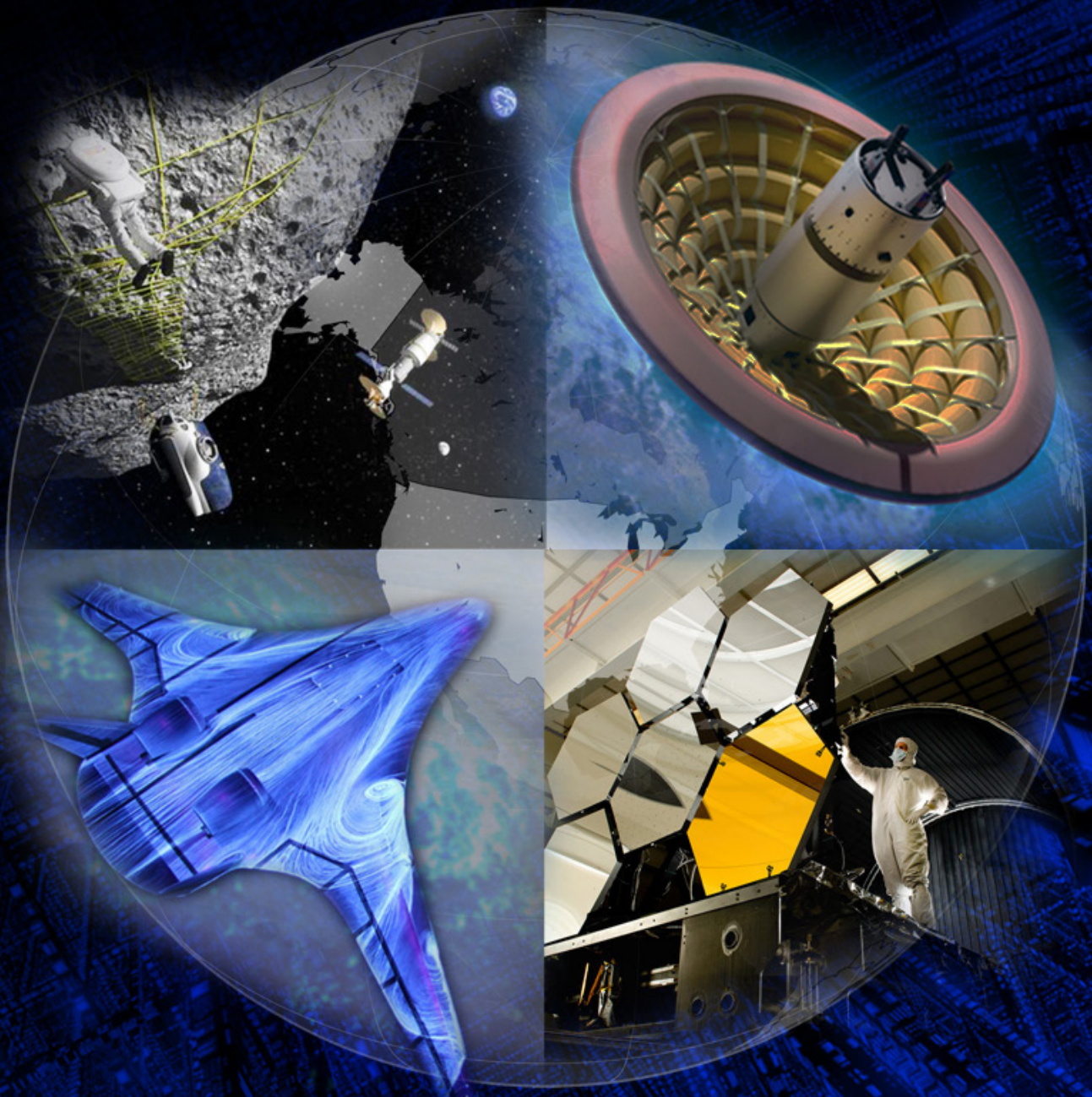
National Aeronautics and Space Administration

NASA Technology Roadmaps

Introduction, Crosscutting Technologies, and Index



May 2015 Draft

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National Aeronautics and Space Administration

Headquarters
Washington DC 20546-0001

"By 2025 we expect new spacecraft designed for long journeys to allow us to begin the first ever crew missions beyond the Moon into deep space," President Obama said. "So, we'll start by sending astronauts to an asteroid for the first time in history. By the mid-2030s, I believe we can send humans to orbit Mars and return them safely to earth, and a landing on Mars will follow."

Formidable challenges must be conquered before humans place the first boot print on Mars. Innovation in and development of new technologies are the indispensable elements that will be used to tackle these challenges and shape our exploration future. NASA's technology developments will support critical needs, enabling humans to be transported to, stay healthy in, and work productively within deep space. NASA's technologies will enable continued operation of the International Space Station and prepare us for human exploration beyond low-Earth orbit. Technologies will allow us to explore the Earth-Sun system, our own solar system, and the universe. They will also enable us to create safer, more secure, efficient, and environmentally friendlier air transportation systems.

The promising new technology candidates that will help NASA achieve its extraordinary missions are identified in the 2015 NASA Technology Roadmaps. The roadmaps are a set of documents that consider a wide range of needed technology candidates and development pathways for the next 20 years. The roadmaps are a foundational element of the Strategic Technology Investment Plan (STIP), an actionable plan that lays out the strategy for developing technologies essential to the pursuit of NASA's mission and achievement of National goals. This plan provides the prioritization and guiding principles of investment for the technologies identified in the roadmaps.

The 2015 NASA Technology Roadmaps have been expanded and enhanced to include a new crosscutting section, a new technical area – Aeronautics, and expanded content for avionics, autonomy, information technology, radiation, and space weather, to name a few. Each roadmap also consists of a set of Technology Candidate Snapshots detailing technology information, performance goals, and challenges. Each snapshot contains standardized information to provide traceability to a capability and associated missions. This allows NASA to consider a suite of evolving capabilities that provide specific functions to solve exploration challenges.

NASA is at the pinnacle of a new phase of space exploration, a phase where commercial companies have joined us on the irresistible journey of exploration and scientific discovery beyond low-Earth orbit. The technology candidates identified in the roadmaps provide capabilities that can be leveraged, reused, and built upon, enabling more complex operations over time and the exploration of more distant solar system destinations. NASA's continued investment in technology development will provide critical capabilities that create new jobs and businesses, inspire our youth, and lead to futures where humans evolve to a species that lives and works throughout the solar system.

David W. Miller
Chief Technologist

Foreword

NASA is leading the way with a balanced program of space exploration, aeronautics, and science research. Success in executing NASA's ambitious aeronautics activities and space missions requires solutions to difficult technical challenges that build on proven capabilities and require the development of new capabilities. These new capabilities arise from the development of novel cutting-edge technologies.

The promising new technology candidates that will help NASA achieve our extraordinary missions are identified in our Technology Roadmaps. The roadmaps are a set of documents that consider a wide range of needed technology candidates and development pathways for the next 20 years. The roadmaps are a foundational element of the Strategic Technology Investment Plan (STIP), an actionable plan that lays out the strategy for developing those technologies essential to the pursuit of NASA's mission and achievement of National goals. The STIP provides prioritization of the technology candidates within the roadmaps and guiding principles for technology investment. The recommendations provided by the National Research Council heavily influence NASA's technology prioritization.

NASA's technology investments are tracked and analyzed in TechPort, a web-based software system that serves as NASA's integrated technology data source and decision support tool. Together, the roadmaps, the STIP, and TechPort provide NASA the ability to manage the technology portfolio in a new way, aligning mission directorate technology investments to minimize duplication, and lower cost while providing critical capabilities that support missions, commercial industry, and longer-term National needs.

The 2015 NASA Technology Roadmaps are comprised of 16 sections: The Introduction, Crosscutting Technologies, and Index; and 15 distinct Technology Area (TA) roadmaps. Crosscutting technology areas, such as, but not limited to, avionics, autonomy, information technology, radiation, and space weather span across multiple sections. The introduction provides a description of the crosscutting technologies, and a list of the technology candidates in each section.

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NASA Technology Roadmap Leadership Team

The 2015 NASA Technology Roadmaps were created through the leadership, dedication and hard work of professionals from the Office of the Chief Technologist (OCT), the NASA field Centers and contributors from other Government agencies. The effort was led by the Office of the Chief Technologist and the 15 Technology Area Chairs and Co-Chairs. The leadership team is highlighted below. Each of the roadmaps were developed by a team of 8-9 experts with the support of internal and external contributors. Each roadmap contains a list of the roadmap team members and contributors.

LEADERSHIP TEAM

Faith Chandler
Director, Strategic Integration, OCT

Rob Ambrose
TA 4 Chair

John F. Carter
TA 15 Chair

Jack Fox
TA 13 Chair

David Israel
TA 5 Co-Chair

Dianne Linne
TA 7 Co-Chair

Mike Meyer
TA 2 Chair

Issa Nesnas
TA 4 Co-Chair

John Scott
TA 3 Chair

Farhad Tahmasebi
TA 15 Co-Chair

Peter Turlington
TA 13 Co-Chair

Tracy Bierman
Office of the Chief Technologist

Sandra Cauffman
Office of the Chief Technologist

Carie Mullins
Office of the Chief Technologist

Alan Zide
Office of the Chief Technologist

Bryan Biegel
TA 11 Co-Chair

Chris Culbert
TA 7 Chair

Edward Glaessgen
TA 11 Chair

Les Johnson
TA 2 Co-Chair

Michael Meador
TA 10 Chair

Brian Motil
TA 14 Co-Chair

Jill Prince
TA 9 Co-Chair

Emilie Siochi
TA 10 Co-Chair

Lanetra Tate
TA 12 Co-Chair

John Vickers
TA 12 Chair

Elaine Gresham
Office of the Chief Technologist

Teresa Kline
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Mark Redlinger
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Thomas Brown
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Chris Edwards
TA 8 Chair

Katy Hurlbert
TA 6 Co-Chair

Mark Kliss
TA 6 Chair

Carolyn Mercer
TA 3 Co-Chair

Michelle Munk
TA 9 Chair

Rick Ryan
TA 1 Co-Chair

Theodore Swanson
TA 14 Chair

Stephen A. Townes
TA 5 Chair

Daniel Winterhalter
TA 8 Co-Chair

Sharon Jefferies
Office of the Chief Technologist

Orlando Melendez
Office of the Chief Technologist

Ryan Stillwater
Office of the Chief Technologist

Introduction

NASA's technology development activities expand the frontiers of knowledge and capabilities in aeronautics, science, and space, creating opportunities, markets, and products for U.S. industry and academia. In 2012, NASA developed a set of 14 Technology Roadmaps to guide the development of space technologies. The 2015 NASA Technology Roadmaps expand and enhance the original roadmaps, providing extensive detail about anticipated mission-capability needs and associated technology-development needs. NASA believes sharing this document with the broader community will increase awareness, generate innovative solutions to provide the capabilities for space exploration and scientific discovery, and inspire others to get involved in America's space program.

NASA is leading the way with a balanced program of space exploration, aeronautics, and science research to enhance knowledge, education, economic vitality, and stewardship of the Earth. Innovation and invention of new technologies are the necessary elements that will facilitate this progress and shape our future. NASA's technologies will enable us to operate the International Space Station and prepare for human exploration beyond low-Earth orbit. Technologies will allow us to explore the Earth-Sun system, our own solar system, and the universe. They will also enable us to create safer, more secure, efficient, and environmentally friendlier air transportation systems.

NASA's ambitious missions require that we expand the frontiers of our technological capabilities to tackle our difficult problems. For space exploration, creating an environment for humans to live and work in space, navigating and traveling to distant locations, manufacturing products in space, landing on and departing from planetary surfaces, and quickly communicating between the Earth and space systems are some of the formidable technology hurdles to be conquered before the first boot print is left on Mars. For Aeronautics, the challenges are equally daunting as we create high-fidelity, integrated, distributed simulation systems; next generation air traffic control; and next generation vehicles; all working to ensure the Nation and world safely and efficiently accommodate the ever increasing commercial air traffic while reducing noise and carbon output.

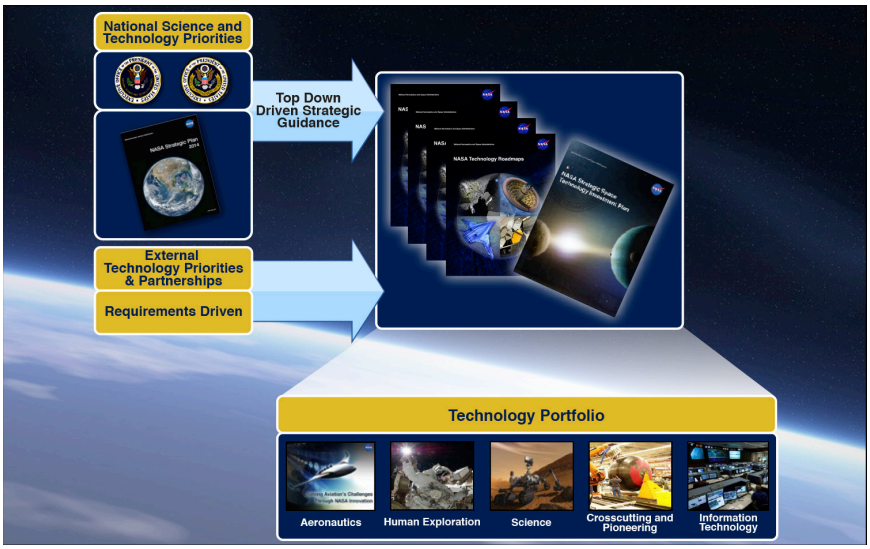


Figure 1. Illustration that represents the contents of the NASA technology portfolio, top-down direction from the Office of Science Technology and Policy, and bottoms-up requirements from NASA's missions, and external stakeholders

Success in executing NASA's missions requires solutions to these and many other difficult technical challenges, building on proven capabilities and creating new capabilities. These new capabilities will arise from the development of cutting-edge technologies. Technologies that have the potential to enable or enhance a NASA mission are referred to as "Technology Candidates" in this set of Technology Roadmaps.

These Technology Roadmaps are a set of documents that consider a wide range of needed technology candidates and development pathways for the next 20 years (2015-2035). The roadmaps focus on applied research and development activities. The roadmaps are comprised of an introduction section, which includes a discussion of key crosscutting technologies, and 15 distinct Technology Area (TA) roadmaps. This first section provides an introduction to the Technology Roadmaps and highlights some of the technology candidates that are encompassed in more than one Technology Area. This first section also includes an index of technology candidates that may enable or enhance individual planned missions and conceptual Design Reference Mission (DRMs). Technologies that support NASA's missions may also support science and exploration missions conducted by the commercial space industry and other government agencies. In addition, NASA technology development results in applications for the general population including devices that improve health, medicine, transportation, public safety and consumer goods.

NASA's Technology Roadmaps are one element of an integrated Agency-wide technology portfolio management process. The technology portfolio receives top-down direction from the Executive Office of the President via Executive Orders, the National Science and Technology Priorities, and the NASA Strategic Plan (see Figure 1). The NASA Strategic Technology Investment Plan (STIP), provides the prioritization and guiding principles of investment for the technology portfolio.

NASA's technology portfolio includes technology development programs and projects from each mission directorate and office that develops technology. This portfolio spans the entire technology maturity life cycle, including a combination of early-stage conceptual studies that are discovering entirely new technologies (technology readiness level (TRL) 1-2); rapid competitive development and ground-based testing to determine feasibility (TRL 3-5); and flight demonstrations in a relevant environment to complete the final step toward mission infusion (TRL 5-7). The portfolio encompasses both near- and long-term development and enables the discovery and advancement of necessary technologies that may fundamentally change the way we live and explore our world and the universe.

To optimize the technology portfolio, NASA is working to align its mission directorates' technology investments to minimize duplication and lower cost while providing critical capabilities that support missions and longer-term national needs. NASA is accomplishing this by identifying and describing the types of capabilities and performance goals needed by each mission. The goals are compared against the state of the art and potential technologies to determine if there is a capability gap. Where a gap exists, technologies are identified that could fill this gap. The Technology Roadmaps provide a description of state of the art capabilities, the performance goals, the proposed technologies to fill identified gaps, and the potential benefits of those technologies. The roadmaps also identify the list of missions where a specific technology candidate may be appropriate.

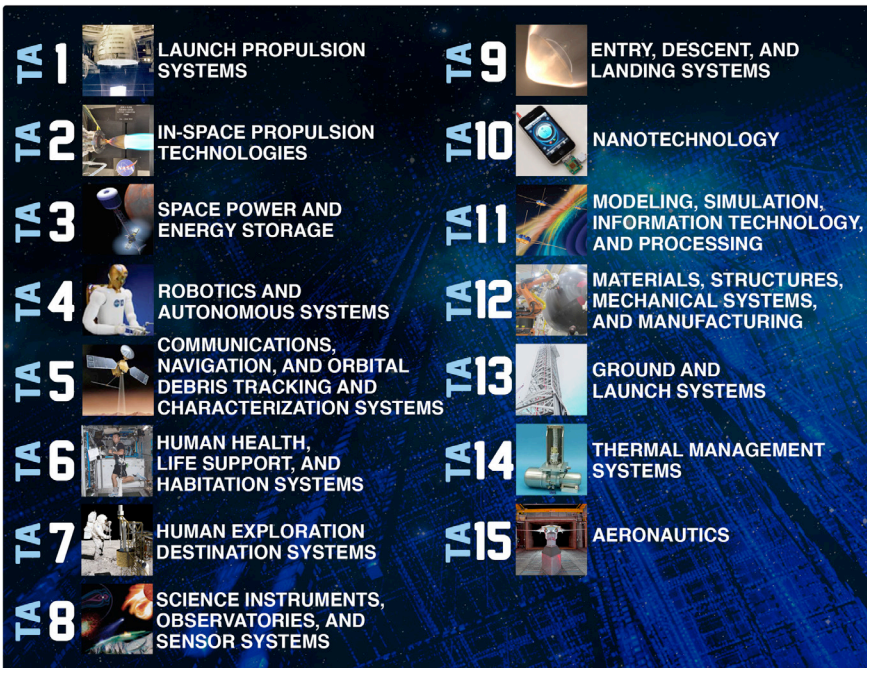


Figure 2. NASA's Roadmap Technology Areas

The Technology Roadmaps are a foundational element of NASA's technology portfolio management process. They contain the possible technology candidates that NASA could develop (Figure 2.) However, there are many more technology candidates than NASA can afford. Consequently, the Agency must prioritize the candidates, and identify those that provide the most benefit to NASA and the Nation. Today, this prioritization is documented in the Strategic Space Technology Investment Plan (SSTIP).

The SSTIP was created by NASA following careful review of the 2012 draft roadmaps by the National Research Council (NRC), and incorporated the recommended priorities from the NRC, combined with input from the public and key stakeholders. The SSTIP is updated every two years to address advances in technology and changing Agency needs. The next version of the SSTIP will include all NASA developed technologies and be called the NASA Strategic Technology Investment Plan (STIP), acknowledging the expanded content of the updated technology roadmaps.

With these technology priorities in hand, NASA uses a senior decision-making body, the NASA Technology Executive Council (NTEC), to make decisions on NASA's technology policy, prioritization, and strategic investments. This Council meets quarterly to evaluate the portfolio; weigh it against the priorities; identify gaps in needed capability and technical solutions; assess technical progress against capability needs; and identify strategies to grow new technical solutions. The STIP coupled with the NTEC decisions directly impact NASA technology investments internally through NASA's budget process and externally through Requests for Information (RFI), Announcements of Opportunity (AO), NASA Research Announcements (NRAs), grants, fellowships, prizes, and challenges.

Once technology investments are made, they are tracked and analyzed in TechPort, a web-based software system that serves as NASA's integrated Agency technology data source and decision support tool. The relational database enables NASA to compare the current portfolio against the Agency's priorities, provide results to NTEC and other decision bodies, and enable efficient management of the portfolio content (Figure 3).

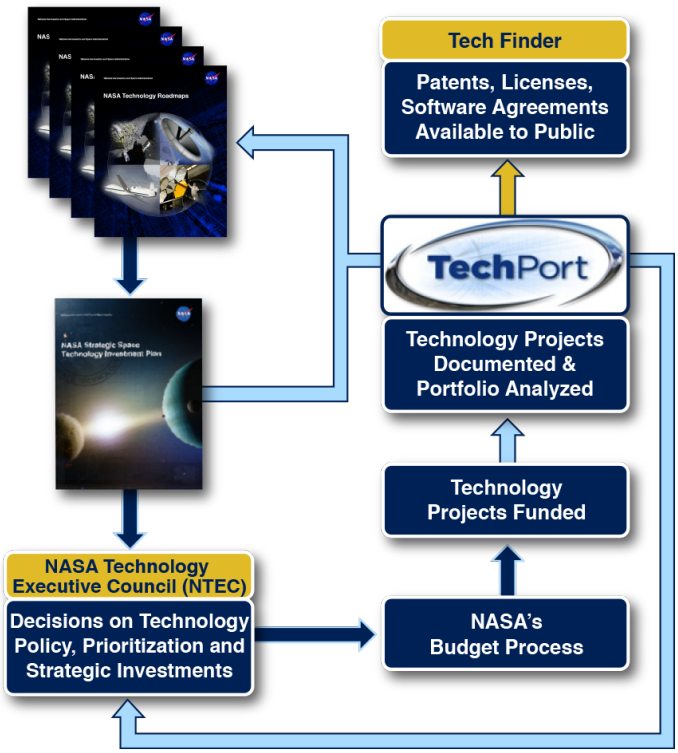


Figure 3. NASA's Technology Portfolio Management Process

TechPort is the public's first comprehensive resource for locating information about NASA-funded technology development activities. This system enables the public to explore NASA's technology portfolio and learn about technology Programs and Projects, as NASA works to mature technologies for aeronautics, space exploration, and scientific discovery missions. It also enables researchers, scientists, industry, and other government agencies to obtain a brief description, and information about the management team, technology readiness level, anticipated benefits, contributing partners, and locations where work is performed. To access TechPort, go to http://techport.nasa.gov.

NASA's future success will be determined largely by the investments and innovations we make in scientific research and technology. NASA's focus has always been to discover, invent, and demonstrate new technologies that will allow our Nation to explore space, advance aeronautics, and improve life on Earth. This is our passion, our purpose, and what drives our Vision and Mission.

2015 Technology Roadmap Outline

The 2015 NASA Technology Roadmaps are comprised of 16 sections: The Introduction, Crosscutting Technologies, and Index section; and 15 distinct Technology Area (TA) roadmaps (Figure 2).

Section 1: Introduction, Crosscutting Technologies, and Index

Section 2: TA1 Launch Propulsion Systems

Section 3: TA 2 In-Space Propulsion Technologies

Section 4: TA 3 Space Power and Energy Storage

Section 5: TA 4 Robotics and Autonomous Systems

Section 6: TA 5 Communications, Navigation, and Orbital Debris Tracking and Characterization Systems

Section 7: TA 6 Human Health, Life Support, and Habitation Systems

Section 8: TA 7 Human Exploration Destination Systems

Section 9: TA 8 Science Instruments, Observatories, and Sensor Systems

Section 10: TA 9 Entry, Descent, and Landing Systems

Section 11: TA 10 Nanotechnology

Section 12: TA 11 Modeling, Simulation, Information Technology and Processing

Section 13: TA 12 Materials, Structures, Mechanical Systems, and Manufacturing

Section 14: TA 13 Ground and Launch Systems

Section 15: TA 14 Thermal Management Systems

Section 16: TA 15 Aeronautics

Section 1 provides an overview of the roadmap contents and development process. It also contains a description of crosscutting technology areas, such as, but not limited to, avionics, autonomy, information technology, radiation, and space weather. Because each of these crosscutting technologies span across more than one Technology Area, section 1 provides a list of the crosscutting Technology Candidate Snapshots in each Technology Area. This first section also includes an index of technology candidates that may enable or enhance individual planned missions and conceptual Design Reference Mission (DRMs), see Appendix E.

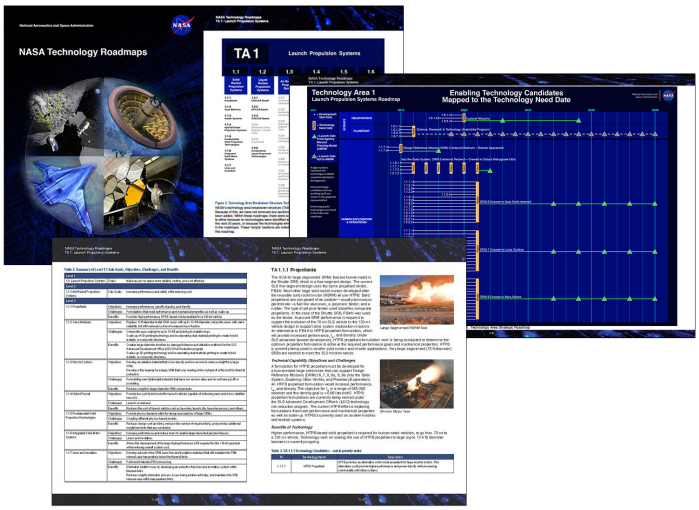


Figure 4: A look into one of the roadmap documents

The remaining sections of the roadmap correspond to the 15 Technology Areas. Each Technology Area contains an executive summary, a set of overarching goals and challenges, a roadmap graphic, a Technology Area Breakdown Structure (TABS) graphic, detailed discussions, and associated Technology Candidate Snapshots (Figure 4). In addition, each Technology Area roadmap section includes an appendix with acronyms, and an appendix with units.

Each Technology Area has a set of Technology Candidate Snapshots (Figure 5). The technology candidate is an individual technology nominee with the potential to support a planned or conceptual NASA Design Reference Mission(s). The Technology Candidate Snapshot includes the following information about the technology being considered:

1. Technology, including a description, challenge, dependencies, state of the art performance level, and a technology performance goal;
2. Capability needed, including a description, state of the art performance level, and a capability performance goal; and
3. Mission linkages, including the launch date (if determined), the technology need date, and the estimated time to mature the technology.

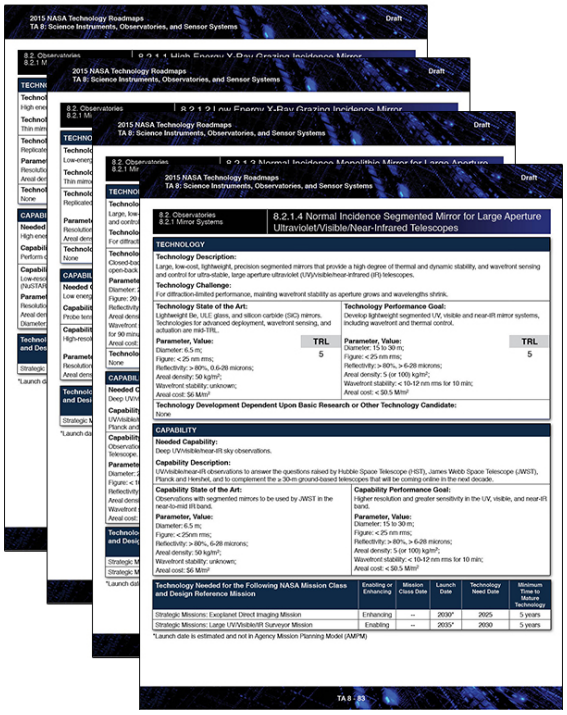


Figure 5: The Technology Candidate Snapshots

For each mission, the technology candidate is designated as enabling (a pull technology) or enhancing (a push technology). Enabling technology candidates satisfy a capability need for a space mission or aeronautics roadmap outcome by providing the desired performance within acceptable cost and risk. The enhancing technology candidates provide significant benefits over the current state of the art, but are not required for a specific mission or aeronautics roadmap outcome. These push technology candidates include emerging or radically different ideas or approaches and often take years to advance, but can inspire new and different missions and mission architectures to accomplish long-term strategic goals. Each Technology Candidate Snapshot includes all associated missions and aeronautics outcomes, and as a result may be enabling for some, and enhancing for others, depending on the desired capability, performance levels, and need date. For conceptual missions, the performance goals are loosely defined in the Technology Candidate Snapshot**s.**

A full list of the human exploration and science DRMs and aeronautics roadmap outcomes are found in Appendix D. Launch dates are included if the human exploration and science missions are documented in the Agency Mission Planning Model (AMPM). These dates (shown in Appendix D and on the snapshots) are aligned with NASA's fiscal year 2015 Congressional request. Launch dates in 2016-2020 are notional. Consistent with the AMPM, launch dates beyond 2020 are tentative.

Science Decadals

NASA relies on the science community to identify and prioritize leading-edge scientific questions and the observations required to answer them. One principal means by which NASA's Science Mission Directorate engages the science community in this task is through the National Research Council (NRC).

2013 – Visions and Voyages for Planetary Science*

2012 – Solar and Space Physics: A Science for a Technological Society*

2010 – New Worlds, New Horizons in Astronomy and Astrophysics*

2007 – Earth Science and Applications from Space: National Imperatives for the Next Decade and Beyond

Figure 6. Science Decadals

In addition to the planned missions in the AMPM, NASA's Human Exploration and Operations Mission Directorate and Science Mission Directorate provided a list of conceptual Design Reference Missions. The Human Exploration mission classes and Design Reference Missions are derived from NASA's capability driven framework and human spaceflight architecture studies. The Science mission classes and associated Design Reference Missions are derived from the Science Decadals (Figure 6) and subsequent Science Plans. Aeronautics content is derived from the Thrust Areas and Aeronautics Research and Development Plans.

Technology Roadmap Development Process

2012 Space Technology Roadmap Process

The effort to develop the Technology Roadmaps began in 2010 when NASA identified 14 Technology Areas, including the Technology Areas' top technical challenges and the spaceflight missions the technologies could impact or enable. The set of draft roadmaps, which covered both human and robotic technologies, was distributed publicly in December 2010. At the same time, NASA contracted the National Research Council (NRC) to perform an independent critique of the draft roadmaps. The NRC established evaluation criteria, identified gaps, and recommended priorities. The NRC's final report, NASA Space Technology Roadmaps and Priorities: Restoring NASA's Technological Edge and Paving the Way for a New Era in Space, was released early in 2012. NASA then augmented the roadmaps with a new section that summarized the NRC's recommendations and comments about the Technology Areas. The final versions where released to the public in April 2012. In addition, the technology priorities recommended by the NRC heavily influenced NASA's 2013 Strategic Space Technology Investment Plan (SSTIP), which prioritized the technology investments outlined in the roadmaps.

Figure 7. NASA Administrator Charles Bolden (center) inspects a Jacquard loom operating at Bally Ribbon Mills in Bally, Pennsylvania, on January 9, 2015. The loom is weaving a 3-D Quartz material that will be used as a key component in Orion's thermal protection heat shield.

2015 Technology Roadmap Development Process

NASA began the effort to update the Technology Roadmaps by determining how the development process, roadmap scope, and roadmap content could be improved. NASA held a series of NASA Technology Executive Council (NTEC) meetings to discuss the roadmap development process and determine the scope of Technology Area 15: Aeronautics, and the scope of the information technology section in Technology Area 11: Modeling, Simulation, Information Technology, and Processing.

In June 2013, NASA hosted a Technical Interchange Meeting with invited professionals from academia, commercial industry and other government agencies to gather input on the NASA's technology portfolio management process, including development of the technology roadmaps and prioritization of future work. Participants provided overviews of their processes, and suggested improvements and enhancements from which NASA could benefit. Similarly, the NASA Center Technology Council (CTC) provided feedback on the 2012 roadmap development process and content.

Using the decisions from NTEC, and the input from the CTC and external stakeholders, NASA made improvements to the development process and the roadmaps content and format. The roadmap process was enhanced by involving the NASA Centers, Mission Directorates and Offices in the identification and selection of the roadmap development team members, and in the review of draft roadmaps. Additionally, the process was improved by adding reviews by external federal agencies.

In 2014, the Technology Roadmap development team was formed. The team used a systematic process to create the draft roadmaps (Figure 8).

Figure 8. Roadmap development process

The roadmap team was provided with a list of Mission Classes and associated planned missions and conceptual Design Reference Missions (DRMs) from the Human Exploration and Operations Mission Directorate (HEOMD) and Science Mission Directorate (SMD); and a list of Aeronautic Thrusts from the Aeronautics Research Mission Directorate (ARMD). Using these lists (found in Appendix D), and detailed supporting information from the HEOMD Human Architecture Team, the HEOMD Systems Maturation Team, the Science Decadals and the Aeronautics Research Plan, the roadmap team documented the capability needed to execute NASA's missions for the next 20 years. (For HEOMD, the Human Architecture Team and the Systems Maturation Team completed extensive work to identify the appropriate capabilities for the architectures that support the Design Reference Missions. The roadmap team worked with these groups to ensure that the capabilities were correctly translated to the appropriate technical areas in the 2015 NASA Technology Roadmaps). Together, the teams evaluated capability gaps and identified potential technologies that could best achieve the desired capabilities. For each potential technology, the roadmap team documented the technology state of the art (SOA) and appropriate technology candidates.

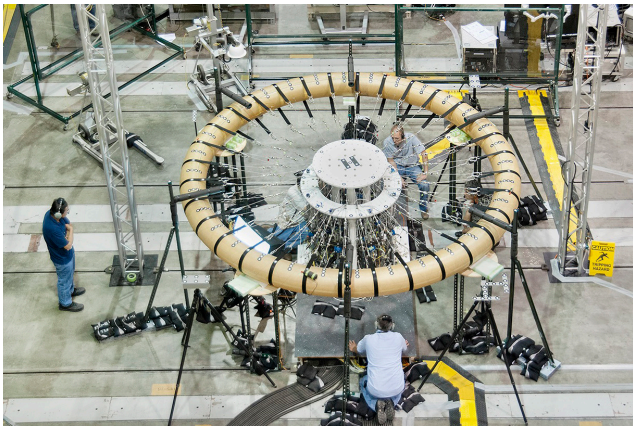


Figure 9. Technicians prepare the "donut" test article for the Hypersonic Inflatable Aerodynamic Decelerator structural loads testing in NASA's Flight Loads Laboratory.

For each technology candidate, the roadmap team created a Technology Candidate Snapshot, documenting the technology performance goal, capability performance goal and the associated missions and aeronautic strategic thrusts that could benefit from the development of the technology. The roadmap team developed Technology Candidate Snapshots for each of the 15 Technology Areas.

As the drafts roadmaps were being developed, NASA held meetings with other government agencies to obtain insights and verify that the Technology Candidate Snapshots correctly documented 'state of the art.' This also enabled NASA to obtain suggestions for technologies that might have been overlooked or missed. The roadmaps then went through a NASA-wide review, with each NASA center organizing the review of all the technical content for each of the 15 roadmaps. Comments were incorporated, as appropriate, and then NASA Headquarters reviewed the roadmaps.

In the spring of 2015, the roadmaps were released to the public for review and comment. This enabled NASA to incorporate input from other government agencies, commercial industry, academia, and the public. This review will ensure that NASA is aware of state of the art technologies and needs, and enable identification of other needed document improvements. The public review will also enable NASA to identify potential public benefits of NASA's technology investments. Mid-summer 2015, the National Research Council will conduct an independent review process of the draft 2015 NASA Technology Roadmaps.

What's New in the 2015 Technology Roadmaps

The 2015 Technology Roadmaps enhance and expand the 2012 Roadmaps responding to NASA's changing needs, advances in technology, and recommended improvements from the National Research Council and other stakeholders. The technologies outlined in these roadmaps focus on applied research and development activities and do not include basic research. These roadmaps include updates from Human Exploration and Operations, Science and Aeronautics by taking into account new Science Decadal Surveys and Plans; Human Architecture Team and Systems Maturation Team work; and Aeronautics Thrust Areas including research and development plans. Consistent with the NASA Strategic Technology Investment Plan, the Roadmaps will produce capabilities that accomplish NASA's goals: to extend and sustain human presence and activities in space; to expand understanding of the Earth and the universe; to explore the structure and origin, and evolution of the solar system and search for life past and present; and to energize the commercial space enterprise and extend benefits of space for the nations.

Some of the improvements include:

Expanded Scope

- New: TA15 Aeronautics
- 7 new level 2 Technology Areas
- 66 new level 3 Technology Areas
- 1,273 new Technology Candidate Snapshots (Level 4)
- More detail about crosscutting technologies

Enhancements

- Traceability to NASA mission concepts, capability needs and aeronautics strategic thrusts;
- A new Introduction, Crosscutting Technology, and Index section that describes the overall context and purpose of the roadmap document, the crosscutting technology areas and the technology candidates associated with each NASA mission concept; and
- Standard organization, definitions, and graphics across Technology Areas.

