2023

THE HUMANS TO MARS REPORT

AN EXPLOREMARS.ORG PUBLICATION

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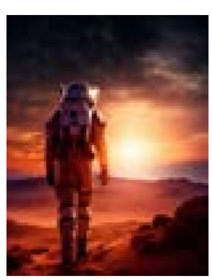

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Explore Mars, Inc. was created to advance the goal of sending humans to Mars within the next two decades. To further that goal, Explore Mars conducts programs and technical challenges to stimulate the development and/or improvement of technologies 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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The HUMANS TO MARS Report 2023

Mars by the 2030s

The Humans to Mars Report (H2MR) is an annual publication that presents a snapshot of current progress in mission architectures, science, domestic 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.

With the extraordinary achievements of the past few years, including the successful landing on Mars of the Perseverance rover, the successful Artemis 1 mission around the Moon and returning Orion safely to Earth, and the first orbital launch attempt of Starship, public interest in Mars shows no signs of wavering. 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 the mid-2030s 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 may also hold the key to the ages old question of “are we alone in the universe?” 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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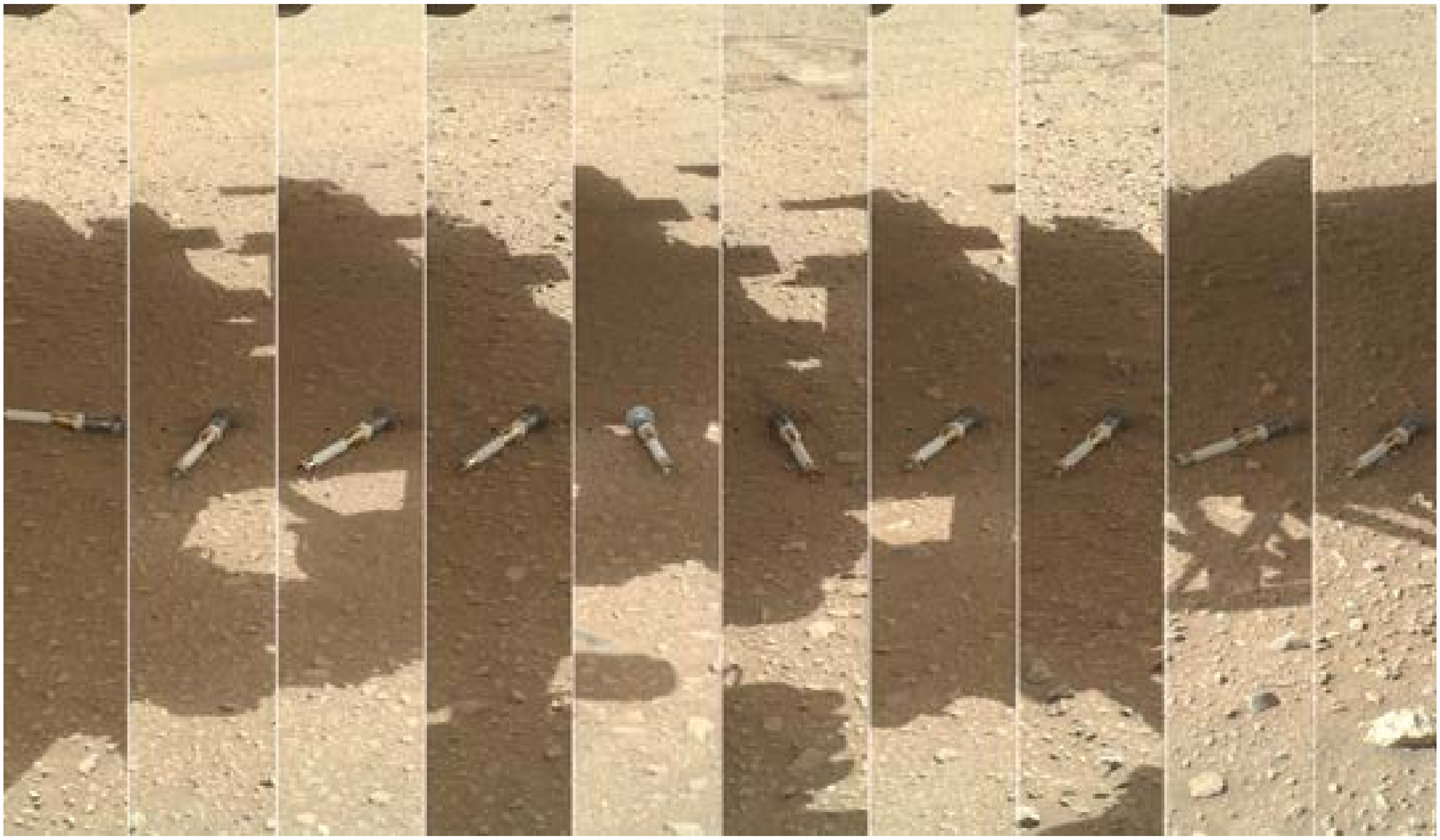
MARS SCIENCE: 2023 and Beyond

Enabling and Supporting the Human Exploration of Mars



The 2020's are proving to be a decade of scientific discovery and of incremental advances towards future human missions to the Red Planet. Three synergistic international missions that each successfully reached Mars in 2021 continue their investigations and are expanding our knowledge via direct contributions to the prospects of human missions to Mars during the 2030s.

CONTINUING SCIENCE AT THE FRONTIER

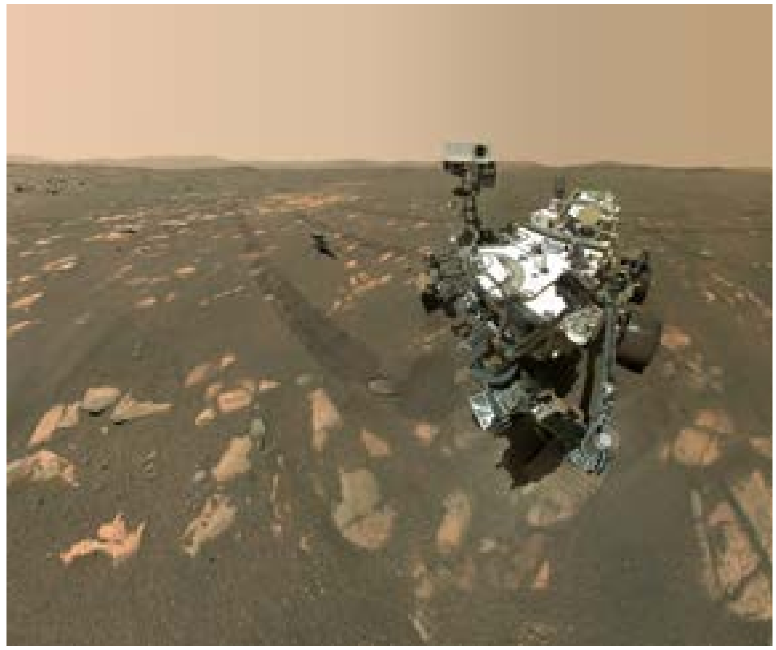
Perseverance

Since February 2021, the NASA *Perseverance* rover has pursued its ambitious mission to acquire and cache samples suitable for return to Earth. *Perseverance* has already demonstrated many unqualified successes, including:

- Mars Sample Return: The *Perseverance* sampling/caching rover is the first leg in the Mars Sample Return (MSR) campaign. In its first two years of operation the rover successfully collected twenty-one of forty-two possible rock, regolith, and atmosphere samples, which are awaiting collection on the Martian surface. Future legs of the MSR campaign will see a lander with fetch helicopters touchdown near Perseverance to collect and launch the samples from the surface to an Earth Return Orbiter. These samples will not only revolutionize our scientific understanding of Mars, but will also inform the design of systems for future human missions. In February 2022, Lockheed Martin received the contract to build the critical elements of the sample return system. In addition, the Biden Administration's 2023 NASA budget proposal sets the goal of returning samples in 2033, two years later than originally planned.

- MOXIE (Mars OXygen In-situ resource utilization Experiment): On April 20, 2021, MOXIE produced oxygen from Mars' carbon dioxide atmosphere for the first time. This technology is critical for a future sustainable human presence on Mars, as in-situ oxygen production can be used not only to provide the 25-30 tons of oxygen needed for propellant but also for breathing. At this point, all mission success criteria have been met and substantial progress has been made on defining a next-generation system to support a human mission.

- *Ingenuity* robotic helicopter: On April 19, 2021, the *Ingenuity* helicopter became the first powered rotorcraft to fly on Mars, or for that matter, on any planet other than Earth. Since that time, this small aerial vehicle has performed more than 47 flights, each one further pushing the limits of the vehicle. *Ingenuity* has far exceeded its baseline technology demonstration requirements to provide unique situational awareness for *Perseverance* as a step toward integrated aerial systems in support of all forms of Martian exploration. Future aerial vehicles offer enormous potential for advancing scientific investigations, for characterizing otherwise inaccessible regions, and for augmenting human capabilities in many of the same ways they have on Earth.



- RIMFAX: The multi-purpose ground penetrating radar on *Perseverance* known as RIMFAX produced seminal results that characterize the uppermost 10 m of the surface layer and its stratigraphy at sub-meter scales for the first time. These measurements help construct a better model of the active surface layer on the planet. Characterizing this region is important for both future human and robotic missions that seek to access the Martian subsurface, not only to answer key science questions (in astrobiology, climatology, and geology), but also to assess resources, such as subsurface ice, for future human use (as drinking water, an ingredient in rocket fuel, construction materials, etc.).

Curiosity

The Curiosity Rover continues to explore as it approaches its eleventh year on the Martian surface. Curiosity is now over 18 miles from its landing site, a journey during which it made important discoveries regarding past surface water on Mars and the prospect of ancient life on Mars.

- During the fall of 2022, Curiosity arrived at a 'sulfate-bearing unit' on Mt Sharp, a region abundant in salty minerals. The rover found ripples in the rocks that are believed to have been formed by a lake on the Martian surface billions of years ago. According to Curiosity project scientist Ashwin Vasavada, "This is the best evidence of water and waves that we've seen in the entire mission…We climbed through thousands of feet of lake deposits and never saw evidence like this – and now we found it in a place we expected to be dry."

- In 2022, Curiosity measured 200 to 273 parts per million of organic carbon in Martian rocks, an amount of carbon that is comparable to low-life areas on Earth, such as the Atacama Desert in South America. Organic carbon is an essential ingredient for life on Earth. This discovery does not prove that there is past or present life on Mars, but it adds to the growing volume of evidence that Mars may once have supported basic forms of life.

China's Tiawen-1 Mission Continues its Exploration in Utopia Planitia

- The China National Space Administration (CNSA) *Tiawen-1* mission arrived in Mars orbit in February 2021. On May 14, 2021, its *Zhurong* rover landed at Utopia Planitia where NASA's Viking-2 mission landed in September 1976. Thus far, this small rover has traversed over 1 km and sent back extraordinary images and related remote sensing data as it pursues its primary science objectives – to search for evidence of life. This is China's first robotic mission to Mars. Unfortunately, the rover appears to have lost contact with Earth after hibernating through the harsh Martian winter and its current status is unknown.

NASA / JPL-Caltech / U. Arizona / MRO HiRISE

United Arab Emirates' "Hope" Orbiter

- The United Arab Emirates' *Hope* mission successfully arrived in Mars orbit in February 2021 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 is the UAE's first robotic mission to Mars. Hemispheric imaging of the planet and its atmosphere have provided new spatio-temporal perspectives, which are furthering understanding of both climate and the role of solar wind on the Martian system in synergy with ongoing results from NASA's MAVEN (Mars Atmosphere and Volatile EvolutioN) mission. This interplay among orbital measurements from HOPE, MAVEN, the Mars Reconnaissance Orbiter (MRO) and ExoMars' Trace Gas Orbiter (TGO) is an essential aspect of precursor robotic efforts to enable safe and successful human access to Mars in the 2030s.

Still Watching from Orbit: ODY, MEX, MRO, MAVEN, TGO, Tianwen-1

- Ongoing orbital reconnaissance by a fleet of international orbiters are sustaining an important "situational awareness" that contributes to the boundary conditions necessary to implement human missions to the Red Planet. This fleet includes NASA's *Odyssey* (now approaching year 22 in Mars orbit, a new record), Mars Reconnaissance Orbiter (MRO), Mars Atmosphere and Volatile EvolutioN (MAVEN) (now led by its new Principal Investigator, Dr. Shannon Curry of UC-Berkeley), the European Space Agency's (ESA) Mars Express, and ExoMars Trace Gas Orbiter. Additional orbital reconnaissance, as described in the report of the Next Orbiter Science Analysis Group (NEX-SAG) of the Mars Exploration Program Analysis Group (MEPAG), published in the Bulletin of the American Astronomical Society (BAAS) in March 2021, will be needed in support of the first men and women to go to Mars. All will build on this legacy of information about the atmosphere, surface, and dynamics of the Mars system.

Gone but not Forgotten: MOM and InSight

- *MOM* (Mars Orbiter Mission) characterized the Martian atmosphere and surface for more than seven years as the Indian Space Research Organization's (ISRO) first mission to Mars. *MOM* assessed mechanisms for atmospheric loss, observed seasonal changes in the Martian polar caps, and measured cloud formation near Valles Marineris among many other investigations. The mission reached its close in Oct. 2022 as the orbiter's fuel and batteries reached critical levels.

- *InSight* (Interior Exploration using Seismic Investigations, Geodesy and Heat Transport mission) explored the interior and surface of Mars, recording some of the strongest Mars-quakes of the mission. Some of these quakes are related to impacts, with several such impacts verified by imaging by MRO from orbit. *InSight* spent four years exploring the Martian subsurface before shutting down in December 2022 due to dust accumulation on its solar panels resulting in reduced power generation.

FUTURE ROBOTIC MISSIONS

EscaPADE (Escape and Plasma Acceleration and Dynamics Explorers)

- NASA plans to launch the twin *EscaPADE* cubesats (named Blue and Gold) in October 2024 to characterize how the Martian magnetosphere interacts with solar winds. The satellites are planned to launch on Blue Origin's New Glenn rocket.

