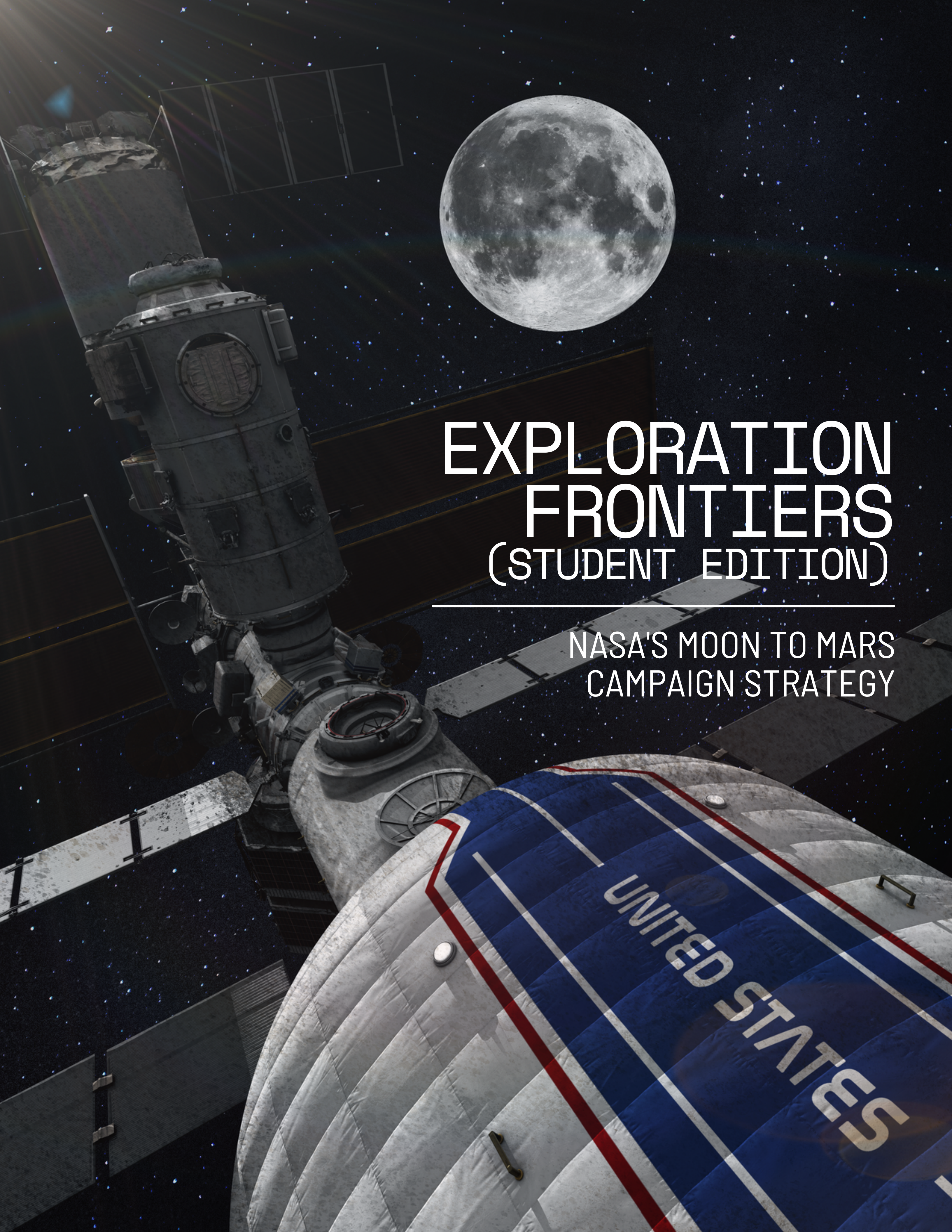


EXPLORATION FRONTIERS
(STUDENT EDITION)

NASA'S MOON TO MARS
CAMPAIGN STRATEGY

CONTENTS

Written in collaboration with NASA's
Exploration Systems Development Mission Directorate (ESDMD)
Moon to Mars Architecture Development Office

By the National Institute of Aerospace

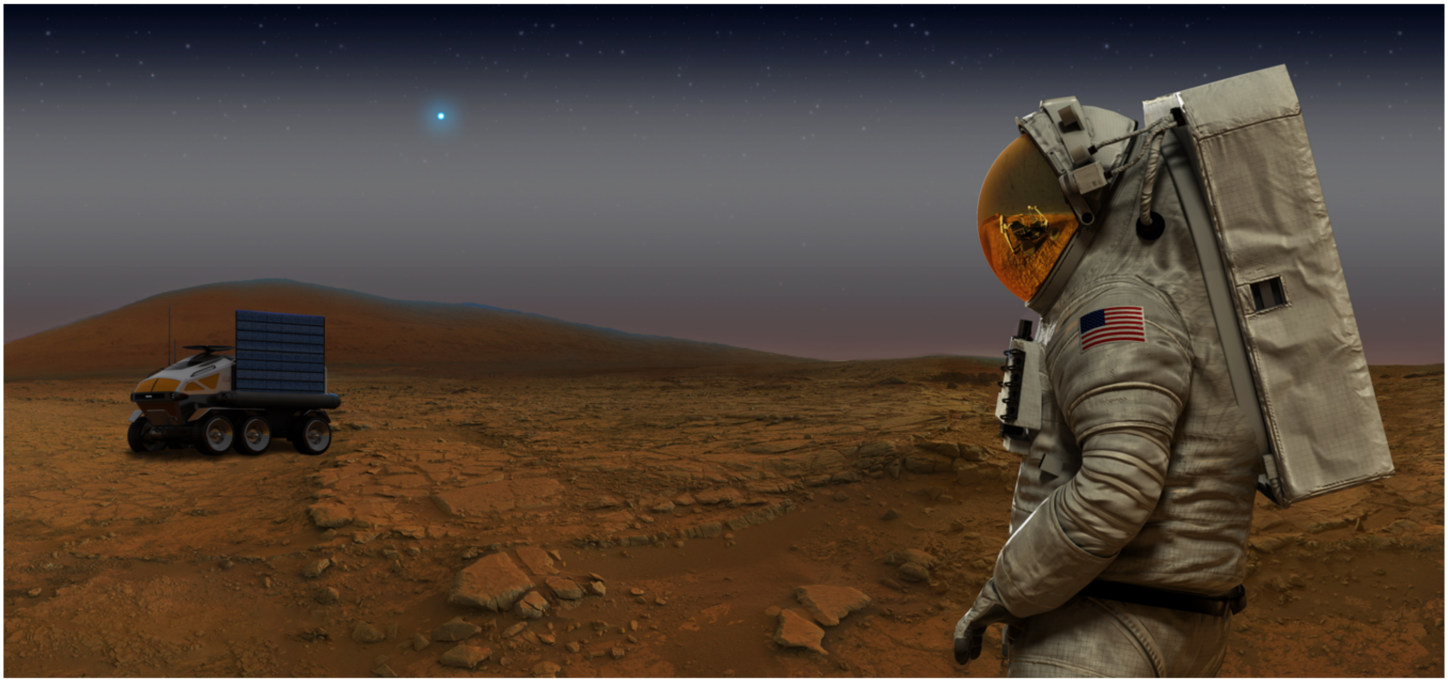
RASC-AL Revolutionary Aerospace Systems Concepts Academic Linkage

National Institute of Aerospace

Statement of Purpose:

The purpose of this guide is to share NASA's Moon-to-Mars strategy in a way that is user-friendly to readers from varying backgrounds. The target audience is university students, with the intention of explaining the campaign strategy, its rationale and its highest-level systems & elements approach. It is meant to facilitate university engagement in NASA design competitions or supporting NASA research to enable them to understand how best to focus and infuse their ideas into the overall strategy. By design, the guide is ***dateless***, ***high-level*** *and* ***uses metaphors*** *to establish a* ***timeless, versatile strategy overview that's engaging, exciting and inspirational.***

Glimpse of the FUTURE



Above the surface of this Red Planet, just above the horizon, is the morning star – Earth, hovering just over the rocky outcropping a few hundred meters away. It will soon disappear below the horizon, so I nod to it as we take in the landscape.

The home planet is inspiration: This red world is a snapshot in time of what a planet that may have once held life looks like in the future. My fellow astronaut and I are searching for signs of life on this 30-day visit – we don't want to disrupt anything that may be here. The quest is one for science as well as paving the way for the future. The hope is that our findings here will inform the development of a human outpost here on the Red Planet. First for science and discovery – so many questions! – then to develop the infrastructure, and then to live and work.

Sometimes I imagine our team as early mountain climbers. After extensive training, preparation and reconnaissance, here we are, setting foot on Mars as the first humans to ever put boot prints in this ironclad soil. It's amazing, really.

Slightly more than 100 years ago, Earth's mountaintops were unknown to us. We knew not how to get there, nor how to support life in a world that could literally take one's breath away. We didn't know what equipment or infrastructure would be needed to conquer the living, moving, peaks.

Now, we're on Mars. We've been months in transit, so life is pretty regular by now, but we still pinch ourselves to remember we are the first humans to travel this far from Earth. Can't think about that too much, though, or the work at hand would be mired by both marvel and painstakingly careful consideration for our safety – It's something indescribable to be in these boots.

We roam in a pressurized habitat on wheels. Earth's engineers created something new here, and it wasn't just NASA. Many industries and nations contributed to this modern marvel, benefiting transportation and renewable energy on Earth. The technology for this rover and the transit habitat that brought us here came from the last decade of missions to the Moon, its orbit and some pre-cursor robotic missions to Mars.

The rover is a living pod capable of supporting us for 30 days, including power, food, and science instruments. NASA put our deep space transit, ground transport and protective gear through the ringer to mitigate risks on this journey. They had to. We lived next to tanks full of explosive propellants, and endured exposure to deep space radiation.

At the end of this mission, we head toward our MAV (Mars Ascent Vehicle) to rejoin our crewmates in Mars orbit. They have been watching over us and preparing for the return home. It will be another long journey through space, through darkness but for the sparkle of stars in the sky, illuminating dust as we travel.

Our findings will return to Earth with us, where engineers and scientists from NASA, our partner international space agencies, commercial partners and academics will look to answer their questions. But, if it's one thing we've learned along the way: Each answer begets more questions.

Driven by DISCOVERY

"In more than one respect, the exploring of the Solar System and homesteading other worlds constitutes the beginning, much more than the end, of history" – Carl Sagan

Imagine the solar system as the majestic Himalayan mountain range, a stark border of ice, rock and snow between Nepal and Tibet. This "abode of snow" is living, moving, and quaking, presenting known and unknown challenges and obstacles. There are heights unimaginable, presenting atmospheric realities threatening to human life. At the time of the first ascent, the life of the mountain and its vast terrain were unknown. The high peaks are ice-capped monoliths that capture the wonder of the ambitious, the explorers, those who will push to the limits to stand at the top of the world.

Like climbers aspiring to summit Earth's highest peaks, in space exploration, the sights are set on Mars. Consider Mt. Everest. A successful ascent requires careful planning, and the ability for new information to allow unbridled decision-making as it relates to benefit, cost and risk. Planning considerations might include:

✓ Route Mapping

What route best leverages propulsion methods? Do we take a longer (but potentially safer) route? Where should we stop, rest, acclimate, and assess? When should we go?

✓ Environment

What will happen with the weather? What if the forecast changes? What threats does the landscape pose and how will we navigate or mitigate those threats?

✓ Habitation

Where will we sleep? What will we eat? What happens if any of this goes wrong?

✓ Mobility

How will we go? Using what technology? For how long and what are the needs once we arrive?