The 2015 Technology Roadmaps, excluding TA 15: Aeronautics, are built upon NASA's capability-driven framework (see Figure 10). This capability-driven approach is based on a set of core evolving capabilities that can be leveraged or reapplied, rather than specialized to enable one specific Design Reference Mission (DRM). This approach focuses on developing a set of capabilities through incremental steps that build, test, refine, and qualify capabilities that lead to flight elements, enabling exploration and scientific discovery at a set of destinations. The set of destinations make up a Mission Class. Developing a set of capabilities that enables more than one mission produces a more robust, affordable, and sustainable space program. Additionally, as NASA tackles increasingly complex missions farther and farther from the Earth, the capabilities can be incrementally advanced, producing a pathway that enables the more distant mission classes. For more information on the Capability Driven Framework and a full list of related capabilities please see the NASA report *Voyages: Charting the Course for Sustainable Human Space Exploration*.

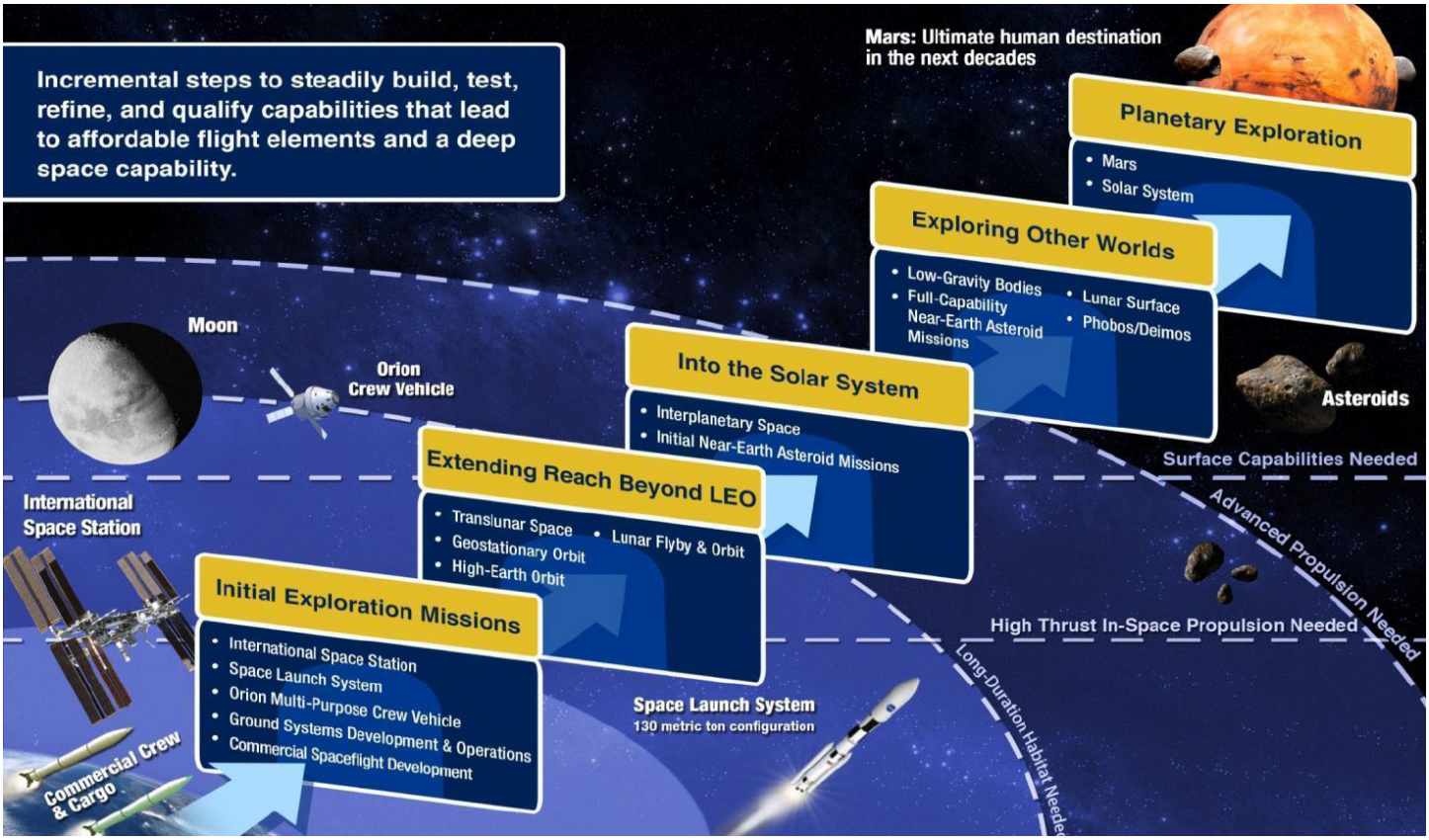


Figure 10. NASA's Capability Driven Framework

NASA is focused on developing a suite of core capabilities for space exploration and scientific discovery. Each capability serves a specific function, designed to solve an exploration challenge, to enable—in combination with other capabilities—unique possibilities for advancing exploration into our solar system. To meet this suite of core capabilities NASA will need to develop and advance technologies across the 15 Technology Areas. The roadmaps identify technologies that will help achieve the goals set out by the mission classes, Design Reference Missions, and capabilities needed to accomplish NASA's exploration, science, and aeronautics missions.

In addition to the new capability-driven focus, the roadmap has been expanded to include an additional Technology Area: TA15: Aeronautics, as well as the addition of 7 new level 2 areas and 66 additional level 3 areas. Areas highlighted by the National Research Council as needing more attention, such as but not limited to, avionics, autonomy, information technology, radiation, and space weather, were expanded to include more detail and highlighted in the crosscutting discussion.

The roadmap graphics have been standardized across all Technology Areas and illustrate technologies within an area that are enabling to each NASA Design Reference Mission. Technology candidates that are enhancing to missions are not shown on the graphic but can be found in the index (Appendix E) and the Technology Candidate Snapshots. Brand new Technology Candidate Snapshots provide consistent data and level of detail for all technologies in the roadmaps.

Changes to the Technology Area Breakdown Structure

The 2015 Technology Roadmap development activities are structured by the Technology Area Breakdown Structure (TABS). The TABS is a four-level hierarchy for grouping and organizing technology candidates. Figure 10 shows the complete breakdown of the TABS structure used in the 2015 Technology Roadmap. Level 1 represents the Technology Area, which is the title of a roadmap (e.g., TA1: Launch Propulsion Systems). Level 2 is a list of the subareas (e.g., TA1.1 Solid Rocket Propulsion Systems). Level 3 categorizes the types of technologies within the subareas (e.g., TA1.1.1 Propellants). Level 4 represents the individual Technology Candidate Snapshot (e.g. TA1.1.1.1 Hydroxyl-Terminated PolyButadiene (HTPB) Propellant).

The organization of the 2015 Technology Roadmap is nearly the same as the 2012 Space Technology Roadmaps, with consistent numbering for the Technology Areas. However, the TABs have a few major changes and a few minor modifications. The most notable differences are the inclusion of Technology Area 15: Aeronautics, the inclusion of Level 4 (the Technology Candidate Snapshots), and the addition of 7 new level 2 areas and 66 additional level 3 areas.

There are minor name changes that improve clarity and reduce duplication across the roadmaps. For example, a technology that was covered in two or more Technology Areas in the 2012 roadmaps is contained in only one Technology Area in the 2015 Technology roadmaps, and pointers direct the reader to the current location.

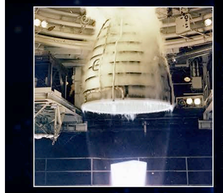
In some cases, previously identified technology needs no longer exist, due to advancement of technology since 2012, adequate existing capability, or changing Agency needs. In these cases, to maintain consistency in the TABS numbering with the previous 2012 TABS, the numbering and Technology Area title remain the same and a short note is provided.

Appendix F provides a comparison of the 2012 Technology Area Breakdown Structure and the 2015 Technology Area Breakdown Structure.

DRAFT

National Aeronautics and Space Administration

NASA



TA1 LAUNCH PROPULSION SYSTEMS

1.1 SOLID ROCKET PROPULSION SYSTEMS
- Propellants
- Case Materials
- Nozzle Systems
- Hybrid Rocket Propulsion Systems
- Fundamental Solid Propulsion Technologies
- Integrated Solid Motor Systems
- Liner and Insulation

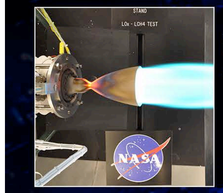
1.2 LIQUID ROCKET PROPULSION SYSTEMS
- LH2/LOX Based
- RP/LOX Based
- CH4/LOX Based
- Detonation Wave Engines – Closed Cycle
- Propellants
- Fundamental Liquid Propulsion Technologies

1.3 AIR BREATHING PROPULSION SYSTEMS
- Turbine-Based Combined Cycle
- Rocket-Based Combined Cycle
- Detonation Wave Engines – Open Cycle
- Turbine-Based Jet Engines
- Ramjet and Scramjet Engines
- Deeply-Cooled Air Cycles
- Air Collection and Enrichment Systems
- Fundamental Air Breathing Propulsion Technologies

1.4 ANCILLARY PROPULSION SYSTEMS
- Auxiliary Control Systems
- Main Propulsion Systems (Excluding Engines)
- Launch Abort Systems
- Thrust Vector Control Systems
- Health Management and Sensors
- Pyro and Separation Systems
- Fundamental Ancillary Propulsion Technologies

1.5 UNCONVENTIONAL AND OTHER PROPULSION SYSTEMS
- Ground Launch Assist
- Air Launch and Drop Systems
- Space Tether Assist
- Beamed Energy and Energy Addition
- Nuclear
- High Energy Density Materials and Propellants

1.6 BALLOON LAUNCH SYSTEMS
- Super-Pressure Balloon
- Materials
- Pointing Systems
- Telemetry Systems
- Balloon Trajectory Control
- Power Systems
- Mechanical Systems: Launch Systems
- Mechanical Systems: Parachute
- Mechanical Systems: Floatation



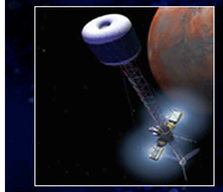
TA2 IN-SPACE PROPULSION TECHNOLOGIES

2.1 CHEMICAL PROPULSION
- Liquid Storable
- Liquid Cryogenic
- Gels
- Solids
- Hybrid
- Cold Gas/Warm Gas
- Micropropulsion

2.2 NON-CHEMICAL PROPULSION
- Electric Propulsion
- Solar and Drag Sail Propulsion
- Thermal Propulsion
- Tether Propulsion

2.3 ADVANCED (TRL<3) PROPULSION TECHNOLOGIES
- Beamed Energy Propulsion
- Electric Sail Propulsion
- Fusion Propulsion
- High-Energy-Density Materials
- Antimatter Propulsion
- Advanced Fission
- Breakthrough Propulsion

2.4 SUPPORTING TECHNOLOGIES
- Engine Health Monitoring and Safety
- Propellant Storage and Transfer
- Materials and Manufacturing Technologies
- Heat Rejection
- Power



TA3 SPACE POWER AND ENERGY STORAGE

3.1 POWER GENERATION
- Energy Harvesting
- Chemical
- Solar
- Radioisotope
- Fission
- Fusion

3.2 ENERGY STORAGE
- Batteries
- Flywheels
- Regenerative Fuel Cells
- Capacitors

3.3 POWER MANAGEMENT AND DISTRIBUTION
- Fault Detection, Isolation, and Recovery
- Management and Control
- Distribution and Transmission
- Wireless Power Transmission
- Conversion and Regulation

3.4 CROSS CUTTING TECHNOLOGY
- Analytical Tools
- Green Energy Impact
- Multi-Functional Structures
- Alternative Fuels

TA4 ROBOTICS AND AUTONOMOUS SYSTEMS

4.1 SENSING AND PERCEPTION
- 3D Sensing
- State Estimation
- Onboard Mapping
- Object, Event, and Activity Recognition
- Force and Tactile Sensing
- Onboard Science Data Analysis

4.2 MOBILITY
- Extreme-Terrain Mobility
- Below-Surface Mobility
- Above-Surface Mobility
- Small-Body and Microgravity Mobility
- Surface Mobility
- Robot Navigation
- Collaborative Mobility
- Mobility Components

4.3 MANIPULATION
- Manipulator Components
- Dexterous Manipulation
- Modeling of Contact Dynamics
- Mobile Manipulation
- Collaborative Manipulation
- Sample Acquisition and Handling
- Grappling

4.4 HUMAN-SYSTEM INTERACTION
- Multi-Modal Interaction
- Supervisory Control
- Proximate Interaction
- Intent Recognition and Reaction
- Distributed Collaboration and Coordination
- Common and Standard Human-System Interfaces
- Safety, Trust, and Interfacing of Robotic and Human Proximity Operations
- Remote Interaction

4.5 SYSTEM-LEVEL AUTONOMY
- System Health Management
- Activity Planning, Scheduling, and Execution
- Autonomous Guidance and Control
- Multi-Agent Coordination
- Adjustable Autonomy
- Terrain Relative Navigation
- Path and Motion Planning with Uncertainty
- Automated Data Analysis for Decision Making

4.6 AUTONOMOUS RENDEZVOUS AND DOCKING
- Relative Navigation Sensors
- GN&C Algorithms
- Docking and Capture Mechanisms and Interfaces
- Mission and System Managers for Autonomy and Automation

4.7 SYSTEMS ENGINEERING
- Modularity, Commonality, and Interfaces
- Verification and Validation of Complex Adaptive Systems
- Robot Modeling and Simulation
- Robot Software
- Safety and Trust

TA5 COMMUNICATIONS, NAVIGATION, AND ORBITAL DEBRIS TRACKING AND CHARACTERIZATION SYSTEMS

5.1 OPTICAL COMMUNICATIONS AND NAVIGATION
- Detector Development
- Large Apertures
- Lasers
- Acquisition and Tracking
- Atmospheric Mitigation
- Optical Tracking
- Integrated Photonics

5.2 RADIO FREQUENCY COMMUNICATIONS
- Spectrum-Efficient Technologies
- Power-Efficient Technologies
- Propagation
- Flight and Ground Systems
- Earth Launch and Re-Entry Communications
- Antennas

5.3 INTERNETWORKING
- Disruption-Tolerant Networking
- Adaptive Network Topology
- Information Assurance
- Integrated Network Management

5.4 POSITION, NAVIGATION, AND TIMING
- Timekeeping and Time Distribution
- Onboard Auto Navigation and Maneuver
- Sensors and Vision Processing Systems
- Relative and Proximity Navigation
- Auto Precision Formation Flying
- Autonomous Approach and Landing

5.5 INTEGRATED TECHNOLOGIES
- Radio Systems
- Ultra Wideband
- Cognitive Networks
- Science from the Communications System
- Hybrid Optical Communications and Navigation Sensors
- Radio Frequency and Optical Hybrid Technology

5.6 REVOLUTIONARY CONCEPTS
- X-Ray Navigation
- X-Ray Communications
- Neutrino-Based Navigation and Tracking
- Quantum Key Distribution
- Quantum Communications
- Superconducting Quantum Interference Filter Microwave Amplifier
- Reconfigurable Large Apertures

5.7 ORBITAL DEBRIS TRACKING AND CHARACTERIZATION
- Tracking Technologies
- Characterization Technologies

TA6 HUMAN HEALTH, LIFE SUPPORT, AND HABITATION SYSTEMS

6.1 ENVIRONMENTAL CONTROL AND LIFE SUPPORT SYSTEMS AND HABITATION SYSTEMS
- Air Revitalization
- Water Recovery and Management
- Waste Management
- Habitation

6.2 EXTRAVEHICULAR ACTIVITY SYSTEMS
- Pressure Garment
- Portable Life Support System
- Power, Avionics, and Software

6.3 HUMAN HEALTH AND PERFORMANCE
- Medical Diagnosis and Prognosis
- Long-Duration Health
- Behavioral Health
- Human Factors

6.4 ENVIRONMENTAL MONITORING, SAFETY, AND EMERGENCY RESPONSE
- Sensors: Air, Water, Microbial, and Acoustic
- Fire: Detection, Suppression, and Recovery
- Protective Clothing and Breathing
- Remediation

6.5 RADIATION
- Risk Assessment Modeling
- Radiation Mitigation and Biological Countermeasures
- Protection Systems
- Space Weather Prediction
- Monitoring Technology

TA7 HUMAN EXPLORATION DESTINATION SYSTEMS

7.1 IN-SITU RESOURCE UTILIZATION
- Destination Reconnaissance, Prospecting, and Mapping
- Resource Acquisition
- Processing and Production
- Manufacturing Products and Infrastructure Emplacement

7.2 SUSTAINABILITY AND SUPPORTABILITY
- Autonomous Logistics Management
- Maintenance Systems
- Repair Systems
- Food Production, Processing, and Preservation

7.3 HUMAN MOBILITY SYSTEMS
- EVA Mobility
- Surface Mobility
- Off-Surface Mobility

7.4 HABITAT SYSTEMS
- Integrated Habitat Systems
- Habitat Evolution
- "Smart" Habitats
- Artificial Gravity

7.5 MISSION OPERATIONS AND SAFETY
- Crew Training
- Planetary Protection
- Integrated Flight Operations Systems
- Integrated Risk Assessment Tools

7.6 CROSS-CUTTING SYSTEMS
- Particulate Contamination Prevention and Mitigation
- Construction and Assembly

TA8 SCIENCE INSTRUMENTS, OBSERVATORIES, AND SENSOR SYSTEMS

8.1 REMOTE SENSING INSTRUMENTS AND SENSORS
- Detectors and Focal Planes
- Electronics
- Optical Components
- Microwave, Millimeter-, and Submillimeter- Waves
- Lasers
- Cryogenic / Thermal

8.2 OBSERVATORIES
- Mirror Systems
- Structures and Antennas
- Distributed Aperture

8.3 IN-SITU INSTRUMENTS AND SENSORS
- Field and Particle Detectors
- Fields and Waves
- In-Situ (other)

TA9 ENTRY, DESCENT, AND LANDING SYSTEMS

9.1 AEROASSIST AND ATMOSPHERIC ENTRY
- Thermal Protection Systems for Rigid Decelerators
- Thermal Protection Systems for Deployable Decelerators
- Rigid Hypersonic Decelerators
- Deployable Hypersonic Decelerators
- Instrumentation and Health Monitoring
- Entry Modeling and Simulation

9.2 DESCENT AND TARGETING
- Attached Deployable Decelerators
- Trailing Deployable Decelerators
- Supersonic Retropropulsion
- GN&C Sensors
- Descent Modeling and Simulation
- Large Divert Guidance
- Terrain-Relative Sensing and Characterization
- Autonomous Targeting

9.3 LANDING
- Propulsion and Touchdown Systems
- Egress and Deployment Systems
- Propulsion Systems
- Large Body GN&C
- Small Body Systems
- Landing Modeling and Simulation

9.4 VEHICLE SYSTEMS
- Architecture Analysis
- Separation Systems
- System Integration and Analysis
- Atmosphere and Surface Characterization
- Modeling and Simulation
- Instrumentation and Health Monitoring
- GN&C Sensors and Systems

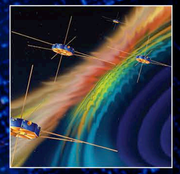
TA10 NANOTECHNOLOGY

10.1 ENGINEERED MATERIALS AND STRUCTURES
- Lightweight Structures
- Damage-Tolerant Systems
- Coatings
- Adhesives
- Thermal Protection and Control

10.2 ENERGY STORAGE, POWER GENERATION, AND POWER DISTRIBUTION
- Energy Storage
- Power Generation
- Power Distribution

10.3 PROPULSION
- Propellants
- Propulsion Components
- In-Space Propulsion

10.4 SENSORS, ELECTRONICS, AND DEVICES
- Sensors and Actuators
- Nanoelectronics
- Miniature Instruments and Instrument Components



TA11 MODELING, SIMULATION, INFORMATION TECHNOLOGY AND PROCESSING

11.1 COMPUTING
- Flight Computing
- Ground Computing

11.2 MODELING
- Software Modeling and Model Checking
- Integrated Hardware and Software Modeling
- Human-System Performance Modeling
- Science Modeling
- Frameworks, Languages, Tools, and Standards
- Analysis Tools for Mission Design

11.3 SIMULATION
- Distributed Simulation
- Integrated System Lifecycle Simulation
- Simulation-Based Systems Engineering
- Simulation-Based Training and Decision Support Systems
- Exascale Simulation
- Uncertainty Quantification and Nondeterministic Simulation Methods
- Multiscale, Multiphysics, and Multifidelity Simulation
- Verification and Validation

11.4 INFORMATION PROCESSING
- Science, Engineering, and Mission Data Lifecycle
- Intelligent Data Understanding
- Semantic Technologies
- Collaborative Science and Engineering
- Advanced Mission Systems
- Cyber Infrastructure
- Human-System Integration
- Cyber Security

TA12 MATERIALS, STRUCTURES, MECHANICAL SYSTEMS AND MANUFACTURING

12.1 MATERIALS
- Lightweight Structural Materials
- Computationally-Designed Materials
- Flexible Material Systems
- Materials for Extreme Environments
- Special Materials

12.2 STRUCTURES
- Lightweight Concepts
- Design and Certification Methods
- Reliability and Sustainment
- Test Tools and Methods
- Innovative, Multifunctional Concepts
- Loads and Environments

12.3 MECHANICAL SYSTEMS
- Deployables, Docking, and Interfaces
- Mechanism Life Extension Systems
- Electro-Mechanical, Mechanical, and Micromechanisms
- Design and Analysis Tools and Methods
- Reliability, Life Assessment, and Health Monitoring
- Certification Methods

12.4 MANUFACTURING
- Manufacturing Processes
- Intelligent Integrated Manufacturing and Cyber Physical Systems
- Electronics and Optics Manufacturing Process
- Sustainable Manufacturing
- Nondestructive Evaluation and Sensors

12.5 CROSS-CUTTING

TA13 GROUND AND LAUNCH SYSTEMS

13.1 OPERATIONAL LIFE-CYCLE
- On-Site Production, Storage, Distribution, and Conservation of Fluids
- Automated Alignment, Coupling, Assembly, and Transportation Systems
- Autonomous Command and Control for Integrated Vehicle and Ground Systems
- Logistics

13.2 ENVIRONMENTAL PROTECTION AND GREEN TECHNOLOGIES
- Corrosion Prevention, Detection, and Mitigation
- Environmental Remediation and Site Restoration
- Preservation of Natural Ecosystems
- Alternate Energy Prototypes
- Curatorial Facilities, Planetary Protection, and Clean Rooms

13.3 RELIABILITY AND MAINTAINABILITY
- Launch Infrastructure
- Environment-Hardened Materials and Structures
- On-Site Inspection and Anomaly Detection and Identification
- Fault Isolation and Diagnostics
- Prognostics
- Repair, Mitigation, and Recovery Technologies
- Communications, Networking, Timing, and Telemetry
- Decision-Making Tools

13.4 MISSION SUCCESS
- Range Tracking, Surveillance, and Flight Safety Technologies
- Landing and Recovery Systems and Components
- Weather Prediction and Mitigation
- Robotics and Telerobotics
- Safety Systems

TA14 THERMAL MANAGEMENT SYSTEMS

14.1 CRYOGENIC SYSTEMS
- Passive Thermal Control
- Active Thermal Control
- Integration and Modeling

14.2 THERMAL CONTROL SYSTEMS
- Heat Acquisition
- Heat Transport
- Heat Rejection and Energy Storage

14.3 THERMAL PROTECTION SYSTEMS
- Ascent/Entry TPS
- TPS Modeling and Simulation
- TPS Sensors and Measurement Systems

TA15 AERONAUTICS

15.1 SAFE, EFFICIENT, GROWTH IN GLOBAL AVIATION
- Improved Efficiency and Hazard Reduction within NextGen Operational Domains
- System-Wide Safety, Predictability, and Reliability through Full NextGen Functionality

15.2 INNOVATION IN COMMERCIAL SUPERSONIC AIRCRAFT
- Supersonic Overland Certification Standard Based on Acceptable Sonic Boom Noise
- Introduction of Affordable, Low-Boom, Low-Noise, and Low-Emission Supersonic Transports

15.3 ULTRA-EFFICIENT COMMERCIAL VEHICLES
- Achieve Community Goals for Improved Vehicle Efficiency and Environmental Performance in 2025
- Achieve Community Goals for Improved Vertical Lift Vehicle Efficiency and Environmental Performance in 2035
- Achieve Community Goals for Improved Vehicle Efficiency and Environmental Performance Beyond 2035

15.4 TRANSITION TO LOW-CARBON PROPULSION
- Introduction of Low-Carbon Fuels for Conventional Engines and Exploration of Alternative Propulsion Systems
- Initial Introduction of Alternative Propulsion Systems

15.5 REAL-TIME SYSTEM-WIDE SAFETY ASSURANCE
- Introduction of Advanced Safety Assurance Tools
- An Integrated Safety Assurance System Enabling Continuous System-Wide Safety Monitoring
- Automated Safety Assurance Integrated with Real-Time Operations Enabling a Self-Protecting Aviation System

15.6 ENABLE ASSURED MACHINE AUTONOMY FOR AVIATION
- Initial Autonomy Applications
- Ability to Fully Certify and Trust Autonomous Systems for NAS Operations

The areas noted in gray above reflect sections of the TABS with no identified technology candidates. This is either because no new technologies were identified for development within the next 20 years, or because the technologies which were previously in this section are now being addressed elsewhere in the roadmaps.

Figure 11. 2015 Technology Area Breakdown Structure (TABS)

Technology Topics that Cross Multiple Technology Areas

The 2015 NASA Technology Roadmaps use the Technology Area Breakdown Structure (TABS) from the 2012 roadmapping efforts. Taxonomies, such as the TABS, have long been used to give structure to large bodies of information. A well-formulated taxonomy organizes the information, making it easy to use. However, there are many ways to group information, and no Technology Area grouping produces a mutually exclusive list. Naturally, some technologies will be found in multiple groupings. For the 2015 NASA Technology Roadmaps, we call these 'crosscutting technologies' because they cross multiple roadmap Technology Areas.

In the NRC's evaluation of the 2012 Technology Roadmaps, it was noted that many technologies cut across the Technology Areas, and were uneven and incomplete. In an effort to address this finding, the 2015 NASA Technology Roadmaps included the Technology Candidate Snapshots, providing more complete information about each technology, and included this section. This section highlights specific crosscutting technologies, provides an expanded description, and lists each Technology Candidate Snapshot number in the roadmap that corresponds to the crosscutting technology.

Specifically addressed are:

- Autonomous Systems and Artificial Intelligence
- Avionics
- Extravehicular Activity
- Information Technology
- In-Situ Resource Utilization
- Orbital Debris
- Radiation and Space Weather
- Sensors
- Thermal Protection Systems

Autonomous Systems and Artificial Intelligence

Autonomy is the capacity of a system to achieve goals while operating independently from external control. Autonomy is enabled by automation, which is the automatically-controlled operation of an apparatus, process, or system using a pre-planned set of instructions (e.g., a command sequence). Autonomy is also facilitated by artificial intelligence techniques, which enable systems to reason and act in a rational manner to achieve specified goals. Autonomy is a critical crosscutting technology for improving the performance and reducing the risks for a wide range of NASA human exploration, robotic, and aeronautics applications. Autonomy can provide significant performance improvements, operational efficiencies, and other benefits to almost every Technology Area in the 2015 NASA Technology Roadmaps.

As exploration missions take humans deeper into space, autonomous systems will be needed to enable astronauts and their vehicles to function effectively and efficiently when operating independently of ground control. In particular, current Concepts of Operations (CONOPS), which are highly manual and ground control-centric, will need to be adapted to include autonomy at all levels. Deep-space human missions will require crews to be self-sufficient when communication with Earth is time delayed or not possible.

Future robotic missions will involve greater complexity and reactivity, which will require increased reliance on autonomy. Deep-space missions that target active, dynamic, or time-varying phenomena will need robots that can adaptively adjust their configurations and behavior to changing circumstances, and robustly handle uncertainty. Robotic missions to Near-Earth Asteroids (NEAs) will require the decision-making and monitoring processes—currently performed by ground control—to be performed by on-board autonomous systems.

In aeronautics, the increasing use of autonomy is driven by requirements to improve the affordability, efficiency, reliability, and safety of civil airspace, airports, and aircraft operations.

Technology development at NASA will focus on enabling autonomous capabilities in three areas:

1. New Autonomous Systems Technologies: Exploration of new technologies and applications to support development of model autonomy functions and concepts, including those supporting vehicle control, health management, adaptation, and multi-vehicle cooperation.
2. Integrated Reasoning and Decision Making: Leverage advances in the areas of cognitive computing and machine learning to integrate autonomous functions into effective human-machine cognitive architectures that provide maximum flexibility and address emergent properties of the system.
3. Verification and Validation of Autonomous Systems: Investigation of issues related to systems certification, and verification and validation to support efforts to promote trust in autonomous systems and acceptance of those systems by the public.

The table below lists the technology candidates where autonomous systems and artificial intelligence technologies can be located across the Technology Areas.

Technology Area	ENABLING Technology Candidate Snapshots Related to Autonomous Systems and Artificial Intelligence	ENHANCING Technology Candidate Snapshots Related to Autonomous Systems and Artificial Intelligence
TA 1 Launch Propulsion Systems	--	1.5.2.1
TA 2 In-Space Propulsion Systems	2.4.2.4	--
TA 3 Space Power and Energy Storage	3.1.3.1, 3.1.3.2, 3.1.3.3, 3.3.2.1	3.3.1.1
TA 4 Robotics and Autonomous Systems	4.1.1.1, 4.1.4.1, 4.1.4.2, 4.1.4.3, 4.2.6.2, 4.2.6.3, 4.2.6.4, 4.2.6.5, 4.3.5.1, 4.5.1.1, 4.5.1.2, 4.5.1.3, 4.5.2.1, 4.5.2.2, 4.5.2.3, 4.5.2.4, 4.5.2.5, 4.5.4.1, 4.5.8.1	4.2.6.1, 4.4.3.2, 4.4.5.1, 4.4.8.2, 4.7.4.1
TA 5 Communications, Navigation, and Orbital Debris Tracking and Characterization Systems	5.1.4.2, 5.2.6.2, 5.2.6.3, 5.2.6.4, 5.2.6.5, 5.2.6.6, 5.4.3.3, 5.4.3.4, 5.4.5.2, 5.4.6.2, 5.5.3.1, 5.6.1.1	5.1.5.1, 5.1.5.2, 5.2.1.1, 5.2.6.1, 5.3.1.1, 5.3.2.1, 5.3.2.2, 5.3.2.3, 5.4.3.1, 5.4.3.2, 5.4.5.1, 5.4.6.1, 5.5.1.1, 5.5.2.1
TA 6 Human Health, Life Support, and Habitation Systems	6.1.1.1, 6.1.1.2, 6.1.1.3, 6.1.1.4, 6.1.1.6, 6.1.1.7, 6.1.2.2, 6.1.2.3, 6.1.2.4, 6.1.3.1, 6.1.3.3, 6.1.3.4, 6.1.4.6, 6.3.1.8, 6.3.1.10	6.1.1.5, 6.1.2.1, 6.1.4.3, 6.1.4.10, 6.1.4.11
TA 7 Human Exploration Destination Systems	7.5.3.1, 7.5.3.2, 7.6.1.17	7.4.3.1, 7.4.3.2, 7.4.3.3
TA 8 Science Instruments, Observatories, and Sensor Systems	8.1.5.4, 8.1.5.8	8.1.4.4
TA 9 Entry, Descent, and Landing Systems	9.2.7.1, 9.2.7.2, 9.2.7.3, 9.2.8.2, 9.2.8.3, 9.2.8.4, 9.2.8.7, 9.2.8.8	9.2.8.5, 9.4.5.7
TA 10 Nanotechnology	10.1.1.3, 10.1.1.7, 10.1.1.8, 10.1.2.1, 10.1.2.2, 10.1.2.4, 10.1.4.1, 10.2.3.1, 10.3.1.4, 10.4.2.3	10.4.1.1, 10.4.1.2, 10.4.1.3, 10.4.1.4, 10.4.1.5, 10.4.1.6, 10.4.2.1, 10.4.2.2, 10.4.2.5, 10.4.2.6, 10.4.2.7, 10.4.3.5

TA 11 Modeling, Simulation, Information Technology, and Processing	11.1.1.3, 11.2.3.1, 11.2.3.2, 11.3.4.1, 11.4.3.3, 11.4.5.4, 11.4.7.2	11.2.2.3, 11.2.4.5, 11.2.6.4, 11.3.1.1, 11.3.1.5, 11.3.2.1, 11.3.2.2, 11.3.2.3, 11.3.3.1, 11.3.3.3, 11.3.3.4, 11.3.4.2, 11.4.2.2, 11.4.4.3, 11.4.5.1
TA 12 Materials, Structures, Mechanical Systems, and Manufacturing	12.2.1.4, 12.2.2.7, 12.2.3.3, 12.2.3.4, 12.2.3.5, 12.2.3.6, 12.2.5.7, 12.2.6.4, 12.2.6.5, 12.2.6.6, 12.3.1.5, 12.3.3.1, 12.3.3.2, 12.3.5.2, 12.3.5.4, 12.4.2.3, 12.4.5.1	12.1.5.3, 12.2.5.6, 12.3.6.4
TA 13 Ground and Launch Systems	13.2.5.5, 13.4.2.1, 13.4.2.2	13.1.3.1, 13.1.3.2, 13.1.3.12, 13.1.4.6, 13.3.1.4, 13.3.3.2, 13.3.4.1, 13.3.5.2, 13.3.5.3, 13.3.6.3, 13.3.6.4, 13.3.7.1, 13.3.8.1, 13.4.1.3, 13.4.1.8, 13.4.3.3
TA 14 Thermal Management Systems	14.3.3.1	14.3.1.5, 14.3.1.6, 14.3.1.7, 14.3.3.2, 14.3.3.3, 14.3.3.4
TA 15 Aeronautics	15.1.1.1, 15.1.1.2, 15.1.1.3, 15.1.1.4, 15.6.1.1, 15.6.1.2, 15.6.1.3, 15.6.1.4	--

Avionics

Avionics are electronic systems at the center of the command, control, and monitoring capabilities, and represent a significant portion of an aerospace system's total mass and power consumption. Examples include electronics for spaceflight instrumentation, communications, tracking, and human interfaces. Within the capability-driven framework context, it is NASA's goal to pursue commonality across the spaceflight and supporting ground systems that use avionics while maintaining highly scalable, upgradeable, and flexible architectures. Avionics commonality creates an environment where sparing and upgrades can take advantage of logistical and training efficiencies for maintenance and sustained engineering approaches.

Key avionics goals include improved reliability and increased autonomy. Long-duration crewed missions, space-based observatories, and solar system exploration will require highly reliable, fault-tolerant systems. Communication delays, the challenging orbital dynamics of Near-Earth Asteroids, and extreme science missions require increased autonomy for on-board decision infrastructures. Advanced avionics technologies and approaches are needed to support these challenging missions. The table below lists the technology candidates that use avionics in their basic implementation and will benefit from increased avionics performance in power, mass, communications, reliability, and autonomy.