European Space Agency's ExoMars Rosalind Frankin Rover

- The European Space Agency (ESA) is now expecting to launch its ExoMars "*R. Franklin*" rover no earlier than 2028, with a new partnership with the United States in development. The lander/rover will land in the *Oxia Planum* region of Mars with a suite of powerful scientific payloads including a drill which will collect samples 2 meters below the surface (never before attempted) with a goal of detecting long-chain organics at these depths. At two meters depths, radiation levels are significantly attenuated, and as such, this unexplored sub-surface is viewed as a key next step in the search for potential life at 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 Phobos in 2029. Instruments from the U.S. will contribute to its success.

International Mars Ice Mapper (I-MIM)

The planned International Mars Ice Mapper mission (I-MIM) would detect the location and abundance of near-surface ice deposits to identify compelling science targets and potential resources future human use and using a Synthetic Aperture Radar (SAR). I-MIM's Measurement Definition Team (MDT) strongly supported the mission concept and found that the mission would accomplish its objectives as detailed in their report released August 2022. The report recommended the mission consider additional science payloads including: a high-resolution imager, a very high frequency (VHF) sounder, and atmospheric sensors to maximize its science return.

As an international collaboration between the Italian Space Agency (ASI), the Canadian Space Agency (CSA), the Japanese Space Agency (JAXA), and NASA I-MIM represents a new model for Mars missions, where each partner would be contributing major elements to the mission. Future human missions to Mars will probably entail similar partnerships of equals, but learning how to do these efficiently with clear roles and responsibilities, is key. The budget situation for I-MIM is challenging for most of the partners, and particularly for NASA as it works to support ExoMars. We sincerely hope that a path for enabling this critical mission will be found by the partners.

SCIENCE OBJECTIVES FOR HUMAN MISSIONS

Human explorers will bring wholly unique capabilities to exploring Mars in transit, in orbit, and on the surface. Assessing how to best leverage these capabilities to meet priority science objectives sooner than later to inform mission design is a critical near-term step for the Mars science community. Thankfully, several efforts are underway or have already been completed including: the Planetary Science and Astrobiology Decadal Survey 2023-2032, the Science Objectives for Human Exploration of Mars Workshop (held May 2022), the Mars Exploration Program Analysis Group's (MEPAG) Assessment of Science Objectives Benefitting from Human Exploration, and the Achieving Mars IX report. Identifying and prioritizing science objectives for human missions is an ongoing effort that requires participation from a diverse range of disciplines, not only in traditional planetary science domains, but also in human science, biological and physical science, and Mars mission engineers.

ARCHITECTURES & SYSTEMS

Current Progress of Elements Required for Mars

Over the past several years, the NASA Mars Architecture Team was directed to perform trajectory trades and architecture studies for Mars transit vehicle concepts, in particular to compare conjunction-class and opposition-class missions. This initiative sparked adjacent work in industry, resulting in multiple papers and public presentations on Mars transit studies. This section of the report will first discuss these trajectory trades. Then it will discuss the report on nuclear propulsion technologies published by the National Academy of Sciences, Engineering, and Medicine (NASEM). The discussion of Mars transit vehicle concepts that have been developed over the last two years are organized by the main propulsion technology that they implement. The final sections discuss development in supportive surface and landing architectures and developments in Artemis that are directly applicable to crewed Mars missions.

TRAJECTORY TRADES

One of the trade spaces for human Mars missions is the design of the trajectory. The trajectory options are often categorized into two types: conjunction-class and opposition-class, illustrated in Figure 1. Opposition-class missions are characterized by a slightly longer transit time, a shorter Mars stay time of about a month compared to about a year for conjunction class, a shorter overall mission duration, and higher propulsion requirements in the form of changes in velocity (ΔV). This combination of attributes can lower some duration-related risks for astronauts because of the shorter overall time spent away from Earth than a typical conjunction mission, but at the expense of a greatly reduced time at Mars for the express purpose of the mission: scientific exploration. Conjunction-class missions optimize the orbital dynamics to minimize the required propellant, resulting in longer overall mission duration and more time at Mars than opposition-class missions. Of note, all missions do not necessarily fall into one of these categories, as there are many possible Mars missions on a continuum between the conjunction and opposition-class missions.

Conjunction Class Mission

Opposition Class Mission

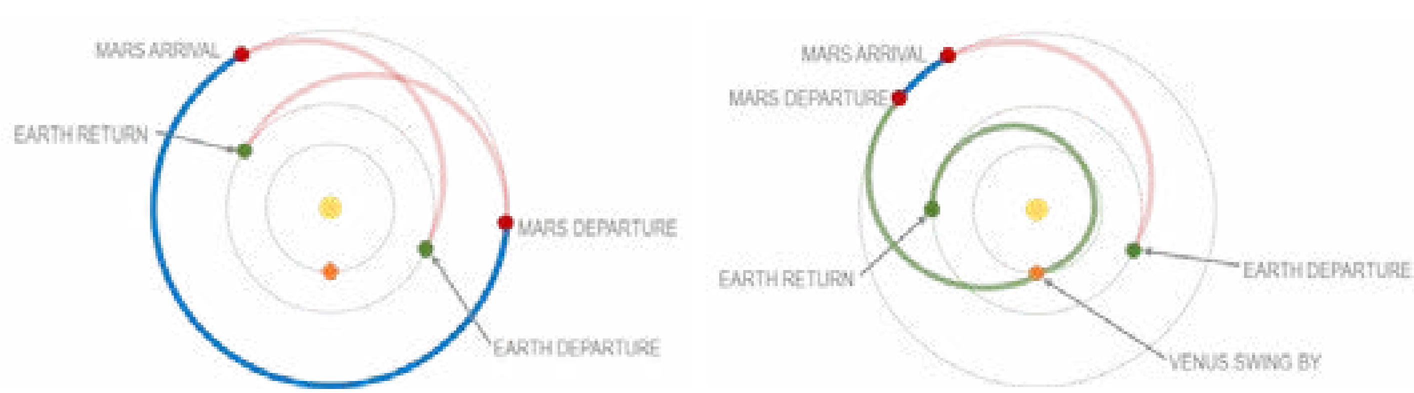


Figure 1. Illustration of Conjunction Class and Opposition Class Missions [1]

The NASA Mars Architecture Team performed trajectory analyses of conjunction-class and opposition-class missions, and developed a graph of the propulsion requirements needed to perform those classes of missions from 2033 to 2050. As shown in Figure 2, the impulsive roundtrip change in velocity (meters per second) required for transit to Mars from a Lunar Distant High Earth Orbit (LDHEO) and return, for an opposition class mission in the 2039 example, is more than twice that of the conjunction class mission. In practical terms, this can equate to hundreds of tons more propellant mass, though in some cases the gravity assist offered by a Venus flyby can aid in reducing propellant mass [2].

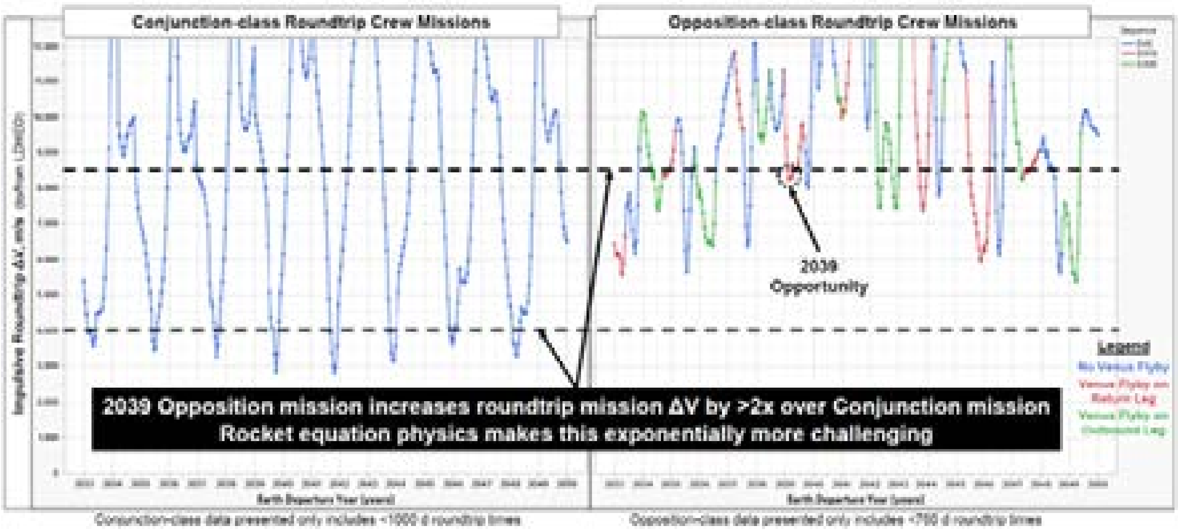


Figure 2. Roundtrip Mars Mission Energy Requirements, Full Synodic Cycle 2033 – 2050 [2]

A 2022 NASA/Baylor College of Medicine journal article estimated that a short-stay mission could result in decreased risk as compared to the standard mission (i.e., long-stay) [3]. Most of the risks cited in the study are associated with the likelihood of a medical emergency arising during the time span of the trip.

The Explore Mars group's assessment of trajectories came to the conclusion that the 420-day trip time used in the Baylor study for the opposition-class mission, however, would be very difficult to achieve, even with advanced propulsion systems. That assessment argued that a more realistic trip time would be 650 days, offsetting much of this benefit [4]. The Explore Mars organization summarized the trajectory trades being considered for human missions to Mars. The trade space is complex, but the overall takeaways were:

- Opposition-class missions use an alternative trajectory to minimize total time away from Earth, but reduce the amount of time spent at Mars to as little as 30 days and require such high levels of ΔV that chemical propulsion missions become challenging and advances in nuclear propulsion become more attractive.
- Conjunction-class missions are a greater challenge for duration-dependent human health issues and require additional consumables to support the mission due to their longer duration, but require less ΔV to perform the mission and allow crews to conduct significant science in the vicinity of Mars for up to a year.

While conjunction-class missions keep crew away from Earth longer, less of the mission duration is typically spent in transit, which can reduce some risks such as microgravity and radiation exposure. On the other hand, if the mission is designed to support longer surface stays, then it requires more landed mass on Mars (not just more consumables, but also more habitable volume for the longer surface stay and potentially more science or utilization equipment) and longer systems reliability requirements, which can increase some risks. However, a conjunction-class mission can be designed to support short-duration sorties to the surface, similar to the kind of sortie that would be supported by opposition-class missions, which equalizes the risks associated with surface stays between the two types of missions.

One variant is a conjunction-class fast-transit mission, which employs additional propulsive capability to reduce the transit times between Earth and Mars. Essentially this requires additional propellant mass to reduce the total transit time by approximately 10 – 30% depending on the departure year [4]. This kind of mission, as a hybrid on that continuum between conjunction-class and opposition-class, could provide a compromise between these pros and cons of the two mission types.

PROPULSION TECHNOLOGIES AND TRADES

In 2021, the Space Nuclear Propulsion Technologies Committee under the National Academy of Sciences, Engineering, and Medicine (NASEM) assessed the primary technical and programmatic challenges, merits, and risks for maturing nuclear thermal propulsion (NTP) and nuclear electric propulsion (NEP) technologies. Their conclusions were that for NEP systems to achieve the megawatt-electric-class power levels needed for a baseline crewed Mars mission, the fundamental challenge would be scaling power and thermal management systems for orders-of-magnitude higher power levels than what have been achieved to date. They also identified the need for parallel development of a large-scale chemical propulsion system that would be used for the higher-thrust maneuvers when departing Earth orbit and entering/departing Mars orbit. Also, because of the low and intermittent investment in NEP technologies over the past several decades, they concluded that an aggressive program would likely not be ready for a mission by 2039 [5].

The NASEM committee identified four challenges for NTP development and concluded that an aggressive program could overcome those challenges to achieve a mission by 2039. Those challenges were heating propellant to approximately 2700 K at the reactor exit, long-term storage of liquid hydrogen, adequate test facilities, and the need to rapidly bring an NTP system to full operating temperature. The development of both NTP and NEP would also require integrated system testing and operational reliability over a period of years before the baseline mission [5].

The Defense Advanced Research Projects Agency (DARPA) program called Demonstration Rocket for Agile Cislunar Operations (DRACO) will demonstrate in space a nuclear thermal propulsion engine. The goal is to launch and demonstrate the NTP engine as soon as 2027. In January 2023, DARPA and NASA announced that they will cooperate on the DRACO program, using a non-reimbursable agreement to share costs. NASA will be responsible for the development of the nuclear engine. DARPA will be responsible for the integration of the NTP propulsion system into a spacecraft and launching it.

Both NTP and NEP offer propulsion efficiency improvements that enable opposition-class missions and faster-transit conjunction-class missions, along with reducing overall propellant requirements significantly, compared to chemical propulsion [5][6]. NTP uses a nuclear reactor to heat propellant, which is then expanded through a converging-diverging nozzle. The target I_{sp} for NTP is 900s, which assumes cryogenic hydrogen propellant and propellant temperatures of 2700K at the nozzle exit. An NEP system uses a nuclear reactor to generate heat, which is then converted to electricity, which in turn powers electric propulsion thrusters. The heat conversion process is inefficient, requiring very large radiators to reject the waste heat to space. Previous tests show an efficiency of 14–27%, but all these tests have been performed at lower power levels than what is needed for NEP [5]. Since electric propulsion thrusters are generally low thrust, the addition of a chemical propulsion system is necessary for orbit insertion and transfer-trajectory insertion for crewed missions. Depending on the efficiency of the chemical propulsion system and the ΔV split between the electric and chemical systems, the overall propellant needs for NEP can be equivalent to NTP. As an example, if a methane chemical system at 360s of I_{sp} performs 1.5 of 6 km/s for a round trip to Mars, assuming an electric propulsion I_{sp} of 2600s, the total propellant required is greater than an NTP system at 900 s I_{sp} [1].

Another method to enable higher ΔV missions, or just reduce the amount of propellant carried for a chemical propulsion option, is to produce propellant on the surface of Mars from the atmosphere and/or water ice. There are risks to relying on In-Situ Resource Utilization, but the MOXIE experiment on Perseverance has recently provided the proof of concept. Some of the risk could be mitigated by not launching the crew on a mission until their return propellant has been successfully produced and stored at Mars. The development and implementation of an ISRU infrastructure has long term sustainability advantages.

