2020
THE HUMANS TO MARS REPORT

AN EXPLORE MARS, INC. PUBLICATION

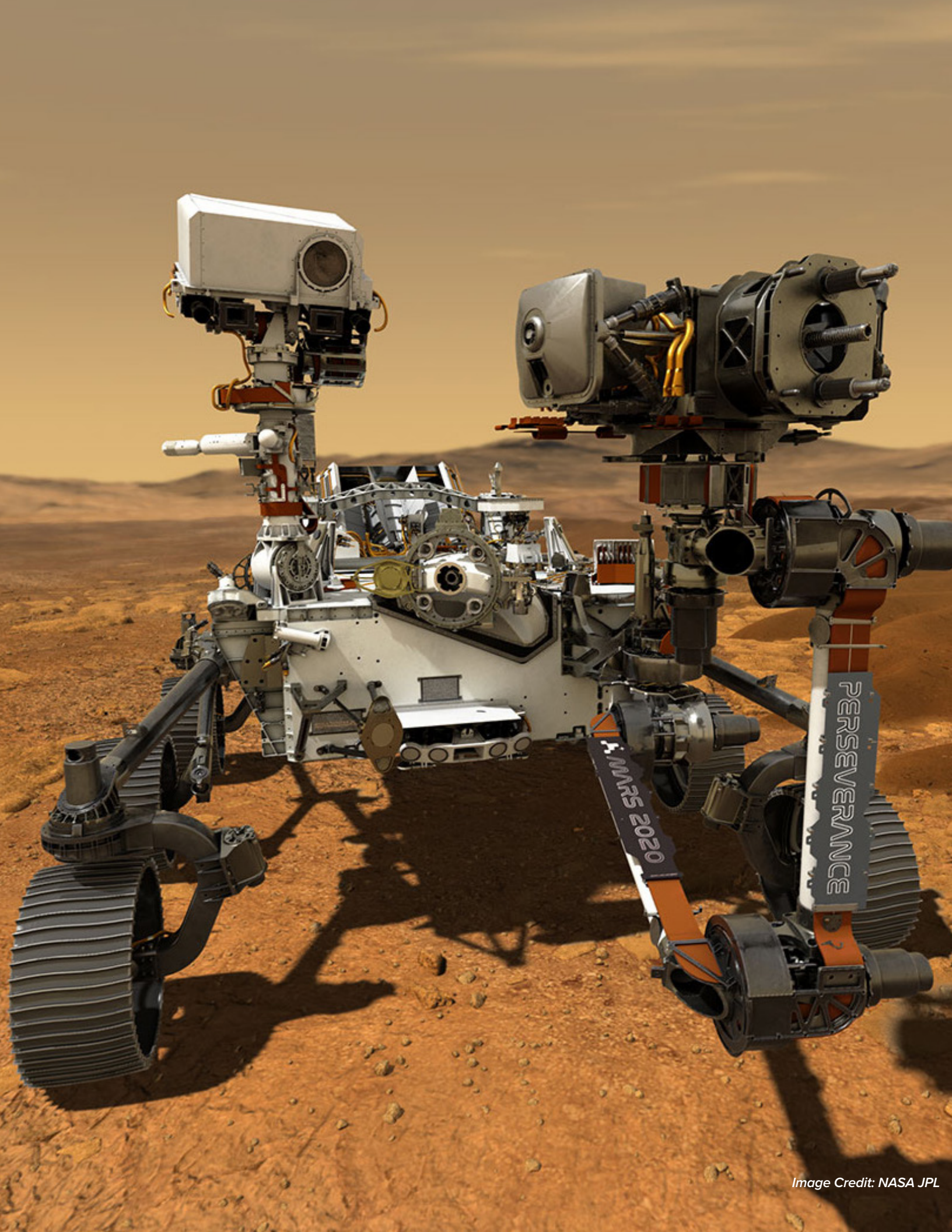

Image Credit: NASA JPL

The HUMANS TO MARS Report 2020

Target Mars 2033

The Humans to Mars Report (H2MR) is an annual publication that presents a snapshot of current progress in mission architectures, science, domestic and international policy, human factors, STEAM Education, and public perception regarding human missions to Mars, as well as highlighting progress and challenges from year to year.

Each year, H2MR provides the general public, space advocates, stakeholders and policy makers with an invaluable resource to assist them in making decisions that are based on facts, not fiction, of the reality of a human expedition on martian soil.

Today our planet is faced with the COVID-19 crisis, which has been extremely challenging for people all around the world, affecting practically every facet of life. However, despite these challenges, aerospace professionals, scientists and other key stakeholders remain focused on the goal of achieving human missions to Mars in the 2030s. As such, this year H2MR also serves to track how these uncertain times have impacted Mars exploration efforts.

From writings by Athanasius Kircher in the 17th century to Emanuel Swedenborg in the early 18th century, learned scholars have mused about voyaging to Mars as both adventurers and explorers. In 1877, Giovanni Schiaparelli observed with his telescope a dense network of linear structures on the surface of Mars that he called “canali” in Italian, meaning “channels”, but the term was mistranslated into English as “canals”. In his book, Life on Mars, however, Schiaparelli wrote, “Rather than true channels in a form familiar to us, we must imagine depressions in the soil that are not very deep, extended in a straight direction for thousands of miles, over a width of 100, 200 kilometers and maybe more. I have already pointed out that, in the absence of rain on Mars, these channels are probably the main mechanism by which the water (and with it organic life) can spread on the dry surface of the planet.”

From Edgar Rice Burroughs to H.G. Wells to Ray Bradbury and so many other past and current authors, it is clear that humans are fascinated by the possibilites of life on Mars.

Today, Mars is more achievable than ever before. Indeed, Congress and the Administration have made clear in their recent policy pronouncements that sending humans to Mars by 2033 is now the goal of the United States.

In addition, public interest in Mars shows no signs of wavering, as evidenced by recent public polling. Furthermore, the Mars and lunar science and engineering communities are together seeking to find synergies between the two destinations, with a focus on lunar missions that will feed forward to human missions to Mars. We maintain that if government, academia, industry, and commercial entities continue to work together to create architectural approaches that work for both the lunar and martian surfaces, humans on Mars in 2033 remains an achievable goal.

This publication does not advocate any particular approach to getting to Mars, nor will this report address speculation or rumor about future architectures, except when such impact public perception and policy decisions. At the same time, Explore Mars, Inc. welcomes human exploration of other destinations in the Solar System. In fact, as with lunar exploration, we embrace all human endeavors in space, and we are especially enthusiastic when those missions are collaborative/cooperative efforts for human missions to Mars.

We maintain that Mars is a critical destination that will enable the exploration and development of space. Mars awaits us, as does the future and long-term survival of our species. We are proud to be part of building a future for humanity on Mars.

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Explore Mars, Inc.

Explore Mars was created to advance the goal of sending humans to Mars within the next two decades. To further that goal, Explore Mars conducts programs and technical challenges to stimulate the development and/or improvement of technologies that will make human Mars missions more efficient and feasible. In addition, to embed the idea of Mars as a habitable planet, Explore Mars challenges educators to use Mars in the classroom as a tool to teach standard STEM curricula.

Explore Mars, Inc. is a 501(c)(3) non-profit corporation organized in the Commonwealth of Massachusetts. Donations to Explore Mars are tax-deductible. You can contact us using our website https://exploremars.org or at the email address info@ExploreMars.org

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Congratulations to NASA and SpaceX for the Successful Launch and Return of the Crew Dragon Capsule Endeavour to ISS

Image Credit SpaceX

On July 21, 2011, the Space Shuttle Atlantis (STS-135) landed at Kennedy Space Center after a two week trip to the International Space Station. This marked not only the completion of a successful mission, but the end of the Space Shuttle program and the beginning of an almost decade-long hiatus in American crewed launch capability.

On May 30, 2020, however, this long gap in American crewed access to space ended when a SpaceX Crew Dragon capsule launched from Pad 39A at the Kennedy Space Center atop a Falcon 9 rocket, transporting NASA astronauts Doug Hurley and Bob Behnken to Low Earth Orbit and the International Space Station (ISS). The Dragon capsule, carrying the two crew members, safely splashed down in the Gulf of Mexico on August 2, 2020.

Explore Mars, Inc. congratulates SpaceX and NASA for this tremendous achievement and for proving a new model for launching humans into space. “This was a truly historic mission,” stated Explore Mars CEO, Chris Carberry. “Not only are astronauts being launched from American soil again, but this mission also represents the beginning of what could be the most significant decade of human spaceflight in history. By the end of the decade, humanity may well be back on the Moon and on the path towards human missions to Mars.”

This mission was part of the NASA Commercial Crew Program that selected SpaceX and Boeing to develop vehicles for the purpose of transporting astronauts to and from the ISS. By selecting two companies to build crew vehicles, NASA aims to establish a redundancy and sustainability in human-rated launch vehicles that has never previously existed.

Explore Mars, Inc. President, Janet Ivey, stated, “Today marks the moment the door has been opened for the students of today and tomorrow to pursue a new dream, a new hope of space, settlement and discovery; space is now accessible, the frontier lies ahead, the Moon and Mars await…today we didn’t just launch a rocket…we launched the lives of future space explorers.”

INTRODUCTION

Our nation has long recognized the immeasurable benefits that our space program brings to our economy, our prosperity, and our national security. This is reflected in the strong and continuing support by political leaders and among the general public for the human exploration of Mars. The momentum that has been building for many years to send humans to Mars in the 2030s has continued unabated, and indeed grown, during the past year.

As we noted in the 2019 Humans to Mars Report (https://www.exploremars.org//wp-content/uploads/2019/12/H2MR_2019_Web.pdf), as plans have advanced for an accelerated return to the Moon, the goal of sending humans to Mars in 2033 has also come into far more focus. Developing a program that is sustainable – both financially and politically – is being embraced by policymakers. Indeed, thanks to efforts such as the 6th and 7th Community Workshops for Achievability and Sustainability of Human Exploration of Mars, held in August 2018 and November 2019 respectively, the lunar and Mars communities are now working together to critically assess how operations, technologies, and facilities required for the exploration of the Moon and its vicinity might feed forward to human missions to the martian surface (https://www.exploremars.org/affording-mars/). Such coordination is essential to create sustainability, reduce critical risks, and to assure that Mars remains the target destination in the 2030s. These goals will also require that sufficient and sustained funding and political support are provided. Otherwise, we run the risk that a return to the Moon could transform into a short-term Moon-only program or might not even be able to achieve that intermediate goal.

Over the past year much work has been done to further planned robotic missions, with three international robotic missions to the Red Planet successfully launched during the summer of 2020. Two of the three missions will, among other things, seek to answer the age-old question whether there is or has ever been life on Mars. One such mission, the United States' Mars 2020 "*Perseverance*" rover, will cache samples of the martian regolith for a future Mars Sample Return mission that is currently in the planning stages as a joint NASA/European Space Agency mission and is considered to be a top priority for the 2020s. Such robotic missions are necessary precursors to future human missions. They will maximize scientific goals as well as advance human exploration in the 2030s.

Work on architectural concepts and refinements has also continued over the past year within NASA, in academia, and in industry. This includes more definition being provided to the Artemis Program, which has evolved into a two-phase approach. The first phase focuses on returning humans to the Moon by 2024. The second phase is aimed at sustained exploration activities that will demonstrate capabilities to prepare for the human exploration of Mars in the 2030s, including such critical capabilities as surface power, mobility, and habitats (both transit and surface).

In addition, exciting work is being conducted on the human health and performance aspects of deep space missions. The extended duration, isolation, and novel operational environment of human missions to Mars will require far more robust health monitoring, maintenance regimens, and autonomous intervention protocols than all prior human spaceflight. Research is also continuing on food and other perishables for such lengthy missions as well as on behavioral health and cognitive function challenges never before faced by astronauts.

Finally, the fascination of the general public for human missions to Mars is perhaps best demonstrated by the extensive and growing number of Mars exploration themes that continue to appear in the media, in the entertainment industry, and even in consumer products. From the space-themed Super Bowl ads by Proctor and Gamble and SodaStream, with the latter featuring a humorous commercial where an astronaut finds water on Mars only to have a crewmate turn it into sparking water using the SodaStream product, to upcoming Mars-themed films, to NASA's "Name the 2020 Mars Rover" contest, in which tens of thousands of students submitted entries (with the winning entry, "Perseverance", being selected in early March 2020), Mars exploration remains firmly embedded within the public consciousness.

The goal of walking on the Red Planet has always held a special place in the collective consciousness of all humanity. The decade of the 2020s is now upon us, and we can now truly say that instead of Mars being two decades away, it is now achievable in the next decade. All we have to do to achieve that goal in that timeframe is to make the decision, and a commitment, to go there.

MARS SCIENCE

Setting the Stage for Human Exploration

As NASA and its partners continue to develop plans to return humanity to the Moon in the 2020s, followed by human missions to Mars in the 2030s, robotic science missions are becoming even more critical to enable our ambitious plans for human exploration. Current robots on and around Mars continue to send back extraordinary data that is critical for human missions of the future. In addition, this year will see the launch of three missions from around the world, including the Mars 2020 rover named *Perseverance*. These missions will serve as essential precursor missions in advance of human missions.

How Do the Upcoming Robotic Missions Advance Human Missions to Mars?

Five robotic Mars missions are scheduled to launch over the next four years. Three missions launched this summer, with additional missions to launch in 2022 and 2024. Never before have so many missions been launched to Mars in such a short period of time.

NASA's Mars 2020 Rover

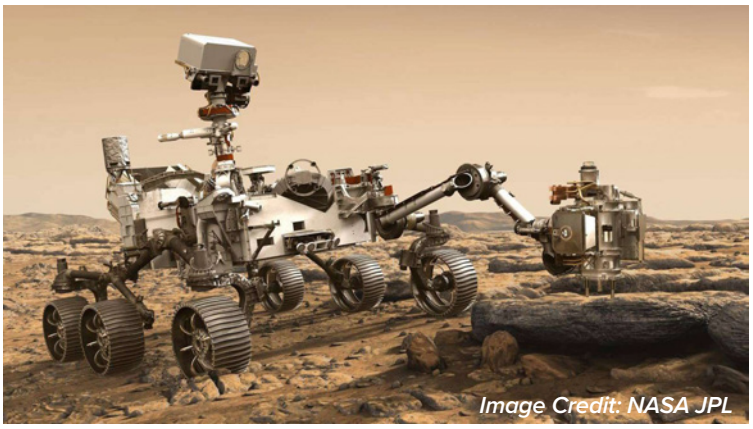


Image Credit: NASA JPL

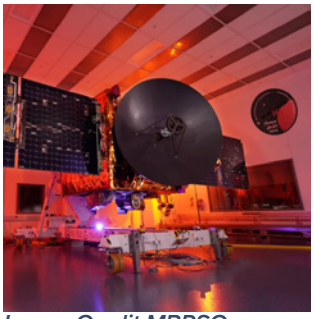
The NASA *Perseverance* rover (https://mars.nasa.gov/mars2020/) is one the most ambitious missions ever attempted, beginning with its entry, descent, and landing that utilizes the same sky crane technology pioneered by the Mars Science Laboratory to survive the "Seven Minutes of Terror" through the martian atmosphere. No less remarkable are the array of instruments it will carry:

- *MOXIE* (Mars OXygen In-situ resource utilization Experiment): MOXIE is the first in-situ resource utilization (ISRU) experiment ever sent to the Red Planet. It is designed to demonstrate a method for extracting oxygen from the martian atmosphere, which consists primarily of carbon dioxide. The precious oxygen obtained from this process can not only be used for propellant, but also for breathing. In short, MOXIE will help determine whether humanity will be able to 'live off the land' using local resources.

