National Research Council
Dialogue to Assess Progress on

NASA’s
Human Exploration Systems and Mobility Capability Roadmap Development

General Background and Introduction

Thomas Inman
March 29, 2005
Why Are We Here?

- NASA wants the National Research Council (NRC) to review Capability Roadmap products and assess progress in four areas:
  - Do the Capability Roadmaps provide a clear pathway to (or process for) technology and capability development?
  - Are technology maturity levels accurately conveyed and used? (Note: Maturity levels will be evaluated using Technology Readiness Levels [TRLs] and Capability Readiness Levels [CRLs] or other appropriate methodologies)
  - Are proper metric for measuring advancement of technical maturity included?
  - Do the Capability Roadmaps have connection points to each other when appropriate
Agenda

- General Background and Introduction of Capability Roadmaps
  - Agency Objective
  - Strategic Planning Transformation
  - Advanced Planning Organizational Roles
  - Public Involvement in Strategic Planning
  - Strategic Roadmaps and Schedule
  - Capability Roadmaps and Schedule
  - Technology and Capability Readiness Levels
  - Relationships Between Roadmaps
  - Purpose of NRC Review
- Capability Roadmap Development (Team Progress to Date)
### Agency Goals and Objectives

<table>
<thead>
<tr>
<th>National Goal</th>
<th>Advance U.S. scientific, security and economic interests through a robust space exploration program.</th>
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</thead>
<tbody>
<tr>
<td><strong>National Objectives</strong></td>
<td>1. Implement a sustained and affordable human and robotic program to explore the solar system and beyond.</td>
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<td>3. Conduct robotic exploration across the solar system for scientific purposes and to support human exploration. In particular, explore Jupiter’s moons, asteroids and other bodies to search for evidence of life, to understand the history of the solar system, and to search for resources. (SRM 3)</td>
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<td>5. Explore the universe to understand its origin, structure, evolution, and destiny. (SRM 8)</td>
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<td>7. Develop a new crew exploration vehicle to provide crew transportation for missions beyond low Earth orbit. First test flight to be by the end of this decade with operational capability for human exploration NLT 2014. (SRM 5)</td>
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<td>9. Conduct the first extended human expedition to the lunar surface as early as 2015, but no later than the year 2020. (SRM 1)</td>
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**NASA Objectives**

1. Undertake robotic and human lunar exploration to further science, and to develop and test new approaches, technologies, and systems to enable and support sustained human and robotic exploration of Mars and more distant destinations. First robotic mission no later than 2008. (SRM 1)

2. Conduct robotic exploration of Mars to search for evidence of life, to understand the history of the solar system, and to prepare for future human exploration. (SRM 2)

3. Conduct robotic exploration across the solar system for scientific purposes and to support human exploration. In particular, explore Jupiter’s moons, asteroids and other bodies to search for evidence of life, to understand the history of the solar system, and to search for resources. (SRM 3)

4. Conduct advanced telescope searches for Earth-like planets and habitable environments around other stars. (SRM 4)

5. Explore the universe to understand its origin, structure, evolution, and destiny. (SRM 8)

6. Return the Space Shuttle to flight and focus its use on completion of the ISS, complete assembly of the ISS, and retire the Space Shuttle as soon as assembly of the ISS is completed, planned for the end of this decade. Conduct ISS activities consistent with U.S. obligations to ISS partners. (SRM 6, 7)

7. Develop a new crew exploration vehicle to provide crew transportation for missions beyond low Earth orbit. First test flight to be by the end of this decade with operational capability for human exploration NLT 2014. (SRM 5)

8. Focus research and use of the ISS on supporting space exploration goals, with emphasis on understanding how the space environment affects human health and capabilities, and developing countermeasures. (SRM 6)

9. Conduct the first extended human expedition to the lunar surface as early as 2015, but no later than the year 2020. (SRM 1)

10. Conduct human expeditions to Mars after acquiring adequate knowledge about the planet using robotic missions and after successfully demonstrating sustained human exploration missions to the Moon. (SRM 2)
### National Goal

