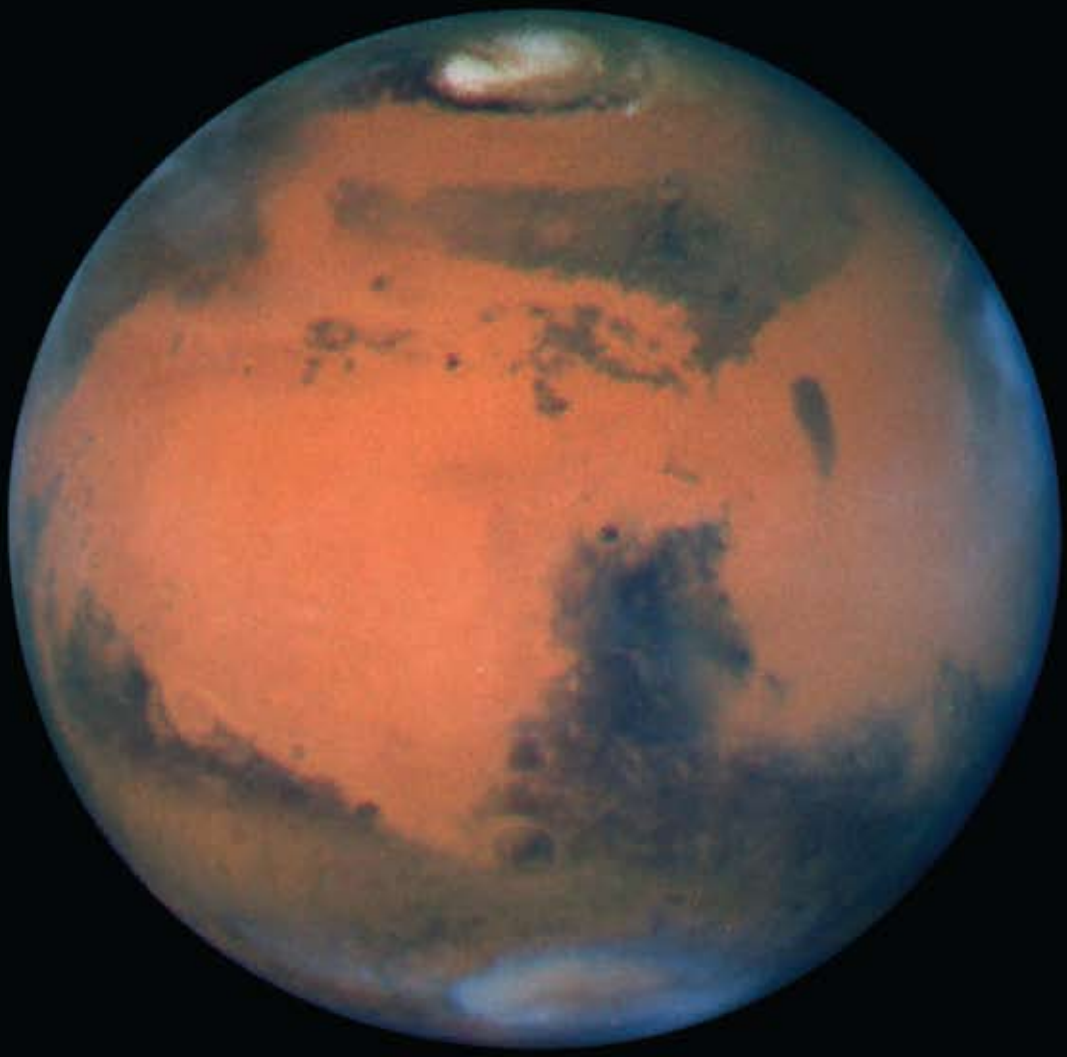
HUMAN SPACEFLIGHT



Mars is the destination that matters.