Technology Area	ENABLING Technology Candidate Snapshots Related to Avionics	ENHANCING Technology Candidate Snapshots Related to Avionics
TA 1 Launch Propulsion Systems	1.6.3.1	1.5.2.1, 1.6.4.1, 1.6.5.1
TA 2 In-Space Propulsion Systems	2.4.2.4	2.3.1.1
TA 3 Space Power and Energy Storage	3.3.2.1	3.3.1.2, 3.3.3.1, 3.3.3.5, 3.3.4.1
TA 4 Robotics and Autonomous Systems	4.1.1.1, 4.1.1.2, 4.1.1.3, 4.1.2.5, 4.1.2.6, 4.1.5.1, 4.1.5.2, 4.2.6.2, 4.2.6.3, 4.2.6.4, 4.2.6.5, 4.3.1.1, 4.3.1.3, 4.3.2.1, 4.3.2.2, 4.5.1.1, 4.5.1.3, 4.5.4.1, 4.6.1.1, 4.6.1.2, 4.6.1.3	4.1.2.1, 4.2.6.1, 4.4.1.1, 4.4.5.1, 4.4.5.2, 4.4.5.3, 4.4.8.1, 4.7.1.2, 4.7.1.4, 4.7.1.5, 4.7.1.6

Technology Area	ENABLING Technology Candidate Snapshots Related to Avionics	ENHANCING Technology Candidate Snapshots Related to Avionics
TA 5 Communications, Navigation, and Orbital Debris Tracking and Characterization Systems	5.1.4.2, 5.2.6.2, 5.2.6.3, 5.2.6.4, 5.2.6.5, 5.2.6.6, 5.4.2.8, 5.4.3.3, 5.4.3.4, 5.4.4.1, 5.4.4.3, 5.4.6.2, 5.5.3.1, 5.6.2.1, 5.6.3.1, 5.6.4.1, 5.6.4.2, 5.6.6.1, 5.7.1.1, 5.7.1.2	5.1.1.1, 5.1.1.2, 5.1.3.1, 5.1.3.2, 5.1.6.1, 5.1.7.1, 5.2.1.1, 5.2.2.1, 5.2.2.2, 5.2.6.1, 5.3.1.1, 5.3.2.1, 5.3.2.2, 5.3.2.3, 5.4.1.1, 5.4.1.2, 5.4.2.2, 5.4.2.9, 5.4.3.1, 5.4.3.2, 5.4.4.1, 5.4.4.2, 5.4.4.3, 5.4.4.4, 5.4.6.1, 5.5.1.1, 5.5.2.1, 5.6.1.1,
TA 6 Human Health, Life Support, and Habitation Systems	6.2.2.9, 6.2.3.2, 6.2.3.3, 6.3.4.1, 6.3.4.2, 6.3.4.6, 6.4.1.1, 6.4.1.2, 6.4.1.3, 6.4.1.4, 6.4.1.7, 6.4.2.2, 6.5.5.1, 6.5.5.2, 6.5.5.3, 6.5.5.4, 6.5.5.5	6.2.2.5
TA 7 Human Exploration Destination Systems	7.2.1.7, 7.6.1.5	7.1.4.7, 7.2.2.1, 7.2.3.10
TA 8 Science Instruments, Observatories, and Sensor Systems	--	8.1.2.2, 8.1.2.3, 8.1.2.4
TA 9 Entry, Descent, and Landing Systems	9.1.4.6, 9.2.3.1, 9.2.6.2, 9.2.6.3, 9.2.7.1, 9.2.7.2, 9.2.7.3, 9.2.8.2, 9.2.8.7, 9.4.6.1, 9.4.6.3, 9.4.6.4, 9.4.6.5	--
TA 10 Nanotechnology	10.1.1.3, 10.1.1.7, 10.1.1.8, 10.1.2.7, 10.2.2.1, 10.2.2.2, 10.2.2.3, 10.2.2.4, 10.2.2.5, 10.2.3.1, 10.4.2.3	10.1.1.6, 10.4.1.1, 10.4.1.2, 10.4.1.3, 10.4.1.4, 10.4.1.5, 10.4.1.6, 10.4.2.1, 10.4.2.2, 10.4.2.4, 10.4.2.5, 10.4.2.6, 10.4.2.7
TA 11 Modeling, Simulation, Information Technology, and Processing	11.1.1.1, 11.1.1.2, 11.1.1.4, 11.1.1.5, 11.2.2.1, 11.2.2.2, 11.4.2.3, 11.4.7.3	11.2.5.2, 11.3.3.3, 11.4.2.1, 11.4.2.5, 11.4.8.1, 11.4.8.2
TA 12 Materials, Structures, Mechanical Systems, and Manufacturing	12.1.4.4, 12.2.3.3, 12.2.4.2, 12.3.5.3	12.1.1.3, 12.3.6.4, 12.4.3.3
TA 13 Ground and Launch Systems	--	13.1.3.10, 13.1.3.11, 13.1.3.12, 13.1.3.13, 13.3.4.1, 13.3.4.4, 13.3.7.1, 13.3.7.2, 13.3.7.3, 13.3.7.4, 13.3.7.5, 13.4.1.4, 13.4.1.8
TA 14 Thermal Management Systems	--	14.3.1.5, 14.3.3.2, 14.3.3.3, 14.3.3.4
TA 15 Aeronautics	15.1.1.1, 15.1.1.2, 15.1.1.3, 15.1.1.4, 15.1.1.5, 15.6.1.1, 15.6.1.2, 15.6.1.3, 15.6.1.4	--

Extravehicular Activity

All human exploration missions require space suits, either for occupant protection during dynamic flight phases and crew survivability during off-nominal events or to facilitate Extravehicular Activities (EVAs) for exploration and repair operations outside of a space vehicle. Space suits are, in effect, miniature human form-fitting spacecraft, containing many of the systems common to a spacecraft, such as life support, thermal control, avionics, power distribution and energy storage, impact protection, propulsion, and communications. Beyond the actual suit itself, many of the systems being developed for exploration interface with spacesuits in a variety of ways such as: physical and mechanical interfaces, life support recharge and regeneration, and dust mitigation. EVA capability also impacts spacecraft vehicle and habitat architecture, including airlocks and suitports. Additionally, EVA capability influences a suite of tools to perform microgravity and planetary exploration, sample collection, and repair of systems external to the pressurized volume.

The table below lists the technology candidates where EVA technologies can be located across the roadmaps.

Technology Area	ENABLING Technology Candidate Snapshots Related to Extravehicular Activity	ENHANCING Technology Candidate Snapshots Related to Extravehicular Activity
TA 1 Launch Propulsion Systems	--	--
TA 2 In-Space Propulsion Systems	--	--
TA 3 Space Power and Energy Storage	3.2.1.1	--
TA 4 Robotics and Autonomous Systems	4.7.1.3	4.1.2.8
TA 5 Communications, Navigation, and Orbital Debris Tracking and Characterization Systems	--	--
TA 6 Human Health, Life Support, and Habitation Systems	6.1.1.7, 6.2.1.1, 6.2.1.2, 6.2.1.3, 6.2.1.4, 6.2.1.5, 6.2.1.6, 6.2.1.9, 6.2.1.10, 6.2.2.1, 6.2.2.2, 6.2.2.3, 6.2.2.6, 6.2.2.7, 6.2.2.9, 6.2.3.1, 6.2.3.2, 6.2.3.3, 6.2.3.4, 6.2.3.5, 6.3.2.5, 6.3.4.9, 6.5.5.1	6.2.1.7, 6.2.1.8, 6.2.1.11, 6.2.1.12, 6.2.2.4, 6.2.2.5, 6.2.2.8, 6.2.2.10, 6.2.2.11
TA 7 Human Exploration Destination Systems	7.3.1.2, 7.3.1.3, 7.3.1.4, 7.3.1.5, 7.5.2.3, 7.6.1.1, 7.6.1.2, 7.6.1.12, 7.6.1.13, 7.6.1.14, 7.6.1.15, 7.6.1.16	7.3.1.1, 7.3.1.6, 7.3.1.7, 7.3.3.1, 7.6.1.4, 7.6.1.9, 7.6.1.11
TA 8 Science Instruments, Observatories, and Sensor Systems	--	--
TA 9 Entry, Descent, and Landing Systems	--	--
TA 10 Nanotechnology	10.1.4.1	10.1.3.2, 10.1.3.5
TA 11 Modeling, Simulation, Information Technology, and Processing	--	--
TA 12 Materials, Structures, Mechanical Systems, and Manufacturing	--	12.1.5.2
TA 13 Ground and Launch Systems	--	--
TA 14 Thermal Management Systems	14.2.3.4	--
TA 15 Aeronautics	--	--

Information Technology

Information Technology (IT) is an element in nearly all systems developed for NASA's missions. The 2015 Technology Roadmaps allow NASA to identify the common IT technology needs. NASA is a data-driven organization that has an ever-increasing demand for larger datasets from multiple, disparate sources, some of which emerge at very high rates of change. Big Data has been a consideration in NASA IT systems for decades, from generation, cataloging, and stewardship through data discovery, access, and understanding. Many IT technologies are needed to support these kinds of data environments. Technology advances in data management and communications, artificial intelligence, statistics, instrumentation, scalable cyber-infrastructures, visualization, and analysis algorithms are needed to support data-intensive operations and Agency objectives. Automated corruption detection or self-healing for massive or rapidly generated datasets are essential to NASA's Big Data support.

As IT evolves, cyber security technology must be built in to protect the confidentiality, integrity, and availability of NASA data. NASA needs the ability to separate data that has been released to the public from data whose access is controlled, to avoid releasing potentially erroneous data or data that requires careful consideration. Similarly, data and technology require protection from natural or malicious alteration or corruption from unauthorized personnel or organizations, particularly in the case of long-duration data collection efforts or flight missions.

Over the next decade, IT will be critical to the success of NASA's long-duration missions. The focus is on improving the unique technologies currently implemented, and on developing new technologies for challenges the Agency will face in the future. The goal is to leverage and develop a deliberate, integrated approach for IT across the Agency. The table below lists the technology candidates related to IT.

Technology Area	ENABLING Technology Candidate Snapshots Related to Information Technology	ENHANCING Technology Candidate Snapshots Related to Information Technology
TA 1 Launch Propulsion Systems	1.1.6.1, 1.1.6.2, 1.2.1.2, 1.2.1.3, 1.2.1.4, 1.2.2.2, 1.6.3.1	1.1.4.1, 1.1.5.1, 1.1.6.3, 1.2.1.1, 1.2.2.3, 1.2.3.1, 1.2.6.1, 1.2.6.2, 1.5.2.1, 1.6.4.1
TA 2 In-Space Propulsion Systems	--	2.2.4.2
TA 3 Space Power and Energy Storage	3.3.2.3	3.2.1.7, 3.3.1.2
TA 4 Robotics and Autonomous Systems	4.1.1.3, 4.1.2.4, 4.1.3.2, 4.1.3.4, 4.1.4.1, 4.1.4.2, 4.1.4.3, 4.2.6.2, 4.2.6.3, 4.2.6.4, 4.2.6.5, 4.5.1.1, 4.5.1.2, 4.5.1.3, 4.5.2.1, 4.5.2.2, 4.5.2.3, 4.5.2.4, 4.5.2.5, 4.5.4.1, 4.5.8.1, 4.7.3.1, 4.7.3.2, 4.7.3.4	4.1.2.2, 4.1.3.1, 4.2.6.1, 4.4.1.1, 4.4.1.2, 4.4.3.1, 4.4.3.2, 4.4.3.3, 4.4.5.1, 4.4.5.2, 4.4.5.3, 4.4.8.2, 4.4.8.3, 4.7.1.6, 4.7.3.3,
TA 5 Communications, Navigation, and Orbital Debris Tracking and Characterization Systems	5.1.2.2, 5.1.2.3, 5.1.4.2, 5.2.6.2, 5.2.6.3, 5.2.6.4, 5.2.6.5, 5.2.6.6, 5.4.2.3, 5.4.2.8, 5.4.5.2, 5.4.6.2, 5.5.3.1, 5.6.2.1, 5.6.4.1, 5.6.4.2, 5.6.6.1, 5.7.1.1, 5.7.1.2, 5.7.2.1	5.1.1.1, 5.1.1.2, 5.1.2.1, 5.1.3.1, 5.1.3.2, 5.1.4.1, 5.1.5.1, 5.1.5.2, 5.1.6.1, 5.1.7.1, 5.2.1.1, 5.2.2.1, 5.2.2.2, 5.2.3.1, 5.2.6.1, 5.3.1.1, 5.3.2.1, 5.3.2.2, 5.3.2.3, 5.4.1.1, 5.4.1.2, 5.4.2.2, 5.4.2.4, 5.4.2.5, 5.4.2.6, 5.4.2.7, 5.4.2.9, 5.4.3.1, 5.4.3.2, 5.4.5.1, 5.4.6.1, 5.5.1.1, 5.5.2.1, 5.5.6.1
TA 6 Human Health, Life Support, and Habitation Systems	6.2.3.2, 6.3.2.7, 6.3.3.6, 6.3.3.7, 6.3.4.1, 6.3.4.3, 6.3.4.5, 6.3.4.6, 6.3.4.7, 6.4.1.1, 6.4.2.2, 6.5.1.4, 6.5.1.8, 6.5.2.5, 6.5.2.6, 6.5.3.7, 6.5.3.9, 6.5.4.4, 6.5.4.5	6.5.1.7
TA 7 Human Exploration Destination Systems	7.1.4.6, 7.2.1.7, 7.2.2.3, 7.5.3.1, 7.5.3.2	7.1.4.7, 7.2.1.3, 7.2.1.4, 7.2.1.5, 7.2.1.6, 7.2.3.15, 7.3.3.1, 7.4.1.6, 7.4.2.1, 7.4.3.1, 7.4.3.2, 7.4.3.3
TA 8 Science Instruments, Observatories, and Sensor Systems	8.1.3.4, 8.2.3.2, 8.2.3.4, 8.2.3.5, 8.2.3.6, 8.2.3.8	--
TA 9 Entry, Descent, and Landing Systems	9.2.7.4, 9.2.8.7, 9.4.5.5, 9.4.5.11	9.4.5.1, 9.4.5.2, 9.4.5.3, 9.4.5.6, 9.4.5.10, 9.4.5.12
TA 10 Nanotechnology	10.1.1.7, 10.1.1.8, 10.2.3.1, 10.4.2.3	10.4.1.3, 10.4.2.1, 10.4.2.2

Technology Area	ENABLING Technology Candidate Snapshots Related to Information Technology	ENHANCING Technology Candidate Snapshots Related to Information Technology
TA 11 Modeling, Simulation, Information Technology, and Processing	11.1.1.1, 11.1.1.2, 11.1.1.3, 11.1.1.4, 11.1.1.5, 11.2.3.1, 11.2.3.2, 11.2.6.2, 11.3.4.1, 11.4.1.11, 11.4.2.3, 11.4.3.3, 11.4.3.4, 11.4.7.1, 11.4.7.2, 11.4.7.3, 11.4.7.4	11.1.2.1, 11.1.2.2, 11.1.2.3, 11.1.2.4, 11.1.2.5, 11.1.2.6, 11.1.2.7, 11.2.1.1, 11.2.1.2, 11.2.1.3, 11.2.2.1, 11.2.2.2, 11.2.2.3, 11.2.3.3, 11.2.4.1, 11.2.4.2, 11.2.4.3, 11.2.4.4, 11.2.4.5, 11.2.5.1, 11.2.5.2, 11.2.5.3, 11.2.5.4, 11.2.6.1, 11.2.6.3, 11.2.6.4, 11.3.1.1, 11.3.1.2, 11.3.1.3, 11.3.1.4, 11.3.1.5, 11.3.2.1, 11.3.2.2, 11.3.2.3, 11.3.3.1, 11.3.3.2, 11.3.3.3, 11.3.3.4, 11.3.3.5, 11.3.3.6, 11.3.4.2, 11.3.4.3, 11.3.5.1, 11.3.5.2, 11.3.5.3, 11.3.6.1, 11.3.6.2, 11.3.6.3, 11.3.6.4, 11.3.6.5, 11.3.6.6, 11.3.7.1, 11.3.7.2, 11.3.7.3, 11.3.7.4, 11.3.7.5, 11.3.7.6, 11.3.8.1, 11.3.8.2, 11.4.1.1, 11.4.1.2, 11.4.1.3, 11.4.1.4, 11.4.1.5, 11.4.1.6, 11.4.1.7, 11.4.1.8, 11.4.1.9, 11.4.1.10, 11.4.2.1, 11.4.2.2, 11.4.2.4, 11.4.2.5, 11.4.2.6, 11.4.3.1, 11.4.3.2, 11.4.4.1, 11.4.4.2, 11.4.4.3, 11.4.5.1, 11.4.5.2, 11.4.5.3, 11.4.5.4, 11.4.6.1, 11.4.6.2, 11.4.6.3, 11.4.6.4, 11.4.7.5, 11.4.7.6, 11.4.7.7, 11.4.8.1, 11.4.8.2, 11.4.8.3, 11.4.8.4, 11.4.8.5
TA 12 Materials, Structures, Mechanical Systems, and Manufacturing	12.1.4.4, 12.2.2.1, 12.2.2.3, 12.2.2.4, 12.2.2.5, 12.2.2.7, 12.2.3.1, 12.2.3.2, 12.2.3.4, 12.2.3.6, 12.2.4.3, 12.2.4.4, 12.2.4.5, 12.2.6.1, 12.2.6.2, 12.2.6.3, 12.2.6.4, 12.2.6.5, 12.2.6.6, 12.3.1.5, 12.3.1.6, 12.3.4.1, 12.3.5.1, 12.3.5.2, 12.3.5.3, 12.3.5.4, 12.4.2.1, 12.4.2.2, 12.4.2.3, 12.4.5.1	12.1.2.1, 12.1.2.2, 12.1.2.3, 12.3.2.1, 12.3.6.1, 12.3.6.2, 12.3.6.3, 12.3.6.4, 12.4.3.3
TA 13 Ground and Launch Systems	13.3.7.7, 13.4.2.1, 13.4.2.2	13.1.1.10, 13.1.1.11, 13.1.1.12, 13.1.2.1, 13.1.2.2, 13.1.2.3, 13.1.2.7, 13.1.2.8, 13.1.2.9, 13.1.3.1, 13.1.3.2, 13.1.3.3, 13.1.3.4, 13.1.3.5, 13.1.3.6, 13.1.3.7, 13.1.3.8, 13.1.3.9, 13.1.3.10, 13.1.3.11, 13.1.3.12, 13.1.3.13, 13.1.3.14, 13.1.3.15, 13.1.3.16, 13.1.3.19, 13.1.3.20, 13.1.4.1, 13.1.4.2, 13.1.4.4, 13.1.4.6, 13.2.3.3, 13.3.1.1, 13.3.1.2, 13.3.1.3, 13.3.1.4, 13.3.1.6, 13.3.1.13, 13.3.3.1, 13.3.4.1, 13.3.4.4, 13.3.5.2, 13.3.7.1, 13.3.7.2, 13.3.7.3, 13.3.7.4, 13.3.7.5, 13.3.7.6, 13.3.8.1, 13.3.8.2, 13.4.1.1, 13.4.1.2, 13.4.1.3, 13.4.1.4, 13.4.1.5, 13.4.1.8, 13.4.3.1, 13.4.3.2, 13.4.3.3, 13.4.3.4, 13.4.3.5, 13.4.3.6, 13.4.3.7, 13.4.5.1, 13.4.5.2, 13.4.5.5
TA 14 Thermal Management Systems	14.1.1.4, 14.1.1.5, 14.3.2.2	14.1.2.5, 14.3.2.1
TA 15 Aeronautics	15.1.1.1, 15.1.1.2, 15.1.1.3, 15.1.1.4, 15.1.2.3, 15.2.1.2, 15.2.2.1, 15.3.1.3, 15.3.3.2, 15.6.1.1, 15.6.1.2, 15.6.1.3, 15.6.1.4	--

In-Situ Resource Utilization

Any program to extend human presence and operations on extraterrestrial bodies requires that we learn how to utilize the indigenous resources. The purpose of In-Situ Resource Utilization (ISRU) is to locate, harness, and utilize resources (both natural and discarded material) at the site of exploration to create products and services for subsequent use. Potential space resources include water/ice, solar wind implanted volatiles (hydrogen, helium, carbon, nitrogen, etc.), metals and minerals, atmospheric constituents, solar energy, regions of permanent light and darkness, trash and waste from human crew, and discarded hardware that has completed its primary purpose.

Products obtained from these resources can then be used to reduce the mass and cost of robotic and human exploration, reduce risk by enabling self-sufficiency, and increase performance or enable new mission concepts compared to bringing everything from Earth. ISRU can also further reduce costs by enabling reusability of equipment and transportation vehicles that were previously discarded once their consumables had been used. The table below lists the technology candidates related to ISRU.

Technology Area	ENABLING Technology Candidate Snapshots Related to In-Situ Resource Utilization	ENHANCING Technology Candidate Snapshots Related to In-Situ Resource Utilization
TA 1 Launch Propulsion Systems	--	--
TA 2 In-Space Propulsion Systems	2.1.2.1, 2.1.2.2, 2.1.2.3, 2.1.2.4	--
TA 3 Space Power and Energy Storage	3.1.2.1, 3.1.2.2, 3.1.2.3, 3.1.3.1, 3.1.3.2, 3.1.3.3, 3.1.3.5, 3.1.3.7, 3.1.3.8, 3.1.3.9, 3.1.3.12, 3.2.1.4, 3.2.1.6, 3.2.3.1, 3.2.3.2	3.1.3.4, 3.1.3.6, 3.1.3.10, 3.1.3.11
TA 4 Robotics and Autonomous Systems	4.2.5.1, 4.2.5.2, 4.3.6.1, 4.3.6.2, 4.3.6.3, 4.3.6.4, 4.3.6.5, 4.3.6.6, 4.3.6.7, 4.7.1.3	4.2.7.1
TA 5 Communications, Navigation, and Orbital Debris Tracking and Characterization Systems	--	--
TA 6 Human Health, Life Support, and Habitation Systems	6.5.3.2, 6.5.3.3	6.1.3.4, 6.1.4.8, 6.1.4.10
TA 7 Human Exploration Destination Systems	7.1.1.1, 7.1.1.2, 7.1.1.3, 7.1.1.4, 7.1.1.5, 7.1.1.7, 7.1.2.1, 7.1.2.2, 7.1.2.3, 7.1.2.4, 7.1.2.7, 7.1.2.8, 7.1.2.9, 7.1.3.6, 7.1.3.7, 7.1.3.8, 7.1.3.10, 7.1.3.11, 7.1.3.12, 7.1.3.13, 7.1.3.14, 7.1.3.15, 7.1.3.16, 7.1.3.17, 7.1.3.18, 7.1.3.19, 7.1.4.6,	7.1.1.6, 7.1.2.5, 7.1.2.6, 7.1.2.10, 7.1.2.11, 7.1.2.12, 7.1.2.13, 7.1.2.14, 7.1.2.15, 7.1.2.16, 7.1.2.17, 7.1.2.18, 7.1.2.19, 7.1.2.20, 7.1.2.21, 7.1.3.1, 7.1.3.2, 7.1.3.3, 7.1.3.4, 7.1.3.5, 7.1.3.9, 7.1.4.1, 7.1.4.2, 7.1.4.3, 7.1.4.4, 7.1.4.5, 7.1.4.7, 7.1.4.8, 7.1.4.9, 7.1.4.10, 7.1.4.11, 7.2.1.1, 7.2.3.4, 7.4.1.7, 7.4.1.8, 7.4.1.9, 7.4.1.10, 7.4.1.11, 7.6.2.1, 7.6.2.2
TA 8 Science Instruments, Observatories, and Sensor Systems	--	--
TA 9 Entry, Descent, and Landing Systems	--	--
TA 10 Nanotechnology	--	--
TA 11 Modeling, Simulation, Information Technology, and Processing	--	--
TA 12 Materials, Structures, Mechanical Systems, and Manufacturing	12.3.3.2	--
TA 13 Ground and Launch Systems	--	13.1.1.9
TA 14 Thermal Management Systems	14.1.2.1, 14.1.2.3, 14.1.2.4, 14.1.2.7, 14.1.2.8	14.1.2.2, 14.1.2.5, 14.1.2.6
TA 15 Aeronautics	--	--

Orbital Debris

After more than 50 years of human space activities, orbital debris has become a serious problem in the near-Earth environment. As of 2015, the total mass of debris in orbit has exceeded 6,000 tons. The U.S. Space Surveillance Network is currently tracking more than 22,000 objects larger than about 10 centimeters (cm). Additional optical and radar data indicate that there are approximately 500,000 pieces of debris larger than 1 cm, and more than 100 million pieces of debris larger than 1 millimeter (mm) in the environment. Because of the high impact speeds between orbiting objects, debris as small as 0.2 mm poses a realistic threat to human spaceflight and robotic missions in the near-Earth environment. Unfortunately, recent modeling studies have indicated that debris mitigation measures commonly adopted by the international community may be insufficient to stop the debris population growth in the future.

As highlighted in the President's 2010 National Space Policy, the orbital debris problem is creating a major challenge for Space Situational Awareness (SSA) and for the safe operation of U.S. space assets. In order to address this challenge, technologies and techniques are needed in many areas to better define the orbital debris population for near-term debris impact risk assessments, protection of critical space assets, and far-term sustainability of the environment.

The following areas are examples of technologies that will be needed to address the orbital debris challenge:

1. Radar, optical, and in-situ measurements to better characterize the orbital debris population from large (> 10 centimeters (cm)) to small (< 0.1 millimeter (mm)) and from low-Earth orbit (LEO) to geostationary orbit (GEO). A critical data gap is for debris between 0.5 and 3 mm in LEO.
2. Modeling of the current and future orbital debris environment.
3. Modeling of satellite explosions and collisions and the fragment mass, density, and shape distributions.
4. Modeling of object reentry survivability assessments.

The table below lists the Technology Areas where orbital debris technology candidates can be located across the roadmaps.

Technology Area	ENABLING Technology Candidate Snapshots Related to Orbital Debris	ENHANCING Technology Candidate Snapshots Related to Orbital Debris
TA 1 Launch Propulsion Systems	--	1.4.6.1
TA 2 In-Space Propulsion Systems	--	--
TA 3 Space Power and Energy Storage	--	--
TA 4 Robotics and Autonomous Systems	--	--
TA 5 Communications, Navigation, and Orbital Debris Tracking and Characterization Systems	5.2.6.2, 5.2.6.3, 5.2.6.4, 5.2.6.5, 5.2.6.6, 5.4.1.3, 5.4.2.3, 5.4.2.8, 5.4.3.3, 5.4.3.4, 5.4.5.2, 5.4.6.2, 5.7.1.1, 5.7.1.2, 5.7.2.1	5.1.1.1, 5.1.1.2, 5.1.3.1, 5.1.3.2, 5.1.5.1, 5.1.5.2, 5.2.3.1, 5.2.6.1, 5.4.1.1, 5.4.1.2, 5.4.2.1, 5.4.2.2, 5.4.2.4, 5.4.2.5, 5.4.2.6, 5.4.2.7, 5.4.2.9, 5.4.3.1, 5.4.3.2, 5.4.5.1, 5.4.6.1, 5.5.6.1
TA 6 Human Health, Life Support, and Habitation Systems	6.5.3.3	--
TA 7 Human Exploration Destination Systems	--	7.5.2.6
TA 8 Science Instruments, Observatories, and Sensor Systems	8.1.5.3	--
TA 9 Entry, Descent, and Landing Systems	--	9.4.5.8, 9.4.5.9
TA 10 Nanotechnology	10.1.1.10, 10.1.2.2, 10.1.2.3, 10.1.2.4, 10.1.2.5	--

Technology Area	ENABLING Technology Candidate Snapshots Related to Orbital Debris	ENHANCING Technology Candidate Snapshots Related to Orbital Debris
TA 11 Modeling, Simulation, Information Technology, and Processing	--	11.1.2.1, 11.3.6.2, 11.3.6.3, 11.3.7.1, 11.3.7.2, 11.3.7.3, 11.3.7.5, 11.4.7.7
TA 12 Materials, Structures, Mechanical Systems, and Manufacturing	12.2.5.2, 12.2.5.3	12.1.1.4, 12.1.5.2
TA 13 Ground and Launch Systems	--	13.4.1.1, 13.4.1.3, 13.4.1.5
TA 14 Thermal Management Systems	14.3.1.8	14.1.1.3, 14.3.1.5, 14.3.1.7, 14.3.2.1
TA 15 Aeronautics	--	--

Radiation and Space Weather

Deep-space and long-duration missions, where both crew members and spacecraft no longer benefit from the protection of Earth's magnetic fields, are considered high risk for adverse radiation impacts. Long term exposure of astronauts to radiation is problematic and the effect that space radiation has on spacecraft electronics and software is equally challenging. The ability to predict space radiation events and protect both human and human-built systems from these events is of crucial interest to NASA in order to explore space beyond low-Earth orbit. Looking across the 2015 Technology Roadmaps, there are multiple Technology Areas where performance improvements are needed in radiation and space weather technologies. To obtain Science measurements, scientists need accurate and comprehensive technologies to predict space weather events, along with better algorithms to analyze captured data. Human radiation and radiobiology technology should focus on exploring the areas of radioprotectants, individual radiation sensitivity toolkits, and advanced imaging. Dosimetry technologies should be made smaller with less power demands, while not jeopardizing the performance or quality of data collected, to allow for placement on more spacecraft and astronauts. Continued work is needed in radiation transport and modeling to improve the models for predicting radiation exposure and the effect exposure has on the human body.

Within the area of space radiation science measurements, there is a need for enhanced development and further investment that includes developing and testing new models that allow both empirical and physics-based analyses of the evolution of significant active regions of the sun that are responsible for major eruptions and solar particle events. Concordantly, there is a need to develop a more complete solar system-wide characterization of space radiation and space weather. The Solar Terrestrial Relations Observatory (STEREO) spacecraft, along with Solar Dynamics Observatory (SDO) and Solar and Heliospheric Observatory (SOHO) have, for the first time, provided a three dimensional view of the sun. However, these capabilities have a limited lifespan and there are no planned missions that will completely replace these assets. This broader picture will become more vital as human missions beyond LEO increase, but are equally important for robotic exploration as well as for assessment of terrestrial impacts.

Space weather technologies and prediction services currently lack scope and real-time applicability, lagging behind the prediction of the onset time and magnitude of space weather events, leading to significant constraints for preparation and diminishing the ability to conduct long-duration missions. Technology advances in these areas will help minimize these constraints.

This Technology Area is complicated by the fact that transport code radiation effects modeling is different for humans, electronics, and materials. The missions themselves – small/short duration vs. large/long duration - present different challenges for electronics and thus require a different level of qualification. In addition, high-performing radiation-tolerant parts are limited and future production is likely more limited.

Another area that requires further technology development is assessing the impact of spacecraft charging as a result of solar events. First, development of ground testing and simulation of surface and radiation-induced charging is needed, as well as surface and Internal Electrostatic Discharge (IESD) codes. Second, the development of in-situ measurements of surface charging and IESD, including mitigation techniques, are required. These areas demand focus due to the progression of technology levels associated with new spacecraft and the desired increase in missions beyond LEO.

Improvements in radiation shielding, both passive and active, remain a significant challenge, with the use of high-hydrogen-content materials or other novel approaches as an area of needed investment. Additionally, there is a need for Solar Particle Event (SPE) shielding system development to be integrated into vehicle and other technology development activities. SPE shielding systems are required for short missions beyond LEO and will become a critical pathway forward for longer duration missions, such as Mars.

Improvements in the area of space radiation technologies are critical to the success of NASA's long duration missions. The focus is on improving the technologies currently implemented while also developing new technologies for challenges NASA will face in the future. The goal is to develop a deliberate, integrated approach, from humans to instruments that extend from forecasting to protecting. The table below lists the radiation and space weather technology candidates across the 2015 NASA Technology Roadmaps.

Radiation

Technology Area	ENABLING Technology Candidate Snapshots Related to Radiation	ENHANCING Technology Candidate Snapshots Related to Radiation
TA 1 Launch Propulsion Systems	--	--
TA 2 In-Space Propulsion Systems	--	--
TA 3 Space Power and Energy Storage	3.1.3.8, 3.1.3.9, 3.3.3.6, 3.3.5.1	3.1.3.10
TA 4 Robotics and Autonomous Systems	--	--
TA 5 Communications, Navigation, and Orbital Debris Tracking and Characterization Systems	5.5.3.1	5.1.1.2, 5.2.2.1, 5.2.2.2, 5.3.1.1, 5.3.2.1, 5.3.2.2, 5.3.2.3, 5.4.2.2, 5.4.2.6, 5.4.2.7, 5.5.1.1
TA 6 Human Health, Life Support, and Habitation Systems	6.3.1.5, 6.5.1.1, 6.5.1.2, 6.5.1.3, 6.5.1.4, 6.5.1.5, 6.5.1.8, 6.5.1.9, 6.5.2.1, 6.5.2.2, 6.5.2.3, 6.5.2.4, 6.5.2.5, 6.5.3.1, 6.5.3.2, 6.5.3.3, 6.5.3.4, 6.5.3.5, 6.5.3.6, 6.5.3.7, 6.5.3.8, 6.5.3.9, 6.5.5.1, 6.5.5.2, 6.5.5.3, 6.5.5.4, 6.5.5.5	6.5.1.6, 6.5.1.7
TA 7 Human Exploration Destination Systems	--	7.2.1.9
TA 8 Science Instruments, Observatories, and Sensor Systems	--	8.3.1.2
TA 9 Entry, Descent, and Landing Systems	--	--
TA 10 Nanotechnology	10.1.1.10, 10.1.2.6, 10.1.2.7	10.2.1.3, 10.4.1.2, 10.4.2.4, 10.4.2.7
TA 11 Modeling, Simulation, Information Technology, and Processing	11.1.1.1, 11.1.1.2, 11.1.1.4, 11.1.1.5	11.2.1.1, 11.2.1.2, 11.3.3.1, 11.3.3.3, 11.3.3.4, 11.3.7.1, 11.3.7.2, 11.3.7.3
TA 12 Materials, Structures, Mechanical Systems, and Manufacturing	12.1.3.2, 12.1.3.3, 12.1.4.4, 12.2.1.3, 12.2.1.6, 12.2.5.2, 12.2.5.3, 12.2.6.1	12.1.1.2, 12.3.2.1, 12.3.2.2, 12.4.3.3
TA 13 Ground and Launch Systems	--	--
TA 14 Thermal Management Systems	14.3.1.8	--
TA 15 Aeronautics	--	--

Space Weather

Technology Area	ENABLING Technology Candidate Snapshots Related to Space Weather	ENHANCING Technology Candidate Snapshots Related to Space Weather
TA 1 Launch Propulsion Systems	--	--
TA 2 In-Space Propulsion Systems	2.2.2.1	--
TA 3 Space Power and Energy Storage	--	--
TA 4 Robotics and Autonomous Systems	--	--
TA 5 Communications, Navigation, and Orbital Debris Tracking and Characterization Systems	--	--
TA 6 Human Health, Life Support, and Habitation Systems	6.5.4.1, 6.5.4.2, 6.5.4.3, 6.5.4.4, 6.5.4.5	--
TA 7 Human Exploration Destination Systems	--	--
TA 8 Science Instruments, Observatories, and Sensor Systems	--	8.3.1.2
TA 9 Entry, Descent, and Landing Systems	--	--
TA 10 Nanotechnology	--	--
TA 11 Modeling, Simulation, Information Technology, and Processing	11.4.2.3	11.1.2.1, 11.1.2.2, 11.1.2.3, 11.2.4.2, 11.2.6.3, 11.3.5.1, 11.3.5.2, 11.3.5.3, 11.3.7.1, 11.3.7.2, 11.3.7.3, 11.4.1.6, 11.4.1.7, 11.4.2.1, 11.4.2.2, 11.4.2.4, 11.4.2.5, 11.4.2.6
TA 12 Materials, Structures, Mechanical Systems, and Manufacturing	12.1.3.2	--
TA 13 Ground and Launch Systems	--	--
TA 14 Thermal Management Systems	--	--
TA 15 Aeronautics	--	--

Sensors

Sensors are devices that respond to external stimuli, such as motion, heat, or light, and respond in a particular way to convert the stimuli into a measurable quantity such as an analog or digital representation. One of the primary users of sensors is NASA's Science Mission Directorate. In order to conduct science missions—whether in-situ on a planetary surface or remotely from orbiting satellites and probes—NASA's scientists need sensors of all types. In addition to science missions, sensors are required for a wide range of the technologies that enable NASA systems. Some examples include flow sensors, which are required for the proper operation of a rocket motor, chemical sensors to detect hazardous chemical leaks on the International Space Station (ISS), and thin film sensors that operate in harsh environments for surface measurement in aeronautics propulsion system research.

Ssensors appear throughout the 2015 NASA Technology Roadmaps, and are important for NASA to meet its mission goals. The table below indicates where these technology candidates are located across NASA's Technology Areas.