✓ Energy

It will take a lot of energy to get there. How do we train and prepare? What can we do to reduce energy needs? How can we get energy along the way? What must we bring?

✓ Technology

The best of the best is necessary to achieve the highest heights of the world: apparel, food, protective equipment, life support, tools, oxygen, etc. How will we engineer these?

OVERVIEW OF NASA'S MOON TO MARS (M2M) CAMPAIGN STRATEGY AND ITS OVERARCHING PHILOSOPHIES

Discovery made during each stage of the journey will inform decisions for the next stage.

In many ways, the Moon for NASA has become much like the Himalayan foothills for mountain climbers. The lower landscape, closest to civilization, is a training ground for the outer reaches and a staging area for logistics. The heights beyond are like Mars: Unknown and intimidating, with lengthy and risky expeditions required to set foot at the summit. The route to Base Camp may be direct or it may be circuitous. And once at Base Camp, the routes to the summit may zig and zag to achieve an ascent in the safest, most efficient way possible, while considering capabilities, necessities, ever-changing conditions, and unknowns.

NASA's M2M campaign strategy has several strategic and overarching philosophies:

- It is a multi-destination campaign (cislunar space, the Moon, and Mars)
- It employs a minimum investment approach, leveraging common investments for use in multiple destinations
- It includes public-private partnerships, investments, commercial innovation infusions, international participation and an open-source workflow that enables broad, rapid advancements to achieve an aggressive timeline
- It is guided by the process of past and future discovery

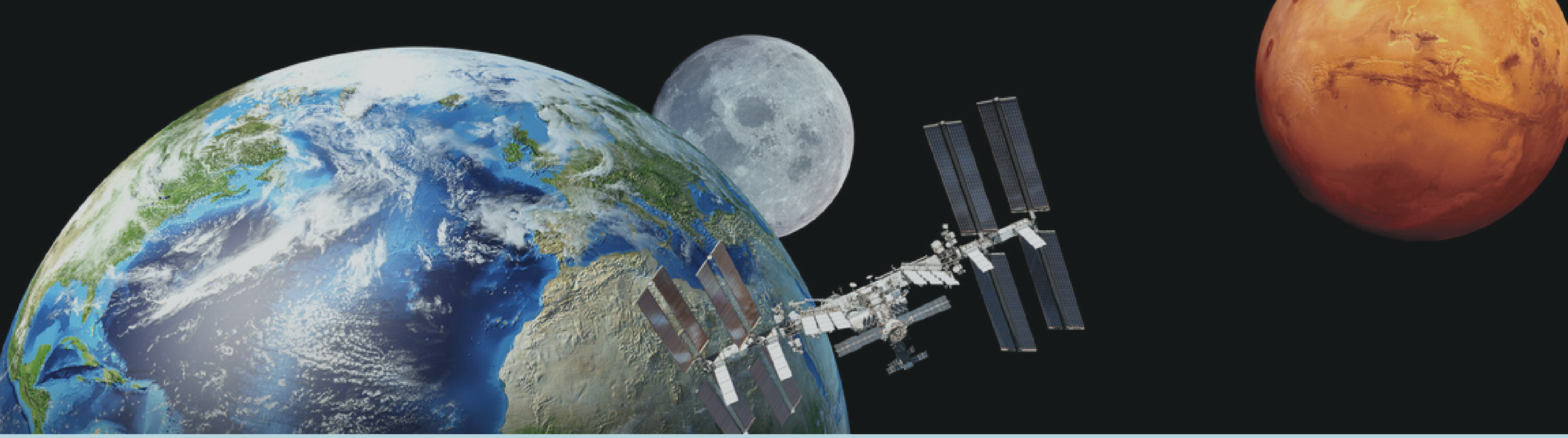
The Mars destination strategy seeks to map a route through the solar system, building a body of knowledge that facilitates not only a successful first mission, but enables a future vision of ongoing transit to established outposts. Like the early Himalayan explorers, NASA will incrementally explore further reaches – low-Earth orbit (LEO, where the International Space Station operates), the space inside the Moon's orbit and the orbital area around the Moon (cislunar space), the surface of the Moon, and a series of deep space "sea trials" on the way to Mars – in an effort to learn, design, and establish the route, technology, and preparations necessary to reach the primary destination: Mars. Along the way, technology advancements will be made to establish a market of space travel goods and life-support technology that's easily mixed, matched, and adaptable to excursions to a variety of interplanetary destinations.

Mission success is inextricably intertwined with commercial industry and international space agency partner efforts.

Much like Earth's mountaineering industry, today's space exploration strategy does not belong to one entity. From space launch systems and surface vehicles propulsion technology to materials engineering for the gamut of space transportation, habitability, personal protection, and more, industry advancements are critical to a successful strategy.

Uniquely, the Mars destination strategy envisions an interplanetary transit system, with each outpost acting as a potential hub for future operations, like camps leading to the summit. At any point, exploration adaptations may be made, informed by the learning and discovery of each mission segment that comes before.

Activities on the International Space Station are foundational to next-step work in cislunar space, and subsequently, putting humans back on the Moon. NASA has named this human-robotic return to the Moon, "Artemis," after the goddess of the Moon and twin sister of Apollo in Greek mythology. Through Artemis, longer duration mission elements will be developed, tested, and validated in support of lunar exploration with lower risk as compared to going directly to Mars. Activities and systems required to enable long-term cislunar presence and human Mars exploration have similarities that allow for shared development activities. The Gateway (the orbital hub for cislunar exploration), surface mobility, the transit habitat and portions of the human lunar access system are common applications for both long-term cislunar presence and human Mars exploration. In the press to achieve the first human steps on Martian soil, leveraging partnerships (international, commercial, and academic) is paramount to develop surface and transportation capabilities in an efficient, sustainable manner to enable both long-term presence on the Moon and sending humans to Mars.



The driving force for the first human mission to Mars is to answer key questions that inform our future Mars exploration strategy and goals.

The questions are everything!

When humans go to Mars, we will be crossing into a new horizon that helps to understand life – life that exists, or may have existed on that planet. What happened to Mars, its oceans, streams, and atmosphere? It may inform whether life is to come on that planet. Going to Mars will help to understand planetary processes and lay a foundation that goes all the way back to the Moon, thereby furthering humanity as an exploration society.

> **At our core, humans are explorers. Our drive to explore is fueled by curiosity that compels us to seek and understand the unknown. Inevitably, that newfound knowledge raises new questions, new possibilities, new horizons to explore, and the cycle of exploration begins again.**
> **– Voyages: Charting the Course for Sustainable Human Exploration (NASA)**

In today's M2M strategy, the destination and methodology are known. But at each stage of the journey, there will be questions to answer, which will generate more questions. The strategic goal is to answer these questions in an effort to put humans on Mars. Mission objectives are informed from what came before, establishing the ground rules and assumptions in place to formulate mission planning. Answers from travel to the space station and LEO are informing missions to cislunar space and the lunar surface. Answers to questions about how to access and operate in deep space will be the foundation for exploring Mars. And along the way, findings may equip NASA to establish feasible human missions to farther reaches of space.

At each stage, NASA will study exploring and living at new destinations. Each stage will equip future space travel and exploration for better efficiency and better success. Each stage will help better understand life and planetary processes. Learnings will circle back home from Mars to the Moon to Earth, where, as history has shown, space exploration leads civilization-changing science and technology, dramatically affecting humanity's life on the home planet.

When humans land on Mars for the first 30-day mission, they will answer key questions that inform future Mars exploration strategy and science goals. If signs of life are found or not, what does that mean? Will the selected landing site be the same landing site for future missions? Perhaps. Will it be the best place to set up an outpost? Perhaps. Will it generate countless new questions? Absolutely. Will human travel on those missions help to understand how best to equip astronauts for these voyages? Absolutely. As with the first reconnaissance mission on Mt. Everest and subsequent expeditions, analog and actual missions that reach closer to the summit will enable better expedition planning and design.

Achievements in space travel will additionally establish American leadership and strategic presence in the solar system, all while driving innovation, ingenuity and achievement and thereby expanding the U.S. global economic impact. In the late 1950s and 1960s, an American spirit of competition ignited. The initial race to the Moon set the stage for the vibrant, commercial space economy of today.

Challenges and
CONSIDERATIONS

"The man who moves mountains begins by carrying away small stones." - Confucius

Getting to Mars is hard. It's a 2-billion-kilometer round trip. The atmosphere of Mars is about 100 times thinner than Earth's and it's 95 percent carbon dioxide. In other words, Mars has 1% of the sea-level atmosphere of Earth; by comparison, the deadly summit of Mt. Everest is 33% of sea level (which equates to 66% less oxygen). The average surface temperature is comparable to inland Antarctica, and temperature swings are very significant, sometimes in excess of 150 degrees. Water may exist in the form of ice, but it requires extensive technology to access and utilize, as once it hits the surface, it may vaporize. Routes to Mars are also challenging. Being so far away, and in a part of space not yet widely explored, much information is required to inform the route.

Substantial technical and programmatic challenges present obstacles to achieving the strategy. However, the campaign is specifically designed to overcome those obstacles.

Design and Integration

The campaign is complex. Hardware, design coordination, and mission planning to support it are by nature exponentially more complex. Element integration is expensive and requires attention to detail over a long timeframe, with a very small margin of error. Additionally, as missions become increasingly autonomous for crew, extensive training is required to equip crew to achieve mission success.

Transition to Partners

NASA's strategy enables commercial and international partners to share in exploration opportunities (as well as lending financial resources and sharing in the risk). This requires working closely together to implement common applications and standardization of elements. Resource sharing and transitioning lessons learned between partners will be crucial to program success.

National Interests

Space-based capabilities are important for military and other government sectors. Technology advances enhance capabilities of the U.S., but also create new vulnerabilities as we rely more on space assets.

International Cooperation

A lasting and effective exploration campaign requires the energy, expertise, innovation & investment from across the world. Navigating, coordinating, and establishing cooperation among each country's goals and priorities will be critical.

Public Engagement

The strategy spans many years, over different political administrations, and will require a multi-decade awareness and engagement effort to maintain public support of the nation's space exploration program.

Technical Risk

NASA seeks to mitigate operational risk through campaign learning and pushing technology to a readiness level that can support strategic goals and objectives. Continual trades of technology, funding, crew time, cost, readiness, etc. will determine the best timeframe and value for getting crew safely to Mars and back.

Sustainability

A stepping-stone strategy positions the campaign for future success while producing immediate science benefits. The multi-destination design is cost-conscious. A broad strategy focusing on national interest spans political leadership changes. Technologies are sustainable in terms of design, versatility, and reliability, and are vetted to ensure acceptable risk.

Launch Needs

Achieving the strategy requires many launches. Leveraging a broad set of launch capabilities across national, commercial, and international assets will ensure cost effectiveness and robustness.