CHEMICAL TRANSIT MISSION CONCEPTS

One recent Mars-transit concept that utilizes chemical propulsion was developed by a group at the Jet Propulsion Laboratory (JPL). The concept is a more traditional, low-risk chemical transit approach, as seen in Figure 3, that would launch as soon as 2033 and serve as an orbital demonstration for further development of eventual crewed landings on Mars [7]. The team developed a round trip mission design for the year 2033 that utilizes 17 conventional hypergolic (hydrazine/nitrogen-tetroxide) in-space propulsion stages featuring a common design for minimized development and mission risk. The proposed RS-72 or XLR-132 engines would have somewhat lower I_{SP} than LOX-methane propellants would provide, however with the lower inert mass fraction typical of non-cryogenic hypergolic stages, the difference in I_{SP} performance could be recovered. With a common design that uses existing technology for hypergolic stages, a production line could be established to manage the development risks in time for 2033 with the only additional factor being human-rating [7].

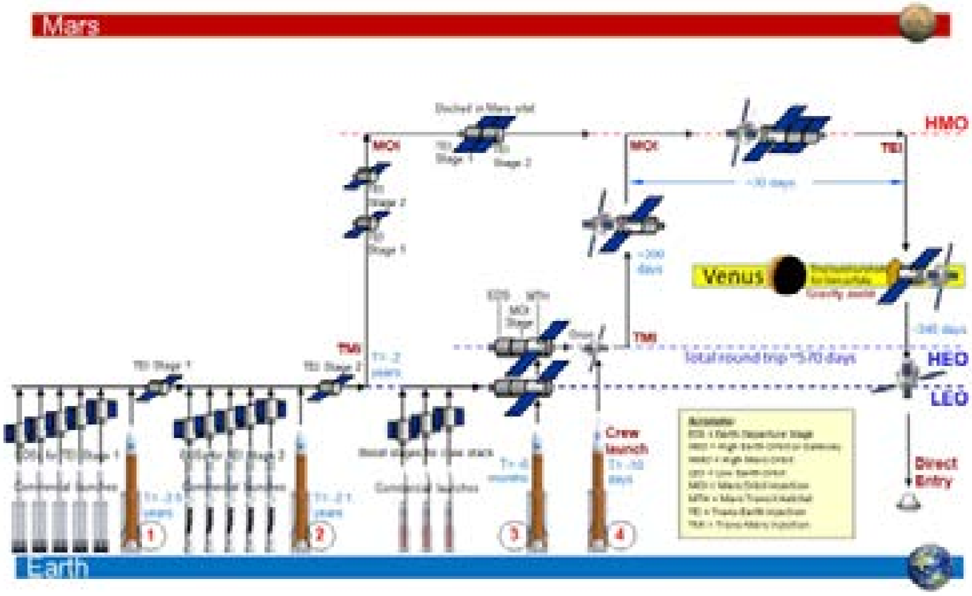


Figure 3: 2033 Mars orbital mission concept would include the following elements: Mars transit habitat (MTH), an Orion spacecraft, the Earth departure stage (EDS), the Mars orbit insertion (MOI) stage, two trans-Earth injection (TEI) stages, and 13 identical chemical boost stages. Achieving this mission would require four SLS Block 2 launches and thirteen commercial launches [7]

Other recent chemical-propulsion architectures for Mars transit include developments that combine Nuclear Electric Propulsion (NEP) with a chemical augmentation. The chemical propulsion is used in this hybrid system to perform departure and capture deep space maneuvers (DSMs) that require high thrust. As discussed above, the NASEM concluded that the application of NEP would need to include the parallel development of a compatible large-scale chemical propulsion system to provide the primary thrust at these DSMs [5]. Architectures that have incorporated these hybrid NEP and chemical systems will be further discussed in the next section.

NUCLEAR PROPULSION TRANSIT MISSION TRADES AND CONCEPTS

The NASA Mars Architecture Team performed a study comparing NTP and NEP architectures for opposition class missions [2]. Figure 4 shows a high-level comparison of the two nuclear-enabled crew transportation systems in an "all up" configuration, meaning they would depart Earth carrying all the propellant needed to get to Mars and back again. Two variants for each architecture were explored: in each case, Variant 1 held time in deep space to two years or less, but Variant 2 relaxed mission duration to optimize mass. The NASA team further developed a mission concept around the relaxed duration NEP/Chemical hybrid transportation system (Variant 2 in Figure 4), paired with a long duration Mars transit habitat sized for four crew. Two of the four crew would descend to the surface, living and working out of a pressurized rover for the 30-sol exploration period before ascending back to the 5-sol orbit in a pre-deployed Mars Ascent Vehicle (MAV) and rejoining their crewmates. As a point of comparison, the shortest duration Variant 1 mission in Figure 4 of 800 days would be 200 days shorter than a typical 1,000 day duration conjunction-class mission. The Variant 2 missions are not appreciably shorter than conjunction-class missions.

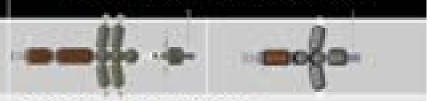
2039 Mission Opportunity Shown	Nuclear Electric Propulsion (NEP)/Chem Hybrid		Nuclear Thermal Propulsion (NTP)	
Vehicle Concept (not to scale)				
Primary Technologies	➢ Deployable modular radiators ➢ 100kWe Class Hall Thrusters ➢ Liquid Oxygen (LOX)/Liquid Methane (LCH_4) Chemical Propulsion ➢ Zero Boiloff LOX/LCH_4 Storage		➢ Nuclear Thermal Rockets 900s Isp, 25k lb_f thrust ➢ Zero Boiloff Liquid Hydrogen (LH_2) Storage	
Mission Characteristics	Variant 1	Variant 2	Variant 1	Variant 2
Total Time Away from Earth	870 days	960 days	800 days	960 days
Time in Deep Space	730 days	850 days	690 days	850 days
Time in Mars Vicinity	50 days	50 days	50 days	50 days
"All-Up" Crew Stack Mass Aggregated in High Earth Orbit	~600 t	~300t	~600t	~285t

Figure 4. Comparison of Mars nuclear-enabled, opposition class transportation options [2]

Aerojet Rocketdyne has been examining architecture options for human missions that encompass the range of propulsion options and mission scenarios under consideration, including Nuclear Electric Propulsion (NEP) and Nuclear Thermal Propulsion (NTP) for either Opposition-class or Conjunction-class missions. Their approach is to look at what is required for preparing the systems for human missions and how they can leverage the work planned under the Artemis program to best accomplish burning down the key risk elements. From that standpoint they have developed a campaign of test missions leading up to an eventual mission to land humans on the surface of Mars. They have dubbed this campaign “Start-up to Steady State.” The following description provides a description of the missions and risk reduction achieved for the example of an NEP system.

The campaign starts in 2032 with a cislunar un-crewed test mission of the NEP system. The system is assembled in LEO and raises the payload (which could be a test version of a Mars Transit Habitat) into a lunar distance highly elliptical orbit (LDHEO). A significant portion of a Mars transit can be demonstrated on the entire NEP system by this mission. Following this in 2033, a second un-crewed mission is sent on a transit to Mars to demonstrate the function of the system through a full Mars mission. The trajectory used is an Opposition-class with a 50 day Mars sphere of influence stay. The third mission starts with cargo deployments on the next opportunity (2035), followed by a human landing mission in 2037 on a similar short-stay profile to the 2033 un-crewed mission. The following mission repeats the cargo deployment in 2039, followed by a Conjunction-class long stay mission to the surface in 2041. All future missions benefit from the systems previous deployed and lead to the “steady-state” scenario where every opportunity (2041+) is a long-stay mission. A notional concept of operations for the first four missions is shown in Figure 5.

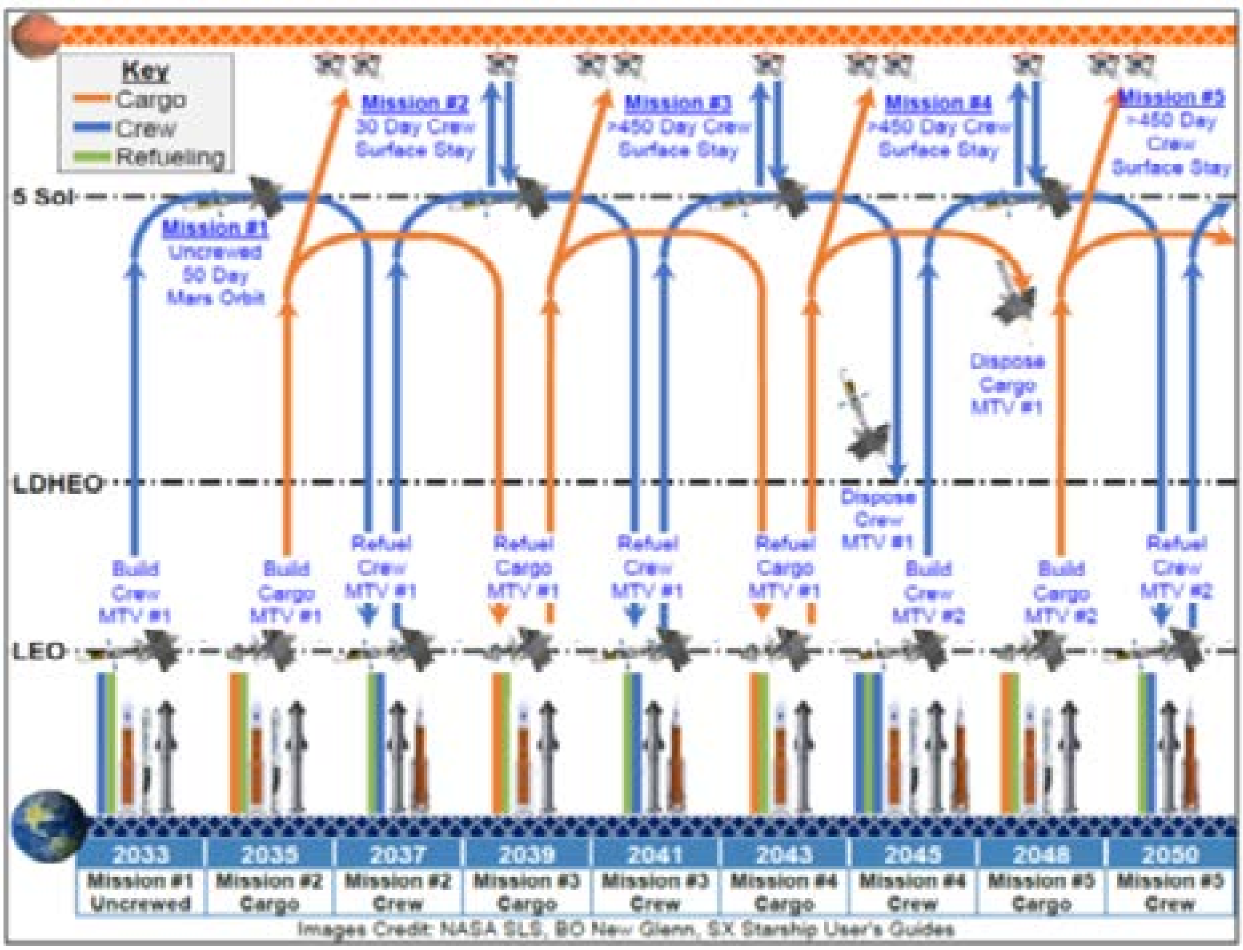
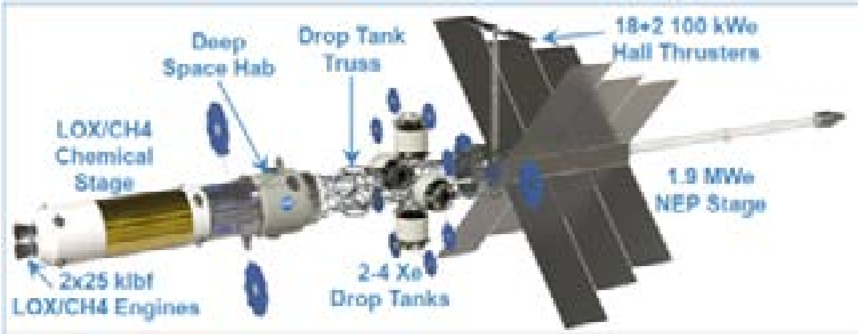


Figure 5. Notional CONOPS for a Human Mars Mission Campaign using NEP

Aerojet Rocketdyne developed a hybrid NEP/chemical propulsion Mars Transit Vehicle (MTV) that could be used for these missions [8]. The design process included parametric trades in the total number of refueling tankers (both LOX/CH4 and Xe) required, as a function of the electric propulsion I_{sp} and NEP stage power levels, and the mission-timing parameters. Figure 6 is an example in-space vehicle configuration from that study, which would transport crew from Earth orbit to Mars orbit and back. It has an initial wet mass in low-Earth orbit (LEO) of up to 519 mT, which includes payload. After completion of the mission, the final mass in LDHEO is 115 mT.



Key Technologies

- 10 MWth (53 MWth-yr Life) High-Assay LEU reactor operating with 1200K exit temperature
- Supercritical CO2 Brayton cycle power conversion system
- 2,500 m² radiator with sodium-potassium coolant, titanium water heat pipes, and composite fins
- 1.9 MWe 480 Vac / 650 Vdc power management and distribution system
- Twenty 100 kWe Hall effect thrusters operating at 2,500 sec Isp
- Two 25 lbf LOX/CH4 pump-fed liquid rocket engines
- 90 K long-duration cryofluid management system

	Mission #1	Mission #2	Mission #3	Mission #4
Mission Time (days)	760 with crew; 1230 incl spirals	760 with crew; 1242 incl spirals	940 with crew; 1367 incl spirals	940 with crew; 1284 incl spirals
Mars SOI Stay (days)	50	50	480	480
Initial Mass in LEO (mT)	500	519	444	335
EP Thruster Operating Time (hrs)	18,300	18,800	13,100	12,500
LOX/CH4 Engine Burn Time (min)	43.2	35.1	29.5	15.4

Figure 6. Aerojet Rocketdyne NEP/Chem Hybrid Crew MTV [8]

Recent architecture development of NTP systems has included a new configuration of Lockheed Martin's concept for Mars Base Camp (MBC) [1]. The first MBC configuration used chemical propulsion to achieve conjunction class Mars missions, showing the feasibility of LOX/LH2 chemical propulsion for Mars missions. The objective was to establish an analytical "existence proof" for safe, affordable, sustainable Mars system exploration within about a decade using technologies available in the mid-2010s. With recent technical and policy advances in nuclear power and propulsion, Lockheed Martin investigated applications of those technologies for short-stay or opposition class missions. Upon completing a set of trades and a safety assessment, this second MBC configuration with NTP for the transit vehicle was developed. The resulting architecture included fewer modules while retaining significant redundancy and self-rescue capability. With the high performance of NTP, the new MBC configuration can achieve both conjunction and opposition class Mars missions.

