2026 Civil Space Shortfalls

Released 12 January, 2026

Shortfall	Need	References
SF01: Perform safe, Earth-independent Extravehicular Activities on the lunar surface.	1.1: Provide lunar spacesuits compatible with lunar surface gravity, dust, thermal environment, and atmosphere, capable of mission relevant EVA duration, dwell time, frequency, and use life.	NASA Extravehicular Activity Technology Roadmaps for Exploration (2024 ICES)
	1.2: Provide lunar spacesuit physiology capable of supporting long duration lunar mission EVA strategy with acceptable risk of adverse outcomes. Reference ESDMD #0406 (Moon) for specific details.	NASA Moon to Mars Architecture Definition Document Architecture-Driven Technology Gap Appendix
	1.3: Provide lunar spacesuits with variable and adjustable sizing to fit the astronaut population.	NASA Extravehicular Activity Technology Roadmaps for Exploration (2024 ICES)
	1.4: Provide crew ingress/egress capabilities that protect the crew, habitat, and suits.	LI-8: Demonstrate technologies supporting cislunar orbital/surface depots, construction and manufacturing maximizing the use of in-situ resources, and support systems needed for continuous human/robotic presence.
	1.5: Provide crew mobility for traverses on lunar surface.	NASA Extravehicular Activity Technology Roadmaps for Exploration (2024 ICES); NASA's Moon to Mars Strategy and Objectives Development Document, LI-6 L: Demonstrate local, regional, and global surface transportation and mobility capabilities in support of continuous human lunar presence and a robust lunar economy.
	1.6: Provide in-situ decision support tools to address identified EVA hazards and risks on the lunar surface.	NASA's Moon to Mars Strategy and Objectives Development Document, OP-10 LM: Demonstrate the capability to operate robotic systems that are used to support crew members on the lunar or Martian surface, autonomously or remotely from the Earth or from orbiting platforms
SF02: Develop infrastructure and capabilities for assets to operate for extended duration in the lunar environment.	2.1: Provide high power, thermal management, and actuation for surface assets to survive and operate in the lunar environment. Reference ESDMD #0301 (fixed assets) for specific details.	NASA Moon to Mars Architecture Definition Document Architecture-Driven Technology Gap Appendix
	2.2: Provide low power, thermal management, and actuation for distributed surface assets to survive and operate in the lunar environment. Reference ESDMD #0301 (mobile assests) for specific details.	NASA Moon to Mars Architecture Definition Document Architecture-Driven Technology Gap Appendix
	2.3: Provide scalable, multi-kWe-scale power generation and storage capable of supporting crew safety and exploration activities in lunar temperatures, dust, and solar availability conditions. Reference ESDMD #0901 for specific details.	NASA Moon to Mars Architecture Definition Document Architecture-Driven Technology Gap Appendix
	2.4: Provide robust and low-mass power management and distribution solutions for long-duration operations in extreme environments. Reference ESDMD #0903 (Lunar) for specific details.	NASA Moon to Mars Architecture Definition Document Architecture-Driven Technology Gap Appendix
	2.5: Operate surface assets efficiently for required durations, preventing extreme wear and tear to systems or mechanisms from lunar dust and regolith. Reference ESDMD #0801 for specific details.	NASA Moon to Mars Architecture Definition Document Architecture-Driven Technology Gap Appendix
	2.6: Provide extreme cold-tolerant robotic and mobility capabilities to enable use cases for surveying and accessing permanently shadowed regions for sample retrieval. Reference ESDMD #0804 for specific details.	NASA Moon to Mars Architecture Definition Document Architecture-Driven Technology Gap Appendix
	2.7: Perform high-performance computing in extreme temperature, high radiation, and dusty environments. Reference ESDMD #0201 (lunar) for specific details.	NASA Moon to Mars Architecture Definition Document Architecture-Driven Technology Gap Appendix
	2.8: Provide electrical charge dissipation sufficient to ensure hardware and crew safety.	LI-8: Demonstrate technologies supporting cislunar orbital/surface depots, construction and manufacturing maximizing the use of in-situ resources, and support systems needed for continuous human/robotic presence.
	2.9: Mitigate and survive high velocity impacts of small particles on lunar surface assets.	LI-8: Demonstrate technologies supporting cislunar orbital/surface depots, construction and manufacturing maximizing the use of in-situ resources, and support systems needed for continuous human/robotic presence.
	3.1: Predict plume surface interaction (PSI) surface erosion, crater width/depth, and ejecta energy flux during landing. Reference ESDMD #1101 (PSI characterization) for specific details.	NASA Moon to Mars Architecture Definition Document Architecture-Driven Technology Gap Appendix

SF03: Safely, routinely, and precisely land large systems on the lunar surface.	3.2: Land on lunar south pole exploration sites in various illumination conditions with appropriate accuracy. Reference ESDMD #1101 (landing accuracy) for specific details.	NASA Moon to Mars Architecture Definition Document Architecture-Driven Technology Gap Appendix
	3.3: Perform stable touchdown and operation of large vehicles on uneven, sloped, and undulating lunar surfaces.	NASA's Moon to Mars Strategy and Objectives Development Document, TH-2L: Develop system(s) that can routinely deliver a range of elements to the lunar surface.