**Advance U.S. scientific, security and economic interests through a robust space exploration program.**

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<thead>
<tr>
<th>National Objectives</th>
<th>NASA Objectives</th>
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<tbody>
<tr>
<td><strong>3.</strong> Develop innovative technologies, knowledge, and infrastructure both to explore and to support decisions about the destinations for human exploration.</td>
<td><strong>11.</strong> Develop and demonstrate power generation, propulsion, life support and other key capabilities required to support more distant, more capable, and/or longer duration human and robotic exploration of Mars and other destinations. (SRM 13 and Capability Roadmaps)</td>
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<tr>
<td><strong>4.</strong> Promote international and commercial participation in exploration to further U.S. scientific, security, and economic interests.</td>
<td><strong>14.</strong> Advance scientific knowledge of the Earth system through space-based observation, assimilation of new observations, and development and deployment of enabling technologies, systems, and capabilities, including those with the potential to improve future operational systems. (SRM 9)</td>
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<tr>
<td><strong>5.</strong> Study the Earth system from space and develop new space-based and related capabilities for this purpose.</td>
<td><strong>17.</strong> Pursue commercial opportunities for providing transportation and other services supporting International Space Station and exploration missions beyond Earth orbit. Separate to the maximum extent practical crew from cargo. (SRM 5, 6, 7)</td>
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<td><strong>12.</strong> Provide advanced aeronautical technologies to meet the challenges of next-generation systems in aviation, for civilian and scientific purposes, in our atmosphere and in the atmospheres of other worlds. (SRM 11)</td>
<td><strong>15.</strong> Explore the Sun-Earth system to understand the Sun and its effects on Earth, the solar system, and the space environmental conditions that will be experienced by human explorers, and demonstrate technologies that can improve future operational Earth observation systems. (SRM 10)</td>
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<td><strong>13.</strong> Use NASA missions and other activities to inspire and motivate the nation’s students and teachers, to engage and educate the public, and to advance the scientific and technological capabilities of the nation. (SRM 12)</td>
<td><strong>16.</strong> Pursue opportunities for international participation to support U.S. space exploration goals. (All SRMs)</td>
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<tr>
<td><strong>14.</strong> Advance scientific knowledge of the Earth system through space-based observation, assimilation of new observations, and development and deployment of enabling technologies, systems, and capabilities, including those with the potential to improve future operational systems. (SRM 9)</td>
<td><strong>18.</strong> Use U.S. commercial space capabilities and services to fulfill NASA requirements to the maximum extent practical and continue to involve, or increase the involvement of, the U.S. private sector in design and development of space systems. (SRM 5, 6, 7)</td>
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</table>
Strategic Planning Transformation - continued

National Policy Direction

Agency Req. (Goals & Objectives)

Aldridge Commission

13 Strategic Roadmaps

15 Capability Roadmaps

National Academy Review

Integrated Strategic Architecture

NASA Integrated Portfolio

MISSION DIRECTORATE IMPLEMENTATION
Advanced Planning Organizational Roles

- NASA Strategic Planning Council (Chair, NASA Administrator)
  - Agency-level strategic decisions & NASA Strategic Plan

- NASA Operations Council (Chair, NASA Deputy Administrator)
  - Implementation of strategies through integrated Agency tactical & operational activities

- Director for Advanced Planning (Charles Elachi)
  - Develops input, options, & assessments for Strategic Planning Council

- Associate Deputy Administrator for Systems Integration (Mary Kicza)
  - Tracks & assesses integrated schedules, progress towards goals, Agency needs, strategic investments

- Advanced Planning & Integration Office (Dir. APIO, Bernie Seery)
  - Provides staff to the Director for Advanced Planning and the Associate Deputy Administrator for Systems Integration

- Mission Directorates (Craig Steidle, Al Diaz, Victor Lebacqz, William Readdy)
  - Technical knowledge & expertise to implement overall Agency architecture(s)
Public Involvement in Strategic Planning

• NASA wants:
  – A broad community perspective when doing its strategic planning
  – Best strategies and most creative and innovative ideas from across the nation to implement the Vision
  – To provide opportunities for community input