The configuration of MBC that incorporates NTP is shown in Figure 7. It has two NTP engines that are each supplied by a liquid-hydrogen core tank and attached to an Orion vehicle. The NTP stage closest to the side tanks is pointed so it is tail-to-sun (sun is on the right in Figure 7), with power supplied by solar arrays. The solar arrays provide the mission with necessary power, including the power needed to manage the liquid hydrogen. This inclusion of two NTP stages and two Orions enables mission capability, redundancy, self-rescue, and abort scenarios. For example, the Orion vehicle and NTP stage can undock from the rest of the MBC vehicle to perform excursion missions to the Mars moons [1]. A docking module provides a docking port so that the Mars lander or other excursion vehicles can dock to MBC. A cupola is also included on the docking module. Robotic arms that can caterpillar-walk along attachments on the outside of the vehicle can provide the ability to berth or reconfigure elements or assist with EVAs. For habitation, there is an inflatable habitat and crew quarters nestled inside propellant tanks for additional radiation shielding. These tanks provide radiation protection for the crew quarters and a safe haven during Solar Particle Events. The habitat expands in volume after launch and would also include laboratory space. Inflatable habitat technology is progressing and provides for the large volume required for long duration missions while mitigating launch vehicle payload fairing packaging issues. While the chemical configuration of MBC had two habitats and two crew quarters, this NTP configuration incorporates just one of each. The volume of each element can be adjusted depending on mission duration. Internal redundancy manages crew safety and contingency scenarios. The conjunction-class missions would require 0-2 side tank launches, and the opposition-class missions would require 4-6 side tank launches [1]. Lockheed Martin advocates that NTP is mission enabling, more mature, and straightforward than Nuclear Electric Propulsion. Long-stay conjunction class missions provide ten times the science and exploration with only a 50% longer mission, with significantly fewer propulsion needs.

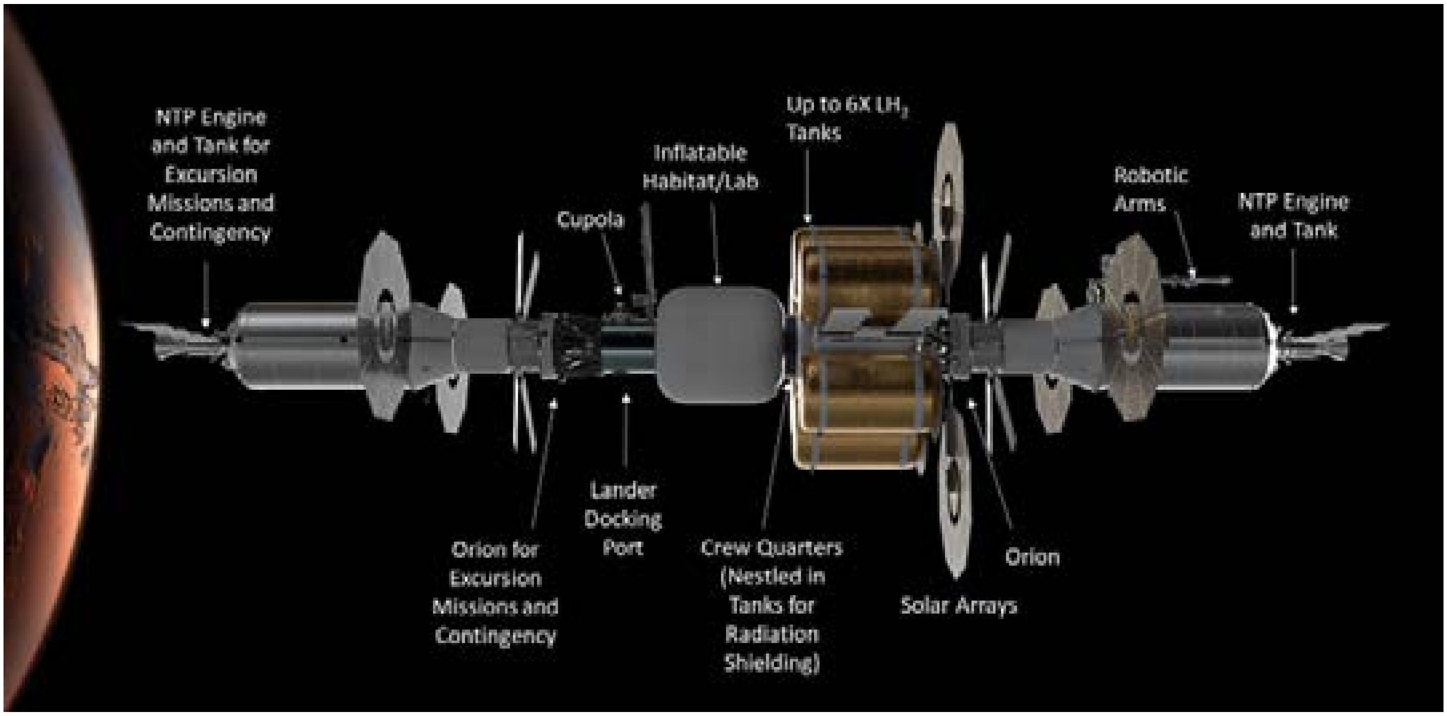


Figure 7. NTP Configuration of Mars Base Camp

MARS SUPPORT ARCHITECTURE

The NASA Mars Architecture Team (MAT) developed a Mars support architecture around a mission profile with a 30-sol minimum surface hardware, short-stay class, crew of two mission [2]. Three primary constraints in the mission profiles were the mobility and life support hardware and capability, the schedule of activities for the crew, and the available surface power to recharge the pressurized rover. In total, their architecture study includes three landers, a crewed MAV, an unpressurized rover, and a pressurized rover (PR). Further discussion of these recent architecture developments are organized by power, communication, logistics, and MAV.

Power: The architectures developed by NASA MAT [2] use a 10kW surface fission power reactor system with a redundant second reactor for contingency operations [9]. Power would be dispersed through cables from the reactor which would be deployed and connected using rovers. The 10kW reactor would power the following surface mission elements including: communications, battery recharge of mobile surface assets, and the thermal management of propellant and electronic systems. While the crew is not expected to maintain any elements of the surface power infrastructure, they would have the ability to directly plug into the grid at a stand-alone access point to power mobile or portable equipment [10]. NASA's MAT has calculated that it would take 1.85kW to maintain the habitability of the pressurized rover (not including mobility recharging) and 2.85kW to power communications, sensors, thermal conditioning, MAV propellant conditioning and maintaining its operational standby condition as well as various other electronics. Calculating for mobility recharging of the pressurized rover, its total power needs are assumed to be 4.85kW total, with the remaining 2.3kW of the power budget being devoted to a "30% growth margin." The MAT additionally figures that losses from recharge inefficiencies and cables can be absorbed by part of the aforementioned margin, and thus are ignored in the conceptual design phase of previous power consumption estimates. Some additional assumptions have been made including: both the pressurized and unpressurized rovers would not have an on-board energy replenishment capability (solar arrays) but other sub-elements such as portable storage units could have the added capability to be a source for recharging [9].

Communications: In regards to communications, there is an awareness of the current eventually-decaying Mars orbital relay infrastructure. Other supporting elements such as the Portable Utility Pallet (PUP) can feature a communications relay from the surface and the Mars transit vehicle can serve as the communications relay back to Earth [9]. Whether there is a reliance on multiple supporting surface assets or a main element that is utilized as a lunar ground relay, it is clear there are multiple options to consider and continue to trade between.

Logistics: While sustaining any multi-sol surface mission, there will be a need for waste management, storage of various supplies and samples, and component- and system-level maintenance. It has been highlighted that the use of PUPs can expand the flexibility and capability of surface exploration endeavors. In addition, storage containers such as Small Pressurized Logistic Carriers (SPLCs) can be fit as a conditioned environment for cargo or be used for waste collection. The goal is to have all the waste storage "units" be placed centrally in the same location, which will vary by site, but most likely be near the landing site. It should be noted that the pressurized rover also has the ability to store up to 14 sols of supplies for a crew of two and would be a frequent SPLC user to remove crew waste during recharging/resupplies. Lastly, maintenance will need to be considered within architectures for elements such as the habitat, mobility, and EVA suits. The EVA equipment experience on the lunar surface gained from the Artemis Program will feed forward to EVA equipment development for utilization on Mars. Components such as joints, rotating bearings, and seals are likely to wear down under Martian surface conditions, however the replacement frequency is unknown. While gathering enough observational data to make reliable predictions for component deterioration or probability of failure, routine inspections and repairs will need to be implemented into mission timelines [10].

Mars Ascent Vehicle (MAV): The NASA Mars Architecture Team has also updated the Mars Ascent Vehicle (MAV) design, the vehicle for launching the crew from Mars. The design incorporates "new understanding of propellant tank insulation options, updates to cryocooler performance predictions, thermal environments during EDL, the effects of engine plumes at liftoff, and a refined modeling of the ascent trajectory" [10]. Additionally, the 2021 country-wide student competition Revolutionary Aerospace Systems Concepts Academic Linkage (RASC-AL), managed by NASA and National Institute of Aerospace (NIA), featured a minimum Mars Ascent Vehicle design challenge. Finalists presented multiple designs that were relatively cost-efficient and leveraged Apollo and ISS heritage as well as innovative ISRU, structures, and communications elements [11].

ARTEMIS DEVELOPMENT DIRECTLY APPLICABLE TO MARS MISSIONS

As part of the Artemis era of space exploration, space agencies will work together with their industry partners to establish systems and infrastructure that enable sustained lunar missions and develop capabilities for Mars. In addition to its deep space science capabilities, the planned Gateway is an aggregation and logistics location in lunar orbit where Orion can dock and transfer crew to lunar landers—and in the future to aggregate Mars mission elements and perform dress rehearsals for Mars. Artemis is expected to provide a testbed to evaluate system functionality and performance and serve as a laboratory to practice and refine critical operations.

The initial Gateway elements are in design and production. Also, a set of regular lunar robotic landing missions from a diversity of countries and companies has begun with the Commercial Lunar Payload Services (CLPS) program.

In September 2023, NASA released the Moon to Mars Objectives which documents an objectives-based approach to the human deep space exploration efforts [12]. There are 63 objectives categorized into 4 major areas: science, infrastructure, transportation and habitation, and operations. These objectives roughly align to the NASA mission directorates of Science, Space Technology, Explorations Systems Development, and Space Operations. There are also nine recurring tenets that are common themes across the objectives. The objectives were developed from a draft of 50 objectives that generated more than 5000 comments from industry, international partners and the general public. Two workshops were held for additional discussions, one for the international community and one for industry. While the objectives do have more of a focus on lunar exploration, a significant number of the objectives apply to both the Moon and Mars, and there are specific Mars objectives as well. Key science objectives include identifying where and when potentially habitable environments existed or exist, how the deep space environment affects human health, and retrieving frozen volatiles. Key infrastructure objectives include surface power, mobility, communication, and navigation. Key transportation and habitation objectives include in-space and surface habitats, surface landing systems for crew, and integrated human and robotic systems that maximize science and exploration. Key operations objectives include characterizing resources and demonstrating their use and optimizing operations, training, and interaction between crews on the surface, in orbit, and back at Earth. And then in April of 2023, NASA released the Moon to Mars architecture, including an Architecture Definition Document and six Architecture Concept Review 2022 white papers [13]. These document the current state of NASA's Lunar and Mars architecture plans, including alignment to the Moon to Mars objectives [13].

Orion and the Space Launch System have completed their last uncrewed flight test mission, Artemis I. Launched occurred on Nov 16, 2022, meeting or exceeding all expectations with performance off by less than 0.3%. Over 25 days the Orion spacecraft performed lunar fly-bys to enter and leave a high Distant Retrograde Orbit around the moon. The maximum distance to the Earth was 268,563 miles, farther than any other spacecraft built for humans. The spacecraft reentered at 24,500 mph, performed a skip to reduce g-forces and have extended range to target the landing site, and successfully splashed down on Dec 11, 2022 within 4 km of the target. The on-going review of the flight test results had found only minor issues that can be addressed ahead of Artemis II. The top minor issues are that the heatshield ablated a little differently than expected, but there was still plenty of heatshield thickness margin, and the power system on the European Service Module had latching current limiters open without being commanded, which had no impact on the mission. Figure 8 shows liftoff of Artemis I and figure 9 shows Orion in high orbit around the moon.

Figure 8. Liftoff of Artemis I. Image courtesy NASA.

Figure 9. Artemis I in Lunar Orbit. Image courtesy NASA.

In 2021 NASA selected SpaceX's Starship for the development of a Human Landing System (HLS). Starship is a fully reusable, super heavy lift launch and planetary landing system that provides a generalized solution to human and large cargo space transportation throughout the solar system enabled by large-scale propellant transfer in Earth orbit and affordable mass production. The target planetary landing capability is greater than 100 metric tons (MT). Starship's production, launch infrastructure, and operations processes are designed to enable affordable high-rate production and very low unit costs. To date, Starship has successfully flown several high-altitude flight tests and been stacked and completed launch preparation tests for the Starship/SuperHeavy stack, as well as activated the "stage 0" launch pad systems. In addition, a ground hot-fire test of the SuperHeavy first stage was completed on February 9, 2023. On April 20, 2023, SpaceX attempted the first integrated SuperHeavy and Starship launch from their Boca Chica site. The launch did succeed in clearing the tower and ascending to nearly 40 km; however, there were several engine shutdowns and other system issues noted. As a result, the staging maneuver was unsuccessful and Starship remained attached to the booster. The Flight Termination System was then activated and the vehicle was destroyed. The "stage 0" launch pad system also suffered severe damage and there were large amounts of concrete and other material ejected from the base of the pad into the surrounding area. SpaceX and the FAA are conducting anomaly and "mishap" investigations. Nevertheless, SpaceX's Elon Musk stated that he expects Starship to fly again within a few months.