LOREN THOMPSON

FINDINGS IN BRIEF

NASA's human spaceflight program has been gradually losing ground since the *Challenger* disaster 25 years ago. Retirement of the Space Shuttle fleet and cancellation of the Bush Administration's Constellation program signal an uncertain future for one of the most important scientific initiatives in human history. Although Congress and the Obama Administration have cobbled together a framework for proceeding with future missions, human spaceflight today lacks a core mission or rationale that can sustain political support during a period of severe fiscal stress.

Mars is the sole destination for the human spaceflight program that can generate sufficient scientific benefits to justify the scale of expenditures required. It is also the only destination likely to sustain political support across multiple presidential administrations. Mars is the most Earth-like place in the known universe beyond our own planet, and it is the one location that could conceivably support a self-sustaining human colony. It has water, seasons, atmosphere and other features that may hold important lessons for the future of the Earth, but unlocking those lessons would require a sustained human presence on the Red Planet's surface.

NASA does not presently possess the technology needed to mount a manned mission to Mars, but with careful preparation a mission to the Red Planet would be feasible in about 20 years without significantly exceeding the space agency's currently planned budgets. The key to making such a plan work is to designate Mars as the ultimate destination and then arrange "stepping stone" missions to intermediate destinations such as near-Earth asteroids so that technologies can gradually be scaled up to the level required for a Mars mission.

The two most important elements in any human spaceflight program that proposes to go beyond low-Earth orbit are an evolvable heavy-lift launch vehicle and a multi-purpose crew vehicle. Congress has directed that NASA's future work on both systems should focus to the maximum degree possible on technologies already under development for the Constellation program. By applying those technologies to a human spaceflight agenda focused on the ultimate destination of Mars, NASA can preserve its investment in a highly skilled space workforce and related infrastructure. Failure to make Mars the centerpiece of future exploration efforts will probably doom the human spaceflight program to a further erosion of political support at a time when its survival is already in question.