Technology Area	ENABLING Technology Candidate Snapshots Related to Sensors	ENHANCING Technology Candidate Snapshots Related to Sensors
TA 1 Launch Propulsion Systems	1.1.6.1, 1.1.6.2, 1.2.1.2, 1.2.1.3, 1.2.1.4, 1.2.2.1, 1.2.2.2, 1.6.3.1	1.1.4.1, 1.1.6.3, 1.2.1.1, 1.2.2.3, 1.2.3.1, 1.5.2.1, 1.6.4.1, 1.6.5.1
TA 2 In-Space Propulsion Systems	2.1.1.3, 2.1.2.1, 2.1.2.2, 2.1.2.3, 2.1.2.4, 2.1.4.1, 2.1.5.1, 2.3.4.1, 2.3.4.3	2.1.1.1, 2.1.1.2, 2.2.3.1, 2.3.3.1, 2.3.6.2
TA 3 Space Power and Energy Storage	3.3.2.2	--
TA 4 Robotics and Autonomous Systems	4.1.1.1, 4.1.1.2, 4.1.1.3, 4.1.2.3. 4.1.2.4, 4.1.2.5, 4.1.2.6, 4.1.3.2, 4.1.3.4, 4.1.4.1, 4.1.4.2, 4.1.4.3, 4.1.5.1, 4.1.5.2, 4.2.6.2, 4.2.6.3, 4.2.6.4, 4.2.6.5, 4.6.1.1, 4.6.1.2, 4.6.1.3	4.1.2.1, 4.1.2.2, 4.1.2.7, 4.1.2.8, 4.1.3.1, 4.1.3.3, 4.2.6.1, 4.6.1.1
TA 5 Communications, Navigation, and Orbital Debris Tracking and Characterization Systems	5.1.2.2, 5.1.2.3, 5.2.6.2, 5.2.6.3, 5.2.6.4, 5.2.6.6, 5.4.3.3, 5.4.3.4, 5.4.5.2, 5.4.6.2, 5.5.3.1, 5.6.1.1, 5.6.6.1, 5.7.1.1, 5.7.1.2, 5.7.2.1	5.1.1.1, 5.1.1.2, 5.1.2.1, 5.1.5.1, 5.1.5.2, 5.2.6.1, 5.3.1.1, 5.3.2.1, 5.3.2.2, 5.3.2.3, 5.4.5.1, 5.5.6.1,
TA 6 Human Health, Life Support, and Habitation Systems	6.2.1.9, 6.2.2.2, 6.2.2.9, 6.2.3.2, 6.2.3.3, 6.3.2.6, 6.3.2.7, 6.3.2.8, 6.4.1.1, 6.4.1.2, 6.4.1.3, 6.4.1.4, 6.4.1.5, 6.4.1.6, 6.4.1.7, 6.4.1.8, 6.4.1.9, 6.4.1.10, 6.4.2.2, 6.4.4.1, 6.4.4.2, 6.4.4.3, 6.5.5.1, 6.5.5.2, 6.5.5.3, 6.5.5.4, 6.5.5.5	6.2.2.5
TA 7 Human Exploration Destination Systems	7.1.1.1, 7.1.1.2, 7.1.1.3, 7.1.1.4, 7.1.1.5, 7.1.1.7, 7.2.1.7, 7.5.2.10	7.1.1.6, 7.2.1.3, 7.2.1.4, 7.2.1.5, 7.4.1.3, 7.5.2.4
TA 8 Science Instruments, Observatories, and Sensor Systems	8.1.1.2, 8.1.1.4, 8.1.1.5, 8.1.1.6, 8.1.1.7, 8.1.1.8, 8.1.1.9, 8.1.1.10, 8.1.3.5, 8.1.5.4, 8.1.5.10, 8.2.3.1, 8.2.3.2, 8.2.3.7, 8.3.1.4, 8.3.3.4, 8.3.3.6, 8.3.3.7	8.1.1.1, 8.1.1.12, 8.1.1.13, 8.1.3.9, 8.1.4.4, 8.1.4.5, 8.3.1.1, 8.3.1.2, 8.3.1.3, 8.3.1.5
TA 9 Entry, Descent, and Landing Systems	9.1.1.8, 9.1.4.6, 9.2.3.1, 9.2.7.1, 9.2.7.2, 9.2.7.3, 9.2.7.4, 9.2.8.8, 9.4.6.1, 9.4.6.2, 9.4.6.3, 9.4.6.4, 9.4.6.5, 9.4.6.6	--
TA 10 Nanotechnology	10.1.2.1, 10.1.2.4, 10.4.3.1, 10.4.3.2, 10.4.3.3, 10.4.3.6	10.3.3.3, 10.4.1.1, 10.4.1.2, 10.4.1.3, 10.4.1.4, 10.4.1.5, 10.4.1.6, 10.4.2.2, 10.4.3.5
TA 11 Modeling, Simulation, Information Technology, and Processing	--	11.2.4.5, 11.2.6.4, 11.3.3.1, 11.3.7.2, 11.3.7.3, 11.3.7.4, 11.3.7.5, 11.3.7.6
TA 12 Materials, Structures, Mechanical Systems, and Manufacturing	12.1.3.3, 12.2.3.3, 12.2.3.4, 12.2.3.5, 12.2.3.6, 12.2.4.2, 12.2.4.4, 12.2.5.1, 12.2.5.2, 12.2.5.3, 12.2.5.7, 12.2.6.1, 12.2.6.2, 12.2.6.3, 12.2.6.4, 12.2.6.5, 12.3.1.5, 12.3.1.6, 12.3.2.2, 12.3.3.1, 12.3.5.2, 12.4.1.4, 12.4.3.4, 12.4.5.1	12.1.1.3, 12.1.5.3, 12.2.5.6, 12.4.3.3
TA 13 Ground and Launch Systems	13.4.2.1, 13.4.2.2, 13.4.5.4	13.1.1.10, 13.1.1.11, 13.1.1.12, 13.1.2.1, 13.1.2.2, 13.1.2.8, 13.1.3.10, 13.1.3.11, 13.1.3.12, 13.1.3.13, 13.1.3.14, 13.1.3.15, 13.1.3.16, 13.1.3.19, 13.1.4.4, 13.1.4.5, 13.2.3.3, 13.3.1.2, 13.3.1.3, 13.3.1.4, 13.3.1.6, 13.3.1.7, 13.3.1.13, 13.3.3.1, 13.3.4.1, 13.3.4.4, 13.3.6.3, 13.4.1.2, 13.4.1.3, 13.4.2.4, 13.4.3.3, 13.4.3.4, 13.4.3.5, 13.4.3.7, 13.4.5.5

Technology Area	ENABLING Technology Candidate Snapshots Related to Sensors	ENHANCING Technology Candidate Snapshots Related to Sensors
TA 14 Thermal Management Systems	14.1.2.3, 14.1.2.4, 14.1.2.7, 14.2.3.9, 14.3.3.1	14.1.1.5, 14.1.1.7, 14.1.1.8, 14.1.2.5, 14.2.1.2, 14.2.1.4, 14.3.1.6, 14.3.3.2, 14.3.3.3, 14.3.3.4
TA 15 Aeronautics	15.1.1.1, 15.1.1.2, 15.1.1.3, 15.1.1.4, 15.1.1.5, 15.6.1.1, 15.6.1.2, 15.6.1.3, 15.6.1.4	--

Thermal Protection Systems

Thermal Protection Systems (TPS) protect spacecraft from extremely high temperatures and heating during all mission phases, and are very often low-to-no-fault-tolerant, critical systems that constitute a significant mass fraction of spacecraft. Predictably, TPS technologies appear in 10 of the Technology Areas, as they require exotic materials and structures necessary for reentry and propulsion systems, and high-temperature sensors and electronics for health monitoring and communication through plasma during reentry.

Many of the current goals for TPS technology development are driven by the need to design systems that can safely return from beyond LEO, or perform high-velocity atmospheric entry of > 11 kilometers per second (km/s), and do so in a mass-efficient manner that minimizes the weight penalty to the spacecraft. The required technology development is not limited to technical solutions, such as hardware, but also requires advancing analysis capabilities and test facilities that will enable those technology development efforts.

Additional goals for TPS technology development stem from material obsolescence issues due to environmental regulations and material availability. In this situation, technology development is required to maintain capability.

Lastly, TPS technologies are critical systems that are highly multi-disciplinary and low-to-no-fault tolerant. Therefore, high-temperature sensors and electronics are critical for enabling health monitoring, as well as obtaining system performance data during missions, data that would aid in risk reduction and increased system optimization for future missions. The table below indicates where these technology candidates are located across NASA's Technology Areas.

Technology Area	ENABLING Technology Candidate Snapshots Related to Thermal Protection Systems	ENHANCING Technology Candidate Snapshots Related to Thermal Protection Systems
TA 1 Launch Propulsion Systems	1.1.3.1, 1.1.3.2, 1.1.7.1, 1.1.7.2	1.4.7.1
TA 2 In-Space Propulsion Systems	--	--
TA 3 Space Power and Energy Storage	--	3.3.3.5
TA 4 Robotics and Autonomous Systems	--	--
TA 5 Communications, Navigation, and Orbital Debris Tracking and Characterization Systems	5.2.6.2, 5.2.6.4, 5.2.6.5, 5.2.6.6, 5.4.1.3, 5.4.2.8, 5.4.5.2, 5.6.2.1, 5.6.4.1, 5.6.4.2, 5.6.6.1, 5.7.1.1	5.1.1.1, 5.1.1.2, 5.1.3.1, 5.1.3.2, 5.1.4.1, 5.1.7.1, 5.2.1.1, 5.2.2.1, 5.2.2.2, 5.4.1.1, 5.4.1.2
TA 6 Human Health, Life Support, and Habitation Systems	--	--
TA 7 Human Exploration Destination Systems	7.6.1.18	7.6.1.21
TA 8 Science Instruments, Observatories, and Sensor Systems	--	--

Technology Area	ENABLING Technology Candidate Snapshots Related to Thermal Protection Systems	ENHANCING Technology Candidate Snapshots Related to Thermal Protection Systems
TA 9 Entry, Descent, and Landing Systems	9.1.1.1, 9.1.1.2, 9.1.1.3, 9.1.1.5, 9.1.1.7, 9.1.1.8, 9.1.2.1, 9.1.2.3, 9.1.3.1, 9.1.4.1, 9.1.4.2, 9.1.4.4, 9.1.4.5, 9.4.5.4, 9.4.5.5, 9.4.6.1, 9.4.6.2, 9.4.6.3, 9.4.6.4, 9.4.6.5, 9.4.6.6	9.1.1.4, 9.1.1.6, 9.1.2.2, 9.1.2.4, 9.1.2.5, 9.1.4.7, 9.4.5.3
TA 10 Nanotechnology	10.1.1.5, 10.1.1.10, 10.1.5.1, 10.1.5.2, 10.1.5.3, 10.3.2.4, 10.3.2.5	10.1.3.1, 10.3.2.2, 10.4.1.1, 10.4.1.3
TA 11 Modeling, Simulation, Information Technology, and Processing	--	11.1.2.1, 11.1.2.2, 11.3.3.1, 11.3.3.2, 11.3.3.3, 11.3.5.1, 11.3.5.2, 11.3.5.3, 11.3.7.1, 11.3.7.2, 11.3.7.3, 11.3.7.4, 11.3.7.5
TA 12 Materials, Structures, Mechanical Systems, and Manufacturing	12.1.3.1, 12.1.3.3, 12.1.4.4, 12.1.4.5, 12.2.3.3, 12.2.3.4, 12.2.3.5, 12.2.6.1, 12.4.1.2, 12.4.1.3, 12.4.1.4	12.1.1.2, 12.1.1.3, 12.1.4.2, 12.1.4.3
TA 13 Ground and Launch Systems	13.4.2.3	13.4.2.4
TA 14 Thermal Management Systems	14.3.1.1, 14.3.1.2, 14.3.1.3, 14.3.1.8, 14.3.2.2, 14.3.3.1	14.1.1.1, 14.3.1.4, 14.3.1.5, 14.3.1.6, 14.3.1.7, 14.3.2.1, 14.3.3.2, 14.3.3.3, 14.3.3.4
TA 15 Aeronautics	--	--

Technology Candidates that Support the Evolvable Mars Campaign

Evolvable Mars Campaign

The ***Evolvable Mars Campaign (EMC)*** is NASA's on-going series of architectural trade analyses that defines the capabilities and elements needed for a sustainable human presence on Mars. The EMC identifies potential options and key decision points to enable a human mission to the Mars system in the 2030s. These analyses promote a flexible strategy that is adaptive to capability developments, scientific discovery, and ever-changing programmatic environments. This study is intended to inform the Agency on near-term key decision options and investment priorities.

NASA is employing a capability-driven approach to its human spaceflight strategy. This approach is based on developing a suite of evolving capabilities that provide specific functions to solve exploration challenges. These investments in initial capabilities can continuously be leveraged and reused, enabling more complex operations over time and exploration of more distant solar system destinations. To provide focus and narrow the trade space, the Evolvable Mars Campaign leverages current investments in the International Space Station (ISS), the Space Launch System (SLS), the Orion crew vehicle, the Asteroid Redirect Mission (ARM), initial beyond-Earth orbit habitation, along with investments in technology development within Human Exploration and Operations Mission Directorate (HEOMD), Space Technology Mission Directorate (STMD), and Science Mission Directorate (SMD).

As seen in Figure 12, four major increments in pioneering capabilities (with corresponding investment requirements), each with unique and more challenging destinations, make up the foundation of the Evolvable Mars Campaign.

Earth Reliant: The first increment is focused on utilization of the ISS, where the bulk of long-duration human research relating to human health and human support systems will be conducted.

Proving Ground: The second increment focuses on using cis-lunar space to develop and validate capabilities required for the Earth Independent phase. Key elements for validation include the Space Launch System (SLS) and the Orion crew vehicle; the Asteroid Redirect Mission (ARM), including the Asteroid Redirect Vehicle (ARV) and Solar Electric Propulsion (SEP); initial beyond-Earth orbit habitation; and a Mars transit habitat protoflight vehicle. This increment also requires investments in Entry, Descent, and Landing (EDL) risk-reduction activities and long-duration Mars surface systems because of the 10-15 year lead time to develop the required capabilities.

Earth Independent: The third and fourth increments focus on exploration of the Mars vicinity, which could include Phobos, Deimos, Mars orbit, and the Martian surface. Crewed exploration missions in this increment exercise the Mars transportation system, explore the moons and facilitate tele-operations of Mars surface systems for reconnaissance and infrastructure deployment required for sustainable human missions on Mars. The fourth increment begins the transition from exploration to pioneering, with extended human presence in the Mars vicinity and eventually on the surface of Mars becoming increasingly less dependent on resources from Earth.

Future Evolvable Mars Campaign analysis work will include a series of refined element concept development activities to drive out technology and capability performance metrics, packaging needs, configuration layouts and refined mass estimates. These will include long-duration habitat systems, exploration mobility systems, surface power, in-space stages, landers, ascent modules and taxis. Further refinement of required pathfinder missions will also be worked. Building on the current body of work, additional options that vary schedule, cadence, destinations and investment phasing will be assessed. The Evolvable Mars Campaign analyses will be updated based upon on-going programmatic changes and will continue to inform the Agency of new risks and solutions in support of strategic decision-making.

Figure 12. Evolvable Mars Campaign Levels of Progression

The table below provides a list of Technology Areas and Technology Candidates in the 2015 NASA Technology Roadmaps that enable the Evolvable Mars Campaign.

Technology Area	Evolvable Mars Campaign Critical Technologies Portfolio	Enabling Technology Areas and Technology Candidate Snapshots for the Evolvable Mars Campaign
TA 1 Launch Propulsion Systems	Advanced, Low Cost Engine Technology for heavy lift launch vehicle	1.2.1.2-4
	Next Generation Booster (Solid or Liquid)	1.1.6.1, 1.1.7.1
TA 2 In-Space Propulsion Systems	Liquid Oxygen (LOX)/Liquid Methane Primary Propulsion System	2.1.2.2
	LOX/Liquid Methane Reaction Control Engines	2.1.2.3
	Electric Propulsion & Power Processing	2.2.1.2, 3.3.5.1
	In-Space Cryogenic Liquid Acquisition	2.4.2.1-2, 2.4.2.4
TA 3 Space Power Energy Storage	High Strength/Stiffness Deployable 10-100 kW Class Solar Arrays	3.1.3.1, 3.3.1.1-2
	Autonomously Deployable 300 kW In-Space Arrays	3.1.3.2, 3.3.1.1-2
	Fission Power for Surface Missions	3.1.5.2-3, 3.3.1.1-2
	Regenerative Fuel Cells, Fuel Cells, and Electrolyzers	3.1.2.1-2, 3.2.3.1
	High Specific Energy Batteries	3.2.1.1
	Long Life Batteries	3.2.1.8
TA 4 Robotics and Autonomous Systems	Autonomous Vehicle Systems Management	4.5.1.1-3, 4.5.3, 4.7.1.5, 4.7.3.1-2
	Crew Autonomy beyond LEO	4.5.2.1, 4.5.2.3-5, 4.5.5, 7.5.3.1
	Mission Control Automation beyond LEO	4.5.1.1-3, 7.5.3.2
	Precision Landing & Hazard Avoidance	5.4.6.1-2
	Telerobotic control of robotic systems with time delay	4.5.8.1, 4.1.1.1, 4.1.1.4, 4.1.2.1, 4.1.2.7, 4.1.3.1, 4.1.3.3, 4.3.1.1, 4.3.1.3, 4.3.2.1-2, 4.3.6.1, 4.3.6.5-7, 4.3.7.1
	Robots Working Side-by-Side with Suited Crew	4.1.4.1, 4.1.4.3, 4.7.4-6, 12.3.3.1
	Surface Mobility	4.2.5.1-2, 12.3.3, 4.2.3.3-4, 4.2.4.2-3, 4.2.7, 4.2.8.1-2
	Automated/Autonomous Rendezvous & Docking, Proximity Operations, and Target Relative Navigation	4.5.6.0, 4.5.7.0, 4.6.1, 4.6.2.2, 12.3.1.5
TA 5 Communications, Navigation, and Orbital Debris Tracking and Characterization	High Data Rate Forward Link (Flight) Communications	5.1.3, 5.5.5
	High Rate, Adaptive, Internetworked Proximity Communications	5.3.2.2, 5.4.4, 5.5.2.1
	In-Space Timing and Navigation for Autonomy	5.4.1, 5.4.6.1-2
	Optical Communications	5.1.3, 5.5.5

Technology Area	Evolvable Mars Campaign Critical Technologies Portfolio	Enabling Technology Areas and Technology Candidate Snapshots for the Evolvable Mars Campaign
TA 6 Human Health, Life Support, and Habitation Systems	Long Duration Spaceflight Medical Care	6.3.1.2, 6.3.1.10
	Long-Duration Spaceflight Behavioral Health and Performance	6.3.3.9, 6.3.3.11
	Microgravity Biomedical Counter-Measures for Long Duration Spaceflight	6.3.2.5
	Microgravity Biomedical Counter-Measures - Optimized Exercise Equipment	6.3.2.4, 6.3.2.11
	Deep Space Mission Human Factors and Habitability	6.3.4.2, 6.3.4.5, 7.4.2.1
	Long Duration Stabilized Foods	6.1.4.11
	Higher closure, High Reliability, Life Support Systems	6.1.1.1-2, 6.1.1.4, 6.1.1.6-7, 6.1.2.2-3, 6.1.3.1
	In-Flight Environmental Monitoring	6.4.1.1, 6.4.1.3-5, 6.4.1.8-10
	Deep Space Suit (Block 1)	6.2.1.1-5, 6.2.1.7, 6.2.1.9, 6.2.2.4-6, 6.2.2.9-11, 6.2.3.1
	Surface Space Suit (Block 2 & 3)	6.2.1.1-6, 6.2.1.7, 6.2.1.9, 6.2.2.4-6, 6.2.2.9-11, 6.2.3.1
	Fire Prevention, Detection & Suppression (reduced pressure)	6.4.2.1-3
	Human Galactic Cosmic Radiation (GCR) Protection	6.5.2.1-5, 6.5.3.1
	Human Solar Particle Event (SPE) Radiation Protection	6.5.2.1-5, 6.5.3.1
	Radiation Exposure Prevention	6.5.1.1-2, 6.5.1.5, 6.5.4.1-2, 6.5.5.3
TA 7 Human Exploration Destination Systems	In-Situ Resource Utilization (ISRU) - Mars: Oxygen from Atmosphere	7.1.2.1-4, 7.1.3.12-15
	In-Situ Resource Utilization (ISRU) - Oxygen/Water Extraction from Regolith	7.1.1.1-7, 7.1.2.5-21, 7.1.3.1-11, 7.1.3.16-18 (in trade space)
	Anchoring Techniques & EVA Tools for µ-G Surface Operations	7.3.1.3, 7.3.1.5
	Suit Port	7.3.1.2, 7.3.1.6
	Dust Mitigation	6.2.1.4, 7.6.1.14-15, 7.6.1.22, 14.2.3.1
TA 8 Science Instruments, Observatories, and Sensor Systems	No Related EMC Critical Technologies	--
TA 9 Entry, Descent, and Landing Systems	Entry, Descent, and Landing (EDL) Technologies - Mars Exploration Class Missions	9.1.1.2, 9.1.1.5, 9.1.2.1, 9.1.2.3, 9.1.3.2, 9.1.3.6, 9.1.4.1-2, 9.1.4.4-6, 9.2.1.1-4, 9.2.3.1-2, 9.4.6.1-5
TA 10 Nanotechnology	No Related EMC Critical Technologies	--

Technology Area	Evolvable Mars Campaign Critical Technologies Portfolio	Enabling Technology Areas and Technology Candidate Snapshots for the Evolvable Mars Campaign
TA 11 Modeling, Simulation, Information Technology, and Processing	Advanced Software Development/Tools	11.2.1.1, 11.2.2, 11.2.5.1, 11.2.5.4, 11.3.1.2-5, 11.3.8.1-2, 11.4.2.3, 11.4.2.5-6, 11.4.3.1-2, 11.4.5.1-3, 11.4.7.2, 7.5.4
	Common Avionics	11.1.1.1-3, 11.1.1.5
TA 12 Materials, Structures, Mechanical Systems, and Manufacturing	Inflatable: Structures & Materials for Inflatable Modules	TBD (in trade space)
	Lightweight and Efficient Structures and Materials	12.1.4, 12.3.4, 12.3.5.1-4
	Mechanisms for Long Duration, Deep Space Missions	12.3.2.2
TA 13 Ground and Launch Systems	Ground Systems: Low Loss Cryogenic Ground Systems Storage and Transfer	13.1.1.4-6, 13.1.1.9
TA 14 Thermal Management Systems	In-Space Cryogenic Propellant Storage (Zero Boil Off LO_2)	14.1.1.4, 14.1.2.2-3, 12.3.2.2, 2.4.2.1-2
	Thermal Control	14.2.1.1, 14.2.3.9
	Robust Ablative Heat Shield (Lunar Return) - Thermal Protection Systems	14.3.1.1-3, 14.3.1.8
TA 15 Aeronautics	No Related EMC Critical Technologies	--

Note: Since the EMC is an on-going study, the capabilities and associated technologies have not been assessed to the same level of review as the other Design Reference Missions. Consequently the EMC Critical (Enabling) Technology mapping table should be considered in preliminary form, reflecting simply a single snapshot in time of the on-going EMC architecture trade studies. Continued analyses of the EMC technology portfolio will be forward work as the architecture matures, eventually providing a level of detail consistent with the other DRMs included in the roadmap documents.

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Appendices

Appendix A – Acronyms

AMPM	Agency Mission Planning Model
AO	Announcement of Opportunity
ARM	Asteroid Redirect Mission
ARMD	Aeronautics Research Mission Directorate
ARV	Asteroid Redirect Vehicle
ASCENDS	Active Sensing of CO_2 Emissions over Nights, Days, and Seasons
CLARREO	CLimate Absolute Radiance and REfractivity Observatory
CONOPS	CONcept of OPerationS
CTR	Center Technology Council
DRA	Design Reference Architecture
DRM	Design Reference Mission
DRO	Distant Retrograde Orbit
DYNAMIC	DYnamical Neutral AtMosphere Ionosphere Coupling
EMC	Evolvable Mars Campaign
ESMD	Exploration Systems Mission Directorate
EVA	ExtraVehicular Activity
GACM	Global Atmosphere Composition Mission
GCR	Galactic Cosmic Radiation
GEO	GEosynchronous Orbit
GEO-CAPE	GEOstationary Coastal and Air Pollution Events
GRACE	Gravity Recovery And Climate Experiment
GRACE-FO	Gravity Recovery And Climate Experiment Follow-On
GRAIL	Gravity Recovery And Interior Laboratory
HEOMD	Human Exploration and Operations Mission Directorate
HTPB	Hydroxyl-Terminated PolyButadiene
HyspIRI	Hyperspectral InfraRed Imager
IESD	Internal ElectroStatic Discharge
IMAP	Interstellar Mapping and Acceleration Probe
ISS	International Space Station
IT	Information Technology
LEO	Low-Earth Orbit
MEDICI	Magnetosphere Energetics, Dynamics, and Ionospheric Coupling Investigation
NRA	NASA Research Announcement
NASA	National Aeronautics and Space Administration
NRC	National Research Council
NTEC	NASA Technology Executive Council
OCT	Office of the Chief Technologist

PDR	Preliminary Design Review
RFI	Request For Information
SCaN	Space Communications and Navigation
SDO	Solar Dynamics Observatory
SEP	Solar Electric Propulsion
SLS	Space Launch System
SMD	Science Mission Directorate
SOHO	SOlar and Heliospheric Observatory
SPE	Solar Particle Event
SSA	Space Situation Awareness
STIP	Strategic Technology Investment Plan
SSTIP	Strategic Space Technology Investment Plan
STEREO	Solar TErrestrial RElations Observatory
STMD	Space Technology Mission Directorate
TA	Technology Area
TABS	Technology Area Breakdown Structure
TIM	Technical Interchange Meeting
TPS	Thermal Protection System
TRL	Technology Readiness Level
U.S.	United States
WFIRST	Wide-Field InfraRed Survey Telescope

Appendix B – Definitions

3D Perception	Technologies required to influence the ability to accurately perform perceptual-motor tasks such as those involved in grasping objects, controlling vehicles or robotic arms, and extravehicular activities.
Adopt	To use a technology that has been developed NASA adopted by an external organization.
Agency Strategic Technology Investment Plan	A comprehensive strategic plan that prioritizes technologies essential to the pursuit of NASA's mission and achievement of national goals.
Applied Research	The systematic study to gain knowledge or understanding necessary to determine the means by which a recognized and specific need may be met.
Architecture	The structure of components, their interrelationships, and the principles and guidelines governing their design and evolution over time.
Avionics	Electronic systems used on aircraft, artificial satellites, and spacecraft. The science and technology of electronics and the development of electronic devices as applied to aeronautics and astronautics.
Autonomous Systems Technologies	Technologies that allow human operators to off-load tasks, or portions of tasks, onto artificial agents.
Basic Research	The systematic study directed toward fuller knowledge or understanding of the fundamental aspects of phenomena and of observable facts without specific applications towards processes or products in mind. Basic research, however, may include activities with broad applications in mind.
Benefits	The advantages provided to mission classes and NASA by technologies under development.
Big Data	High-volume, high-velocity and high-variety information assets that demand cost-effective, innovative forms of information processing for enhanced insight and decision-making. Big Data is also a term for a collection of data sets so large and complex that it becomes difficult to process using on-hand database management tools or traditional data processing applications.
Capability	In the systems engineering sense, is defined as the ability to execute a specified course of action. A capability may or may not be accompanies by an intention. Within NASA's Capability Driven Framework, a capability is a specific function designed to solve an exploration challenge, to enable—in combination with other capabilities—unique possibilities for advancing human presents into our solar system.
Capability Gap	The difference between the ability of existing technologies and current operational requirements and expectations for technologies. A capability gap analysis is the determination of needed capabilities that do not yet exist.
Capability State of the Art	The highest level of general development that provides the capability.

Cyber Security	The collection of tools, policies, security concepts, security safeguards, guidelines, risk management approaches, actions, training, best practices, assurance and technologies that can be used to protect the cyber environment and organization and user's assets.
Design Reference Mission	A mission scenario developed by potential customers or users of a mission to help guide mission design.
Development	Development is defined as systematic application of knowledge or understanding, directed toward the production of useful materials, devices, and systems or methods, including design, development, and improvement of prototypes and new processes to meet specific requirements.
Enabling Technology	A technology that satisfies a capability need for a space mission or aeronautics strategic thrust by providing the desired performance within acceptable cost and risk. (also known as "Pull" technology).
Enhancing Technology	A technology that provides significant benefits over the current state of the art, but are not required for a specific mission or strategic thrust. (Also known as "Push" technologies). These push technology candidates include emerging or radically different ideas or approaches and often take years to advance, but can inspire new and different missions and mission architectures to accomplish long-term strategic goals.
Information Technology	Any equipment or interconnected system or subsystem of equipment, that is used in the automatic acquisition, storage, manipulation, management, movement, control, display, switching, interchange, transmission, or reception of data or information by the executive agency. Information technology includes computers, ancillary equipment, software, firmware and similar procedures, services (including support services), and related resources.
In-Situ Resource Utilization (ISRU)	In-situ resource utilization (ISRU) is the extraction and processing of local resources, both natural and discarded, into useful products and services. For example, the production of oxygen, water, and methane for life support, propellants, and power, the use of raw or processed regolith for radiation and blast protection and structures, and the manufacturing of structures and spare parts from extracted and recycled metals and plastics can significantly reduce the mass, cost, and risk of short term and sustained human exploration.
Lead	NASA is the lead investor and creates or invents novel technologies through research, development, and demonstration in areas that are critical enablers of NASA Mission Directorate's capability needs, priorities, and requirements.
Massless Exploration	Technologies required to change the ratio of mass launched from Earth to mass used in space. Exploring space without mass from Earth—i.e., massless–at least from the launch perspective.
Mission	A major activity required to accomplish an Agency goal or to effectively pursue a scientific, technological, or engineering opportunity directly related to an Agency goal. Mission needs are independent of any particular system or technological solution.
Mission Class	Mission classes represent a collection of missions with similar capability requirements.

Orbital Debris	Orbital debris comprises all human-made objects in orbit about the Earth that no longer serve any useful purpose. Examples of orbital debris include derelict spacecraft and upper stages of launch vehicles, debris intentionally released during spacecraft separation from its launch vehicle or during mission operations, debris created as a result of spacecraft or upper stage explosions or collisions, solid rocket motor effluents, and tiny flecks of paint released by thermal stress or small particle impacts. Orbital debris technologies are those technologies specifically developed for the detection, identification, tracking, and avoidance of orbital debris.
Pull Technology	A technology that satisfies a capability need for a space mission or aeronautics strategic thrust by providing the desired performance within acceptable cost and risk (also known as “Enabling” technology).
Push Technology	A technology that provides significant benefits over the current state of the art, but are not required for a specific mission or strategic thrust. (Also known as “Enhancing” technologies.)
Radiation Technologies	Technologies developed for the identification, characterization, mitigation, and protection from the harmful effects of ionizing and non-ionizing radiation and charging on humans and human made systems.
Reference Architecture	A graphically represented, high-level system overview that is intentionally free of implementation details. It generally includes high-level descriptions of the system components, a definition of relationships between components, definitions of relationships between system components and elements external to the system, and identification of performance drivers and capacity requirements. Where applicable, reference architecture also provides high-level definitions of key data sources, data stores produced, and interfaces between the system components.
Research and Development Facilities	Research and development facilities include the acquisition, design, and construction of, or major repairs or alterations to, all physical facilities for use in research and development activities. Facilities include land, buildings, and fixed capital equipment, regardless of whether the facilities are being used by the Government or by a private organization, and regardless where title to the property may rest. This category includes such fixed facilities as reactors, wind tunnels, and particle accelerators.
Roadmap Outcome	For Technology Area 15, Aeronautics, this is the equivalent of a Design Reference Mission that states desired future-state capabilities to advance Aeronautics technologies.
Sensors	Technologies or devices that respond to external stimuli, such as motion, heat or light and respond in a particular way to convert the stimuli into a measurable quantity such as an analog or digital representation.
State of The Art	The highest level of general development, as of a device, technique, or scientific field achieved at a particular time and being used in the relevant environment.
Strategic Thrust	A NASA Aeronautics technology focus area that has been coordinated and collaborated among government, academia, and industry. Serves the same function for the aeronautics community as a Mission Class does for the space community.
Structures	Manipulation of the geometry of materials to produce physical forms to withstand intended environments. Technologies include computational design, manufacturing, modeling, test methods, validation and verification.

Technical Capability Objectives	Specific functions and performance metrics that must be achieved to enable mission classes.
Technical Risk	Risk (the severity and likelihood of the consequence) associated with the achievement of a technical goal, criterion, or objective. It this context, it applies to undesired consequences related to technical performance, human safety, mission assets, or environment.
Technology	A solution that arises from applying the discipline of engineering science to synthesize a device, process, or subsystem, to enable a specific capability.
Technology Candidate Snapshot	The technology candidate is an individual technology nominee with the potential to enable or enhance a planned or conceptual NASA Design Reference Missions(s). The Technology Candidate Snapshot includes information about the technology being considered. The Technology Candidate Snapshots provide a consistent and in-depth look at the technologies discussed in the roadmaps. The snapshots provide a description of the technology, dependencies, technology performance goal, a description of the capability, and the capability performance goal. The snapshots also link the technologies to NASA space missions or Aeronautics strategic thrusts, designating them as either enabling or enhancing to those activities.
Technology Gap	The delta between the performance of the state of the art technologies and the needed performance of the technology. Technology gaps are identified to determine where future technology development investments are required.
Technology Priority	A highly ranked technology in terms of importance (to achieve needed capability) or urgency (to achieve NASA mission).
Technology Readiness Level	Provides a scale against which to measure the maturity of a technology. TRLs range from 1, Basic Technology Research, to 9, Systems Test, Launch, and Operations. Typically, a TRL of 6 (i.e., technology demonstrated in a relevant environment) is required for a technology to be integrated into a flight system.
Technology Roadmaps	A set of documents that consider a wide range of needed technologies and development pathways for the next 20 years. The roadmaps focus on “applied research” and “development” activities. The roadmaps are a foundational element of the Strategic Technology Investment Plan (STIP).

Appendix C – Abbreviations and Units

Abbreviation	Definition
CH_4	Methane
cm	Centimeter
CO_2	Carbon Dioxide
Km/s	Kilometers per Second
LH_2	Liquid Hydrogen
LO_2 / LOX	Liquid Oxygen
mm	Millimeter

Appendix D – Design Reference Missions and Aeronautic Thrusts

The tables below provide a compiled list of the planned and conceptual Design Reference Missions (DRMs) for the Human Exploration and Science missions. Additionally, there are equivalent tables that outline the Aeronautic Strategic Thrusts.

The Human Exploration mission classes and DRMs are derived from NASA's capability driven framework and human spaceflight architecture studies. The Science mission classes and associated DRMs are derived from the Science Decadals and subsequent Science Plans. Aeronautics content is derived from the Thrust Areas and Aeronautics Research and Development Plans.

Summary of Tables

8 Human Exploration missions

38 Science Missions

16 Aeronautic Strategic Thrusts

Source of Dates in the Table

Most launch dates included in the table are taken from the fiscal year 2015 Agency Mission Planning Model (AMPM) found at http://www.nasa.gov/sites/default/files/files/FY15_AMPM.pdf. Consistent with the AMPM, launch dates in 2016-2020 are notional and launch dates beyond 2020 are tentative. If a launch date is estimate, it is specified with an asterisk.

The NASA mission directorates provided the associated Need Date for Technology. The Science Mission Directorate prefers technology to be at a Technology Readiness Level of 6 (TRL6) at Preliminary Design Review (PDR). The Human Exploration and Operations Mission Directorate prefers the technology to have a higher maturity prior to incorporation into the flight program.

The dates found in these tables are used in the Roadmap Graphic and the Technology Candidate Snapshots.