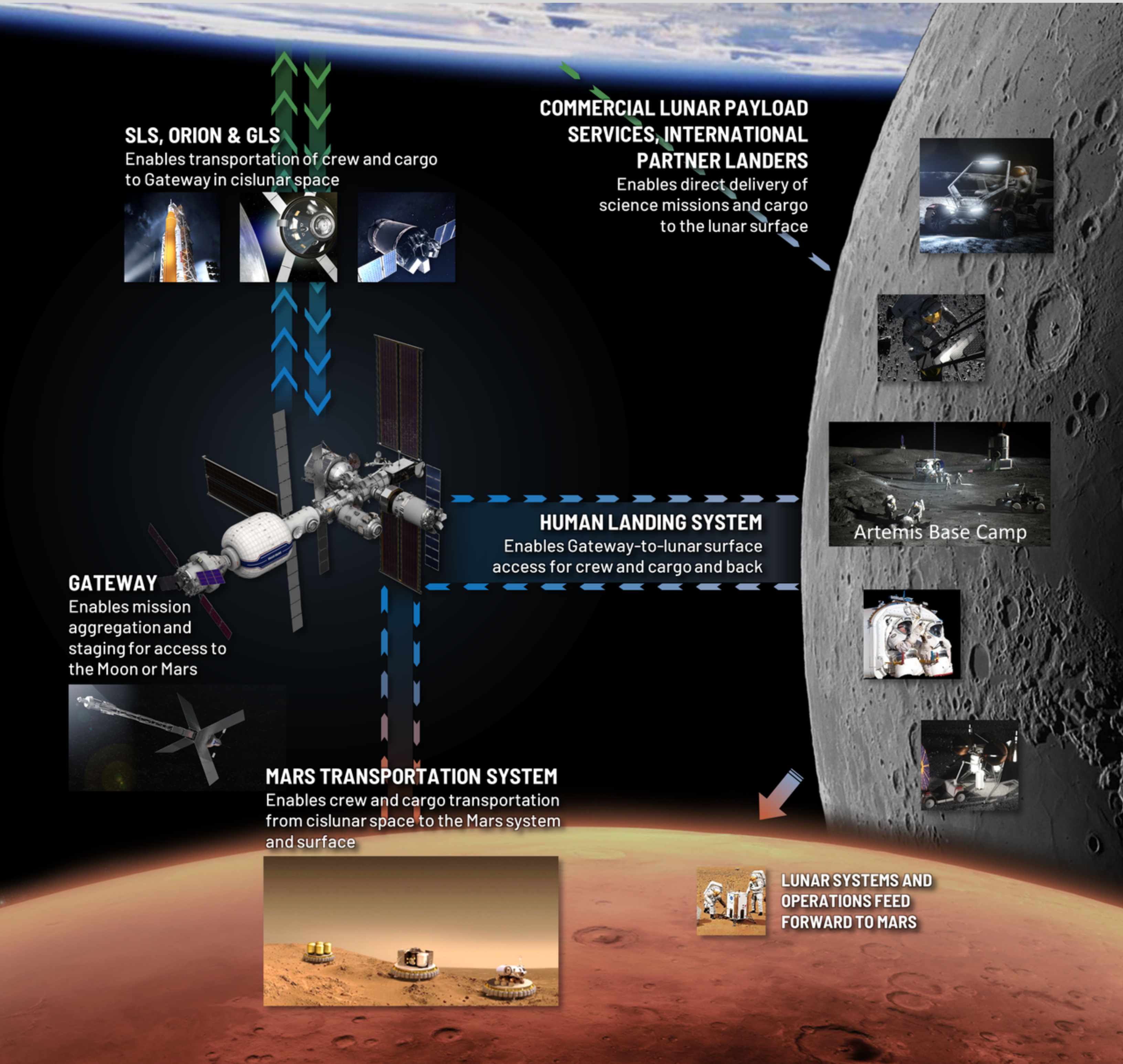
Driving Economy

As NASA paves the way, its technology leadership and initial government funding will enable a future space economy. These early investments lay the foundation for an economically viable private-sector space enterprise.

Mapping the COURSE

NASA path to Mars leverages the Moon as much as possible. As the architecture unfolds, each piece of the path provides intel that will inform the next mission. The path is like a trail map; a main trail leading to a junction with spurs leading to different destinations.

The main trail from Earth goes to cislunar space via Orion and the Space Launch System (SLS). The trail expands with Gateway Logistics Services (GLS) cargo resupply. Commercial Lunar Payload Services (CLPS) represents an alternate trail, delivering science and technology payloads directly to the lunar surface. Gateway becomes a junction to access the Moon's surface via the Human Landing System (HLS) spur and to outfit the Mars Transportation System. At Gateway, astronauts are days from Earth, but from an energy perspective, they are halfway to the Moon and halfway to Mars. The Artemis Base Camp (ABC) is a junction for expanded lunar surface exploration and a model for a future base camp on Mars.

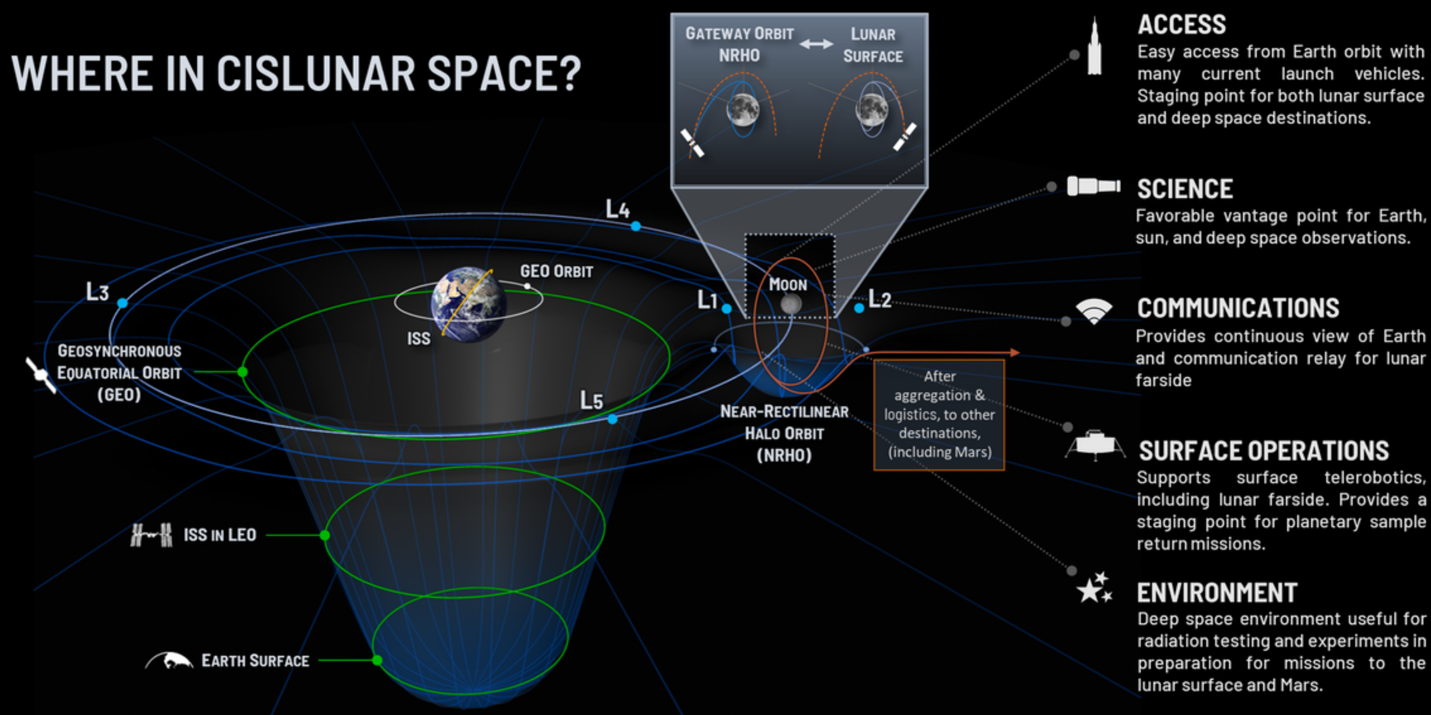


CISLUNAR SPACE - AN INTEGRAL PART OF THE STRATEGY

Why cislunar space?

Exploring cislunar space will extend human presence beyond space station operations in Low Earth Orbit (LEO) and prepare for more complex missions beyond Earth's gravitational influence. Being only days away from Earth (yet farther than Apollo went), crewed missions in cislunar space can grow knowledge of living in space for long periods of time, with relatively low risk.

As an orbiting outpost, the Gateway will serve as a base to establish a route for astronauts to the lunar surface (and later, to prepare for the trip to Mars). The Gateway will be a place for astronauts to prepare for surface missions and to receive materials. Achievements here will be informational and form a physical infrastructure foundation for future missions.



Cislunar space is an interesting place from an orbital mechanics perspective. The Earth-Moon system is somewhat a binary planet system, with two distinct gravity wells while also having gravitation balance areas (Lagrange points) that spacecraft can orbit about. The Lagrange points (L_1-L_5 in image) are on the edge of the gravity wells and moving between them takes very little energy. The Near-Rectilinear Halo Orbit – NRHO – is an orbit in the L_2 family of orbits that can be used for the Gateway as a stable and energy-efficient position for staging transportation systems, including refurbishing, refueling and reusing craft. The NRHO additionally supports missions to the lunar surface and destinations farther into the solar system (including Mars), swinging to 1,500 km at its closest to the lunar surface and 70,000 km at its farthest.

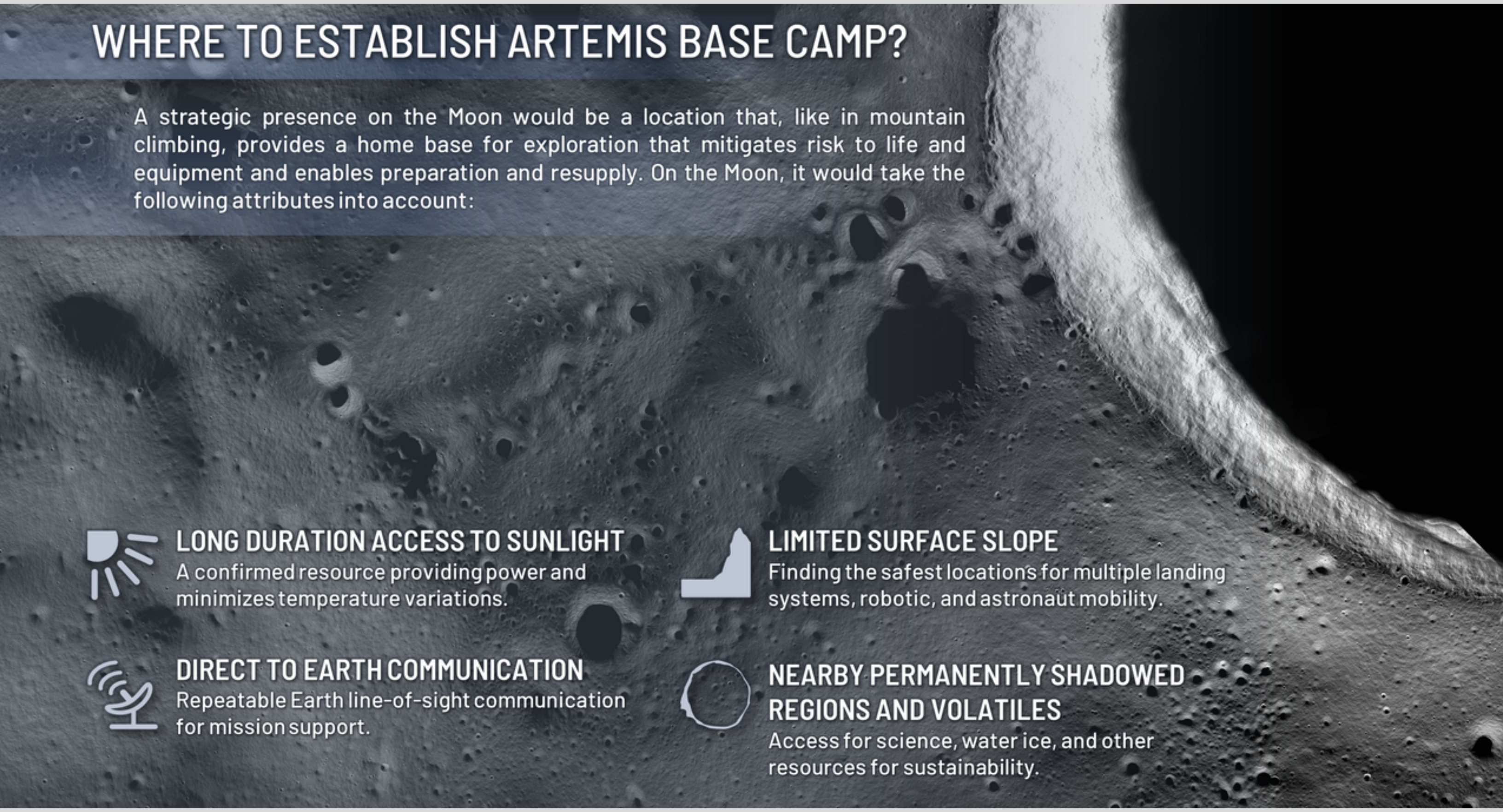
By stationing the Gateway in a stable, energy-efficient cislunar orbit (NRHO, see image above), it puts this interplanetary outpost at a strategic location for access from Earth, as well as to other locations such as the lunar surface and Mars, from an energy perspective. Additionally, the environment mirrors a true deep-space radiation environment, similar to what astronauts in a Mars transit vehicle will endure. Location considerations also include lack of orbital debris, minimal station-keeping, stable orbits, minimal orbital phasing and transfer energy requirements, infrequent and/or avoidable eclipse periods, and a thermal environment compatible with propulsion systems.