TABLE OF CONTENTS

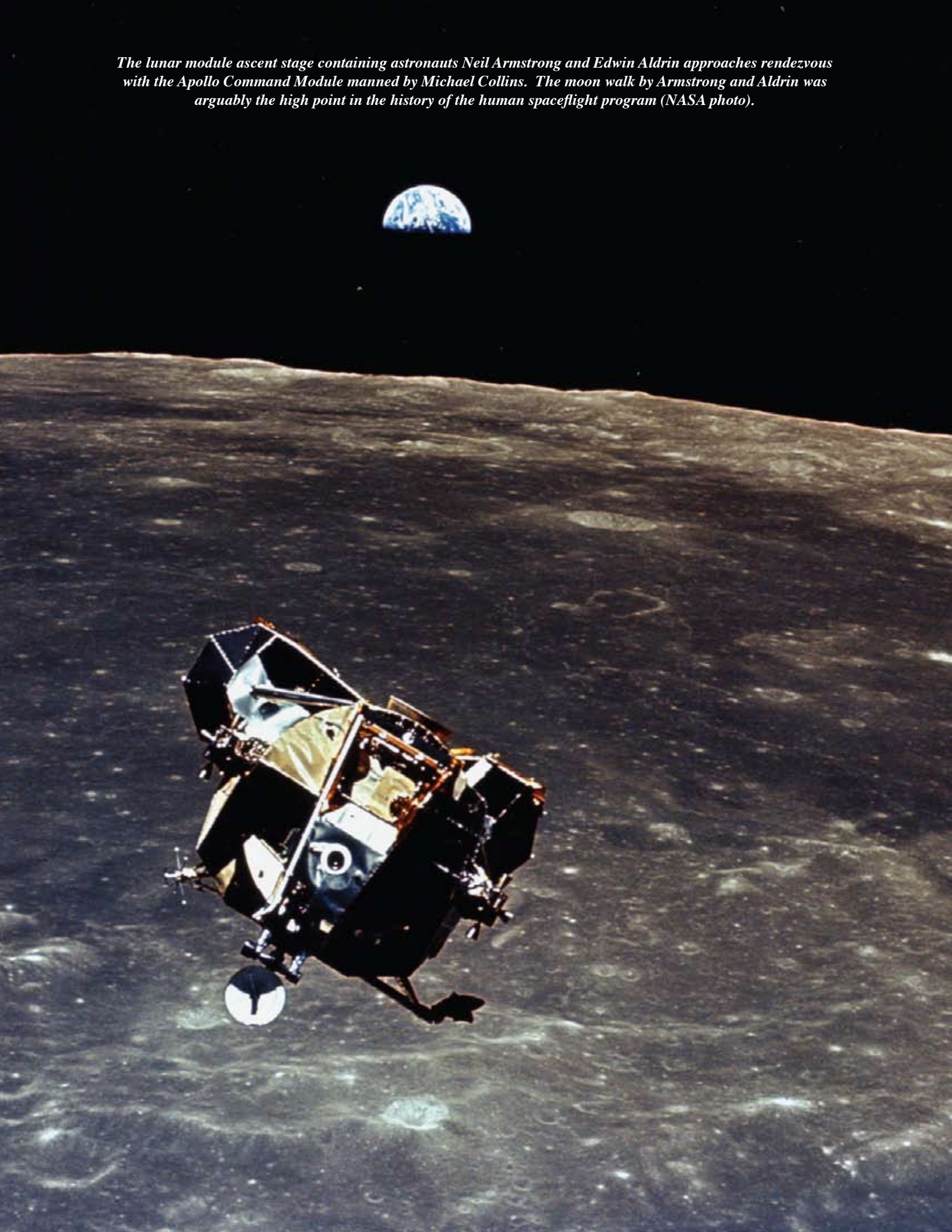
IN HUMAN SPACEFLIGHT, MARS IS THE DESTINATION THAT MATTERS

The National Aeronautics and Space Administration's human spaceflight program is one of the greatest scientific achievements in history. However, the program has been slowly dying since the *Challenger* Space Shuttle disaster 25 years ago. Faltering political support, failed technologies and competing claims on an under-funded federal budget have made it difficult to sustain a coherent program from administration to administration. The Obama Administration has offered a bold plan for nudging human spaceflight out of its decaying orbit, but the plan received only mixed support in Congress and looks unlikely to sustain political momentum over the long term.

Although NASA consumes less than one-percent of the federal budget, it does not connect well with the current economic or social agendas of either major political party. The broad support for the human spaceflight program early in its history was traceable largely to the ideological rivalry between America and Russia that produced the Moon race. Today, no such external driver exists to sustain support of human spaceflight across the political spectrum. The program therefore must generate some intrinsic rationale -- some combination of high purpose and tangible benefit -- to secure funding. Recent efforts at generating a compelling rationale, such as the "flexible path" and "capabilities-driven" approaches currently favored by the space agency, are inadequate. They do not resonate with the political culture.

In the current fiscal and cultural environment, there is only one goal for the human spaceflight program that has a chance of capturing the popular imagination: Mars. The Red Planet is by far the most Earth-like object in the known universe beyond the Earth itself, with water, seasons, atmosphere and other features that potentially make it habitable one day by humans. In addition, its geological characteristics make it a potential treasure trove of insights into the nature of the solar system -- insights directly relevant to what the future may hold for our own world. And Mars has one other key attraction: it is reachable. Unlike the hundreds of planets now being discovered orbiting distant stars, astronauts could actually reach Mars within the lifetime of a person living today, perhaps as soon as 20 years from now.

This report makes the case for reorienting NASA's human spaceflight program to focus on an early manned mission to Mars. It begins by briefly reviewing the history of the human spaceflight program and explaining why current visions of the program's future are unlikely to attract sustained political support. It then describes the appeal of Mars as an ultimate destination, and the range of tangible benefits that human missions there could produce. It concludes by describing the budgetary resources and scientific tools needed to carry out such missions. The basic thesis of the report is that human missions to Mars can be accomplished within NASA's currently projected budgets; that proposed missions to other destinations such as near-Earth asteroids should be reconfigured as stepping-stones to the ultimate goal of the Red Planet; and that if Mars does not become the official goal of the human spaceflight program, then the program will effectively be dead by the end of the current decade.



