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FRESH THINKING

For NASA to get humans to Mars in the 2030s, it's going to have to target research wisely and devise a realistic strategy for the journey. Dennis M. Bushnell and Robert W. Moses of NASA's Langley Research Center describe some alternatives going forward.

ABOUT MARS

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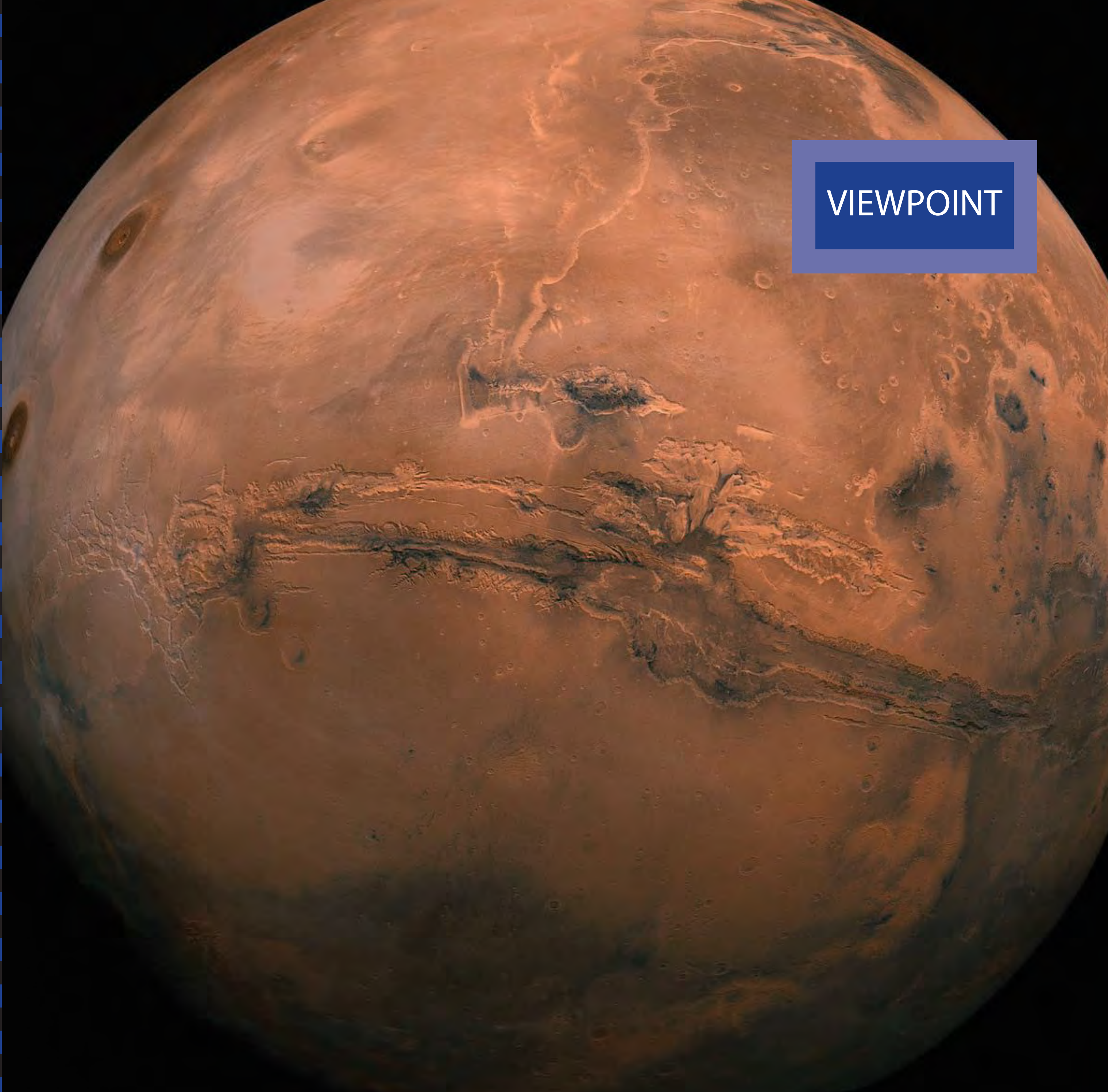


NASA/Jet Propulsion Laboratory-CalTech

NASA has a timetable for getting humans to Mars. But the mission must be safe and affordable.

Human exploration and pioneering of Mars is a top goal of the U.S. civilian space program. In fact, it might be the most important goal. Today's target date of the 2030s gives us enough time to prepare for such a mission.

NASA over the years has drafted a series of Design Reference Missions describing the primary critical elements. The most recent of these calls for sending about 900 metric tons of equipment and fuel into Earth orbit and then on toward Mars to deliver 10 to 20 metric tons of food, scientific equipment and a crew of four to six astronauts to the surface of Mars.