When launched on the SLS, the Orion has sufficient capability on its service module to insert into the NRHO and then once the mission is done perform the trans-Earth Injection and course-correction maneuvers, with some margin. Essentially, Orion serves as the crew taxi from the surface of the Earth to the edge of cislunar space, where the crew transfers either to systems that take them to the Moon or to Mars and back.

THE MOON

Why the Moon?

Simply put - lunar missions prepare for Mars while also advancing science and economic opportunities in deep space. Like in mountain climbing, training on lower peaks is preparation before ascending to the summit. On the Moon, it's possible to take reasonable risks while astronauts are just three days away from home. In this training ground, technologies will be tested and proven, systems matured, and risk reduced enable living and working on another world. Going to Mars is a two-to-three-year mission, compared to much shorter lunar missions, so technologies tested on the Moon will be the foundation for the mission to Mars. Returning to the Moon will also open new opportunities for the commercial space industry and provide substantial capabilities for performing lunar science. Through a lunar outpost, astronauts will demonstrate the technology needed to extract resources like water and oxygen, and use these components to sustain life and create fuel.



VARIOUS ROUTES TO MARS

What is the best way to get to Mars?

The route to get to Mars is currently via Gateway in cislunar space, where the propulsion and habitation systems are aggregated and outfitted. The Mars vehicle then uses minimum energy transfer over several months to meet with the crew in a high Earth orbit. From there, they will transfer to the desired Mars trajectory at the proper time in the mission window of opportunity. There are currently two ways to get from cislunar to Mars: via opposition class and conjunction class missions.

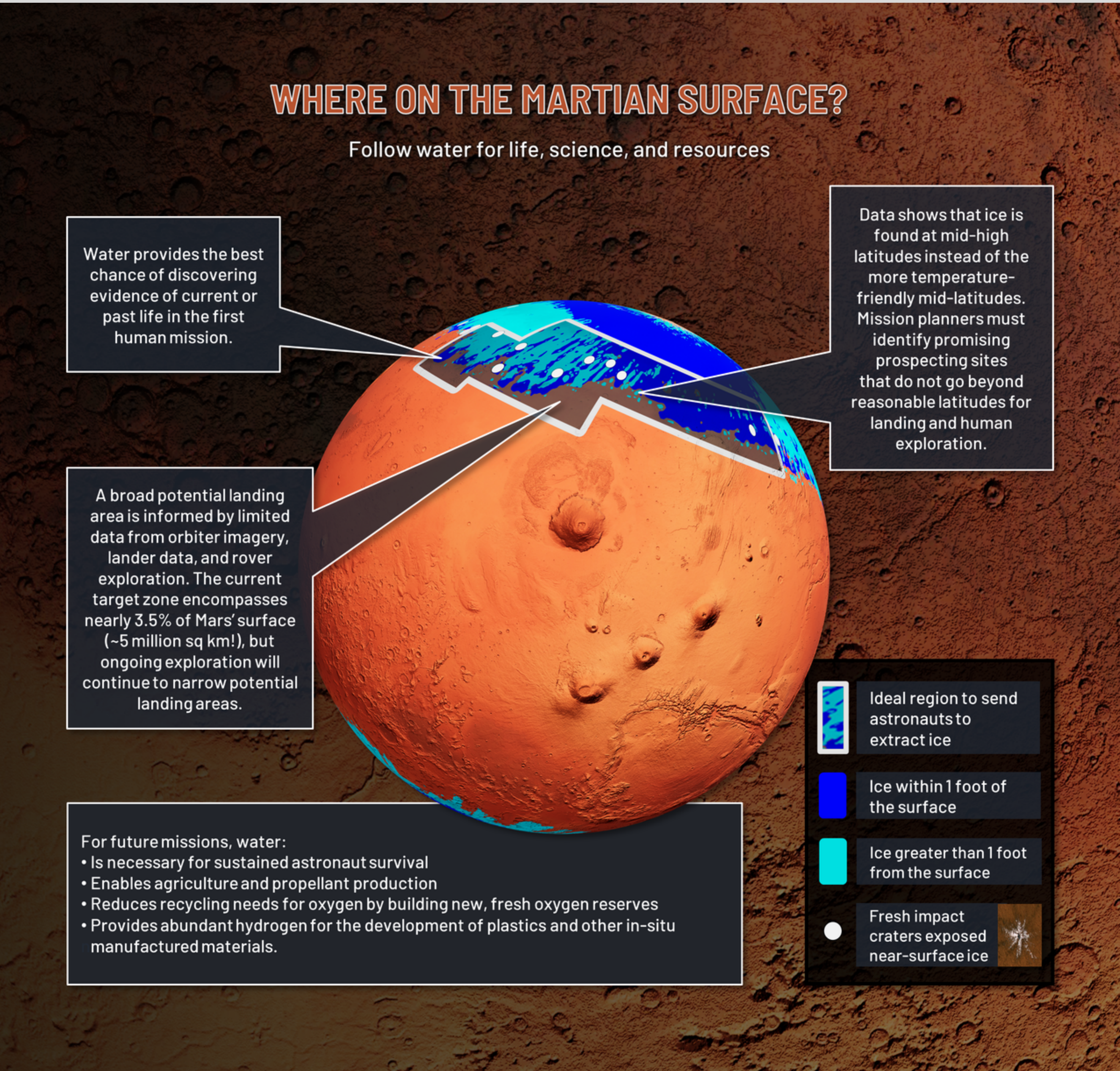
Conjunction class missions are quicker and more direct to Mars, requiring less energy. Conjunction class missions also provide more time for the crew at Mars but at the cost of a longer total mission duration (approximately 2.5 years) away from Earth due to orbital alignments limiting return transit options. This longer duration puts more time on the systems that keep the crew alive while also exposing the crew to longer periods of radiation and microgravity. An opposition class mission reduces the total trip time the crew is away from Earth by up to a year, benefitting crew and system health, but allows only 30 days on the surface of Mars. The opposition class mission requires substantially more energy, leading to the need for advanced nuclear propulsion. NASA is exploring all options, as the transportation system chosen for Mars will be a function of available technology, affordability, mission risk, and mission value.

MARS

"One doesn't discover new lands without losing sight of the shore." – Andre Gible

Why Mars?

Aside from Earth, Mars appears to be the most habitable planet in our solar system. Consider Earth: Everywhere there is water, there is life. In the distant past, Mars was a water world too, with oceans, lakes, flowing water, and hot springs. The possibilities of finding evidence of past or present life in Martian ice located just below the surface can help scientists better understand lifecycle patterns on Earth and beyond. Additionally, harvesting water on Mars offsets the need to launch multiple tons of it from Earth. Martian water could be used for astronaut consumables, or to generate propellant for the ascent vehicle that will initiate the journey back to Earth. Other considerations for Mars over other destinations include comparatively moderate temperatures, proximity to the sun for power purposes, existence of gravity and atmosphere (albeit fractions of those on Earth), and similar day/night rhythms.



Leveraging the Past to Build a BETTER FUTURE

"Learning is not attained by chance, it must be sought for with ardor and attended to with diligence." – Abigail Adams

How does previous work impact the M2M strategy?

Previous research informs the path ahead, posing questions based on past learning, and developing missions to achieve those answers. Future tactics in the M2M strategy are informed by years of assessing various opportunities in analogs and real-time demonstrations. These tests focus on human and robotic exploration plans, given different overall objectives, constraints, and destinations. Through this work, NASA develops operational concepts and identifies capabilities that enable effective and low-risk exploration. In an iterative process, activities studied and tested will become the basis of next-step concepts guiding human missions to the Moon and Mars.

Past studies establish a knowledge base of analysis tools, modeling, and simulation tools, cost and risk estimates and analysis techniques that can be employed to quickly inform and assess new exploration concepts. Like the numerous early expeditions on Mt. Everest prior to reaching the summit, this work will be foundational to the first astronauts stepping onto the surface of Mars. Continuing the ongoing cycle of asking and answering questions that inform progress, future missions will become past missions as the campaign strategy unfolds.

Constellation Informs Lunar Mission Segments & Structure

Lunar activities from the Constellation Program identified that permanent human presence at a large lunar base requires a substantial amount of logistics delivered into the lunar gravity well, even with in-situ resource utilitization (ISRU) production systems. This led to a more minimal approach of targeting only the foundational elements required for a two-crew, 30-day initial mission as opposed to a permanent presence. Eventually, through replication of Artemis Base Camp (ABC) elements, a larger and longer lunar presence can occur. Constellation also informed the target lunar destination: the lunar South Pole, which is energy-friendly due to abundant solar viewing and moderate temperatures without wild fluctuations.

DesertRATS Analog Furthers System Elements

In an operation known as Desert Research and Technology Studies (DesertRATS), NASA built full scale prototypes of proposed lunar surface exploration systems, field-testing them in analog Earth environments with end-to-end mission simulations.

Through DesertRATS, NASA confirmed that:

- Lunar surface mobility is key to long-term presence.
- Pressurized rovers greatly extend the range of crew exploration while keeping astronauts in a safe environment.

Earth-based desert analogs demonstrated innovation in integrating mobility and rapid EVA capability through a suitport. This technology will be tested on the Moon and implemented on Mars, allowing astronauts to explore the surface efficiently and effectively while minimizing transfer of dust and maximizing planetary protection.

- Linking a pressurized rover with an unpressurized rover extends exploration exponentially by providing a suitable abort option that allows astronauts to utilize spacesuits and the unpressurized rover to return to the ascent vehicle quickly if needed.
- Suitport technology provides quick and efficient crew surface access with integrated dust mitigation.

Additional lessons from DesertRATS include:

- A lunar surface habitat is desirable for long-term presence at one location on the lunar surface.
- Several different preferred approaches exist for offloading payloads from landers, depending on the lander design.
- Bandwidth increases, advances in data transmission, and improvements to communications lag enable greater crew autonomy and the use of teleoperations of surface assets over the course of the campaign.