Design Reference Mission	Mission Class	Mission Class Date	Launch Date	Need Date for Technology
Human Exploration and Operations Mission Directorate				
DRM 5 Asteroid Redirect – Robotic Spacecraft	Extending Reach Beyond LEO	2015-2021	EM1 2018	Robotic spacecraft: 2015
DRM 5 Asteroid Redirect – crewed in Distant Retrograde Orbit (DRO)	Into the Solar System	2022-2027	EM2– 2022 EM3–2023 EM4–2025 EM5–2027	Human spacecraft: 2015-2021
DRM 6 Crewed to NEA	Exploring Other Worlds	2027-2035	EM5–2027 EM6–2029 EM7–2031 EM8—2033 EM9—2035	Human spacecraft: 2021 Robotic spacecraft: 2023
DRM 7 Crewed to Lunar Surface	Exploring Other Worlds	2027-2035	EM5–2027 EM6–2029 EM7–2031 EM8—2033 EM9—2035	Human spacecraft: 2021 Robotic spacecraft: 2023
DRM 8 Crewed to Mars Moons	Exploring Other Worlds	2027-2035	EM5–2027 EM6–2029 EM7–2031 EM8—2033 EM9—2035	Human spacecraft: 2021 Robotic spacecraft: 2023
DRM 8a Crewed Mars Orbital	Planetary Exploration	2033 +	Launch date not in AMPM	Human spacecraft: 2027 Robotic spacecraft: 2029
DRM 9 Crewed Mars Surface mission (DRA 5.0)	Planetary Exploration	2033 +	Launch date not in AMPM	Human spacecraft: 2027 Robotic spacecraft: 2029
DRM 9a Crewed Mars Surface Mission (Minimal)	Planetary Exploration	2033 +	Launch date not in AMPM	Human spacecraft: 2027 Robotic spacecraft: 2029

Design Reference Mission	Mission Class	Mission Class Date	Launch Date	Need Date for Technology	Source
Science Mission Directorate					
Wide Field Infrared Survey Telescope (WFIRST)	Strategic Missions	Not Determined	2025	2018	Astrophysics Decadal
Gravitational Wave Surveyor Mission	Strategic Missions	Not Determined	2035*	2040	Astrophysics Decadal
CMB Polarization Surveyor Mission	Strategic Missions	Not Determined	2035*	2035	Astrophysics Decadal
Far Infrared Surveyor Mission	Strategic Missions	Not Determined	2035*	2035	Astrophysics Decadal
Large UV/Visible/IR Surveyor Mission	Strategic Missions	Not Determined	2035*	2030	Astrophysics Decadal
X-ray Surveyor Mission	Strategic Missions	Not Determined	2035*	2030	Astrophysics Decadal
Exoplanet Direct Imaging Mission	Strategic Missions	Not Determined	2030*	2025	Astrophysics Decadal
Science, Research & Technology (suborbital program)	Suborbital	Not Determined	2015-2035 (yearly)		Astrophysics Decadal
Pre-Aerosol, Clouds, and ocean Ecosystem (PACE)	Earth Systematic Missions	Not Determined	2020	2016	Earth Science Decadal
Gravity Recovery and Climate Experiment Follow On (GRACE-FO)	Earth Systematic Missions	Not Determined	2017	2015	Earth Science Decadal
Active Sensing of CO_2 Emissions over Nights, Days, and Seasons (ASCENDS)	Earth Systematic Missions	Not Determined	2023	2016	Earth Science Decadal
Aerosol-Cloud-Ecosystems (ACE)	Earth Systematic Missions	Not Determined	2024*	2020	Earth Science Decadal
Hyperspectral Infrared Imager (HyspIRI)	Earth Systematic Missions	Not Determined	2023*	2020	Earth Science Decadal
Geostationary Coastal and Air Pollution Events (GEO-CAPE)	Earth Systematic Missions	Not Determined	2024*	2019	Earth Science Decadal
Climate Absolute Radiance and Refractivity Observatory (CLARREO)	Earth Systematic Missions	Not Determined	2021*	2016	Earth Science Decadal
Lidar Surface Topography (LIST)	Earth Systematic Missions	Not Determined	>2024*	2019	Earth Science Decadal
Precision and All-Weather Temperature and Humidity (PATH)	Earth Systematic Missions	Not Determined	>2024*	2019	Earth Science Decadal
Gravity Recovery and Climate Experiment (GRACE)-II	Earth Systematic Missions	Not Determined	>2024*	2019	Earth Science Decadal
Snow and Cold Land Processes (SCLP)	Earth Systematic Missions	Not Determined	>2024*	2019	Earth Science Decadal
Global Atmosphere Composition Mission (GACM)	Earth Systematic Missions	Not Determined	>2024*	2019	Earth Science Decadal
Three-Dimensional Tropospheric Winds from Space-based Lidar (3D Winds)	Earth Systematic Missions	Not Determined	>2030*	2025	Earth Science Decadal
Earth Venture Suborbital	Suborbital	Not Determined	2015-2035 (yearly)		Earth Science Decadal
Interstellar Mapping and Acceleration Probe (IMAP)	Solar Terrestrial Probes	Not Determined	2022	2019	Heliophysics Decadal

*Launch date is estimated and not in Agency Mission Planning Model (AMPM)

Design Reference Mission	Mission Class	Mission Class Date	Launch Date	Need Date for Technology	Source
Science Mission Directorate					
Dynamical Neutral Atmosphere Ionosphere Coupling (DYNAMIC)	Solar Terrestrial Probes	Not Determined	2025	2021	Heliophysics Decadal
Magnetosphere Energetics, Dynamics, and Ionospheric Coupling Investigation (MEDICI)	Solar Terrestrial Probes	Not Determined	2032	2030	Heliophysics Decadal
Geospace Dynamics Constellation (GDC)	Living with a Star	Not Determined	2030	2019	Heliophysics Decadal
Solar Wind Measurements		Not Determined	On-going*		Heliophysics Decadal
Explorer missions	Explorer Class	Not Determined	2023, 2029	2017, 2020, 2023, 2026	Heliophysics Decadal
Science, Research & Technology (suborbital program)	Suborbital	Not Determined	2015-2035 (yearly)		Heliophysics Decadal
Mars 2020	Strategic Missions	Not Determined	2020	2017	Planetary Decadal
Discovery 13	Discovery	Not Determined	2020	2017	Planetary Decadal
Discovery 14	Discovery	Not Determined	2023	2020	Planetary Decadal
Later Discovery Program	Discovery	Not Determined	2026, 2029, 2032	2023, 2026, 2029, 2032	Planetary Decadal
New Frontiers Program 4 (NF4/~2017 AO Release) • Comet Surface Sample Return • Lunar South Pole-Aitken Basin Sample Return • Saturn Probe • Trojan Tour and Rendezvous • Venus In-Situ Explorer	New Frontiers	Not Determined	2024	2016-2018	Planetary Decadal
Europa	Planetary Flagship	Not Determined	2022-2024*	2019-2021	Planetary Decadal
New Frontiers 5 (NF5 / ~2022 AO release) • Io Observer • Lunar Geophysical Network	New Frontiers	Not Determined	2029	2021-2023	Planetary Decadal
Mars Sample Return	Planetary Flagship	Not Determined	> 2026*	>2023	Planetary Decadal
Science, Research & Technology (suborbital program)	Suborbital	Not Determined	On-going*		Planetary Decadal

*Launch date is estimated and not in Agency Mission Planning Model (AMPM)

Strategic Thrusts	Roadmap Outcome	Technical Challenge Need Date
Aeronautics Research Mission Directorate		
Enable Assured Machine Autonomy For Aviation	Ability to Fully Certify and Trust Autonomous Systems for NAS Operations	2035
Enable Assured Machine Autonomy For Aviation	Human-machine Teaming in Key Applications	2035
Enable Assured Machine Autonomy For Aviation	Initial Autonomy Applications	2025
Innovation in Commercial Supersonic Aircraft	Introduction of Affordable, Low-boom, Low-noise, and Low-emission Supersonic Transports	2035
Innovation in Commercial Supersonic Aircraft	Supersonic Overland Certification Standard Based on Acceptable Sonic Boom Noise	2025
Real-Time System-Wide Safety Assurance	An Integrated Safety Assurance System Enabling Continuous System-Wide Safety Monitoring	2035
Real-Time System-Wide Safety Assurance	Automated Safety Assurance Integrated with Real-time Operations Enabling a Self-protecting Aviation System	2035
Real-Time System-Wide Safety Assurance	Introduction of Advanced Safety Assurance Tools	2025
Safe, Efficient Growth in Global Operations	Improved efficiency and hazard reduction within NextGen operational domains	2025
Safe, Efficient Growth in Global Operations	System-wide Safety, Predictability, and Reliability Through Full NextGen Functionality	2035
Transition to Low-Carbon Propulsion	Initial Introduction of Alternative Propulsion Systems	2035
Transition to Low-Carbon Propulsion	Introduction of Alternative Propulsion Systems to Aircraft of All Sizes	2035
Transition to Low-Carbon Propulsion	Introduction of Low-carbon Fuels for Conventional Engines and Exploration of Alternative Propulsion Systems	2025
Ultra-Efficient Commercial Vehicles	Achieve Community Goals for Improved Vehicle Efficiency and Environmental Performance in 2025	2025
Ultra-Efficient Commercial Vehicles	Achieve Community Goals for Improved Vehicle Efficiency and Environmental Performance Beyond 2035	2035
Ultra-Efficient Commercial Vehicles	Achieve Community Goals for Improved Vertical Lift Vehicle Efficiency and Environmental Performance in 2035	2035

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HUMAN EXPLORATION AND OPERATIONS MISSION DIRECTORATE

Exploring Other Worlds: DRM 6 Crewed to NEA

Enabling Technologies Referencing this Mission

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HUMAN EXPLORATION AND OPERATIONS MISSION DIRECTORATE

Exploring Other Worlds: DRM 7 Crewed to Lunar Surface

Enabling Technologies Referencing this Mission

1.1.1.1, 1.1.2.1, 1.1.2.2, 1.1.2.3, 1.1.2.4, 1.1.3.1, 1.1.3.2, 1.1.6.2, 1.1.7.1, 1.1.7.2, 1.2.1.3, 1.2.1.4, 1.2.2.1, 1.2.2.2, 2.1.2.1, 2.1.2.3, 2.1.2.4, 2.4.2.1, 2.4.2.4, 3.1.2.1, 3.1.3.1, 3.1.3.2, 3.1.3.4, 3.2.1.1, 3.2.3.1, 3.3.2.1, 3.3.2.2, 3.3.2.3, 3.3.3.4, 3.3.5.1, 3.3.5.2, 4.2.1.1, 4.2.1.2, 4.2.4.4, 4.2.5.1, 4.2.6.2, 4.2.8.1, 4.2.8.2, 4.2.8.4, 4.3.1.4, 4.3.6.4, 4.3.6.7, 4.5.1.1, 4.5.1.2, 4.5.2.1, 4.5.2.2, 4.5.2.3, 4.5.2.4, 4.5.2.5, 4.5.4.1, 4.5.8.1, 4.6.1.1, 4.6.1.2, 4.6.1.3, 4.6.3.1, 4.7.3.3, 5.2.5.1, 5.2.6.4, 5.2.6.6, 6.1.1.1, 6.1.1.2, 6.1.1.3, 6.1.1.4, 6.1.1.6, 6.1.1.7, 6.1.2.2, 6.1.2.3, 6.1.3.1, 6.1.3.3, 6.1.4.2, 6.1.4.6, 6.2.1.1, 6.2.1.2, 6.2.1.3, 6.2.1.4, 6.2.1.5, 6.2.1.9, 6.2.1.10, 6.2.2.6, 6.2.2.7, 6.2.2.9, 6.2.3.1, 6.2.3.2, 6.2.3.3, 6.2.3.4, 6.2.3.5, 6.3.1.1, 6.3.1.2, 6.3.1.5, 6.3.1.7, 6.3.1.8, 6.3.1.9, 6.3.2.4, 6.3.2.5, 6.3.2.6, 6.3.2.7, 6.3.2.8, 6.3.3.1, 6.3.3.2, 6.3.3.3, 6.3.3.4, 6.3.3.5, 6.3.3.6, 6.3.3.7, 6.3.3.8, 6.3.3.9, 6.3.3.10, 6.3.3.11, 6.3.3.12, 6.3.4.1, 6.3.4.2, 6.3.4.3, 6.3.4.4, 6.3.4.5, 6.3.4.6, 6.3.4.7, 6.3.4.8, 6.3.4.9, 6.4.1.1, 6.4.1.2, 6.4.1.3, 6.4.1.4, 6.4.1.5, 6.4.1.6, 6.4.1.7, 6.4.1.8, 6.4.1.9, 6.4.1.10, 6.4.2.1, 6.4.2.2, 6.4.2.3, 6.4.3.1, 6.4.3.2, 6.4.4.1, 6.4.4.2, 6.4.4.3, 6.5.1.1, 6.5.1.5, 6.5.3.7, 6.5.3.8, 6.5.4.1, 6.5.4.2, 6.5.4.3, 6.5.4.4, 6.5.4.5, 7.1.1.1, 7.1.1.2, 7.1.1.3, 7.1.1.4, 7.1.1.5, 7.1.1.7, 7.1.2.7, 7.1.2.8, 7.1.2.9, 7.1.3.6, 7.1.3.7, 7.1.3.8, 7.1.3.10, 7.1.3.13, 7.1.3.14, 7.1.3.16, 7.1.3.17, 7.1.3.19, 7.1.4.6, 7.2.1.7, 7.2.4.1, 7.3.1.2, 7.3.1.3, 7.3.1.4, 7.4.1.13, 7.4.1.14, 7.4.1.16, 7.6.1.5, 7.6.1.12, 7.6.1.14, 7.6.1.15, 7.6.1.16, 7.6.1.18, 7.6.1.19, 10.2.2.1, 10.2.2.2, 10.2.2.3, 10.2.2.4, 10.3.2.1, 11.1.1.4, 11.1.1.5, 11.3.4.1, 12.2.1.1, 12.2.1.2, 12.2.1.6, 12.2.2.1, 12.2.2.2, 12.2.2.3, 12.2.2.5, 12.2.2.6, 12.2.2.7, 12.2.3.1, 12.2.3.2, 12.2.3.3, 12.2.4.4, 12.2.4.5, 12.2.5.7, 12.2.6.1, 12.2.6.2, 12.2.6.3, 12.2.6.4, 12.2.6.5, 12.2.6.6, 12.3.1.5, 12.3.2.2, 12.3.3.1, 12.3.3.2, 12.3.4.1, 12.3.5.1, 12.3.5.2, 12.3.5.3, 12.3.5.4, 12.4.1.1, 12.4.1.2, 12.4.1.3, 12.4.2.1, 12.4.2.2, 12.4.2.3, 12.4.3.1, 12.4.4.1, 12.4.5.1, 13.4.2.3, 14.1.1.4, 14.1.2.1, 14.1.2.7, 14.2.3.8, 14.3.1.1, 14.3.1.2, 14.3.1.8

Enhancing Technologies Referencing this Mission

1.1.5.1, 1.2.1.1, 1.2.6.1, 1.2.6.2, 1.4.1.1, 1.4.1.2, 1.4.2.1, 1.4.3.1, 1.4.3.2, 1.4.3.3, 1.4.4.1, 1.4.4.2, 1.4.4.3, 1.4.7.1, 1.4.7.2, 1.4.7.3, 2.1.1.2, 2.2.1.2, 2.4.2.2, 3.1.3.6, 3.1.3.10, 3.1.3.11, 3.1.5.1, 3.1.5.2, 3.2.1.2, 3.2.1.3, 3.2.1.7, 3.2.2.1, 3.2.2.3, 3.3.1.1, 3.3.3.1, 3.3.3.2, 3.3.3.3, 3.3.3.5, 3.3.4.1, 3.3.4.2, 3.3.5.3, 4.2.1.3, 4.2.2.1, 4.2.2.3, 4.2.3.1, 4.2.3.4, 4.2.6.4, 4.2.7.1, 4.2.8.3, 4.3.1.1, 4.3.1.2, 4.3.1.3, 4.3.2.1, 4.3.2.2, 4.3.4.1, 4.3.5.1, 4.3.6.1, 4.3.7.1, 4.4.1.1, 4.4.1.2, 4.4.3.1, 4.4.3.2, 4.4.3.3, 4.4.5.1, 4.4.5.2, 4.4.5.3, 4.4.8.1, 4.4.8.2, 4.4.8.3, 4.6.3.2, 4.7.1.1, 4.7.3.2, 4.7.4.1, 4.7.5.1, 5.2.6.5, 5.4.2.2, 5.4.2.4, 5.4.2.5, 5.4.4.1, 5.4.4.2, 5.4.4.3, 5.4.4.4, 5.5.1.1, 5.5.2.1, 5.5.3.1, 6.1.1.5, 6.1.2.1, 6.1.2.4, 6.1.3.2, 6.1.3.4, 6.1.4.1, 6.1.4.3, 6.1.4.4, 6.1.4.5, 6.1.4.7, 6.1.4.8, 6.1.4.9, 6.1.4.10, 6.1.4.11, 6.2.1.7, 6.2.1.8, 6.2.1.11, 6.2.2.4, 6.2.2.5, 6.2.2.8, 6.2.2.10, 6.2.2.11,6.3.1.6, 6.5.1.2, 6.5.1.3, 6.5.1.4, 6.5.2.2, 6.5.2.3, 6.5.2.4, 6.5.2.5, 6.5.3.1, 6.5.3.2, 6.5.3.3, 6.5.5.1, 6.5.5.2, 6.5.5.3, 6.5.5.4, 6.5.5.5, 7.1.1.6, 7.1.2.5, 7.1.2.6, 7.1.2.10, 7.1.2.11, 7.1.2.12, 7.1.2.13, 7.1.2.14, 7.1.2.15, 7.1.2.16, 7.1.2.17, 7.1.2.18, 7.1.2.19, 7.1.2.20, 7.1.2.21, 7.1.3.1, 7.1.3.2, 7.1.3.3, 7.1.3.4, 7.1.3.5, 7.1.3.9, 7.1.4.1, 7.1.4.2, 7.1.4.3, 7.1.4.4, 7.1.4.5, 7.1.4.7, 7.1.4.8, 7.1.4.9, 7.1.4.10, 7.2.1.1, 7.2.1.2, 7.2.1.3, 7.2.1.4, 7.2.1.5, 7.2.1.6, 7.2.1.8, 7.2.1.9, 7.2.2.1, 7.2.3.5, 7.2.3.7, 7.2.3.8, 7.2.3.9, 7.2.3.10, 7.2.3.11, 7.2.3.12, 7.2.3.15, 7.3.1.1, 7.3.1.6, 7.3.1.7, 7.3.2.1, 7.3.2.2, 7.3.3.1, 7.4.1.1, 7.4.1.2, 7.4.1.3, 7.4.1.4, 7.4.1.5, 7.4.1.6, 7.4.1.7, 7.4.1.8, 7.4.1.9, 7.4.1.10, 7.4.1.12, 7.4.1.15, 7.4.1.17, 7.4.2.1, 7.4.3.1, 7.4.3.2, 7.4.3.3, 7.6.1.1, 7.6.1.2, 7.6.1.3, 7.6.1.4, 7.6.1.6, 7.6.1.7, 7.6.1.8, 7.6.1.9, 7.6.1.10, 7.6.1.11, 7.6.1.13, 7.6.1.17, 7.6.1.20, 7.6.1.21, 7.6.1.22, 7.6.2.1, 7.6.2.2, 8.2.3.3, 8.2.3.4, 8.2.3.5, 9.2.2.3, 9.2.2.4, 10.1.1.1, 10.1.1.2, 10.1.1.3, 10.1.1.4, 10.1.1.5, 10.1.1.7, 10.1.1.8, 10.1.1.10, 10.1.2.1, 10.1.2.2, 10.1.2.3, 10.1.2.4, 10.1.2.6, 10.1.2.7, 10.1.3.3, 10.1.4.1, 10.1.5.2, 10.1.5.3, 10.2.1.1, 10.2.1.2, 10.2.1.4, 10.2.1.5, 10.2.1.6, 10.3.1.1, 10.3.2.3, 11.1.1.1, 11.1.1.2, 11.1.1.3, 11.2.2.1, 11.2.2.2, 11.2.2.3, 11.2.5.1, 11.2.5.2, 11.2.5.3, 11.2.5.4, 11.3.1.1, 11.3.1.2, 11.3.1.3, 11.3.1.4, 11.3.1.5, 11.3.4.2, 11.3.5.1, 11.3.5.3, 11.3.6.1, 11.3.6.2, 11.3.6.3, 11.3.6.4, 11.3.6.5, 11.3.6.6, 11.3.7.4, 11.3.7.5, 11.3.8.1, 11.3.8.2, 11.4.1.1, 11.4.1.2, 11.4.1.3, 11.4.1.4, 11.4.1.5, 11.4.1.6, 11.4.1.7, 11.4.1.9, 11.4.1.10, 11.4.2.6, 11.4.3.1, 11.4.4.1, 11.4.4.2, 11.4.4.3, 11.4.5.4, 11.4.6.1, 11.4.6.2, 11.4.6.3, 11.4.7.1, 11.4.7.2, 11.4.7.5, 11.4.7.6, 11.4.8.1, 11.4.8.2, 11.4.8.3, 11.4.8.4, 11.4.8.5, 12.1.1.1, 12.1.1.2, 12.1.1.3, 12.1.1.4, 12.1.4.4, 12.1.5.1, 12.1.5.2, 12.1.5.3, 12.2.5.1, 12.2.5.2, 12.2.5.3, 12.2.5.5, 12.3.1.1, 12.3.1.2, 12.3.1.4, 12.3.2.1, 13.4.2.4, 14.1.1.1, 14.1.1.2, 14.1.1.3, 14.1.2.2, 14.1.2.5, 14.1.2.6, 14.2.2.5, 14.2.2.6, 14.2.2.10, 14.2.3.1, 14.3.1.4, 14.3.1.5, 14.3.1.6, 14.3.1.7, 14.3.2.1, 14.3.2.2, 14.3.3.2, 14.3.3.3, 14.3.3.4

HUMAN EXPLORATION AND OPERATIONS MISSION DIRECTORATE

Exploring Other Worlds: DRM 8 Crewed to Mars Moons

Enabling Technologies Referencing this Mission

1.1.1.1, 1.1.2.1, 1.1.2.2, 1.1.2.3, 1.1.2.4, 1.1.3.1, 1.1.3.2, 1.1.6.2, 1.1.7.1, 1.1.7.2, 1.2.1.3, 1.2.1.4, 1.2.2.1, 1.2.2.2, 2.1.2.1, 2.1.2.2, 2.1.2.3, 2.1.2.4, 2.4.2.1, 2.4.2.4, 3.1.3.3, 3.1.3.4, 3.2.1.1, 3.3.2.1, 3.3.2.2, 3.3.2.3, 3.3.3.4, 3.3.5.1, 3.3.5.2, 3.3.5.4, 4.2.1.1, 4.2.1.2, 4.2.4.4, 4.2.5.1, 4.2.6.2, 4.2.8.1, 4.2.8.2, 4.2.8.4, 4.3.1.4, 4.3.6.4, 4.5.1.1, 4.5.1.2, 4.5.2.1, 4.5.2.2, 4.5.2.3, 4.5.2.4, 4.5.2.5, 4.5.4.1, 4.5.8.1, 4.6.1.1, 4.6.1.2, 4.6.1.3, 4.6.3.1, 5.2.6.6, 5.6.1.1, 6.1.1.1, 6.1.1.2, 6.1.1.3, 6.1.1.4, 6.1.1.6, 6.1.1.7, 6.1.2.2, 6.1.2.3, 6.1.3.1, 6.1.3.3, 6.1.4.2, 6.1.4.6, 6.2.1.1, 6.2.1.2, 6.2.1.3, 6.2.1.4, 6.2.1.5, 6.2.1.6, 6.2.1.9, 6.2.1.10, 6.2.2.1, 6.2.2.2, 6.2.2.3, 6.2.2.6, 6.2.2.7, 6.2.2.9, 6.2.3.1, 6.2.3.2, 6.2.3.3, 6.2.3.4, 6.2.3.5, 6.3.1.1, 6.3.1.2, 6.3.1.3, 6.3.1.4, 6.3.1.5, 6.3.1.8, 6.3.1.9, 6.3.2.1, 6.3.2.2, 6.3.2.3, 6.3.2.6, 6.3.2.7, 6.3.2.8, 6.3.3.1, 6.3.3.2, 6.3.3.3, 6.3.3.4, 6.3.3.5, 6.3.3.6, 6.3.3.7, 6.3.3.8, 6.3.3.9, 6.3.3.10, 6.3.3.11, 6.3.3.12, 6.3.4.1, 6.3.4.2, 6.3.4.3, 6.3.4.4, 6.3.4.5, 6.3.4.6, 6.3.4.7, 6.3.4.8, 6.3.4.9, 6.4.1.1, 6.4.1.2, 6.4.1.3, 6.4.1.4, 6.4.1.5, 6.4.1.6, 6.4.1.7, 6.4.1.8, 6.4.1.9, 6.4.1.10, 6.4.2.1, 6.4.2.2, 6.4.2.3, 6.4.3.1, 6.4.3.2, 6.4.4.1, 6.4.4.2, 6.4.4.3, 6.5.1.1, 6.5.1.2, 6.5.1.3, 6.5.1.4, 6.5.1.5, 6.5.2.1, 6.5.2.2, 6.5.2.3, 6.5.2.4, 6.5.2.5, 6.5.2.6, 6.5.3.1, 6.5.3.2, 6.5.3.3, 6.5.3.7, 6.5.4.1, 6.5.4.2, 6.5.4.3, 6.5.4.4, 6.5.4.5, 6.5.5.1, 6.5.5.2, 6.5.5.3, 6.5.5.4, 6.5.5.5, 7.1.1.1, 7.1.1.2, 7.1.1.3, 7.1.1.4, 7.1.1.5, 7.1.4.6, 7.2.1.7, 7.2.4.1, 7.3.1.3, 7.3.1.4, 7.3.1.5, 7.4.1.13, 7.4.1.14, 7.4.1.16, 7.4.4.1, 7.5.2.1, 7.5.2.3, 7.5.2.5, 7.5.2.9, 7.5.2.10, 7.5.2.11, 7.5.3.1, 7.5.3.2, 7.6.1.1, 7.6.1.5, 7.6.1.12, 7.6.1.14, 7.6.1.15, 7.6.1.16, 10.1.1.1, 10.1.1.2, 10.1.1.3, 10.1.1.4, 10.1.1.5, 10.1.1.7, 10.1.1.8, 10.1.1.10, 10.1.2.1, 10.1.2.2, 10.1.2.3, 10.1.2.4, 10.1.2.6, 10.1.2.7, 10.1.3.3, 10.1.4.1, 10.1.5.1, 10.1.5.2, 10.1.5.3, 10.2.1.1, 10.2.1.2, 10.2.2.1, 10.2.2.2, 10.2.2.3, 10.2.3.1, 10.3.1.1, 10.3.2.1, 11.1.1.4, 11.1.1.5, 12.2.1.1, 12.2.1.2, 12.2.1.3, 12.2.1.4, 12.2.1.6, 12.2.2.1, 12.2.2.2, 12.2.2.3, 12.2.2.4, 12.2.2.5, 12.2.2.6, 12.2.2.7, 12.2.3.1, 12.2.3.2, 12.2.3.3, 12.2.3.4, 12.2.4.1, 12.2.4.2, 12.2.4.3, 12.2.4.4, 12.2.4.5, 12.2.5.1, 12.2.5.2, 12.2.5.3, 12.2.5.7, 12.2.6.1, 12.2.6.2, 12.2.6.3, 12.2.6.4, 12.2.6.5, 12.2.6.6, 12.3.2.2, 12.3.3.1, 12.3.3.2, 12.3.4.1, 12.3.5.1, 12.3.5.2, 12.3.5.3, 12.3.5.4, 12.4.1.1, 12.4.1.2, 12.4.1.3, 12.4.1.4, 12.4.2.1, 12.4.2.2, 12.4.2.3, 12.4.3.1, 12.4.4.1, 12.4.5.1, 14.1.1.4, 14.1.2.1, 14.2.1.1, 14.2.3.8, 14.3.1.1, 14.3.1.2, 14.3.1.8, 14.3.2.2

Enhancing Technologies Referencing this Mission

1.1.5.1, 1.2.6.1, 1.2.6.2, 1.4.1.1, 1.4.1.2, 1.4.2.1, 1.4.3.1, 1.4.3.2, 1.4.3.3, 1.4.4.1, 1.4.4.2, 1.4.4.3, 1.4.7.1, 1.4.7.2, 1.4.7.3, 2.1.1.2, 2.1.4.1, 2.1.5.1, 2.2.1.1, 2.2.1.2, 2.2.1.3, 2.2.1.4, 2.2.1.11, 2.2.3.1, 2.4.2.2, 2.4.2.3, 3.1.3.6, 3.1.3.10, 3.1.3.11, 3.2.1.2, 3.2.1.3, 3.2.1.7, 3.2.2.1, 3.3.1.1, 3.3.1.2, 3.3.3.1, 3.3.3.2, 3.3.3.3, 3.3.3.5, 3.3.4.1, 3.3.4.2, 3.3.5.3, 4.2.2.3, 4.2.3.1, 4.2.3.4, 4.2.4.2, 4.2.4.3, 4.2.5.2, 4.2.6.4, 4.2.6.5, 4.2.8.3, 4.3.1.1, 4.3.1.2, 4.3.1.3, 4.3.2.1, 4.3.2.2, 4.3.4.1, 4.3.5.1, 4.3.6.1, 4.3.7.1, 4.4.1.1, 4.4.1.2, 4.4.3.1, 4.4.3.2, 4.4.3.3, 4.4.5.1, 4.4.5.2, 4.4.5.3, 4.4.8.1, 4.4.8.2, 4.4.8.3, 4.6.3.2, 4.7.1.1, 4.7.3.2, 4.7.4.1, 4.7.5.1, 5.2.6.5, 5.4.2.2, 5.4.2.3, 5.4.2.4, 5.4.2.5, 5.4.4.1, 5.4.4.2, 5.4.4.3, 5.4.4.4, 5.4.5.1, 5.5.1.1, 5.5.2.1, 5.5.3.1, 6.1.1.5, 6.1.2.1, 6.1.2.4, 6.1.3.2, 6.1.3.4, 6.1.4.1, 6.1.4.3, 6.1.4.4, 6.1.4.5, 6.1.4.7, 6.1.4.8, 6.1.4.9, 6.1.4.10, 6.1.4.11, 6.2.1.7, 6.2.1.8, 6.2.1.11, 6.2.2.4, 6.2.2.5, 6.2.2.8, 6.2.2.10, 6.2.2.11, 6.3.1.6, 7.1.1.7, 7.1.2.1, 7.1.2.2, 7.1.2.3, 7.1.2.4, 7.1.2.5, 7.1.2.6, 7.1.2.7, 7.1.2.8, 7.1.2.9, 7.1.2.10, 7.1.2.11, 7.1.2.12, 7.1.2.13, 7.1.2.14, 7.1.2.15, 7.1.2.16, 7.1.2.17, 7.1.2.18, 7.1.2.19, 7.1.2.20, 7.1.2.21, 7.2.1.3, 7.2.1.4, 7.2.1.5, 7.2.1.6, 7.2.1.8, 7.2.1.9, 7.2.2.1, 7.2.3.1, 7.2.3.2, 7.2.3.3, 7.2.3.4, 7.2.3.5, 7.2.3.6, 7.2.3.7, 7.2.3.8, 7.2.3.9, 7.2.3.10, 7.2.3.11, 7.2.3.12, 7.2.3.13, 7.2.3.14, 7.2.3.15, 7.3.1.1, 7.3.1.2, 7.3.1.6, 7.3.2.1, 7.3.2.2, 7.3.3.1, 7.4.1.1, 7.4.1.2, 7.4.1.3, 7.4.1.4, 7.4.1.5, 7.4.1.6, 7.4.1.7, 7.4.1.8, 7.4.1.9, 7.4.1.10, 7.4.1.12, 7.4.1.15, 7.4.1.17, 7.4.2.1, 7.4.3.1, 7.4.3.2, 7.4.3.3, 7.4.4.2, 7.5.2.6, 7.5.2.7, 7.6.1.2, 7.6.1.3, 7.6.1.4, 7.6.1.6, 7.6.1.7, 7.6.1.8, 7.6.1.9, 7.6.1.10, 7.6.1.11, 7.6.1.13, 7.6.1.17, 8.2.3.3, 8.2.3.4, 8.2.3.5, 9.2.2.3, 9.2.2.4, 10.2.1.4, 10.2.1.5, 10.2.1.6, 10.3.3.1, 10.3.3.2, 11.1.1.1, 11.1.1.2, 11.1.1.3, 11.2.1.1, 11.2.1.2, 11.2.1.3, 11.2.2.1, 11.2.2.2, 11.2.2.3, 11.2.5.1, 11.2.5.2, 11.2.5.3, 11.2.5.4, 11.3.1.1, 11.3.1.2, 11.3.1.3, 11.3.1.4, 11.3.1.5, 11.3.3.1, 11.3.3.2, 11.3.3.3, 11.3.3.4, 11.3.3.5, 11.3.3.6, 11.3.5.2, 11.3.6.1, 11.3.6.2, 11.3.6.3, 11.3.6.4, 11.3.6.5, 11.3.6.6, 11.3.7.1, 11.3.7.2, 11.3.7.3, 11.3.7.4, 11.3.8.1, 11.3.8.2, 11.4.2.6, 11.4.3.1, 11.4.5.1, 11.4.5.2, 11.4.5.3, 12.1.1.1, 12.1.1.2, 12.1.1.3, 12.1.1.4, 12.1.4.1, 12.1.4.4, 12.1.5.1, 12.1.5.2, 12.1.5.3, 12.2.5.5, 12.3.1.1, 12.3.1.2, 12.3.1.4, 12.3.2.1, 12.3.6.1, 12.3.6.2, 12.3.6.3, 12.3.6.4, 14.1.1.1, 14.1.1.2, 14.1.1.3, 14.1.1.5, 14.1.1.6, 14.1.1.7, 14.1.2.2, 14.1.2.5, 14.1.2.6, 14.2.3.1, 14.3.1.4, 14.3.1.5, 14.3.1.6, 14.3.1.7, 14.3.2.1, 14.3.3.2, 14.3.3.3, 14.3.3.4

HUMAN EXPLORATION AND OPERATIONS MISSION DIRECTORATE

Planetary Exploration: DRM 8a Crewed Mars Orbital

Enabling Technologies Referencing this Mission

1.1.1.1, 1.1.2.1, 1.1.2.2, 1.1.2.3, 1.1.2.4, 1.1.3.1, 1.1.3.2, 1.1.6.2, 1.1.7.1, 1.1.7.2, 1.2.1.3, 1.2.1.4, 1.2.2.1, 1.2.2.2, 2.1.2.1, 2.1.2.2, 2.1.2.3, 2.1.2.4, 2.4.2.1, 2.4.2.4, 3.1.2.3, 3.1.3.3, 3.1.5.6, 3.1.6.1, 3.3.5.1, 3.3.5.2, 4.3.6.4, 4.5.1.1, 4.5.1.2, 4.5.1.3, 4.5.2.1, 4.5.2.2, 4.5.2.3, 4.5.2.4, 4.5.2.5, 4.5.4.1, 4.5.8.1, 4.6.1.1, 4.6.1.2, 4.6.1.3, 4.6.3.1, 4.7.3.3, 5.6.1.1, 5.6.5.1, 6.1.1.1, 6.1.1.2, 6.1.1.3, 6.1.1.6, 6.1.1.7, 6.1.2.2, 6.1.2.3, 6.1.3.1, 6.1.3.3, 6.1.4.2, 6.1.4.6, 6.2.1.1, 6.2.1.2, 6.2.1.3, 6.2.1.4, 6.2.1.5, 6.2.1.6, 6.2.1.9, 6.2.1.10, 6.2.2.1, 6.2.2.2, 6.2.2.3, 6.2.2.6, 6.2.2.7, 6.2.2.9, 6.2.3.1, 6.2.3.2, 6.2.3.3, 6.2.3.4, 6.2.3.5, 6.3.1.1, 6.3.1.2, 6.3.1.3, 6.3.1.4, 6.3.1.5, 6.3.1.6, 6.3.1.7, 6.3.1.8, 6.3.1.9, 6.3.2.1, 6.3.2.4, 6.3.2.5, 6.3.2.6, 6.3.2.7, 6.3.2.8, 6.3.3.1, 6.3.3.2, 6.3.3.3, 6.3.3.4, 6.3.3.5, 6.3.3.6, 6.3.3.7, 6.3.3.8, 6.3.3.9, 6.3.3.10, 6.3.3.11, 6.3.3.12, 6.3.4.1, 6.3.4.2, 6.3.4.3, 6.3.4.4, 6.3.4.5, 6.3.4.6, 6.3.4.7, 6.3.4.8, 6.3.4.9, 6.4.1.1, 6.4.1.2, 6.4.1.3, 6.4.1.4, 6.4.1.5, 6.4.1.6, 6.4.1.7, 6.4.1.8, 6.4.1.9, 6.4.1.10, 6.4.2.1, 6.4.2.2, 6.4.2.3, 6.4.3.1, 6.4.3.2, 6.4.4.1, 6.4.4.2, 6.4.4.3, 6.5.1.1, 6.5.1.2, 6.5.1.3, 6.5.1.4, 6.5.1.5, 6.5.1.6, 6.5.1.7, 6.5.2.1, 6.5.2.2, 6.5.2.3, 6.5.2.4, 6.5.2.5, 6.5.2.6, 6.5.3.1, 6.5.3.2, 6.5.3.4, 6.5.3.5, 6.5.3.6, 6.5.3.7, 6.5.3.9, 6.5.4.1, 6.5.4.2, 6.5.4.3, 6.5.4.4, 6.5.4.5, 6.5.5.1, 6.5.5.2, 6.5.5.3, 6.5.5.4, 6.5.5.5, 7.1.4.6, 7.2.1.7, 7.2.4.1, 7.3.1.3, 7.3.1.4, 7.4.1.13, 7.4.1.14, 7.4.1.16, 7.4.4.1, 7.5.2.1, 7.5.2.3, 7.5.2.5, 7.5.2.9, 7.5.2.10, 7.5.2.11, 7.5.3.1, 7.5.3.2, 7.6.1.1, 7.6.1.2, 7.6.1.3, 7.6.1.5, 7.6.1.6, 7.6.1.7, 7.6.1.8, 7.6.1.12, 7.6.1.13, 7.6.1.14, 7.6.1.15, 7.6.1.16, 7.6.1.17, 10.1.1.1, 10.1.1.2, 10.1.1.3, 10.1.1.4, 10.1.1.5, 10.1.1.7, 10.1.1.8, 10.1.1.10, 10.1.2.1, 10.1.2.3, 10.1.2.4, 10.1.2.5, 10.1.2.6, 10.1.2.7, 10.1.3.3, 10.1.4.1, 10.1.5.1, 10.1.5.2, 10.1.5.3, 10.2.1.1, 10.2.1.2, 10.2.2.1, 10.2.2.2, 10.2.2.3, 10.2.3.1, 10.3.1.1, 10.3.2.1, 10.4.2.3, 11.1.1.4, 11.1.1.5, 11.2.3.1, 11.4.7.2, 12.2.1.1, 12.2.1.2, 12.2.1.3, 12.2.1.4, 12.2.1.6, 12.2.2.1, 12.2.2.2, 12.2.2.3, 12.2.2.4, 12.2.2.5, 12.2.3.1, 12.2.3.2, 12.2.3.3, 12.2.3.4, 12.2.3.5, 12.2.3.6, 12.2.4.1, 12.2.4.2, 12.2.4.3, 12.2.4.4, 12.2.4.5, 12.2.5.1, 12.2.5.2, 12.2.5.3, 12.2.5.7, 12.2.6.1, 12.2.6.2, 12.2.6.3, 12.2.6.4, 12.2.6.5, 12.2.6.6, 12.3.1.5, 12.3.2.2, 12.3.3.1, 12.3.3.2, 12.3.4.1, 12.3.5.1, 12.3.5.2, 12.3.5.3, 12.3.5.4, 12.4.1.1, 12.4.1.2, 12.4.1.3, 12.4.1.4, 12.4.2.1, 12.4.2.2, 12.4.2.3, 12.4.3.1, 12.4.4.1, 12.4.5.1, 13.4.2.3, 14.1.1.4, 14.1.2.1, 14.2.3.8, 14.3.1.1, 14.3.1.2, 14.3.1.8, 14.3.2.2