We have not yet determined the safety-related equipment, procedures or reliability features that would be required for a crew to survive and perform meaningful research in such a harsh environment. Living in micro and partial gravity for years will affect crews in ways we do not fully understand. The same is true for galactic cosmic radiation, which courses through the solar system beyond Earth's protective magnetosphere. Mars is famously dusty, and based on our experiences with robotic missions, the dust infiltrates everything. That will pose a reliability challenge for equipment and a health hazard for astronauts. In short, a Mars mission may not yet be in what program managers call the combined cost and safety box. There may not be enough cost margin to afford safety and reliability.

How do we get into the box? One approach is by rethinking today's Mars architecture to take advantage of unfolding advances in autonomous control and additive manufacturing. We could, for instance, adjust our research and development spending to examine the possibility of sending systems to Mars ahead of human explorers to begin robotic autonomous in situ resource utilization and in situ fabrication and repair.

A role for robotics

Many who think about human exploration of Mars have known for years that in situ resource utilization could be the key. Studies indicate that every 1 kilogram of equipment or supplies produced on Mars reduces the requisite mass that must be sent to low Earth orbit by some 7 to 11 kilograms. A 2012 National Research Council review of the NASA Space Tech Roadmaps concluded that "the use of lunar- and Martian-derived propellants could reduce launch masses by over 60 percent," and the review called this a "game changer for exploration."

ISRU concepts are further described in the paper, "Capability and Technology Performance Goals for the Next Step in Affordable Human Exploration of Space," presented at the AIAA 2015 SciTech Forum.

The new thinking is that robots would take ISRU far beyond gleaning water and oxygen from the ice beneath the Martian surface and at its poles. With extensive ISRU, the robots would turn Martian resources into plastics, metals and other construction materials. Also, sintering processes allow us to produce construction materials from the regolith, in addition to making the plastics and metals feedstocks. Additive manufacturing equipment on the surface would then turn this material into rovers, habitats, life support equipment and piping — in short, nearly everything. This will further reduce dependence on Earth-made logistics. This is described in "Sustaining Human Presence on Mars Using ISRU and a Reusable Lander," presented at the AIAA Space 2015 Forum.

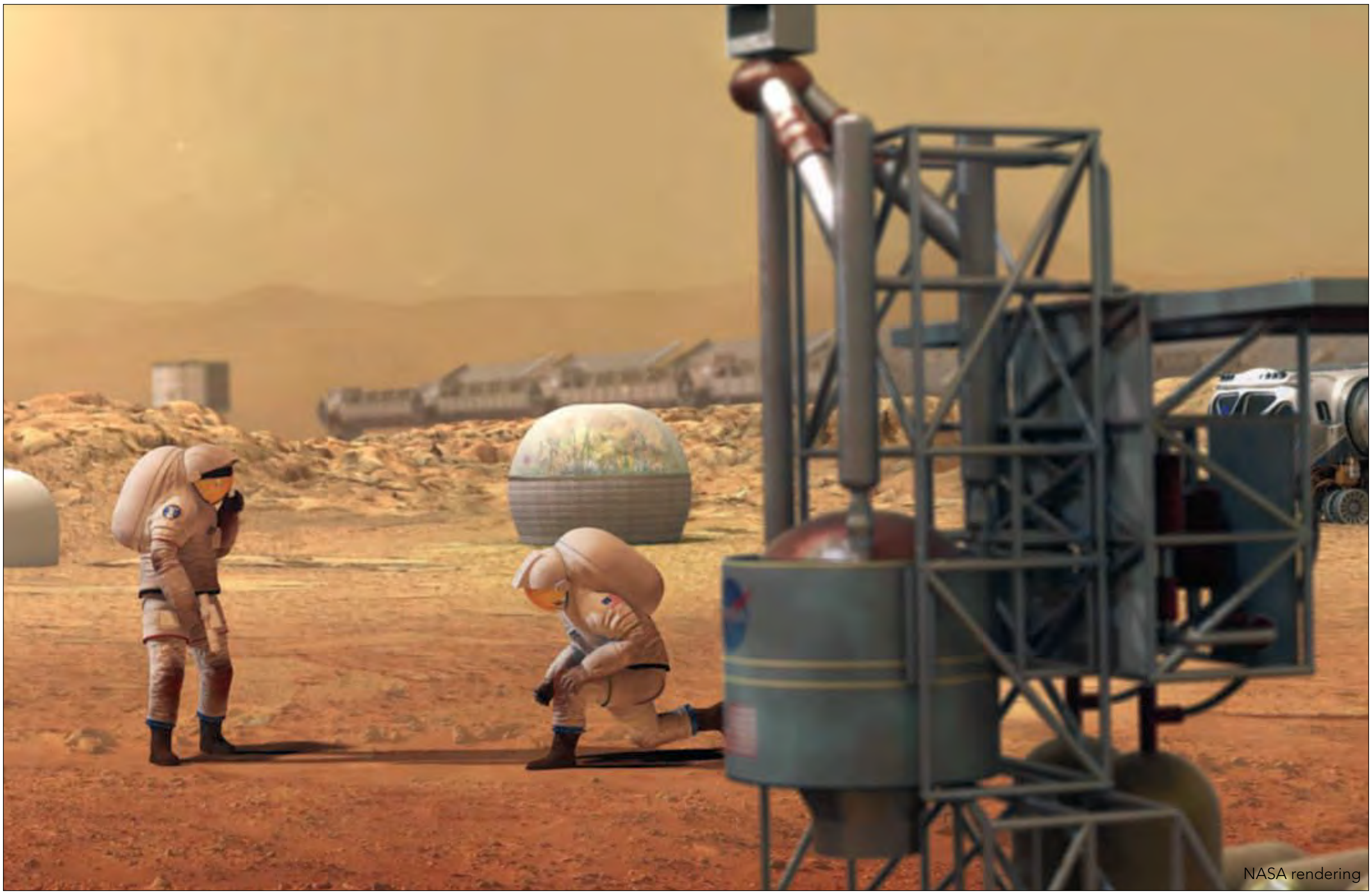
We could send to Mars the equipment that would achieve safety and reliability prior to human arrival. Mars would become a proving ground to demonstrate the reliability of the equipment required by the crew before the crew ever leaves Earth. Robots, after all, don't need paychecks.

