, contextual and detailed photographic observations
• Orion RCS thrusters are used to return the stack to its nominal solar inertial attitude
• Contingency margin, Housekeeping, Departure Prep
Crewed Visit to a Redirected Asteroid Transportation Concept of Operations

Transportation:
- Block 1 SLS
- ICPS
- Crewed Mission Duration: 24-30 d
- 2 Crew members

Destination:
- Time at Destination: ~6 d
- Samples/Cargo returned to Earth: ~10 kg
  - Type: n/a

Icons not to scale
# Crewed Visit to a Redirected Asteroid Capabilities Required Beyond State of the Art (1 of 1)

<table>
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<th>Capability Areas</th>
<th>Potential HAT TechDev Technologies</th>
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<tr>
<td>Block 1 SLS</td>
<td>Block 1 SLS to LEO</td>
<td>BEO Access</td>
<td>• Advanced, low Cost Engine Technology for HLLV</td>
</tr>
<tr>
<td>ICPS</td>
<td>Possible in-space restart, $I_p = 466$ s</td>
<td>BEO Access</td>
<td></td>
</tr>
<tr>
<td>SM</td>
<td>Long-duration propellant storage, Multiple restarts, $I_p = 316$ s (NTO/MMH), provide power generation and energy storage for Orion</td>
<td>BEO Access; In-Space Propulsion; Power</td>
<td></td>
</tr>
<tr>
<td>Orion</td>
<td>Support 2 crew for ~22-day transit to/from ARV; Rendezvous and grapple (or dock with) ARV; Provide communications between EVA suits, ARV, and Earth; Support approximately 2-3 two-crewmember EVAs; Provide Earth entry capability from lunar speeds (~11 km/s); Provide EVA mobility aids (EVA boom)</td>
<td>BEO Access; Habitation; ECLSS; EVA; Radiation; Avionics; Communication &amp; Navigation.; Thermal; Structures, Materials &amp; Mechanisms</td>
<td>• Common Avionics • High Rate, Adaptive, Internetworked Proximity Communications • Robust Ablative Heat Shield – Thermal Protection System • Space Radiation Protection and Shielding – SPE • Deep Space Suit</td>
</tr>
<tr>
<td>Robotic Spacecraft</td>
<td>Autonomously rendezvous and dock with asteroid; Provide mechanism to capture asteroid; 40 kW SEP; Provide solar arrays to produce ~50 kW; Provide communications with Earth, Orion, and EVA suits</td>
<td>In-Space Propulsion; Structures, Materials &amp; Mechanisms; Robotics; Power and Energy Storage; Avionics; Comm. &amp; Nav.</td>
<td>• AR&amp;D and Proximity Operations • Common Avionics • Deep Space Suit • High Rate, Adaptive, Internetworked Prox. Comm. • Suit Port</td>
</tr>
</tbody>
</table>

Note: Capability needs still under assessment
Crewed Mars Moons Mission
Crewed Mars Moons Mission

**Achievements**
- Crewed mission to the Martian system
- Deep-space use of advanced propulsion (NTP, NEP, and/or SEP)
- Multi-year flight of DSH
- Farthest distance that humans have traveled from Earth

**Mission Operations**
- Launch, Earth-orbit rendezvous and delivery to Martian system of pre-deployed cargo & propulsive elements
- Launch and Earth-orbit rendezvous of crewed systems & propulsive elements
- Launch of crew and rendezvous with stack and delivery to Martian System
- Total mission duration with direct entry at Earth: ~600 day (opposition-class/short-stay) to ~1000 day (conjunction-class/long-stay)

**Assumed Element Capabilities**
- TBD t Class SLS
- CPS
- Orion “Block N”
- LSS
- Long Duration DSH
- Advanced EVA Systems
- Teleoperated Robots
- Advanced Propulsion (NTP shown)
- Mars Orbital Excursion Vehicle (MOEV) (SEV + Transfer Stage)

**Cross-Cutting Capabilities**
- Advanced propulsion (NTP, NEP, and/or SEP) & trade aerocapture and In-Situ Propellant Production
- Long-duration spaceflight healthcare and countermeasures
- Autonomous vehicle systems management
- AR&D
- Low-gravity body anchoring systems, proximity ops, & target relative navigation
- Mechanisms for long-duration, deep-space missions
**Mars Orbit**

1. Capture into HMO (Day 0)
2. Leave MTV in parking orbit
3. Prepare for orbital operations
4. Utilize MOEVs to explore Phobos for 24 (TBR) days (~1,370 - 3,170 m/s $\Delta V$ required)
5. Utilize MOEVs to explore Deimos for 12 (TBR) days (~1,700 - 2,770 m/s $\Delta V$ required)
6. Prepare for Mars departure
7. Trans-Earth injection

**Mars Moon Surface (Phobos/Deimos)**

- Phobos survey
- MOEV anchoring
- Test EVA procedures & mobility
- Test payload anchoring methods
- Collect samples
- Science package deployment
- Drilling operations
- In-situ Resource Utilization

- Deimos survey
- MOEV anchoring
- Test EVA procedures & mobility
- Test payload anchoring methods
- Collect samples
- Science package deployment
- Drilling operations
- In-situ Resource Utilization

**Mission Summary**

- **Assumed Mars Orbit Strategy**
  1. Capture into 1-sol parking orbit with proper plane change to match departure asymptote
  2. Leave MTV in parking orbit
  3. Prepare for orbital operations
  4. Utilize MOEVs to explore Phobos for 24 (TBR) days (~1,370 - 3,170 m/s $\Delta V$ required)
  5. Utilize MOEVs to explore Deimos for 12 (TBR) days (~1,700 - 2,770 m/s $\Delta V$ required)
  6. Prepare for Mars departure
  7. Trans-Earth injection

- **Crew:** 4

- **Deimos:**
  - 23,459 km ~circular
  - 0.9 deg incl.; 1.26 day period

- **Phobos:**
  - 9,378 km ~circular
  - 1.1 deg incl.; 0.32 day period
Crewed Mars Moons Mission Notional Destination Operations

Short-Stay Mars Vicinity Operations

- The stack (DSH and Orion) captures into High-Mars Orbit
  - Potential docking to pre-deployed cargo
- 2 crew transfer from stack to MOEV-1 and 2 crew transfer from stack to MOEV-2
- MOEVs with transfer stages depart from stack and perform orbital maneuvers to rendezvous with Phobos
- MOEVs use robotic arms to anchor to the Phobos surface and provides astronaut platforms during EVA
- Perform Phobos exploration (6 sites)
  - Phobos survey
  - MOEV anchoring, test EVA procedures, mobility, and payload anchoring methods
  - Collect samples, science package deployment, drilling operations, and In-Situ Resource Utilization
- MOEVs with transfer stages return to stack and crew transfer back to DSH
- 2 crew transfer from stack to MOEV-1 and 2 crew transfer from stack to MOEV-2
- MOEVs with transfer stages depart from stack and perform orbital maneuvers to rendezvous with Deimos
- MOEVs use robotic arms to anchor to the Phobos surface and provides astronaut platforms during EVA
- Perform Deimos exploration (3 sites)
  - Deimos survey
  - MOEV anchoring, test EVA procedures, mobility, and payload anchoring methods
  - Collect samples, science package deployment, drilling operations, and In-Situ Resource Utilization
- MOEVs with transfer stages return to stack and crew transfer back to DSH
- MOEVs and transfer stages are jettisoned with the potential to perform uncrewed exploration and science activities
- The stack (DSH and Orion) departs Mars orbit with crew for return to Earth
Crewed Mars Moons Mission Notional Destination Operations

Long-Stay Mars Vicinity Operations

**Mission Sequence**

1. Capture into 1-sol parking orbit with proper plane change to Deimos inclination
2. Lower Mars Transfer Vehicle to Deimos orbit
3. Prepare for orbital operations
4. Utilize MOEV(s) to explore Deimos numerous times
5. Lower Mars Transfer Vehicle to Phobos orbit
6. Utilize MOEV(s) to explore Phobos numerous times
7. Raise to parking orbit (planar)
8. Trans-Earth Injection including plane change

**Mission Summary**

- **Assumed Mars Orbit Strategy**
  1. Capture into 1-sol parking orbit with proper plane change to Deimos inclination
  2. Lower Mars Transfer Vehicle to Deimos orbit
  3. Prepare for orbital operations
  4. Utilize MOEV(s) to explore Deimos numerous times
  5. Lower Mars Transfer Vehicle to Phobos orbit
  6. Utilize MOEV(s) to explore Phobos numerous times
  7. Raise to parking orbit (planar)
  8. Trans-Earth Injection including plane change