Enhancing Technologies Referencing this Mission

1.1.5.1, 1.2.6.1, 1.2.6.2, 1.4.1.1, 1.4.1.2, 1.4.2.1, 1.4.3.1, 1.4.3.2, 1.4.3.3, 1.4.4.1, 1.4.4.2, 1.4.4.3, 1.4.7.1, 1.4.7.2, 1.4.7.3, 2.1.1.2, 2.1.3.1, 2.1.4.1, 2.1.5.1, 2.2.1.1, 2.2.1.2, 2.2.1.3, 2.2.1.4, 2.2.1.11, 2.2.3.2, 2.3.7.1, 2.4.2.2, 2.4.2.3, 3.1.5.5, 3.2.1.7, 3.2.2.1, 3.3.3.1, 3.3.3.2, 3.3.3.3, 3.3.3.5, 3.3.4.1, 3.3.4.2, 3.3.5.3, 4.2.3.1, 4.2.3.4, 4.3.1.1, 4.3.1.2, 4.3.1.3, 4.3.2.1, 4.3.2.2, 4.3.4.1, 4.3.5.1, 4.3.6.1, 4.4.1.1, 4.4.1.2, 4.4.3.1, 4.4.3.2, 4.4.3.3, 4.4.5.1, 4.4.5.2, 4.4.5.3, 4.4.8.1, 4.4.8.2, 4.4.8.3, 4.6.3.2, 4.7.3.1, 4.7.4.1, 5.5.1.1, 5.5.2.1, 5.5.3.1, 6.1.1.4, 6.1.1.5, 6.1.2.1, 6.1.2.4, 6.1.3.2, 6.1.3.4, 6.1.4.1, 6.1.4.3, 6.1.4.4, 6.1.4.5, 6.1.4.7, 6.1.4.8, 6.1.4.9, 6.1.4.10, 6.1.4.11, 6.2.1.7, 6.2.1.8, 6.2.1.11, 6.2.2.4, 6.2.2.5, 6.2.2.8, 6.2.2.10, 6.2.2.11, 7.2.1.3, 7.2.1.4, 7.2.1.5, 7.2.1.6, 7.2.1.8, 7.2.1.9, 7.2.2.1, 7.2.3.1, 7.2.3.2, 7.2.3.3, 7.2.3.4, 7.2.3.5, 7.2.3.6, 7.2.3.7, 7.2.3.8, 7.2.3.9, 7.2.3.10, 7.2.3.11, 7.2.3.12, 7.2.3.15, 7.3.1.1, 7.3.1.2, 7.3.1.6, 7.3.2.1, 7.3.2.2, 7.3.3.1, 7.4.1.1, 7.4.1.2, 7.4.1.3, 7.4.1.4, 7.4.1.5, 7.4.1.6, 7.4.1.7, 7.4.1.8, 7.4.1.9, 7.4.1.10, 7.4.1.12, 7.4.1.15, 7.4.1.17, 7.4.2.1, 7.4.3.1, 7.4.3.2, 7.4.3.3, 7.4.4.2, 7.5.2.6, 7.5.2.7, 7.6.1.9, 7.6.1.10, 7.6.1.11, 8.2.3.3, 8.2.3.4, 8.2.3.5, 9.2.2.3, 9.2.2.4, 10.2.1.4, 10.2.1.5, 10.3.1.2, 10.3.3.1, 10.3.3.2, 10.4.2.2, 10.4.2.4, 10.4.2.5, 10.4.2.6, 10.4.2.7, 10.4.2.8, 11.1.2.1, 11.1.2.2, 11.1.2.3, 11.1.2.5, 11.1.2.6, 11.2.1.1, 11.2.1.2, 11.2.1.3, 11.4.2.4, 11.4.7.5, 11.4.7.6, 11.4.7.7, 12.1.1.1, 12.1.1.2, 12.1.1.3, 12.1.1.4, 12.1.4.1, 12.1.4.2, 12.1.4.3, 12.1.5.1, 12.1.5.2, 12.1.5.3, 12.2.5.5, 12.3.1.1, 12.3.1.2, 12.3.1.3, 12.3.1.4, 12.3.2.1, 12.3.6.1, 12.3.6.2, 12.3.6.3, 12.3.6.4, 13.4.2.4, 14.1.1.1, 14.1.1.2, 14.1.1.3, 14.1.1.5, 14.1.1.6, 14.1.1.7, 14.1.2.2, 14.1.2.5, 14.1.2.6, 14.2.2.5, 14.2.2.10, 14.2.3.1, 14.3.1.4, 14.3.1.5, 14.3.1.6, 14.3.1.7, 14.3.2.1, 14.3.3.2, 14.3.3.3, 14.3.3.4

HUMAN EXPLORATION AND OPERATIONS MISSION DIRECTORATE

Planetary Exploration: DRM 9 Crewed Mars Surface Mission (DRA 5.0)

Enabling Technologies Referencing this Mission

1.1.1.1, 1.1.2.1, 1.1.2.2, 1.1.2.3, 1.1.2.4, 1.1.3.1, 1.1.3.2, 1.1.6.2, 1.1.7.1, 1.1.7.2, 1.2.1.3, 1.2.1.4, 1.2.2.1, 1.2.2.2, 2.1.2.1, 2.1.2.2, 2.1.2.3, 2.1.2.4, 2.2.3.2, 2.4.2.1, 2.4.2.3, 2.4.2.4, 3.1.2.1, 3.1.2.2, 3.1.2.3, 3.1.3.2, 3.1.3.3, 3.1.5.3, 3.1.5.4, 3.1.5.6, 3.1.6.1, 3.2.1.1, 3.2.1.8, 3.2.3.1, 3.2.3.2, 3.3.2.1, 3.3.2.2, 3.3.2.3, 3.3.3.4, 3.3.5.1, 3.3.5.2, 4.2.1.1, 4.2.1.2, 4.2.3.3, 4.2.4.4, 4.2.5.1, 4.2.6.2, 4.2.8.1, 4.2.8.2, 4.3.6.2, 4.3.6.3, 4.3.6.4, 4.3.6.7, 4.5.1.1, 4.5.1.2, 4.5.1.3, 4.5.2.1, 4.5.2.2, 4.5.2.3, 4.5.2.4, 4.5.2.5, 4.5.4.1, 4.5.8.1, 4.6.1.1, 4.6.1.2, 4.6.1.3, 4.6.3.1, 4.7.3.3, 5.4.2.8, 5.6.5.1, 6.1.1.1, 6.1.1.2, 6.1.1.3, 6.1.1.4, 6.1.1.6, 6.1.1.7, 6.1.2.2, 6.1.2.3, 6.1.3.1, 6.1.3.3, 6.1.4.2, 6.1.4.6, 6.2.1.1, 6.2.1.2, 6.2.1.3, 6.2.1.4, 6.2.1.5, 6.2.1.6, 6.2.1.9, 6.2.1.10, 6.2.2.1, 6.2.2.2, 6.2.2.3, 6.2.2.6, 6.2.2.7, 6.2.2.9, 6.2.3.1, 6.2.3.2, 6.2.3.3, 6.2.3.4, 6.2.3.5, 6.3.1.1, 6.3.1.2, 6.3.1.3, 6.3.1.4, 6.3.1.5, 6.3.1.6, 6.3.1.7, 6.3.1.8, 6.3.1.9, 6.3.2.1, 6.3.2.2, 6.3.2.3, 6.3.2.4, 6.3.2.5, 6.3.2.6, 6.3.2.7, 6.3.2.8, 6.3.3.1, 6.3.3.2, 6.3.3.3, 6.3.3.4, 6.3.3.5, 6.3.3.6, 6.3.3.7, 6.3.3.8, 6.3.3.9, 6.3.3.10, 6.3.3.11, 6.3.3.12, 6.3.4.1, 6.3.4.2, 6.3.4.3, 6.3.4.4, 6.3.4.5, 6.3.4.6, 6.3.4.7, 6.3.4.8, 6.3.4.9, 6.4.1.1, 6.4.1.2, 6.4.1.3, 6.4.1.4, 6.4.1.5, 6.4.1.6, 6.4.1.7, 6.4.1.8, 6.4.1.9, 6.4.1.10, 6.4.2.1, 6.4.2.2, 6.4.2.3, 6.4.3.1, 6.4.3.2, 6.4.4.1, 6.4.4.2, 6.4.4.3, 6.5.1.1, 6.5.1.2, 6.5.1.3, 6.5.1.4, 6.5.1.5, 6.5.1.6, 6.5.1.7, 6.5.2.1, 6.5.2.2, 6.5.2.3, 6.5.2.4, 6.5.2.5, 6.5.2.6, 6.5.3.1, 6.5.3.2, 6.5.3.3, 6.5.3.4, 6.5.3.5, 6.5.3.6, 6.5.3.7, 6.5.3.8, 6.5.3.9, 6.5.4.1, 6.5.4.2, 6.5.4.3, 6.5.4.4, 6.5.4.5, 6.5.5.1, 6.5.5.2, 6.5.5.3, 6.5.5.4, 6.5.5.5, 7.1.1.1, 7.1.1.2, 7.1.1.3, 7.1.1.4, 7.1.1.5, 7.1.1.7, 7.1.2.1, 7.1.2.2, 7.1.2.3, 7.1.2.4, 7.1.2.7, 7.1.2.8, 7.1.2.9, 7.1.3.7, 7.1.3.8, 7.1.3.10, 7.1.3.11, 7.1.3.12, 7.1.3.13, 7.1.3.14, 7.1.3.15, 7.1.3.16, 7.1.3.17, 7.1.3.18, 7.1.3.19, 7.1.4.6, 7.2.1.7, 7.2.4.1, 7.3.1.2, 7.3.1.3, 7.3.1.4, 7.4.1.13, 7.4.1.14, 7.4.1.16, 7.5.2.1, 7.5.2.3, 7.5.2.5, 7.5.2.9, 7.5.2.10, 7.5.2.11, 7.5.3.1, 7.5.3.2, 7.6.1.5, 7.6.1.12, 7.6.1.14, 7.6.1.15, 7.6.1.16, 7.6.1.18, 7.6.1.19, 9.1.1.1, 9.1.1.2, 9.1.1.5, 9.1.1.7, 9.1.2.1, 9.1.2.3, 9.1.3.2, 9.1.3.5, 9.1.3.6, 9.1.3.7, 9.1.4.1, 9.1.4.2, 9.1.4.4, 9.1.4.5, 9.1.4.6, 9.2.3.1, 9.2.3.2, 9.2.6.1, 9.2.6.2, 9.2.6.3, 9.2.7.1, 9.2.7.2, 9.2.7.4, 9.2.8.6, 9.4.5.5, 9.4.5.11, 9.4.6.1, 9.4.6.2, 9.4.6.3, 9.4.6.4, 9.4.6.5, 10.1.1.1, 10.1.1.2, 10.1.1.3, 10.1.1.4, 10.1.1.5, 10.1.1.7, 10.1.1.8, 10.1.1.10, 10.1.2.1, 10.1.2.3, 10.1.2.4, 10.1.2.5, 10.1.2.6, 10.1.2.7, 10.1.3.3, 10.1.4.1, 10.1.5.1, 10.1.5.2, 10.1.5.3, 10.2.1.1, 10.2.1.2, 10.2.2.1, 10.2.2.2, 10.2.2.3, 10.2.2.4, 10.2.2.5, 10.2.3.1, 10.3.1.1, 10.3.2.1, 11.1.1.1, 11.1.1.2, 11.1.1.4, 11.1.1.5, 11.2.3.1, 11.2.3.2, 11.3.4.1, 11.4.3.4, 11.4.7.1, 11.4.7.2, 12.1.3.1, 12.2.1.1, 12.2.1.2, 12.2.1.3, 12.2.1.4, 12.2.1.6, 12.2.2.1, 12.2.2.2, 12.2.2.3, 12.2.2.4, 12.2.2.5, 12.2.2.6, 12.2.2.7, 12.2.3.1, 12.2.3.2, 12.2.3.3, 12.2.3.4, 12.2.3.5, 12.2.3.6, 12.2.4.1, 12.2.4.2, 12.2.4.3, 12.2.4.4, 12.2.4.5, 12.2.5.1, 12.2.5.2, 12.2.5.3, 12.2.5.7, 12.2.6.1, 12.2.6.2, 12.2.6.3, 12.2.6.4, 12.2.6.5, 12.2.6.6, 12.3.1.5, 12.3.2.2, 12.3.3.1, 12.3.3.2, 12.3.4.1, 12.3.5.1, 12.3.5.2, 12.3.5.3, 12.3.5.4, 12.4.1.1, 12.4.1.2, 12.4.1.3, 12.4.1.4, 12.4.2.1, 12.4.2.2, 12.4.2.3, 12.4.3.1, 12.4.4.1, 12.4.5.1, 13.4.2.3, 14.1.1.4, 14.1.2.1, 14.1.2.3, 14.1.2.7, 14.2.3.2, 14.2.3.4, 14.2.3.8, 14.2.3.9, 14.3.1.1, 14.3.1.2, 14.3.1.3, 14.3.1.8, 14.3.2.2, 14.3.3.1

Enhancing Technologies Referencing this Mission

1.1.5.1, 1.2.6.1, 1.2.6.2, 1.4.1.1, 1.4.1.2, 1.4.2.1, 1.4.3.1, 1.4.3.2, 1.4.3.3, 1.4.4.1, 1.4.4.2, 1.4.4.3, 1.4.7.1, 1.4.7.2, 1.4.7.3, 2.1.1.2, 2.1.3.1, 2.2.1.2, 2.2.1.11, 2.3.7.1, 2.4.2.2, 3.1.3.12, 3.1.5.1, 3.1.5.2, 3.1.5.5, 3.2.1.7, 3.2.2.1, 3.3.1.1, 3.3.1.2, 3.3.3.1, 3.3.3.2, 3.3.3.3, 3.3.3.5, 3.3.4.1, 3.3.4.2, 3.3.5.3, 4.2.1.3, 4.2.2.1, 4.2.2.2, 4.2.3.1, 4.2.3.4, 4.2.5.2, 4.3.1.1, 4.3.1.2, 4.3.1.3, 4.3.2.1, 4.3.2.2, 4.3.4.1, 4.3.5.1, 4.3.6.1, 4.4.1.1, 4.4.1.2, 4.4.3.1, 4.4.3.2, 4.4.3.3, 4.4.5.1, 4.4.5.2, 4.4.5.3, 4.4.8.1, 4.4.8.2, 4.4.8.3, 4.6.3.2, 4.7.1.1, 4.7.1.2, 4.7.1.3, 4.7.1.4, 4.7.2.1, 4.7.3.1, 4.7.4.1, 5.4.2.1, 5.4.3.3, 5.4.3.4, 5.4.5.2, 5.5.1.1, 5.5.2.1, 5.5.3.1, 6.1.1.5, 6.1.2.1, 6.1.2.4, 6.1.3.2, 6.1.3.4, 6.1.4.1, 6.1.4.3, 6.1.4.4, 6.1.4.5, 6.1.4.7, 6.1.4.8, 6.1.4.9, 6.1.4.10, 6.1.4.11, 6.2.1.7, 6.2.1.8, 6.2.2.4, 6.2.2.5, 6.2.2.8, 6.2.2.10, 6.2.2.11, 7.1.2.5, 7.1.2.6, 7.1.2.10, 7.1.2.11, 7.1.2.12, 7.1.2.13, 7.1.2.14, 7.1.2.15, 7.1.2.16, 7.1.2.17, 7.1.2.18, 7.1.2.19, 7.1.2.20, 7.1.2.21, 7.1.3.2, 7.1.3.3, 7.1.3.4, 7.1.3.5, 7.1.4.5, 7.1.4.7, 7.1.4.8, 7.1.4.9, 7.1.4.10, 7.2.1.1, 7.2.1.2, 7.2.1.3, 7.2.1.4, 7.2.1.5, 7.2.1.6, 7.2.1.8, 7.2.1.9, 7.2.2.1, 7.2.3.1, 7.2.3.2, 7.2.3.3, 7.2.3.4, 7.2.3.5, 7.2.3.6, 7.2.3.7, 7.2.3.8, 7.2.3.9, 7.2.3.10, 7.2.3.11, 7.2.3.12, 7.2.3.13, 7.2.3.14, 7.2.3.15, 7.3.1.1, 7.3.1.6, 7.3.1.7, 7.3.2.1, 7.3.2.2, 7.3.3.1, 7.4.1.1, 7.4.1.2, 7.4.1.3, 7.4.1.4, 7.4.1.5, 7.4.1.6, 7.4.1.7, 7.4.1.8, 7.4.1.9, 7.4.1.10, 7.4.1.11, 7.4.1.12, 7.4.1.15, 7.4.1.17, 7.4.2.1, 7.4.3.1, 7.4.3.2, 7.4.3.3, 7.5.2.2, 7.5.2.4, 7.5.2.6, 7.5.2.7,7.5.2.8, 7.6.1.1, 7.6.1.2, 7.6.1.3, 7.6.1.4, 7.6.1.6, 7.6.1.7, 7.6.1.8, 7.6.1.9, 7.6.1.10, 7.6.1.11, 7.6.1.13, 7.6.1.17, 7.6.1.20, 7.6.1.21, 7.6.1.22, 7.6.2.1, 7.6.2.2, 8.2.3.3, 8.2.3.4, 8.2.3.5, 9.1.1.4, 9.1.1.6, 9.1.1.8, 9.1.2.2, 9.1.2.4, 9.1.2.5, 9.1.3.3, 9.1.4.3, 9.1.4.7, 9.2.1.1, 9.2.1.2, 9.2.1.3, 9.2.1.4, 9.2.2.1, 9.2.2.2, 9.2.2.3, 9.2.2.4, 9.2.8.3, 9.2.8.4, 9.3.1.2, 9.4.5.1, 9.4.5.2, 9.4.5.3, 9.4.5.4, 9.4.5.6, 9.4.5.7, 9.4.5.12, 9.4.6.6, 10.2.1.4, 10.2.1.5, 10.3.1.2, 11.1.2.1, 11.1.2.2, 11.1.2.3, 11.1.2.4, 11.1.2.5, 11.1.2.6, 11.2.2.1, 11.2.2.2, 11.2.2.3, 11.2.3.3, 11.2.5.1, 11.2.5.2, 11.2.5.3, 11.2.5.4, 11.2.6.1, 11.2.6.2, 11.2.6.3, 11.3.1.1, 11.3.1.2, 11.3.1.3, 11.3.1.4, 11.3.1.5, 11.3.4.2, 11.3.4.3, 11.3.5.2, 11.3.6.1, 11.3.6.2, 11.3.6.3, 11.3.6.4, 11.3.6.5, 11.3.6.6, 11.3.7.1, 11.3.7.2, 11.3.7.4, 11.3.7.5, 11.3.7.6, 11.3.8.1, 11.3.8.2, 11.4.2.4, 11.4.7.5, 11.4.7.6, 11.4.7.7, 12.1.1.1, 12.1.1.2, 12.1.1.3, 12.1.1.4, 12.1.2.1, 12.1.2.2, 12.1.2.3, 12.1.5.1, 12.1.5.2, 12.1.5.3, 12.2.5.5, 12.3.1.1, 12.3.1.2, 12.3.1.4, 12.3.2.1, 12.3.6.1, 12.3.6.2, 12.3.6.3, 12.3.6.4, 13.4.2.4, 14.1.1.1, 14.1.1.2, 14.1.1.3, 14.1.1.6, 14.1.1.7, 14.1.2.2, 14.1.2.5, 14.1.2.6, 14.2.2.10, 14.2.3.1, 14.3.1.4, 14.3.1.5, 14.3.1.6, 14.3.1.7, 14.3.2.1, 14.3.3.2, 14.3.3.3, 14.3.3.4

HUMAN EXPLORATION AND OPERATIONS MISSION DIRECTORATE

Planetary Exploration: DRM 9a Crewed mars Surface Mission (Minimal)

Enabling Technologies Referencing this Mission

1.1.1.1, 1.1.2.1, 1.1.2.2, 1.1.2.3, 1.1.2.4, 1.1.3.1, 1.1.3.2, 1.1.6.2, 1.1.7.1, 1.1.7.2, 1.2.1.3, 1.2.1.4, 1.2.2.1, 1.2.2.2, 2.1.2.1, 2.1.2.2, 2.1.2.3, 2.1.2.4, 2.4.2.1, 2.4.2.4, 3.1.2.3, 3.1.5.6, 3.1.6.1, 4.2.1.1, 4.2.1.2, 4.2.3.3, 4.2.4.4, 4.2.5.1, 4.2.6.2, 4.2.8.1, 4.2.8.2, 4.3.6.2, 4.3.6.3, 4.3.6.4, 4.3.6.7, 4.5.1.1, 4.5.1.2, 4.5.1.3, 4.5.2.1, 4.5.2.2, 4.5.2.3, 4.5.2.4, 4.5.2.5, 4.5.4.1, 4.5.8.1, 4.6.1.1, 4.6.1.2, 4.6.1.3, 4.6.3.1, 4.7.3.3, 5.6.5.1, 6.1.1.1, 6.1.1.2, 6.1.1.3, 6.1.1.4, 6.1.1.6, 6.1.1.7, 6.1.2.2, 6.1.2.3, 6.1.3.1, 6.1.3.3, 6.1.4.2, 6.1.4.6, 6.2.1.1, 6.2.1.2, 6.2.1.3, 6.2.1.4, 6.2.1.5, 6.2.1.6, 6.2.1.9, 6.2.1.10, 6.2.2.1, 6.2.2.2, 6.2.2.3, 6.2.2.6, 6.2.2.7, 6.2.2.9, 6.2.3.1, 6.2.3.2, 6.2.3.3, 6.2.3.4, 6.2.3.5, 6.3.1.1, 6.3.1.2, 6.3.1.3, 6.3.1.4, 6.3.1.5, 6.3.1.6, 6.3.1.7, 6.3.1.8, 6.3.1.9, 6.3.2.1, 6.3.2.4, 6.3.2.5, 6.3.2.6, 6.3.2.7, 6.3.2.8, 6.3.3.1, 6.3.3.2, 6.3.3.3, 6.3.3.4, 6.3.3.5, 6.3.3.6, 6.3.3.7, 6.3.3.8, 6.3.3.9, 6.3.3.10, 6.3.3.11, 6.3.3.12, 6.3.4.1, 6.3.4.2, 6.3.4.3, 6.3.4.4, 6.3.4.5, 6.3.4.6, 6.3.4.7, 6.3.4.8, 6.3.4.9, 6.4.1.1, 6.4.1.2, 6.4.1.3, 6.4.1.4, 6.4.1.5, 6.4.1.6, 6.4.1.7, 6.4.1.8, 6.4.1.9, 6.4.1.10, 6.4.2.1, 6.4.2.2, 6.4.2.3, 6.4.3.1, 6.4.3.2, 6.4.4.1, 6.4.4.2, 6.4.4.3, 6.5.1.1, 6.5.1.2, 6.5.1.3, 6.5.1.5, 6.5.1.6, 6.5.1.7, 6.5.2.1, 6.5.2.2, 6.5.2.3, 6.5.2.4, 6.5.2.5, 6.5.2.6, 6.5.3.1, 6.5.3.2, 6.5.3.7, 6.5.3.8, 6.5.4.1, 6.5.4.2, 6.5.4.3, 6.5.4.4, 6.5.4.5, 6.5.5.1, 6.5.5.2, 6.5.5.3, 6.5.5.4, 6.5.5.5, 7.1.1.1, 7.1.1.2, 7.1.1.7, 7.1.2.1, 7.1.2.2, 7.1.2.3, 7.1.2.4, 7.1.2.8, 7.1.2.9, 7.1.3.7, 7.1.3.8, 7.1.3.10, 7.1.3.11, 7.1.3.12, 7.1.3.13, 7.1.3.14, 7.1.3.15, 7.1.3.16, 7.1.3.17, 7.1.3.18, 7.1.3.19, 7.1.4.6, 7.2.1.7, 7.2.4.1, 7.3.1.2, 7.3.1.3, 7.3.1.4, 7.4.1.13, 7.4.1.14, 7.4.1.16, 7.5.2.1, 7.5.2.3, 7.5.2.5, 7.5.2.9, 7.5.2.10, 7.5.2.11, 7.5.3.1, 7.5.3.2, 7.6.1.5, 7.6.1.12, 7.6.1.14, 7.6.1.15, 7.6.1.16, 7.6.1.19, 9.1.1.5, 10.1.1.1, 10.1.1.2, 10.1.1.3, 10.1.1.4, 10.1.1.5, 10.1.1.7, 10.1.1.8, 10.1.1.10, 10.1.2.1, 10.1.2.3, 10.1.2.4, 10.1.2.5, 10.1.2.6, 10.1.2.7, 10.1.3.3, 10.1.4.1, 10.1.5.1, 10.1.5.2, 10.1.5.3, 10.2.1.1, 10.2.1.2, 10.2.2.1, 10.2.2.2, 10.2.2.3, 10.2.2.4, 10.2.2.5, 10.2.3.1, 10.3.1.1, 10.3.2.1, 11.1.1.4, 11.1.1.5, 11.4.3.4, 12.2.1.1, 12.2.1.2, 12.2.1.3, 12.2.1.4, 12.2.1.6, 12.2.2.1, 12.2.2.2, 12.2.2.3, 12.2.2.4, 12.2.2.5, 12.2.2.6, 12.2.2.7, 12.2.3.1, 12.2.3.2, 12.2.3.3, 12.2.3.4, 12.2.3.5, 12.2.3.6, 12.2.4.1, 12.2.4.2, 12.2.4.3, 12.2.4.4, 12.2.4.5, 12.2.5.1, 12.2.5.2, 12.2.5.3, 12.2.5.7, 12.2.6.1, 12.2.6.2, 12.2.6.3, 12.2.6.4, 12.2.6.5, 12.2.6.6, 12.3.1.5, 12.3.2.2, 12.3.3.1, 12.3.3.2, 12.3.4.1, 12.3.5.1, 12.3.5.2, 12.3.5.3, 12.3.5.4, 12.4.1.1, 12.4.1.2, 12.4.1.3, 12.4.1.4, 12.4.2.1, 12.4.2.2, 12.4.2.3, 12.4.3.1, 12.4.4.1, 12.4.5.1, 13.4.2.3, 14.1.1.4, 14.1.2.1, 14.2.3.4, 14.2.3.8, 14.3.1.1, 14.3.1.2, 14.3.2.2, 14.3.3.1

Enhancing Technologies Referencing this Mission

1.1.5.1, 1.2.6.1, 1.2.6.2, 1.4.1.1, 1.4.1.2, 1.4.2.1, 1.4.3.1, 1.4.3.2, 1.4.3.3, 1.4.4.1, 1.4.4.2, 1.4.4.3, 1.4.7.1, 1.4.7.2, 1.4.7.3, 2.1.1.2, 2.1.3.1, 2.2.1.2, 2.2.3.2, 2.3.7.1, 2.4.2.2, 2.4.2.3, 3.2.1.7, 3.2.2.1, 3.3.3.1, 3.3.3.2, 3.3.3.3, 3.3.3.5, 3.3.4.1, 3.3.4.2, 3.3.5.3, 4.2.1.3, 4.2.2.1, 4.2.3.1, 4.2.3.4, 4.2.5.2, 4.3.1.1, 4.3.1.2, 4.3.1.3, 4.3.2.1, 4.3.2.2, 4.3.4.1, 4.3.5.1, 4.3.6.1, 4.3.7.1, 4.6.3.2, 4.7.3.1, 4.7.3.2, 4.7.5.1, 5.5.1.1, 5.5.2.1, 5.5.3.1, 6.1.1.5, 6.1.2.1, 6.1.2.4, 6.1.3.2, 6.1.3.4, 6.1.4.1, 6.1.4.3, 6.1.4.4, 6.1.4.5, 6.1.4.7, 6.1.4.8, 6.1.4.9, 6.1.4.10, 6.1.4.11, 6.2.1.7, 6.2.1.8, 6.2.1.11, 6.2.2.4, 6.2.2.5, 6.2.2.8, 6.2.2.10, 6.2.2.11, 7.1.2.10, 7.1.2.11, 7.1.2.12, 7.1.2.13, 7.1.2.14, 7.1.2.15, 7.1.2.16, 7.1.2.17, 7.1.2.18, 7.1.2.19, 7.1.2.20, 7.1.2.21, 7.1.3.2, 7.1.3.3, 7.1.3.4, 7.1.3.5, 7.1.4.5, 7.1.4.7, 7.1.4.8, 7.1.4.9, 7.1.4.10, 7.2.1.1, 7.2.1.2, 7.2.1.3, 7.2.1.4, 7.2.1.5, 7.2.1.6, 7.2.1.8, 7.2.1.9, 7.2.2.1, 7.2.3.1, 7.2.3.2, 7.2.3.3, 7.2.3.4, 7.2.3.5, 7.2.3.6, 7.2.3.7, 7.2.3.8, 7.2.3.9, 7.2.3.10, 7.2.3.11, 7.2.3.12, 7.2.3.13, 7.2.3.14, 7.2.3.15, 7.3.1.1, 7.3.1.6, 7.3.1.7, 7.3.2.1, 7.3.2.2, 7.3.3.1, 7.4.1.1, 7.4.1.2, 7.4.1.3, 7.4.1.4, 7.4.1.5, 7.4.1.6, 7.4.1.7, 7.4.1.8, 7.4.1.9, 7.4.1.10, 7.4.1.12, 7.4.1.15, 7.4.1.17, 7.4.2.1, 7.4.3.1, 7.4.3.2, 7.4.3.3, 7.5.2.2, 7.5.2.4, 7.5.2.6, 7.5.2.7, 7.5.2.8, 7.6.1.1, 7.6.1.2, 7.6.1.3, 7.6.1.4, 7.6.1.6, 7.6.1.7, 7.6.1.8, 7.6.1.9, 7.6.1.10, 7.6.1.11, 7.6.1.13, 7.6.1.17, 7.6.1.20, 7.6.1.22, 7.6.2.1, 7.6.2.2, 8.2.3.3, 8.2.3.4, 8.2.3.5, 9.1.1.4, 9.2.2.3, 9.2.2.4, 10.2.1.4, 10.2.1.5, 10.3.1.2, 10.3.3.1, 10.3.3.2, 11.2.6.1, 11.2.6.2, 11.2.6.3, 12.1.1.1, 12.1.1.2, 12.1.1.3, 12.1.1.4, 12.1.5.1, 12.1.5.2, 12.1.5.3, 12.2.5.5, 12.3.1.1, 12.3.1.2, 12.3.1.4, 12.3.2.1, 12.3.6.1, 12.3.6.2, 12.3.6.3, 12.3.6.4, 13.4.2.4, 14.1.1.1, 14.1.1.2, 14.1.1.3, 14.1.1.6, 14.1.1.7, 14.1.2.2, 14.1.2.5, 14.1.2.6, 14.2.3.1, 14.3.1.4, 14.3.1.5, 14.3.1.6, 14.3.1.7, 14.3.2.1

SCIENCE MISSION DIRECTORATE
Strategic Missions: Wide Field Infrared Survey Telescope (WFIRST)
Enabling Technologies Referencing this Mission
No enabling technologies identified
Enhancing Technologies Referencing this Mission
8.1.1.1, 8.1.1.7, 8.1.3.1, 10.1.3.5, 10.1.3.6
Strategic Missions: Gravitational Wave Surveyor Mission
Enabling Technologies Referencing this Mission
8.1.3.3, 8.1.5.13
Enhancing Technologies Referencing this Mission
5.2.6.2, 5.6.7.1, 5.7.1.1, 5.7.1.2, 5.7.2.1, 8.1.3.9, 11.1.2.4
Strategic Missions: CMB Polarization Surveyor Mission
Enabling Technologies Referencing this Mission
8.1.1.5, 8.1.6.2
Enhancing Technologies Referencing this Mission
5.2.6.2, 5.6.7.1, 5.7.1.1, 5.7.1.2, 5.7.2.1, 10.4.3.2, 11.1.2.4
Strategic Missions: Far-Infrared Surveyor Mission
Enabling Technologies Referencing this Mission
14.1.2.4
Enhancing Technologies Referencing this Mission
5.2.6.2, 5.6.7.1, 5.7.1.1, 5.7.1.2, 5.7.2.1, 8.1.6.1, 8.1.6.2, 10.4.3.4, 11.4.2.5, 14.1.1.8
Strategic Missions: Large UV/Visible/IR Surveyor Mission
Enabling Technologies Referencing this Mission
2.2.1.5, 8.1.1.6, 8.1.1.7, 8.1.3.2, 8.1.3.4, 8.1.3.5, 8.2.1.3, 8.2.1.4, 8.2.3.1, 8.2.3.2, 8.2.3.3, 8.2.3.4, 8.2.3.5, 10.4.3.3, 12.2.1.5, 12.3.1.6, 12.4.3.4
Enhancing Technologies Referencing this Mission
4.7.4.2, 5.2.6.2, 5.6.7.1, 5.7.1.1, 5.7.1.2, 5.7.2.1, 8.1.1.11, 8.1.1.12, 8.1.1.13, 11.1.2.1, 11.1.2.2, 11.1.2.3, 11.1.2.5, 11.1.2.6, 11.4.7.7, 11.4.8.1, 11.4.8.2, 11.4.8.3, 11.4.8.4, 11.4.8.5, 12.4.3.2
Strategic Missions: X-Ray Surveyor Mission
Enabling Technologies Referencing this Mission
8.1.1.8, 8.2.1.1, 8.2.1.2, 12.2.1.5, 12.2.5.7, 12.4.3.4
Enhancing Technologies Referencing this Mission
5.2.6.2, 5.6.7.1, 5.7.1.1, 5.7.1.2, 5.7.2.1, 8.1.6.2, 11.3.5.3, 12.2.5.6, 12.4.3.2, 14.1.2.4

SCIENCE MISSION DIRECTORATE
Strategic Missions: Exoplanet Imaging Mission
Enabling Technologies Referencing this Mission
8.1.3.1, 8.1.3.2, 8.1.3.4, 8.1.3.5, 8.2.3.6, 8.2.3.7
Enhancing Technologies Referencing this Mission
5.2.6.2, 5.6.7.1, 5.7.1.1, 5.7.1.2, 5.7.2.1, 8.1.1.7, 8.1.1.12, 8.2.1.3, 8.2.1.4, 11.4.2.3, 11.4.2.4, 11.4.2.6, 12.2.1.5, 12.3.1.6
Suborbital: Science, Research & Technology (Suborbital Program)
Enabling Technologies Referencing this Mission
1.6.1.1, 1.6.1.2, 1.6.3.1, 1.6.7.1, 2.1.6.1, 2.1.7.1, 2.1.7.2, 2.1.7.3, 2.2.1.5, 2.2.1.7, 2.2.1.8, 2.2.1.9, 2.2.1.10, 2.2.2.1, 13.3.1.8, 13.3.1.9, 13.3.1.10, 13.3.1.11, 13.3.7.7
Enhancing Technologies Referencing this Mission
1.1.2.5, 1.1.4.1, 1.1.6.3, 1.2.2.3, 1.2.3.1, 1.4.1.3, 1.4.6.1, 1.5.2.1, 1.6.2.1, 1.6.4.1, 1.6.5.1, 10.3.3.3, 11.4.5.1
Earth Systematic Missions: Pre-Aerosol, Clouds, and Ocean Ecosystem (PACE)
Enabling Technologies Referencing this Mission
No enabling technologies identified
Enhancing Technologies Referencing this Mission
No enhancing technologies identified
Earth Systematic Missions: Gravity Recovery and Climate Experiment Follow On (GRACE-FO)
Enabling Technologies Referencing this Mission
No enabling technologies identified
Enhancing Technologies Referencing this Mission
3.2.1.2
Earth Systematic Mission: Active Sensing of CO_2 Emissions over Nights, Days, and Seasons (ASCENDS)
Enabling Technologies Referencing this Mission
8.1.5.5
Enhancing Technologies Referencing this Mission
8.1.5.6, 14.2.1.2, 14.2.2.9
Earth Systematic Missions: Aerosol-Cloud-Ecosystems (ACE)
Enabling Technologies Referencing this Mission
8.1.4.3, 10.1.3.6, 10.4.3.3
Enhancing Technologies Referencing this Mission
5.2.6.2, 5.6.7.1, 5.7.1.1, 5.7.1.2, 5.7.2.1, 8.1.4.2, 10.1.1.6, 10.1.3.5, 11.1.2.7, 11.2.4.1, 11.2.4.2, 11.2.4.3, 11.2.4.4, 11.3.5.1, 11.3.5.2, 11.3.5.3, 11.4.1.11, 11.4.2.5, 11.4.6.4, 14.2.2.9, 14.2.2.11