There would also be health benefits. Consider again the Martian dust. Without protection, perchlorates in the dust would attack the astronauts' thyroids. There may be lethal components of the dust such as hexavalent chromium. By robotically establishing an operating habitat on the surface, the failure modes of protective equipment could be understood and accounted for prior to the crew leaving Earth. We would effectively be demonstrating safety and reliability on planet. Making and setting a habitat in the ground and covering it with 5 meters of regolith should provide excellent radiation, thermal, micrometeorite and "dust devil" protection. With gravity 38 percent of Earth's, the pressure inside the inflatable is more than sufficient to hold up the few meters of regolith resting on top.

Revolutionary technologies

The current NASA architecture focuses mainly on evolutionary improvements to extant technologies, but it is not clear that those will safely and affordably get us to the Earth independence phase as described in the "Evolvable Mars Campaign" proposed by Jason Crusan, director of NASA's Advanced Exploration Systems Division. EMC suggests we explore Mars in three phases, starting with an Earth Reliant phase, moving to the Proving Ground phase and then to Earth Independence. EMC's proving ground is not Mars, however, but cis-lunar space.

The seeds of a transition to greater resource utilization on Mars have been planted. A 2014 blog on the White House website, "Bootstrapping a Solar System



NASA envisions deriving oxygen, water and fuel from the Martian atmosphere and soil, greatly reducing the supply mass needed to be transported ahead of human exploration.

Civilization," refers to expansive ISRU as "massless exploration," for instance. A public announcement in May 2014 by NASA Administrator Charles Bolden, "Pioneering Space: NASA's Next Steps on the Path to Mars" defines "living off the land" of Mars as one of NASA's top priorities. In October, NASA announced its "Journey to Mars: Pioneering Next Steps in Space Exploration," which aims to align future rover missions with preparations for future human explorers on Mars.

For the extensive ISRU we propose, we'll need revolutionary improvements to the underlying technologies. These revolutionary solutions could, we believe, make Mars exploration even more safe and affordable.

The good news is there is time to do this work. Such revolutionary technologies typically require low technology-readiness-level research and triage of several approaches to determine the most efficacious and viable ways forward. Nominally, technologists require some 10 years to execute the low TRL ideation and research phase, followed by about 10 years of development prior to the mission. Some of the ideation work has been done, so given the target date of the 2030s, the required time frame may be achieveable.

Resource-rich target

The fundamental enabler for this extensive ISRU is the massive amount of resources known to exist on Mars, described for example in the 2009 book, "Mars: Prospective Energy and Material Resources," a compilation by Viorel Badescu of the most recent papers on the resources of Mars and some latest thought on their utilization. The carbon dioxide in the atmosphere can be cooled and collected, providing a supply of carbon and oxygen. There is water nearly everywhere, at the poles, in the regolith and in huge ice lakes. Above 60 degrees latitude, some 40 percent of the regolith is water. Then there is the water tied up in hydrated materials. Estimates indicate there is sufficient water to put an ocean over the whole planet. Estimates vary with respect to the depth of such an ocean, ranging from tens to many hundreds of meters. Much of this water, simplistically, could be vaporized and collected via a cart with a microwave device affixed to it. Alternatives include a greenhouse "solar tent." The resulting supply of hydrogen, oxygen and carbon from the atmosphere, enables the manufacture of major amounts of methane and hydrogen fuel and plastics.