- *Mars helicopter*: The *Perseverance* rover is carrying a small helicopter. If successful, it will be the first aircraft to fly on Mars or, for that matter, on any planet other than Earth. Helicopters/drones may be able to explore locations that are otherwise inaccessible – such as cliff sides – and cover far more territory than rovers at a resolution that cannot be achieved by current orbital assets. Aerial systems could one day explore terrain and identify science targets in advance of human crews, a technique that has already improved the science capabilities of crews at Mars analog sites on Earth.

- *Sample return*: The *Perseverance* rover is the first leg in the Mars Sample Return Campaign. The rover is designed to collect martian samples to be packaged and later shipped by other assets: a Sample Return Lander, a Sample Fetch Rover, a Mars Ascent Vehicle, and an Earth Return Orbiter. The mission increases international collaboration while serving as a promising method to understand the planet's geological and biological history.

In March 2019, the Mars Sample Return Science Planning Group released a report from its three-day workshop in Columbia, Maryland. The executive summary includes three conclusions concerning the handling of previously sterilized samples, including the method at which they are contained, shipped, and processed. Ultimately, the group determined that if samples are previously sterilized, it is preferred for scientists to conduct research in their home labs due to the reduced need for containment of samples. Samples that are sensitive to time or are unsterilized are to be done in containment. (https://mepag.jpl.nasa.gov/reports/Science%20in%20Containment%20Report%20Final.pdf)



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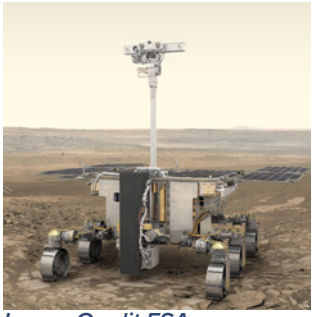


Image Credit ESA

Image Credit JAXA

United Arab Emirates' "Hope" Orbiter

Celebrating the 50th anniversary of that nation's independence, the United Arab Emirates Space Agency (UAESA) launched its Hope mission to Mars on July 19, 2020 to orbit the Red Planet in February 2021 (https://www.mbrsc.ae/emirates-mars-mission). The mission is aimed to answer questions about the planet's climate and the loss of its atmosphere by tracking hydrogen and oxygen activity over the duration of one martian year. This will be the UAE's first robotic mission to Mars.

China's Tiawen-1 Mission

China's Tiawen-1 mission launched toward Mars on July 23, 2020, carrying an orbiter, lander, and rover (https://en.wikipedia.org/wiki/Tianwen-1). One of the primary goals of the mission is the search for evidence of life. This will be China's first robotic mission to Mars.

European Space Agency's ExoMars Rover

The European Space Agency (ESA), in partnership with the Russian space agency Roscomos, is expected to launch its ExoMars rover in 2022 (http://www.esa.int/Science_Exploration/Human_and_Robotic_Exploration/Exploration/ExoMars). One of the primary goals for this mission is to search for signs of past or present life, utilizing a drill that will collect samples up to a depth of two meters below the surface. The ExoMars rover, "Rosalind Franklin," will search for evidence of life on Mars utilizing the Pasteur payload and joint Germany/US Mars Organic Molecule Analyser (MOMA-MS), the first biosignature exploration instrument capable of uniquely recognizing biogenic organic molecules on Mars.

Japanese Space Agency (JAXA)

JAXA's Martian Moons eXpedition (MMX) mission, currently scheduled to launch in 2024, will explore the martian moons, Phobos and Deimos, and will bring back samples from the former (http://mmx.isas.jaxa.jp/en/).

The Search for Past and Present Life: As indicated above, three of the international robotic missions scheduled to be launched in 2020/2022 will search for past or present life. The discovery of life on another planet would be one of the most significant discoveries in human history and transform our understanding of life in the universe. However, it also would have a significant impact on human missions to Mars. If microbial life is confirmed, issues involving preservation, ecology, and planetary protection (i.e., both forward and backward contamination), among others, must become commonplace in the planning for the exploration of our planetary neighbor.

Updates on Current Missions and How They Advance Human Missions to Mars

Once again, there have been important discoveries in Mars science over the past year. Current missions continue to characterize the planet's environment and to advance our understanding of how its climate has changed and the potential habitability of its diverse regions, as well as the possible location of resources that could aid future exploration. Current operational missions are:

- *CURIOSITY ROVER* (MSL): *Curiosity* was launched in November 2011 and landed at Gale Crater on August 6, 2012. This car-sized rover was sent to Mars to investigate whether Mars ever had conditions suitable for life and what the role of water has been, and to examine the geology and climate of the Red Planet.

- InSight lander: InSight (Interior Exploration using Seismic Investigations, Geodesy and Heat Transport mission) landed on the surface in November 2018 to study the deep interior subsurface of Mars.

- *MARS ODYSSEY*: *Mars Odyssey* orbiter is NASA's longest-lasting Mars mission. This spacecraft arrived in orbit in October 2001 with the goal of creating the first planet-wide map of surface chemical elements and minerals. It completed this mission in 2004. *Odyssey* also serves as a vital communications relay for other robots.

- *MARS RECONNAISSANCE ORBITER* (MRO): Arriving in orbit in 2006, MRO was sent to investigate whether water ever flowed persistently on the surface and, if so, whether it flowed long enough to have sustained life.

- MARS ATMOSPHERE AND VOLATILE EVOLUTION (MAVEN): MAVEN arrived in orbit in September 2014 with the goal of studying the planet's atmosphere as well as the reasons for water disappearing over time.

- *EXOMARS TRACE GAS ORBITER* (TGO): The *ExoMars Trace Gas Orbiter* (TGO) began its science activities in April of 2018. TGO began developing improved-resolution maps of hydrogen detections, and has been mapping the water in the planet's upper crust, providing more refined details of localized 'wet' and 'dry' regions. With its NASA-provided relay package, TGO bolstered the Mars Relay Network. It currently returns more than half of the total data downlinked from *Curiosity* and the InSight Lander.

- *MARS EXPRESS* (EUROPE): ESA's *Mars Express* has captured detailed views of the small, scarred and irregularly shaped moon Phobos from different angles during a unique flyby. Mars has two moons: the smaller and more distant Deimos and Phobos, which is considered as a potential landing site for a human mission. At the end of 2019 *Mars Express* skimmed past Phobos at a distance of just 45 kilometers, and used its High Resolution Stereo Camera to take incredibly detailed 360-degree images of Phobos's intriguingly marked surface.

- *MARS ORBITER MISSION* (India): The Mars Orbiter Mission, also called *Mangalyaan*, arrived in Mars orbit in September 2014. This mission by the Indian Space Research Organisation is intended as a demonstration for technologies needed to conduct interplanetary missions. In addition, this mission is also tasked with examining the Martian atmosphere, surface features, mineralogy, and morphology.

Some of the more significant discoveries from the above missions include

Methane on Mars

The Curiosity rover recently detected the largest methane spike that it has observed to date. This spike was thirty times above the previously defined background seasonal peak. The transient nature of these "spikes" are not understood, although they may be related to local, intermittent, and rapid releases of the gas. While the nature of the source of the methane is unknown, subsurface geochemical or biological processes could potentially produce methane.

Geology on Mars

The *Curiosity* rover (Mars Science Laboratory, or MSL) has now driven more than halfway through a region called "the clay-bearing unit," previously identified on the slopes of Mount Sharp via remote sensing from orbit by MRO. Although clays have been identified at several locations along the rover traverse, samples drilled and analyzed by Curiosity in this unit show the highest amounts of clay minerals. Curiosity continues to work its way towards the sulfate-unit, the last of the hydrated mineral zones identified from orbit. Comparison of in-situ and remote sensing data has indicated that when interesting minerals are identified from orbit, the rover typically finds evidence of those same minerals, but the rover data also show that not everything can be seen from orbit, due to dust cover or unexpected changes in grain size. So, orbiters can point the way, but ground truth is essential.

In addition, the InSight lander continues its mission detecting the first definitive measurements of Mars quakes.

Mars Atmosphere and Weather

Examination of the martian atmosphere and weather continues from orbit utilizing MRO, TGO, and Mars Odyssey. This includes the investigation of atmospheric and surface processes and of subsurface structure, particularly in the icy zones at higher latitudes. Exposures of water ice in ice cliffs have been observed in the high mid-latitudes, and a combination of MRO data sets (radar, thermal inertia, morphology) have been used to gain confidence in the location of near-surface water ice.

New analysis of atmospheric temperature and dust profiles from MRO have detected towering dust clouds, reaching 70 km during major dust storms. These dust towers were initially thought to be restricted to high topography, such as the Tharsis volcanoes, although now have been observed over the surrounding high plains as well. These towers may be essential to maintaining the high-altitude dust during major dust events. Meanwhile, on the surface of Mars, InSight and *Curiosity* have provided meteorological measurements of the near-surface atmosphere. InSight, in particular, with wind, temperature, and pressure measurements made throughout the day and night, has provided new perspectives on boundary layer processes. Hundreds of dust devil vortices have been detected in the meteorological fields, even though no dust-filled vortex has yet been captured by the InSight and Curiosity cameras.

Water on Mars

A key interest in the Red Planet is that its ancient surface shows evidence of widespread liquid surface water, unlike the present environment where water is solid (ice) or gas (vapor). MAVEN observations of the current loss of hydrogen (water) and the measurement of key isotopes (e.g., argon) indicate that Mars has lost much water and carbon dioxide to space over its 4.5 billion-year history. Extrapolating loss rates back in time indicates that an early atmosphere was possibly 100 times more massive than today's thin, cold regime.

In addition to ice, hydrated minerals may serve as a modern resource of water or as an indicator of past and present habitable environments. Mars Odyssey data has revealed numerous chloride deposits, and an improved algorithm has enabled the discovery of more than 700 new deposits. MRO continues to add to detections of hydrated minerals, and improved processing of older data has teased out new deposits as well.

COMMUNICATIONS

One role of the NASA and ESA orbiters has been to relay data from surface assets such as Curiosity and InSight back to Earth, providing a big boost to the amount of data returned. The arrival of TGO and the increasing contribution of MAVEN to relay has nearly doubled the volume of data that MRO and Mars Odyssey can return each sol (martian day) from the Mars surface. This capability will be challenged once Mars 2020 and ExoMars rovers are operating on the martian surface. As such, there is great need for bolstering deep space communications for continued robotic missions and for eventual human missions.

RECONNAISSANCE

Three teams combined existing data sets to bridge knowledge gaps about hydrated minerals and subsurface water ice deposits. The combined efforts of all teams are essential to help inform future landing sites, the tools needed to extract water, and how to prioritize observations of the next generation orbiters.

The Subsurface Water-Ice Mapping (SWIM) team made a global map expanding coverage of the Southern Hemisphere while integrating all fresh-exposing impacts for enhanced ice-consistency mapping.

The Mars Orbital Catalog of Chemical Alteration Signatures (MOCCAS) Project produced five high-resolution maps for better identification, characterization, and derivation of water abundance of hydrated minerals across the planet. After ten years of mapping and utilizing CRISM and OMEGA's spectroscopy data, the team identified hundreds of thousands of hydrated mineral deposits and identified tens of types. The team found that limitations of spectroscopy prevent certainty in hydrated minerals as a resource for human missions, and that ground truth may be necessary before advancing human missions reliant on aqueous minerals.

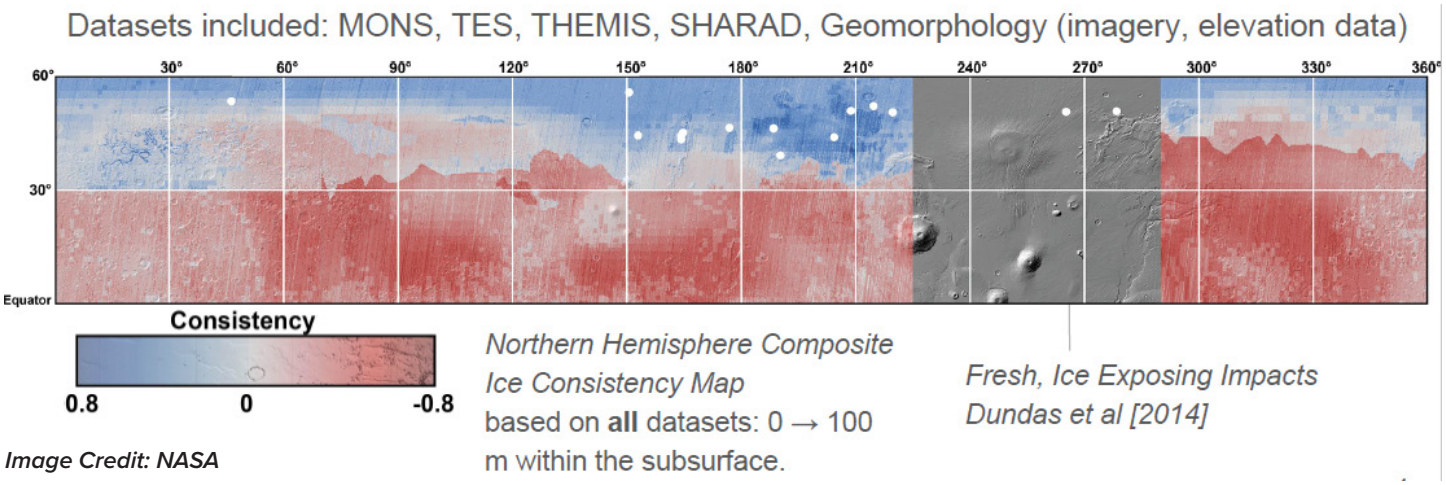


Image Credit: NASA

WATER-ICE DEPTH MAP

In December 2019, a team from NASA's Jet Propulsion Laboratory released a treasure map for water ice. The team processed over a decade of data from Mars Climate Sounder (MCS) surface temperature observations to derive regional and local maps of ice depth. To process this MCS data, the team developed a two-layer thermal model to simulate temperatures on the martian surface arising from different thicknesses of dry regolith overlying a subsurface layer of water ice. By comparing MCS measurements of martian surface temperature with the results of the thermal model across different seasons of the martian year, the team derived regional and local maps of ice depth.

FINDINGS and OBSERVATIONS:

- Stronger collaboration between NASA mission directorates will help assure that the science missions of the 2020s maximize both scientific goals as well as advance human exploration in the 2030s.

- A compelling public relations campaign by NASA and its partners coordinated with the launch and landing of the *Perseverance* rover will advance the goal of sending humans to Mars in the 2030s. This campaign could be modeled on the successful Curiosity/MSL publicity efforts conducted in 2012.

- Implementing next-generation orbiters and surface missions in the near future to prospect for resources (notably water ice) will reduce the overall cost of missions to Mars while providing significant science gains. For example, funded for study in collaboration with Canada is the Ice Mapper, a remote-sensing mission intended to map the near-surface (3-15 meters) water ice, particularly that which lies in the mid-latitude regions. The mission has a target date of 2027. In addition, drilling for sub-surface ice deposits in the planet's Special Regions is especially exciting as there is growing scientific consensus that these ice deposits may be among the most likely places to find evidence of life. Even if in-situ resource utilization (ISRU) is not needed for initial human missions, such reconnaissance is essential for selecting human landing sites. Moreover, an orbiter is also key to replacing an aging telecommunications infrastructure at the planet.

- A round-trip demonstration mission to the martian system would accomplish the National Academies' Planetary Decadal Survey's highest priority, which is Mars Sample Return. Such samples would not only achieve revolutionary science, but they would also allow scientists to assess the material characteristics of martian dust and its potential toxicity to human explorers, as well as to develop appropriate planetary-protection measures.

