National Aeronautics and
Space Administration

MOON TO MARS OBJECTIVES

SEPTEMBER 2022

Moon To Mars Objectives
September 2022

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FOREWORD

I am pleased to share NASA's Moon to Mars Objectives, and wish to acknowledge the individuals, companies, academic institutions, international space agencies, and our very own workforce, who contributed thousands of inputs to enhance them.

NASA Deputy Administrator Pam Melroy

This kind of collaboration is critical to our exploration success as an unparalleled development effort is ahead of us. Never has humanity endeavored to simultaneously architect multinational infrastructures in lunar orbit, on the lunar surface, and at Mars — all while maintaining high-demand government and private-sector operations in low-Earth orbit. What an incredible time to be a part of human spaceflight, and NASA.

Our first draft of the Moon to Mars Objectives were intentionally broad, and the overwhelming responses we received encouraged us to be even broader in some areas, yet more specific in others. We grew from 50 objectives to 63, spanning multidisciplinary science, transportation and habitation, lunar and Martian infrastructure, operations, and a new domain: recurring tenets.

These objectives provide the connective tissue between deep space human exploration destinations and the capabilities required to accomplish our goals at the Moon, Mars, and beyond. We will continue to revisit our objectives in the years ahead as our architecture matures, new knowledge and technological capabilities emerge, and more stakeholders come to the table.

I appreciate the positive energy from everyone who has engaged in this effort thus far, and NASA remains committed to transparency in our exploration plans. I look forward to future collaborations as we push human exploration farther into the solar system than ever before.

Pam Melroy
Deputy Administrator
NASA

BACKGROUND

The purpose of NASA's Moon to Mars Objectives effort is to develop and document an objectives-based approach to its human deep space exploration efforts. In contrast to a capabilities-based approach, an objectives-based approach focuses on the big picture, the "what" and "why" of what NASA should be doing in terms of deep space exploration before prescribing the "how" (e.g., a specific launch vehicle, technology, or acquisition approach).

Senior leaders and staff from each of NASA's mission directorates worked over the past several months to develop this final set of objectives, which incorporate inputs gathered from U.S. industry and academia, international partner space agencies, NASA Center leadership, and the NASA workforce via written input and two in-person workshops conducted in the summer of 2022. These workshops were held in Houston for U.S. industry and academia and in London for our international partners. This refined set of objectives also addresses gaps from NASA's internal analysis on its 50 initial objectives carried out in the spring.

The methodology for the Moon to Mars Objectives is guided by five inter-related principles:

OBJECTIVE-BASED APPROACH

- Know your goal up front (the "what") and create an integrated plan to achieve it.

ARCHITECT FROM THE RIGHT / EXECUTE FROM THE LEFT

- Work backwards from the defined goal to establish the complete set of elements that will be required for success.
- Execute development of all elements in regular fashion, integrating as you move right according to the established architecture.

CONSTANCY OF PURPOSE

- Stick with the Plan: once documented, the goal, top-level objectives, and overall plan should be clear and remain consistent over time.

UNITY OF PURPOSE

- Everyone (inside and outside the Agency) should understand and be able to articulate the vision, goals, and objectives.

ENHANCED COMMUNICATION & ENGAGEMENT

- The lifeblood that drives the reinforcing cycle of the other principles, and promotes political resilience.
- Raise public awareness and support for Moon to Mars activities through robust outreach and engagement efforts.
- Collaborate with international partners, industry, and academia to achieve common goals and objectives.
- Engage NASA workforce continuously to promote understanding of the plan, sustain awareness of respective roles, and solicit feedback.