SCIENCE MISSION DIRECTORATE
Earth Systematic Missions: Hyperspectral Infrared Imager (HysplRI)
Enabling Technologies Referencing this Mission
8.1.1.11, 11.1.1.3, 12.1.4.4
Enhancing Technologies Referencing this Mission
5.1.7.1, 5.2.2.2, 5.2.3.1, 5.2.6.2, 5.5.1.1, 5.6.7.1, 5.7.1.1, 5.7.1.2, 5.7.2.1, 11.1.1.1, 11.1.1.2, 11.2.6.1, 11.2.6.2, 11.4.1.1, 11.4.1.2, 11.4.1.6, 11.4.1.7, 11.4.1.9, 11.4.1.10, 11.4.1.11, 11.4.2.1, 11.4.2.2, 11.4.4.2, 11.4.4.3, 11.4.6.1, 11.4.6.2, 11.4.6.3
Earth Systematic Missions: Geostationary Coastal and Air Pollution Events (GEO-CAPE)
Enabling Technologies Referencing this Mission
12.2.5.7
Enhancing Technologies Referencing this Mission
5.7.1.1, 5.7.1.2, 5.7.2.1, 11.2.4.3, 11.2.4.5, 11.4.3.1, 12.2.5.6
Earth Systematic Missions: Climate Absolute Radiance and Refractivity Observatory (CLARREO)
Enabling Technologies Referencing this Mission
No enabling technologies identified
Enhancing Technologies Referencing this Mission
5.2.2.2, 10.4.1.2, 14.2.2.9, 14.2.2.11
Earth Systematic Missions: Lidar Surface Topography (LIST)
Enabling Technologies Referencing this Mission
8.1.5.3
Enhancing Technologies Referencing this Mission
5.2.3.1, 5.7.1.1, 5.7.1.2, 5.7.2.1
Earth Systematic Missions: Precision and All-Weather Temperature and Humidity (PATH))
Enabling Technologies Referencing this Mission
No enabling technologies identified
Enhancing Technologies Referencing this Mission
5.2.2.2, 5.7.1.1, 5.7.1.2, 5.7.2.1, 11.2.4.4
Earth Systematic Missions: Gravity Recovery and Climate Experiment (GRACE)-II
Enabling Technologies Referencing this Mission
No enabling technologies identified
Enhancing Technologies Referencing this Mission
5.7.1.1, 5.7.1.2, 5.7.2.1, 11.4.3.2

SCIENCE MISSION DIRECTORATE
Earth Systematic Missions: Snow and Cold Land Processes (SCLP)
Enabling Technologies Referencing this Mission
5.2.6.3
Enhancing Technologies Referencing this Mission
5.7.1.1, 5.7.1.2, 5.7.2.1, 8.1.4.1, 8.1.4.2
Earth Systematic Missions: Global Atmosphere Composition Mission (GACM)
Enabling Technologies Referencing this Mission
No enabling technologies identified
Enhancing Technologies Referencing this Mission
5.7.1.1, 5.7.1.2, 5.7.2.1, 8.1.4.5, 11.1.2.7, 11.2.4.3, 11.2.4.5, 11.2.6.4, 11.4.2.5, 11.4.6.4
Earth Systematic Missions: Three-Dimensional Tropospheric Winds from Space-based Lidar (3D Winds)
Enabling Technologies Referencing this Mission
8.1.5.1, 8.1.5.2, 8.1.5.6
Enhancing Technologies Referencing this Mission
5.2.6.2, 5.6.7.1, 5.7.1.1, 5.7.1.2, 5.7.2.1, 10.1.1.6, 11.1.2.6, 11.2.4.5, 11.4.7.7, 11.4.8.1, 11.4.8.5
Suborbital: Earth Venture Suborbital
Enabling Technologies Referencing this Mission
4.2.6.3, 8.1.6.3
Enhancing Technologies Referencing this Mission
1.1.2.5, 1.1.4.1, 1.1.6.3, 1.2.2.3, 1.2.3.1, 1.4.1.3, 1.4.6.1, 1.5.2.1, 4.2.2.4
Solar Terrestrial Probes: Interstellar Mapping and Acceleration Probe (IMAP)
Enabling Technologies Referencing this Mission
8.3.1.4
Enhancing Technologies Referencing this Mission
5.7.1.1, 5.7.1.2, 5.7.2.1, 8.3.1.2, 11.2.2.2, 11.4.2.5
Solar Terrestrial Probes: Dynamical Neutral Atmosphere Ionosphere Coupling (DYNAMIC)
Enabling Technologies Referencing this Mission
No enabling technologies identified
Enhancing Technologies Referencing this Mission
5.2.6.2, 5.6.7.1, 5.7.1.1, 5.7.1.2, 5.7.2.1, 8.1.1.3, 8.1.1.9, 8.1.3.7, 8.1.3.8, 11.1.2.2, 11.1.2.3, 11.1.2.5, 11.2.2.1, 11.2.2.2, 11.2.2.3, 11.2.5.1, 11.2.5.2, 11.2.5.3, 11.2.5.4, 11.4.2.5

SCIENCE MISSION DIRECTORATE
Solar Terrestrial Probes: Magnetosphere Energetics, Dynamics, and Ionospheric Coupling Investigation (MEDICI)
Enabling Technologies Referencing this Mission
8.1.1.9
Enhancing Technologies Referencing this Mission
5.2.6.2, 5.6.7.1, 5.7.1.1, 5.7.1.2, 5.7.2.1, 8.1.1.3, 8.1.1.7, 8.1.3.7, 8.1.3.8, 11.1.2.1, 11.1.2.2, 11.1.2.3, 11.1.2.5, 11.1.2.6
Living With a Star: Geospace Dynamics Constellation (GDC)
Enabling Technologies Referencing this Mission
3.1.3.4, 8.1.1.3, 8.1.1.9, 11.2.6.2
Enhancing Technologies Referencing this Mission
3.1.3.6, 3.1.3.10, 8.1.1.7, 8.1.3.7, 8.1.3.8, 8.3.1.2, 11.2.6.1, 11.2.6.3, 11.4.1.11, 11.4.2.3
Solar Wind Measurements
Enabling Technologies Referencing this Mission
2.2.2.1, 12.1.3.2
Enhancing Technologies Referencing this Mission
2.3.2.1, 11.2.6.4
Explorer Class: Explorer Missions
Enabling Technologies Referencing this Mission
1.6.1.1, 1.6.1.2, 1.6.3.1, 2.1.5.1, 2.2.1.4, 2.2.1.7, 2.2.1.8, 3.1.3.8, 8.1.1.4, 8.1.1.7, 8.1.1.9, 8.1.5.7, 8.1.5.8, 8.1.5.9, 8.1.5.10, 8.1.5.11, 8.1.5.12, 8.1.6.3, 14.1.2.8
Enhancing Technologies Referencing this Mission
1.1.2.5, 1.1.4.1, 1.1.6.3, 1.2.2.3, 1.2.3.1, 1.4.1.3, 1.4.6.1, 1.5.2.1, 1.6.4.1, 1.6.5.1, 2.1.4.1, 2.2.1.1, 2.2.1.3, 2.2.1.5, 2.2.1.6, 5.5.1.1, 8.1.3.6, 8.1.3.7, 8.3.1.3, 11.2.2.1, 11.2.2.2, 11.2.2.3, 11.2.5.1, 11.2.5.2, 11.2.5.3, 11.2.5.4, 11.3.1.1, 11.3.1.2, 11.3.1.3, 11.3.1.4, 11.3.1.5, 11.3.2.1, 11.3.2.2, 11.3.2.3, 11.4.1.1, 11.4.1.2, 11.4.1.3, 11.4.1.4, 11.4.1.5, 11.4.1.6, 11.4.1.7, 11.4.1.9, 11.4.1.10, 11.4.4.1, 11.4.4.2, 11.4.4.3, 11.4.5.4, 11.4.6.1, 11.4.6.2, 11.4.6.3
Strategic Missions: Mars 2020
Enabling Technologies Referencing this Mission
9.2.7.3, 9.2.7.4, 9.2.8.1, 9.2.8.2, 11.2.3.2, 11.4.7.3
Enhancing Technologies Referencing this Mission
4.1.2.6, 4.4.1.1, 4.4.5.2, 4.4.5.3, 4.4.8.2, 4.4.8.3, 5.3.1.1, 5.5.1.1, 7.6.1.4, 7.6.1.7, 7.6.1.8, 7.6.1.9, 8.3.1.5, 9.1.2.4, 9.1.2.5, 9.2.1.1, 9.2.8.4, 9.2.8.6, 9.4.5.2, 9.4.5.3, 9.4.5.4, 9.4.5.12, 11.3.3.2, 11.3.3.3, 11.3.3.4, 11.3.3.5, 11.3.3.6, 11.3.4.3, 11.3.7.2, 11.3.7.3, 11.3.7.4, 11.3.7.5, 11.4.2.2

SCIENCE MISSION DIRECTORATE
Discovery: Discovery 13
Enabling Technologies Referencing this Mission
3.1.3.1, 3.1.3.2, 3.1.3.4, 5.4.1.3, 5.6.1.1, 8.1.5.7, 9.1.1.1, 9.1.1.3, 9.4.6.1, 9.4.6.2, 9.4.6.4, 9.4.6.5
Enhancing Technologies Referencing this Mission
3.2.1.2, 3.2.1.7, 3.2.4.1, 5.1.1.1, 5.1.1.2, 5.1.3.1, 5.1.4.1, 5.1.5.1, 5.1.6.1, 5.2.6.1, 5.4.2.1, 5.4.2.6, 5.4.2.7, 5.4.3.1, 5.4.3.2, 5.4.3.3, 5.4.3.4, 5.4.6.1, 5.5.1.1, 9.1.3.2, 9.2.1.1, 9.4.5.1, 9.4.5.2, 9.4.5.3, 9.4.5.4, 9.4.6.6, 11.3.7.1, 11.3.7.2, 11.3.7.3, 11.3.7.4, 11.3.7.5, 11.3.7.6, 11.4.7.3, 14.2.1.1
Discovery: Discovery 14
Enabling Technologies Referencing this Mission
2.2.1.7, 2.2.1.8, 3.1.3.1, 3.1.3.2, 3.1.3.7, 4.1.2.3, 4.1.2.4, 4.1.3.2, 4.1.4.1, 4.1.5.2, 4.2.3.2, 5.6.1.1, 8.1.1.4, 8.1.5.4, 8.1.5.7, 8.1.5.8, 8.1.5.9, 8.1.5.10, 8.1.5.11, 8.1.5.12, 8.3.3.6, 9.1.1.1, 9.1.1.3, 9.4.6.1, 9.4.6.2, 9.4.6.3, 9.4.6.4, 9.4.6.5, 12.4.3.1, 14.2.3.2
Enhancing Technologies Referencing this Mission
2.1.1.1, 2.1.2.4, 4.1.1.2, 4.1.2.5, 4.1.2.6, 4.1.3.3, 4.1.3.4, 4.1.4.3, 4.1.5.1, 4.2.6.3, 5.1.2.1, 5.1.4.2, 5.1.5.2, 5.2.6.1, 5.4.2.1, 5.4.2.6, 5.4.2.7, 5.4.3.1, 5.4.3.2, 5.4.3.3, 5.4.3.4, 5.4.5.2, 5.4.6.1, 5.5.6.1, 9.1.1.8, 9.1.2.2, 9.1.2.3, 9.1.2.4, 9.1.2.5, 9.1.3.1, 9.1.3.2, 9.1.3.3, 9.1.4.2, 9.1.4.4, 9.1.4.5, 9.2.1.1, 9.4.5.1, 9.4.5.2, 9.4.5.3, 9.4.5.4, 9.4.6.6, 10.3.2.6, 11.3.1.1, 11.3.1.2, 11.3.1.3, 11.3.1.4, 11.3.1.5, 12.3.1.2, 12.3.1.3, 12.3.1.4
Discovery: Later Discovery Program
Enabling Technologies Referencing this Mission
2.2.1.6, 5.4.2.3, 5.6.2.1, 5.6.3.1, 11.1.1.1, 11.1.1.2, 11.1.1.3, 12.1.4.4
Enhancing Technologies Referencing this Mission
2.2.4.2, 4.4.1.1, 4.4.5.2, 4.4.5.3, 4.4.8.2, 4.4.8.3, 5.1.2.2, 5.1.2.3, 8.1.4.4, 9.1.1.4, 9.1.3.1, 9.1.3.3, 9.1.3.5, 9.1.4.1, 9.1.4.2, 9.1.4.3, 9.1.4.4, 9.1.4.5, 9.2.1.2, 9.2.1.3, 9.2.1.4, 9.2.2.1, 9.2.2.2, 9.2.7.2, 11.4.1.1, 11.4.1.2, 11.4.1.3, 11.4.1.4, 11.4.1.5, 11.4.1.6, 11.4.1.7, 11.4.1.9, 11.4.1.10, 11.4.3.1, 11.4.4.1, 11.4.4.2, 11.4.4.3, 11.4.6.1, 11.4.6.2, 11.4.6.3, 11.4.7.3
New Frontiers: New Frontiers Program 4 (NF4/~2017 AO Release) – Comet Surface Sample Return, Lunar South Pole-Aitken Basin Sample Return, Saturn Probe, Trojan Tour and Rendezvous, and Venus In-Situ Explorer
Enabling Technologies Referencing this Mission
3.1.3.4, 3.1.3.5, 3.1.3.9, 3.2.1.4, 3.2.1.6, 3.3.3.6, 4.3.6.4, 8.1.1.2, 8.2.3.3, 8.2.3.4, 8.2.3.5, 8.3.3.1, 8.3.3.3, 9.1.1.1, 9.1.1.3, 9.1.4.2, 9.1.4.4, 9.1.4.5, 9.1.4.6, 9.2.1.2, 9.2.7.2, 9.2.7.4, 9.2.8.1, 9.2.8.2, 9.2.8.3, 9.2.8.4, 9.2.8.6, 9.2.8.7, 9.2.8.8, 9.3.1.1, 9.4.6.1, 9.4.6.2, 9.4.6.3, 9.4.6.4, 9.4.6.5, 10.2.2.7, 10.4.2.3, 10.4.3.6, 13.2.5.1, 13.2.5.2, 13.2.5.3, 13.2.5.4, 13.2.5.5, 13.2.5.6, 13.2.5.7, 13.4.2.1, 13.4.2.2, 13.4.2.3, 13.4.5.4, 14.1.2.8, 14.2.3.3, 14.3.1.3
Enhancing Technologies Referencing this Mission
2.2.1.2, 3.1.1.1, 3.1.3.6, 3.1.3.10, 3.1.4.3, 3.1.4.4, 3.1.4.5, 3.2.1.5, 3.2.1.7, 3.2.4.1, 3.3.1.1, 3.3.3.1, 3.3.3.2, 4.1.1.2, 4.1.1.3, 4.1.5.1, 4.2.1.3, 4.2.8.1, 4.2.8.2, 4.2.8.4, 4.3.1.1, 4.3.1.2, 4.3.1.3, 4.3.2.1, 4.3.2.2, 4.3.4.1, 4.3.6.1, 4.4.5.2, 4.4.5.3, 4.4.8.2, 4.4.8.3, 5.4.2.1, 5.4.2.6, 5.4.3.3, 5.4.3.4, 5.4.5.1, 8.1.1.12, 8.3.3.5, 9.1.1.4, 9.1.1.8, 9.1.2.2, 9.1.2.3, 9.1.2.4, 9.1.2.5, 9.1.3.1, 9.1.3.2, 9.1.3.3, 9.1.3.5, 9.1.3.6, 9.1.4.1, 9.2.1.1, 9.2.7.2, 9.2.7.4, 9.4.5.1, 9.4.5.2, 9.4.5.3, 9.4.5.4, 9.4.6.6, 10.2.1.3, 10.4.2.4, 10.4.2.5, 10.4.2.7, 10.4.2.9, 10.4.3.1, 10.4.3.7, 11.4.7.3, 12.4.3.3, 13.4.2.43.1.1.1, 3.1.3.6, 3.1.3.10, 3.1.4.3, 3.1.4.4, 3.1.4.5, 3.2.1.5, 3.2.1.7, 3.2.4.1, 3.3.1.1, 3.3.3.1, 3.3.3.2, 4.1.1.2, 4.1.1.3, 4.1.5.1, 4.2.1.3, 4.2.8.1, 4.2.8.2, 4.2.8.4, 4.3.1.1, 4.3.1.2, 4.3.1.3, 4.3.2.1, 4.3.2.2, 4.3.4.1, 4.3.6.1, 4.4.5.2, 4.4.5.3, 4.4.8.2, 4.4.8.3, 5.4.2.1, 5.4.2.6, 5.4.3.3, 5.4.3.4, 5.4.5.1, 8.1.1.12, 8.3.3.5, 9.1.1.4, 9.1.1.8, 9.1.2.2, 9.1.2.3, 9.1.2.4, 9.1.2.5, 9.1.3.1, 9.1.3.2, 9.1.3.3, 9.1.3.5, 9.1.3.6, 9.1.4.1, 9.2.1.1, 9.2.7.2, 9.2.7.4, 9.4.5.1, 9.4.5.2, 9.4.5.3, 9.4.5.4, 9.4.6.6, 10.2.1.3, 10.4.2.4, 10.4.2.5, 10.4.2.7, 10.4.2.9, 10.4.3.1, 10.4.3.7, 11.4.7.3, 12.4.3.3, 13.4.2.4

SCIENCE MISSION DIRECTORATE
Planetary Flagship: Europa
Enabling Technologies Referencing this Mission
3.1.3.7, 3.1.5.1, 3.1.5.2, 3.3.3.6, 5.2.2.1, 10.2.2.6, 10.2.2.7, 10.4.3.1, 13.2.5.1, 13.2.5.2, 13.2.5.3, 13.2.5.6, 13.2.5.7, 13.4.5.4, 12.3.1.5, 14.1.2.8
Enhancing Technologies Referencing this Mission
2.1.3.1, 2.2.1.2, 3.1.4.1, 3.1.4.2, 4.1.4.3, 5.1.1.1, 5.1.1.2, 5.1.2.1, 5.1.3.1, 5.1.4.1, 5.1.6.1, 5.4.1.1, 5.4.2.1, 5.4.3.3, 5.4.3.4, 5.4.5.2, 8.1.1.2, 8.1.1.12, 8.1.4.5, 9.2.6.1, 9.2.6.2, 9.2.6.3, 9.2.8.4, 9.3.1.1, 10.2.1.3, 10.4.1.4, 10.4.2.9, 11.1.1.1, 11.1.1.2, 11.1.1.3, 11.3.5.2, 11.4.1.1, 11.4.1.2, 11.4.1.3, 11.4.1.4, 11.4.1.5, 11.4.1.6, 11.4.1.7, 11.4.1.9, 11.4.1.10, 11.4.2.2, 11.4.4.1, 11.4.4.2, 11.4.4.3, 11.4.5.4, 11.4.6.1, 11.4.6.2, 11.4.6.3, 11.4.7.3, 12.1.4.4, 12.1.4.5, 12.3.1.2, 12.3.1.4, 12.4.3.3, 13.4.2.4
New Frontiers: New Frontiers 5 (NF5 / ~2022 AO release) – Io Observer and Lunar Geophysical Network
Enabling Technologies Referencing this Mission
2.2.1.7, 2.2.1.8, 3.1.3.7, 3.1.5.1, 3.1.5.2, 3.3.3.6, 4.1.2.3, 4.1.2.4, 4.1.3.2, 4.1.5.2, 4.2.3.2, 8.1.5.4, 10.2.2.6, 10.2.2.7, 14.2.3.2
Enhancing Technologies Referencing this Mission
2.1.1.1, 2.1.1.2, 2.1.2.4, 2.1.3.1, 2.2.1.2, 3.1.4.1, 3.1.4.2, 4.1.1.2, 4.1.1.3, 4.1.2.5, 4.1.2.6, 4.1.3.3, 4.1.3.4, 4.1.4.3, 4.2.6.3, 5.1.3.2, 5.4.1.2, 9.1.3.1, 9.1.3.3, 9.1.3.5, 9.1.3.6, 9.1.4.1, 9.1.4.2, 9.1.4.3, 9.1.4.4, 9.1.4.5, 9.2.1.2, 9.2.1.3, 9.2.1.4, 9.2.2.1, 9.2.2.2, 9.2.7.2, 10.2.1.3, 10.2.1.6, 10.4.2.9, 10.4.3.1, 11.3.5.1,11.3.5.3, 11.4.7.3
Planetary Flagship: Mars Sample Return
Enabling Technologies Referencing this Mission
2.1.1.3, 2.1.1.4, 2.1.4.1, 2.2.1.6, 2.2.1.7, 2.2.1.8, 4.1.4.2, 4.1.4.3, 4.1.5.1, 4.2.1.1, 4.2.1.2, 4.2.8.1, 4.2.8.4, 4.3.6.4, 4.3.6.6, 4.5.1.2, 4.5.1.3, 4.5.8.1, 4.7.3.4, 5.4.6.2, 7.5.2.1, 9.1.1.8, 9.1.3.1, 9.2.6.1, 9.2.6.2, 9.2.6.3, 9.2.7.2, 9.2.7.4, 9.4.6.5, 9.4.6.6, 11.2.3.2, 12.3.1.5, 13.2.5.1, 13.2.5.2, 13.2.5.3, 13.2.5.4, 13.2.5.5, 13.2.5.6, 13.2.5.7, 13.4.2.3, 13.4.5.4
Enhancing Technologies Referencing this Mission
2.1.5.1, 2.2.1.2, 4.1.1.1, 4.1.1.4, 4.1.2.1, 4.1.2.2, 4.1.2.7, 4.1.2.8, 4.1.3.1, 4.1.3.3, 4.1.4.1, 4.2.1.3, 4.2.2.2, 4.2.5.2, 4.2.6.1, 4.2.6.2, 4.2.8.2, 4.2.8.3, 4.3.1.1, 4.3.1.2, 4.3.1.3, 4.3.2.1, 4.3.2.2, 4.3.4.1, 4.3.6.1, 4.3.6.5, 4.4.1.1, 4.4.5.2, 4.4.5.3, 4.4.8.2, 4.4.8.3, 4.5.1.1, 4.5.2.1, 4.5.2.3, 4.5.2.4, 4.5.2.5, 5.4.2.2, 5.4.2.4, 5.4.2.5, 5.4.4.1, 5.4.4.2, 5.4.4.3, 5.4.4.4, 5.5.1.1, 7.6.1.4, 7.6.1.7, 7.6.1.8, 7.6.1.9, 7.6.1.18, 8.2.3.3, 8.2.3.4, 8.2.3.5, 9.1.1.1, 9.1.1.2, 9.1.1.5, 9.1.2.3, 9.1.2.4, 9.1.2.5, 9.1.3.2, 9.1.3.3, 9.1.3.5, 9.1.4.1, 9.2.1.1, 9.2.1.2, 9.2.1.3, 9.2.1.4, 9.2.2.1, 9.2.2.2, 9.2.7.1, 9.2.8.1, 9.2.8.2, 9.2.8.3, 9.2.8.4, 9.2.8.6, 9.2.8.7, 9.3.1.1, 9.4.5.1, 9.4.5.2, 9.4.5.3, 9.4.5.4, 9.4.5.12, 9.4.6.1, 9.4.6.2, 9.4.6.3, 9.4.6.4, 11.3.4.3, 11.4.7.3, 12.3.1.2, 12.3.1.3, 12.3.1.4, 12.4.3.3, 13.4.2.1, 13.4.2.2, 13.4.2.4

AERONAUTICS RESEARCH MISSION DIRECTORATE
Safe, Efficient Growth in Global Aviation: Improved Efficiency and Hazard Reduction Within NextGen Operational Domains
Enabling Technologies Referencing this Mission
11.2.3.1, 11.2.3.2, 15.1.1.1, 15.1.1.2, 15.1.1.3, 15.1.1.4, 15.1.1.5
Enhancing Technologies Referencing this Mission
10.1.3.2, 10.1.3.4, 11.2.3.3, 11.3.8.1, 11.3.8.2, 11.4.3.1, 11.4.3.3, 11.4.5.1, 11.4.5.2, 11.4.5.3
Safe, Efficient Growth in Global Aviation: System-Wide Safety, Predictability, and Reliability Through Full NextGen Functionality
Enabling Technologies Referencing this Mission
15.1.2.1, 15.1.2.2, 15.1.2.3
Enhancing Technologies Referencing this Mission
11.3.4.2, 11.3.4.3, 11.4.2.4, 11.4.3.3, 11.4.5.3
Innovation in Commercial Supersonic Aircraft: Supersonic Overland Certification Standard Based on Acceptable Sonic Boom Noise
Enabling Technologies Referencing this Mission
15.2.1.1, 15.2.1.2
Enhancing Technologies Referencing this Mission
11.3.1.1, 11.3.1.2, 11.3.1.4, 11.3.1.5, 11.3.5.1, 11.3.5.2, 11.3.5.3
Innovation in Commercial Supersonic Aircraft: Introduction of Affordable, Low-Boom, Low-Noise, and Low-Emission Supersonic Transports
Enabling Technologies Referencing this Mission
15.2.2.1
Enhancing Technologies Referencing this Mission
11.1.2.1, 11.1.2.2, 11.1.2.3, 11.1.2.5, 11.1.2.6, 11.3.2.1, 11.3.2.2, 11.3.2.3, 11.3.5.1, 11.3.5.2, 11.3.5.3, 11.3.7.1, 11.3.7.2, 11.3.7.3, 11.3.7.4, 11.3.7.5, 11.3.7.6, 11.3.8.1, 11.3.8.2, 11.4.7.7, 11.4.8.1, 11.4.8.2, 11.4.8.3, 11.4.8.4, 11.4.8.5, 12.1.2.1, 12.1.2.2, 12.1.2.3
Ultra-Efficient Commercial Vehicles: Achieve Community Goals for Improved Vehicle Efficiency and Environmental Performance in 2025
Enabling Technologies Referencing this Mission
12.1.3.3, 15.3.1.1, 15.3.1.2, 15.3.1.3, 15.3.1.4, 15.3.1.5, 15.3.1.6, 15.3.1.7
Enhancing Technologies Referencing this Mission
10.1.3.2, 10.1.3.4, 11.1.2.1, 11.1.2.2, 11.1.2.3, 11.1.2.5, 11.1.2.6, 11.3.2.1, 11.3.2.2, 11.3.2.3, 11.3.3.1, 11.3.3.2, 11.3.3.3, 11.3.3.4, 11.3.3.5, 11.3.3.6, 11.3.5.2, 11.3.5.3, 11.3.6.1, 11.3.6.2, 11.3.6.3, 11.3.6.4, 11.3.6.5, 11.3.6.6, 11.3.7.1, 11.3.7.2, 11.3.7.3, 11.3.7.4, 11.3.7.5, 11.3.7.6, 11.3.8.1, 11.3.8.2, 11.4.7.7, 11.4.8.1, 11.4.8.2, 11.4.8.3, 11.4.8.4, 11.4.8.5

AERONAUTICS RESEARCH MISSION DIRECTORATE
Ultra-Efficient Commercial Vehicles: Achieve Community Goals for Improved Vertical Lift Efficiency and Environmental Performance in 2035
Enabling Technologies Referencing this Mission
12.1.3.3, 15.3.2.1, 15.3.2.2
Enhancing Technologies Referencing this Mission
10.1.3.2, 10.1.3.4
Ultra-Efficient Commercial Vehicles: Achieve Community Goals for Improved Vehicle Efficiency and Environmental Performance Beyond 2035
Enabling Technologies Referencing this Mission
15.3.3.1, 15.3.3.2, 15.3.3.3, 15.3.3.4, 15.3.3.5, 15.3.3.6, 15.3.3.7, 15.3.3.8
Enhancing Technologies Referencing this Mission
No enhancing technologies identified
Transition to Low-Carbon Propulsion: Introduction of Low-carbon Fuels for Conventional Engines and Exploration of Alternative Propulsion Systems
Enabling Technologies Referencing this Mission
15.4.1.1, 15.4.1.2, 15.4.1.3
Enhancing Technologies Referencing this Mission
11.3.5.1
Transition to Low-Carbon Propulsion: Initial Introduction of Alternative Propulsion Systems
Enabling Technologies Referencing this Mission
15.4.2.1
Enhancing Technologies Referencing this Mission
11.2.2.1, 11.2.2.2, 11.2.2.3, 11.2.5.1, 11.2.5.2, 11.2.5.3, 11.2.5.4
Transition to Low-Carbon Propulsion: Introduction of Alternative Propulsion Systems to Aircraft of All Sizes
Enabling Technologies Referencing this Mission
No enabling technologies identified
Enhancing Technologies Referencing this Mission
No enhancing technologies identified
Real-Time System-Wide Safety Assurance: Introduction of Advanced Safety Assurance Tools
Enabling Technologies Referencing this Mission
15.5.1-3.1, 15.5.1-3.2
Enhancing Technologies Referencing this Mission
10.4.1.1, 11.3.3.1, 11.3.3.2, 11.3.3.3, 11.3.3.4, 11.3.3.5, 11.3.3.6, 11.3.8.1, 11.3.8.2, 11.4.3.1

AERONAUTICS RESEARCH MISSION DIRECTORATE
Real-Time System-Wide Safety Assurance: An Integrated Safety Assurance System Enabling Continuous System-Wide Safety Monitoring
Enabling Technologies Referencing this Mission
4.5.1.1, 4.5.1.2, 4.5.1.3, 4.5.2.1, 4.5.2.5, 15.5.1-3.1, 15.5.1-3.2
Enhancing Technologies Referencing this Mission
11.2.3.3, 11.3.4.3, 11.3.6.1, 11.3.6.2, 11.3.6.3, 11.3.6.4, 11.3.6.5, 11.3.6.6
Real-Time System-Wide Safety Assurance: Automated Safety Assurance Integrated with Real-Time Operations Enabling a Self-Protecting Aviation System
Enabling Technologies Referencing this Mission
15.5.1-3.1, 15.5.1-3.2
Enhancing Technologies Referencing this Mission
No enhancing technologies identified
Enable Assured Machine Autonomy For Aviation: Initial Autonomy Applications
Enabling Technologies Referencing this Mission
4.5.1.1, 4.5.1.2, 4.5.1.3, 4.5.2.1, 4.5.2.5, 4.5.8.1
Enhancing Technologies Referencing this Mission
11.3.3.1, 11.3.3.2, 11.3.3.3, 11.3.3.4, 11.3.3.5, 11.3.3.6
Enable Assured Machine Autonomy For Aviation: Human-Machine Teaming in Key Applications
Enabling Technologies Referencing this Mission
11.2.3.1, 11.2.3.2
Enhancing Technologies Referencing this Mission
11.2.3.3, 11.3.4.2, 11.3.4.3
Enable Assured Machine Autonomy For Aviation: Ability to Fully Certify and Trust Autonomous Systems for NAS Operations
Enabling Technologies Referencing this Mission
11.4.3.3, 11.4.7.4, 15.6.2.1
Enhancing Technologies Referencing this Mission
11.4.3.1, 11.4.5.1, 11.4.5.3

Appendix F – Comparison of 2012 Technology Breakdown Structure and 2015 Technology Breakdown Structure

NASA's Technology Area Breakdown Structure (TABs) is in wide use in technology organizations around the world. Because of this, sections that were previously in the structure have not been moved or renumbered to ensure that users of the TABs can track the changes and update their corresponding systems.

This section has been provided to enable easy comparison of the 2012 NASA Technology Roadmap Structure with the 2015 NASA Technology Roadmap Structure.

The most notable changes are the addition of Technical Area 15: Aeronautics, and the addition of 7 Level 2 areas, and 66 Level 3 areas. Within these roadmaps, there are sections of the TABs with no identified Technology Candidate Snapshots. This is either because in the previous roadmap technologies in this section were duplicative with technologies in other sections, or because no technologies were identified as enabling or enhancing the Design Reference Missions in Appendix D.

For cases were the roadmap previously duplicated technologies, the roadmap teams determined were to best locate the candidates, and they were place in that one location. All other locations the roadmaps provide a pointer to the new location of the technology candidates. This ensures that each technology candidate only occurs one time in the 2015 NASA Technology Roadmaps.