- Improved weather stations at Mars would permit better understanding of atmospheric dynamics for human entry, descent, and landing, but also improve prediction of dust storms and how human-borne microbes will spread once astronauts are on the surface.

- Improvement in high-resolution imaging coverage of Mars will allow better assessment of such things as rock abundance, local geomorphology, and slope analysis, all key factors in selecting a viable human landing site.

- Improvement in communications infrastructure at Mars is highly desirable. As current telecommunications assets (i.e., repurposed science orbiters) age and the fleet of assets heading to Mars grows, our communications bandwidth will become more strained. Dedicated communications orbiters are essential to maximizing science return and for enabling small missions (e.g., cubesats, small landers, impactors). The data demand will only grow as humans reach the martian system

- Characterizing regolith is not only important to meet science goals, it will inform the design of surface infrastructure (e.g., habitats, labs, rovers, etc.) and potential human health hazards (e.g., toxicity, abrasiveness, extant biology, etc.). Moreover, there is an emerging consensus that civil engineering may be necessary at human bases due to the interactions of the rocket plumes and the surface material on entry. Leveraging local resources to enable civil engineering at the human landing site requires improved reconnaissance of surface material.

ARCHITECTURES AND SYSTEMS

Current Progress of Elements Required for Mars

The year 2019 saw further refinement of NASA's objectives and plans to expand and accelerate human exploration of the Moon in preparation for sending humans to Mars. The Artemis Program (https://www.nasa.gov/specials/artemis/) has evolved into a two-phase approach, with the first phase focusing on returning humans to the Moon by 2024 and the second phase aimed at continued human exploration in a sustainable manner. As this plan has evolved and recently become more detailed, several of NASA's industrial partners have also fine-tuned their approaches to both lunar and Mars exploration. This year's Humans to Mars Report provides a survey of the latest thinking from many of these stakeholders.

NASA SUMMARY

As stated above, NASA has defined the Artemis Program in two phases. Figure 1 shows the overall plan for Phase 1, which culminates in the return of a human crew to the lunar surface.

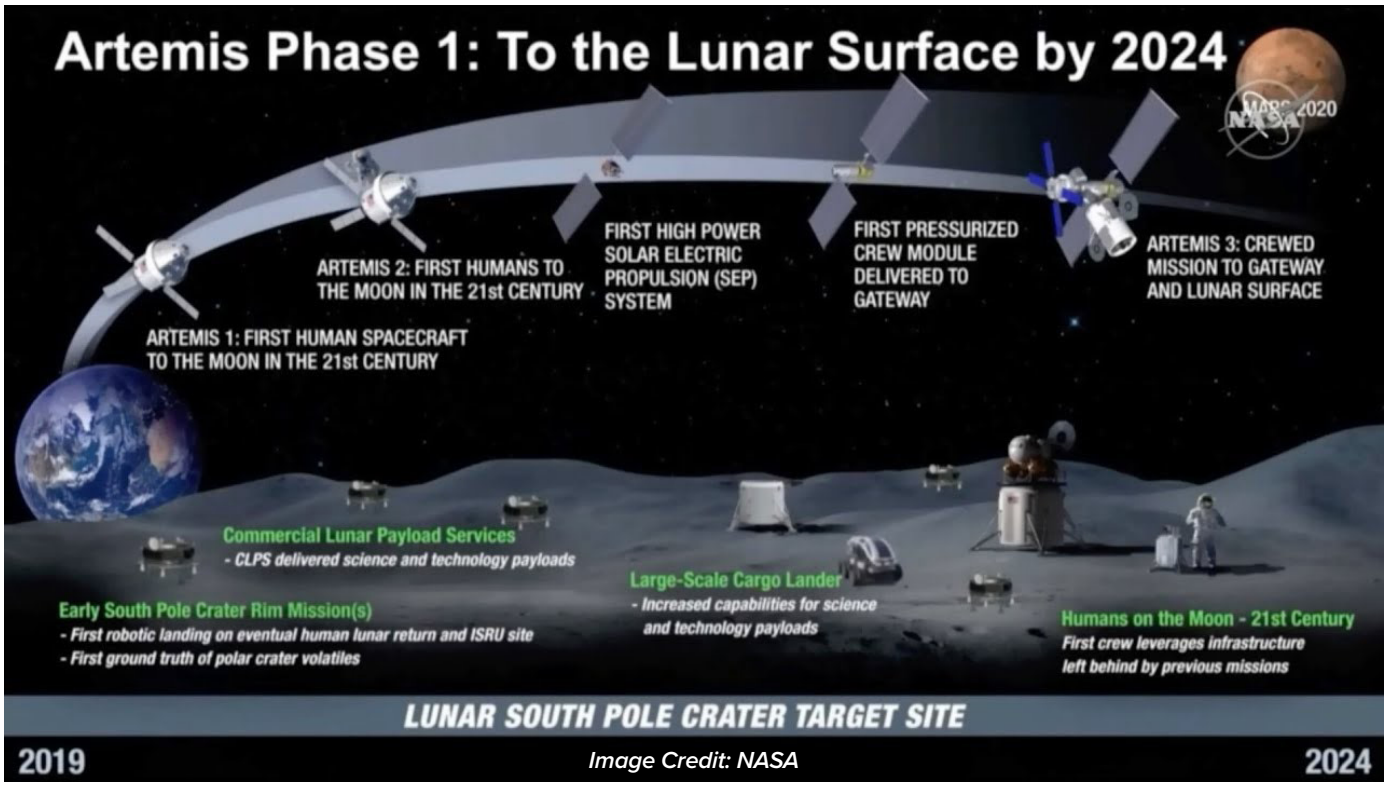


Image Credit: NASA

Figure 1— Overview of Artemis Phase 1

This includes notable steps such as the delivery of precursor payloads to the lunar south pole region using Commercial Lunar Payload Services (CLPS) including the Volatiles Investigating Polar Exploration Rover (VIPER) that can map and detect the presence of volatiles and water ice. Also, as precursors, elements of the cislunar Gateway will be launched and readied for use, including the Power and Propulsion Element (PPE), which will provide a demonstration of high-power solar electric propulsion (SEP).

The second phase of the Artemis Program implements even more activities that will lead to a sustainable presence on the Moon and demonstrate capabilities to prepare for the human exploration of Mars. These are summarized in Figure 2.

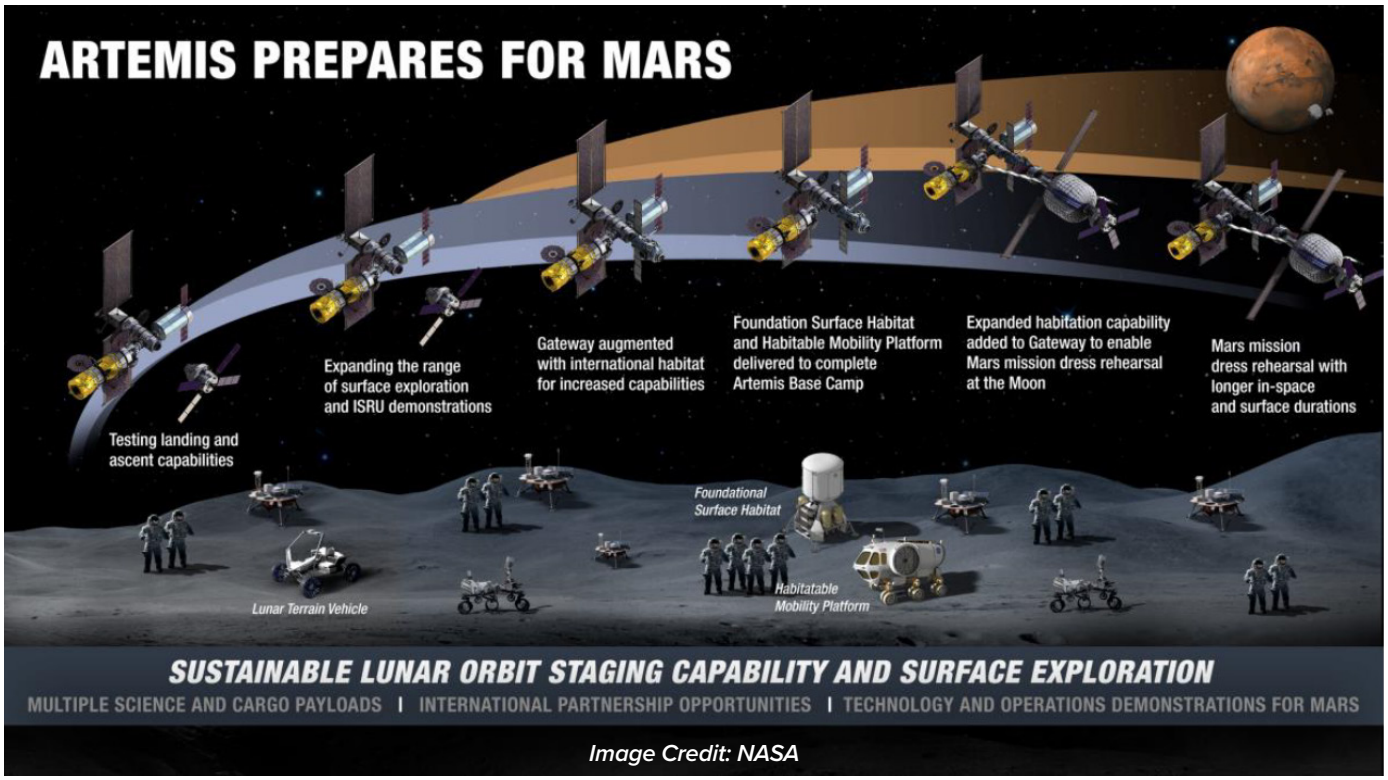


Figure 2 – Artemis Phase 2 develops capabilities for human Mars missions

In Phase 2, the sustainable aspects such as surface power and mobility begin to play a significantly larger role. Tests of surface nuclear power evolving up to as much as 30 kW will pave the way for similar approaches at Mars. Together with additional robotic surface and orbital assets, these will provide support for lunar in-situ resource utilization (ISRU) demonstrations. Key capabilities that will be part of Artemis Phase 2 include the Habitable Mobility Platform (a pressurized rover) and a Foundational Surface Habitat. Operationally, methods for aggregating spacecraft in deep space will be developed and demonstrated in cislunar orbit using the Gateway as the proving ground. Technologies that support crew stays of greater than 30 days will be demonstrated. Eventually, as these are brought online, it will be possible to perform a full Mars mission dress rehearsal in cislunar space utilizing the Gateway and lunar surface assets. All of this will be extensible to Mars missions in the 2030s, a stated goal of NASA.

On April 30, 2020 NASA announced the selection of three awards under the Human Landing Systems (HLS) portion of the NextStep Broad Agency Announcement (BAA). The three winners were The National Team (Blue Origin, Lockheed Martin, Northrop Grumman, and Draper Labs), Dynetics, and SpaceX. The awards are for 10-month studies of the landing systems architecture that can transition after completion into hardware development and fabrication contracts if NASA elects to do so.

Listed below are (in alphabetical order) some of the recent architecture activities that have been underway supporting NASA's Moon-to-Mars pursuits.

NASA's industrial partners have developed and modified Mars mission architecture concepts over the past decade. Many of these concepts have influenced how NASA is planning to return to the Moon and then send humans to Mars. Listed below are (in alphabetical order) some of the recent updated architecture activities that have been underway supporting NASA's Moon-to-Mars pursuits

Aerojet Rocketdyne (AR)

Architecture work in 2019 has concentrated in three areas: support for NASA's Phase 1 Artemis efforts, evolving thinking on Phase 2 Artemis activities (including surface power), and refining efforts on Mars mission architecture. A short description follows for each area.

For the Phase 1 Artemis efforts, AR performed utility analysis of 326,656 possible architectures that could be used to achieve a 2024 landing. This was done as part of a NASA NextSTEP BAA Appendix E award. (This process was presented publicly in detail on January 29 and may be found at http://fiso.spiritastro.net/archivelist.htm). The results showed several interesting trends based on an assessment of many weighted factors including risk, cost, and alignment with long term exploration goals such as use of cryogenic propellants, global lunar surface access, etc. For the 2024 Phase 1 landing, the attributes with the highest weightings were chosen to be reliability and schedule. The utility analysis was used to select 21 architectures for more detailed analysis. Based on criteria including cost (both non-recurring and recurring), schedule (program Authority to Proceed to lunar landing), system hardware reliability, extensibility, and margin on both launch vehicle envelope and payload mass, six final configurations were chosen. These are shown in Figure 3.

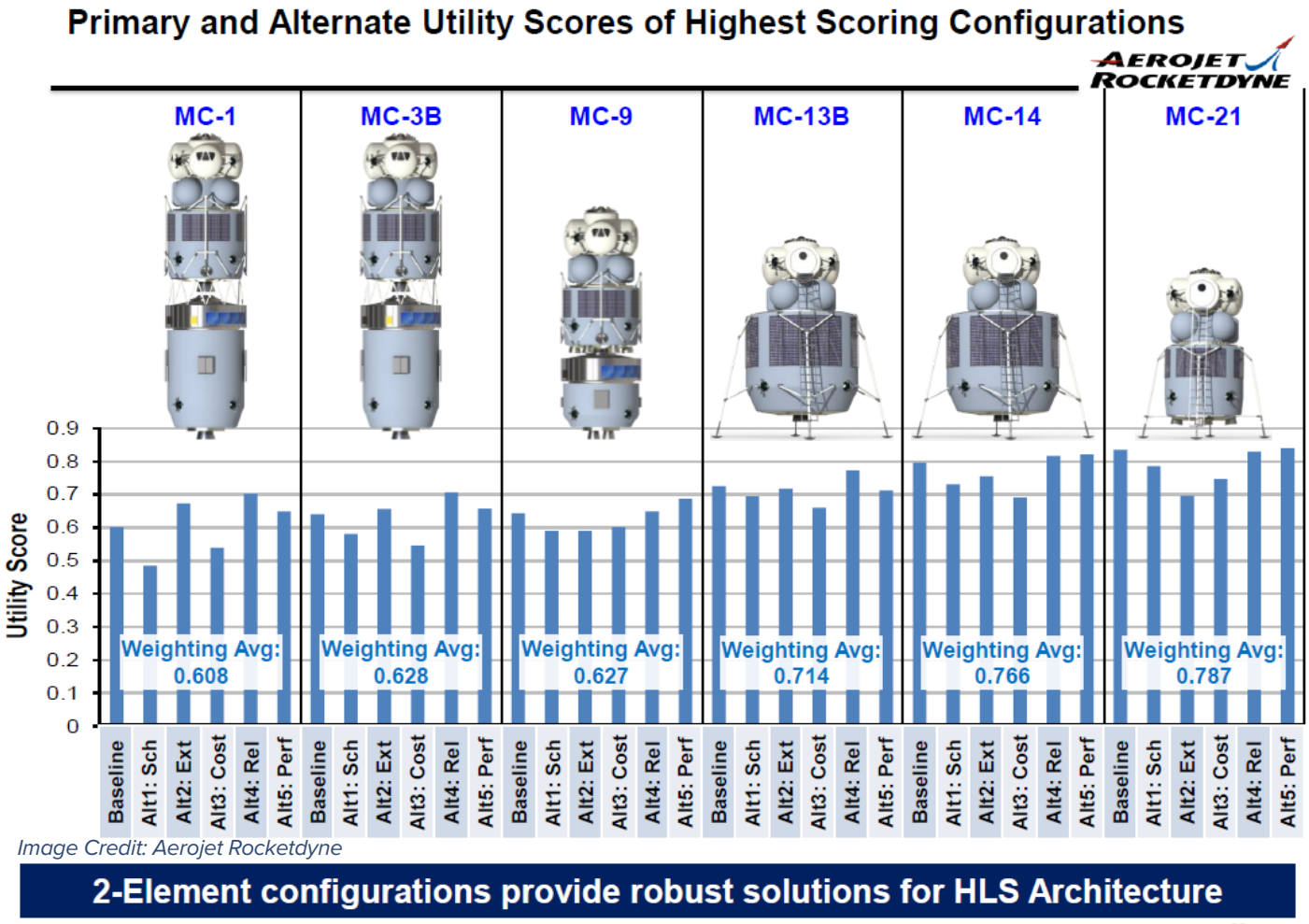


Figure 3 – Six final configurations and utility scores for various criteria weightings (Aerojet Rocketdyne)

The results showed that two-element landers scored higher across the range of weightings examined in the alternate weightings analysis and uncertainty analysis. This approach also puts a premium on minimization of the ascent element and potentially requires the rendezvous with either Gateway or Orion for Earth return to occur in a lower lunar orbit than a Near Rectilinear Halo Orbit (NRHO).