While retaining our focus on mission success for the Artemis Campaign today, our Moon to Mars Objectives ensure we have a comprehensive framework in place that supports all of our exploration goals in the future. These objectives will guide the success of NASA's exploration strategy through the return of astronauts to the Moon, continued lunar science and exploration, and all the way to the first crewed landings on Mars, with the associated science and technology development required to achieve them along the way. Additionally, NASA will measure our progress toward achieving our Moon to Mars Objectives and periodically update them as the Artemis Campaign and future efforts evolve. In the end, this will ensure our basic approach remains the same regardless of where the frontier lies: creating an objectives-based blueprint for the sustained human exploration of deep space.

RECURRING TENETS
Common Themes Across Objectives

RT-1:	International Collaboration: partner with international community to achieve common goals and objectives.
RT-2:	Industry Collaboration: partner with U.S. industry to achieve common goals and objectives.
RT-3:	Crew Return: return crews safely to Earth while mitigating adverse impacts to crew health.
RT-4:	Crew Time: maximize crew time available for science and engineering activities within planned mission durations.
RT-5:	Maintainability and Reuse: when practical, design systems for maintainability, reuse, and/or recycling to support the long-term sustainability of operations and increase Earth independence.
RT-6:	Responsible Use: conduct all activities for the exploration and use of outer space for peaceful purposes consistent with international obligations, and principles for responsible behavior in space.
RT-7:	Interoperability: enable interoperability and commonality (technical, operations and process standards) among systems, elements, and crews throughout the campaign.
RT-8:	Leverage Low-Earth Orbit: leverage infrastructure in low-Earth orbit to support Moon to Mars activities.
RT-9:	Commerce and Space Development: foster the expansion of the economic sphere beyond Earth orbit to support U.S. industry and innovation.

SCIENCE OBJECTIVES
Lunar and Planetary Heliophysics

Lunar/Planetary Science (LPS) Goal: Address high priority planetary science questions that are best accomplished by on-site human explorers on and around the Moon and Mars, aided by surface and orbiting robotic systems.

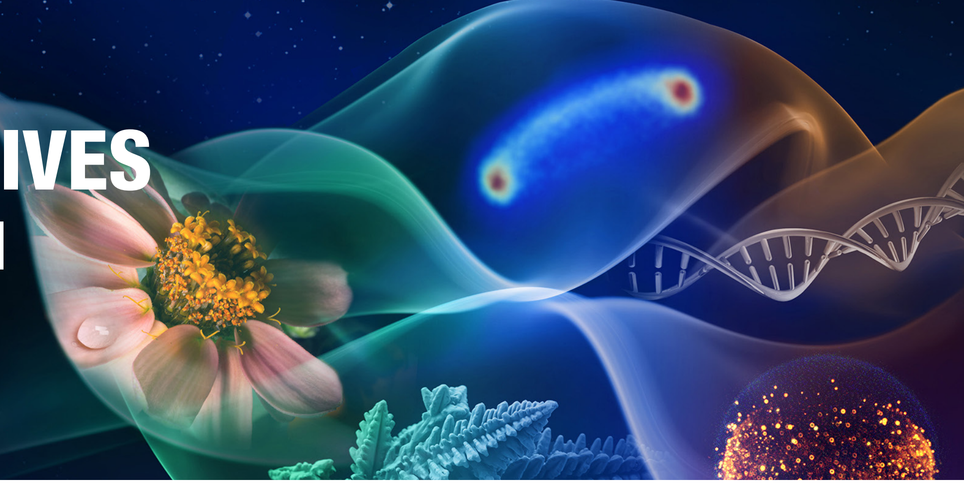
LPS-1^{LM}:	Uncover the record of solar system origin and early history, by determining how and when planetary bodies formed and differentiated, characterizing the impact chronology of the inner solar system as recorded on the Moon and Mars, and characterize how impact rates in the inner solar system have changed over time as recorded on the Moon and Mars.
LPS-2^{LM}:	Advance understanding of the geologic processes that affect planetary bodies by determining the interior structures, characterizing the magmatic histories, characterizing ancient, modern, and evolution of atmospheres/exospheres, and investigating how active processes modify the surfaces of the Moon and Mars.
LPS-3^{LM}:	Reveal inner solar system volatile origin and delivery processes by determining the age, origin, distribution, abundance, composition, transport, and sequestration of lunar and Martian volatiles.
LPS-^{4M}:	Advance understanding of the origin of life in the solar system by identifying where and when potentially habitable environments exist(ed), what processes led to their formation, how planetary environments and habitable conditions have co-evolved over time, and whether there is evidence of past or present life in the solar system beyond Earth.