	3.4: Provide surface support infrastructure to routinely land on and ascend from the lunar surface.	LI-8: Demonstrate technologies supporting cislunar orbital/surface depots, construction and manufacturing maximizing the use of in-situ resources, and support systems needed for continuous human/robotic presence.
SF04: Deploy, assemble, and construct complex structures on the lunar surface.	4.1: Perform site preparation and bulk regolith manipulation for infrastructure construction, including landing pads, berms, regolith overburden for radiation protection. Reference ESDMD #0605 (manipulation) for specific details.	NASA Moon to Mars Architecture Definition Document Architecture-Driven Technology Gap Appendix
	4.2: Deploy load-bearing structures on the lunar surface.	LI-8: Demonstrate technologies supporting cislunar orbital/surface depots, construction and manufacturing maximizing the use of in-situ resources, and support systems needed for continuous human/robotic presence.
	4.3: Autonomously assemble and construct structures on the lunar surface. Reference ESDMD #0504 for specific details.	NASA Moon to Mars Architecture Definition Document Architecture-Driven Technology Gap Appendix
	4.4: Construct structures on the lunar surface through advanced manufacturing techniques. Reference ESDMD #0505 for specific details.	NASA Moon to Mars Architecture Definition Document Architecture-Driven Technology Gap Appendix
SF05: Produce propellant, consumables, and other usable materials from lunar resources to support human exploration and commercial activities.	5.1: Locate, characterize, and map the useful resources on the lunar surface.	NASA's Moon to Mars Strategy and Objectives Development Document, OP-03 LM: Characterize accessible resources, gather scientific research data, and analyze potential reserves to satisfy science and technology objectives and enable use of resources on successive missions.
	5.2: Excavate and transport lunar regolith at a scale relevant for a demonstration mission. Reference ESDMD #0605 (excavation and transportation) for specific details.	NASA Moon to Mars Architecture Definition Document Architecture-Driven Technology Gap Appendix
	5.3: Extract metal and manufacturing feedstock from lunar regolith at a scale relevant for a demonstration mission. Reference ESDMD #0604 for specific details.	NASA Moon to Mars Architecture Definition Document Architecture-Driven Technology Gap Appendix
	5.4: Produce oxygen from lunar regolith at a scale relevant for a demonstration mission. Reference ESDMD #0601 for specific details.	NASA Moon to Mars Architecture Definition Document Architecture-Driven Technology Gap Appendix
	5.5: Produce water from icy lunar regolith at a scale relevant for a demonstration mission. Reference ESDMD #0603 for specific details.	NASA Moon to Mars Architecture Definition Document Architecture-Driven Technology Gap Appendix
	5.6: Produce power components derived from in-situ resources.	LI-8: Demonstrate technologies supporting cislunar orbital/surface depots, construction and manufacturing maximizing the use of in-situ resources, and support systems needed for continuous human/robotic presence.
	5.7: Excavate and transport lunar regolith at a scale relevant for sustained lunar exploration.	OP-11: Demonstrate the capability to use commodities produced from planetary surface or in-space resources to reduce the mass required to be transported from Earth.
	5.8: Produce metals, oxygen, and water at a scale relevant for sustained lunar exploration.	OP-11: Demonstrate the capability to use commodities produced from planetary surface or in-space resources to reduce the mass required to be transported from Earth.
	5.9: Manage, store, and distribute in-situ-produced materials and products at a scale relevant to sustained lunar exploration.	OP-11: Demonstrate the capability to use commodities produced from planetary surface or in-space resources to reduce the mass required to be transported from Earth.
	5.10: Manage conversion, storage, and handling of oxygen into breathing air sufficient to support sustained lunar exploration mission needs.	NASA's Moon to Mars Strategy and Objectives Development Document, TH-3L : Develop system(s) to allow crew to explore, operate, and live on the lunar surface and in lunar orbit with scalability to continuous presence; conducting scientific and industrial utilization as well as Mars analog activities.
SF06: Develop infrastructure and capabilities for assets to operate for extended duration in the Martian environment	6.1: Provide robust and low-mass power management and distribution solutions for long-duration operations in extreme environments. Reference ESDMD #0903 (Mars) for specific details.	NASA Moon to Mars Architecture Definition Document Architecture-Driven Technology Gap Appendix
	6.2: Operate surface assets efficiently for long durations, preventing extreme wear and tear to systems or mechanisms from Martian dust and regolith. Reference ESDMD #0802 for specific details.	NASA Moon to Mars Architecture Definition Document Architecture-Driven Technology Gap Appendix
	6.3: Mitigate and survive high velocity impacts of small particles on Martian surface assets.	TH-7: Develop systems for crew to explore, operate, and live on the Martian surface to address key questions with respect to science and resources.