The lunar module ascent stage containing astronauts Neil Armstrong and Edwin Aldrin approaches rendezvous with the Apollo Command Module manned by Michael Collins. The moon walk by Armstrong and Aldrin was arguably the high point in the history of the human spaceflight program (NASA photo).

AMERICA HAS LED HUMAN SPACEFLIGHT EFFORTS FOR FIFTY YEARS

The U.S. human spaceflight program was born in the midst of a national crisis. When Russia orbited the Sputnik satellite on October 4, 1957, it signaled that America's principal rival for global influence had surpassed the U.S. in rocketry and other facets of space science. That sparked fear in Washington, because the same boosters used to launch the satellite could be employed to deliver nuclear warheads against America, and the U.S. had no defenses against such an attack. More generally, Sputnik was viewed as a challenge to American education and science at a time when the two countries were straining to prove the superiority of their respective systems to other nations. The impact on the American psyche was so profound that U.S. leaders are still invoking Sputnik today as a metaphor for urgent challenges -- as President Obama did in discussing economic competitiveness in his 2011 State of the Union address.

One of the responses to the Sputnik challenge was the creation of the National Aeronautics and Space Administration, which became operational in October of 1958 with a mandate to beat Russia in what quickly came to be known as the "space race." However, it took years for America to catch up, and on April 12, 1961 the Russians scored another first by launching astronaut Yuri Gagarin into orbit. America's first manned spaceflight the following month was a less impressive achievement, because astronaut Alan Shepard did not actually orbit the Earth. But that same month President John F. Kennedy went before a joint session of Congress to propose something far bolder: landing a man on the Moon and then returning him safely to Earth by the end of the decade. That goal -- which was accomplished only 98 months later -- became the driving force behind NASA's manned spaceflight program during a period many now view as its golden age.

There were numerous trials and triumphs as NASA worked its way through the Mercury, Gemini and Apollo programs to a point where technology was in hand to attempt a Moon landing. On July 20, 1969, though, astronauts Neil Armstrong and Buzz Aldrin stepped onto the Moon in the first of six missions proving that America had become the undisputed global leader in space technology. Few events in history have proven a more powerful inspiration to the human imagination, or a more potent endorsement of the American way of life. With the Moon conquered, NASA then turned to the challenge of making human spaceflight a routine, reasonably affordable activity. The concept it embraced was the Space Transportation System -- better known as the Space Shuttle -- which consisted of reusable boosters and vehicles that could carry seven astronauts and heavy payloads into orbit.

Although it was only designed to reach low-earth orbit, the Space Shuttle was a logical progression beyond the expendable systems used to reach the Moon. NASA devoted most of the human spaceflight budget to its development and operation during the 1970s and 1980s, with the first launch of Shuttle *Columbia* taking place on April 12, 1981. The four vehicles in the Shuttle fleet were soon reaching orbit on a regular basis, and while costs never fell to a point where space travel could become routine, the availability of a flexible and reusable launch system enabled the U.S. to pursue other space objectives such as operation of the International Space Station -- the biggest research facility ever put into orbit. NASA accomplished many other feats during the Shuttle's early years, but manned spaceflight remained the centerpiece of its budget and its identity. And then, on January 28, 1986, the Space Shuttle *Challenger* exploded, marking an end to NASA's golden age.

Space Shuttle Discovery launches from the Kennedy Space Center on its 35th flight. The Space Shuttle was an impressive scientific achievement, but the tragic loss of Challenger in 1986 began the downward spiral of the human spaceflight program that has brought it to its current low ebb (NASA photo).