- **Mission Site: Phobos / Deimos**
  - **Phobos**
    - 5981 km circular
    - 1 deg, 0.32 day period
  - **Deimos**
    - 20,063 km circular
    - 0.9 deg, 1.26 day period

- **Crew**
  - 4

- **Jettison (Potential for MOEV to continue uncrewed operations)**
Crewed Mars Moons Mission Notional Destination Operations

Long-Stay Mars Vicinity Operations

- The stack (DSH and Orion) captures into High-Mars Orbit
  - Potential docking to pre-deployed cargo
- Stack performs orbital maneuvers to rendezvous with Deimos
- 2 crew transfer from stack to MOEV-1
- MOEV-1 uses robotic arms to anchor to the Deimos surface and provides astronaut platforms during EVA
- Perform Deimos exploration (TBD sites)
  - Deimos survey
  - MOEV anchoring, test EVA procedures, mobility, and payload anchoring methods
  - Collect samples, science package deployment, drilling operations, and In-Situ Resource Utilization
- MOEV-1 returns to stack and crew transfer back to DSH
- MOEV-based exploration of Deimos is repeated with alternating MOEVs and 2-person crews for TBD period of time
- Stack performs orbital maneuvers to rendezvous with Phobos
- 2 crew transfer from stack to MOEV-1
- MOEV-1 uses robotic arms to anchor to the Phobos surface and provides astronaut platforms during EVA
- Perform Phobos exploration (TBD sites)
  - Phobos survey
  - MOEV anchoring, test EVA procedures, mobility, and payload anchoring methods
  - Collect samples, science package deployment, drilling operations, and In-Situ Resource Utilization
- MOEV-1 returns to stack and crew transfer back to DSH
- MOEV-based exploration of Phobos is repeated with alternating MOEVs and 2-person crews for TBD period of time
- MOEVs are jettisoned with the potential to perform uncrewed exploration and science activities
- The stack (DSH and Orion) departs Mars orbit with crew for return to Earth
Crewed Mars Moons Mission Architecture – Short-Stay
High-Thrust Missions

Mars Orbit
High Mars Orbit
(500 x 33,563 km)

Mars Orbit Insertion
Trans-Mars Injection
Mars Orbit Insertion
~60 Days in Mars System
Plane change
Trans-Earth Injection
Deep Space Maneuver and/or Venus Swing-by
Deep Space Maneuver and/or Venus Swing-by
Earth Slow-Down Maneuver (as required)

LEO
(ref. 400 km circ)
TBD SLS Launches
(TBD days between launches)

TBD SLS Launches
1 SLS Block 1+ Crew Launch
(TBD days between launches)

Orion with crew
Drop Tank
Prop. System
Cargo
Jettison Prop. System
Jettison Drop Tank

Pre-Deploy Cargo
Crew to Mars

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<tr>
<td>SLS</td>
<td>105 t - 130 t to LEO, TBD launches/year</td>
<td>BEO Access</td>
<td>• Advanced, low Cost Engine Technology for Heavy Lift Launch Vehicle</td>
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<tr>
<td></td>
<td>Parametric design with each stage optimized; Zero-boil off cryo management; Stage fraction ~ 23%; Specific impulse = 465 s (LOX/LH2)</td>
<td>BEO Access; In-Space Propulsion; Thermal</td>
<td>• High Rate, Adaptive, Internetworked Proximity Communications • High Strength/Stiffness Deployable 10-100kW Arrays • In Space Cryogenic Liquid Acquisition • In-Space Cryogenic Propulsion Storage (ZBO LO2, Reduced LH2)</td>
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<tr>
<td>CPS (trade)</td>
<td>Long-duration propellant storage; Multiple restarts; Isp = 315 s (NTO/MMH); AR&amp;D with lunar orbit facility; provide power generation and energy storage for Orion</td>
<td>BEO Access; In-Space Propulsion; Robotics; Comm. &amp; Nav.; Power and Energy Storage; Avionics</td>
<td>• Common Avionics • High Rate, Adaptive, Internetworked Proximity Communications • Robust Ablative Heat Shield – Beyond Lunar • Space Radiation Protection and Shielding – SPE</td>
</tr>
<tr>
<td>SM</td>
<td>Support 4 crew for ~21 days (during ascent and reentry); 600-1000 days dormant; Operating pressure: 10.2 to 14.7 psia; AR&amp;D; Re-enter at Earth from Mars velocity</td>
<td>Habitation; ECLSS; EVA; Crew Health &amp; Protection; Avionics; Comm. &amp; Nav.; EDL; Radiation</td>
<td>• Autonomous Vehicle Systems Management • Closed-Loop, High Reliability, Life Support Systems • Common Avionics • Crew Autonomy Beyond LEO • Deep Space Mission Human Factors and Habitability • Deep Space Suit • Fire Prevention, Detection, &amp; Suppression • High Data Rate Forward Link (Flight) Communications • High Rate, Adaptive, Internetworked Proximity Comm • High Reliability Life Support Systems • In-Flight Environmental Monitoring • Long Duration Spaceflight Behavioral Health • Long Duration Spaceflight Medical Care • Mechanisms for Long Duration, Deep Space Missions • Microgravity Biomedical Counter-Measures • Microgravity Biomedical – Optimized Exercise • Mission Control Automation Beyond LEO • Quad function Hybrid RF/Optical Communication, Optical Ranging, RF Imaging System • Space Radiation Protection – GCR • Space Radiation Protection and Shielding – SPE • Suit Port • Thermal Control</td>
</tr>
<tr>
<td>Orion</td>
<td>Mass Range : 28-65 t; Support and protect crew of 4 for 600 days (short stay) or ~1000 days (long stay); Consumables loaded based on crew size &amp; mission duration; Provide communications between mission elements and to Earth</td>
<td>Habitation; ECLSS; Crew Health &amp; Protection; Destination Systems; Avionics; Logistics; Radiation; Comm. &amp; Nav.</td>
<td>• Advanced, low Cost Engine Technology for Heavy Lift Launch Vehicle</td>
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Note: Capability needs still under assessment
## Crewed Mars Moons Mission Potential Capabilities (2 of 2)

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<th>Capability Areas</th>
<th>Potential HAT TechDev Technologies</th>
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</table>
| **SEV**          | Crew of 2 for 14 days; Nominal mass = 6.7 t; LOX/CH4 Stage when needed: Stage Fraction: 15%, isp: 355 s; Enable EVA; Provide communications; Provide power; Perform science collection activities at Phobos and/or Deimos                                                                 | Habitation; ECLSS; EVA; Crew Health & Protection; Destination Systems; Robotics; Avionics; Logistics; In-Space Propulsion; Autonomous Mission Operations; Comm. & Nav.; Power and Energy Storage | • AR&D and Proximity Operations  
• Deep Space Suit  
• High Data Rate Forward Link (Flight) Communications  
• High Rate, Adaptive, Internetworked Proximity Communications  
• In-Space Timing and Nav for Autonomy  
• Mechanisms for Long Duration, Deep Space Missions  
• Quad Function Comm., Optical Ranging, RF Imaging  
• Space Radiation Protection – GCR  
• Space Radiation Protection – SPE  
• Space Radiation Shielding – SPE  
• Suit Port                                                                                                                                 |
| **EVA**          | Advanced EVA suits and mobility for exploration                                                                                                                                                                                   | EVA                                                                              | • Deep Space Suit  
• Suit Port                                                                                                                                                         |
| **LSS / Potential Transfer Stage (trade)** | TBD t storable propellant load; Long-duration propellant storage and transfer to support transfers to and from Phobos and Deimos for short-stay mission; isp = 315 s (NTO/MMH) or 353 s (LOX/CH4); AR&D | In-Space Propulsion; Robotics                                                    | Technologies for LOX/CH4 Only:  
• In-Space Cryogenic Liquid Acquisition  
• In-Space Cryogenic Propulsion Storage (ZBO LO2, Reduced LH2)  
• Unsettled Cryogenic Propellant Transfer                                                                                                                                 |
| **SEP (trade)**  | Spacecraft alpha ~30 kg/kw, Specific impulse = 1800-6000 s Xe tank fraction = 5%, Total power varies                                                                                                                                 | In-Space Propulsion                                                              | • Autonomously Deployable 300 kW In-Space Arrays  
• Electric Propulsion & Power Processing                                                                                                                                 |
| **NEP (trade)**  | Spacecraft alpha ~20 kg/kw, Specific impulse = 1800-6000 s Xe tank fraction = 5%, Total power varies                                                                                                                                 | In-Space Propulsion                                                              | • 300 kWe Fission Power for Electric Propulsion  
• Multi-MWe Nuclear Power for Electric Propulsion                                                                                                                                 |
| **NTP (trade)**  | NERVA-derived common core propulsion (20 t core); 3 x 111 kN engines; Specific Impulse = 900 s; All LH2 fuel with zero boil-off; Drop tanks @ 27% tank fraction                                                                                                                                   | In-Space Propulsion; Thermal; Structures, Materials, & Mechanisms                | • Nuclear Thermal Propulsion (NTP) Engine                                                                                                                                 |
| **Robotics**     | Uncrewed operations, used for collection of samples at destination                                                                                                                                                                | Robotics                                                                         | • Robots Working side-by-side with Suited Crew                                                                                                                                 |
| **Robotics Precursor** | Independent scientific mission for mapping of Phobos and Deimos, system and technology testing, resource characterization                                                                                                          | Robotics                                                                         |                                                                                                                                                                     |
Crewed Mars Orbital Mission
Crewed Mars Orbit Mission