Martian environment.	6.4: Provide scalable, multi-kWe-scale power generation and storage capable of supporting assets and crew safety in Martian temperatures, dust, and solar availability conditions. Reference ESDMD #0902 for specific details.	NASA Moon to Mars Architecture Definition Document Architecture-Driven Technology Gap Appendix
	6.5: Perform high-performance computing in extreme temperature, high radiation, and dusty environments. Reference ESDMD #0201 (Mars) for specific details.	NASA Moon to Mars Architecture Definition Document Architecture-Driven Technology Gap Appendix
SF07: Provide communication solutions to assets and crew during missions to Mars.	7.1: Provide reliable uplink and downlink solutions that prevent or mitigate data disruptions between Earth and Mars. Reference ESDMD #0102 (data reliability) for specific details.	NASA Moon to Mars Architecture Definition Document Architecture-Driven Technology Gap Appendix
	7.2: Transfer data at sufficient rates to supply high-definition streaming and still imagery between Earth and Mars. Reference ESDMD #0102 (data rate) for specific details.	NASA Moon to Mars Architecture Definition Document Architecture-Driven Technology Gap Appendix
	7.3: Transfer data at sufficient rates to accommodate science operations at Mars.	
SF08:Perform safe, Earth-independent Extravehicular Activities on the Martian surface.	8.1: Provide Martian spacesuits compatible with Mars surface gravity, dust, thermal environment, and atmosphere, capable of mission relevant EVA duration, dwell time, frequency, and use life. Reference ESDMD #0803 for specific details.	NASA Moon to Mars Architecture Definition Document Architecture-Driven Technology Gap Appendix
	8.2: Provide Martian spacesuit physiology capable of supporting Mars mission EVA strategy with acceptable risk of adverse outcomes. Reference ESDMD #0406 (Mars) for specific details.	NASA Moon to Mars Architecture Definition Document Architecture-Driven Technology Gap Appendix
	8.3: Provide Martian spacesuits with variable and adjustable sizing to fit the astronaut population.	NASA Extravehicular Activity Technology Roadmaps for Exploration (2024 ICES)
	8.4: Provide ingress and egress between surface habitat, other surface elements, and the Martian surface.	TH-7: Develop systems for crew to explore, operate, and live on the Martian surface to address key questions with respect to science and resources.
	8.5: Provide appropriate water purity, oxygen, and power needed for Martian spacesuits.	NASA Extravehicular Activity Technology Roadmaps for Exploration (2024 ICES)
	8.6: Provide in-situ decision support tools to address identified EVA hazards and risks on the Martian surface.	TH-7: Develop systems for crew to explore, operate, and live on the Martian surface to address key questions with respect to science and resources.
	8.7: Provide crew mobility for long traverses on Martian surface.	NASA's Moon to Mars Strategy and Objectives Development Document, OP-05 LM: Operate surface mobility systems, e.g., extra-vehicular activity (EVA) suits, tools and vehicles.
SF09: Safely, reliably, and precisely land large systems on the Martian surface.	9.1: Characterize and predict plume surface interaction (PSI) surface erosion, crater width/depth, and ejecta energy flux, and mitigate effects of PSI ejecta on Martian surface assets. Reference ESDMD #1102 (PSI Characterization) for specific details.	NASA Moon to Mars Architecture Definition Document Architecture-Driven Technology Gap Appendix
	9.2: Predict Mars entry mission performance before flight with validated entry models. Reference ESDMD #1103 (modeling) for specific details.	NASA Moon to Mars Architecture Definition Document Architecture-Driven Technology Gap Appendix
	9.3: Decelerate large payloads to the Martian surface. Reference ESDMD #1103 (entry and descent) for specific details.	NASA Moon to Mars Architecture Definition Document Architecture-Driven Technology Gap Appendix
	9.4: Land large payloads within an intended target range on Mars while detecting and avoiding obstacles. Reference ESDMD #1102 (landing accuracy) for specific details.	NASA Moon to Mars Architecture Definition Document Architecture-Driven Technology Gap Appendix
	9.5: Perform stable touchdown and operation of large vehicles on uneven, sloped, and undulating Martian surfaces.	NASA's Moon to Mars Strategy and Objectives Development Document, TH-6M: Develop transportation systems that can deliver a range of elements to the Martian surface.
SF10: Produce propellant, consumables, and other usable materials from Martian resources to support human exploration.	10.1: Locate, characterize, and map the useful resources on the Martian surface.	NASA's Moon to Mars Strategy and Objectives Development Document, MI-04: Demonstrate Mars ISRU capabilities to support an initial human Mars exploration campaign
	10.2: Excavate/accumulate, manipulate, and transport Martian resources at mission relevant scale.	NASA's Moon to Mars Strategy and Objectives Development Document, MI-04: Demonstrate Mars ISRU capabilities to support an initial human Mars exploration campaign
	10.3: Produce consumables, propellant, and other usable materials at mission relevant scale to support human Mars missions. Reference ESDMD #0606 for specific details.	NASA's Moon to Mars Strategy and Objectives Development Document, MI-04: Demonstrate Mars ISRU capabilities to support an initial human Mars exploration campaign
	10.4: Manage, store, and distribute propellants, consumables, and other usable materials sufficient for mission needs on Mars.	MI-04: Demonstrate Mars ISRU capabilities to support an initial human Mars exploration campaign
SF11: Land science payloads on planetary surfaces	11.1: Develop and validate performance models for entry systems.	Science Mission Directorate
	11.2: Develop low cost, high performance entry systems.	