Artemis Phase 2 activities that have taken a larger role in 2019 for AR included further consideration about how the Gateway can be used to prepare for future Mars missions, including use of solar electric propulsion (SEP) for Mars cargo missions. An example is shown in Figure 4, where the SEP aboard Gateway is used to lower the orbit with a small lander attached to reduce the propellant load required of the lander. AR has also been studying the role that surface power will play in activities such as ISRU and how the surface power architecture interacts with the overall surface outpost design and construction. AR also continues to evaluate how technologies such as nuclear thermal propulsion (NTP) can enable more sustainable missions to Mars.

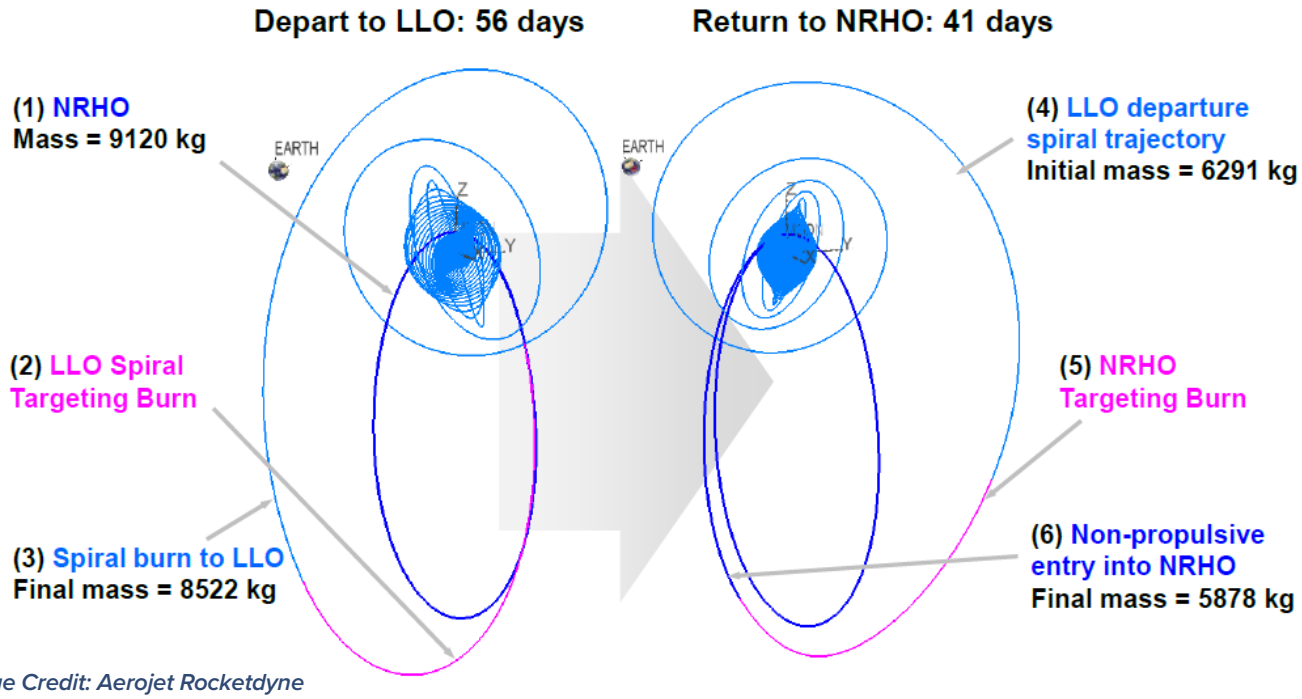


Image Credit: Aerojet Rocketdyne

Figure 4 – SEP transfer of Gateway to deliver cargo lander to low lunar orbit (Earth-Moon two body rotating view) (Aerojet Rocketdyne)

Boeing

The NASA Artemis Program that will return the first woman and next man to the Moon in 2024 is an ambitious undertaking that will further American leadership in space exploration. These missions not only return humanity to our closest celestial neighbor, but also provide a uniquely suited proving ground to mature technologies via flight demonstration that are necessary for successful and safe Mars exploration in the 2030s. NASA will work with industry, academia, and our international partners to demonstrate key capabilities in the cis-lunar environment during the Artemis Program.

Key technologies that should be part of this effort include cryogenic propulsion, cryogenic fluid management (CFM), and precision landing and hazard avoidance (PLHA). Boeing is working with NASA to mature these key technologies as part of the NextSTEP-2 Appendix E HLS Architecture Studies and Prototype Demonstration contract.

Cryogenic propulsion is a critical capability for Mars exploration, which provides much higher performance as compared to storable systems. Cryogenic propellants are also a potentially renewable Martian resource where there is an abundance of CO2 and potentially water from which rocket propellants can be produced. Methane, liquid oxygen, and liquid hydrogen can be produced and used as propellants given planned and forecast ISRU capabilities. This local availability of propulsion resources dramatically reduces the required amount of logistics mass and launch vehicles required for a Mars campaign. Using Artemis to deploy cryogenic propulsion systems in spacecraft reduces Mars exploration schedule risk and provides a long-term opportunity to develop and refine cryogenic propulsion system operations in cis-lunar space well before they are needed for the long-duration Mars missions.

CFM is a key capability that is tightly coupled with cryogenic propulsion technology and has been pursued for decades to enhance in-space transportation system performance. It has been matured through ground development and testing to a point whereby the only remaining step is to demonstrate this technology in space. CFM will be critical to Mars exploration by enabling the storage and transfer of cryogenic propellants produced locally at Mars. This technology significantly simplifies the architecture and logistics requirements for future Mars missions. Artemis will provide the opportunity to demonstrate CFM as part of the sustainable lunar exploration campaign beyond 2026, when cryogenic propulsion can be incorporated into the HLS architecture. Controlling cryogenic boiloff and demonstrating propellant transfer can be achieved in cis-lunar orbit during the Artemis

Program via reusable, cryogenic-propelled HLS elements. Proving this capability on operational cryogenic propulsion systems will increase confidence and reduce risk in pursuing a cryogen-based propulsion system for Mars exploration.

PLHA is another key capability necessary for Mars exploration. Missions to the Red Planet will require prepositioned assets that autonomously land within a tight error band (10s of meters). The Moon is an ideal proving ground for this technology that is key to safely delivering crew and cargo to the desired surface location. Hazard avoidance is also key, as local landing site conditions may have undetectable hazards (boulders, craters, depressions) not visible from on-orbit surveys. Developing and perfecting this technology during Artemis provides the opportunity to mature systems and ConOps for planetary landing maneuvers multiple times prior to the first crewed Mars landing.

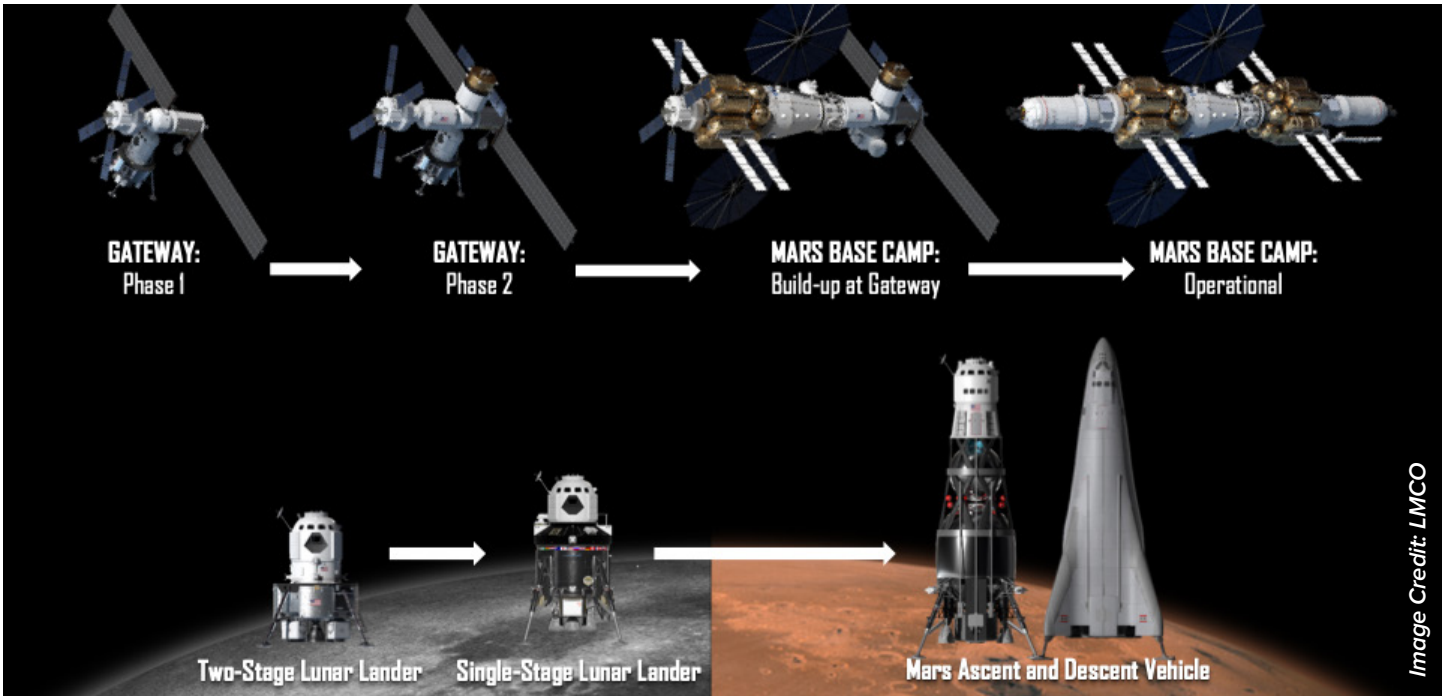


Fig 5 LMCO

Lockheed Martin

Lockheed Martin's architecture and systems work in 2019 focused on supporting NASA's Artemis missions and exploration phases, especially related to evolvability for long-term human habitation on the lunar surface, in Mars transit, and on the martian surface. The upcoming lunar campaign should not offer point solutions for the Moon alone. Making elements of lunar orbital and surface exploration forward compatible reduces the cost, complexity, and development times for future martian missions. Evolvability is a key thread in risk reduction, but also in developing and validating key technologies that feed forward to Mars. Relying on flight-proven technology for the Artemis Ascent Element is critical to maintaining crew safety and schedule credibility. However, using cryogenic hydrogen for the lunar Descent Element adds a direct feed-forward to the propulsion systems needed for Mars transit. Additionally, using the Gateway as an aggregation point for sustained lunar surface missions is critical for element reusability and sustainable logistics operations. The Gateway also provides an ideal point for Mars Transit Vehicle elements to be assembled.

When looking at the extensibility of the Gateway Habitat to the lunar surface or Mars transportation system, there were two interesting findings. One is there are significant infrastructure and logistics required to outfit and support long-term human missions in either environment. The other finding is that testing a Mars transport system through multi-phase shakedown missions greatly reduces the risks for crew on the first Mars mission. Last, using an architecture similar to Lockheed Martin's Mars Base Camp (MBC) provides astronauts headed to Mars with a fully redundant, self-reliant transport vehicle with a fully reusable, single-stage Mars ascent and descent vehicle (MADV) with elements that build upon element and technology developments at the Gateway and lunar landing systems.

Northrop Grumman

Northrop Grumman (NG) continues to support formulation of NASA's integrated Humans-to-Mars enterprise, building off of its heritage, flight-proven vehicles, and advanced, mission-enabling technologies, to provide a highly-capable and affordable solution for a sustainable deep-space exploration enterprise. Its Cygnus vehicle, providing commercial logistics resupply services to the International Space Station (ISS), provides the first step in a long-term roadmap that is demonstrated through the continuous evolution in capabilities toward future Cygnus-derived vehicles (Figure 6) to enable the ultimate goal of landing humans on Mars.

Figure 6--Future Cygnus-derived vehicles, such as HALO, will support Exploration to the Moon, Mars, and beyond. (Northrop Grumman)

While the challenge of Humans-to-Mars is today's ultimate ambition for human exploration, the realism of achieving this goal is highly-dependent on leveraging existing, proven systems and technologies to the greatest extent practicable. Given the criticality of development of enabling technologies such as aerobraking, that do not exist today, minimizing new technology developments to the greatest extent maximizes technical, cost, schedule, and risk realism to enable a sustainable Mars program.

NASA's Habitation and Logistics Outpost (HALO) (Figure 7), awarded to NG in 2019, as the first deep-space crew habitation module ever developed, provides the starting point for future deep-space, crew-inhabited platforms that can support long-duration, deep-space missions.

As Cygnus's evolution has expanded from its primary mission of logistics mission to provide support and augmentation of ISS and Low Earth Orbit (LEO) commercial activities for utilization, NG's in-formulation Cygnus-derived vehicles will support a wide range of functions/missions including habitation (such as HALO), utilization, logistics, node, and airlock. This flexibility enables common production with the ability to have mission-specific configurations built on modularity.

Leveraging Cygnus, HALO provides the next step toward the vehicles and capabilities necessary to support Humans-to-Mars, with extensibility for both in-space and surface operations, for a wide-range of crew, logistics, and support system missions from habitat to pressurized rover. The in-space and surface applicability of NG's Cygnus-derived vehicles provides the ability to deploy heritage, flight-proven vehicles to support Mars exploration in transit, orbit, and on the surface, through operational deployment in support of the Artemis Program.