Each mission to the lunar surface, both crewed and robotic, offers the opportunity to demonstrate new technologies and operations. As illustrated in Figure 9, these new technologies and operations enhance exploration and scientific discovery, build upon previous missions, and mature those same capabilities for Mars.

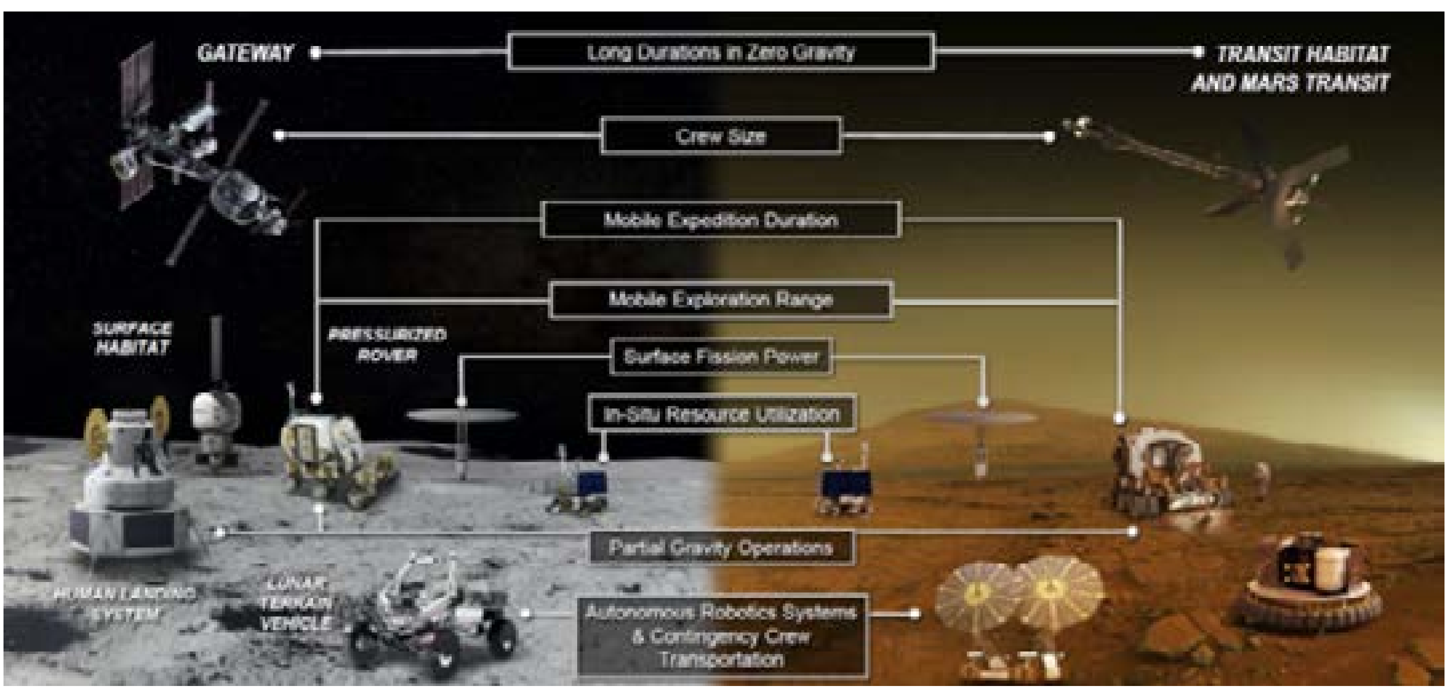


Figure 10 . Capabilities Developed in Artemis that Feed-Forward to Mars. Image courtesy NASA. [14]

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Karen Nyberg performing fundoscopy (Credit: NASA)

HUMAN HEALTH AND PERFORMANCE

Human System Risk for a Mission to Mars

Humans traveling to Mars will face risks that are qualitatively different from those faced by astronauts living in Low Earth Orbit (LEO) or on the Moon. The protocols that minimized operational risk during early lunar missions and on International Space Station (ISS) will need to be significantly modified to serve as well for crews in transiting to and serving on Mars. In order to send Humans to Mars and return them safely to Earth, there are several key areas of risk that the international space community must address. Systems to be developed and areas of risk to be mitigated to the greatest extent possible include, but are not limited, to:

MEDICAL EVENTS AND AUTONOMOUS CREW HEALTH: Medical events on Mars missions entail increased risk of an individual astronaut dying or suffering debilitating injury than has previously been seen in any era of human space exploration.

SUSTAINABLE FOOD SYSTEMS: There is currently no food system that can provide safe, acceptable food throughout the length of time necessary to complete a Mars mission. Inadequate nutrition leads to a host of other issues including performance, behavioral, and immune system risks.

ISOLATION AND CONFINEMENT: Isolation and confinement experienced by crews engaged in Mars missions will be significantly longer than anything we have experienced in the history of human spaceflight. The potential for significant in-mission behavioral health challenges and issues with group dynamics should be anticipated and treatment modalities created and tested.

PLANETARY EXTRAVEHICULAR ACTIVITIES (EVAS): Frequent planetary EVAs in .38 g will be a new operational experience that poses increased risks to both crew health and performance.

AUTONOMOUS CREW HABITAT AND VEHICLE SYSTEMS: Without real time communication with Mission Control, Mars mission systems need to be far more autonomous, robust, and easily accessible by the human crew to solve time-critical problems.

The solutions to these challenges require unprecedented cooperation and integration among experts in medicine, life sciences, operations, and engineering. Each of these areas is discussed in greater detail below.

MEDICAL EVENTS AND AUTONOMOUS CREW HEALTH

A round-trip mission to Mars will take somewhere between 730 and 1100 days, depending on how long the astronauts spend on the surface of the red planet and in orbit around it. Most human missions in space have lasted 6 months or less, with only a handful of astronauts and cosmonauts having flown one-year missions in low Earth orbit. In fact, the current record for continuous space habitation is 437 days. The multi-year length of Mars missions means there is more time for medical events to occur and more time for the hazardous spaceflight environment to degrade the health of the crew.

On the ISS, the majority of medical risks are addressed by rigorous selection requirements for healthy astronauts, real-time telemedicine, resupply, and/or medical evacuation. Today, teams of flight surgeons, pharmacists, psychologists, and biomedical engineers provide real-time telemedicine support 24/7 to crews. Medical teams in Mission Control provide expertise when crew members need medical attention and advice; including remote guidance of instruments to assist crew in performing medical diagnosis and treatment. NASA quickly supplies ISS crews with medications and medical supplies when they are needed unexpectedly and regularly resupplies expired or used items. In a worst-case scenario, crews can be evacuated for treatment on Earth within a day if needed.

Mars missions will be very different. Soon after departing Earth, the Mars crew will lose real time-communications: it will take up to 45 minutes to get a message down to Earth and back to the spacecraft. Because of this light-time delay, Mars crews must be able to diagnose and treat urgent medical issues more and more independently as they get farther from Earth. In addition, Mars missions will have extremely limited opportunities to receive medication or equipment resupply shipments from Earth. Finally, Mars crews will not be able to return to Earth for treatment of severe injury or illness. As completely resolving medical issues becomes more technically and logistically challenging, the frequency of medical issues will increase. NASA's probabilistic risk assessments suggest that there may be more than five times as many medical issues on a Mars mission as on a standard ISS mission today.

Because of these challenges, it is critical that NASA develop a robust Crew Health and Performance (CHP) System. Early detection of potential medical issues through appropriate monitoring is key to ensuring the Mars crew can treat minor problems before they become major medical issues that endanger crew health and mission success. Integrated data architectures must be included in the CHP system to ensure that diagnostic capability is adequate to avoid costly mistakes in treatment that cause more problems than they solve, and that information flows seamlessly back to Mission Control to help further guide appropriate treatments. In emergency situations, Mars crew will need to be trained, empowered, and equipped to act independently. It is therefore crucial that we improve the CHP Systems to the point where the astronauts can address emergencies sufficiently to protect their health and ensure that the mission stays on track.

SUSTAINABLE FOOD SYSTEMS

A mission to Mars will require crews to stay healthy and productive for several years without access to fresh foods from Earth. Extensive research has shown that nutrition affects crew performance, as well as physical and mental health. However, no space organization currently has a food system capable of providing safe, nutritious, and acceptable crew sustenance for the duration of a Mars mission. On the ISS, food and medications are re-supplied regularly; even so, crewmember complaints commonly focuses on the taste or quantity of food items available to them. Fresh fruits and vegetables that arrive on regular resupply missions from Earth also provide critical nutritional supplements to packaged mission meals. The food system currently in use on the ISS and planned for near-term missions to the Moon cannot produce the type, quality, or volume of fresh food we hope to provide astronauts en route to Mars.

A food system for Mars must ensure long-term food safety, nutrition, and acceptability to the crew. It is not sufficient to just provide sustenance: in Mars simulation missions where nutritious but unappealing food was available, crews under ate, lost weight, and reported decreased mood. Over a three-year mission, this could lead to significant harm to crew health and performance. The Mars food system must also include water recycling, quality, and rations for the crew.

NASA is conducting research on the ISS that may allow Mars crews to grow their own fresh food. In the last year, ISS crews have grown and harvested small volumes of fresh vegetables such as lettuce. These experiments are paving the way for sustainable fresh food production for Mars missions. However, available equipment and storage space on a Mars mission will be at a premium. Historically, food systems are often one of the first things to be pared back when programs have to reduce weight and volume. For these reasons, it is imperative to prioritize the development of sacled, robust food and hydration subsystems of the CHP System.

ISOLATION AND CONFINEMENT

Humans perform best as part of a strong team, and teamwork will be essential to the success of any Mars mission. The makeup and size of the Mars crew and the robustness of the team's operational capacity will be critical elements of their overall performance. In addition, a Mars crew will be spending extended time in isolated and cramped conditions, adapting on-demand to changing environments as the mission's operational parameters shift from microgravity during the transit to Mars to partial gravity operations on the surface of the planet and back to microgravity conditions for the journey home. Landing on and launching from Mars for the first time will be immensely stressful for the astronauts, as will the need to respond to the vehicle problems likely to occur during any mission of this duration and technical complexity. Additionally, it is still unclear to what extent the increased radiation might affect astronaut cognition. Each of these factors can negatively affect teamwork as well as individual performance at a time when the crew needs to be at their best.

Currently, space agencies minimize the occurrence of in-mission behavioral health issues by screening for behavioral health and cognitive function during astronaut selection. Most interventions currently used to support crew mental health occur in real-time, including private meetings with NASA psychologists, communication with loved ones on the Earth, and use of video, audio, social media. While communication will be available during a Mars mission, it will be significantly delayed and limited. Due this light-time delay and the extended duration and isolation, Mars missions will have many more stressors and fewer opportunities to receive support for mitigating these stressors from support systems on Earth.

Mars mission success will depend on selecting strong teams in addition to strong individual astronauts. It will also depend on the development of behavioral health monitoring systems and countermeasures that are part of a larger CHP System. Monitoring and evaluation must leverage CHP data systems to ensure that crews and Mission Control have sufficient insight into crew behavioral and cognitive status throughout a mission and provide tools to prevent adverse issues and events from occurring. Accurate, timely behavioral health insights will be critical to keep small problems from growing into untenable situations when team cohesion is required to realize successful mission outcome.

PLANETARY EXTRAVEHICULAR ACTIVITY (EVA)

Mars crews will land on the planet's surface and explore it. While we have some experience with EVAs on the Moon, lessons-learned from these Apollo-era EVA include numerous design and operational issues that have yet to be addressed. Because of the light-time delay between Earth and Mars, future Mars explorers will need to conduct surface operations more independently than any previous astronaut group. As a group, Mars astronauts are likely to conduct longer and more frequent EVAs than were seen on the Moon and the ISS and, therefore, encounter more EVA-related injuries. The design of planetary exploration EVA suits for Mars must minimize injury potential and maximize performance. Additionally, systems that monitor and protect crew health must be integrated across vehicles, rovers, and spacesuits.

Surface exploration is a major factor motivating human-centered missions to Mars. Therefore, a failure of EVA ability during a crewed Mars mission is not an acceptable option. Systems and procedures supporting Mars surface EVAs must be tested and improved at every opportunity during upcoming Artemis Moon missions.

AUTONOMOUS CREW HABITATS AND VEHICLE SYSTEMS

System failures and sub-optimal performance are unavoidable in structures as complex as spacecraft and off-world habitats. Mars missions will encounter numerous technical problems that require crew intervention. On the ISS, crews rely on real-time, on-demand access to over 80 experts in Mission Control to identify, diagnose, and repair vehicle malfunctions. On a Mars mission, the first hour of any vehicle emergency may need to be handled solely by the crew while they wait for remote support to arrive via delayed communications from Mission Control. This shift in primary response from Mission Control to mission crew requires increasing crew autonomy significantly beyond what has been utilized during human spaceflight to date.

The technical challenges inherent to diagnosing and addressing vehicle and habitat malfunctions are many. Successfully addressing space system issues without causing more problems requires significantly improving the design of these systems. Including human-centered design and Human Systems Integration (HSI) processes throughout the development, testing, and deployment of space-based architecture is key to ensuring that the vehicles and habitats can be maintained and repaired, and that data needed to detect and diagnose problems is directed in a timely manner the crew and Mission Control members responsible for system upkeep.