EMC Links the Moon to Mars

The Evolvable Mars Campaign (EMC) evaluated capabilities and technologies needed to establish sustainable human presence on the surface of Mars, focusing on continual trade analysis. The EMC emphasized programmatic flexibility, common applications, phasing the cadence of missions to maintain affordability, and a modular, progressive approach of building toward Mars surface missions. Other key takeaways from EMC include:

- The International Space Station (ISS) is required for human research and technology development, particularly the Environmental Control and Life Support Systems (ECLSS) that will be needed for human missions to Mars. The station is also an unparalleled destination to conduct early Mars analogs.
- Gateway is a key piece of the infrastructure, providing deep-space biological research and systems stress-testing. It also serves to assemble and outfit deep space transport as well as to refuel and aggregate propulsion systems for subsequent Mars missions.
- The Near-Rectilinear Halo Orbit (NRHO) is the preferred lunar orbit for the Gateway.
- The Mars Entry, Descent, and Landing (EDL) capability must be developed for a 22.5t payload
- Common short- and long-term in-space and on-surface habitation capabilities reduce cost and schedule.

NextSTEP Leverages the Space Industry

Next Space Technologies for Exploration Partnerships (NextSTEP) habitation studies identified innovative ideas from industry that leverage commercial capabilities to drive NASA objectives. NextSTEP findings demonstrated that:

- Short-duration habitats can be built using existing technologies; longer-duration habitats require additional ECLSS investments.
- Interoperability standards are necessary to foster meaningful contributions, commitments, and investments from the broadest range of stakeholders.
- Ground-based human-in-the-loop testing is advantageous for early determination of key system layout, features, and requirements.
- Larger habitats foster more efficiency for crew tasks due to less interference amongst competing activities.

NextSTEP studies also provided greater confidence in mass, power, volume, and cost estimates of the spacecraft and subsystem designs.

Summary

Years of NASA, partner, and industry work establishes the global point of departure for the current campaign strategy. As missions unfold, implications of advanced technology will be traded with required funding, impacts to crew time, cost, and readiness in effort to determine the best value for getting crew safely to the Moon, Mars and back.

Moon to Mars

CAMPAIGN SEGMENTS

"Civilization never recedes; the law of necessity ever forces it onwards." - Jules Verne

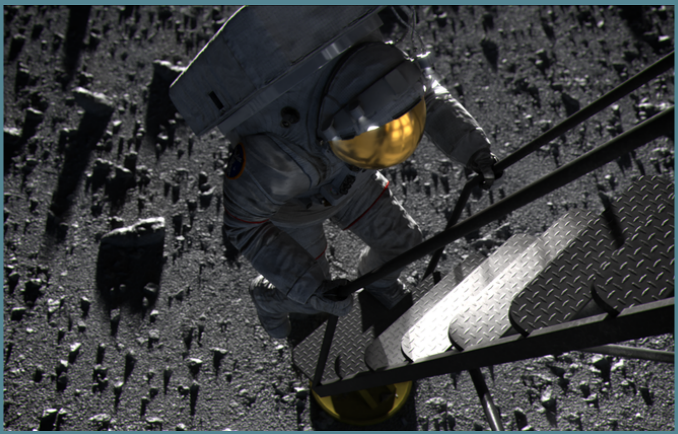
What will we be doing on the Moon and Mars?
The Moon-to-Mars Campaign features f**our primary theaters for exploration.** These are not temporal phases, as one may not end as another begins. Instead, they are considered campaign segments, each with goals and objectives that support the strategy. Each segment contains missions designed to converge technology, systems, research, demonstrations, testing, and more inform next steps and successfully build toward the overarching architecture. Through this practice-prepare-perform methodology, lunar exploration and landing the first humans on Mars will come to fruition.

SEGMENT: HUMAN PRESENCE IN LEO

LEO exploration will develop and test systems for long-duration spaceflight (ECLSS, logistics, etc.,) as well as study human physiology with respect to long-duration microgravity and space environment exposure. Additional focus areas are on commercial crew and cargo delivery systems; Mars-forward analog missions to assess effects on crew and equipment; and pretesting of operational procedures in the space environment. Operations in this segment have already begun and will transition to commercial LEO elements, if available.

The ISS is the training ground for testing long-duration systems and monitoring human physiology effects of long-term space habitation.

SEGMENT: HUMAN LUNAR RETURN



On the lunar surface, astronauts will be able to explore the Moon and test Mars-forward systems.

Returning humans to the Moon enables testing and exercising human landing systems and transit systems, including habitats and surface mobility, as crew deploy to the lunar surface for relatively short periods at a time. Each mission focuses on innovative human-robotic exploration, conducting fundamental science research (such as in permanently shadowed regions), and studying human physiology effects of long-term living in deep space.

Once established on the Moon, human presence can be sustained by adding infrastructure in a commercially enabled economic environment.

SEGMENT: SUSTAINED LUNAR PRESENCE

Sustained lunar presence represents long-term exploration of the entire Moon, and preparing to get to Mars. The Moon has long been viewed as a proving ground upon which to learn the art of extraterrestrial surface exploration. Technology, equipment and operations demonstrations can happen on the lunar surface to test common campaign elements such as the Gateway, surface mobility, enhanced habitation, power, and portions of the human lunar access system.

The lunar environment and gravity differs from that of Mars, and will thereby not provide a perfectly analogous environment. However, just as Base Camp on Mt. Everest prepares mountain climbers upcoming challenges, the remoteness, limited logistics and harsh conditions on the Moon provide an environment that can be used to evaluate systems extensible to Mars.

Artemis Base Camp (ABC) systems, operability and integration is the focus of this segment, including delivery and testing of foundation elements required for sustained lunar presence: surface habitation, power generation and storage, crew and cargo transport, ISRU technology, and pressurized and unpressurized rovers.

With infrastructure delivered and in place, crews can descend to the surface to utilize these mission elements for 30-day exploration missions. Put together, the ABC elements are designed to significantly extend exploration of the surface, enhance science return from each mission, demonstrate the needs for working and living on the Moon, and improve ABC operations (such as power, ISRU utilization, etc.) over long durations.

ABC missions also include specific, task-oriented missions that support progress toward the Humans to Mars segment. Analogs on the Moon will inform and reduce risk in the development of key elements of the Mars exploration system, such as transportation propulsion and deep-space habitation.

Key to these analogs is developing and testing ways to speed acclimation of the crew from zero gravity to partial gravity, much like mountaineers acclimate as they approach the summit. Extended durations of crews in microgravity from six months to a year can happen in the transit habitat attached to Gateway. Given the first crewed Mars mission allows about 30 days on the surface, it is imperative that exploration activities commence as soon as safely possible once crews are physically on Mars, without significant impediment from adapting to the environment.

Analogs of increasingly fidelity on the lunar surface with respect to the Mars mission surface operations will be performed until the risks associated with partial gravity acclimation, logistics transfer, EVA operations and mobility reach an acceptable level, while also informing any upgrades required from the lunar systems to their Mars surface systems counterparts.

SEGMENT: HUMANS TO MARS

Balancing risk and achievement, using the best combination of robots and humans, and using advanced technologies such as nuclear propulsion, the Mars segment will visit new ground, yield new discoveries, and answer questions fundamental to human existence. The campaign will culminate with a short-duration human mission to the surface that utilizes human in-situ abilities to the maximum benefit possible. Discoveries and knowledge obtained on this mission will determine the path for future human activity on Mars. Putting humans on Mars demands synergy of mission design, technology, systems, physiology research, risk-reduction, and other activities conducted in previous segments for a successful return trip. Objectives for this segment include: autonomous deployment and validation of systems necessary for crewed mission support; successful human landing and return; and science and technology demonstrations on the Martian surface.

Establishing a sustained lunar presence and taking steps toward the first human mission to Mars will be a great feat of engineering. These steps will mark a transformative moment for human civilization, just as achieving the world's highest peak and overcoming its challenges was a momentous time in history. As they come together, campaign segments will drive technology and innovation using unparalleled scientific capabilities, a dynamic economy, and a robust industrial base. Achievements in this campaign will inspire generations of science, technology, engineering, the arts, and mathematics (STEAM) professionals and countless other disciplines, while offering opportunities to partners in government, industry, and academia.

The M2M campaign strategy is composed of strategy segments, designed to be components that make up the whole. Segment structure and decision-making are governed by four core principles.

CORE PRINCIPLES

FAST MISSIONS

Limits on knowledge, risk, and technology readiness govern an expedition. Shorter missions allow risk mitigation on crew health, system operations, and radiation exposure. Technology needed for a Mars mission will be to converge at a readiness level appropriate for the mission timeframe.

MINIMAL MISSION ARCHITECTURE & INVESTMENT

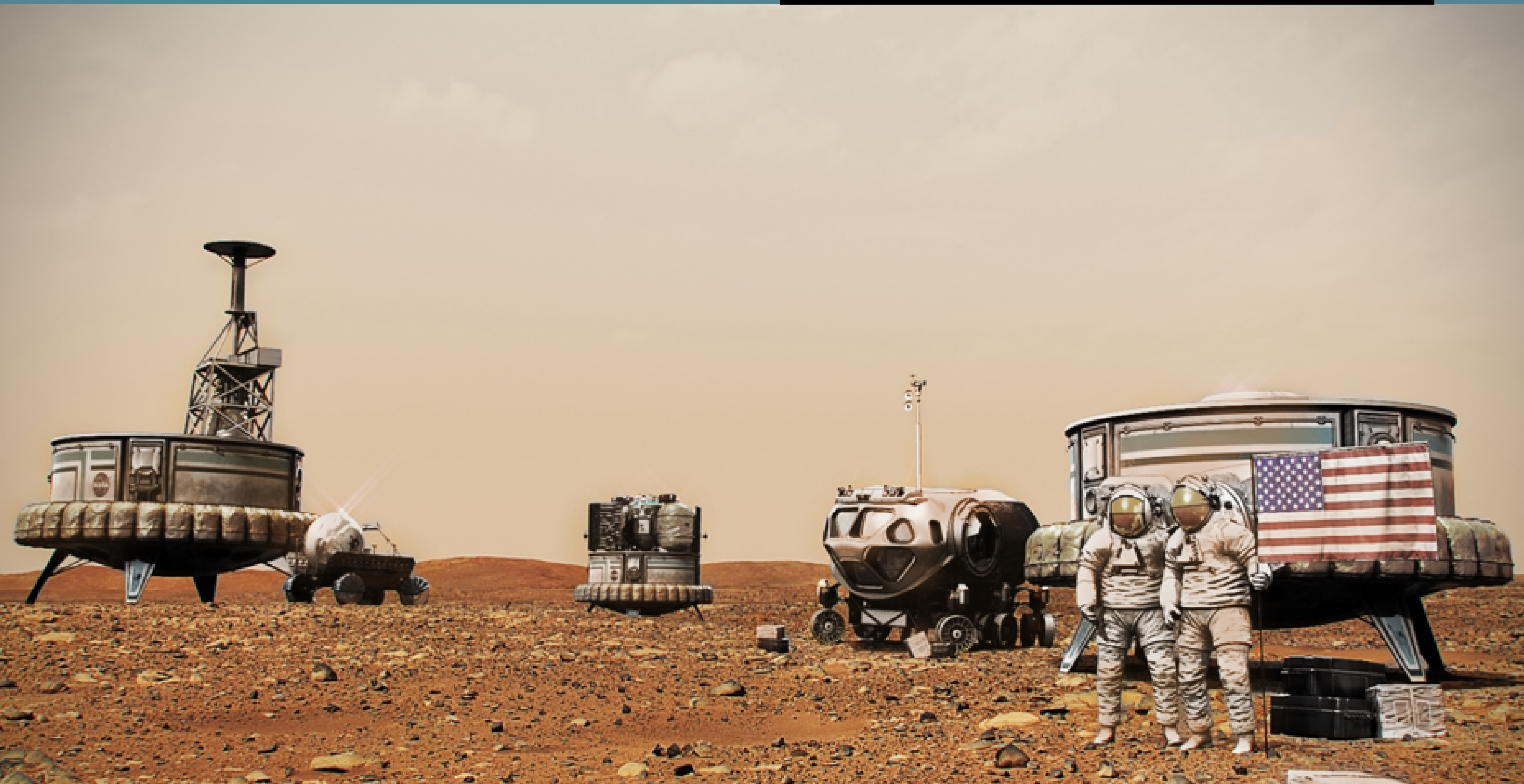
Weight, materials access, logistics, and propulsion are elements of all expedition planning. A minimal first Mars mission reduces complexity and thereby risk of mission element failure. Implementing a philosophy of "build for Mars, test on the Moon" provides opportunities for evolving infrastructure and realizing cost savings that enables mission feasibility over the entire exploration campaign.