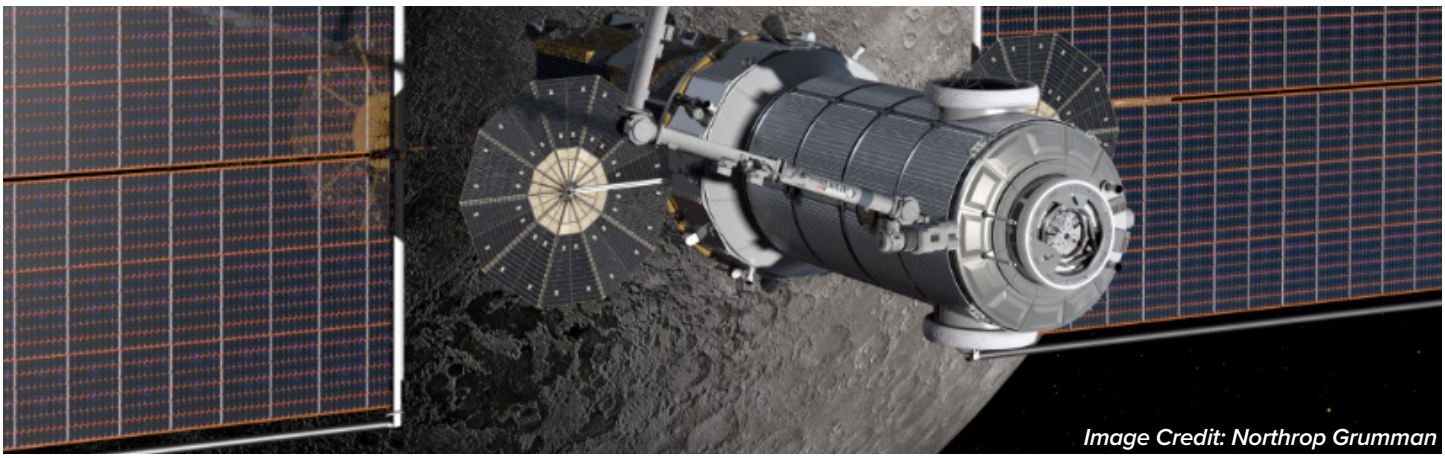


Figure 7— HALO provides the next Cygnus-derived step toward supporting crew transit and habitation to, and living on the surface of, Mars. (Northrop Grumman)

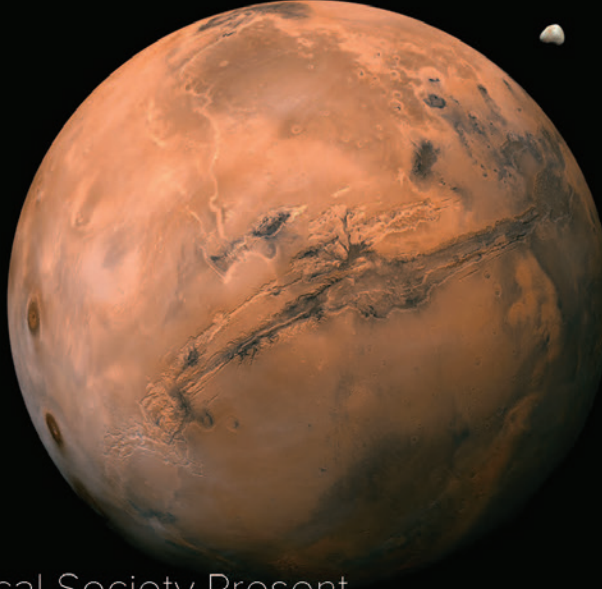
SPACEX

In 2019, we saw a marked increase in progress with SpaceX's Starship system, which the company is building to enable travel to Earth orbit, the Moon, and Mars. SpaceX conducted the first test flights of a Starship prototype test vehicle called Starhopper, and launch and production infrastructure development projects ramped up visibly in Texas. The Starhopper test vehicle was powered by the same Raptor engine and LOX-methane propellants used by Starship and also served as an early manufacturing pathfinder for the program. The culmination of the Starhopper test campaign was a flight to 150 m, followed by a translational maneuver and propulsive landing on a nearby pad. In a live event at SpaceX's launch facility in South Texas, SpaceX Chief Engineer Elon Musk unveiled a full-scale structural prototype of Starship and provided a comprehensive design and development update on Starship and its booster stage called Super Heavy. His presentation highlighted how Starship's super heavy class mass to orbit, full reusability, in-space propellant refilling architecture, and optimization for mass production will enable development of a city on Mars as well as outposts on the Moon. Work on Starship has continued to accelerate as the company rapidly progresses through construction and testing of more mature Starship prototypes. Production and testing of SpaceX's Raptor engine has also ramped up, with engines rolling out of the company's Hawthorne, CA facility on an increasingly regular basis. On August 4, 2020, SpaceX completed a successful hop test of their Starship prototype, reaching an altitude of 150 meters.

Figure 8 – SpaceX's Starhopper in flight (SpaceX)

With the further definition of the Artemis Program, it is clear that NASA sees a path forward from the Moon to Mars. The summaries here are indicative of the progress that is being made toward flights of hardware in the next few years into cislunar space. These flights will begin the process of pathfinding the way to the Red Planet. As the architectures become further refined and the first flights of Orion and Gateway elements take place, we can look forward to a long-duration human presence in deep space for the first time in 50 years. These are the first steps necessary to prepare for humans to Mars in the next decade.

The progress is real and we are on our way!



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HUMAN HEALTH AND PERFORMANCE

Human System Risk for a Mission to Mars

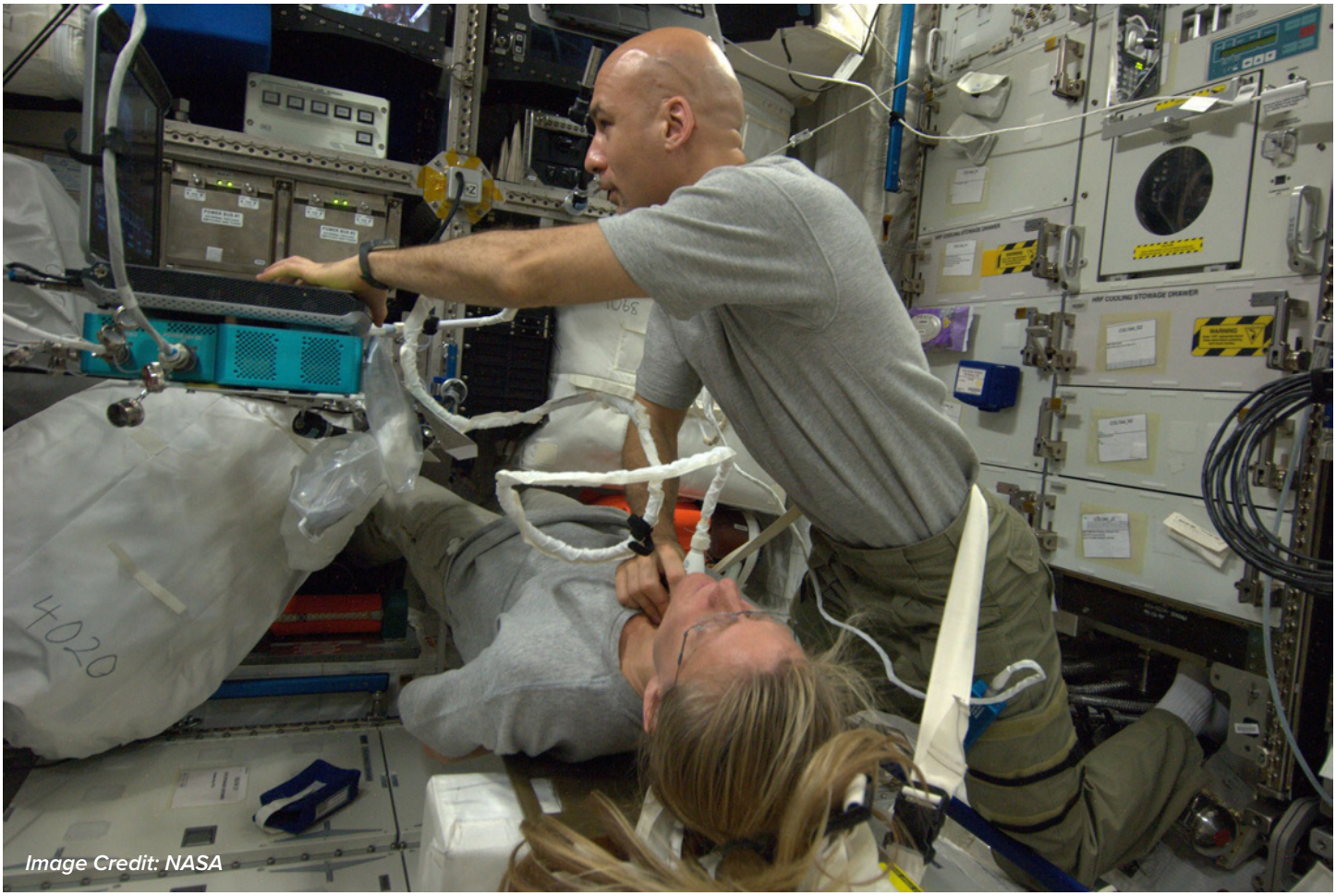


Image Credit: NASA

Journeys to Mars will be the next great endeavor in human exploration, and keeping the people making that journey healthy and productive is a profound challenge. There are both known and unknown risks in current architectures for human missions to Mars that will need to be planned for and countered.

Maintenance of Health

The extended duration, isolation, and novel operational environment of a human Mars mission necessitates more robust health monitoring, maintenance regimen, and autonomous intervention protocol than any previous spaceflight mission in order to maintain crew heath and performance. In comparison to the Low Earth Orbit operations of the International Space Station (ISS) and all prior human spaceflight, a mission to Mars has very restricted re-supply capability, delayed ground-support communication, and no ability to abort to a higher level of medical care during most phases of the mission.

On the ISS, crewmembers have 24/7 ground support, with near-instant communication to physicians, specialists, and biomedical engineers, to address medical issues and to troubleshoot equipment malfunctions. Mars missions will have significant delays of up to 40 minutes in communication, reducing the amount of real-time guidance for procedures or diagnostics. Although improvements to existing communications infrastructure at Mars are expected, the delay in communications will still impact our ability to detect subtle changes in health that could

predict mission-impacting issues before they occur. The communication delay necessitates more emphasis on intelligent systems that can provide decision support and monitoring to assist crewmembers assigned to medical operations. Along the same lines, significant autonomy and robust operations will need to be incorporated into the medical system design as evacuation to a higher level of care will be a functional impossibility during most phases of the mission. In addition, mission operations will need to be prepared to face medical event outcomes that might have a higher morbidity and mortality than is expected on Earth due to the duration and resource limitations of Mars missions. The duration alone (1,100 days) will limit the efficacy of pre-screening the longer the astronauts are away. These realities may require a fundamental culture shift in mission operations and an increased reliance on intelligent systems to ensure crew health.

Current work in this area is focused on designing on-board medical support software to function as an assistant to the crew medical officer without direct ground control and operation. NASA and the medical research community are focused on developing and updating risk models with clinical data over time to better predict real-time health status, changes, and in-flight medical event risks. These models will help identify which specific health conditions will have the largest mission impact through either acuity or likelihood. From there separate research efforts can start or be refocused on countermeasures for the highest-priority conditions. These countermeasure efforts can then be fed back into the prediction model for a feedback model to monitor how overall risk of medical issues is impacting overall mission-risk models.

Exercise is a known countermeasure that improves and maintains crew health and performance, but the existing hardware on ISS is likely too large, maintenance-heavy, and resource-intensive for an exploration mission to Mars. Smaller, more efficient devices will need to be developed and deployed with meaningful run-times to validate their efficacy. Alternatively, medication-assisted muscle and bone-maintenance regimens that reduce the amount of exercise required to maintain muscle and bone function may be developed. Currently crewmembers must exercise 2-3 hours/day, which is a significant driver of daily schedules. Whichever option mission planners pursue, recovering from the 9 months in zero-g transit from Earth to Mars is expected to require significant exertion and strength from deconditioned crewmembers. As such, maintaining crewmember's strength and function is not only for crewmember comfort but may be the difference between survival and death for the first crew to arrive on Mars. The ISS should be used to better understand how crew members will perform during the initial days of mission-critical tasks on the surface of Mars. In a 2018 study presented at the *ISS4Mars conference*, scenarios were outlined that modeled both Mars transit and the first days of a Mars landing using ISS crew. After a stay at ISS, crew members could occupy a mobile facility that can simulate a pre-positioned habitat for a period of between 1 and 3 days. During the stay on ISS, crew should also be subjected to simulated technical problems or medical emergencies.

Immune system dysregulation is another known risk of long-duration spaceflight that is an active area of research for the space life-science community. Recent work has confirmed that the human immune system is less effective during spaceflight and the pathogens that can affect humans are more virulent. The causes of these phenomena are still unknown although many of the countermeasures used to address other human health issues are also effective in improving immune health. Additionally, the burgeoning field of precision medicine may inform targeted pharmacologic interventions that are crewmember-specific and can be identified prior to flight.

With extended-duration crew rotations greater than one year, the ISS is an ideal testbed for these technologies. Isolation and communications delay can be simulated in a very similar analog environment with a higher margin of safety in terms of evacuation potential. Furthermore, the Artemis Program that is NASA's current priority can serve as an excellent testbed for several of the health maintenance technologies needed for sustained Mars exploration. More specifically, Gateway has been proposed in a number of architectures as a critical demonstration site for capabilities, including health management, necessary to have onboard the Mars transit vehicle.

It is also worth noting that we do not yet fully understand all of the hazards that exist on the martian surface. There may be health risks associated with the regolith/dust due to its toxicity, potential for respiratory harm, or biological risk from extant life, if it exists. These risks may not impact the success of the mission, although further study will be required to rule them out. Mars sample return missions and missions to access martian subsurface ice may prove vital to answering open questions in this area. This is a key area of further collaboration between NASA's science and human space flight programs.

Image Credit: NASA

CONSUMABLES

Good diet leads to better health outcomes, both in physiology and behavioral health contexts. On the ISS, food and medications are re-supplied at every opportunity, yet still one of the most common crewmember complaints is the taste or quantity of the preferred food available to them. On a Mars mission the food available at the outset is the amount available for the entire trip, absent food grown during transit or obtained at pre-placed depots although these supplies will be older than the food brought with the crew. Food and other perishable goods are exposed to the same gravitational and radiation environment as the rest of the spacecraft, impacting their flavor, stability, nutritional content, and potency. Ideally, crew could use the significant transit time during a Mars mission to grow and harvest a fresh, flavorful, and sustainable food source to be used during the mission. This is an active area of ISS research, and in the last year the ISS crew has grown and harvested fresh vegetables such as lettuce. Spacecraft-grown plants and food also could provide further benefits of supplemental carbon dioxide scrubbing, removal of nitrates from water supply, plants with pharmacologic applications, and radiation shielding from the soil/water stores. There also could be behavioral health improvements from the presence of greenery, hypothesized to provide psychological benefit, although currently not a validated countermeasure.

Providing effective medications incur their own challenges. For instance, identifying a medical condition early is not sufficient if the medications required to treat that condition have degraded due to the spaceflight environments, so efforts are needed to monitor pharmaceuticals for efficacy during the flight and design the storage environment to reduce radiation and vacuum exposure degradation. It is not currently known whether the existing food and medication storage procedures for ISS will suffice for a Mars mission, as most methods only certify stability for approximately 2 years and a Mars mission is projected to take approximately 3 years. Also, many storage options available for extending the duration of consumables require significant refrigeration systems that challenge mass, volume, and power constraints for an extended duration mission. Development of appropriate storage technology and maintenance protocols will require extended duration ground and ISS analogs for Mars missions to longitudinally test performance and efficacy.

Deciding which and how many of various medications the crew will bring will guide storage and maintenance decisions. Using models of human health and performance, the goal should be to determine the fewest amounts and types of medication that will treat the broadest indications and medical conditions that are likely to develop in-flight during a Mars mission.

Behavioral Health and Cognitive Function

Humans can be greater than the sum of their parts when working in a team. However, the makeup and size of the team and the context of the team's operation are essential elements in optimal performance. A Mars mission will be extended-duration, isolated, and cramped, and require adaptation to different environments (e.g., deep space, Mars orbit, Mars surface) across mission phases. Each of these factors can negatively affect teamwork and performance. Also, potential radiation effects on cognitive function could exacerbate these dynamics.

Currently, space agencies do most of the work of behavioral health and cognitive function assessment during the selection phase of astronaut training. During ISS increments, crewmembers are given almost free-range to communicate with their families and the Earth through telephone calls, emails, and social media, which may be available during a Mars mission, although significantly delayed and in limited capacity. Furthermore, due to the extended duration and isolation, Mars missions will have many more stressors with fewer opportunities for mitigation compared to ISS, presumably leading to higher incidences of behavioral or psychological issues. Current management strategies include verbal behavioral health counseling with the ground and potential pharmaceutical intervention. Real-time counseling will be limited and likely frustrating with communication delays inherent in a Mars mission, and resource constraints will limit the ability to utilize medications, both of which could further stress an already stressful environment.