RECOMMENDATIONS:

- Develop a robust Crew Health and Performance System for Mars to make up for the loss of real-time communication, resupply, and evacuation capability.
- Invest in improved food and nutrition systems to support health and performance throughout a Mars mission.
- Advance integrated data systems and decision support to ensure that medical, psychological, and vehicle issues that arise can be identified, diagnosed, and resolved.
- Ensure integrated systems development across the whole mission architecture including suits, vehicles, habitats, and Mission Control to address challenges such as planetary EVAs.
- Leverage ISS and lunar missions to test and demonstrate progressively independent human system integration for the spacesuits, vehicles, and habitats needed for future Mars missions.

POLICY:
ACHIEVING THE HUMAN EXPLORATION OF BOTH THE MOON AND MARS

UNITED STATES POLICY (2021-2023)

In a time when political polarization has become the norm and achieving a consensus agreement on any issue frequently is beyond reach, the one arena where bipartisan support remains a constant is in our elected officials' continued support for our nation's space program.

1. SUPPORT FOR NASA BY THE EXECUTIVE AND LEGISLATIVE BRANCHES:

Shortly after taking office, the Biden Administration expressed support for the Artemis Program and the overall goals of the United States space program. During a press conference on February 4, 2021, White House Press Secretary Jennifer Psaki stated, "…through the Artemis program, the United States government will work with industry and international partners to send astronauts to the surface of the moon to conduct new and exciting science, prepare for future missions to Mars, and demonstrate America's values." Psaki then added, "To date only 12 humans have walked on the moon. That was half a century ago. The Artemis program, a waypoint to Mars, provides exactly the opportunity to add numbers to that."

The Biden Administration's support, as well as that of Congress, for space exploration was also demonstrated in the FY22 *Consolidated Appropriations Act, 2022*, signed by President Biden on March 15, 2022. The enacted spending authorization of $24.041 billion for NASA, which received bipartisan support in both the House and the Senate, included the full requested funding levels for the agency's foundational exploration systems, the Space Launch System (SLS) rocket, the Orion Spacecraft, the Human Landing System, and the Exploration Ground Systems.

Congress also demonstrated continued strong bi-partisan support with the passage, in August 2022, of the *NASA Authorization Act of 2022*, the first time in five years that an authorization was passed and enacted into law. The 2022 Authorization Act was included in the *Creating Helpful Incentives to Produce Semiconductors (CHIPS) Act*, and demonstrated Congressional commitment to operating the International Space Station (ISS) through 2030. It also included strong support for linking the return to the Moon under NASA's Artemis program with to the human exploration of Mars, a concept referred to as the "Moon to Mars Program." In addition, the Act directed NASA to establish a "Moon to Mars Program Office" within the new Exploration Systems Development Mission Directorate (ESDMD) that will oversee these efforts. The establishment of a "Moon to Mars Program Office" in conjunction with the Artemis program has been a longstanding advocacy positions of Explore Mars, Inc., in addition to recommendations that have been made by the independent "Achieving Mars Workshops" (https://www.exploremars.org/affording-mars/) that are hosted by Explore Mars, Inc.

In March 2023, the Biden Administration released its Fiscal Year 2024 NASA Budget proposal. This budget, if approved by Congress, would increase NASA's budget to $27.2 billion which would represent a 7% increase over 2023 levels. Funding would increase for the Artemis lunar exploration program (a total of $8.1 billion as proposed) and Mars Sample Return ($949 million as proposed), as well as for Earth Science and also technology research and development.

2. NASA LEADERSHIP:

Administrator: On May 3, 2021, Bill Nelson, former Senator from the state of Florida, was sworn in as NASA's 14th Administrator. A staunch advocate for NASA while serving in both the United States House and Senate, Nelson is also a former astronaut. While serving as chair of the House Space Subcommittee, Nelson flew in 1986 as a payload specialist aboard the space shuttle Columbia on the STS-61C mission. During this mission, Nelson became friends with Charles Bolden, who would later serve as NASA Administrator for eight years, beginning in July 2009.

Deputy Administrator: Pam Melroy was sworn in as NASA Deputy Administrator on June 21, 2021. Prior to becoming Deputy Administrator, Melroy served many years in NASA as an astronaut, logging 38 days in space. She was one of only two women to serve as mission commander on a Space Shuttle mission. She also served as pilot on two of her flights. Prior to her NASA career, Melroy was a test pilot, and flew more than 200 combat missions during Operation Desert Shield/Desert Storm and Operation Just Cause. At her confirmation ceremony she stated, "It is a joy to be back in the NASA family, the smartest and most dedicated workforce of any place that I've ever worked. I always knew this was the most exciting place to work from the time I was a child, inspired by the first landing on the Moon." Melroy added, "I'm very honored to be teamed with Administrator Nelson and our Associate Administrator Bob Cabana and (the) rest of the NASA team. We do have a lot of work to do, but it's our intention not to just lead today's NASA, but also lead us forward into the future and support the generations of fantastic things that NASA will continue to do."

3. NATIONAL SPACE COUNCIL:

In early 2021, the Biden Administration announced its intentions regarding the future of the National Space Council (NSC). In a statement reported by *Politico* on March 29, 2021, a National Security Council spokesperson was quoted as saying, "At a time of unprecedented activity and opportunity generated by America's activities in space, the National Space Council will be renewed to assist the president in generating national space policies, strategies, and synchronizing America's space activities." (https://spacenews.com/biden-administration-to-continue-the-national-space-council/)

National Space Council Meetings:

- The Vice President (who chairs the Council)
- The Secretary of State
- The Secretary of Defense
- The Secretary of the Interior
- The Secretary of Agriculture
- The Secretary of Commerce
- The Secretary of Labor
- The Secretary of Transportation
- The Secretary of Energy
- The Secretary of Education
- The Secretary of Homeland Security
- The Director of the Office of Management and Budget
- The Director of National Intelligence
- The Director of the Office of Science and Technology Policy
- The Assistant to the President for National Security Affairs
- The Assistant to the President for Economic Policy
- The Assistant to the President for Domestic Policy
- The Assistant to the President and National Climate Advisor
- The Chairman of the Joint Chiefs of Staff
- The Administrator of the National Aeronautics and Space Administration

During the December 2021 meeting, Vice President Harris and Administrator Nelson focused their remarks on the benefits of space exploration to improving life on Earth, STEM education, job creation, and addressing the climate crisis. Vice President Harris stated, “Today, our nation and our world are more active in space than ever before…In this new era, we must see all the ways in which space can benefit … the people of our nation and of all humanity. This perspective is central to our work as a council because, while exploration of space defined the 20th century, the opportunity of space must guide our work in the 21st.” In his remarks during the meeting, Administrator Nelson noted how space exploration is a source of inspiration for future generations of scientists, engineers, and technicians as was demonstrated by the influx of students in STEM education fields for the Apollo generation. Nelson stated, “Just look at the sparkle in the eyes of children when the topic of space and spaceflight come up. It opens their …. eyes into working to get involved.” In fact, added Nelson, “…30% of our interns come to work for NASA. That’s why STEM is so important.”

Second meeting: The NAC’s second meeting occurred on September 9, 2022. Its agenda included presentations and discussions about climate change, commercial and industry partnerships, international collaboration, and program management and acquisition, as well as diversity, inclusion, equity, and accessibility.

On December 16, 2022, Vice President Kamala Harris announced new members of the National Space Council Users Advisory Group (UAG). These members are:

- **General (USAF, Ret) Lester Lyles**, UAG Chair
- **Mr. Rajeev Badyal**, VP of Technology, Amazon Project Kuiper
- **Mr. Charles Bolden**, Former NASA Administrator and Former Astronaut
- **Mr. Salvatore T. Bruno**, CEO, United Launch Alliance
- **Dr. Lance Bush**, President & CEO, Challenger Center
- **Ms. Bridget Chatman**, Chairwoman, Women in Aerospace
- **Mr. Theodore “Ted” Colbert**, CEO, Boeing Defense, Space & Security
- **Ms. Nancy Colleton**, President, Institute for Global Environmental Strategies
- **Ms. Karina Drees**, President, Commercial Spaceflight Federation
- **Mr. Eric Fanning**, President and CEO, Aerospace Industries Association
- **Dr. Daniel Hastings**, Head, Department of Aeronautics & Astronautics, Massachusetts Institute of Technology
- **Ms. Dawne Hickton**, Subject Matter Expert
- **Mr. Daniel Jablonsky,** President & CEO, Maxar Technologies
- **Dr. Dave Kaufman**, President, Ball Aerospace
- **Mr. Patrick Lin**, Director of the Ethics & Emerging Sciences Program, California Polytechnic State University
- **Mr. Ron Lopez**, President & Managing Director, Astroscale US
- **Dr. Harold Lee Martin**, Chancellor of North Carolina Agricultural & Technical State University
- **Dr. Kate Marvel**, Climate Scientist at Project Drawdown
- **Maj Gen (Ret) Roosevelt “Ted” Mercer,** CEO & Director, Virginia Space
- **Dr. Marla Perez-Davis**, Former Director, NASA Glenn Research Center
- **Dr. Sian Proctor**, Geoscience Professor, South Mountain Community College
- **Ms. Gwynne Shotwell**, President & COO, SpaceX
- **Dr. Robert Smith, CEO**, Blue Origin
- **Mr. James Taiclet**, President & CEO, Lockheed Martin
- **Dr. Mandy Vaughn**, Subject Matter Expert
- **Ms. Kathy Warden**, Chairwoman & CEO, Northrop Grumman Corp
- **Mr. Robbie Schingler, Jr.**, Co-Founder & Chief Strategy Officer, Planet Labs
- **Ms. Melanie Stricklan**, Co-Founder & CEO, Slingshot Aerospace
- **Dr. Jeremy Williams**, Head, Climate Corporation & Digital Farming, Bayer Crop Science
- **Ms. Katrina Harden Williams**, Middle School Teacher, Ames Middle School, Iowa

4. CONGRESSIONAL HEARINGS: There have been several recent Congressional hearings of note dealing with space.

On October 20, 2021, the House Subcommittee on Space and Aeronautics held a hearing entitled, *Accelerating Deep Space Travel with Space Nuclear Propulsion*. The panel of expert witnesses included Dr. Roger M. Myers, Co-Chair, Committee on Space Nuclear Propulsion Technologies, National Academies of Sciences, Engineering, and Medicine; Dr. Bhavya Lal, Senior Advisor for Budget and Finance, NASA; Mr. Greg Meholic, Senior Project Leader, The Aerospace Corporation; Mr. Michael French, Vice President, Space Systems, Aerospace Industries Association; and Dr. Franklin Chang-Diaz, Founder and CEO, Ad Astra Rocket Company. This hearing focused on the challenges and prospects for developing nuclear propulsion in the future. https://science.house.gov/hearings/accelerating-deep-space-travel-with-space-nuclear-propulsion
On March 1, 2022, the same House Committee held a hearing entitled, *Keeping Our Sights on Mars Part 3: A Status Update and Review of NASA'S Artemis Initiative.* The charter for this hearing stated, "The purpose of the hearing is to examine the status of plans and progress on the National Aeronautics and Space Administration's Artemis initiative; to review challenges related to the implementation of those activities; and to understand the factors that contribute to overall success in the nation's Moon to Mars efforts, among other issues." Expert witnesses were Mr. James Free, Associate Administrator, Exploration Systems Development Mission Directorate, NASA; Mr. William Russell, Director, Contracting and National Security Acquisitions, Government Accountability Office; Dr. Patricia Sanders, Chair, Aerospace Safety Advisory Panel; The Honorable Paul K. Martin, Inspector General, NASA; and Mr. Daniel Dumbacher, Executive Director, American Institute of Aeronautics and Astronautics. https://science.house.gov/2022/3/space-aeronautics-subcommittee-hearing-keeping-our-sights-on-mars-part-3-a-status-update-and-review-of-nasa-s-artemis-initiative

On February 9, 2022, the Senate Subcommittee on Space and Science convened a hearing entitled, *NASA Accountability and Oversight.* The charter for this hearing stated that the hearing's purpose was to examine NASA's private sector partnerships to identify potential best practices, including programmatic risk management, cost and schedule control, and necessary oversight structures. Topics included NASA's multi-directorate approach to Artemis, International Space Station transition and low Earth orbit ("LEO") commercialization, commercial Earth observation data buys, and other collaboration models. The panel of expert witnesses consisted of Mr. James Free, Associate Administrator, NASA Exploration Systems Development Mission Directorate; Mr. James Reuter, Associate Administrator, NASA Space Technology Mission Directorate; Dr. Thomas Zurbuchen, Associate Administrator, NASA Science Mission Directorate; Mr. W. William Russell, Director, Government Accountability Office Contracting & National Security Acquisitions Team; and Dr. Scott Pace, Director, Space Policy Institute and Professor of the Practice of International Affairs at The George Washington University. https://www.commerce.senate.gov/2022/2/nasa-accountability-and-oversight

5. CREATION OF NEW NASA MISSION DIRECTORATES:

In September 2021, Administrator Nelson announced that the agency's human spaceflight division, the Human Exploration and Operations Mission Directorate (HEOMD), would split into two new mission directorates, one focused on space operations and the other on deep space exploration. The new Exploration Systems Development Mission Directorate (ESDMD) is led by Mr. James Free, and the new Space Operations Mission Directorate (SOMD) is led by former HEOMD Associate Administrator Mr. Ken Bowersox. In suggesting that HEOMD had become too large, Administrator Nelson said the reorganization is "about setting up NASA for success. Creating two separate mission directorates ensures these critical areas have focused oversight." He added that the abilities "of two brilliant people to run the respective responsibilities" are needed.

ESDMD is responsible for the development of systems and technologies critical for the Artemis program and will include a Mission Implementation Manager for each Artemis mission, looking across the roles of the Gateway, Orion, SLS, and EGS ((Exploration Ground Systems) in launching and executing missions in lunar orbit and on the lunar surface. These "super program managers," as described by Mr. Free, will begin their efforts with Artemis II, the first crewed mission of SLS and Orion. ESDMD is also responsible for defining the technologies needed for Mars missions and will eventually include programs such as landers and a Mars transit habitation module.
SOMD is responsible for operational programs and organizations including the International Space Station, the Commercial Space Division, Space Communications and Navigation, Human Spaceflight Capabilities, Launch Services, and the newly established Exploration Operations Division.