Heliophysics Science (HS) Goal: Address high priority heliophysics science and space weather questions that are best accomplished using a combination of human explorers and robotic systems at the Moon, at Mars, and in deep space.

HS-1^{LM}:	Improve understanding of space weather phenomena to enable enhanced observation and prediction of the dynamic environment from space to the surface at the Moon and Mars.
HS-2^{LM}:	Determine the history of the Sun and solar system as recorded in the lunar and Martian regolith.
HS-3^{LM}:	Investigate and characterize fundamental plasma processes, including dust-plasma interactions, using the cislunar, near-Mars, and surface environments as laboratories.
HS-4^{LM}:	Improve understanding of magnetotail and pristine solar wind dynamics in the vicinity of the Moon and around Mars.

Superscript text indicates the applicability to Lunar (L), Martian (M) or both (LM).

SCIENCE OBJECTIVES
Human and Biological Physics and Physical



Human and Biological Science (HBS) Goal: Advance understanding of how biology responds to the environments of the Moon, Mars, and deep space to advance fundamental knowledge, support safe, productive human space missions and reduce risks for future exploration.

HBS-1^{LM}:	Understand the effects of short- and long-duration exposure to the environments of the Moon, Mars, and deep space on biological systems and health, using humans, model organisms, systems of human physiology, and plants.
HBS-2^{LM}:	Evaluate and validate progressively Earth-independent crew health & performance systems and operations with mission durations representative of Mars-class missions.
HBS-3^{LM}:	Characterize and evaluate how the interaction of exploration systems and the deep space environment affect human health, performance, and space human factors to inform future exploration-class missions

Physics and Physical Science (PPS) Goal: Address high priority physics and physical science questions that are best accomplished by using unique attributes of the lunar environment.

PPS-1^{L}:	Conduct astrophysics and fundamental physics investigations of space and time from the radio quiet environment of the lunar far side.
PPS-2^{LM}:	Advance understanding of physical systems and fundamental physics by utilizing the unique environments of the Moon, Mars, and deep space.

SCIENCE OBJECTIVES
Science-Enabling
Applied

Science-Enabling (SE) Goal: Develop integrated human and robotic methods and advanced techniques that enable high-priority scientific questions to be addressed around and on the Moon and Mars.

SE-1^{LM}:	Provide in-depth, mission-specific science training for astronauts to enable crew to perform high-priority or transformational science on the surface of the Moon, and Mars, and in deep space.
SE-2^{LM}:	Enable Earth-based scientists to remotely support astronaut surface and deep space activities using advanced techniques and tools.
SE-3^{LM}:	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.
SE-4^{LM}:	Return representative samples from multiple locations across the surface of the Moon and Mars, with sample mass commensurate with mission-specific science priorities.
SE-5^{LM}:	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.
SE-6^{LM}:	Enable long-term, planet-wide research by delivering science instruments to multiple science-relevant orbits and surface locations at the Moon and Mars.
SE-7^{LM}:	Preserve and protect representative features of special interest, including lunar permanently shadowed regions and the radio quiet far side as well as Martian recurring slope lineae, to enable future high-priority science investigations.

Applied Science (AS) Goal: Conduct science on the Moon, in cislunar space, and around and on Mars using integrated human and robotic methods and advanced techniques, to inform design and development of exploration systems and enable safe operations.