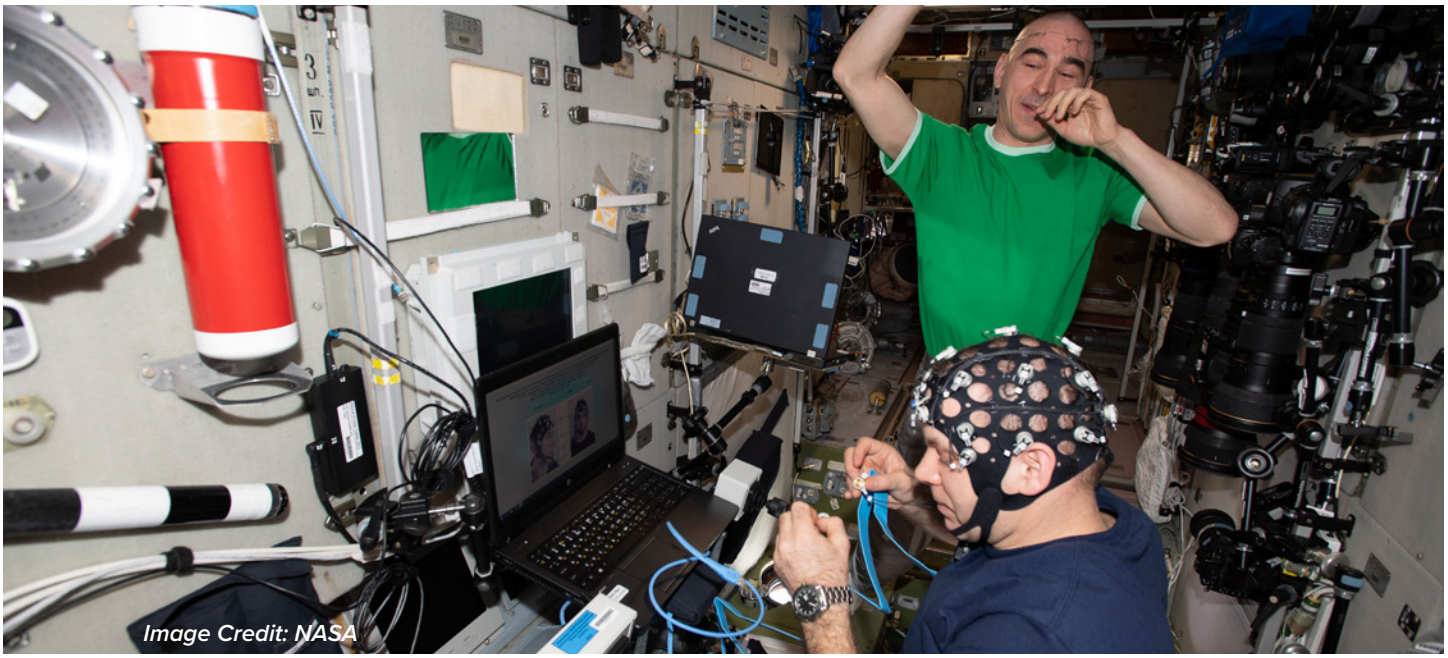


Image Credit: NASA

Of the many unknown effects of radiation, damage to the neurologic system due to continued exposure to the interplanetary radiation environment is a potent unknown. Any decrease in cognitive function is known to increase aggression and decrease interpersonal skills, a potentially toxic combination in an environment dependent on cohesive team dynamics.

Countermeasure development in this area is focused on monitoring of behavioral health, assessments of cognitive function, investigation of relevant biomarkers, and efforts to characterize the effect of radiation exposure on neurologic processes to further inform medical interventions that may alleviate these effects. At this point in time, most radiologic testing is being done in tissue and rodent models, while other behavioral health research and interventions are being studied in analog environments such as Antarctica and the Human Exploration Research Analog (HERA) system at NASA.

There are several interventions that are currently being developed from ongoing research, including better-defined selection criteria based on ideal team dynamics, monitoring and trending radiation-associated biomarkers for pharmaceutical targeting, virtual reality assisted behavioral health counseling for real-time interventions with interpersonal conflict, and modification of exercise regiments to optimize their positive psychologic effects.

Integrating Humans into the Overall System

Utilizing all of the above research and development will require a change in the way humans are integrated into the overall flight system from the way NASA and other space agencies have operated in the past. Crew will have to be integrated into the vehicle as design elements rather than treating them as crewmembers who will be trained to perform specific tasks. It will likely be impossible to train crew to the depth of knowledge currently required for every mission-critical task known or likely to occur during a Mars mission, or for mission-critical tasks that are not likely to occur, but if they do nevertheless occur would cause mission failure if not addressed properly. This is due not only to the duration of the mission, but also to the sheer number of events that might occur during a multi-phase three year-plus mission, as well as the retention of skills required for rare events. This gap in current procedure and required training regimens drives requirements both for new approaches in training as well as integrating information and crew training to a system that is designed with the vehicles from their earliest inception.

Training crewmembers in concepts rather than rote procedures, and treating crewmembers as a component of mission design rather than operators of mission procedures, are promising approaches. Further research and development in just-in-time training including virtual and augmented reality-assisted training, decision support systems, systems designed for in-flight maintenance and modification, human-robot interaction, and crew resource management are all part of managing these risks as well.

Integrating the crewmembers into the wider flight system will involve planning for the ergonomic differences due to the increased diversity and gender differences in current and future crew populations. As seen with the delayed plan to undertake the ultimately successful first all-female spacewalk at ISS in 2019, the majority of the systems and equipment in previous systems were inventoried and designed with male astronauts as the baseline design type. It should be assumed that female astronauts will likely comprise at least half of the crew population intended for Mars and exploration flight and, as such, we should assure that systems and equipment are designed in a manner to accommodate a wider range of body shapes and physiologies. Indeed, the mission operations changes required by delays in the Commercial Crew Development program led to the second “year-long” ISS mission being completed by Christina Koch. This is providing a wealth of female adaptation data to compare and augment the data generated by Scott Kelly’s mission.

NASA is aware of these integration challenges and, as an engineering-focused agency that has had difficulties in the past in appropriately integrating the contributions of physicians and life-scientists, published a lessons learned technical report entitled, “Engineering, Life Sciences, and Health/Medicine Synergy in Aerospace Human Systems Integration: The Rosetta Stone Project” (NASA SP-2017-633). This report, commissioned by NASA’s Chief Engineer and Chief Health and Medical Officer, details the results of the failures and successes of this integration over NASA’s history and proposes methods and ideas to prevent future failures and build on the successes to improve the chances of getting Humans to Mars.

Recent Events

The COVID-19 pandemic has shown what is possible – and what is not – when the medical, science, and engineering infrastructure of the United States comes together to solve problems that affect all of humanity. Telemedicine has advanced tremendously in the relatively short time span since the pandemic was declared, showing that more medical care can be done remotely than previously thought possible and that the patients by and large are team players in their medical care. Also, distributed 3D printing for medical devices has allowed hospitals and health systems to compensate to some extent for supply deficiencies, and show that an idea developed in one location can be tested in another and then be reproduced and put into clinical practice with only the exchange of electronic information between locations. NASA has also contributed to the national effort in this regard, putting out a call to its workforce to contribute ideas to a central agency website that can be coordinated at a high level. All these technologies and concepts, including the de novo isolation equipment being produced as needed to protect health care workers, will be needed on a journey to the Red Planet.

Image Credit: NASA

FINDINGS and OBSERVATIONS:

- More consistent and better-defined exploration goals and timelines than currently provided by the Administration and Congress. This should guide research and development outcomes for Human Health and Performance system design.
- Multiple additional year-long missions with diverse populations in Low Earth Orbit that evolve to the duration of human Mars missions will be required. Consider sending astronauts directly from the ISS to Mars analogs to investigate how self-guided recovery impacts both health and productivity with realistic communications delay.
- Missions beyond Low Earth Orbit will be required to study issues specific to long-distance/duration and confined spaceflight that can only be effectively addressed via a facility similar to the habitation system for Mars exploration (including Gateway).
- Stable, adequate funding, and prioritization of human health in space research initiatives, are required, with increased partnerships and collaboration amongst governmental agencies, commercial providers, physicians, researchers, spaceflight participants, etc.
- Design and integration of the human system to account for the wider ergonomic and physiologic diversity of crew gender and body types.
- Expand plans to conduct Mars mission simulations utilizing both ISS and ground analogs. After initial analog missions mentioned earlier in this section, missions of greater length and complexity should be conducted.

POLICY: OPPORTUNITY and CHALLENGES
Achieving the Moon and Mars

UNITED STATES POLICY

As highlighted in the *2019 Humans to Mars Report* (https://www.exploremars.org//wp-content/uploads/2019/12/H2MR_2019_Web.pdf), in March 2019 the Administration announced plans to (1) return humanity to the Moon by 2024, including the first woman, (2) establish sustainable lunar exploration by 2028, and (3) send human to Mars by 2033. This announcement took place at the 5th National Space Council (NSC) meeting, which was held in Huntsville, Alabama. While human missions to Mars had been an integral part of United States space policy for several years, this new policy directive established clear and ambitious timelines for both human missions to Mars as well as returning to the Moon.

In the ensuing time, there have been further pronouncements and developments, making for a very busy year in policy circles.

Naming of the New Return to the Moon Policy

In May, NASA Administrator Jim Bridenstine proclaimed that the new program would be named Artemis, who in Greek mythology is the twin sister of Apollo and the goddess of the Moon. In addition, NASA would be seeking additional funding to begin development of a commercial landing system to take astronauts to the lunar surface.

Image Credit: NASA

6th National Space Council Meeting (https://www.space.commerce.gov/wp-content/uploads/2019-08-20-National-Space-Council-Recommendations.htm)

The National Space Council held its 6th meeting in August, this time at the Smithsonian National Air and Space Museum's Udvar-Hazy Center at Washington's Dulles International Airport.

Image Credit: NASA

As a result of this meeting, the following recommendations on exploration and international cooperation were made:

- Within 60 days, the NASA Administrator will submit a plan to the NSC for sustainable lunar surface exploration and development, including necessary technologies and capabilities, to enable initial human missions to Mars.
- NASA and the Department of State will continue joint efforts to engage international partners in identifying prospective cooperation involving the 2024 Moon landing and subsequent activities around and on the Moon. Lunar surface operations will be NASA's top priority for international cooperation.
- At the next Council meeting, the NASA Administrator will present a plan to stabilize the Space Launch System and Orion programs and prevent future cost and schedule overruns. The plan will include the current projected launch windows for the first two launches of these vehicles. In addition, Council members will report on support to NASA in implementing Space Policy Directive-1 (https://www.whitehouse.gov/presidential-actions/presidential-memorandum-reinvigorating-americas-human-space-exploration-program/).

This meeting also produced a variety of recommendations on commercial space and industrial base issues, on NASA acquisition and workforce reform, and on updating the launch safety approval process for spacecraft using nuclear power sources.

This meeting also heard from four distinguished experts who, in a panel entitled "Innovative Space Initiatives," discussed critical technologies and requirements including power generation, lunar resource utilization, gender studies, and mission design.

The panel featured

- Rex Geveden, President and Chief Executive Officer, BWX Technologies, Inc. (Nuclear Power)
- Dr. Clive Neal, Professor, College of Engineering, University of Notre Dame (Lunar In-Situ Resource Utilization)
- Dr. Saralyn Mark, Founder and President, iGIANT® and SolaMed Solutions, LLC (Gender Studies)
- Dr. Elizabeth Turtle, Planetary Scientist, Johns Hopkins University Applied Physics Laboratory (New Frontiers Mission to Titan)

The Artemis Accords

On May 15, 2020, NASA released "The Artemis Accords: Principles for a Safe, Peaceful, and Prosperous Future," in which NASA promulgated its vision for the establishment of a common set of principles to govern the civil exploration and use of outer space. (https://www.nasa.gov/specials/artemis-accords/index.html)

In the Artemis Accords, NASA indicated that "International space agencies that join NASA will do so by executing bilateral Artemis Accords agreements, which will describe a shared vision for principles, grounded in the Outer Space Treaty of 1967, to create a safe and transparent environment which facilitates exploration, science, and commercial activities for all of humanity to enjoy". The Artemis Accords would require signatory nations to abide by the following guiding principles in space: (1) peaceful purposes, (2) transparency, (3) interoperability, (4) emergency assistance, (5) registration of space objects, (6) release of scientific data, (7) protection of heritage, (8) extraction and utilization of space resources (with specific emphasis on Articles II, VI, and XI of the Outer Space Treaty), (9) deconfliction of activities, and (10) mitigation of orbital debris and safe, timely and efficient spacecraft disposal.

7th National Space Council Meeting

The seventh meeting of the National Space Council was originally scheduled to take place on March 24, 2020, but this meeting was postponed due to the progression of the COVID-19 crisis. The rescheduled live-streamed meeting occurred on May 19, 2020. Among the highlights of this meeting was NASA Administrator Jim Bridenstine's statement that the Artemis I mission would now take place by the end of 2021. This would be an uncrewed test flight of NASA's Space Launch System (SLS) and Orion spacecraft, with Orion going around the Moon. In addition, it was announced that the State Department is already in discussions with five countries not identified at the meeting about the Artemis Accords.

NASA Authorization Bills

Both houses of Congress presented new NASA authorization language over the past year. Both support plans to return to the Moon and then send humans to Mars, although they vary notably on priorities and timelines for achieving these goals:

- *United States Senate*: In November, the Senate Subcommittee on Science and Space introduced the *NASA Authorization Act of 2019* (https://www.congress.gov/bill/116th-congress/senate-bill/2800). This piece of legislation called for an extension of the life of the International Space Station and called on NASA to complete an upgraded version of the Space Launch System by 2024. It also called for the NASA budget to be set at $22.75 billion in fiscal year 2020, which is the same amount in the Appropriations bill passed by the Senate several days earlier.
- *United States House of Representatives*: In January 2020, the House Space and Aeronautics Subcommittee introduced the NASA Authorization Act of 2020 (https://www.congress.gov/bill/116th-congress/house-bill/5666).This bill appeared to deemphasize lunar exploration and to push back the target date for returning to the Moon from 2024 to no later than 2028, with an orbital mission to Mars in 2033.

Congressional Hearings

Both houses of Congress continued to conduct hearings on the overall goals and execution of our space program. These include:

- July 17, 2019: Hearing before the Senate's Committee on Commerce, Science, and Transportation, entitled, "Moon to Mars: NASA's Plans for Deep Space Exploration". (https://www.commerce.senate.gov/2019/7/moon-to-mars-nasa-s-plans-for-deep-space-exploration)

  Witness: NASA Administrator Jim Bridenstine

  During this hearing, Administrator Bridenstine stated that, "We are working on a sustainable campaign of exploration, transitioning the International Space Station (ISS), returning humans to the surface of the Moon and lunar orbit, where we will build the systems, deep space infrastructure, and operational capabilities to expand human presence into the solar system, eventually embarking on human missions to Mars and other destinations."