SUSTAINABLE LUNAR PRESENCE

NASA, together with public-private partnerships, will establish an outpost on the Moon's surface. To get here, elements and activities will be prioritized to meet the needs of Moon and Mars operations simultaneously.

SCIENTIFIC DISCOVERY & EXPLORATION

Beyond exploration, science performed beyond Earth's bounds will enhance understanding of Earth, it's relationship to the universe, and the universe at large. Equally vital is the need to demonstrate research and technology findings as the campaign progresses to continue to inform strategic action.



Paving the Way with COMMON SYSTEMS

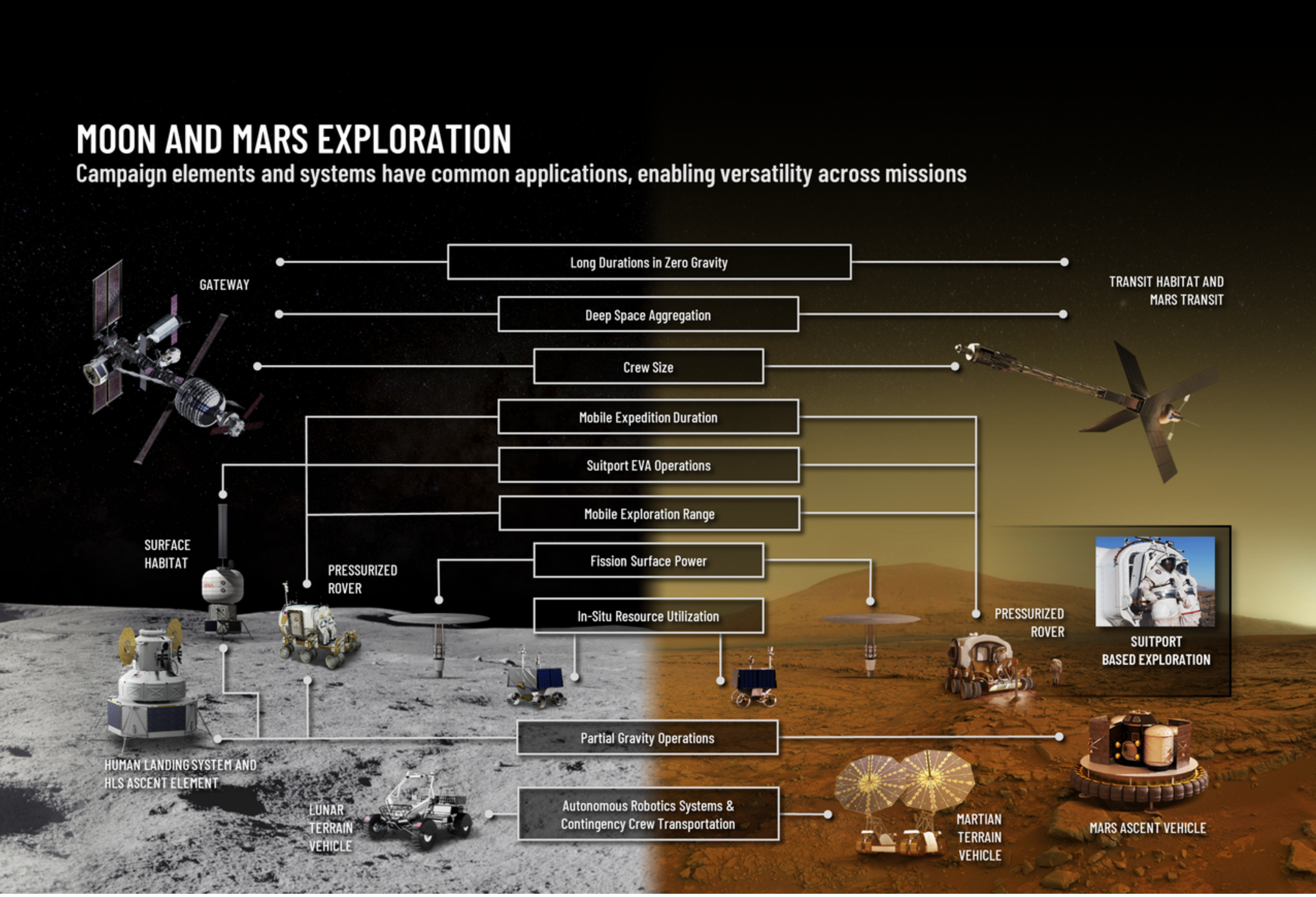
"Never interrupt someone doing what you said couldn't be done." – Amelia Earhart

CRITICAL SHARED TECHNOLOGIES, APPLICATIONS, AND CAPABILITIES

How does the campaign and its systems work?
The strategy and its elements are flexible and adaptable as new learning happens. The strategy works precisely because the segments build upon one another.

Utilizing the same launch vehicles for Earth to cislunar space and highly similar surface systems between the Moon and Mars makes the components customizable with minimal cost between missions to varying destinations and with varying scale, complexity, and sustainability. By definition, the campaign is versatile, so current system designs embrace the philosophy of leveraging common investments for launch, aggregation, and surface infrastructure.

While slightly more investment is needed for versatile systems, this approach pays off because it meets the needs of a variety of destinations – potentially even beyond the Earth-Moon-Mars neighborhood. In addition, synergistic component development enables re-use and/or baseline design similarities to facilitate new construction to help meet aggressive target timelines.



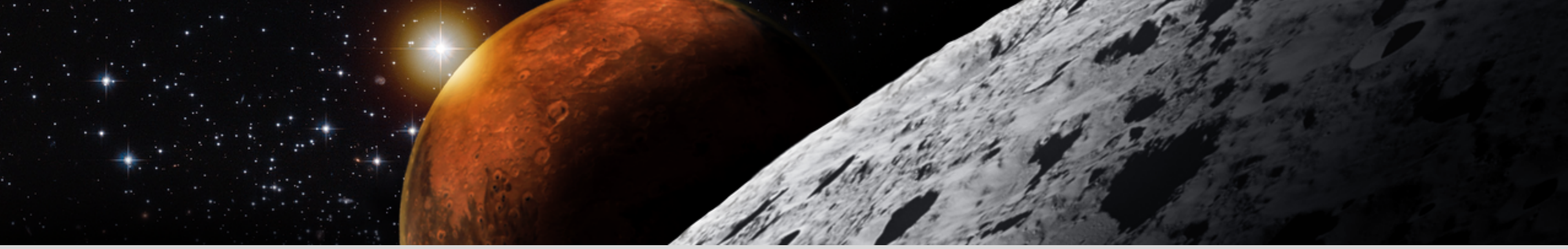
Exploration is driven by discovery and technology, so a good strategy is informed by discovery and changes in technology.

By design, lunar and Mars systems share common heritage and intent. Similar to lunar crewed missions, the concept of operations for the first human mission to the surface of Mars features a pressurized mobile habitat (pressurized rover) with crew operating for several weeks on the surface. A small unpressurized rover with long range on a single charge travels alongside the pressurized rover, carrying science and technology payloads. By offering a rapid escape strategy, this rover mitigates risk and extends exploration area and opportunity by an order of magnitude.

The pressurized rover is fully equipped with suitports, all human support systems and large cargo carrying capabilities such as a core sample drill and analysis systems. This enables 30-day surface mission, as the crew lands in the vehicle they will live and explore in, lessening the impact of the acclimation from zero gravity to partial gravity. Meanwhile, additional crew will orbit in the transit habitat, performing exploration functions as well as surface mission oversight and ship readiness activities for the return home.

This structure is commonly accepted as the minimal capability to support mission objectives. Pressurized mobility allows vastly increased range and capability (mass, power, and crew time) for science exploration. In addition, suitport EVA architecture plays a primary role to minimize mass and dust contamination, while maximizing EVA productivity. Parallel activities on the surface and in orbit allow for an opposition class mission profile, which permits only 30 days to perform all mission functions, but also could easily be accommodated with a conjunction class mission profile.

The Mars concept of operations involving pressurized and unpressurized mobility also pushes the boundaries of electric vehicle capabilities, spurring innovation for electric vehicles on Earth with respect to advanced energy storage, autonomous driving, and resilience to extreme terrain.



Moon to Mars

SEQUENCE OF EVENTS

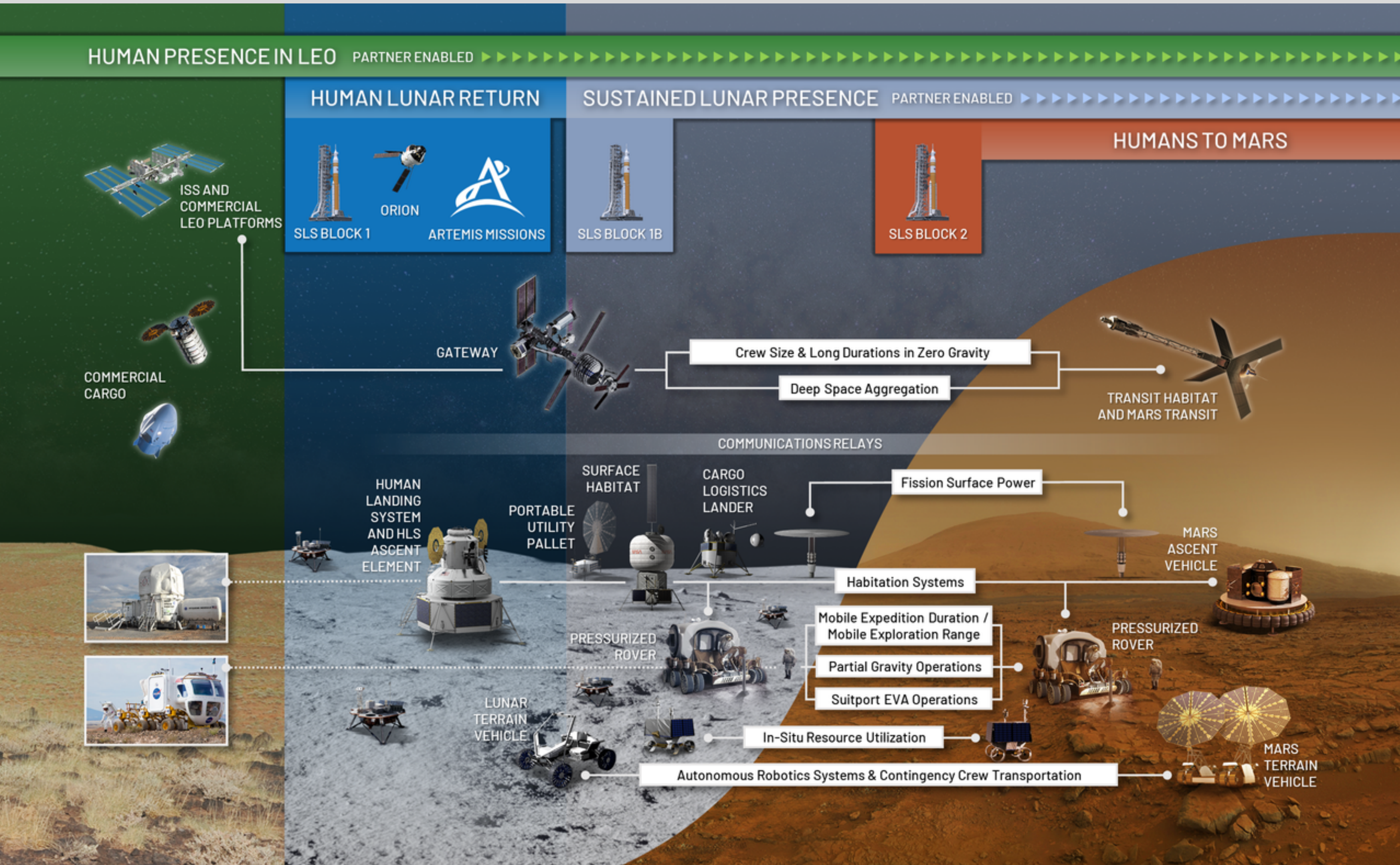
"Living at risk is jumping off the cliff and building your wings on the way down." - Ray Bradbury

When are we going back to the Moon and on to Mars?