AS-1^{LM}:	Characterize and monitor the contemporary environments of the lunar and Martian surfaces and orbits, including investigations of micrometeorite flux, atmospheric weather, space weather, space weathering, and dust, to plan, support, and monitor safety of crewed operations in these locations.
AS-2^{LM}:	Coordinate on-going and future science measurements from orbital and surface platforms to optimize human-led science campaigns on the Moon and Mars.
AS-3^{LM}:	Characterize accessible lunar and Martian resources, gather scientific research data, and analyze potential reserves to satisfy science and technology objectives and enable In-Situ Resource Utilization (ISRU) on successive missions.
AS-4^{LM}:	Conduct applied scientific investigations essential for the development of bioregenerative-based, ecological life support systems
AS-5^{LM}:	Define crop plant species, including methods for their productive growth, capable of providing sustainable and nutritious food sources for lunar, Deep Space transit, and Mars habitation.
AS-6^{LM}:	Advance understanding of how physical systems and fundamental physical phenomena are affected by partial gravity, microgravity, and general environment of the Moon, Mars, and deep space transit.

INFRASTRUCTURE OBJECTIVES
Lunar
Mars

Lunar Infrastructure (LI) Goal: Create an interoperable global lunar utilization infrastructure where U.S. industry and international partners can maintain continuous robotic and human presence on the lunar surface for a robust lunar economy without NASA as the sole user, while accomplishing science objectives and testing for Mars.

LI-1^{L}:	Develop an incremental lunar power generation and distribution system that is evolvable to support continuous robotic/human operation and is capable of scaling to global power utilization and industrial power levels.
LI-2^{L}:	Develop a lunar surface, orbital, and Moon-to-Earth communications architecture capable of scaling to support long term science, exploration, and industrial needs.
LI-3^{L}:	Develop a lunar position, navigation and timing architecture capable of scaling to support long term science, exploration, and industrial needs.
LI-4^{L}:	Demonstrate advanced manufacturing and autonomous construction capabilities in support of continuous human lunar presence and a robust lunar economy.
LI-5^{L}:	Demonstrate precision landing capabilities in support of continuous human lunar presence and a robust lunar economy.
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.
LI-7^{L}:	Demonstrate industrial scale ISRU capabilities in support of continuous human lunar presence and a robust lunar economy.
LI-8^{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.
LI-9^{L}:	Develop environmental monitoring, situational awareness, and early warning capabilities to support a resilient, continuous human/robotic lunar presence.

Mars Infrastructure (MI) Goal: Create essential infrastructure to support initial human Mars exploration campaign.

MI-1^{M}:	Develop Mars surface power sufficient for an initial human Mars exploration campaign.
MI-2^{M}:	Develop Mars surface, orbital, and Mars-to-Earth communications to support an initial human Mars exploration campaign.
MI-3^{M}:	Develop Mars position, navigation and timing capabilities to support an initial human Mars exploration campaign.
MI-4^{M}:	Demonstrate Mars ISRU capabilities to support an initial human Mars exploration campaign.

TRANSPORTATION & HABITATION

Transportation and Habitation Goal: Develop and demonstrate an integrated system of systems to conduct a campaign of human exploration missions to the Moon and Mars, while living and working on the lunar and Martian surface, with safe return to Earth.

TH-1^{L}:	Develop cislunar systems that crew can routinely operate to and from lunar orbit and the lunar surface for extended durations.
TH-2^{L}:	Develop system(s) that can routinely deliver a range of elements to the lunar surface.
TH-3^{L}:	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.
TH-4^{LM}:	Develop in-space and surface habitation system(s) for crew to live in deep space for extended durations, enabling future missions to Mars.
TH-5^{M}:	Develop transportation systems that crew can routinely operate between the Earth-Moon vicinity and Mars vicinity, including the Martian surface.
TH-6^{M}:	Develop transportation systems that can deliver a range of elements to the Martian surface.
TH-7^{M}:	Develop systems for crew to explore, operate, and live on the Martian surface to address key questions with respect to science and resources.
TH-8^{LM}:	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.
TH-9^{L}:	Develop integrated human and robotic systems with inter-relationships that enable maximum science and exploration during lunar missions.
TH-10^{M}:	Develop integrated human and robotic systems with inter-relationships that enable maximum science and exploration during Martian missions.
TH-11^{L}:	Develop systems capable of returning a range of cargo mass from the lunar surface to Earth, including the capabilities necessary to meet scientific and utilization objectives.
TH-12^{M}:	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.