- September 18: Hearing before the House Subcommittee on Space and Aeronautics entitled, "Developing Core Capabilities for Deep Space Exploration: An Update on NASA's SLS, Orion, and Exploration Ground Systems". (https://science.house.gov/hearings/developing-core-capabilities-for-deep-space-exploration-an-update-on-nasas-sls-orion-and-exploration-ground-systems)

In her opening statement, Representative Kendra Horn (D-OK), Chairwoman of the Subcommittee, stated, "As I said in the first hearing of the Subcommittee this Session, 'Mars is the horizon goal and I want Americans to be the first to set foot on the Red Planet.' It is a goal worthy of this great nation and NASA's Space Launch System—SLS—Orion Crew Vehicle, and Exploration Ground Systems—EGS—are essential core capabilities for getting us into deep space and onward to Mars. Because I believe moving human exploration beyond low Earth orbit in a safe, sustainable, and affordable way is a goal we all share and want to achieve."

This hearing featured the following panelists:

- Mr. Kenneth Bowersox, Associate Administrator (Acting), Human Exploration and Operations, National Aeronautics and Space Administration
- Ms. Cristina Chaplain, Director, Contracting and National Security Acquisitions, U.S. Government Accountability Office
- Mr. Doug Cooke, Owner, Cooke Concepts and Solutions; Former Associate Administrator, Exploration Systems, National Aeronautics and Space Administration

Note: On October 16, Administrator Bridenstine and NASA Acting Associate Administrator for Human Exploration and Operations, Kenneth Bowersox also testified to a hearing of the House Subcommittee on Commerce, Science, Justice, and Related Agencies called "NASA's Proposal to Advance the Next Moon Landing by Four Years."

Administration and NASA statements on Using the Moon to Enable Mars Exploration

Several times throughout 2019, NASA Administrator Jim Bridenstine reiterated that the Moon will be utilized to enable sustainable missions to Mars. For example, he stated at the 2019 International Astronautical Congress that took place in Washington, DC in October, "If we are accelerating the moon landing, we are accelerating the Mars landing…I suggest we can do it by 2035."

Vice President Mike Pence also made statements articulating the goal of utilizing the Moon to help send humans to Mars. At the 5th National Space Council meeting, he stated that we will "return American astronauts to the moon for the first time since 1972 for long-term exploration and use," not only to "plant our flag and leave our footprint," but we will go there to "establish a foundation for an eventual mission to Mars." Then, on July 20, at the 50th Anniversary celebration of the Apollo 11 lunar landing that was held at the Kennedy Space Center, he stated, "In the coming years, American astronauts will return to the moon aboard the Orion, and they'll return with new ambitions. We will spend weeks and months, not days and hours, on the lunar surface. This time we're going to the moon to stay — and to explore and develop new technologies. We will extract water from ice in the permanently shadowed craters of the South Pole. We will fly on a new generation of spacecraft that will enable us to reach Mars, not in years but in months."

In his February 2020 State of the Union address, President Trump referenced returning humans to the Moon and then having them land on the surface of Mars. He stated, "In reaffirming our heritage as a free nation, we must remember that America has always been a frontier nation. Now we must embrace the next frontier: America's manifest destiny in the stars…I am asking Congress to fully fund the Artemis program to ensure that the next man and the first woman on the moon will be American astronauts, using this as a launching pad to ensure that America is the first nation to plant its flag on Mars".

NASA's Plan for Sustained Lunar Exploration and Development

On April 2, 2020, and in response to the request issued by Vice President Mike Pence at the August 2019 meeting of the National Space Council, NASA released its report entitled, "NASA's Plan for Sustained Lunar Exploration and Development". (https://www.nasa.gov/sites/default/files/atoms/files/a_sustained_lunar_presence_nspc_report4220final.pdf). This report indicated that after the initial lunar landing that is planned for 2024, subsequent lunar missions would be conducted to prepare for the "mission durations and activities that we will experience during the first human mission to Mars, while also emplacing and building the infrastructure, systems, and robotic missions that enable a sustained lunar surface presence." This sustained lunar presence would be achieved by utilizing the "Artemis Base Camp", which would be established at the lunar South Pole. This report indicated that there are three primary mission elements of Artemis Base Camps: A "lunar terrain vehicle" or LTV, which would be an unpressurized rover; a "habitable mobility platform" for long-duration trips away from Artemis Base Camp; and a "foundation surface habitat" that will enable short-stays for four crew on the lunar South Pole. Over time additional supporting infrastructure would be added, including communications, power, radiation shielding, a landing pad, waste disposal, and storage planning.

On April 30, 2020, NASA announced that it had selected three U.S. companies to design and develop human landing systems for the agency's Artemis Program: (1) Blue Origin, which is developing the Integrated Lander Vehicle (ILV), a three-stage lander to be launched on its own New Glenn Rocket System and the ULA Vulcan launch system, (2) Dynetics, which is developing the Dynetics Human Landing System (DHLS), a single structure providing the ascent and descent capabilities that will launch on the ULA Vulcan Launch system, and (3) SpaceX, which is developing the Starship, a fully integrated lander that will use the SpaceX SuperHeavy rocket. (https://www.nasa.gov/press-release/nasa-names-companies-to-develop-human-landers-for-artemis-moon-missions)

Administration FY 2021 Budget Request for NASA

In February 2020, the Administration requested $25.246 billion in its FY2021 budget proposal for NASA, which would represent an approximately 12% increase from the $22.629 billion budget that Congress appropriated for NASA for FY 2020. Much of this increase would support the Artemis Program such as more than $3.3 billion (as opposed to the $6 billion in the FY 2020 budget) to develop human landing systems. The Administration's FY2021 budget proposal also includes initial funding for the development of various lunar surface equipment, such as $212 million for development of lunar rovers and a surface habitat, $175 million for development of a new lunar spacesuit, and $430 million devoted to a Lunar Surface Innovation Initiative that would fund technology demonstrations, including lunar in-situ resource utilization (ISRU) and power generation.

LEGISLATIVE OUTREACH

Space advocacy organizations continued their support for a sustained commitment by the United States and its partners to go beyond Low Earth Orbit (LEO), including human missions to Mars in the 2030s. Several grassroots visits to Capitol Hill to advocate for our nation's space program were organized in early 2020, including the annual "Legislative Blitz" held under the banner of the Space Exploration Alliance (SEA; https://spaceexplorationalliance.org/), a collaboration of non-profit space advocacy organizations. In such events, laypeople from around the country come to Washington, D.C. to convey to elected officials the importance that the general public attaches to our nation's space exploration efforts. In addition, these individuals advocate for appropriate and sustained funding for our civil space program so that NASA can accomplish all that it has been tasked with by the legislative and executive branches. For example, in the SEA's February 2020 Legislative Blitz, participants called for, among other things, at least a $3 billion increase in NASA's budget.

POLICY OPPORTUNITIES

- Policymakers of both parties should continue to work together in the bi-partisan manner that has characterized our space program initiatives so as to assure that our ambitious space exploration goals will be achieved.
- Policymakers and stakeholders should fully appreciate and utilize the publicity that will be generated by the three international Mars robotics missions that are scheduled to launch in 2020. Never before has there been such a tremendous opportunity to highlight the importance of Mars exploration.
- As lunar activities are developed, such plans should be constructed in a manner that should feed forward to and therefore advance the goal of human missions to Mars in the 2030s and should not hinder achieving that goal.
- NASA and its international and industrial partners should advance the development of systems, technologies, and operations that show promise in enabling human missions to both the Moon and Mars, as indicated in the *Sixth and Seventh Community Workshops for Achievability and Sustainability of Human Exploration of Mars* (AM VI and AM VII) – see https://www.exploremars.org/affording-mars/.
- Multiple opportunities exist to foster synergies and collaboration between government and private entities to create policies and programs that effectively utilize the Moon on the path to Mars.

International Policy

International partnerships and investment will be essential to achieving the goal of sending human missions to Mars in the 2030s. While there are currently no definitive international agreements regarding such missions, the world is nevertheless very much focused on the exploration of the Red Planet.

This is demonstrated by the numerous international robotic precursor missions that are slated to be sent to Mars over the next few years, three of which were launched in July 2020. Never in human history has there been so many international missions being launched to a planetary body. In addition, over the past year, international interest has risen for partnership on the Gateway. This includes the European Space Agency (ESA), the Japanese Aerospace Exploration Agency (JAXA), and Russia's Roscosmos State Corporation for Space Activities (Roscosmos), each of which has expressed interest in joining this partnership. The Gateway has become a critical step in NASA's plans on returning to the Moon in the 2020s and then sending humans to Mars in the 2030s. The Gateway has for many years been identified as a demonstration site for capabilities necessary to be developed in advance of long-duration human missions to Mars; that is, it has been proposed to play a central role in applying the lessons learned developed in building and operating the International Space Station (ISS) to international cooperation on the Moon-to-Mars effort.

Some of the current international Mars missions or programs include:

EUROPE:

ESA Budget and Partnerships

In November 2019, ESA ministers committed to the largest space budget in its history, and member states confirmed European support for a ground-breaking Mars Sample Return mission, in cooperation with NASA. European commitment to the International Space Station is extended until 2030. A smooth transition is planned to the next generation of launchers, Ariane 6 and Vega-C, and a green light has been given to Space Rider, ESA's new reusable spacecraft. ESA reinforced its relationship with the European Union aiming for a joint future in space of all members of the union.

There has also been steadily growing interest among ESA and members of the European space community to support the Gateway. This could serve as a catalyst to expand the International Space Station (ISS) partnership to activities beyond low Earth orbit. ESA's potential contributions include the International Habitat and the ESPRIT module to provide communications and refuelling of the Gateway. Europe expects to use Ariane rockets for ferrying astronauts to this facility.

Mars Robotic Missions

Two European-led Mars orbiters have expanded our understanding of the red planet.

ExoMars: Trace Gas Orbiter (TGO): In April 2018, TGO began its science activities, developing improved-resolution maps of hydrogen detections, and has been mapping the water in the upper crust of Mars and providing more refined details of localized 'wet' and 'dry' regions.

Mars Express: Launched to Mars in December 2003, ESA's Mars Express has captured detailed views of the small, scarred and irregularly shaped moon Phobos from different angles during a unique flyby. This moon is considered a potential landing site for a human mission.

The ExoMars rover, named "*Rosalind Franklin*," now scheduled to launch in 2022, will search for evidence of life on Mars. This rover will probe the near-subsurface and drill down 2 meters for material to be analyzed in-situ. The rover's rotary drill will validate the technologies necessary to access subsurface ice on Mars.

Sample Return

European interest also remains strong for conducting an international Mars sample return campaign. Studying Mars samples on Earth will allow scientists to share resources and send samples to the best laboratories anywhere in the world for analysis.

AMADEE-20

Europe is also participating in valuable Mars analog missions. In October – November 2020, the Austrian Space Forum, in cooperation with D-Mars and hosted by the Israel Space Agency, will conduct AMADEE-20, a Mars analog field simulation in the Negev Desert, Israel. Sixteen peer-reviewed experiments from nine countries, representing scientific disciplines that will be essential to the human exploration of Mars, in engineering, geology, biology, human factors, and psychology, will be conducted during the simulation. Participating institutions come from France, Germany, Israel, Italy, Portugal, Sweden, the United Kingdom, the U.S.A., and Austria. The Israel Space Agency and D-Mars are building a full-scale habitat for AMADEE-20 according to the specifications of the Austrian Space Forum, creating an advanced analog research field habitat for six analog astronauts. A new 600 m2 Mission Support Center is currently under construction.

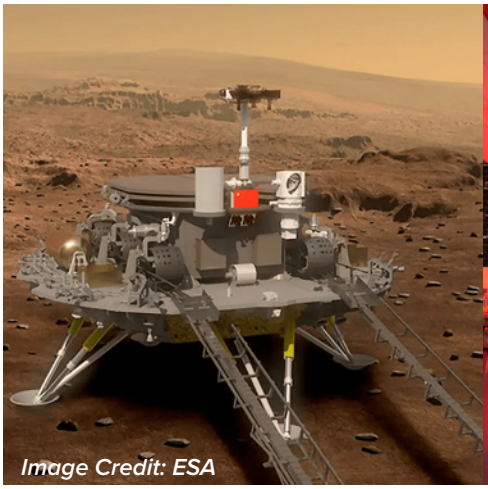


Image Credit: ESA

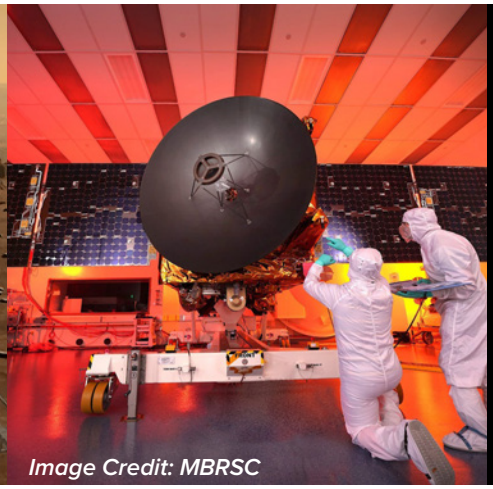


Image Credit: MBRSC

Image Credit: JAXA

ASIA:

- *China's Tiawen-1* mission luanched July 23, 2020, carrying an orbiter, lander, and rover (https://en.wikipedia.org/wiki/Tianwen-1). One of the primary goals of the mission is to search for evidence of life. This will be China's first robotic mission to Mars. China has increasingly expressed its desire to ultimately establish human settlements on Mars.

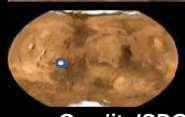
- The *United Arab Emirates* (UAE) continues to be committed to Mars exploration. The Emirates Mars Mission, "Hope," with its unmanned orbiter that will study the planet's atmosphere and climate, launched July 19, 2020 and will arrive in February. In addition, the UAE's Mars Science City, currently in the design phase, will be built near Dubai. Scheduled to be completed by 2023, this simulated, prototype city analog will stimulate international collaboration to advance exploration and will inspire STEM education throughout the Middle East and around the world.

  The UAE also saw the launch of its first astronaut, Hazzaa Ali Almansoori, to the ISS in September 2019 for an eight-day mission.

- The *Indian Space Research Organisation* (ISRO) continues to plan a follow-up mission to its successful Mars Orbiter Mission (MOM) spacecraft of 2016. MOM-2 (also called Mangalyaan 2) may also include India's first Mars lander. Although no firm launch date has been selected for MOM-2, there are reports that launch might be scheduled for some time in 2024.

- The Japanese "Martian Moons eXploration" (MMX) mission is designed to clarify the origin of the Martian moons and the process of evolution for the Mars region. It is tentatively scheduled to launch in 2024 and will be the first sample return mission from the Martian system as well as the first round-trip demonstrator.

Mars Orbiter Mission (MOM) views the Valles of Marineris : A Large Martian Canyon



Images of Valles Marineris and adjoining regions of Mars taken by Mars Colour Camera on board Mars Orbiter Mission on 05-12-2014 at a spatial resolution of 1.2 km from an altitude of 24000 km. Valles Marineris is largest canyon system about 4000 km and 200 km wide and 7 km deep.

Image Credit: ISRO

Findings and Observations

- Based on the success of The Sixth and Seventh Community Workshops for Achievability and Sustainability of Human Exploration of Mars (see https://www.exploremars.org/affording-mars/), similar workshops and programs should be conducted around the world not only to identify overlapping requirements/capabilities for sending humans to both the Moon and Mars, but also how to build an effective international coalition to achieve these goals sustainably.

- While most of these missions/programs promote international collaboration, there is a need for far greater coordination of efforts in order to truly advance international science and human missions to Mars. This coordination among the respective agencies, organizations, and/or partnerships could start with data sharing agreements in such a manner that science/robotic missions to Mars can build on one another to maximize readiness for future human missions.

- As long as valid security concerns by the United States and its international partners are sufficiently addressed, the role of China in future international efforts to reach Mars should be considered by Congressional and Administration policy makers.