**Achievements**
- Crewed mission to the Martian system
- Multi-year flight of DSH
- Farthest distance that humans have traveled from Earth

**Mission Operations**
- Launch, Earth-orbit rendezvous and delivery to Martian system of pre-deployed cargo & propulsive elements
- Launch and Earth-orbit rendezvous of crewed systems & propulsive elements
- Launch of crew and rendezvous with stack and delivery to Martian System
- Teleoperation of robotic surface assets
- Total mission duration with direct entry at Earth: ~600 day (opposition-class/short-stay) to ~1000 day (conjunction-class/long-stay)

**Assumed Element Capabilities**
- TBD t
  - Class SLS
  - Orion “Block N”
  - Teleoperated Robots
  - Propulsion (O$_2$/CH$_4$ shown)
  - DSH

**Cross-Cutting Capabilities**
- Trade advanced propulsion & aerocapture
- Long-duration spaceflight healthcare and countermeasures
- Autonomous vehicle systems management
- AR&D
- ISRU surface demo
- Mechanisms for long-duration, deep-space missions
Crewed Mars Orbit Mission Notional Destination Operations

Mission Summary
- Crew orbits Mars for ~2-18 months, depending on mission class.
- Crew tele-operates surface assets while in orbit.

Mission Site: Mars Orbit
- One or more pre-emplaced tele-operated robots on Martian surface or its Moons, operating at one or more different sites
- Option for real time sample return
- In addition to science, surface robots could facilitate reconnaissance necessary for future human landing

Mission Sequence
- Cargo arrives at Mars Orbit
- Crew orbits Mars for ~2-18 months, depending on mission class.
- Crew tele-operates surface assets while in orbit.
- One or more pre-emplaced tele-operated robots on Martian surface or its Moons, operating at one or more different sites
- Option for real time sample return
- In addition to science, surface robots could facilitate reconnaissance necessary for future human landing
- 180 days back to Earth
• Crewed mission performs propulsive maneuvers for Mars orbit capture
• Stack performs orbital maneuvers to rendezvous with pre-deployed assets
• Perform Mars exploration via in-system telerobotics
  – Mars survey
  – Sample collection and analysis, science package deployment
  – Conduct technology, operations, and infrastructure demonstrations
• The stack (DSH and Orion) departs Mars orbit with crew for return to Earth
• The surface assets will continue to perform uncrewed exploration and science activities
Crewed Mars Orbit Mission Architecture
Notional Long-Stay Mars Orbit Operations

Mars
Orbit

Pre-Deploy Cargo
Cargo
Robotic systems pre-deployed to surface

TBD SLS Launches (TBD days between launches)

Trans-Mars Injection

Mars Orbit Insertion

Ref. Assembly
Orbit

Pre-Deploy Cargo
Pre-Deploy Cargo

SLS-Cargo
SLS-Cargo

SLS-Cargo
SLS-Cargo

Jettison Drop Tank
Jettison Drop Tank

Deep Space Maneuver and/or Venus Swing-by

Deep Space Maneuver and/or Venus Swing-by

Deep Space Maneuver and/or Venus Swing-by

Earth Slow-Down Maneuver (as required)

Direct Earth Entry

Orion with crew

TBD SLS Launches
1 SLS Block 1+ Crew Launch (TBD days between launches)

TBD SLS Launches (TBD days between launches)

Icons not to scale
## Crewed Mars Orbit Mission Potential Capabilities (1 of 2)

<table>
<thead>
<tr>
<th>Element</th>
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<th>Capability Areas</th>
<th>Potential HAT TechDev Technologies</th>
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<tbody>
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<td>SLS</td>
<td>105 t - 130 t to LEO, TBD launches/year</td>
<td>BEO Access</td>
<td>• Advanced, low Cost Engine Technology for HLLV</td>
</tr>
<tr>
<td></td>
<td>Parametric design with each stage optimized, Zero-boil off cryo management, Stage fraction ~ 23%, Specific impulse = 465 s</td>
<td>In-Space Propulsion</td>
<td>• High Rate, Adaptive, Internetworked Proximity Communications</td>
</tr>
<tr>
<td></td>
<td>BEO Access; In-Space Propulsion; Robotics; Comm. &amp; Nav.; Power and Energy Storage; Avionics</td>
<td></td>
<td></td>
</tr>
<tr>
<td>CPS (trade)</td>
<td>Long-duration propellant storage; Multiple restarts; Isp = 315 s (NTO/MMH); AR&amp;D with lunar orbit facility; provide power generation and energy storage for Orion</td>
<td>BEO Access; In-Space Propulsion; Robotics; Comm. &amp; Nav.; Power and Energy Storage; Avionics</td>
<td>• Robust Ablative Heat Shield – Beyond Lunar</td>
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<td></td>
<td>Orion</td>
<td>Habitation; ECLSS; EVA; Crew Health &amp; Protection; Avionics; Comm. &amp; Nav.; EDL; Radiation</td>
<td>• Space Radiation Protection and Shielding – SPE</td>
</tr>
<tr>
<td></td>
<td>Support 4 crew for ~21 days (during ascent and reentry); 600-1000 days dormant; Operating pressure: 10.2 to 14.7 psia; AR&amp;D; Re-enter at Earth from Mars velocity</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>DSH</td>
<td>Mass Range : 28-65 t; Support and protect crew of 4 for 600 days (short stay) or ~1000 days (long stay); Consumables loaded based on crew size &amp; mission duration; Provide communications between mission elements and to Earth</td>
<td>Habitation; ECLSS; Crew Health &amp; Protection; Destination Systems; Avionics; Logistics; Radiation; Comm. &amp; Nav.</td>
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<td>• Closed-Loop, High Reliability, Life Support Systems</td>
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<td>• Long Duration Spaceflight Behavioral Health</td>
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<td>• Microgravity Biomedical Counter-Measures</td>
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<td>• Microgravity Biomedical – Optimized Exercise</td>
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<td>• Suit Port</td>
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<td></td>
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<td></td>
<td>• Thermal Control</td>
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**Note:** Capability needs still under assessment
## Crewed Mars Orbit Mission Potential Capabilities (1 of 2)

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<th>Capability Areas</th>
<th>Capability Needs</th>
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<tbody>
<tr>
<td>SEP (trade)</td>
<td>Spacecraft alpha ~30 kg/kw, Specific impulse = 1800-6000 s&lt;br&gt;Xe tank fraction = 5%, Total power varies</td>
<td>In-Space Propulsion</td>
<td>• Autonomously Deployable 300 kW In-Space Arrays&lt;br&gt;• Electric Propulsion &amp; Power Processing</td>
</tr>
<tr>
<td>NEP (trade)</td>
<td>Spacecraft alpha ~20 kg/kw, Specific impulse = 1800-6000 s&lt;br&gt;Xe tank fraction = 5%, Total power varies</td>
<td>In-Space Propulsion</td>
<td>• Multi-MWe Nuclear Power for Electric Propulsion</td>
</tr>
<tr>
<td>NTP (trade)</td>
<td>NERVA-derived common core propulsion (20 t core); 3 x 111 kN engines; Specific Impulse = 900 s; All LH2 fuel with zero boil-off; Drop tanks @ 27% tank fraction</td>
<td>In-Space Propulsion; Thermal; Structures, Materials, &amp; Mechanisms</td>
<td>• Nuclear Thermal Propulsion (NTP) Engine</td>
</tr>
<tr>
<td>Robotics</td>
<td>Used for surface/Mars moons exploration while crew is in orbit</td>
<td>Robotics</td>
<td>• Robots Working side-by-side with Suited Crew</td>
</tr>
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</table>