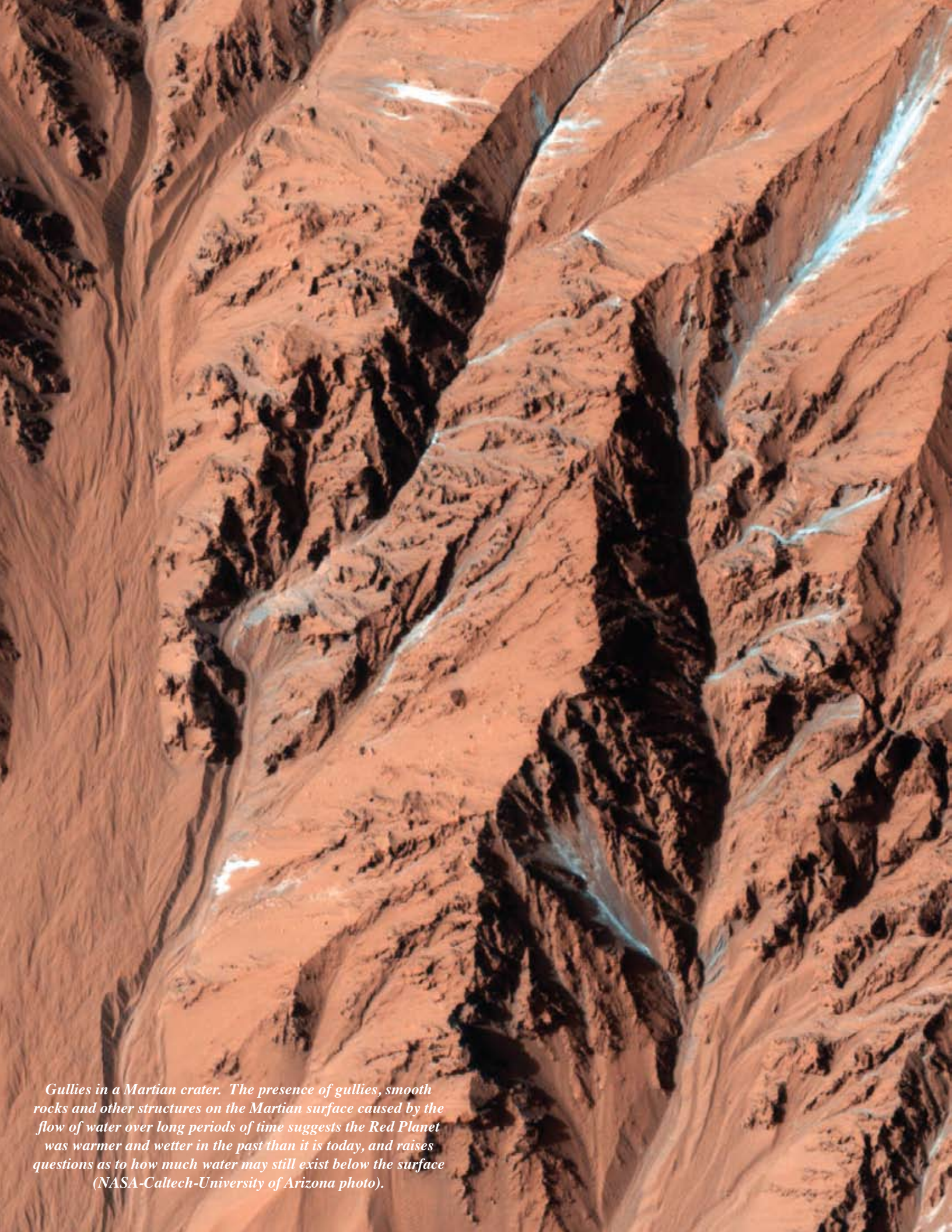
HUMAN SPACEFLIGHT FALTERED AFTER THE CHALLENGER DISASTER

The *Challenger* disaster was the worst trauma in NASA's history, killing seven astronauts and grounding the Shuttle fleet for over two years. Investigation into the cause of the disaster revealed a design flaw compounded by miscommunication at the Marshall Space Flight Center. A new vehicle was constructed to replace *Challenger* and the fleet returned to service in September of 1988, but public perceptions of the program were irreparably damaged. When a second Shuttle, *Columbia*, disintegrated while reentering the atmosphere on February 1, 2003, it was clear that the Shuttle's days were numbered. Critics again cited errors by NASA personnel that contributed to loss of the orbiter and all seven astronauts aboard, reinforcing a widespread suspicion that the space agency's culture had eroded in the years since the Apollo program.