	11.3: Develop new atmospheric entry systems to reduce risk and mass requirements for precision landing.	

planetary surfaces.	11.4: Land science payloads on sites in various illumination conditions.	
	11.5: Perform stable touchdown, deployment, and operation of science payloads on uneven, sloped, and undulating surfaces.	
SF12: Transport crew and cargo from Earth to the Moon and Mars and back.	12.1: Transport crew and cargo from near Earth to near Mars and return crew safely back to near Earth. Reference ESDMD #1104 for specific details.	NASA Moon to Mars Architecture Definition Document Architecture-Driven Technology Gap Appendix
	12.2: Integrate propellant resources across systems to maximize resource efficiency in transit.	TH-5 Develop transportation systems that crew can routinely operate between the Earth-Moon vicinity and Mars vicinity, including the Martian surface.
	12.3: Efficiently store propellant for appropriate durations in microgravity environments while minimizing boil-off. Reference ESDMD #1106 (in-space) for specific details.	NASA Moon to Mars Architecture Definition Document Architecture-Driven Technology Gap Appendix
	12.4: Transfer Earth-storable propellant and pressurized gases between exploration assets in space. Reference ESDMD #0503 (in-space) for specific details.	NASA Moon to Mars Architecture Definition Document Architecture-Driven Technology Gap Appendix
	12.5: Transfer low-loss cryogenic fluid between spacecraft in microgravity environments at scales sufficient for human exploration missions. Reference ESDMD #1107 (in-space) for specific details.	NASA Moon to Mars Architecture Definition Document Architecture-Driven Technology Gap Appendix
	12.6: Robotically assemble modular flight elements for large transportation systems.	ISAM National Strategy; National ISAM Implementation Plan
	12.7: Ascend with crew and cargo from the surface of Mars to Mars-orbit. Reference ESDMD #1105 for specific details.	NASA Moon to Mars Architecture Definition Document Architecture-Driven Technology Gap Appendix
	12.8: Reliably and safely land crew and cargo return vehicles at designated landing sites on Earth.	NASA's Moon to Mars Strategy and Objectives Development Document, TH-12LM: Develop systems capable of returning a range of cargo mass from the Martian surface to Earth, including the capabilities necessary to meet scientific and utilization objectives.
SF13: Perform advanced remote sensing and science measurements with improved sensing capabilities and autonomy.	13.1: Increase sensitivity and resolution of science instruments by orders of magnitude with quantum technologies.	Science Mission Directorate
	13.2: Increase sensitivity and performance of photon detectors.	Science Mission Directorate
	13.3: Provide high-performance imagery for remote sensing across the energy spectrum.	
	13.4: Study and discover highly energetic phenomena in the universe.	
	13.5: Provide a cosmic-dust-penetrating view into the early universe.	
	13.6: Detect biosignatures at exoplanets.	
	13.7: Deliver non-imaging science measurement capabilities for particle and field sensors needed in distributed spacecraft systems conducting multi-point solar observations.	
	13.8: Autonomously perform science operations on commercial LEO destinations and lunar surface laboratories.	Science Mission Directorate
	13.9: Provide advanced networking needed for multi-spacecraft responsive space operations.	National Cislunar Science and Technology Strategy (2022), Objective 4: Implement Cislunar communications and positioning, navigation, and timing capabilities with scalable and interoperable approaches; DoD State of the Space Industrial Base (2023); Bryce Tech "Smallsats by the numbers 2025"
	13.1: Provide a holistic, efficient, and effective wildland fire crisis management system.	The Report of the Wildland Fire Mitigation and Management Commission
SF14: Perform missions with small spacecraft beyond low Earth orbit.	14.1: Miniaturize sensors and instrumentation on small spacecraft.	DoD State of the Space Industrial Base (2023); Bryce Tech "Smallsats by the numbers 2025" ; National Space Policy (2020)
	14.2: Increase power generation and storage systems for small spacecraft.	DoD State of the Space Industrial Base (2023)
	14.3: Efficiently reject heat in small spacecraft.	DoD State of the Space Industrial Base (2023)
	14.4: Provide reliable transportation for small spacecraft to destinations beyond cislunar space.	DoD State of the Space Industrial Base (2023)
	14.5: Perform entry, descent, and/or landing for small spacecraft efficiently and cost effectively.	DoD State of the Space Industrial Base (2023)
SF15: Operate multi-agent robotic and crewed systems in cooperative planetary surface	15.1: Provide scalable, reliable surface-to-surface communications between assets on the lunar surface that is usable by all participating elements. Reference ESDMD #0103 (Moon) for specific details.	NASA Moon to Mars Architecture Definition Document Architecture-Driven Technology Gap Appendix
	15.2: Provide dust-tolerant docking and berthing systems and utility connections that enable transfer of crew, cargo, and commodities between modules for cooperative surface operations. Reference ESDMD #0807 for specific details.	NASA Moon to Mars Architecture Definition Document Architecture-Driven Technology Gap Appendix

cooperative planetary surface activities.	15.3: Achieve safe, efficient human-robot interactions for exploration missions, secure command and control over high-latency, bandwidth-limited networks, or implement reliable automated safing sequences. Reference ESDMD #1005 for specific details.	NASA Moon to Mars Architecture Definition Document Architecture-Driven Technology Gap Appendix
	15.4: Perform Earth-independent cooperative tasks on planetary bodies using autonomous software tools in multi-agent robotic systems.	OP-9: Demonstrate the capability of integrated robotic systems to support and maximize the useful work performed by crewmembers on the surface, and in orbit.