- International Space Station (ISS): The ISS is being used today to test equipment, to develop operations concepts, and to better understand the physiological and psychological impacts of being in space for extended durations. It is also an important model of a successful international partnership in space exploration, as well as a model of a sustainable program. This partnership should be extended by the current ISS partners as well as new partners to form an international cooperative effort aimed at moving humanity beyond low Earth orbit and on to Mars.


Image Credit: NASA

MARS AND EDUCATION: Give STEM an "A" (and more!)

Mars as aspiration, inspiration, and the best kind of education is the trifecta that will enable the innovation, exploration, and ultimate human habitation of Mars.

Today public support is the highest it has ever been for sending humans to Mars. According to a Gallup poll conducted in 2019, a majority of the American public – 53% - now supports the idea. By comparison, just after the first Moon landing in 1969, Gallup asked the same question but only 39% were in favor at that time. The public now envisions and supports the human habitation of Mars.

However, according to the White House, only 16% of American high school students are interested in a career in a STEM field (Science, Technology, Education, and Mathematics) and, for example, are proficient in mathematics. It is **imperative** that we create learning opportunities that are more closely aligned to the public's support of a human mission to Mars.

Rachael Mann, author of *Martians In Your Classroom* and *Oh The Spaces You'll Go* says, "Education has always been about the future, and the mission to put humans on Mars will drastically change the world as we know it. The Martians of the future are alive today. They are in the learning spaces of today's classrooms. Space exploration and future missions to Mars and beyond are powerful tools to propel students into this future that, ultimately, they themselves will create. Connecting studies in all content areas to real-life applications in space exploration generates the excitement in the classroom that is needed to make classes more interesting, and the related careers more appealing."

The importance of invention on a broader scale will move to the forefront; and the possibility of doing everything anew will require creative thinkers, doers, and makers. The need is immediate for revised educational methods and practices that will prepare the next generation of space sector professionals to effectively address a wider array of challenges related to long-term Mars habitation.

Some examples of how Mars enriches education include:

- *NASA's online Mars education resources* offer a wide variety of in-depth information organized around self-guided lesson plans requiring minimal resources.
- *AdvancingX*: The AdvancingX initiative, STEM-X, is taking space industry-based content and transforming it into engaging student-led projects, in collaboration with over 87 colleges across the United States and Europe.
- *Martians in Your Classroom*, by Rachael Mann and Stephen Sandford, is a tool for educators to use to tap into the drawing power of space to encourage students to pursue STEM-related areas and careers, both on and off our home planet Earth.
- The privately funded Space Nation initially offered free virtual online astronaut training delivered directly to a mobile device, and now includes for-profit, real-world astronaut expeditions.
- *Cities in Space*, via STEAMSPACE in Austin, Texas, is an annual competition in which students come together to present, compete, and learn from one another about building a new world beyond Earth and how to create a surviving and thriving community.
- *Project Mars*, a competition presented by SciArt Exchange and NASA, invites students, undergraduates, and early career professionals to submit films, music, and posters about humans going to the Moon, Mars, and beyond.
- Similarly, *Mars Academy USA* offers simulated Mars missions in a variety of earthly locations, from downtown Los Angeles to the remote mountains of Nepal.
- *Mission to Mars*, a children's book by Buzz Aldrin and Marianne Dyson, discusses what it will take to travel to and live and work on Mars.
- *Model Mars*, an interdisciplinary platform for exploring space that is currently in development, is designed to engage youth globally, especially those that are under-represented, as they work collaboratively to imagine and create their own futures on Mars, to expand their thinking, and to acquire new skillsets that will enable them to create practical solutions for sustainable lives on both Mars and Earth.
- *Challenger Center*: Challenger Centers continue their extraordinary hands-on STEM education programing, including their 'Journey to Mars' program that guides students through five phases of a Mars settlement. According to their website, this includes "planning, launching, feeling the health effects of lower gravity, living on Mars, and working on Mars." According to Jen Breslin and Jan Millsapps, the creators of ***Model Mars***, "The importance of STEM education must be augmented by additional liberal and creative arts disciplines that will provide the necessary information, skills and tools that humans will need to maintain and expand the functional, thriving communities that they have built. This will enable these communities to not only manage their physical assets and resources, but also themselves as groups of interdependent humans living on Mars for long durations, perhaps permanently. The importance of invention on a broader scale will move to the forefront; the possibility of doing everything anew will require creative thinkers, doers and makers. In short, **STEM will become, with the necessary addition of the Arts, STEAM (and more).**"

When we address the challenges related to going to Mars, the knowledge and innovations created for human survival will present solutions to solving problems and challenges that we face here on Earth. These include food insecurity, water shortages, alternative energy/fuel sources, and so much more. The promise of Mars will foster once again the imaginations of students and of our country as a whole student's and create partnerships and collaboration with other nations. A human mission to Mars could be the greatest thought boon and global uniter we could ever create.

The right stuff for getting us to Mars therefore requires a kind of Mars educational mandate to craft and deliver the interdisciplinary preparation needed for future generations of Martians via a rigorous *STEM +A (and much more) educational platform. Mars is an *invitation*: to wonder, to explore, to ask, and to discover. It is an outstretched hand to the students of today and the explorers of tomorrow, beckoning them to come and discover its mysteries. We must set our educational course for Mars, and we must do it now.

THE PERCEPTION ELEMENT
Mars in the Public Consciousness

As momentum builds for a return to the Moon, Mars exploration nevertheless remains firmly embedded within the public consciousness, with Mars themes consistently appearing within popular culture over the past year.

It is difficult to fully estimate the impact of the worldwide COVID-19 crisis on public perception and overall interest in Mars exploration. At the time of publication of this report, various conferences, workshops, social gatherings, and even space mission-related activities have been postponed or even canceled. However, as a result of these efforts to combat the spread of the virus and the need for social distancing, the demand for online content has grown to an unprecedented level. The space community has increasingly risen to the task of meeting this demand, conducting such activities as:

- Webinars: Online webinars, talks and meetings almost instantly became the primary method of business and dissemination starting in early March 2020.
- STEM programs: Student programming became essential as schools across the United States and elsewhere shut down during the worldwide quarantine. Numerous organizations and individuals are producing high-quality STEM and space programs. An example of this is Janet's Planet Online Astronaut Academy, which is a daily student program produced by Janet's Planet and Explore Mars, Inc.
- Virtual Social Gatherings: With the closure of bars, restaurants, parties and receptions, the general public started pursuing virtual social activities. One example is "Drinks with Explore Mars", which is a weekly online social gathering that features speakers, musical acts, and games.

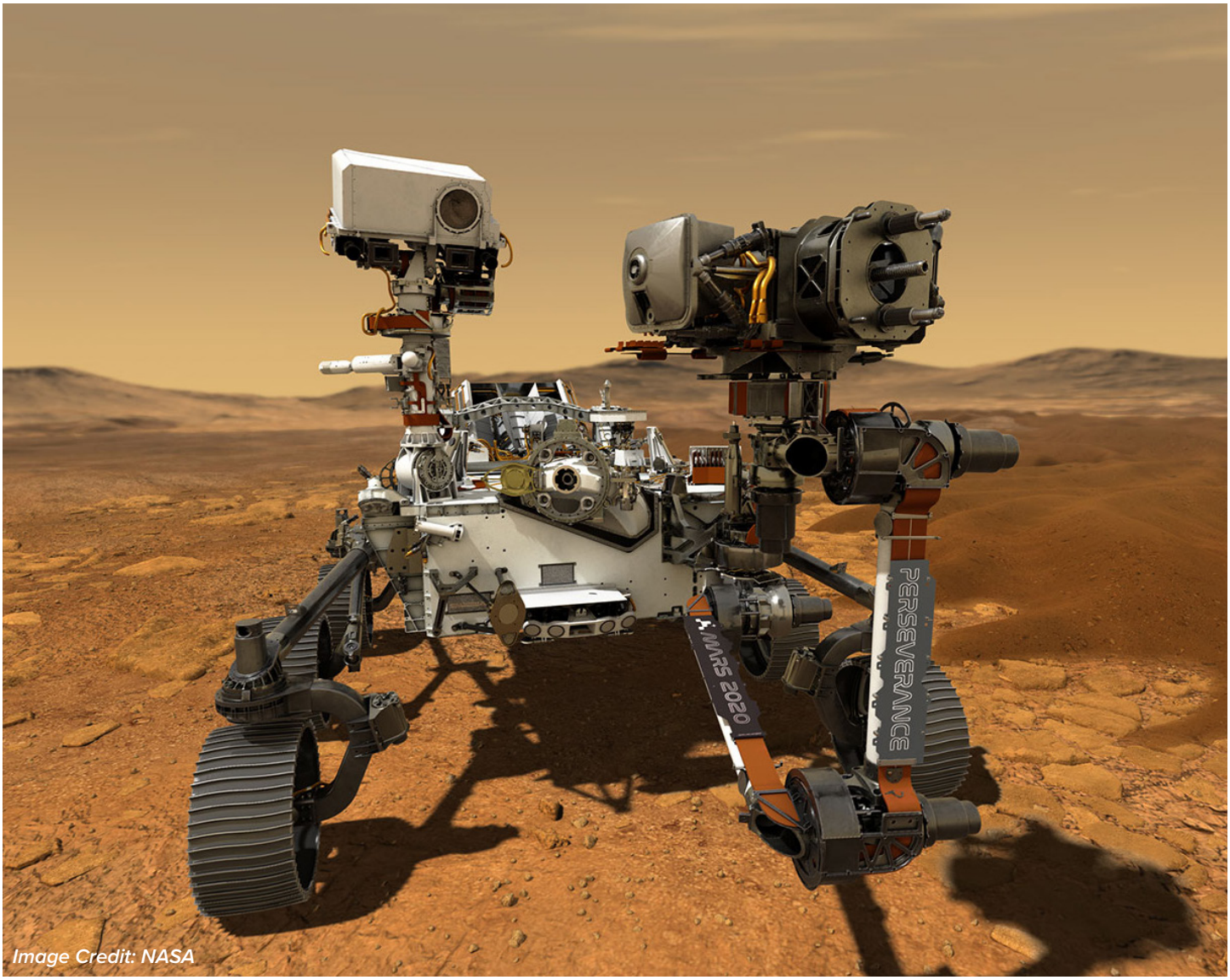


Image Credit: NASA

Mars Perseverance Rover

Preparations for the launch of the Perseverance rover began to capture the public imagination, particularly two programs that directly engaged the public:

- Perseverance: Name the Rover Contest: NASA's naming competition for the 2020 rover generated significant publicity in 2019 and early 2020. Over 28,000 students submitted entries and essays for this competition, which inspired thousands of news stories and social media posts around the world. On March 5, 2020, Alexander Mather, a seventh grader from Lake Braddock Secondary School in Virginia, whose entry was "Perseverance," was selected as the winner of the competition. Due to the fact that so many impressive entries were submitted in this Name the Rover contest, NASA decided, after selecting Perseverance as the name of its rover, to also select a name for the helicopter from those entries. On April 29, 2020, the name Ingenuity, submitted by Vaneeza Rupani, a junior at Tuscaloosa County High School in Northport, Alabama, was selected by NASA as the name of its Mars helicopter.
- Send Your Name to Mars: As NASA has offered with previous Mars launches, the public was given the opportunity to send their names on the Mars 2020 Rover. Participants in this program received a "Boarding Pass," which listed their name as well as the launch site (Cape Canaveral), the landing site (Jezero Crater on Mars), the launch vehicle (an Atlas V541 rocket), and the launch month (July 2020). Over 10 million people participated in this program, with 2.6 million people submitting their names in the first 48 hours.

2020-2021 Mars Missions:

Public enthusiasm for Mars should expand dramatically throughout 2020-2021 as multiple robotic Mars missions will be launched by NASA, the United Arab Emirates, and China. [Note: The European ExoMars mission that was also scheduled to launch in 2020 was postponed until 2022, in part because of COVID-19.] As was the case when the Curiosity rover landed in 2012, the unprecedented convoy of missions launching in 2020 will almost certainly stimulate unparalleled excitement and highlight growing international partnerships and competition to understand the martian environment in preparation for humans missions.

Television and Movies

- New Mars: This short film from the United Kingdom, released in 2019, depicts an underground Mars colony after civilization on Earth has ended. https://www.imdb.com/title/tt9575514/
- Rendezvous with Mars – This short animated film depicts the struggles of a young woman from Bombay, India as she prepares for a voyage to Mars. The film is produced by Bombay based writer/director, Divya More and Mayukh Goswami, a New York-based designer/animator, and is distributed by DUST. https://www.youtube.com/watch?v=7n5L5E88LtU
- Stowaway: Starring Anna Kenrick and Daniel Dae Kim, Stowaway tells the story of a Mars mission that carries an accidental passenger. Since the mission is only provided with enough supplies to sustain the intended crew size, difficult decisions are contemplated. Stowaway will be released in 2020.
- Life on Mars: This upcoming film has yet to move to pre-production, but it is slated to tell the story of a woman who lives on Mars and discovers that she can breathe in the Martian atmosphere. This film will likely be co-produced by John Karsinski in partnership with the production company, Platinum Dunes.
- Mars 2080: Tentatively set to be released in late 2021, this film will be a partnership between Imagine Entertainment and Proctor & Gamble. It will tell the story of a family moving to Mars and how they deal with the dramatic change in lifestyle. The film will be produced by Brian Grazer, Ron Howard and Justin Wilkes.

Image Credit: OLAY

Super Bowl Ads

- SodaStream: The Israel-based carbonated water company, SodaStream, produced a humorous Mars-themed Super Bowl commercial where astronauts find water on Mars only to have one of their crewmates turn it into sparkling water using the SodaStream product. This commercial featured Bill Nye, 'The Science Guy,' and teenaged aspiring astronaut, Alyssa Carson.
- Olay: Procter and Gamble also utilized space in their Super Bowl ad. While this ad is not Mars-focused, P&G assembled a star-studded cast, including Katie Couric, Lilly Singh, Busy Phillips, Taraji P. Henson, and former NASA astronaut, Nicole Stott. The theme of this ad was 'make space for women.'

Social Media

Each year, social media plays a larger role in influencing public perception. According to a 2019 Pew Research Poll, 55 percent of American adults receive their news through social media, 'often' or 'sometimes.' NASA and the space community have been particularly effective at utilizing various social media platforms, which is probably the single greatest factor in the success of the Mars 2020 Rover naming competition as well as inspiring people to 'send their name to Mars.' According to NASA Associate Administrator of the Science Mission Directorate, Thomas Zurbuchen, "Over the past decade, social media has become an integral way NASA shares its science and research with the public. Social media not only allows us to reach a variety of audiences, ages and demographics, but it enables NASA to be more accessible to the public."

Image Credit: Budweiser

Mars Booze

- Budweiser continued toward its goal of being the first beer manufacturer on Mars, sending its fourth experiment to the International Space Station.
- Mars wine: A study appearing in Frontiers in Physiology suggested that the consumption of red wine on missions to Mars would help astronauts remain physically fit. Specifically, resveratrol, an antioxidant in the skin of grapes, could help human crews counter loss of musculature as they live for years in both microgravity and the one-third gravity of Mars.

Findings and Observations

- 2020 Scientific Poll: A new scientific poll should be conducted to gauge public support for human missions to Mars in the 2030s. However, this poll must be conducted in a manner that provides proper budgetary context and accurate information. While polling for Mars has tended to be strong, there is still a major misconception on the part of the general public about the actual size of the NASA budget and why we are going to Mars.
- The space community must harness the excitement surrounding the Mars missions launching in 2020. A united effort could dramatically increase excitement and support for robotic and human exploration of Mars around the world.

https://ExploreMars.Org

Image Credit: NASA