**Note:** Capability needs still under assessment
Crewed Mars Surface Mission (DRA 5.0)

NASA-SP-2009-566
NASA-SP-2009-566-ADD
Crewed Mars Surface Mission
DRA 5.0 Derived

**Achievements**
- First human landing on Mars
- Farthest distance that humans have traveled from Earth
- Extensive exploration of the surface of Mars
- First use of large scale EDL

**Mission Operations**
- Launch, Earth-orbit rendezvous and delivery to Martian system of pre-deployed cargo & propulsive elements
- Launch and Earth-orbit rendezvous of crewed systems & propulsive elements
- Total mission duration with direct entry at Earth ~1000 day
- Cargo elements are captured in Mars orbit using aerocapture.
- Selected surface assets pre-deployed at the landing site using advanced entry-descent-landing (EDL) technology
- Crewed vehicle utilizes propulsive capture at Mars
- 6-crew, ~540-day surface stay
- Crew lives in DSH for in-space operations, habitat lander for surface stay

**Assumed Element Capabilities**

**Cross-Cutting Capabilities**
- Advanced propulsion & trade crew mission aerocapture
- Long-duration spaceflight healthcare and countermeasures
- Autonomous vehicle systems management
- AR&D
- ISRU
- Mechanisms for long-duration, deep-space missions
Crewed Mars Surface Mission Notional Destination Operations
DRA 5.0 Derived

Mission Summary

- Long surface stays with visits to multiple sites provides scientific diversity
- Each mission to a different exploration site to maximize scientific return
- Mobility at great distances (100s kilometers) from the landing site enhances science return (diversity)
- Subsurface access of 100s meters or more highly desired
- Advanced laboratory and sample assessment capabilities necessary for high-grading samples for return

Expedition Activities
- Exploration
- Science
- Sample Collection

Mission Site: Mars Surface

- MAV lander to surface
- Crew arrival
- Habitat lander & crew to surface
- ~26 months
- In-situ propellant production for MAV lander
- Up to 18 months
- 180 days back to Earth
- Crew ascent
Cargo Pre-deploy

- Cargo uses aerocapture for Mars orbit insertion.
- MAV lander and surface assets depart from stack and perform descent maneuvers for pre-deploy to Mars surface.
- Habitat lander remains in Mars orbit for crew.
- After landing, all systems will undergo a systems check.
- An Offloading Device will assist in offloading necessary surface assets.
- Surface power system deployed.
- Ascent oxygen produced from atmosphere and stored directly in MAV.
- Surface assets will perform verification of precursor data, final scouting of landing and explorations sites, and follow up scientific measurements if needed.

Crewed Mission

- Crewed mission performs propulsive orbit capture.
- Orion docks to habitat lander and crew transfer to habitat.
- Habitat lander departs from stack and performs descent maneuvers to Mars surface.
- Habitat provides adequate time/function for crew adaptation to Martian gravity environment.
- Crew performs up to ~500 day mission living in surface assets.
- During mission, the crew will perform multiple excursions from the landing site to meet science and exploration objectives.
- After completion of the mission, the crew will transfer from the surface assets to the lander.
- Prior to ascent, mobile surface assets will park behind the horizon or surface feature to avoid ejecta.
- After crewed launch, the surface assets will continue to perform uncrewed exploration and science activities.
Crewed Mars Surface Mission Architecture
DRA 5.0 Derived

Icons not to scale
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<td>BEO Access</td>
<td>• Advanced, low Cost Engine Technology for HLLV</td>
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<tr>
<td>CPS (trade)</td>
<td>Parametric design with each stage optimized, Zero-boiloff cryo management, Stage fraction ~ 23%, Specific impulse = 465 s</td>
<td>In-Space Propulsion; Thermal</td>
<td>• High Rate, Adaptive, Internetworked Proximity Communications • High Strength/Stiffness Deployable 10-100kW Arrays • In Space Cryogenic Liquid Acquisition • In-Space Cryo Prop Storage (ZBO LO2, Reduced LH2)</td>
</tr>
<tr>
<td>SM</td>
<td>Long-duration propellant storage; Multiple restarts; Isp = 315 s (NTO/MMH); AR&amp;D with lunar orbit facility; provide power generation and energy storage for Orion</td>
<td>BEO Access; In-Space Propulsion; Robotics; Comm. &amp; Nav.; Power and Energy Storage; Avionics</td>
<td></td>
</tr>
<tr>
<td>DSH</td>
<td>Mass Range : 28-65 t; Support and protect crew of 6 for ~360 days (outbound and return); Consumables loaded based on crew size &amp; mission duration; Provide communications between mission elements and to Earth</td>
<td>Habitation; ECLSS; Crew Health &amp; Protection; Destination Systems; Avionics; Logistics; Radiation; Comm. &amp; Nav.</td>
<td>• Autonomous Vehicle Systems Management • Closed-Loop, High Reliability, Life Support Systems • Common Avionics • Crew Autonomy Beyond LEO • Deep Space Mission Human Factors and Habitation • Deep Space Suit • Fire Prevention, Detection, &amp; Suppression • High Data Rate Forward Link (Flight) Communications • High Rate, Adaptive, Internetworked Proximity Communications • High Reliability Life Support Systems • In-Flight Environmental Monitoring • Long Duration Spaceflight Behavioral Health • Long Duration Spaceflight Medical Care • Mechanisms for Long Duration, Deep Space Missions • Microgravity Biomedical Counter-Measures • Microgravity Biomedical – Optimized Exercise • Mission Control Automation Beyond LEO • Quad function Hybrid RF/Optical Comm, Optical Ranging, RF Imaging System • Space Radiation Protection – GCR • Space Radiation Protection and Shielding – SPE • Suit Port • Thermal Control</td>
</tr>
<tr>
<td>Orion</td>
<td>Support 6 crew for TBD days (during ascent and reentry); 500 days dormant; Operating pressure: 10.2 to 14.7 psia; AR&amp;D; Re-enter at Earth from Mars velocity</td>
<td>Habitation; ECLSS; EVA; Crew Health &amp; Protection; Avionics; Comm. &amp; Nav.; EDL; Radiation</td>
<td>• Common Avionics • High Rate, Adaptive, Internetworked Proximity Communications • Robust Ablative Heat Shield (beyond Lunar return conditions) • Thermal Protection Systems • Space Radiation Protection and Shielding – SPE • Mission Control Automation Beyond LEO • Entry, Descent and Landing (EDL) Technologies – Earth Return</td>
</tr>
</tbody>
</table>

Note: Capability needs still under assessment
## Crewed Mars Surface Mission Potential Capabilities (2 of 3)