SF16: Provide surface mobility and logistics for crew and assets on planetary surfaces.	16.1: Autonomously maneuver and navigate to achieve faster mobility with an order of magnitude greater range. Reference ESDMD #0805 for specific details.	NASA Moon to Mars Architecture Definition Document Architecture-Driven Technology Gap Appendix
	16.2: Offload, handle, and manipulate payloads from elevated heights on planetary surfaces. Reference ESDMD #0806 for specific details.	NASA Moon to Mars Architecture Definition Document Architecture-Driven Technology Gap Appendix
	16.3: Relocate large assets on planetary surfaces. Reference ESDMD #0808 for specific details.	NASA Moon to Mars Architecture Definition Document Architecture-Driven Technology Gap Appendix
	16.4: Efficiently store propellant for appropriate durations in partial gravity environments while minimizing boil-off. Reference ESDMD #1106 (surface) for specific details.	NASA Moon to Mars Architecture Definition Document Architecture-Driven Technology Gap Appendix
	16.5: Transfer low-loss cryogenic fluid between spacecraft in partial gravity environments at scales sufficient for human exploration missions. Reference ESDMD #1107 (surface) for specific details.	NASA Moon to Mars Architecture Definition Document Architecture-Driven Technology Gap Appendix
	16.6: Store Earth-storable fluids in extreme thermal environments.	NASA's Moon to Mars Strategy and Objectives Development Document, LI-08 L: Demonstrate technologies supporting cislunar orbital/surface depots, construction and manufacturing maximizing the use of in-situ resources, and support systems needed for continuous human/robotic presence.
	16.7: Transfer Earth-storable propellant between exploration assets on planetary surfaces. Reference ESDMD #0503 (surface) for specific details.	NASA Moon to Mars Architecture Definition Document Architecture-Driven Technology Gap Appendix
	16.8: Transfer pressurized gases between exploration assets on planetary surfaces.	NASA's Moon to Mars Strategy and Objectives Development Document, LI-08 L: Demonstrate technologies supporting cislunar orbital/surface depots, construction and manufacturing maximizing the use of in-situ resources, and support systems needed for continuous human/robotic presence.
	16.9: Minimize crew manual labor through efficient tools to enable fluid transfer on a planetary surface.	LI-8: Demonstrate technologies supporting cislunar orbital/surface depots, construction and manufacturing maximizing the use of in-situ resources, and support systems needed for continuous human/robotic presence.
SF17: Provide robotic access to subsurface and atmospheric regimes.	17.1: Autonomously perform deep drilling operations in sub-surface regions beyond current capability for pristine/unmodified materials.	
	17.2: Provide autonomous mobility in subsurface applications (solid, granular, and fluid).	
	17.3: Provide aerial mobility on Mars.	
	17.4: Provide aerial mobility on Venus.	
	17.5: Provide aerial mobility on Titan.	
SF18: Efficiently and responsibly manage waste streams during long duration missions.	18.1: Manage logistics and waste streams to maximize reuse, minimize logistics footprint and waste, and prevent microbial and volatile releases that contaminate the vehicle and planetary surfaces. Reference ESDMD #0702 for specific details.	NASA Moon to Mars Architecture Definition Document Architecture-Driven Technology Gap Appendix
	18.2: Identify, quantify, and mitigate contamination at exploration destinations with minimal crew effort and operational complexity. Reference ESDMD #1202 for specific details.	NASA Moon to Mars Architecture Definition Document Architecture-Driven Technology Gap Appendix
	18.3: Recycle metabolic waste in-situ.	TH-4: Develop in-space and surface habitation system(s) for crew to live in deep space for extended durations, enabling future missions to Mars.
	18.4: Utilize recycled material as feedstock in space-based manufacturing.	NASA's Moon to Mars Strategy and Objectives Development Document, LI-04 L: Demonstrate advanced manufacturing and autonomous construction capabilities in support of continuous human lunar presence and a robust lunar economy.; OP-8 LM: Demonstrate the capability to find, service, upgrade, or utilize instruments and equipment from robotic landers or previous human missions on the surface of the Moon and Mars.
	18.5: Manage the thermal energy waste stream.	OP-12: Establish procedures and systems that will minimize the disturbance to the local environment, maximize the resources available to future explorers, and allow for reuse/recycling of material transported from Earth (and from the lunar surface in the case of Mars) to be used during exploration.