  ➢ RFI for Capability and Strategic Roadmap Input
    • Public workshop held in Washington DC on November 30th for Capability Roadmaps (509 people attended, 514 papers submitted)
    • White Papers submitted for Strategic Roadmaps
  ➢ Roadmap team members drawn from NASA, other Government Agencies, Academia, and Industry
  ➢ Review by the National Research Council (NRC)
  ➢ Presentations to professional societies, workshops, and conferences
Strategic Roadmaps

• Strategic Roadmap
  – One of thirteen elements of the NASA Strategy that will explore options and establish pathways for implementing the Vision for Exploration

• Roadmaps will include:
  – Broad human and robotic science and exploration goals, priorities, anticipated discoveries
  – High-level milestones, options, and decision points
  – Implementation approaches, suggested missions
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<tr>
<th>Roadmap</th>
<th>Chairs (HQ Directorate, Center)</th>
<th>External chair</th>
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</table>
| Robotic and Human Lunar Exploration          | Adm. (Ret.) Craig Steidle (HQ/ESMD) and William Readdy (HQ/SOMD)  
                                                Gen. (Ret.) Jefferson Howell (JSC)                                            | Gen. (Ret.) Tom Stafford                             |
| Robotic and Human Exploration of Mars       | Al Diaz (HQ/SMD)  
                                                Dr. Charles Elachi (JPL)                                                                                  | Tom Young (Lockheed Martin, Ret.)                    |
| Solar System Exploration                    | Orlando Figueroa (HQ/SMD)  
                                                Scott Hubbard (ARC)                                                                                 | Dr. Jonathan Lunine (Uni. of Arizona)                |
| Search for Earth-Like Planets               | Dr. Ghassem Asrar (HQ/SMD)  
                                                Dr. Charles Beichman (JPL)                                                                            | Dr. Adam Burrows (Uni. of Arizona)                   |
| Exploration Transportation System           | Adm. (Ret.) Craig Steidle (HQ/ESMD)  
                                                Jim Kennedy (KSC)                                                                                    | Gen. (Ret.) Charles Bolden                           |
| International Space Station                 | Mark Uhran (HQ/SOMD)  
                                                Bob Cabana (JSC)                                                                                     | Adm. (Ret.) Tom Betterton                           |
| Space Shuttle                               | Deferred                                                                                                         | Deferred                                            |

Directorate and APIO Coordinators also with each team

= DoD Participation
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<th>Roadmap</th>
<th>Chairs (HQ Directorate, Center)</th>
<th>External Chair</th>
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<tr>
<td>Universe Exploration</td>
<td>Dr. Anne Kinney (HQ/SMD)</td>
<td>Dr. Kathy Flanagan (MIT)</td>
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<td>Dr. Nick White (GSFC)</td>
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<td>Earth Science and Applications from Space</td>
<td>Orlando Figueroa (HQ/SMD)</td>
<td>Dr. Charles Kennel (UCSD/Scripps)</td>
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<td>Dr. Diane Evans (JPL)</td>
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<td>Sun-Solar System Connection</td>
<td>Al Diaz (HQ/SMD)</td>
<td>Dr. Timothy Killeen (NCAR)</td>
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<td>Dr. Franco Einaudi (GSFC)</td>
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<tr>
<td>Aeronautical Technologies</td>
<td>Terry Hertz (HQ/ARMD)</td>
<td>James Jamieson (Boeing)</td>
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<tr>
<td>Education</td>
<td>Dr. Adena Loston (HQ/Office of Education)</td>
<td>Dr. France Cordova (Uni. of Cal., Riverside)</td>
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<td>Dr. Julian Earls (GRC)</td>
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<td>Nuclear Systems</td>
<td>Adm. (Ret.) Craig Steidle (HQ/ESMD)</td>
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<td>Chris Scolese (GSFC)</td>
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Capability is defined as a set of systems (or system of systems) with associated technologies & knowledge that enable NASA to perform a function (e.g. scientific measurements) required to accomplish the NASA mission.

Capability Roadmap is a description of the developments (including alternate paths and options) required to achieve the capability.
NASA, in response to the Presidential Commission recommendations, will prepare roadmaps and related implementation plans that define national capabilities needed to meet the Agency’s strategic roadmaps. The roadmaps are based on the Presidential Commission’s recommendation of technologies, updated by the NASA Strategic Council.

The capability roadmap development process will be accomplished in two phases.