### DRA 5.0 Derived

<table>
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<th>High-level Capability Assumptions</th>
<th>Capability Areas</th>
<th>Potential HAT TechDev Technologies</th>
</tr>
</thead>
<tbody>
<tr>
<td>Mars Descent Module</td>
<td>Perform terminal Mars descent, Precision landing, cargo and crewed versions, Propellant storage and transfer</td>
<td>In-Space Propulsion; Destination Systems; Robotics; Avionics</td>
<td>• Common Avionics&lt;br&gt; • High Rate, Adaptive, Internetworked Proximity Communications&lt;br&gt; • In Space Cryogenic Liquid Acquisition&lt;br&gt; • LOX/Liquid Methane Cryogenic Propulsion System&lt;br&gt; • LOX/Liquid Methane Reaction Control Engines&lt;br&gt; • Precision Landing &amp; Hazard Avoidance&lt;br&gt; • Unsettled Cryogenic Propellant Transfer</td>
</tr>
<tr>
<td>Mars Ascent Vehicle</td>
<td>Habitation (6 crew, &lt; 2 days), egress/ingress, Perform Mars ascent, R&amp;D with return stack, Propellant storage and transfer</td>
<td>In-Space Propulsion; Habitation; ECLSS; EVA; Robotics; Avionics; Logistics; Destination Systems</td>
<td>• Common Avionics&lt;br&gt; • Dust Mitigation&lt;br&gt; • Fire Prevention, Detection, &amp; Suppression&lt;br&gt; • High Rate, Adaptive, Internetworked Prox. Comm.&lt;br&gt; • In Space Cryogenic Liquid Acquisition&lt;br&gt; • LOX/Liquid Methane Cryo Prop System&lt;br&gt; • LOX/Liquid Methane Reaction Control Engines&lt;br&gt; • Unsettled Cryogenic Propellant Transfer&lt;br&gt; • Deep Space Mission Human Factors and Habitability</td>
</tr>
<tr>
<td>EVA</td>
<td>Advanced EVA suits and mobility for exploration</td>
<td>EVA; Robotics</td>
<td>• Mars Space Suit (Block 3)&lt;br&gt; • Suit Port</td>
</tr>
<tr>
<td>NEP (trade)</td>
<td>Spacecraft alpha ~20 kg/kw; Specific impulse = 1800-6000 s; Xe tank fraction = 5%; Total power varies</td>
<td>In-Space Propulsion; Power and Energy Storage</td>
<td>• 300 kWe Fission Power for Electric Propulsion&lt;br&gt; • Multi-MWe Nuclear Power for Electric Propulsion</td>
</tr>
<tr>
<td>NTP (trade)</td>
<td>NERVA-derived common core propulsion (20 t core); 3 x 111 kN engines; Specific Impulse = 900 s; All LH2 fuel with zero boil-off; Drop tanks @ 27% tank fraction</td>
<td>In-Space Propulsion; Power and Energy Storage; Thermal</td>
<td>• Nuclear Thermal Propulsion (NTP) Engine</td>
</tr>
<tr>
<td>Robotics</td>
<td>Uncrewed operations, used for collection of samples at destination&lt;br&gt; Crewed operations, used for collection of samples at destination</td>
<td>Robotics; Autonomous Mission Operations</td>
<td>• Robots Working side-by-side with Suited Crew</td>
</tr>
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**Note:** Capability needs still under assessment
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</thead>
</table>
| Surface Systems  | Support 6 crew for ~500 days on surface; Operating pressure: 8 to 10.2 psia; Surface EVA capability; Crewed and uncrewed operations; Provide surface power; SPE protection and dust mitigation; Surface mobility; Provide communications | Habitation; ECLSS; EVA; Crew Health & Protection; Destination Systems; Robotics; Comm. & Nav.; Logistics; Robotics; Autonomous Mission Operations; Power and Energy Storage | - Autonomous Vehicle Systems Management  
- Deep Space Mission Human Factors & Habitability  
- Dust Mitigation  
- Fire Prevention, Detection, & Suppression  
- High Rate, Adaptive, Internetworked Proximity Communications  
- High Reliability Life Support Systems  
- In-Flight Environmental Monitoring  
- Lightweight and Efficient Structures and Materials  
- Long Life Batteries  
- Low Temperature Mechanisms  
- Robots Working side-by-side with Suited Crew  
- Space Radiation Protection and Shielding – SPE  
- Suit Port  
- Surface Mobility  
- Thermal Control  
- Fission Power for Surface Missions  
- Regenerative Fuel Cells  
- High Specific Energy Batteries  
- Quad Function Hybrid RF/Optic Comm, Optical Ranging, RF Imaging Systems  
- Mars Surface Space Suit (Block 3)  
- Mars ISRU: Oxygen from Atmosphere & Water Extraction from Soil  
- Deep Space Mission Human Factors & Habitability  
- Mechanisms for Long Duration, Deep Space Missions  
- Inflatable: Structures and Materials for Inflatable Modules  |
| Aeroassist System| Mars decelerator approaches; operational under low-g(0.1g) propulsion accelerations; for transition from supersonic flight to powered descent at Mars, and for earth re-entry vehicle | EDL; Structures, Materials, and Mechanisms; In-Space Propulsion; Thermal          | - Entry, Descent and Landing (EDL) Technologies – Mars Exploration Class Missions                                                                                     |
Crewed Mars Surface Mission (Minimal)
Crewed Mars Surface Mission

Minimal Mars Surface Mission

**Achievements**
- First human landing on Mars
- Farthest distance that humans have traveled from Earth
- Minimal human exploration of the surface of Mars (days)
- First use of large scale EDL

**Mission Operations**
- Launch and Earth-orbit rendezvous of crewed systems & propulsive elements
- Total mission duration with direct entry at Earth ~1000 day
- Cargo elements are captured in Mars orbit using aerocapture
- Crewed vehicle utilizes propulsive capture at Mars
- 3-crew to Mars orbit, 2-crew for 7-day surface stay
- Crew lives in DSH for in-space operations, lander for surface stay

**Assumed Element Capabilities**

![Diagram with icons representing various mission elements]

**Cross-Cutting Capabilities**
- Trade advanced propulsion & crew mission aerocapture
- Long-duration spaceflight healthcare and countermeasures
- Autonomous vehicle systems management
- AR&D
- ISRU demonstration on surface
- Mechanisms for long-duration, deep-space missions
Crewed Mars Surface Mission Notional Destination Operations

Minimal Mars Surface Mission

Mission Summary

- Short surface stay provides scientific diversity
- Sustainability objectives favor return missions to a single site (objectives lend themselves best to repeated visits to a specific site on Mars)
- Collect 100 kg of samples for return

Mission Site: Mars Surface

- Similar in scope to Apollo Lunar exploration capability
  - Exploration radius limited by mobility options
  - EVA a function of astronaut ability to adapt rapidly to partial g environment

Expedition Activities

- Exploration
- Science
- Sample Collection
• Crewed mission performs propulsive maneuvers for Mars orbit
• Mars lander departs from stack and performs descent maneuvers to Mars surface
• After landing, all systems will undergo a systems check
• An offloading device will assist in offloading necessary surface assets
• Crew performs up to 7 day mission living in surface assets
• During mission, the crew will perform multiple excursions from the landing site to meet science and exploration objectives
• After completion of the mission, the crew will transfer from the surface assets to the lander
• Prior to ascent, mobile surface assets will park behind the horizon or surface feature to avoid ejecta
• After crewed launch, the surface assets will continue to perform uncrewed exploration and science activities
Crewed Mars Surface Mission Architecture

Minimal Mars Surface Mission

- **High Mars Orbit** (250 x 33,813 km)
- **High Earth Orbit** (~14,000 x 400 km)
- **Trans-Mars Injection** (~27,000 x 400 km)
- **Aerocapture Mars Orbit**
- **Propulsive Mars Orbit Insertion**
- **Trans-Earth Injection**
- **Earth Slow-Down Maneuver** (as required)
- **Direct Earth Entry** @ 11.5 km/s

**3 SLS-130 Launches** (TBD days between launches)
1. Lander
2. Stage (TMI)
3. Stage (TMI)

**5 SLS-130 Launches** (TBD days between launches)
1. DSH
2. Stage (TEI)
3. Stage (MOI)
4. Stage (TMI)
5. Stage (TMI)

**Icon Not to Scale**

Pre-Deploy Cargo
Crew to Mars
SLS-Cargo
SLS-Crew
# Crewed Mars Surface Mission Potential Capabilities (1 of 2)
## Minimal Mars Surface Mission

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| CPS     | Parametric design with each stage optimized; Zero-boil off cryo management; Stage fraction ~ 23%; Specific impulse = 465 s | BEO Access; In-Space Propulsion; Thermal | • High Rate, Adaptive, Internetworked Proximity Communications  
• High Strength/Stiffness Deployable 10-100kW Arrays  
• In Space Cryogenic Liquid Acquisition |
| SM      | Long-duration propellant storage; Multiple restarts; Isp = 315 s (NTO/MMH); AR&D with lunar orbit facility; provide power generation and energy storage for Orion | BEO Access; In-Space Propulsion; Robotics; Comm. & Nav.; Power and Energy Storage; Avionics | • Common Avionics  
• High Rate, Adaptive, Internetworked Proximity Communications  
• Robust Ablative Heat Shield – Beyond Lunar  
• Space Radiation Protection & Shielding – SPE  
• Mission Control Automation Beyond LEO  
• Entry, Descent and Landing (EDL) Technologies – Earth Return |
| Orion   | Support 3 crew for TBD days (during ascent and reentry); Operating pressure: 10.2 to 14.7 psia; AR&D; Re-enter at Earth from Mars velocity | Habitation; ECLSS; EVA; Crew Health & Protection; Avionics; Comm. & Nav.; EDL; Radiation | • Autonomous Vehicle Systems Management  
• Closed-Loop, High Reliability, Life Support Systems  
• Common Avionics  
• Crew Autonomy Beyond LEO  
• Deep Space Mission Human Factors and Habitability  
• Deep Space Suit  
• Fire Prevention, Detection, & Suppression  
• High Data Rate Forward Link (Flight) Communications  
• High Rate, Adaptive, Internetworked Proximity Communications  
• High Reliability Life Support Systems  
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• Long Duration Spaceflight Medical Care  
• Mechanisms for Long Duration, Deep Space Missions  
• Microgravity Biomedical Counter-Measures  
• Microgravity Biomedical – Optimized Exercise  
• Mission Control Automation Beyond LEO  
• Quad function Hybrid RF/Optical Comm, Optical Ranging, RF Imaging System  
• Space Radiation Protection – GCR  
• Space Radiation Protection & Shielding – SPE  
• Suit Port  
• Thermal Control |
| DSH     | Mass Range: 28-65 t; Support and protect crew of 3 for ~1000 days (outbound, stay time, and return); Consumables loaded based on crew size & mission duration; Provide communications between mission elements and to Earth | Habitation; ECLSS; Crew Health & Protection; Destination Systems; Avionics; Logistics; Radiation; Comm. & Nav. | |