SF19: Provide efficient, outfitted habitation capable of long duration missions.	19.1: Monitor atmospheric quality, microbes, airborne particles, trace contaminants, and acoustics to prevent health/operational issues and guide off-nominal responses, without Earth sample return and with minimal consumables and crew time. Reference ESDMD #0304 (atmosphere) for specific details.	NASA Moon to Mars Architecture Definition Document Architecture-Driven Technology Gap Appendix
	19.2: Provide mass-efficient habitat structures capable of supporting mission relevant crew size and duration. Reference ESDMD #0306 for specific details.	NASA Moon to Mars Architecture Definition Document Architecture-Driven Technology Gap Appendix
	19.3: Manage the thermal environment of habitation systems for long duration missions.	TH-4: Develop in-space and surface habitation system(s) for crew to live in deep space for extended durations, enabling future missions to Mars.
	19.4: Provide Earth-independent planning, scheduling, and troubleshooting capabilities for long duration missions.	TH-4: Develop in-space and surface habitation system(s) for crew to live in deep space for extended durations, enabling future missions to Mars.
	19.5: Provide audio and visual crew interfaces for long duration missions.	TH-4: Develop in-space and surface habitation system(s) for crew to live in deep space for extended durations, enabling future missions to Mars.
SF20: Provide adequate food, water, and supplies to ensure crew mental and physical wellbeing during long duration missions.	20.1: Provide potable water systems with safe and effective long-term maintenance and recovery that meet the chemical and microbial potable water requirements during long duration missions. Reference ESDMD #0303 for specific details.	NASA Moon to Mars Architecture Definition Document Architecture-Driven Technology Gap Appendix
	20.2: Monitor water quality, microbes, and trace contaminants to prevent health/operational issues and guide off-nominal responses without Earth sample return and with minimal consumables and crew time. Reference ESDMD #0304 (water) for specific details.	NASA Moon to Mars Architecture Definition Document Architecture-Driven Technology Gap Appendix
	20.3: Deliver food, supplements, and supplies in low-mass, interoperable containers—both conditioned and unconditioned—that are human-robotic compatible, transportable, thermally stable, recyclable/reusable, and maintainable for year+ missions. Reference ESDMD #0701 for specific details.	NASA Moon to Mars Architecture Definition Document Architecture-Driven Technology Gap Appendix
	20.4: Provide a variety of food systems that are safe and palatable during long duration missions, contain nutritional shelf life, and can withstand the environment within the habitat. Reference ESDMD #0305 (food storage) for specific details.	NASA Moon to Mars Architecture Definition Document Architecture-Driven Technology Gap Appendix
	20.5: Grow crops for long-duration missions. Reference ESDMD #0305 (food production) for specific details.	NASA Moon to Mars Architecture Definition Document Architecture-Driven Technology Gap Appendix
SF21: Provide Earth-independent safety and crew health and performance countermeasures during long duration missions.	21.1: Increase crew safety from fire hazards in low and partial gravity environments at reduced pressures and increased oxygen levels. Reference ESDMD #0302 for specific details.	NASA Moon to Mars Architecture Definition Document Architecture-Driven Technology Gap Appendix
	21.2: Monitor and forecast space and planetary weather sufficient to ensure safety of crew and assets for mission relevant durations. Reference ESDMD #0307 for specific details.	NASA Moon to Mars Architecture Definition Document Architecture-Driven Technology Gap Appendix
	21.3: Reduce adverse crew health outcomes due to radiation exposure via mass-efficient, mission compatible countermeasures in alignment with NASA-STD-3001 V1 4030 & 4031. Reference ESDMD #0308 for specific details.	NASA Moon to Mars Architecture Definition Document Architecture-Driven Technology Gap Appendix
	21.4: Accurately monitor and maintain physical health and performance during long duration missions. Reference ESDMD #0401 for specific details.	NASA Moon to Mars Architecture Definition Document Architecture-Driven Technology Gap Appendix
	21.5: Meet crew health and performance standards for sensorimotor health during long duration missions. Reference ESDMD #0402 for specific details.	NASA Moon to Mars Architecture Definition Document Architecture-Driven Technology Gap Appendix
	21.6: Reduce adverse crew physical health and performance outcomes via mission-compatible countermeasures under communication delay and without resupply. Reference ESDMD #0403 for specific details.	NASA Moon to Mars Architecture Definition Document Architecture-Driven Technology Gap Appendix
	21.7: Prevent or address anticipated mental health needs experienced during exploration missions via Earth-Independent mental and behavioral health countermeasures. Reference ESDMD #0404 for specific details.	NASA Moon to Mars Architecture Definition Document Architecture-Driven Technology Gap Appendix
	21.8: Provide Earth-Independent health and medical care capabilities sufficient to address anticipated medical needs experienced during exploration. Reference ESDMD #0405 for specific details.	NASA Moon to Mars Architecture Definition Document Architecture-Driven Technology Gap Appendix
	21.9: Operate crewed missions without Earth-based instruction during safety critical operations that require immediate response.	TH-8LM: Develop systems that monitor and maintain crew health and performance throughout all mission phases, including during communication delays to Earth, and in an environment that does not allow emergency evacuation or terrestrial medical assistance.