There is increasing evidence that food could be grown on Mars inside greenhouses. Produce could include mushrooms, insects for essential fats, cyanobacteria for protein and duckweed, to name a few.

Also, as a general design approach, equipment produced on Mars just has to work. It does not have to be fancy or finely finished. Studies are needed to determine the minimal initial payload size, weight, cost and composition of the requisite autonomous robotics. These robotic machines could initially replicate themselves to increase productive capacity and capability and then execute resource location, extraction, refining, fabrication and operations. Relatively small initial "seedling" packages of autonomous robotics may be sufficient. Transport of initial ISRU autonomous robotics and printing payloads could conceivably be via solar electric propulsion or "slow boats."

Nearly everything that humans would require on Mars is rapidly becoming feasible to produce on planet. Advances in machine intelligence are pointing the way toward autonomous robotic and 3D printing. By knitting these advances together, a smallish supply package could possibly be sent to Mars some five years or so before humans go.

Getting to the surface

In addition to prepositioning supplies and addressing the many health concerns ahead, there is the physics of landing a crew on Mars. Today's state-of-the-art technology for entry, descent, and landing limits payload mass to around one metric ton, far below the 10 to 20 metric ton payloads anticipated for human missions to Mars.

An enabler for serious ISRU is a reusable Mars Truck, sometimes called a Mars Ferry. The idea is described in the paper, "Sustaining Human Presence on Mars Using ISRU and a Reusable Lander," by our colleague Dale Arney at Langley. The Mars Truck would transport materials and eventually humans to and from the planet to Mars orbit, using Mars-produced fuel, while certifying the vehicle for crew flights. Such a craft could possibly enable inexpensive Mars fuel and products to provide resources for colonization of the inner solar system, effectively turning Mars into Walmart.

Landing the crew is not the only large payload taxing entry, descent and landing capabilities. The nuclear-energy device necessary on the surface to power the ISRU equipment, habitats, and recharge batteries weighs several metric tons. It also requires a heavy cable to transfer the electrical power from the nuclear device to the equipment and habitat. Therefore, more mobile lighter-weight devices are needed.

Energy

The energy to execute serious pre- and post-human-arrival ISRU could be sourced from scaled fission reactors, solar and chemical fuels. This approach also could be applied to in-space and other propulsion applications. However, within a nominal 10-year low TRL research window, there are several other extremely interesting alternative energetics approaches that could be considered, investigated and triaged.

Russian researchers have developed a fluidized bed vortex reactor that is exceedingly compact.

Sang Choi here at Langley has invented a Nuclear Thermal Avalanche Cell approach to dramatically increase RTG (radio thermoelectric isotope generator) energy production.

Researchers also have some 25 years of experiments with Low Energy Nuclear Reactions (LENR), which provides energy with negligible radiation. Large commercial investments are now being made to understand, scale and engineer LENR to be safe. This technology could conceivably power the Variable Specific Impulse Magnetoplasma Rocket designed for fast, in-space propulsion.

There is also the concept of Osmatic Power utilizing solar regeneration.

Energy conversion advances are being made, including in the fields of thermoelectrics, pyroelectrics, thermal photovoltiacs, fuel cells and Sterling cycles.

For Energy storage, there is research on zeolites, which could hold four times more heat than water. Advances are also being made to metal air batteries and flow batteries, and storing either hydrogen or electricity as an ultra capacitor in nanotube structures, skins and chemical fuels.

Martian-derived fuels such as methane and hydrogen could be used for transportation in Mars orbit and for trips to Earth and back, in addition to powering rovers and other surface operations. Mars-derived fuel could be placed in orbits between Earth and Mars, creating the game-changing option of en route fuel depots and refueling. Another use for the fuels would be powered entry, descent and landing. The current state of the art with respect to EDL involves inflatable drag producing decelerators and lower speed systems, but it might also be possible to utilize the plasma generated during entry.

These are just some of the alternative approaches that may get humans to Mars safety and affordably.

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Robert W. Moses *is an aerospace engineer at Langley specializing in developing systems and technologies to enable mission capabilities. Since 2003, he has led studies into a variety of entry, descent and landing techniques for Mars. He serves on the Office of Chief Engineer's Systems Capabilities Leadership Team on ISRU and is an associate fellow of AIAA.*