Note: Capability needs still under assessment
## Crewed Mars Surface Mission Potential Capabilities (2 of 2)

### Minimal Mars Surface Mission

<table>
<thead>
<tr>
<th>Element</th>
<th>High-level Capability Assumptions</th>
<th>Capability Areas</th>
<th>Potential HAT TechDev Technologies</th>
</tr>
</thead>
</table>
| Mars Descent Module      | Perform terminal Mars descent, Precision landing, Deliver crew and cargo on same descent, Propellant storage and transfer | In-Space Propulsion; Destination Systems; Robotics; Avionics | • Common Avionics  
• High Rate, Adaptive, Internetworked Proximity Communications  
• In Space Cryogenic Liquid Acquisition  
• LOX/Liquid Methane Cryo Prop System  
• LOX/Liquid Methane Reaction Control Engines  
• Precision Landing & Hazard Avoidance |
| Mars Ascent Vehicle      | Habitation (2 crew, 7 days), egress/ingress, Perform Mars ascent, R&D with return stack, Propellant storage and transfer | In-Space Propulsion; Habitation; ECLSS; EVA; Crew Health & Protection; Robotics; Avionics; Logistics; Destination Systems | • Common Avionics  
• Dust Mitigation  
• Fire Prevention, Detection, & Suppression  
• High Rate, Adaptive, Internetworked Proximity Communications  
• In Space Cryogenic Liquid Acquisition  
• LOX/Liquid Methane Cryo Prop System  
• LOX/Liquid Methane Reaction Control Engines |
| Robotics                 | Uncrewed operations, used for collection of samples at destination  
Crewed operations, used for collection of samples at destination | Robotics; Autonomous Mission Operations  
EVA; Robotics | • Robots Working side-by-side with Suited Crew  
• Mars Space Suit (Block 3)  
• Suit Port |
| EVA                      | Advanced EVA suits and mobility for exploration                                                | EVA; Robotics                                        | • Entry, Descent and Landing (EDL) Technologies – Mars Exploration Class Missions |
| Aeroassist System        | Mars decelerator approaches, operational under low-g(0.1g) propulsion accelerations, for transition from supersonic flight to powered descent at Mars, and for earth re-entry vehicle | EDL; Structures, Materials, and Mechanisms; In-Space Propulsion; Thermal | |

**Note:** Capability needs still under assessment
## NASA Support of Internationally Led Design Reference Missions

### Mission Under Development

<table>
<thead>
<tr>
<th>DRM Title</th>
<th>Destination</th>
<th>Mission Class</th>
</tr>
</thead>
<tbody>
<tr>
<td>EM-1: Exploration Mission 1 (not currently in package)</td>
<td>Translunar</td>
<td>Extending Reach Beyond LEO</td>
</tr>
<tr>
<td>EM-2: Exploration Mission 2 (not currently in package)</td>
<td>Translunar</td>
<td>Extending Reach Beyond LEO</td>
</tr>
<tr>
<td>EM-X: Exploration Mission X (not currently in package)</td>
<td>Translunar</td>
<td>Extending Reach Beyond LEO</td>
</tr>
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</table>

### Primary DRMs

<table>
<thead>
<tr>
<th>DRM Title</th>
<th>Destination</th>
<th>Mission Class</th>
</tr>
</thead>
<tbody>
<tr>
<td>DRM - 5: Crewed Visit to a Redirected Asteroid</td>
<td>Lunar DRO</td>
<td>Into the Solar System</td>
</tr>
<tr>
<td>DRM - 8: Crewed Mars Moons Mission</td>
<td>Mars Moons</td>
<td>Exploring Other Worlds</td>
</tr>
<tr>
<td>DRM - 8a: Crewed Mars Orbital Mission</td>
<td>Mars Orbit</td>
<td>Planetary Exploration</td>
</tr>
<tr>
<td>DRM - 9: Crewed Mars Surface Mission (DRA 5.0)</td>
<td>Mars Surface</td>
<td>Planetary Exploration</td>
</tr>
<tr>
<td>DRM - 9a: Crewed Mars Surface Mission (Minimal)</td>
<td>Mars Surface</td>
<td>Planetary Exploration</td>
</tr>
</tbody>
</table>

### NASA Support of Internationally Led Design Reference Mission

| DRM - 7: Crew to Lunar Surface (ISECG GER)   | Moon        | Exploring Other Worlds         |

### Secondary DRMs

<table>
<thead>
<tr>
<th>DRM Title</th>
<th>Destination</th>
<th>Mission Class</th>
</tr>
</thead>
<tbody>
<tr>
<td>Translunar Missions (not currently in package)</td>
<td>Translunar</td>
<td>Extending Reach Beyond LEO</td>
</tr>
<tr>
<td>DRM - 6: 3-Launch SLS-Class Crewed NEA Mission (not currently in package)</td>
<td>NEA</td>
<td>Exploring Other Worlds</td>
</tr>
<tr>
<td>DRM - 7a: Crew to Lunar Surface (Minimal) (not currently in package)</td>
<td>Moon</td>
<td>Exploring Other Worlds</td>
</tr>
<tr>
<td>DRM - 7b: Mars Test on Moon (not currently in package)</td>
<td>Moon</td>
<td>Exploring Other Worlds</td>
</tr>
</tbody>
</table>
DRM – 7: Crew to Lunar Surface (ISECG GER)

Note: NASA involvement assumes other International partners lead the effort along with the requisite contribution of resources and hardware from those partners (e.g. dissimilar crew transportation, landers, cargo, surface elements, in-space elements, etc.).
Achievements

• Return human presence to the Moon
• Repeated crewed access to lunar polar regions

Mission Operations

• Crew access Lunar surface with a RLM utilizing an in-space facility in lunar vicinity
• ICPS + Large Storable Stage (LSS) performs TLI and LOI
• A disposable braking stage (LSS or SM) will perform up to 90% of the descent burn
• Surface systems will be pre-deployed on separate cargo missions
• 4-crew (will strive for 4, but most likely 2 in orbit, 2 to surface due to transportation constraints), build to 28-day surface stays, 5 crewed missions over 5 years
• Crew lives in mobile assets (RLM is a taxi)
• 2 x Evolved (Block 1+) SLSs (>105t to LEO, >25t to lunar orbit insertion) required per crewed mission

Assumed Element Capabilities

Block 1+ SLS  ICPS or CPS  Orion "Block 0 Lunar"  Braking Stage/LSS  Reusable LM  Surface Systems

Cross-Cutting Capabilities

• AR&D (Assumed for Facility docking)
• Automated Landing/Hazard Avoidance
• Communications (surface and in-space)
• Avionics
• Propellant Transfer (NTO/MMH or LOx/CH₄)
• Propellant Storage (~1 year for LOx/CH₄ LM only)
• Power generation and energy storage (surface and in-space)
• Advanced EVA (surface and contingency in-space)
Crew to Lunar Surface (ISECG GER) Notional Destination Operations

Mission Summary

- Crew docks to facility
- Test Future Exploration Operations
- Communicate with & control surface assets
- Demonstrate future exploration technologies
- Facility remains in orbit & surface elements remain at destination for future missions

Mission Benefits

- Reduces risk for future human and robotic exploration missions
- Enhances lunar and space science
- Develops capabilities required for future Mars missions
Crew to Lunar Surface (ISECG GER) Destination Operations