Establishing a sustained human presence on the Moon and conducting the first human mission to the surface of Mars will be among the most challenging technical enterprises in human history. It requires technical approaches and systems that may not yet exist. A condensed timeline will require necessary investments of expertise, time, innovation, and funding from both NASA and its commercial and international partners to collectively achieve the campaign.

Why are there no dates in this document?

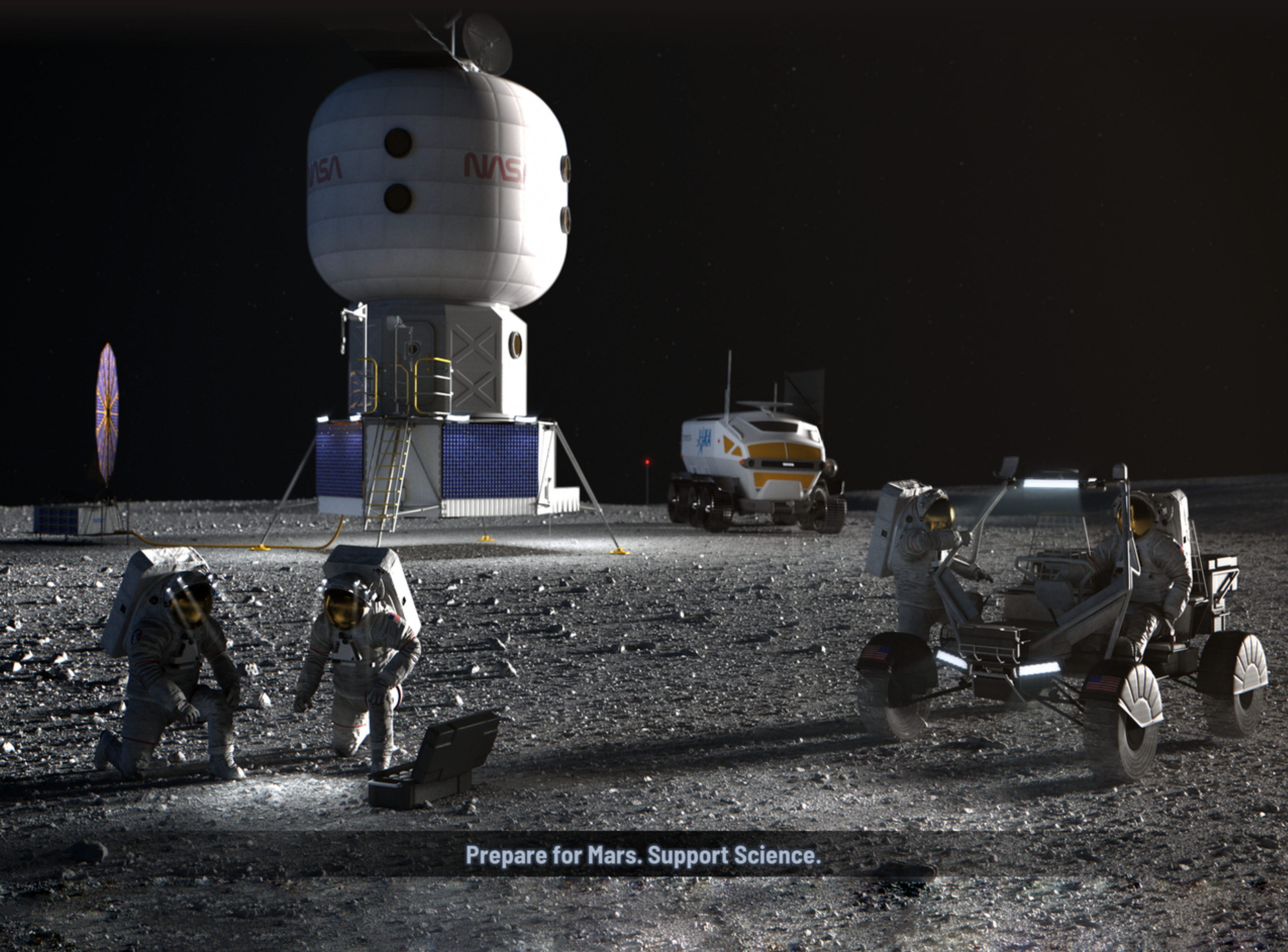
Just as past work informs the current strategy, current work is underway to inform next steps as campaign segments unfold. NASA's ability to start work or fund development to support missions is dependent on the budget the agency receives, which determines the ability and pace for progress through the campaign strategy segments. Campaign strategy segments, even those that can run in parallel, are structured to provide a build-up of capabilities that provides best opportunity, mitigate risk, and ensure sustainability of human exploration on the Moon and Mars. Each mission refines the campaign over time, with new learning bettering each mission and new questions forming the basis of exploration to continue the quest toward humans on Mars.



As it relates to the Mars-forward campaign strategy, Artemis Base Camp (ABC) serves as a foundation for Moon exploration and as a practice field for Mars. As a Gateway spur, ABC becomes a permanent staging ground for lunar exploration, much like Camp 1 on a mountain expedition is a next-level camp designed specifically for the ascent of a particular peak. What's next for Artemis Base Camp?

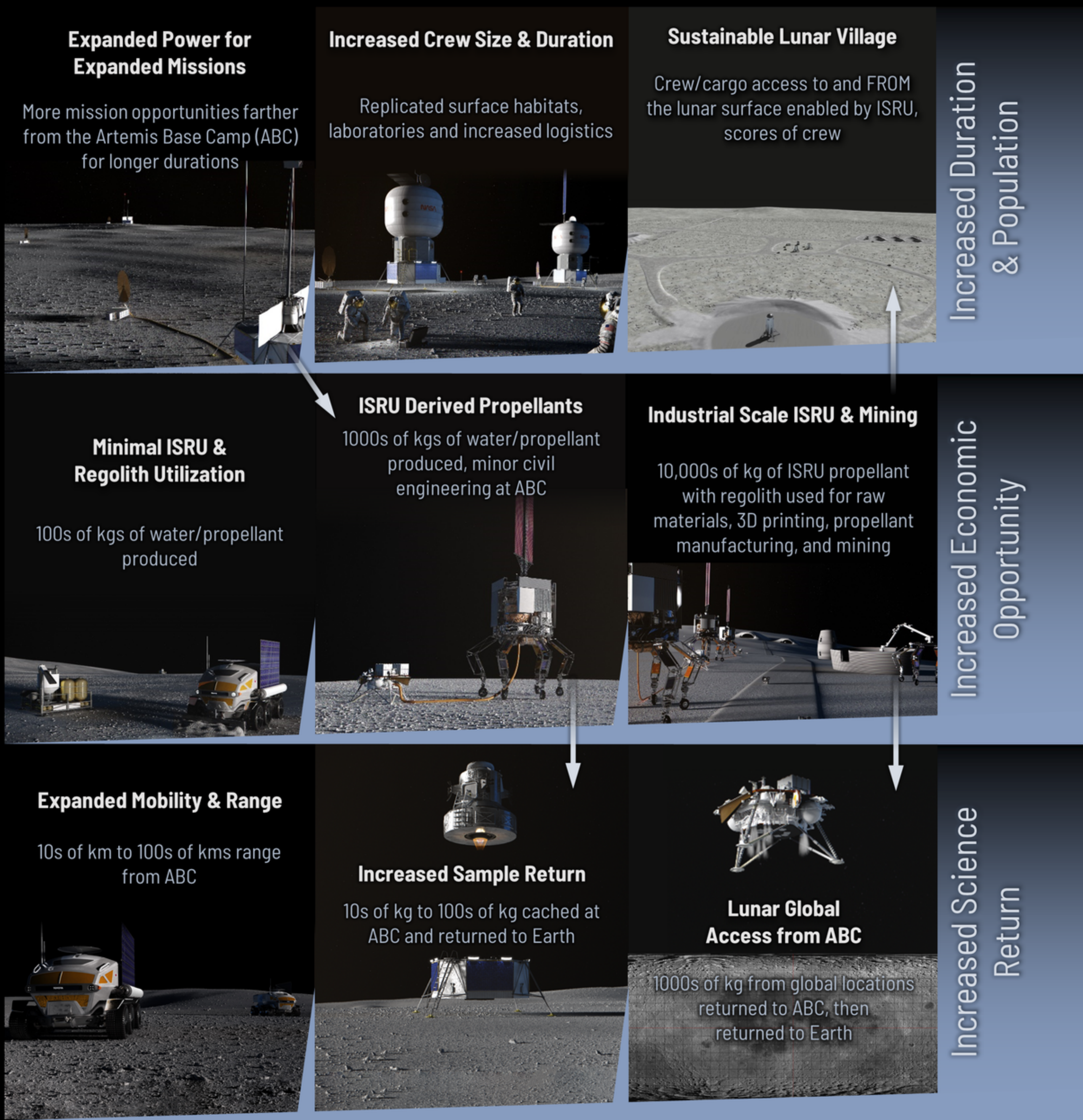
ARTEMIS BASE CAMP EVOLUTION PATHS

Foundational Capabilities for Lunar Surface Access, Mobility, Habitation, Logistics, Power, and In-Situ Resource Utilization



Prepare for Mars. Support Science.

Through increased partnerships, ABC will be industrialized. It will become a lunar village. It will be a global home base for robotic ISRU. It will be home to top scientists gathering together to understand the history of the solar system. And, much like the rest of the strategy, this will mirror what NASA hopes to eventually achieve on the Red Planet after the initial Mars missions.