These changes were implemented to ensure that NASA and its partners will progress efficiently with human exploration plans over the coming decades, and to ensure that operational activities related to ISS and other programs receive the level of stakeholders' and decision-makers' attention that they require.

It should also be noted that, in response to Congressional direction in the 2022 NASA Authorization Act, NASA has announced the establishment of the new Moon to Mars Program Office at NASA Headquarters within the Exploration Systems Development Mission Directorate.

NASA's Moon to Mars Objectives and Workshop, July 20-21, 2022 Image Credit UK Space Agency

6. NASA'S MOON TO MARS OBJECTIVES AND WORKSHOP

On May 17, 2022, NASA issued a draft set of high-level objectives, identifying 50 points that fell under four overarching categories of exploration, including transportation and habitation, Moon and Mars infrastructure, operations, and science. NASA invited comments from domestic as well as international stakeholders, with the deadline for submissions initially being at the end of May. This deadline was extended to June 3, 2022 because numerous potential respondents requested additional time to provide higher quality feedback. NASA received over 4000 submissions in response, and then selected approximately 24 of the respondents to attend, and make presentations at, an in-person workshop held at the Johnson Space Center in Houston at the end of June 2022 (for domestic submissions) or at a similar workshop for international submissions at the end of July 2022. Explore Mars, Inc. submitted comments, and was selected to attend and present at the Moon to Mars Objectives Workshop held at the end of June.

In September 2022, NASA, after consideration of the input and feedback it received from these workshops, released a revised set of 63 final objectives. These objectives reflect a mature strategy, enabling NASA and its partners to develop a blueprint for sustained human presence and exploration throughout the solar system. https://www.nasa.gov/sites/default/files/atoms/files/m2m-objectives-exec-summary.pdf

7. ARTEMIS ACCORDS:

The Artemis Accords were first signed on October 13, 2020 by the national space agencies of eight countries: Australia, Canada, Italy, Japan, Luxembourg, the United Arab Emirates, the United Kingdom, and the United States. Subsequent signatories are Ukraine, the Republic of (South) Korea, New Zealand, Brazil, Poland, Mexico, Israel, Romania, Bahrain, Singapore, Colombia, France, Saudi Arabia, Rwanda, Czech Republic, Nigeria, Spain, Ecuador, India, and Argentina. (The territory of the Isle of Man is also a signatory).

As stated in the Artemis Accords, which build upon the Outer Space Treaty and other related documents, the purpose of the Accords "is to establish a common vision via a practical set of principles, guidelines, and best practices to enhance the governance of the civil exploration and use of outer space with the intention of advancing the Artemis Program… These activities may take place on the Moon, Mars, comets, and asteroids, including their surfaces and subsurfaces, as well as in orbit of the Moon or Mars, in the Lagrangian points for the Earth-Moon system, and in transit between these celestial bodies and locations." (https://www.nasa.gov/specials/artemis-accords/img/Artemis-Accords-signed-13Oct2020.pdf)

The current total of 25 signatories of the Artemis Accords demonstrates the growing international commitment to returning humans to the Moon and then to the surface of Mars.

RECOMMENDATIONS:

- To assure the beginning of a sustainable presence on Mars in the 2030s, plans for sending humans to Mars should be referred to as the 'Mars Campaign' rather than a mission (s) to Mars.
- NASA, Congress, and stakeholders should accelerate steps to assure that vital Mars long pole technologies are developed in parallel with lunar surface efforts. In this spirit, our lunar and Mars goals should be referred to as **"Moon and Mars" rather than "Moon to Mars."**
- Policymakers should continue to encourage NASA and stakeholders to achieve an initial human presence at Mars by the mid-2030s.
- NASA, stakeholders, and policymakers should increase and improve programs that demonstrate the major benefits to society that are likely to result from our return to the Moon and the Mars campaign. This includes highlighting the role of skilled tradespeople in achieving our space exploration goals.

THE PERCEPTION ELEMENT:
An Overview of the Red Planet in the Public Eye

Mars has held a firm place in culture ever since humans looked up and spotted the glowing red orb in the sky. It has captured our imagination in both science and science fiction like no other planet. From H.G. Wells' *The War of the Worlds* and Edgar Rice Burrough's *John Carter of Mars* to Ray Bradbury's *The Martian Chronicles* and Andy Weir's *The Martian,* stories and news about the Red Planet have inspired generations of young readers and budding scientists.

The intrigue of Mars and its presence in the public consciousness has been as strong as ever in recent years. It continues to be a focus across pop culture, particularly as the efforts of Elon Musk and others to eventually populate the Red Planet push science fiction closer to becoming science fact. And with the Perseverance rover and Ingenuity helicopter consistently making mainstream headlines, the knowledge we gain is hardly limited to the science and aerospace community.

The culmination of it all is keeping the exploration of Mars on our collective minds. In fact, according to a July 2021 YouGov survey, more than half (53%) of Americans support sending astronauts on the arduous journey to the Red Planet. In addition, an AP-NORC May 2019 poll shows nearly a third of them (31%) would be willing to travel there themselves if possible.

LAUNCHES AND LANDINGS: The robot population of Mars is growing. Three successful missions from around the world are adding to our overall knowledge and keeping the public captivated.

- **Perseverance Rover**: Its landing on February 18, 2021, drew wide public interest, earning coverage from CNN, FOX News, *The New York Times, The New Yorker*, BuzzFeed, and many other media outlets. The NASA live stream alone has been viewed on YouTube more than 24 million times. While Covid-19 was still devastating the country, the landing engaged the nation and gave us all something to cheer for. Beyond traditional media, Perseverance took social media by storm with memes instantly appearing, linking Mars with other timely cultural moments (including Bernie Sanders seated on Mars with Mittens, and Ted Cruz dragging his vacation suitcase across the surface).

- **Ingenuity**: While the February landing created a spike in interest, just months later, on April 19, the Ingenuity helicopter led to another surge with its successful ascent from the surface of Mars. In doing so, it became the first powered controlled flight by an aircraft on another planet. As of April 13, 2023—days before its two-year anniversary—it has made 50 successful flights covering more than seven miles.
- **China's Zhurong Mars Rover**: Its arrival on May 14, 2021, marked the first successful landing of a non-American robot on the Red Planet.
- **Hope Mars Orbiter**: The United Arab Emirates' Hope spacecraft launched on July 19, 2020, aboard a Japanese rocket and arrived successfully in orbit around Mars on February 9, 2021.
- **Virgin Galactic and Blue Origin**: The battle of the billionaires heated up with their first official space tourism launches in July 2021. Though they certainly did not get anywhere close to Mars, their coverage was widespread across media (Blue Origin even sent William Shatner into space), and it sparked conversation about the future of space travel. As a result, SpaceX and its efforts to reach Mars rode the

wave of coverage, appearing in articles from NPR, *The New York Times, National Geographic*, CNET, and other publications. "That's right, there's another insanely rich man who also has space in his sights," wrote CNET. "The SpaceX head honcho with plans to establish a colony on Mars? Yes, SpaceX does have plans to take private citizens into the cosmos, too—and much farther than Branson or Bezos will be able to achieve with their spacecraft."

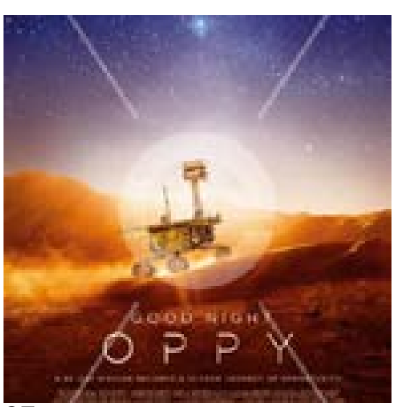
- In July 2022, two startup space companies in California, Relativity Space and Impulse Space, announced a joint venture to launch the first commercial mission to Mars in 2024.

SOCIAL MEDIA: From Twitter to Instagram to every other platform on a device, Mars continues to have an ever-growing audience on social media.

- **@NASAPersevere:** NASA's Perseverance Mars Rover Twitter account launched in February 2020 and has 3 million followers. Its posting of the rover landing earned more than 84,000 retweets. Earlier accounts, including @NASAMars and @MarsCuriosity continue to grow, with 1.3M and 4.3M Twitter followers, respectively.
- **@SpaceX:** With 28.4 million Twitter followers, everything SpaceX says and does about reaching Mars has an avid and engaged audience ready to share.
- **Influencers**: Outside of NASA's accounts and third-party companies like SpaceX, influencers continue to grow and inform followers about Mars and space in general. These influencers tend to be young—Millennials and Gen Z— and reach a young audience. On Instagram, for example, Abigail Harrison, @AstronautAbbyOfficial, has 369K followers. The aspiring astronaut and Harvard Medical School research scientist's stated goal is to be the first astronaut to reach Mars. She's also the founder of @TheMarsGeneration, a Space and STEM outreach nonprofit, which has 38.2K followers. Athena Brensberger, @astroathens, is a space evangelist to her 262.5k TikTok followers and 82.9k more on Instagram, and frequently posts Mars-related content and lectures at schools. Influencers like Athena, Abby, and many others are informing and exciting a younger generation about Mars and inspiring them to pursue careers in science.

TELEVISION AND MOVIES: Mars has a rich history in television and film, dating all the way back to Thomas Edison's 1910 silent film, *A Trip To Mars*. B-movies dominated the '50s, *My Favorite Martian* visited homes on the small screen every week in the '60s, and Tim Burton's *Mars Attacks* spoofed it all in the '90s. With each generation, writers worked with the most recent science surrounding Mars and pushed their imaginations to project the possibilities. Recent films and shows depict what realities could come to pass in the near future.

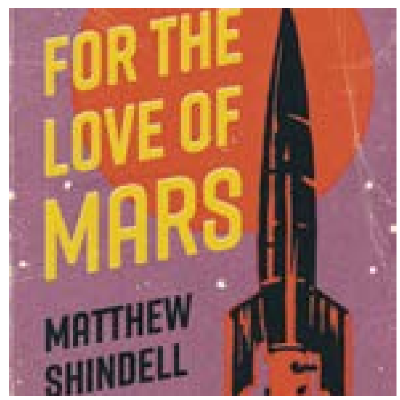
- ***Stars on Mars*** (June 2023) – Hosted by William Shatner, this FOX unscripted series stars a diverse crew of "celebronauts," including Marshawn Lynch, Lance Armstrong, Ronda Rousey, Christopher Mintz-Plasse, Porsha Williams, and others. Living in a simulated Mars environment, they'll compete to see who can best survive on the Red Planet.
- ***Fired on Mars*** (April 2023) – HBO Max's animated series stars Luke Wilson as the voice of a graphic designer who gets fired from his job at Mars.ly shortly after arriving on the Red Planet. Without a quick return to Earth, he has to find ways to survive the corporate world on a whole new world.



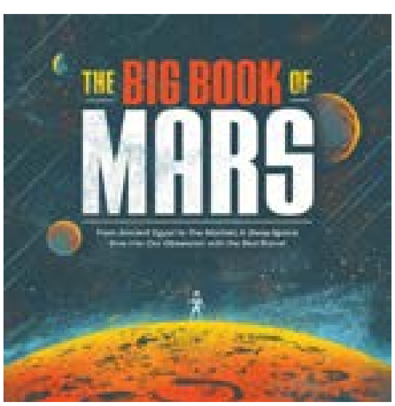
- ***Space Oddity*** – (March 2023) – This sci-fi romantic comedy tells the story of a man training for a one-way trip to Mars to escape life on a farm. Directed by Kyra Sedgwick and starring Kevin Bacon.
- ***Good Night Oppy*** (November 2022) – Narrated by Angela Bassett, this documentary streaming on Amazon Prime tells the amazing story of the Opportunity rover that was scheduled to last 90 days and lived on for 15 years.
- ***For All Mankind*** (Season 3, June 2022) – The latest season of the alternate-reality Apple TV+ show takes place in the early 1990s and focuses on Mars as the next stage of the US/Soviet Union space race.
- ***Moonshot*** (March 2022) – In this sci-fi rom-com, a woman searches for her boyfriend on the Red Planet, which has been colonized by Earth's finest humans.

- ***Stowaway*** (April 2021) – The Netflix sci-fi thriller stars Anna Kendrick, Toni Collette, Daniel Dae Kim and Shamier Anderson. The small crew is headed to Mars for a two-year mission when a stowaway interrupts their journey and they must figure out how to sustain an extra passenger with limited resources.
- ***Space Jam: A New Legacy*** (July 2021) – The sequel to 1996's *Space Jam* introduced Marvin the Martian to a new generation. Marvin the Martian first appeared in 1948 and continues to bring Mars to the imaginations of children.
- ***Settlers*** (July 2021) – The first settlers on the Martian frontier face the elements—and each other. The film had its world premiere at the Tribeca Film Festival on June 18, 2021.
- ***Away*** (September 2020) – The Netflix sci-fi series starring Hilary Swank follows the first crewed expedition to Mars, launched from the Moon.
- ***Marte Um (Mars One)*** (January 2022) – Brazilian writer/director Gabriel Martins tells the story of a lower-middle-class Black family in Brazil with a young boy who's obsessed with Neil deGrasse Tyson and dreams of joining the Mars One mission.
- **Greta Thunberg**: The teenage environmental activist leveraged Mars in a satirical tourism ad for her climate change organization, Fridays for Future. The ad's release was timed to coincide with the Perseverance landing, and portrays the Red Planet as "56 million square miles of untouched land, breathtaking landscapes, and incredible views." It then reminds viewers: "And for the 99% who will stay on Earth we'd better fix climate change."

BOOKS: From nonfiction to science fiction to young adult and children's books, Mars always has stories to tell—and an eager audience waiting to read them.