- Phase 1 will be the development of capability roadmaps and associated technical products.
  - During this phase, technical experts both internal and external to NASA will provide the technical knowledge and expertise in the development of roadmaps which identify the capabilities that are needed to meet the missions of the Agency. The capability roadmap team will identify and analyze each of the associated technologies and assess the capability performance afforded by the current state of the art, the performance level needed by the strategic mission and trace the development required.

- Phase 2 will be the development of Investment Plans.
  - During this phase, a NASA team will develop investment plans for the capability roadmaps. This team will be working to determine the critical capabilities that are identified on the roadmaps and to develop an investment plan for each individual roadmap area to include schedules and yearly budgets. The activity of the Investment Plan Teams consists of using the perspectives and values described by the Capability Roadmaps and selecting and then formulating an optimized development plan suitable for consideration by the Agency in its budget submissions.
• Strategic roadmaps are being developed in parallel with the Capability roadmaps
  – Assumptions were made to begin the Capability roadmap development.
    ➢ Created a missions assumptions framework
    ➢ Provided a set of design reference missions

• The Capability roadmaps being presented today are based on mission assumptions which will be updated by the agency strategic roadmap effort

• This dialogue review is, therefore, a work in progress

• Another NRC review in the June timeframe will include the integrated strategic and capability roadmap product
• Guidelines for Team Member Selection
  – Small teams of 12 -15 members with participation from:
    ➢ 1/3 Industry
    ➢ 1/3 NASA & other Government Agencies
    ➢ 1/3 Academia

• Strategic Planning Council assigned roadmaps to Mission Directorate

• Mission Directorates assigned a NASA Chair with roadmap expertise

• NASA Chairs chose team members from industry, academia, other Government & within NASA who are recognized experts
Capability Roadmaps - continued

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<thead>
<tr>
<th>Capability</th>
<th>NASA chair</th>
<th>External chair</th>
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<tbody>
<tr>
<td>High-Energy Power and Propulsion</td>
<td>Joe Nainiger (GRC)</td>
<td>Dr. Tom Hughes (Penn State Uni.)</td>
</tr>
<tr>
<td>In-Space Transportation</td>
<td>Paul McConnaughey (MSFC)</td>
<td>Col. Joe Boyles (US Air Force SMC)</td>
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<tr>
<td>Advanced Telescopes and Observatories</td>
<td>Lee Feinberg (GSFC)</td>
<td>Dr. Howard MacEwen (SRS Technologies)</td>
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<tr>
<td>Communication and Navigation</td>
<td>Bob Spearing (HQ/SOMD)</td>
<td>Michael Regan (DoD)</td>
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<tr>
<td>Robotic Access to Planetary Surfaces</td>
<td>Mark Adler (JPL)</td>
<td>Dr. Robert Braun (Georgia Tech)</td>
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<td>Human Planetary Landing Systems</td>
<td>Robert Manning (JPL)</td>
<td>Dr. Harrison Schmitt</td>
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<tr>
<td>Human Health and Support Systems</td>
<td>Dennis Grounds (JSC)</td>
<td>Al Boehm (Ret, Hamilton-Sundstrand)</td>
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<tr>
<td>Human Exploration Systems and Mobility</td>
<td>Chris Culbert (JSC)</td>
<td>Dr. Jeff Taylor (Uni. of Hawaii)</td>
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Directorate and APIO Coordinators also with each team