Doubts about the future of the Shuttle fleet undermined other parts of the human spaceflight program, especially the International Space Station that Congress had authorized in 1984. The space station was a partnership between NASA and space agencies in Russia, Europe, Japan and Canada that depended on the Shuttle for its construction and sustainment. Although it was the most ambitious international space partnership in history, it was very costly and the human spaceflight program had lost much of its political support with the waning of the Cold War. In 2008, NASA Administrator Michael Griffin alleged that the White House budget office was actively seeking to undermine the space station as a way of saving money.

By that time, though, President George W. Bush had articulated a new "Vision for Space Exploration" that proposed to return to the use of expendable launchers as the principal means of lofting humans into space. Efforts to develop a reusable successor to the Space Shuttle had encountered technical challenges that made traditional launch concepts the only feasible way of supplying the space station and continuing the human spaceflight program once the Shuttle fleet was retired around 2010. Bush's vision evolved into a program called Constellation, which funded a new heavy-lift launch vehicle and crew capsule that could return humans to the Moon and then provide the basis for a manned mission to Mars. However, a presidential commission reported in 2009 (shortly after Bush left office) that the Constellation program was under-funded and therefore could not meet its intended goals.

NASA's human spaceflight program, begun during the national crisis that followed launch of Sputnik in 1957, was now itself in crisis. In an attempt to salvage the program, President Obama proposed in February of 2010 that Constellation be scrapped and the space agency embark on a new research agenda similar to the "flexible path" proposed by the presidential commission. Rather than setting a firm goal of going to the Moon or Mars, NASA would seek to develop capabilities suitable for reaching a variety of destinations, and scale up its ambitions as those capabilities became available. The new plan was not well received in Congress, which saw it as a threat to the NASA workforce and infrastructure. Congress directed that money be spent to continue key elements of the Constellation program while relying on private entrepreneurs to develop innovative ways of supplying the space station. Despite these efforts to keep the human spaceflight effort intact, though, NASA's signature program had reached a low ebb.



Gullies in a Martian crater. The presence of gullies, smooth rocks and other structures on the Martian surface caused by the flow of water over long periods of time suggests the Red Planet was warmer and wetter in the past than it is today, and raises questions as to how much water may still exist below the surface (NASA-Caltech-University of Arizona photo).