- ***For the Love of Mars: A Human History of the Red Planet***, by Matthew Shindell (University of Chicago Press, May 2023) – The curator of the National Air and Space Museum offers a tour of Mars spanning the human experience, from ancient astrologers to today's explorers.
- ***There's No Basketball on Mars***, by Craig Leener (Green Buffalo Press, April 2022) – In this young adult novel, an autistic teen is called upon by NASA to assist a crew as the mathematics flight specialist on its first-ever manned mission to Mars.
- ***Missions to Mars***, by Dr. Larry Crumpler (Harper Design, November 2021) – Crumpler, a member of NASA's Mars Perseverance rover mission team, gives an insider account of some of NASA's most incredible missions to the Red Planet. Full-color photographs throughout help chronicle NASA's scientific endeavors and the search for evidence of life on Mars.
- ***How to Mars***, by David Ebenbach (Tachyon Publications/May 2021) – Sci-fi novelist David Ebenbach explores the ways in which colonists on Mars are still entirely human. Though they face the many challenges of living on the Red Planet, they find themselves facing equally difficult problems, such as boredom, cabin fever, and corporate nonsense.
- ***Mars! Earthlings Welcome***, by Stacy McAnulty and illustrator Stevie Lewis (Henry Holt and Co./February 2021). This picture book about the Red Planet is narrated by Mars himself. The fourth planet from the Sun introduces himself to children and invites humans to visit. Young readers getting to know Mars might just be the right age to accept his invitation in the coming years.



- ***The Lion of Mars***, by Jennifer L. Holm (Random House/January 2021) – Award-winning author Jennifer Holm's novel for young readers stars an eleven-year-old kid raised on Mars who learns that sometimes he has to be braver than the adults around him. Readers (and our potential future scientists) learn about what life on Mars might be like and what challenges must be dealt with.
- ***The Big Book of Mars: From Ancient Egypt to The Martian, A Deep-Space Dive into Our Obsession with the Red Planet***, by Marc Hartzman (Quirk Books/July 2020) – Hartzman's book treats Mars as a pop culture star and is written with a humorous touch for a mass audience. Filled with entertaining history, archival images, pop culture ephemera, and interviews

with NASA scientists, *The Big Book of Mars* offers anyone interested in science, sci-fi, and history a comprehensive look at our relationship with Mars—yesterday, today, and tomorrow. (Available in Russian and Polish, 2022.)

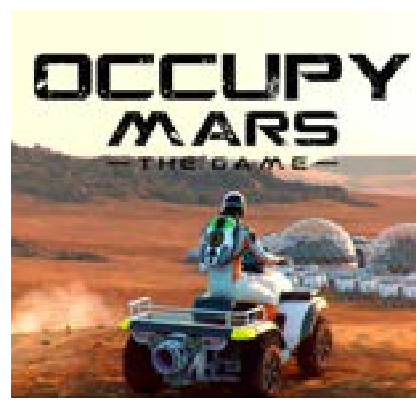
- ***The Sirens on Mars: Searching For Life on Another World***, by Sarah Stewart Johnson (Crown/Hardcover, July 2020; Paperback, July 2021) – Associate professor of planetary science at Georgetown University, Sarah Stewart Johnson, tells the story of her personal interest in Mars as well as humanity's over the centuries. The book reached a mass audience through its coverage by *The New York Times*, *Washington Post*, *Wall Street Journal*, and other mainstream publications.

MUSIC – Mars most notably served as David Bowie's muse, leading to his classic song, "Life on Mars?" and the *Ziggy Stardust and the Spiders From the Mars* album and persona. Over the decades, the Red Planet has inspired other artists, from Paul McCartney and Wings to Kelis to Rob Zombie, and band names, like The Mars Volta and Thirty Seconds to Mars. Recent songs in the past year have added to the Mars soundtrack.

- **Smith & Thell** – The Swedish folk-pop duo released their single, "Planet Mars" in September 2022. The dystopian love song speaks to the great distance that grows in struggling relationships.
- **Megadeth** – The legendary heavy metal band released "Mission to Mars" on its 2022 album, *The Sick, The Dying, … And The Dead!* The song tells the story of a young astronaut eager to embark on the long journey to Mars—and his experience upon landing there.

VIDEO GAMES – The video game market continues to grow, reaching $97.7 billion in the U.S. in 2022 (and $211.2 billion worldwide). Naturally, Mars lends itself to open-world gaming and exploration from the comfort of a terrestrial gaming chair.

- **Deliver Us Mars** – Launched in February 2023 by Frontier Foundry, this sequel to "Deliver Us To The Moon" is an interactive sci-fi adventure offering gamers an immersive, high-stakes astronaut experience on the surface of Mars.
- **Surviving Mars** – The Paradox Interactive game launched in 2018, but released new content for players in March 2021. The Sim City-style strategy game uses real Martian data and challenges players to build a colony on Mars and, of course, keep the colonists alive.
- **Occupy Mars: The Game** – The Pyramid Games title is expected to launch in 2023, though an Early Access version is currently available. The highly technical open-world game lets players build a base, explore the planet, retrieve water, generate oxygen, grow crops, and fix broken parts—all in an effort to survive and colonize Mars. *Occupy Mars* will be released on Steam, an online gaming platform with an estimated 120 million monthly users (as of 2022).



- **Opportunity** – Set to launch on Steam in 2023 from DIMANCHE CORP., the game is a narrative exploration dedicated to NASA's Mars rover, Opportunity. Players will take control of the rover after it lost contact in 2018, and embark upon a new journey across the Red Planet. The immersive gaming experience teaches users about the Opportunity's scientific research capabilities and the challenges of the Martian terrain.

At the time of this writing, Perseverance has just celebrated its two-year anniversary on Mars and has enjoyed a consistent wave of press coverage. Its journey has already covered 5 miles, captured amazing photos, video, and through its two microphones, the first-ever audio recordings of Mars. The rover has also collected 18 rock samples as part of the Mars Sample Return program.

Its mission is certain to continue generating news, while also inspiring students, authors, screenwriters, and countless other Earthlings.

MARS AND EDUCATION

"It is hard to say what is impossible, for the dream of yesterday is the hope of today and the reality of tomorrow." Robert Goddard

As humanity sets its sights on establishing a permanent human presence on Mars, the importance of space education becomes even more crucial. With the unique challenges and demands of living on a different planet, such as radiation exposure, limited resources, and the psychological effects of isolation, the need for a strong foundation in space education is essential to prepare future astronauts for life on the red planet. As we continue to expand our understanding of the universe and push the boundaries of human exploration, space education will play an increasingly vital role in ensuring the success and safety of our endeavors on Mars and beyond. Reaching Mars, combined with human habitation, exploration and experimentation on Mars adds new dimensions that will challenge us and our conventional approaches. The possibility of reaching Mars and beyond not only requires a significant investment in STEM fields, but also in the arts to cultivate the creativity necessary to solve the complex challenges of space exploration. As we strive to push the boundaries of our knowledge and capabilities, space education plays a crucial role in preparing the next generation of explorers, innovators, and leaders to take us further than ever before.

As space and the Artemis missions begin to grow in popularity and visibility, public support for sending humans to Mars is growing exponentially. In reference to a Gallup poll conducted in 2019, a majority of the American public – 53% - now supports the idea of the human exploration of Mars. By comparison, just after the first Moon landing in 1969, Gallup asked the same question but only 39% were in favor at that time. Source: https://news.gallup.com/poll/260543/first-time-majority-backs-human-mission-mars.aspx)

In our rapidly evolving and increasingly complex world, there has been no better time than now to engage, motivate and inspire our nation's youth to embrace science, technology, engineering, art and math. These subjects help prepare and empower our youth with knowledge and skills to solve problems, interpret information, and give them the requisite skills to gather and evaluate evidence to innovate and solve real world, real space challenges. If we desire students all over the globe to be competitive, scientifically literate, and be the work force that can solve complex problems while adapting and working in an ever evolving space economy, then we need to invest in and have space education be an integral part of their education. We should always be cognizant of the fact that opportunities to access quality space science content should not be determined by a student's locale. It is incumbent upon us to ensure that all students, irrespective of their place of abode or financial standing, enjoy access to high-quality learning environments.Investing in SPACE education is of paramount importance.

Although the public supports the human habitation of Mars, we have a significant crisis with the small numbers of High School students that are interested in STEM careers. 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. We also notice that as girls progress through their schooling, they become less interested in pursuing the sciences and higher maths. In high school alone, 60% of girls who were interested in STEM as a freshman are no longer interested by graduation. One of the reasons for this is that 35% of high school girls feel as if they get no support in STEM.

We need to think long and hard about how we nurture the talent and skills of our youth and how we promote the importance of space, science, engineering, design, art, and math. If we are going to increase support for human habitation on Mars then we need to look at the areas that our current education system is ignoring. If the pandemic has taught us anything, it is that our curriculums need to be updated, our teaching methodologies need to be modernized, and there needs to be better career preparation for students. It is important for students to have a clear aim to strive towards. Did you know that a significant percentage of future jobs have not even been created yet? In such an ever-changing job market, proficiency in science, technology, engineering, arts, and math offers a better chance for individuals to adapt and succeed. By honing these foundational skills, students will be better equipped to navigate the challenges and seize the opportunities of the future.

Don't be misled! The acronym STEAM, which stands for Science, Technology, Engineering, The Arts, and Mathematics, encompasses much more than what STEM implies. STEAM involves a vast array of fields, from coding and robotics to a wide range of art forms. STEAM education goes beyond STEM with just a sprinkle of Art. Instead, it is a model that integrates the Arts as an equal partner with the STEM subjects. These skills are critical in providing context and building connections between the sciences, creating a more holistic understanding of our world.

With the fast growth and development of the space industry, opportunities will increasingly become available. Thanks to access to social media, the youth of today are very aware of when rockets have launched, commercial space flights are planned, and when the Artemis missions will commence. The reality of human habitation on Mars is approaching rapidly, and it's crucial that schools recognize the significance of this achievement. The first human to step foot on the red planet could very well be a college student right now, with high school and middle school students next in line. It's time to ask ourselves if a 20th-century curriculum is sufficient for a 21st-century world. To ensure that our future generations are prepared for the challenges and opportunities of space exploration, we need to foster a greater partnership between industry and education. The space industry must guide our schools in the skills and knowledge required to thrive in their field, and space challenges, competitions and expos are excellent ways to keep students engaged and excited about these subjects.

We know that Mars is coming – it's no longer matter of "if" but rather of "when". Some schools are taking a strong view about building STEM and STEAM into their curriculums. While these are essential tools to keep students engaged and excited about their future in space and science, schools and educational institutions need to scaffold this with relevant and engaging content. Our end goal is long-term Mars habitation so our immediate goals should involve taking the appropriate steps to build a strong community of Mars-Empowered students that are proficient at problem solving, critical thinking, creativity, communicating the sciences, math, science, computer, robotics, coding, engineering, making, designing and technology.

Here are a few examples of some excellent Mars resources that enrich education:

- **NASA's online Mars education resources** offer a wide variety of in-depth information organized around self-guided lesson plans requiring minimal resources.
- **Generation Mars** is a series of children's books by Douglas Meredith that follows the first group of kids born on Mars as they grow into their own.
- **The Saving Mars Series** by Cidney Swanson, When the food supply of Mars' human settlement is decimated, seventeen-year-old Jessamyn Jaarda, the best pilot Mars has ever seen, flies to Earth to raid for food. Earth-Mars relations couldn't be worse, and her brother is captured during the raid. Breaking rules of secrecy and no contact, Jess finds an ally in Pavel, nephew to a government official, but their friendship only makes more agonizing the choice before her: Save her brother or save her new planet?
- **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.
- **Space Nation**, which is privately funded, 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 STEAM-SPACE 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.

- **Janet's Planet**, www.janetsplanet.com offers lots of opportunities to engage with leading Mars experts. Contact Janet at janet@janetsplanet.com to request a virtual meeting to talk about Mars and engage with a Mars Subject Matter Expert.
- **Living Maths**, www.livingmaths.com has been future proofing students since 1995 and offers classes in math and science with Global Educator, Steve Sherman.
- **Mars Academy USA** offers simulated Mars missions in a variety of earthly locations, from downtown Los Angeles to the remote mountains of Nepal. The analogs are fully immersive "in-person" real-time simulations and crews live, work and collaborate together during the mission.
- **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 Centers: 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."

Humans to Mars Summit Outreach: Every year, at Explore Mars, Inc.'s annual conference, the Humans to Mars Summit (H2M), the H2M team offers live interactive interviews with many of the top guest speakers at the annual summit. Students and teachers from around the world join these zoom sessions and are provided with the unique opportunity to ask questions and engage with experts on Mars.

Space Foundation Teacher Liaison: This is a body of educators from around the world that is dedicated to bringing space education into the classroom for grades K-12. Educators and organizations can make connections with them to access quality resources about Mars.

When the first several phases of building a sustainable human presence on Mars occur, and children emerge from the pioneering residents of Mars…what will they need to learn to be able to survive? To graduate if there is such a thing on Mars? To be employable on Mars? What will the classroom of Mars look like? What will the teachers teach on Mars? What skills will students need to focus on Mars? To survive and thrive on Mars, we will have to take these questions seriously. On Mars, a failing education system could mean the end of a human presence on the Red Planet and all that have ventured there. We will need to get the best out of every person, learn how to work in harmony with intelligent machines and ensure that what is taught is highly relevant.

Mars is not just a lofty goal, it is a human destination looming in our near future. Going there and staying there addresses a range of issues, critical to human survival, that we will face in the future. These include food insecurity, water shortages, alternative energy/fuel sources, habitable environments, and so much more.
So as we prepare for the grand human endeavor of living, working, and having families on Mars…let's think ahead. Let's ask how education on Earth, or education on Mars, could truly unleash human potential and make life better on Earth and life sustainable on Mars. Space education should be an integral part of global education, as it is a vital component of understanding our place in the universe and the potential for humanity to explore and expand beyond our planet. Incorporating space education into the core curriculum is essential to ensure that all students have the opportunity to develop a fundamental understanding of space science, technology, and exploration. Moreover, space education is a global imperative, as it is a critical driver of scientific progress, innovation, and international cooperation.

Humans on Mars is more than just a dream - it is an ever closer reality that reminds us of the boundless potential that exists within humanity. Humans aiming for Mars is a call to action for countries and people around the globe to come together to achieve something truly extraordinary, together, in a shared purpose. With the right educational initiatives and industry guidance, we can steer the trajectory of schools towards equipping students for this exciting mission. Mars represents limitless possibilities for discovery, adventure, and a better future, and by advocating for a global space education initiative, we can ensure this generation and the next, and the next, is prepared for the epic mission to Mars.


EXPLORE MARS
Explore More at https://ExploreMars.Org