Cargo Pre-deploy

- After landing, all systems will undergo a systems check
- An offloading device will assist in offloading all surface assets (all assets are mobile or connected to a mobile asset)
- Surface assets will perform verification of precursor data, final scouting of landing and explorations sites, and follow up scientific measurements if needed
- Prior to crewed landing, surface assets will park behind horizon or surface feature to avoid ejecta

Crewed Mission

- Within hours of crewed landing, the surface assets approach the lander
- Crew transfer from lander cabin to surface assets (method TBD)
- Crew performs up to 28 day mission living in surface assets
- During mission, the crew will perform TBD excursions from the landing site to meet science and exploration objectives
- After completion of the mission, the crew will transfer from the surface assets to the lander (method TBD)
- Prior to ascent, surface assets will park behind the horizon or surface feature to avoid ejecta
- After crewed launch, the surface assets will continue perform uncrewed exploration and science activities
- Surface assets traverse to next crewed landing site
Crew to Lunar Surface (ISECG GER) Mission Architecture – Pre-deploy to Lunar Orbit

One-Way Cargo Pre-deploy Mission and LM Pre-deploy Mission

Transportation:
- Lunar Surface
- Block 1+ SLS
- CPS
- SM

Destination:
- Time at Destination: TBD d
- Cargo Mass: TBD kg
  - Type: TBD
- Resources/Trash left: TBD kg
  - Type: TBD
- Samples/Cargo returned to Earth: n/a kg
  - Type: n/a

Moon
- Facility
- CPS
- RLM & Cargo remains at destination

LLO (241 km)
- Arrival burn: CPS & SM
- Descent: RLM + SM
- Departure: CPS ~5 d Transit
- Circ to 241 km

RLM & Cargo Facility
- RLM & Cargo
- SM
- CPS

RLM Pre-deploy
- SM
- CPS
- TBD LV

Surface Cargo Pre-deploy
- OR

TBD opportunities for additional surface pre-deployment

Icons not to scale
Two-Launch Crewed Mission (Recurring)

Transportation:
- Lunar Surface
- Crewed mission duration ~28 d on surface
- 4 crew members
- Block 1+ SLS
- CPS
- SM

Destination:
- Time at Destination: ~28 d
- Cargo Mass: 500 kg (TBR)
  - Type: TBD
- Resources left: TBD kg
  - Type: TBD
- Samples/Cargo returned to Earth: 250 kg (TBR)

Example: ConOps will be optimized for each trade

Icons not to scale
## Crew to Lunar Surface (ISECG GER) Potential Capabilities (1 of 2)

<table>
<thead>
<tr>
<th>Element</th>
<th>High-level Capability Assumptions</th>
<th>Capability Areas</th>
<th>Potential HAT TechDev Technologies</th>
</tr>
</thead>
<tbody>
<tr>
<td>Block 1+ SLS</td>
<td>Block 1+ to LEO; 2 launches per mission</td>
<td>BEO Access</td>
<td>• Advanced, low Cost Engine Technology for HLLV</td>
</tr>
<tr>
<td>ICPS (trade option)</td>
<td>TLI capability; short duration stage; Isp = 465 s</td>
<td>BEO Access; In-Space Propulsion</td>
<td>• In Space Cryogenic Liquid Acquisition</td>
</tr>
<tr>
<td>CPS</td>
<td>TLI and LOI capability; 5-day lifetime with multiple restarts; Isp = 465 s; AR&amp;D with lunar orbit facility</td>
<td>BEO Access; In-Space Propulsion</td>
<td>• LOX/Liquid Methane Cryogenic Propulsion System</td>
</tr>
<tr>
<td>SM</td>
<td>Long-duration propellant storage; Multiple restarts; Isp = 315 s (NTO/MMH); AR&amp;D with lunar orbit facility</td>
<td>BEO Access; In-Space Propulsion; Robotics; Comm. &amp; Nav.; Power and Energy Storage; Avionics</td>
<td>• LOX/Liquid Methane Reaction Control Engines</td>
</tr>
<tr>
<td>LSS (trade option)</td>
<td>10 - 48t storable propellant load; Long-duration propellant storage; Isp = 315 s (NTO/MMH) or 353 s (LOX/CH4); AR&amp;D with lunar orbit facility</td>
<td>In-Space Propulsion; Robotics; Comm. &amp; Nav.; Avionics</td>
<td>• Common Avionics; High Rate, Adaptive, Internetworked Proximity Communications; Robust Ablative Heat Shield – Thermal Protection Sys; Space Radiation Protection and Shielding – SPE</td>
</tr>
<tr>
<td>Orion</td>
<td>Support 4 crew for ~10 days (transit to/from Moon); Operating pressure: 10.2 to 14.7 psia; rendezvous and dock with lunar orbit facility; Re-enter at Earth from lunar velocity</td>
<td>Habitation; ECLSS; EVA; Crew Health &amp; Protection; Avionics; Comm. &amp; Nav.; EDL; Radiation</td>
<td>• AR&amp;D and Proximity Operations; Common Avionics; Dust Mitigation; Fire Prevention, Detection, &amp; Suppression; High Rate, Adaptive, Internetworked Proximity Communications; In Space Cryogenic Liquid Acquisition; LOX/Liquid Methane Cryogenic Propulsion System; LOX/Liquid Methane Reaction Control Engines; Precision Landing &amp; Hazard Avoidance</td>
</tr>
<tr>
<td>Reusable LM</td>
<td>Provide habitation (4 crew, &lt; 3 days) during descent and ascent; Operating pressure: 8 to 10.2 psia; IVA or EVA egress/ingress; Perform terminal lunar descent and ascent; Survive for 5 missions in 5 yrs.; ~10s of restarts; Precision landing; AR&amp;D with lunar facility; Propellant storage and transfer; Batteries for ascent/descent with solar arrays to recharge during surface stay</td>
<td>Habitation; ECLSS; EVA; Crew Health &amp; Protection; In-Space Propulsion; Destination Systems; Robotics; Avionics; Power and Energy Storage; Radiation</td>
<td>• AR&amp;D and Proximity Operations; Common Avionics; Dust Mitigation; Fire Prevention, Detection, &amp; Suppression; High Rate, Adaptive, Internetworked Proximity Communications; In Space Cryogenic Liquid Acquisition; LOX/Liquid Methane Cryogenic Propulsion System; LOX/Liquid Methane Reaction Control Engines; Precision Landing &amp; Hazard Avoidance</td>
</tr>
<tr>
<td>Lunar Vicinity Facility</td>
<td>Habitation (4 crew, TBD days); Operating pressure: 10.2-14.7 psia (trade); IVA and EVA egress/ingress; 10 year lifetime; Allow for AR&amp;D and docking; Provide logistics for surface missions; Provide power while crew are docked and between missions</td>
<td>Habitation; ECLSS; EVA; Crew Health &amp; Protection; Robotics; Avionics; Logistics; Power and Energy Storage; Radiation</td>
<td>• AR&amp;D and Proximity Operations; Common Avionics; Fire Prevention, Detection, &amp; Suppression; High Rate, Adaptive, Internetworked Proximity Communications</td>
</tr>
</tbody>
</table>

Note: Capability needs still under assessment
<table>
<thead>
<tr>
<th>Element</th>
<th>High-level Capability Assumptions</th>
<th>Capability Areas</th>
<th>Potential HAT TechDev Technologies</th>
</tr>
</thead>
</table>
| Surface Systems  | Support 4 crew for 28 days on surface; Operating pressure: 8 to 10.2 psia; Surface EVA capability; Crewed and uncrewed operations; 5 missions in 5 yrs; Provide surface power (PUP); SPE protection and dust mitigation; Provide surface mobility (rovers); Provide communications between surface elements and with Earth | Habitat; ECLSS; EVA; Crew Health & Protection; Destination Systems; Robotics; Mobility Systems; Comm. & Nav.; Logistics; Autonomous Mission Operations; Radiation | • Autonomous Vehicle Systems Management  
• Deep Space Mission Human Factors & Habitability  
• Dust Mitigation  
• Fire Prevention, Detection, & Suppression  
• High Rate, Adaptive, Internetworked Prox. Comm.  
• High Reliability Life Support Systems  
• In-Flight Environmental Monitoring  
• Lightweight and Efficient Structures and Materials  
• Long Life Batteries  
• Low Temperature Mechanisms  
• Lunar ISRU: Oxygen/Water Extraction  
• Lunar Surface Space Suit (Block 2)  
• Robots Working side-by-side with Suited Crew  
• Space Radiation Protection and Shielding – SPE  
• Suit Port  
• Surface Mobility  
• Thermal Control |