= DoD Participation
## Capability Roadmaps - continued

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<tr>
<th>Capability</th>
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<tbody>
<tr>
<td>Autonomous Systems and Robotics</td>
<td>Dr. Steve Zornetzer (ARC)</td>
<td>Doug Gage (Ret. DARPA)</td>
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<td>Transformational Spaceport/Range</td>
<td>Karen Poniatowski (HQ/SOMD)</td>
<td>Gen. (Ret.) Jimmy Morrell</td>
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<td>Col. Dennis Hilley (OSD)</td>
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<td>Scientific Instruments/Sensors</td>
<td>Rich Barney (GSFC)</td>
<td>Dr. Maria Zuber (MIT)</td>
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<tr>
<td>In Situ Resource Utilization</td>
<td>Jerry Sanders (JSC)</td>
<td>Dr. Mike Duke (Colorado School of Mines)</td>
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<tr>
<td>Advanced Modeling, Simulation, Analysis</td>
<td>Dr. Erik Antonsson (JPL)</td>
<td>Dr. Tamas Gombosi (Uni. Of Michigan)</td>
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<td>Systems Engineering Cost/Risk Analysis</td>
<td>Steve Cavanaugh (LaRC)</td>
<td>Dr. Alan Wilhite (Georgia Institute of Technology)</td>
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<td>Nanotechnology</td>
<td>Dr. Murray Hirschbein (HQ/ARMD) and</td>
<td>Dr. Dimitris Lagoudas (Texas A&amp;M)</td>
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<td>Dr. Minoo Dastoor (HQ/ESMD)</td>
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Directorate and APIO Coordinators also with each team

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## Capability Roadmap Schedule

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Technology Readiness Levels

9. Actual System Proven in Operation
8. Actual System Qualified by Demonstration
7. System Prototype Demonstration in an Operational Environment
6. System/Subsystem Model or Prototype Demonstration in a Relevant Environment
5. Component and/or Breadboard Validation in a Relevant Environment
4. Component and/or Breadboard Validation in a Laboratory Environment
3. Analytical and Experimental Critical Functions Characteristic Proof-of-Concept
2. Technology Concept and/or Application Formulated
1. Basic Principles Observed and Reported
### Capability Readiness Levels

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<thead>
<tr>
<th>Level</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>7</td>
<td>Capability Operational Readiness</td>
</tr>
<tr>
<td>6</td>
<td>Integrated Capability Demonstrated in an Operational Environment</td>
</tr>
<tr>
<td>5</td>
<td>Integrated Capability Demonstrated in a Relevant Environment</td>
</tr>
<tr>
<td>4</td>
<td>Integrated Capability Demonstrated in a Laboratory Environment</td>
</tr>
<tr>
<td>3</td>
<td>Sub-Capabilities* Demonstrated in a Relevant Environment</td>
</tr>
<tr>
<td>2</td>
<td>Sub-Capabilities* Demonstrated in a Laboratory Environment</td>
</tr>
<tr>
<td>1</td>
<td>Concept of Use Defined, Capability, Constituent Sub-capabilities* and Requirements Specified</td>
</tr>
</tbody>
</table>

- A Capability is defined as a set of systems (or system of systems) with associated technologies & knowledge that enable NASA to perform a function (e.g. scientific measurements) required to accomplish the NASA mission.
- Sub-capabilities include Technologies, Infrastructure, and Knowledge (process, procedures, training, facilities).
# Relationships between Roadmaps

## Human Exploration Systems and Mobility

|-----------------------------------|--------------------------|----------------------------------------|-----------------------------|-----------------------------------|-------------------------------|---------------------------------|----------------------------------|---------------------------------|-------------------------------------|----------------------------------|-----------------------------|-------------------------|-----------------------------|-----------------------------|