SF22: Provide a ground support infrastructure capable of supporting a launch cadence sufficient for continuous lunar access and missions to Mars.	22.1: Provide efficient public safety measures for the increase cadence of launches and return configurations.	OP-4: Establish command and control processes, common interfaces, and ground systems that will support expanding human missions at the Moon and Mars.
	22.2: Provide space nuclear systems infrastructure support and launch readiness.	OP-4: Establish command and control processes, common interfaces, and ground systems that will support expanding human missions at the Moon and Mars.
	22.3: Provide vehicle and payload processing facilities sufficient for lunar and Mars missions.	OP-4: Establish command and control processes, common interfaces, and ground systems that will support expanding human missions at the Moon and Mars.
	22.4: Provide fueling facilities sufficient to support lunar and Mars missions.	OP-4: Establish command and control processes, common interfaces, and ground systems that will support expanding human missions at the Moon and Mars.
SF23: Transport and maneuver uncrewed spacecraft for missions in cislunar and deep space.	23.1: Access atmospheric planetary bodies with resiliency to launch date using aerocapture.	Science Mission Directorate
	23.2: Provide low-cost science observations from orbits requiring continuous propulsive activity.	Science Mission Directorate
	23.3: Transfer storable propellant between science, communication, or other satellites in near-Earth space.	
	23.4: Develop novel power and propulsion technologies for rapid and efficient in-space transportation across the solar system.	
	23.5: Provide in-space diagnostics for electric propulsion.	Gateway Program
	23.6: Provide magnetically shielded, human-rated electric propulsion.	Gateway Program
	23.7: Transfer electric propulsion propellant between assets in space.	Gateway Program
SF24: Provide tracking and navigation of crew and assets in space.	24.1: Achieve absolute localization of crew, mobile, and other surface assets in the lunar surface environment. Reference ESDMD #0101 for specific details.	NASA Moon to Mars Architecture Definition Document Architecture-Driven Technology Gap Appendix
	24.2: Provide high-availability, Earth-independent tracking of position, navigation, and timing targeting continued coverage despite disruptions and/or blackout periods, for deep space surface missions. Reference ESDMD #0104 for specific details.	NASA Moon to Mars Architecture Definition Document Architecture-Driven Technology Gap Appendix
	24.3: Provide autonomous orbit determination, navigation, and pointing of operating spacecraft in deep space.	Science Mission Directorate
	24.4: Extend U.S. space situational awareness capabilities to cislunar space.	National Cislunar Science and Technology Action Plan, NSTC/OSTP
	24.5: Develop a lunar position, navigation, and timing architecture capable of scaling to long term operational needs.	National Cislunar Science and Technology Action Plan, NSTC/OSTP; NASA's Moon to Mars Strategy and Objectives Development Document, LI-3L: Develop a lunar position, navigation and timing architecture capable of scaling to support long term science, exploration, and industrial needs.
SF25: Provide on-board advanced computing capabilities for space operations.	25.1: Provide radiation-tolerant onboard computing operations to support autonomy, navigation, and other high-performance use cases in relevant environments. Reference ESDMD #0202 for specific details.	NASA Moon to Mars Architecture Definition Document Architecture-Driven Technology Gap Appendix
	25.2: Develop space-based computing technology needed for autonomous on-board operations.	Science Mission Directorate
	25.3: Distribute avionics systems and functions within spacecraft or surface systems.	
	25.4: Provide advanced computing needed for multi-spacecraft responsive space operations.	Science Mission Directorate
SF26: Collect and return preserved science samples and other products to Earth facilities.	26.1: Collect, manipulate, and verify samples and products from planetary bodies, while preserving sample integrity.	Add SE-3: Develop the capability to retrieve core samples of frozen volatiles from permanently shadowed regions on the Moon and volatile-bearing sites on Mars and to deliver them in pristine states to modern curation facilities on Earth.
	26.2: Identify and classify samples of scientific interest on planetary bodies.	SE-5: Use robotic techniques to survey sites, conduct in-situ measurements, and identify/stockpile samples in advance of and concurrent with astronaut arrival, to optimize astronaut time on the lunar and Martian surface and maximize science return.
	26.3: Store and process conditioned samples for return to Earth. Reference ESDMD #1201 (conditioned) for specific details.	NASA Moon to Mars Architecture Definition Document Architecture-Driven Technology Gap Appendix
	26.4: Store and process cryogenically cold samples for return to Earth. Reference ESDMD #1201 (cryo) for specific details.	NASA Moon to Mars Architecture Definition Document Architecture-Driven Technology Gap Appendix

	26.5: Return conditioned samples/products to Earth.	SE-4: Return representative samples from multiple locations across the surface of the Moon and Mars, with sample mass commensurate with mission-specific science priorities.
	26.6: Transport preserved samples from Earth lander to Earth laboratory, while preserving sample integrity.	SE-4: Return representative samples from multiple locations across the surface of the Moon and Mars, with sample mass commensurate with mission-specific science priorities.