Note: Capability needs still under assessment
BACKUP
<table>
<thead>
<tr>
<th>Acronym</th>
<th>Definition</th>
</tr>
</thead>
<tbody>
<tr>
<td>A/L</td>
<td>Airlock</td>
</tr>
<tr>
<td>ACES</td>
<td>Advanced Crew Escape Suit</td>
</tr>
<tr>
<td>ACS</td>
<td>Attitude Control System</td>
</tr>
<tr>
<td>AES</td>
<td>Advanced Exploration Systems</td>
</tr>
<tr>
<td>ALC</td>
<td>Airlock-derived Logistics Carrier</td>
</tr>
<tr>
<td>AM</td>
<td>Ascent Module</td>
</tr>
<tr>
<td>AR&amp;D</td>
<td>Autonomous Rendezvous and Docking Mission</td>
</tr>
<tr>
<td>ARM</td>
<td>Asteroid Retrieval Mission</td>
</tr>
<tr>
<td>ARV</td>
<td>Asteroid Redirect Vehicle</td>
</tr>
<tr>
<td>ATP</td>
<td>Authority to Proceed</td>
</tr>
<tr>
<td>BEO</td>
<td>Beyond Earth Orbit</td>
</tr>
<tr>
<td>C3</td>
<td>Square of the Hyperbolic Excess Velocity</td>
</tr>
<tr>
<td>CEV</td>
<td>Crew Exploration Vehicle</td>
</tr>
<tr>
<td>CM</td>
<td>Crew Module</td>
</tr>
<tr>
<td>CLS</td>
<td>Cis-Lunar Spacecraft</td>
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<tr>
<td>ConOps</td>
<td>Concept of Operations</td>
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<tr>
<td>CPS</td>
<td>Chemical Propulsion System</td>
</tr>
<tr>
<td>DAV</td>
<td>Descent/Ascent Vehicle</td>
</tr>
<tr>
<td>DM</td>
<td>Descent Module</td>
</tr>
<tr>
<td>DRA</td>
<td>Design Reference Architecture</td>
</tr>
<tr>
<td>DRM</td>
<td>Design Reference Mission</td>
</tr>
<tr>
<td>DRO</td>
<td>Distance Retrograde Orbit</td>
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<tr>
<td>DSH</td>
<td>Deep Space Habitat</td>
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<tr>
<td>DSM</td>
<td>Deep Space Maneuver</td>
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<tr>
<td>ECLSS</td>
<td>Environmental Control and Life Support System</td>
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<tr>
<td>EDL</td>
<td>Entry, Descent, Landing System</td>
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<tr>
<td>E-M L1</td>
<td>Earth-Moon Lagrange point 1</td>
</tr>
<tr>
<td>E-M L2</td>
<td>Earth-Moon Lagrange point 2</td>
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<td>EM-1</td>
<td>Exploration Mission 1</td>
</tr>
<tr>
<td>EM-2</td>
<td>Exploration Mission 2</td>
</tr>
<tr>
<td>EVA</td>
<td>Extravehicular Activity Unit</td>
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<tr>
<td>FPR</td>
<td>Flight Performance Reserve</td>
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<tr>
<td>FSP</td>
<td>Fission Surface Power</td>
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<tr>
<td>FY</td>
<td>Fiscal Year</td>
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<tr>
<td>GCR</td>
<td>Galactic Cosmic Rays</td>
</tr>
<tr>
<td>GEO</td>
<td>Geostationary Earth Orbit</td>
</tr>
<tr>
<td>GER</td>
<td>Global Exploration Roadmap</td>
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<tr>
<td>HAID</td>
<td>Hypersonic Inflatable Aerodynamic Decelerator</td>
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<td>Human Spaceflight Architecture Team</td>
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<td>Human Exploration Framework Team</td>
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<tr>
<td>HELO</td>
<td>High Elliptical Lunar Orbit (100 x 10,000 km)</td>
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<tr>
<td>HEO</td>
<td>High Earth Orbit</td>
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<tr>
<td>HLLV</td>
<td>Heavy Lift Launch Vehicle</td>
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<td>HLR</td>
<td>Human Lunar Return</td>
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<td>HMO</td>
<td>High Mars Orbit</td>
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<td>HRP</td>
<td>Human Research Program</td>
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<td>ICPS</td>
<td>Interim Chemical Propulsion System</td>
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<td>ISECG</td>
<td>International Space Exploration Coordination Group</td>
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<tr>
<td>ISRU</td>
<td>In-Situ Resource Utilization</td>
</tr>
<tr>
<td>ISS</td>
<td>International Space Station</td>
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<tr>
<td>IVA</td>
<td>Intra-Vehicular Activities</td>
</tr>
<tr>
<td>JSC</td>
<td>Johnson Space Center</td>
</tr>
<tr>
<td>LCM</td>
<td>Lunar Crew Module</td>
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<tr>
<td>LDRO</td>
<td>Lunar distant retrograde orbit</td>
</tr>
<tr>
<td>LEO</td>
<td>Low Earth Orbit</td>
</tr>
<tr>
<td>LLO</td>
<td>Low Lunar Orbit (100 km circular)</td>
</tr>
<tr>
<td>LM</td>
<td>Lander Module</td>
</tr>
<tr>
<td>LOI</td>
<td>Lunar Orbit Insertion</td>
</tr>
<tr>
<td>LPM</td>
<td>Lunar Propulsion Module</td>
</tr>
<tr>
<td>LPMA</td>
<td>Lunar Propulsion Module Ascent</td>
</tr>
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<td>LPMD</td>
<td>Lunar Propulsion Module Descent</td>
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<td>LSM</td>
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<td>LSS</td>
<td>Large Storable Stage</td>
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<td>LV</td>
<td>Launch Vehicle</td>
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<td>MACES</td>
<td>Modified Advanced Crew Escape Suit</td>
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<td>MAS</td>
<td>Mars Ascent Stage</td>
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<td>MAV</td>
<td>Mars Ascent Vehicle</td>
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<td>Mid-Course Correction</td>
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<td>MDS</td>
<td>Mars Descent Stage</td>
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<td>MEPAG</td>
<td>Mars Exploration Program Analysis Group</td>
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<tr>
<td>MGA</td>
<td>Mass Growth Allocation</td>
</tr>
<tr>
<td>MFR</td>
<td>Mission Formulation Review</td>
</tr>
<tr>
<td>MLO</td>
<td>Medium Lunar Orbit (1,000 km circular)</td>
</tr>
<tr>
<td>MOE</td>
<td>Mars Orbital Excursion Vehicle</td>
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<tr>
<td>MOI</td>
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<td>MR</td>
<td>Mass Ratio</td>
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<td>Mars Surface Habitat</td>
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<td>MSR</td>
<td>Mars Sample Return</td>
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<td>MTV</td>
<td>Mars Transfer Vehicle</td>
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<tr>
<td>NBL</td>
<td>Neutral Buoyancy Laboratory</td>
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<tr>
<td>NEA</td>
<td>Near-Earth Asteroid</td>
</tr>
<tr>
<td>NEP</td>
<td>Nuclear Electric Propulsion</td>
</tr>
<tr>
<td>NTP</td>
<td>Nuclear Thermal Propulsion</td>
</tr>
<tr>
<td>NTR</td>
<td>Nuclear Thermal Rocket</td>
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<tr>
<td>OMS</td>
<td>Orbital Maneuvering System</td>
</tr>
<tr>
<td>PCT</td>
<td>Portable Communications Terminal</td>
</tr>
<tr>
<td>PHA</td>
<td>Potentially Hazardous Asteroid</td>
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<tr>
<td>PLSS</td>
<td>Portable Life Support System</td>
</tr>
<tr>
<td>PNT</td>
<td>Position determination, Navigation, and Timing</td>
</tr>
<tr>
<td>PPBE</td>
<td>Planning Programming Budgeting and Execution</td>
</tr>
<tr>
<td>PRM</td>
<td>Propellant Resupply Module</td>
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<tr>
<td>PUP</td>
<td>Portable Utility Pallet</td>
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<td>RCS</td>
<td>Reaction Control System</td>
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<td>REM</td>
<td>Robotics EVA Module</td>
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<td>RLM</td>
<td>Reusable Lander Module</td>
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<td>RPOD</td>
<td>Rendezvous Proximity Operations &amp; Docking</td>
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<tr>
<td>SA</td>
<td>Spacecraft Adapter</td>
</tr>
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