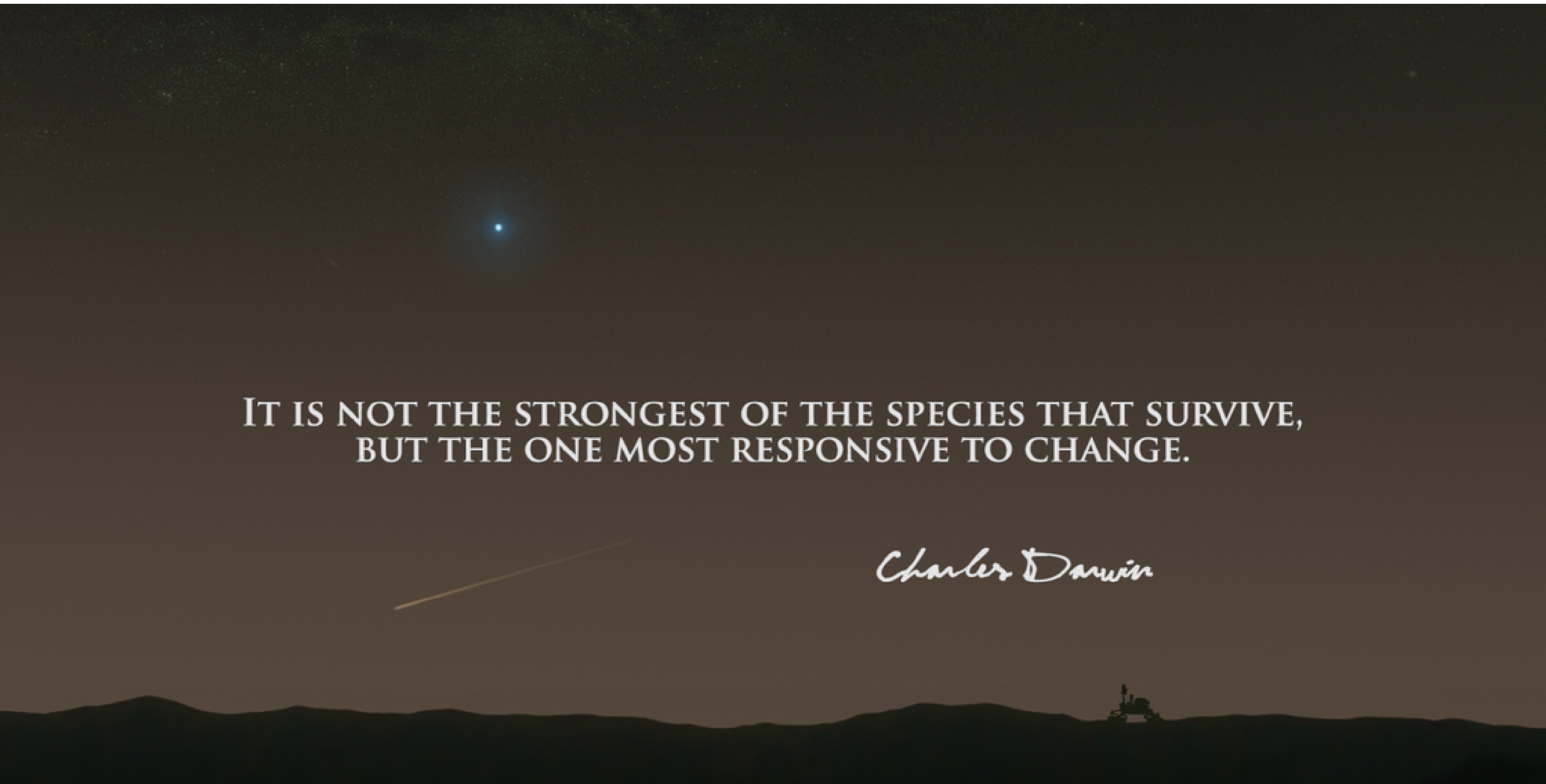
FORGING AHEAD

"In order to succeed, your desire for success should be greater than your fear of failure." – Albert Einstein

What does the future of space exploration look like?
Imagine a world where space travel is the norm. New jobs are on the horizon that cannot yet be conceived. Space innovation isn't a far-fetched sci-fi dream; it is an everyday reality with applications ranging from Earth to Mars. In the early 1900s, automobiles were only just becoming common alongside horse carriages on streets. Flight through the air was barely a concept, and commercial air travel was not yet conceived. Standing atop the tallest mountain in the world was but a hazy dream, as a specialized outdoors industry did not yet exist. Over the course of the 20th century, the world transformed drastically and today, dreams are not just reality, they are commercial industries with robust global economies built around them. Getting to this point took contributions across industries known (and unknown) to achieve progress leading to today's incredible accomplishments and establishments.

As a critical partner, the commercial space industry brings brings innovative ideas and advances new technologies to make space exploration possible. These contributions enable missions to operate at a lower cost, with greater capabilities than could happen under a single agency.

Who will get us to the Moon and Mars?
The United States is forging the path, but this campaign belongs to all of Earth. It belongs to its leaders; its manufacturers; its engineers, planners, designers, academics, innovators. The astronauts who set foot on Martian soil and those who orbit above will be this expedition's heroes, supported by NASA civil servants and contractors who will pave the way. Together with industry, academia (through official solicitations and engineering design challenges) and international collaborators, NASA will move the needle on technology demonstrations, deployment and use, and will press forward toward humans on Mars.



ACKNOWLEDGEMENTS

RESOURCES

NASA Human Exploration & Operations Mission Directorate, "Moon to Mars Campaign Overview Description (DRAFT)," (NASA Headquarters, December 2019)
Unpublished. For more information, contact Pat Troutman patrick.a.troutman@nasa.gov.

NASA Human Exploration & Operations Mission Directorate, "Strategic Campaign Operations Plan for Exploration [SCOPE] (DRAFT)" (NASA Headquarters, January 2020)
Unpublished. For more information, contact Pat Troutman patrick.a.troutman@nasa.gov.

NASA HEOMD, "Element Rationales & Dependencies;" "Why Suitport;" "Artemis Implementation Strategy;" "Why Opposition;" "Why Cis-Lunar" (NASA Langley Research Center, May 2020)

Patrick Troutman et al., "Strategic Analysis Cycle 2021 Mars Government Reference Architecture Description Document (DRAFT)," (NASA Headquarters, June 2021)
Unpublished. For more information, contact Pat Troutman patrick.a.troutman@nasa.gov.

Patrick Troutman, "RASC-AL: Mars to Moon Strategy," presented at the 2021 RASC-AL Virtual Forum, (NASA Langley Research Center: June, 2021)

Patrick Troutman et al., "Artemis Architecture for UAG" (NASA Langley Research Center, January 2020)

Andrew Good, JPL; Alana Johnson, NASA HQ, "NASA's Treasure Map for Water Ice on Mars," (NASA Headquarters, December 2019)

Patrick Troutman et al., "Artemis Plan: NASA's Lunar Exploration Program Overview," (NASA Headquarters, September 2020)

"NASA's Journey to Mars: Pioneering Space," (NASA Headquarters, May 2015)

The Tauri Group, "Voyages: Charting the Course for Sustainable Human Space Exploration," (NASA Headquarters, June 2012)

International Space Exploration Coordination Group, "The Global Exploration Roadmap," (NASA Headquarters, September 2011)

John F. Connolly, Constellation Program Office, "Constellation Program Overview," (NASA Headquarters, October 2006)

AUTHORS & EDITORS

Patrick Troutman
ESDMD Systems Engineering & Integration Division, Space Mission Analysis Branch, Strategies & Architectures Lead
NASA Langley Research Center

Douglas Craig
ESDMD Systems Engineering & Integration Division, Architecture and Strategic Analysis Manager
NASA Headquarters

Janice Kurbjun Miller
Project Manager
Writer/ Editor/Layout
National Institute of Aerospace

Amber Bettis
Graphic Art/Cover Art
Advanced Concepts Laboratory
NASA Langley Research Center

Stacy Dees
Editor
National Institute of Aerospace

Kevin Greer
Graphic Artist
Advanced Concepts Laboratory
NASA Langley Research Center

Shelley Spears
Editor
National Institute of Aerospace

Bisked Evangelista
Graphic Artist
Advanced Concepts Laboratory
NASA Langley Research Center

Nathan Kreuzman
Graphic Artist
Advanced Concepts Laboratory
NASA Langley Research Center

Christopher Jones
Editor
NASA Langley Research Center

Dan Mazanek
Editor
NASA Langley Research Center

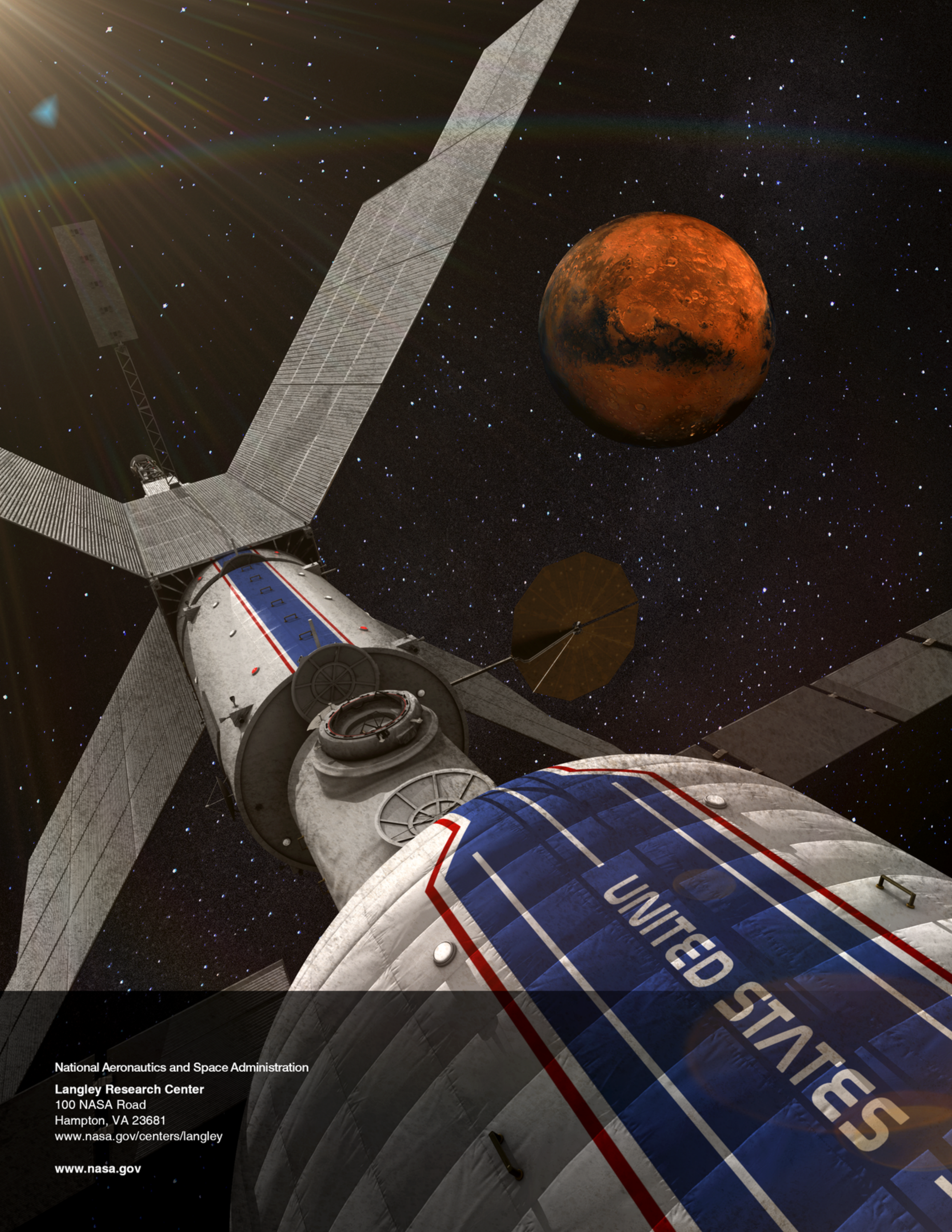
Kandyce Goodliff
Editor
NASA Langley Research Center

Erin Mahoney
Editor
NASA Headquarters

IMAGE CREDITS

Advanced Concepts Laboratory (ACL)
Graphic Art Studio
NASA Langley Research Center
Pages 1, 2, 3, 6, 7, 8, 9, 10, 13, 14, 15, 16, 17, 18, 19, 20, 21

All other images courtesy of NASA, unless otherwise noted.



National Aeronautics and Space Administration

Langley Research Center
100 NASA Road
Hampton, VA 23681
www.nasa.gov/centers/langley

www.nasa.gov