SF27: Emplace and maintain large, stable space platforms and observatories.	27.1: Provide precise attitude control for ultra-stable observatories.	Science Mission Directorate
	27.2: Reduce spacecraft exposure to vibration to enable high precision pointing accuracy.	Science Mission Directorate
	27.3: Achieve required structural accuracy and stability for space structures of varying magnitudes and precision requirements.	
	27.4: Robotically upgrade large space observatory instruments and avionics.	Habitable Worlds Observatory
	27.5: Create and evolve systems beyond current launch size limitations.	Astrophysics Decadal on assembled telescopes. Page 384, 397
SF28: Autonomously monitor, inspect, maintain, and repair space assets.	28.1: Implement space-based manufacturing techniques for in-situ repairs and replacement of hardware components. Reference ESDMD #0502 for specific details.	NASA Moon to Mars Architecture Definition Document Architecture-Driven Technology Gap Appendix
	28.2: Provide robotic systems capable of inspection, maintenance, and repair operations that function autonomously and as part of a human-robot team. Reference ESDMD #0501 for specific details.	NASA Moon to Mars Architecture Definition Document Architecture-Driven Technology Gap Appendix
	28.3: Provide environmentally robust robotic, imaging, and sensing components with sufficient performance for challenging exploration missions. Reference ESDMD #1001 for specific details.	NASA Moon to Mars Architecture Definition Document Architecture-Driven Technology Gap Appendix
	28.4: Autonomously monitor systems and crew that support human exploration including during Mars-distance communication delays and blackouts. Reference ESDMD #1002 for specific details.	NASA Moon to Mars Architecture Definition Document Architecture-Driven Technology Gap Appendix
	28.5: Autonomously detect and diagnose off-nominal conditions and events; safe, reliable, autonomous control of systems; and automated control and safing sequences. Reference ESDMD #1003 for specific details.	NASA Moon to Mars Architecture Definition Document Architecture-Driven Technology Gap Appendix
	28.6: Provide software platforms that can analyze data and make decisions autonomously while providing explainable reasoning or inspection capabilities necessary to establish trust. Reference ESDMD #1004 for specific details.	NASA Moon to Mars Architecture Definition Document Architecture-Driven Technology Gap Appendix
SF29: Protect Earth from destructive impacts from naturally occurring objects near Earth.	29.1: Detect, track, and characterize Near Earth Objects.	NASA Planetary Defense Strategy and Action Plan; National Preparedness Strategy & Action Plan For Near-Earth Object Hazards and Planetary Defense
	29.2: Model, predict, and integrate data on Near Earth Objects.	NASA Planetary Defense Strategy and Action Plan; National Preparedness Strategy & Action Plan For Near-Earth Object Hazards and Planetary Defense
	29.3: Deflect and disrupt collision paths.	NASA Planetary Defense Strategy and Action Plan; National Preparedness Strategy & Action Plan For Near-Earth Object Hazards and Planetary Defense
SF30: Reduce likelihood and consequence of impacts with in-space objects.	30.1: Characterize small debris in LEO and cis-lunar space.	National Orbital Debris Implementation Plan
	30.2: Protect payloads in high micrometeoroid flux locations from micrometeoroid impacts.	National Orbital Debris Implementation Plan
	30.3: Detect, attribute, and characterize orbital debris strikes and effects upon spacecraft on orbit.	National Orbital Debris Implementation Plan
	30.4: Autonomously generate feasible close approach mitigation and maneuver instructions consistent with the physics-based and operational constraints of spacecraft and operators.	National Orbital Debris Implementation Plan
	30.5: Remediate large debris in space.	National Orbital Debris Implementation Plan
SF31: Provide space technology demonstration environments.	31.1: Provide surface-based platforms for technology demonstrations.	
	31.2: Provide environmental simulators, test facilities, and test sites for technology development in relevant environments.	
	31.3: Provide a platform for astronauts to develop skills and maintain proficiency operating in microgravity.	NASA's Low Earth Orbit Microgravity Strategy; National Space Policy (2020); National Cislunar Science and Technology Strategy (2022); DoD State of the Space Industrial Base (2023)
	31.4: Provide on-orbit platforms and interfaces for technology and operations demonstrations.	LEO Microgravity Strategy - Research and Technology Development for Exploration ET-1 through ET-6
	31.5: Access higher altitude and longer duration flights for suborbital and orbital vehicles and high-altitude balloons.	
	31.6: Provide accommodations and opportunities on launch vehicles or for re-entry and return capabilities.	

SF32: Develop an affordable and resilient supply chain for space exploration.	32.1: Manufacture low-cost, mass-efficient, large flight components.	
	32.2: Provide readily available, low size, weight, power, and cost (SWaP-C) high bandwidth deep-space-compatible communication systems.	
	32.3: Provide high-efficiency power conversion using alternative radioisotopes to maximize the effectiveness of existing plutonium sources.	Science Mission Directorate
	32.4: Ensure a sufficient number of domestic suppliers can provide space qualified systems within required lead times.	ISAM National Strategy; National ISAM Implementation Plan