- **Same element**
- **Critical Relationship (dependent, synergistic, or enabling)**
- **Moderate Relationship (enhancing, limited impact, or limited synergy)**
- **No Relationship**
- **No CBS Available**
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</thead>
<tbody>
<tr>
<td>9.1 Exploration Activities; Operations</td>
<td>10.1 Crew-Centered Operations; Logistics, Support Tools, EVA Support Exploration</td>
<td>EVA/IVA performance and support, Analysis and operations tools</td>
<td></td>
<td></td>
</tr>
<tr>
<td>9.1 Exploration Activities; Command and Control</td>
<td>10.5 Robotics for Solar System Exploration</td>
<td>Telerobotic and crew-assist operations</td>
<td></td>
<td></td>
</tr>
<tr>
<td>9.1 Exploration Activities; Observation</td>
<td>10.7 Robotics for In-Space Operations</td>
<td>Telerobotic and crew-assist remote sensing</td>
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</tr>
<tr>
<td>9.2 Mobility; Surface Transportation of Crew /Robots</td>
<td>10.6 Robotics for Lunar and Planetary Habitation</td>
<td>Crew transportation (rovers, tethers, jet packs, etc.), Robot and equipment transportation (hoppers, crawlers, rail carts, wagons, etc.)</td>
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<tr>
<td>9.2 Mobility; In-Space Transportation of Crew /Robots</td>
<td>10.7 Robotics for In-Space Operations</td>
<td>Crew transportation (tethers, jet packs, etc.), Robot and equipment transportation (manipulation arms, cranes, rail carts, etc.)</td>
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<tr>
<td>9.3 Assembly and Deployment; Staging and Construction</td>
<td>10.3 Autonomous Vehicle Control</td>
<td>AR&amp;D, Capture and berthing systems</td>
<td></td>
<td></td>
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<tr>
<td>9.3 Assembly and Deployment; Staging and Construction</td>
<td>10.7 Robotics for In-Space Operations</td>
<td>Positioning, joining and assembly of systems</td>
<td></td>
<td></td>
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<tr>
<td>9.4 Servicing; Inspection, Maintenance and Repair</td>
<td>10.2 Integrated Systems Health Management</td>
<td>Monitoring, inspection and repair of vehicle systems</td>
<td></td>
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<tr>
<td>9.4 Servicing; Inspection, Maintenance and Repair</td>
<td>10.4 Autonomous Process Control and Embedded Autonomy</td>
<td>&quot;Smart&quot; systems and crew-assisted operations</td>
<td></td>
<td></td>
</tr>
<tr>
<td>9.5 Construction; Habitat Outfitting</td>
<td>10.6 Robotics for Lunar and Planetary Habitation</td>
<td>Robotic or crew-assisted assembly and verification (manipulation arms, tools, instruments, etc.)</td>
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</tbody>
</table>
• NASA wants the National Research Council (NRC) to review Capability Roadmap products and assess progress in four areas:
  - Do the Capability Roadmaps provide a clear pathway to (or process for) technology and capability development?
  - Are technology maturity levels accurately conveyed and used? (Note: Maturity levels will be evaluated using Technology Readiness Levels [TRLs] and Capability Readiness Levels [CRLs] or other appropriate methodologies)
  - Are proper metric for measuring advancement of technical maturity included?
  - Do the Capability Roadmaps have connection points to each other when appropriate
Back-up charts
• CRL 1: Concept of Use Defined, Capability, Constituent Sub-capabilities* and Requirements Specified
  – The Capability is defined in written form. The use/application of the Capability is described in a concept paper. The uses are speculative, and no proof or detailed analysis exists to support the concept. The constituent Sub-capabilities and requirements of the Capability are specified.

• CRL 2: Sub-Capabilities* Demonstrated in a Laboratory Environment:
  – A Proof-of-Concept analysis of the Capability is performed. Analytical and laboratory studies of the Sub-capabilities are performed to physically validate separate elements of the Capability. Analytical studies are performed to determine how constituent Sub-capabilities will work together.

• CRL 3: Sub-Capabilities* demonstrated in a Relevant Environment:
  – Sub-capabilities are demonstrated with realistic supporting elements to simulate an operationally relevant environment (e.g. to the Capability).
    - of appropriate scale
    - functionally equivalent flight articles
    - major system interactions identified
  – Limited analytical modeling of the integrated Capability can be performed.

• CRL 4: Integrated Capability Demonstration in a Laboratory Environment
  – A representative model or prototype of the integrated Capability is tested in a laboratory environment. Performance of the constituent Sub-capabilities are observed in addition to the Capability as an integrated system. are specified.

• CRL 5: Integrated Capability Demonstration in a Relevant Environment
  – An integrated prototype of the Capability is demonstrated with realistic supporting elements to simulate an operationally relevant environment (e.g. to the Capability).
    - of appropriate scale
    - actual flight articles
    - all system interactions identified

• CRL 6: Integrated Capability Demonstration in an Operational Environment
  – The Capability is near or at the completed system stage. This level represents the demonstration of an integrated Capability in an operational environment with representatives of the intended user organization(s).
    - full scale flight articles
    - demonstration in appropriate operational ‘envelope’

• CRL 7: Capability Operational Readiness
  – The Capability has been proven to work in its final form and under expected operational conditions. This level represents the application of the Capability in its operational configuration and under “mission” conditions.