OPERATIONS

Operations Goal: Conduct human missions on the surface and around the Moon followed by missions to Mars. Using a gradual build-up approach, these missions will demonstrate technologies and operations to live and work on a planetary surface other than Earth, with a safe return to Earth at the completion of the missions.

OP-1[L]:	Conduct human research and technology demonstrations on the surface of Earth, low-Earth orbit platforms, cislunar platforms, and on the surface of the moon, to evaluate the effects of extended mission durations on the performance of crew and systems, reduce risk, and shorten the timeframe for system testing and readiness prior to the initial human Mars exploration campaign.
OP-2[LM]:	Optimize operations, training and interaction between the team on Earth, crew members on orbit, and a Martian surface team considering communication delays, autonomy level, and time required for an early return to the Earth.
OP-3L[M]:	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.
OP-4[LM]:	Establish command and control processes, common interfaces, and ground systems that will support expanding human missions at the Moon and Mars.
OP-5[LM]:	Operate surface mobility systems, e.g., extra-vehicular activity (EVA) suits, tools and vehicles.
OP-6[L]:	Evaluate, understand, and mitigate the impacts on crew health and performance of a long deep space orbital mission, followed by partial gravity surface operations on the Moon.
OP-7[LM]:	Validate readiness of systems and operations to support crew health and performance for the initial human Mars exploration campaign.
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.
OP-9[LM]:	Demonstrate the capability of integrated robotic systems to support and maximize the useful work performed by crewmembers on the surface, and in orbit.
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.
OP-11[LM]:	Demonstrate the capability to use commodities produced from planetary surface or in-space resources to reduce the mass required to be transported from Earth.
OP-12[LM]:	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.

Glossary of Terms

ARCHITECTURE:
A set of functional capabilities, their translation into elements, their interrelations and operations. The architecture enables the implementation of various mission scenarios that achieve a set of given goals and objectives.

CAMPAIGN:
A series of interrelated missions that together achieve agency goals and objectives.

CONTINUOUS PRESENCE:
Steady cadence of human/robotic missions in subject orbit/surface with the desired endpoint of 365/24/7 operations.

DEMONSTRATE:
Deploy an initial capability to enable system maturation and future industry growth in alignment with architecture objectives.

DEVELOP:
Design, build, and deploy a system, ready to be operated by the user, to fully meet architectural objectives.

EXPLORE:
Excursion-based expeditions focused on science and technology tasks.

GLOBAL:
Infrastructure and capabilities that support human and robotic operations and utilization across the subject planetary surface.

INCREMENTAL:
Building compounding operational capabilities within the constraints of schedule, cost, risk, and access.

LIVE:
The ability to conduct activities beyond tasks on a schedule. Engage in hobbies, maintain contact with friends and family, and maintain healthy work-life balance.

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.

MOBILITY:
Powered surface travel that extends the exploration range beyond what is possible for astronauts to cover on foot. Spans robotic and crewed systems, and can be accomplished on and above the surface.

ROUTINE:
Recurring subject operations performed as part of a regular procedure rather than for a unique reason.

SCALABILITY:
Initial systems designed such that minimal recurring DDT&E is needed to increase the scale of a design to meet end state requirements.

UTILIZATION:
Use of the platform, campaign and/or mission to conduct science, research, test and evaluation, public outreach, education, and industrialization.

VALIDATE:
Confirming that a system satisfies its intended use in the intended environment (Did we build the right system?).

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