Technology Area Breakdown Structure Changes

TABS	2012	2015	Name Change	Name Grammar Change	New Branch	2015 TABS Addressed in Other Areas or Having No Snapshots
1	Launch Propulsion Systems	Launch Propulsion Systems				
1.1	Solid Rocket Propulsion Systems	Solid Rocket Propulsion Systems				
1.1.1	Propellants	Propellants				
1.1.2	Case Materials	Case Materials				
1.1.3	Nozzle Systems	Nozzle Systems				
1.1.4	Hybrid Rocket Propulsion Systems	Hybrid Rocket Propulsion Systems				
1.1.5	Fundamental Solid Propulsion Technologies	Fundamental Solid Propulsion Technologies				
1.1.6	-	Integrated Solid Motor Systems			X	
1.1.7	-	Liner and Insulation			X	
1.2	Liquid Rocket Propulsion Systems	Liquid Rocket Propulsion Systems				
1.2.1	LH_2/LOX Based	LH_2/LOX Based				
1.2.2	RP/LOX Based	RP/LOX Based				
1.2.3	CH_4/LOX Based	CH_4/LOX Based				
1.2.4	Detonation Wave Engines (Closed Cycle)	Detonation Wave Engines - Closed Cycle		X		No snapshots
1.2.5	Propellants	Propellants				No snapshots
1.2.6	Fundamental Liquid Propulsion Technologies	Fundamental Liquid Propulsion Technologies				

Technology Area Breakdown Structure Changes

TABS	2012	2015	Name Change	Name Grammar Change	New Branch	2015 TABS Addressed in Other Areas or Having No Snapshots
1.3	Air Breathing Propulsion Systems	Air Breathing Propulsion Systems				
1.3.1	TBCC	Turbine-Based Combined-Cycle		X		Addressed in roadmap for TA 15 (Aeronautics)
1.3.2	RBCC	Rocket-Based Combined Cycle		X		Addressed in roadmap for TA 15 (Aeronautics)
1.3.3	Detonation Wave Engines (Open Cycle)	Detonation Wave Engines - Open Cycle		X		Addressed in roadmap for TA 15 (Aeronautics)
1.3.4	Turbine Based Jet Engines (Flyback Boosters)	Turbine-Based Jet Engines	X			Addressed in roadmap for TA 15 (Aeronautics)
1.3.5	Ramjet/Scramjet Engines (Accelerators)	Ramjet and Scramjet Engines	X			Addressed in roadmap for TA 15 (Aeronautics)
1.3.6	Deeply-cooled Air Cycles	Deeply-Cooled Air Cycles				Addressed in roadmap for TA 15 (Aeronautics)
1.3.7	Air Collection & Enrichment System	Air Collection and Enrichment Systems		X		Addressed in roadmap for TA 15 (Aeronautics)
1.3.8	Fundamental Air Breathing Propulsion Technologies	Fundamental Air Breathing Propulsion Technologies				Addressed in roadmap for TA 15 (Aeronautics)
1.4	Ancillary Propulsion Systems	Ancillary Propulsion Systems				
1.4.1	Auxiliary Control Systems	Auxiliary Control Systems				
1.4.2	Main Propulsion Systems (Excluding Engines)	Main Propulsion Systems (Excluding Engines)				
1.4.3	Launch Abort Systems	Launch Abort Systems				
1.4.4	Thrust Vector Control Systems	Thrust Vector Control Systems				
1.4.5	Health Management & Sensors	Health Management and Sensors		X		No snapshots
1.4.6	Pyro & Separation Systems	Pyro and Separation Systems		X		
1.4.7	Fundamental Ancillary Propulsion Technologies	Fundamental Ancillary Propulsion Technologies				
1.5	Unconventional / Other Propulsion Systems	Unconventional and Other Propulsion Systems		X		
1.5.1	Ground Launch Assist	Ground Launch Assist				No snapshots
1.5.2	Air Launch / Drop Systems	Air Launch and Drop Systems		X		
1.5.3	Space Tether Assist	Space Tether Assist				Addressed in roadmap for TA 2 (In-Space Propulsion Technologies)
1.5.4	Beamed Energy / Energy Addition	Beamed Energy and Energy Addition		X		No snapshots
1.5.5	Nuclear	Nuclear				No snapshots
1.5.6	High Energy Density Materials/ Propellants	High Energy Density Materials and Propellant		X		No snapshots

Technology Area Breakdown Structure Changes

TABS	2012	2015	Name Change	Name Grammar Change	New Branch	2015 TABS Addressed in Other Areas or Having No Snapshots
1.6	-	Balloon Launch Systems			X	
1.6.1	-	Super-Pressure Balloon			X	
1.6.2	-	Materials			X	
1.6.3	-	Pointing Systems			X	
1.6.4	-	Telemetry Systems			X	
1.6.5	-	Balloon Trajectory Control			X	
1.6.6	-	Power Systems			X	
1.6.7	-	Mechanical Systems: Launch Systems			X	
1.6.8	-	Mechanical Systems: Parachute			X	
1.6.9	-	Mechanical Systems: Floatation			X	
2	In-Space Propulsion Technologies	In-Space Propulsion Technologies				
2.1	Chemical Propulsion	Chemical Propulsion				
2.1.1	Liquid Storable	Liquid Storable				
2.1.2	Liquid Cryogenic	Liquid Cryogenic				
2.1.3	Gels	Gels				
2.1.4	Solid	Solids		X		
2.1.5	Hybrid	Hybrid				
2.1.6	Cold Gas/Warm Gas	Cold Gas/Warm Gas				
2.1.7	Micro-propulsion	Micropropulsion		X		
2.2	Non-Chemical Propulsion	Non-Chemical Propulsion				
2.2.1	Electric Propulsion	Electric Propulsion				
2.2.2	Solar Sail Propulsion	Solar and Drag Sail Propulsion		X		
2.2.3	Thermal Propulsion	Thermal Propulsion				
2.2.4	Tether Propulsion	Tether Propulsion				
2.3	Advanced (TRL<3) Propulsion Technologies	Advanced (TRL<3) Propulsion Technologies				
2.3.1	Beamed Energy Propulsion	Beamed Energy Propulsion				
2.3.2	Electric Sail Propulsion	Electric Sail Propulsion				
2.3.3	Fusion Propulsion	Fusion Propulsion				
2.3.4	High Energy Density Materials	High-Energy-Density Materials		X		
2.3.5	Antimatter Propulsion	Antimatter Propulsion				
2.3.6	Advanced Fission	Advanced Fission				
2.3.7	Breakthrough Propulsion	Breakthrough Propulsion				

Technology Area Breakdown Structure Changes

TABS	2012	2015	Name Change	Name Grammar Change	New Branch	2015 TABS Addressed in Other Areas or Having No Snapshots
2.4	Supporting Technologies	Supporting Technologies				
2.4.1	Propellant Storage & Transfer	Engine Health Monitoring and Safety		X		Addressed in TA 4 (Robotics and Autonomous Systems), TA 8 (Science Instruments, Observatories, and Sensor Systems), TA 11 (Modeling, Simulation, Information Technology, and Processing), TA 12 (Materials, Structures, Mechanical Systems, and Manufacturing)
2.4.2	-	Propellant Storage and Transfer			X	
2.4.3	-	Materials and Manufacturing Technologies			X	Addressed in TA 10 (Nanotechnology) and TA 12 (Materials, Structures, Mechanical Systems, and Manufacturing)
2.4.4	-	Heat Rejection			X	Addressed in TA 14 (Thermal Management Systems)
2.4.5	-	Power			X	Addressed in TA 3 (Space Power and Energy Storage)
3	Space Power & Energy Storage	Space Power and Energy Storage		X		
3.1	Power Generation	Power Generation				
3.1.1	Energy Harvesting	Energy Harvesting				
3.1.2	Chemical (Fuel Cells, Heat Engines)	Chemical	X			
3.1.3	Solar (Photo-Voltaic & Thermal)	Solar	X			
3.1.4	Radioisotope	Radioisotope				
3.1.5	Fission	Fission				
3.1.6	Fusion	Fusion				
3.2	Energy Storage	Energy Storage				
3.2.1	Batteries	Batteries				
3.2.2	Flywheels	Flywheels				
3.2.3	Regenerative Fuel Cells	Regenerative Fuel Cells				
3.2.4	-	Capacitors			X	

Technology Area Breakdown Structure Changes

TABS	2012	2015	Name Change	Name Grammar Change	New Branch	2015 TABS Addressed in Other Areas or Having No Snapshots
3.3	Power Management & Distribution	Power Management and Distribution		X		
3.3.1	FDIR	Fault Detection, Isolation, and Recovery		X		
3.3.2	Management & Control	Management and Control		X		
3.3.3	Distribution & Transmission	Distribution and Transmission		X		
3.3.4	Wireless Power Transmission	Wireless Power Transmission				
3.3.5	Conversion & Regulation	Conversion and Regulation		X		
3.4	Cross Cutting Technology	Cross Cutting Technology				
3.4.1	Analytical Tools	Analytical Tools				Addressed in TA 11.2.4 (Science Modeling) and 11.2.5 (Frameworks, Languages, Tools and Standards).
3.4.2	Green Energy Impact	Green Energy Impact				Addressed TA 15.4.1 (Introduction of Low Carbon Fuels for Conventional Engines and Exploration of Alternative Propulsion Systems).
3.4.3	Multi-functional Structures	Multi-Functional Structures				Addressed in TA 10.2.2 (Power Generation) and TA 12.1.1 (Lightweight Structural Materials).
3.4.4	Alternative Fuels	Alternative Fuels				Addressed TA 15.4.2 (Introduction of Alternative Propulsion Systems).
4	Robotics, TeleRobotics & Autonomous Systems	Robotics and Autonomous Systems	X			
4.1	Sensing & Perception	Sensing and Perception		X		
4.1.1	3-D Perception	3D Sensing		X		
4.1.2	Relative Position & Velocity Estimation	State Estimation	X			
4.1.3	Terrain Mapping, Classification & Characterization	Onboard Mapping	X			
4.1.4	Natural & Man-made Object Recognition	Object, Event, and Activity Recognition	X			
4.1.5	Sensor Fusion for Sampling & Manipulation	Force and Tactile Sensing	X			

Technology Area Breakdown Structure Changes

4.1.6	Onboard Science Data Analysis	Onboard Science Data Analysis				Addressed in TA 4.1.4 (Object, Event, and Activity Recognition) and TA 4.5.8 (Automated Data Analysis for Decision Making)
4.2	Mobility	Mobility				
4.2.1	Extreme Terrain Mobility	Extreme-Terrain Mobility		X		
4.2.2	Below-Surface Mobility	Below-Surface Mobility				
4.2.3	Above-Surface Mobility	Above-Surface Mobility				
4.2.4	Small Body/Microgravity Mobility	Small-Body and Microgravity Mobility		X		
4.2.5	-	Surface Mobility			X	
4.2.6	-	Robot Navigation			X	
4.2.7	-	Collaborative Mobility			X	
4.2.8	-	Mobility Components			X	
4.3	Manipulation	Manipulation				
4.3.1	Robot Arms	Manipulator Components	X			
4.3.2	Dexterous Manipulators	Dexterous Manipulation	X			
4.3.3	Modeling of Contact Dynamics	Modeling of Contact Dynamics				Addressed in TA 4.7.3 (Robot Modeling and Simulation)
4.3.4	Mobile Manipulation	Mobile Manipulation				
4.3.5	Collaborative Manipulation	Collaborative Manipulation				
4.3.6	Robotic Drilling & Sample Processing	Sample Acquisition and Handling	X			
4.3.7	-	Grappling			X	
4.4	Human-Systems Integration	Human-System Interaction		X		
4.4.1	Multi-Modal Human-Systems Interaction	Multi-Modal Interaction	X			
4.4.2	Supervisory Control	Supervisory Control				Addressed in TA 4.4.8 (Remote Interaction)
4.4.3	Robot-to-Suit Interfaces	Proximate Interaction	X			
4.4.4	Intent Recognition & Reaction	Intent Recognition and Reaction		X		Addressed in TA 4.4.3 (Proximate Interaction)
4.4.5	Distributed Collaboration	Distributed Collaboration and Coordination	X			
4.4.6	Common Human-Systems Interfaces	Common and Standard Human-System Interfaces	X			Addressed in TA 4.7.1 (Modularity, Commonality, and Interfaces)

Technology Area Breakdown Structure Changes

4.4.7	Safety, Trust, & Interfacing of Robotic/Human Proximity Operations	Safety, Trust, and Interfacing of Robotic and Human Proximity Operations		X		Addressed in TA 4.7.5 (Safety and Trust)
4.4.8	-	Remote Interaction			X	
4.5	Autonomy	System-Level Autonomy	X			
4.5.1	Vehicle Systems Management & FDIR	System Health Management	X			
4.5.2	Dynamic Planning & Sequencing Tools	Activity Planning, Scheduling, and Execution	X			
4.5.3	Autonomous Guidance & Control	Autonomous Guidance and Control		X		Addressed in TA 5.4 (Position, Navigation, and Timing)
4.5.4	Multi-Agent Coordination	Multi-Agent Coordination				
4.5.5	Adjustable Autonomy	Adjustable Autonomy				No snapshots
4.5.6	Terrain Relative Navigation	Terrain Relative Navigation				Addressed in TA 4.1.2 (State Estimation)
4.5.7	Path & Motion Planning with Uncertainty	Path and Motion Planning with Uncertainty		X		Addressed in TA 4.2.6 (Robot Navigation) and 4.3.2 (Dexterous Manipulation)
4.5.8	-	Automated Data Analysis for Decision Making			X	
4.6	Autonomous Rendezvous & Docking	Autonomous Rendezvous and Docking		X		
4.6.1	Relative Navigation Sensors (long-, mid-, near-range)	Relative Navigation Sensors	X			
4.6.2	Guidance Algorithms	GN&C Algorithms	X			
4.6.3	Docking & Capture Mechanisms/ Interfaces	Docking and Capture Mechanisms and Interfaces		X		
4.6.4	Mission/System Managers for Autonomy/Automation	Mission and System Managers for Autonomy and Automation		X		Addressed in TA 4.5.2 (Activity Planning, Scheduling and Execution)
4.7	RTA Systems Engineering	Systems Engineering	X			
4.7.1	Modularity/Commonality	Modularity, Commonality, and Interfaces	X			
4.7.2	Verification & Validation of Complex Adaptive Systems	Verification and Validation of Complex Adaptive Systems		X		
4.7.3	Onboard Computing	Robot Modeling and Simulation	X			
4.7.4	-	Robot Software			X	
4.7.5	-	Safety and Trust			X	

Technology Area Breakdown Structure Changes

5	Communication & Navigation	Communications, Navigation, and Orbital Debris Tracking and Characterization Systems	X			
5.1	Optical Comm. & Navigation	Optical Communications and Navigation		X		
5.1.1	Detector Development	Detector Development				
5.1.2	Large Apertures	Large Apertures				
5.1.3	Lasers	Lasers				
5.1.4	Acquisition & Tracking	Acquisition and Tracking		X		
5.1.5	Atmospheric Mitigation	Atmospheric Mitigation				
5.1.6	-	Optical Tracking			X	
5.1.7	-	Integrated Photonics			X	
5.2	Radio Frequency Communications	Radio Frequency Communications				
5.2.1	Spectrum Efficient Technologies	Spectrum-Efficient Technologies		X		
5.2.2	Power Efficient Technologies	Power-Efficient Technologies		X		
5.2.3	Propagation	Propagation				
5.2.4	Flight & Ground Systems	Flight and Ground Systems		X		Addressed in TA 5.5 (Integrated Technologies)
5.2.5	Earth Launch & Reentry Comm.	Earth Launch and Re-Entry Communications		X		
5.2.6	Antennas	Antennas				
5.3	Internetworking	Internetworking				
5.3.1	Disruptive Tolerant Networking	Disruption-Tolerant Networking	X			
5.3.2	Adaptive Network Topology	Adaptive Network Topology				
5.3.3	Information Assurance	Information Assurance				No snapshots
5.3.4	Integrated Network Management	Integrated Network Management				No snapshots
5.4	Position, Navigation, and Timing	Position, Navigation, and Timing				
5.4.1	Timekeeping & Time Distribution	Timekeeping and Time Distribution		X		
5.4.2	Onboard Auto Navigation & Maneuver	Onboard Auto Navigation and Maneuver		X		
5.4.3	Sensors & Vision Processing Systems	Sensors and Vision Processing Systems		X		
5.4.4	Relative & Proximity Navigation	Relative and Proximity Navigation		X		
5.4.5	Auto Precision Formation Flying	Auto Precision Formation Flying				
5.4.6	Auto Approach & Landing	Autonomous Approach and Landing		X		
5.5	Integrated Technologies	Integrated Technologies				
5.5.1	Radio Systems	Radio Systems				

Technology Area Breakdown Structure Changes

TABS	2012	2015	Name Change	Name Grammar Change	New Branch	2015 TABS Addressed in Other Areas or Having No Snapshots
5.5.2	Ultra Wideband	Ultra Wideband				
5.5.3	Cognitive Networks	Cognitive Networks				
5.5.4	Science from the Comm. System	Science from the Communications System		X		Addressed in TA 5.5.1 (Radio Systems), TA 5.4.1 (Timekeeping and Time Distribution), and TA 5.7.1 (Tracking Technologies).
5.5.5	Hybrid Optical Comm. & Nav. Sensors	Hybrid Optical Communications and Navigation Sensors		X		Addressed in TA 5.1 (Optical Communications and Navigation)
5.5.6	RF/Optical Hybrid Technology	Radio Frequency and Optical Hybrid Technology		X		
5.6	Revolutionary Concepts	Revolutionary Concepts				
5.6.1	X-Ray Navigation	X-Ray Navigation				
5.6.2	X-Ray Communications	X-Ray Communications				
5.6.3	Neutrino-Based Navigation & Tracking	Neutrino-Based Navigation and Tracking		X		
5.6.4	Quantum Key Distribution	Quantum Key Distribution				
5.6.5	Quantum Communications	Quantum Communications				
5.6.6	SQIF Microwave Amplifier	Superconducting Quantum Interference Filter Microwave Amplifier		X		
5.6.7	Reconfigurable Large Apertures Using Nanosat Constellations	Reconfigurable Large Apertures	X			
5.7	-	Orbital Debris Tracking and Characterization			X	
5.7.1	-	Tracking Technologies			X	
5.7.2	-	Characterization Technologies			X	
6	Human Health, Life Support & Habitation Systems	Human Health, Life Support, and Habitation Systems		X		
6.1	Environmental Control & Life Support Systems & Habitation Systems	Environmental Control and Life Support Systems and Habitation Systems		X		
6.1.1	Air Revitalization	Air Revitalization				
6.1.2	Water Recovery & Management	Water Recovery and Management		X		
6.1.3	Waste Management	Waste Management				
6.1.4	Habitation	Habitation				

Technology Area Breakdown Structure Changes

TABS	2012	2015	Name Change	Name Grammar Change	New Branch	2015 TABS Addressed in Other Areas or Having No Snapshots
6.2	Extravehicular Activity Systems	Extravehicular Activity Systems				
6.2.1	Pressure Garment	Pressure Garment				
6.2.2	Portable Life Support System	Portable Life Support System				
6.2.3	Power, Avionics & Software	Power, Avionics, and Software		X		
6.3	Human Health & Performance	Human Health and Performance		X		
6.3.1	Medical Diagnosis / Prognosis	Medical Diagnosis and Prognosis		X		
6.3.2	Long-Duration Health	Long-Duration Health				
6.3.3	Behavioral Health	Behavioral Health				
6.3.4	Human Factors	Human Factors				
6.4	Environmental Monitoring, Safety & Emergency	Environmental Monitoring, Safety, and Emergency Response	X			
6.4.1	Sensors: Air, Water, Microbial, etc.	Sensors: Air, Water, Microbial, and Acoustic		X		
6.4.2	Fire: Detection, Suppression, Recovery	Fire: Detection, Suppression, and Recovery		X		
6.4.3	Protective Clothing / Breathing	Protective Clothing and Breathing		X		
6.4.4	Remediation	Remediation				
6.5	Radiation	Radiation				
6.5.1	Risk Assessment Modeling	Risk Assessment Modeling				
6.5.2	Radiation Mitigation	Radiation Mitigation and Biological Countermeasures	X			
6.5.3	Protection Systems	Protection Systems				
6.5.4	Radiation Prediction	Space Weather Prediction	X			
6.5.5	Monitoring Technology	Monitoring Technology				
7	Human Exploration Destination Systems	Human Exploration Destination Systems				
7.1	In-Situ Resource Utilization	In-Situ Resource Utilization				
7.1.1	Destination Reconnaissance, Prospecting, & Mapping	Destination Reconnaissance, Prospecting, and Mapping		X		
7.1.2	Resource Acquisition	Resource Acquisition				
7.1.3	Consumables Production	Processing and Production	X			
7.1.4	Manufacturing Products & Infrastructure Emplacement	Manufacturing Products and Infrastructure Emplacement		X		
7.2	Sustainability & Supportability	Sustainability and Supportability		X		
7.2.1	Autonomous Logistics Management	Autonomous Logistics Management				
7.2.2	Maintenance Systems	Maintenance Systems				
7.2.3	Repair Systems	Repair Systems				

Technology Area Breakdown Structure Changes

TABS	2012	2015	Name Change	Name Grammar Change	New Branch	2015 TABS Addressed in Other Areas or Having No Snapshots
7.2.4	Food Protection, Processing, & Preservation	Food Production, Processing, and Preservation		X		
7.3	“Advanced” Human Mobility Systems	Human Mobility Systems	X			
7.3.1	EVA Mobility	EVA Mobility				
7.3.2	Surface Mobility	Surface Mobility				
7.3.3	Off-Surface Mobility	Off-Surface Mobility				
7.4	“Advanced” Habitat Systems	Habitat Systems	X			
7.4.1	Integrated Habitat Systems	Integrated Habitat Systems				
7.4.2	Habitat Evolution	Habitat Evolution				
7.4.3	“Smart” Habitats	"Smart" Habitats				
7.4.4	Artificial Gravity	Artificial Gravity				
7.5	Mission Operations & Safety	Mission Operations and Safety		X		
7.5.1	Crew Training	Crew Training				Addressed in TA 11.3.4 (Simulation-Based Training and Decision Support Systems)
7.5.2	Planetary Safety	Planetary Protection	X			
7.5.3	Integrated Flight Operations Systems	Integrated Flight Operations Systems				
7.5.4	Integrated Risk Assessment Tools	Integrated Risk Assessment Tools				Addressed in TA 11.3.6 (Uncertainty Quantification and Nondeterministic Simulation Methods)
7.6	Cross-Cutting Systems	Cross-Cutting Systems				
7.6.1	Modeling, Simulations & Destination Characterization	Particulate Contamination Prevention and Mitigation	X			
7.6.2	Construction & Assembly	Construction and Assembly		X		
7.6.3	Dust Prevention & Mitigation	-	X			
8	Science Instruments, Observatories and Sensor Systems	Science Instruments, Observatories, and Sensor Systems		X		
8.1	Remote Sensing Instruments / Sensors	Remote Sensing Instruments and Sensors		X		
8.1.1	Detectors & Focal Planes	Detectors and Focal Planes		X		
8.1.2	Electronics	Electronics				
8.1.3	Optical Components	Optical Components				
8.1.4	Microwave / Radio	Microwave, Millimeter-, and Submillimeter-Waves	X			
8.1.5	Lasers	Lasers				
8.1.6	Cryogenic / Thermal	Cryogenic / Thermal				

Technology Area Breakdown Structure Changes

TABS	2012	2015	Name Change	Name Grammar Change	New Branch	2015 TABS Addressed in Other Areas or Having No Snapshots
8.2	Observatories	Observatories				
8.2.1	Mirror Systems	Mirror Systems				
8.2.2	Structures & Antennas	Structures and Antennas		X		
8.2.3	Distributed Aperture	Distributed Aperture				
8.3	In-Situ Instruments / Sensor	In-Situ Instruments and Sensors		X		
8.3.1	Particles: Charged & Neutral	Field and Particle Detectors	X			
8.3.2	Fields & Waves	Fields and Waves		X		Addressed in TA 8.3.1 (Field and Particle Detectors) and TA 8.3.3 (In-Situ (other))
8.3.3	In-Situ	In-Situ (other)	X			
9	Entry, Descent & Landing Systems	Entry, Descent, and Landing Systems		X		
9.1	Aeroassist & Atmospheric Entry	Aeroassist and Atmospheric Entry		X		
9.1.1	Rigid Thermal Protection Systems	Thermal Protection Systems for Rigid Decelerators	X			
9.1.2	Flexible Thermal Protection Systems	Thermal Protection Systems for Deployable Decelerators	X			
9.1.3	Rigid Hypersonic Decelerators	Rigid Hypersonic Decelerators				
9.1.4	Deployable Hypersonic Decelerators	Deployable Hypersonic Decelerators				
9.1.5	-	Instrumentation and Health Monitoring			X	Addressed in TA 9.4.6 (Instrumentation and Health Monitoring)
9.1.6	-	Entry Modeling and Simulation			X	Addressed in TA 9.4.5 (Modeling and Simulation) and TA 14 (Thermal Management Systems)
9.2	Descent	Descent and Targeting	X			
9.2.1	Attached Deployable Decelerators	Attached Deployable Decelerators				
9.2.2	Trailing Deployable Decelerators	Trailing Deployable Decelerators				
9.2.3	Supersonic Retropropulsion	Supersonic Retropropulsion				
9.2.4	-	GN&C Sensors			X	Addressed in TA 9.2.6 (Large Divert Guidance), TA 9.2.7 (Terrain-Relative Sensing and Characterization), and TA 9.2.8 (Autonomous Tracking)

Technology Area Breakdown Structure Changes

TABS	2012	2015	Name Change	Name Grammar Change	New Branch	2015 TABS Addressed in Other Areas or Having No Snapshots
9.2.5	-	Descent Modeling and Simulation			X	Addressed in TA 9.4.5 (Modeling and Simulation)
9.2.6	-	Large Divert Guidance			X	
9.2.7	-	Terrain-Relative Sensing and Characterization			X	
9.2.8	-	Autonomous Targeting			X	
9.3	Landing	Landing				
9.3.1	Touchdown Systems	Propulsion and Touchdown Systems	X			
9.3.2	Egress & Deployment Systems	Egress and Deployment Systems		X		Addressed in TA 7.3 (Human Mobility Systems)
9.3.3	Propulsion Systems	Propulsion Systems				Addressed in TA 2 (In-Space Propulsion Systems), TA 7.6.1 (Particulate Contamination Prevention and Mitigation), and TA 9.1.1 (Thermal Protection Systems)
9.3.4	Small Body Systems	Large Body GN&C	X			Addressed in TA 9.1.3 (Rigid Hypersonic Decelerators), TA 9.1.4 (Deployable Hypersonic Decelerators), and TA 9.2.7 (Terrain-Relative Sensing and Characterization)
9.3.5	-	Small Body Systems			X	Addressed in TA 9.2.8 (Autonomous Targeting) and TA 4 (Robotics and Autonomous Systems)
9.3.6	-	Landing Modeling and Simulation			X	Addressed in TA 9.4.5 (Modeling and Simulation)
9.4	Vehicle Systems Technology	Vehicle Systems	X			
9.4.1	Separation Systems	Architecture Analysis	X			Addressed in TA 11.3 (Simulation)
9.4.2	System Integration & Analyses	Separation Systems	X			Addressed in TA 12.3 (Mechanical Systems)
9.4.3	Atmosphere & Surface Characterization	System Integration and Analysis	X			Addressed in TA 11.3 (Simulation)

Technology Area Breakdown Structure Changes

TABS	2012	2015	Name Change	Name Grammar Change	New Branch	2015 TABS Addressed in Other Areas or Having No Snapshots
9.4.4	Modeling and Simulation	Atmosphere and Surface Characterization	X			Addressed in TA 8.1.1 (Detectors and Focal Planes)
9.4.5	Instrumentation and Health Monitoring	Modeling and Simulation	X			
9.4.6	GN&C Sensors and Systems	Instrumentation and Health Monitoring	X			
9.4.7	-	GN&C Sensors and Systems			X	Addressed in TA 9.1.3 (Rigid Hypersonic Decelerators), TA 9.2.6 (Large Divert Guidance), TA 9.2.7 (Terrain-Relative Sensing and Characterization), and TA 9.2.8 (Autonomous Targeting)
10	Nanotechnology	Nanotechnology				
10.1	Engineered Materials & Structures	Engineered Materials and Structures		X		
10.1.1	Lightweight Structures	Lightweight Structures				
10.1.2	Damage Tolerant System	Damage-Tolerant Systems		X		
10.1.3	Coatings	Coatings				
10.1.4	Adhesives	Adhesives				
10.1.5	Thermal Protection & Control	Thermal Protection and Control		X		
10.2	Energy Generation & Storage	Energy Storage, Power Generation, and Power Distribution	X			
10.2.1	Energy Storage	Energy Storage				
10.2.2	Energy Generation	Power Generation		X		
10.2.3	-	Power Distribution			X	
10.3	Propulsion	Propulsion				
10.3.1	Propellants	Propellants				
10.3.2	Propulsion Components	Propulsion Components				
10.3.3	In-Space Propulsion	In-Space Propulsion				
10.4	Sensors, Electronics & Devices	Sensors, Electronics, and Devices		X		
10.4.1	Sensors & Actuators	Sensors and Actuators		X		
10.4.2	Nanoelectronics	Nanoelectronics				
10.4.3	Miniature Instruments	Miniature Instruments and Instrument Components	X			
11	Modeling, Simulation, Information Technology & Processing	Modeling, Simulation, Information Technology and Processing		X		

Technology Area Breakdown Structure Changes

TABS	2012	2015	Name Change	Name Grammar Change	New Branch	2015 TABS Addressed in Other Areas or Having No Snapshots
11.1	Computing	Computing				
11.1.1	Flight Computing	Flight Computing				
11.1.2	Ground Computing	Ground Computing				
11.2	Modeling	Modeling				
11.2.1	Software Modeling & Model-Checking	Software Modeling and Model Checking		X		
11.2.2	Integrated Hardware & Software Modeling	Integrated Hardware and Software Modeling		X		
11.2.3	Human-System Performance Modeling	Human-System Performance Modeling				
11.2.4	Science Modeling	Science Modeling				
11.2.5	Frameworks, Languages, Tools & Standards	Frameworks, Languages, Tools, and Standards		X		
11.2.6	-	Analysis Tools for Mission Design			X	
11.3	Simulation	Simulation				
11.3.1	Distributed Simulation	Distributed Simulation				
11.3.2	Integrated System Lifecycle Simulation	Integrated System Lifecycle Simulation				
11.3.3	Simulation-Based Systems Engineering	Simulation-Based Systems Engineering				
11.3.4	Simulation-Based Training & Decision Support Systems	Simulation-Based Training and Decision Support Systems		X		
11.3.5	-	Exascale Simulation			X	
11.3.6	-	Uncertainty Quantification and Nondeterministic Simulation Methods			X	
11.3.7	-	Multiscale, Multiphysics, and Multifidelity Simulation			X	
11.3.8	-	Verification and Validation			X	
11.4	Information Processing	Information Processing				
11.4.1	Science, Engineering & Mission Data Lifecycle	Science, Engineering, and Mission Data Lifecycle		X		
11.4.2	Intelligent Data Understanding	Intelligent Data Understanding				
11.4.3	Semantic Technologies	Semantic Technologies				
11.4.4	Collaborative Science & Engineering	Collaborative Science and Engineering		X		
11.4.5	Advanced Mission Systems	Advanced Mission Systems				
11.4.6	-	Cyber Infrastructure			X	
11.4.7	-	Human-System Integration			X	
11.4.8	-	Cyber Security			X	

Technology Area Breakdown Structure Changes

TABS	2012	2015	Name Change	Name Grammar Change	New Branch	2015 TABS Addressed in Other Areas or Having No Snapshots
12	Materials, Structures, Mechanical Systems & Manufacturing	Materials, Structures, Mechanical Systems and Manufacturing		X		
12.1	Materials	Materials				
12.1.1	Lightweight Structure	Lightweight Structural Materials	X			
12.1.2	Computational Design	Computationally-Designed Materials	X			
12.1.3	Flexible Material Systems	Flexible Material Systems				
12.1.4	Environment	Materials for Extreme Environments	X			
12.1.5	Special Materials	Special Materials				
12.2	Structures	Structures				
12.2.1	Lightweight Concepts	Lightweight Concepts				
12.2.2	Design & Certification Methods	Design and Certification Methods		X		
12.2.3	Reliability & Sustainment	Reliability and Sustainment		X		
12.2.4	Test Tools & Methods	Test Tools and Methods		X		
12.2.5	Innovative, Multifunctional Concepts	Innovative, Multifunctional Concepts				
12.2.6	-	Loads and Environments			X	
12.3	Mechanical Systems	Mechanical Systems				
12.3.1	Deployables, Docking and Interfaces	Deployables, Docking, and Interfaces		X		
12.3.2	Mechanism Life Extension Systems	Mechanism Life Extension Systems				
12.3.3	Electro-mechanical, Mechanical & Micromechanisms	Electro-Mechanical, Mechanical, and Micromechanisms		X		
12.3.4	Design & Analysis Tools and Methods	Design and Analysis Tools and Methods		X		
12.3.5	Reliability / Life Assessment / Health Monitoring	Reliability, Life Assessment, and Health Monitoring		X		
12.3.6	Certification Methods	Certification Methods				
12.4	Manufacturing	Manufacturing				
12.4.1	Manufacturing Processes	Manufacturing Processes				
12.4.2	Intelligent Integrated Manufacturing and Cyber Physical Systems	Intelligent Integrated Manufacturing and Cyber Physical Systems				
12.4.3	Electronics & Optics Manufacturing Process	Electronics and Optics Manufacturing Process		X		
12.4.4	Sustainable Manufacturing	Sustainable Manufacturing				
12.4.5	-	Nondestructive Evaluation and Sensors			X	
12.5	Cross-Cutting	12.5 Cross-Cutting				
12.5.1	Nondestructive Evaluation	-	X			
12.5.2	Model-Based Certification & Sustainment Methods	-	X			

Technology Area Breakdown Structure Changes

TABS	2012	2015	Name Change	Name Grammar Change	New Branch	2015 TABS Addressed in Other Areas or Having No Snapshots
12.5.3	Loads and Environments	-	X			
13	Ground & Launch Systems Processing	Ground and Launch Systems		X		
13.1	Technologies to Optimize the Operational Life-Cycle	Operational Life-Cycle	X			
13.1.1	Storage, Distribution & Conservation of Fluids	On-Site Production, Storage, Distribution, and Conservation of Fluids	X			
13.1.2	Automated Alignment, Coupling, & Assembly Systems	Automated Alignment, Coupling, Assembly, and Transportation Systems		X		
13.1.3	Autonomous Command & Control for Ground and Integrated Vehicle/ Ground Systems	Autonomous Command and Control for Integrated Vehicle and Ground Systems		X		
13.1.4	-	Logistics			X	
13.2	Environmental and Green Technologies	Environmental Protection and Green Technologies		X		
13.2.1	Corrosion Prevention, Detection, & Mitigation	Corrosion Prevention, Detection, and Mitigation		X		
13.2.2	Environmental Remediation & Site Restoration	Environmental Remediation and Site Restoration		X		
13.2.3	Preservation of Natural Ecosystems	Preservation of Natural Ecosystems				
13.2.4	Alternate Energy Prototypes	Alternate Energy Prototypes				
13.2.5	-	Curatorial Facilities, Planetary Protection, and Clean Rooms			X	
13.3	Technologies to Increase Reliability and Mission Availability	Reliability and Maintainability	X			
13.3.1	Advanced Launch Technologies	Launch Infrastructure	X			
13.3.2	Environment-Hardened Materials and Structures	Environment-Hardened Materials and Structures				
13.3.3	Inspection, Anomaly Detection & Identification	On-Site Inspection and Anomaly Detection and Identification		X		
13.3.4	Fault Isolation and Diagnostics	Fault Isolation and Diagnostics				
13.3.5	Prognostics Technologies	Prognostics		X		
13.3.6	Repair, Mitigation, and Recovery Technologies	Repair, Mitigation, and Recovery Technologies				
13.3.7	Communications, Networking, Timing & Telemetry	Communications, Networking, Timing, and Telemetry		X		
13.3.8	-	Decision-Making Tools			X	

Technology Area Breakdown Structure Changes

TABS	2012	2015	Name Change	Name Grammar Change	New Branch	2015 TABS Addressed in Other Areas or Having No Snapshots
13.4	Technologies to Improve Mission Safety/Mission Risk	Mission Success	X			
13.4.1	Range Tracking, Surveillance & Flight Safety Technologies	Range Tracking, Surveillance, and Flight Safety Technologies		X		
13.4.2	Landing & Recovery Systems & Components	Landing and Recovery Systems and Components		X		
13.4.3	Weather Prediction and Mitigation	Weather Prediction and Mitigation				
13.4.4	Robotics / Telerobotics	Robotics and Telerobotics		X		Addressed in TA 4 (Robotics and Autonomous Systems)
13.4.5	Safety Systems	Safety Systems				
14	Thermal Management Systems	Thermal Management Systems				
14.1	Cryogenic Systems	Cryogenic Systems				
14.1.1	Passive Thermal Control	Passive Thermal Control				
14.1.2	Active Thermal Control	Active Thermal Control				
14.1.3	Integration & Modeling	Integration and Modeling		X		Addressed in TA 14.1 (Cryogenic Systems) and TA 14.2 (Thermal Control Systems)
14.2	Thermal Control Systems	Thermal Control Systems				
14.2.1	Heat Acquisition	Heat Acquisition				
14.2.2	Heat Transfer	Heat Transport	X			
14.2.3	Heat Rejection & Energy Storage	Heat Rejection and Energy Storage		X		
14.3	Thermal Protection Systems	Thermal Protection Systems				
14.3.1	Entry / Ascent TPS	Ascent/Entry TPS	X			
14.3.2	Plume Shielding (Convective & Radiative)	TPS Modeling and Simulation	X			
14.3.3	Sensor Systems & Measurement Technologies	TPS Sensors and Measurement Systems	X			
15		Aeronautics			X	
15.1		Safe, Efficient, Growth in Global Aviation			X	
15.1.1		Improved Efficiency and Hazard Reduction within NextGen Operational Domains			X	
15.1.2		System-Wide Safety, Predictability, and Reliability through Full NextGen Functionality			X	

Technology Area Breakdown Structure Changes

TABS	2012	2015	Name Change	Name Grammar Change	New Branch	2015 TABS Addressed in Other Areas or Having No Snapshots
15.2		Innovation in Commercial Supersonic Aircraft			X	
15.2.1		Supersonic Overland Certification Standard Based on Acceptable Sonic Boom Noise			X	
15.2.2		Introduction of Affordable, Low-Boom, Low-Noise, and Low-Emission Supersonic Transports			X	
15.3		Ultra-Efficient Commercial Vehicles			X	
15.3.1		Achieve Community Goals for Improved Vehicle Efficiency and Environmental Performance in 2025			X	
15.3.2		Achieve Community Goals for Improved Vertical Lift Vehicle Efficiency and Environmental Performance in 2035			X	
15.3.3		Achieve Community Goals for Improved Vehicle Efficiency and Environmental Performance Beyond 2035			X	
15.4		Transition to Low-Carbon Propulsion			X	
15.4.1		Introduction of Low-Carbon Fuels for Conventional Engines and Exploration of Alternative Propulsion Systems			X	
15.4.2		Initial Introduction of Alternative Propulsion Systems			X	
15.5		Real-Time System-Wide Safety Assurance			X	
15.5.1		Introduction of Advanced Safety Assurance Tools			X	
15.5.2		An Integrated Safety Assurance System Enabling Continuous System-Wide Safety Monitoring			X	
15.5.3		Automated Safety Assurance Integrated with Real-Time Operations Enabling a Self-Protecting Aviation System			X	
15.6		Enable Assured Machine Autonomy for Aviation			X	
15.6.1		Initial Autonomy Applications			X	
15.6.2		Ability to Fully Certify and Trust Autonomous Systems for NAS Operations			X	