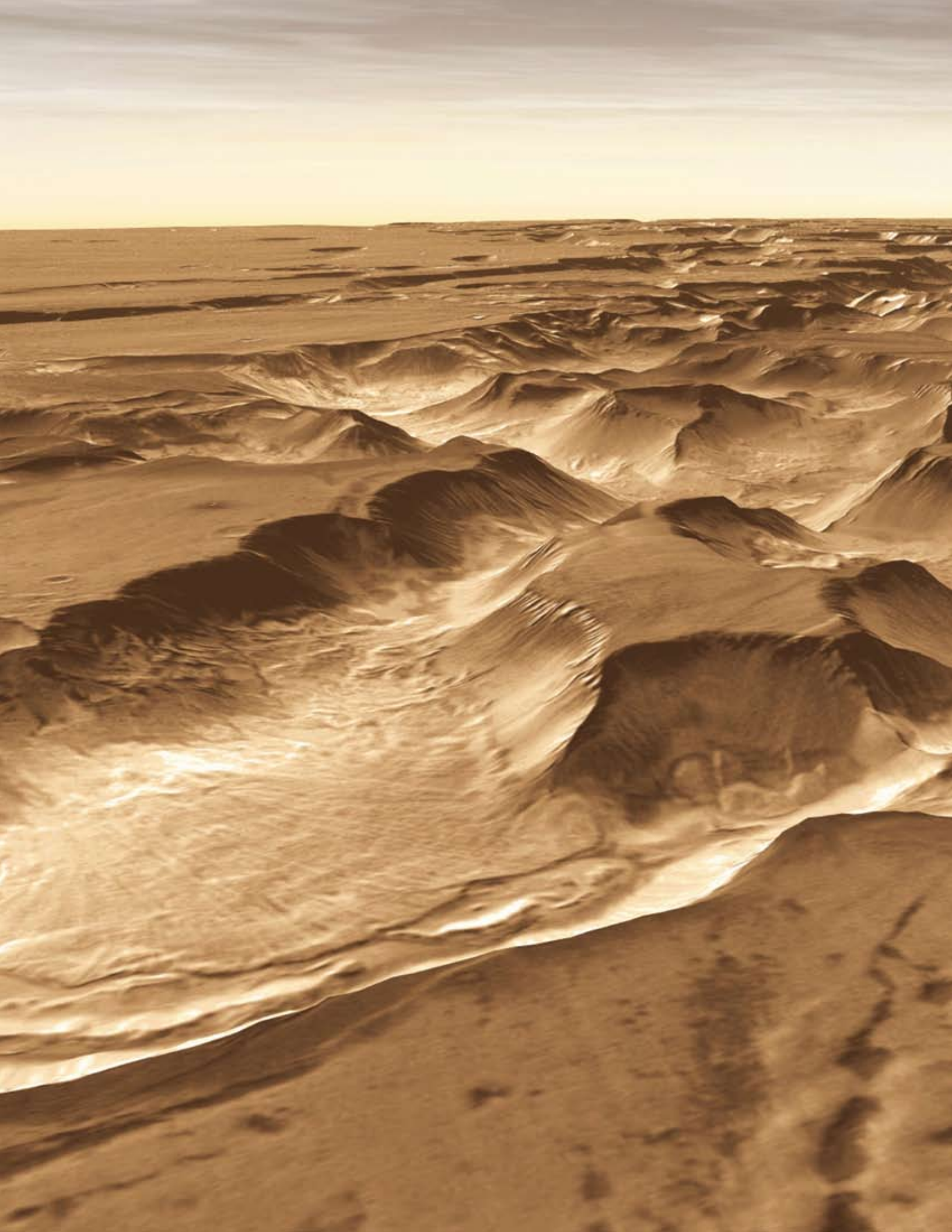
MARS IS THE ONLY GOAL THAT WILL SUSTAIN POLITICAL SUPPORT

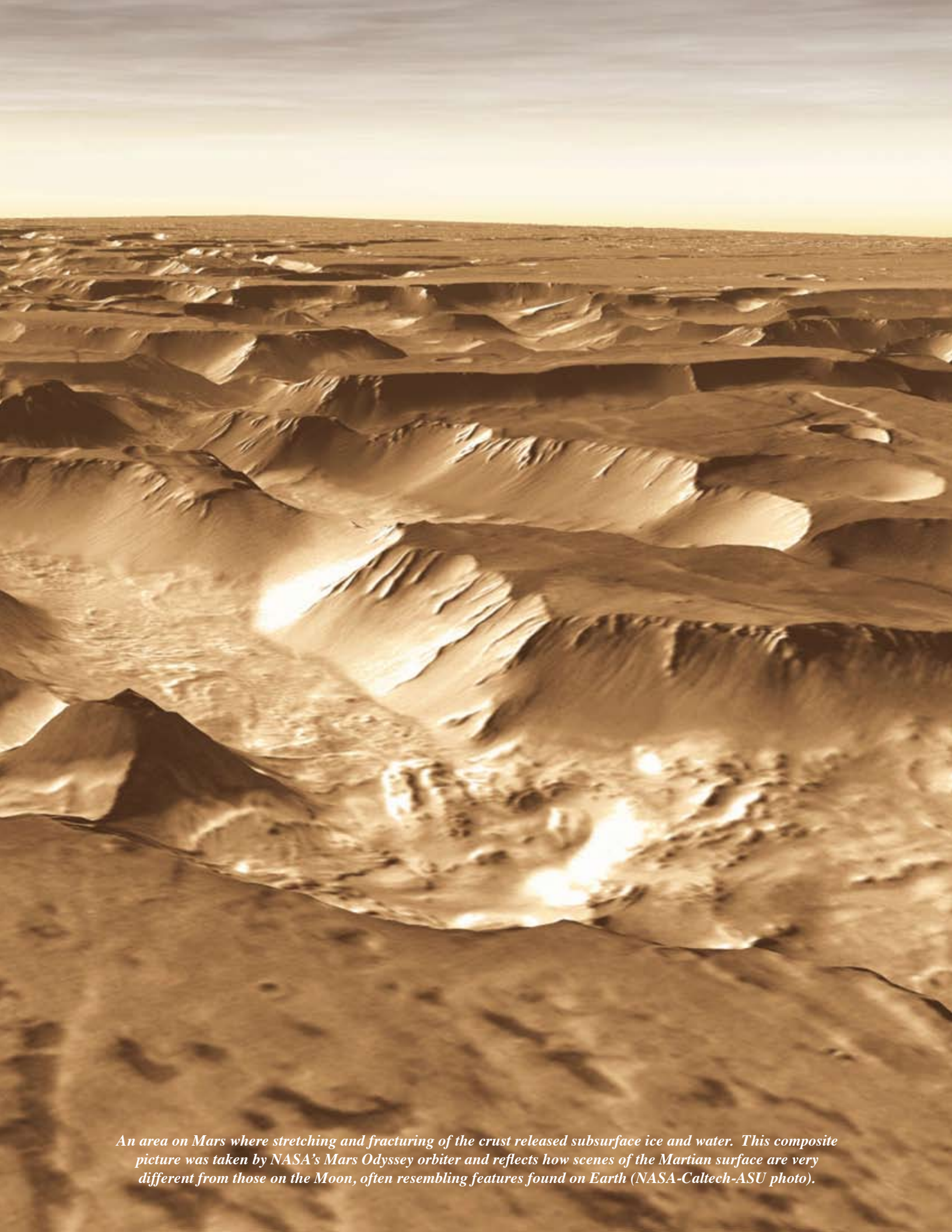
The 2009 commission recommending a flexible path was only one of two dozen presidential panels that had assessed the human spaceflight program since Neil Armstrong stepped onto the Moon 40 years earlier. Like previous bodies, it was better at diagnosing problems than framing politically sustainable solutions. That became apparent when President Obama sought to implement the commission's findings and met strong resistance in Congress. Much of the resistance centered on likely workforce impacts arising out of the proposed cancellation of the Constellation program, but an additional concern was the absence of clear goals for the reorganized human spaceflight effort. Past experience strongly suggests that without a core initiative such as the Moon race or the Space Shuttle that can inspire popular support, it will be hard to sustain the human spaceflight program from administration to administration -- especially in a period of unprecedented budget deficits.

Among the various destinations that have been proposed under the flexible path -- a return to the Moon, visits to asteroids, etc. -- only the goal of a manned mission to Mars offers the hope of generating scientific benefits sufficient to justify the amounts of money required. This potential for a big scientific payoff arises from the fact that Mars is the most Earth-like object in the reachable universe, and the only other planet in the solar system that could plausibly host a self-sustaining human colony someday. Although the Martian environment is a harsher setting than anyplace on Earth, it has water, it has an atmosphere, it has seasons and it has other attributes typically associated with the cycle of life on our own planet. Its geophysical and climatological features offer lessons about the past and future of Earth that cannot be gleaned from any other destination. And it presents scientists with a number of puzzles, such as the presence of methane typically produced by living organisms, that can only be resolved through human exploration.

Robotic probes of the Martian surface have tended to raise more questions than they answer. For example, the discovery of sand dunes, gullies, pebbles and composite rock clearly points to the presence of water over long periods of time, but scientists at present can only speculate about where the water came from, or where it has gone. This is a vital question, since if Mars has large reserves of water as many scientists suspect, that would make it a more plausible place to have produced life. Life first emerged on Earth over three billion years ago, when conditions were much different than today and in some respects similar to the present environment of the Red Planet. The relevance of lessons learned from exploration of Mars to the future of mankind on Earth makes any mission there fundamentally more important than visits to other destinations that the human spaceflight program might undertake.

However, the logical path to Mars involves visiting many of those other destinations first, since NASA would have to scale up its capabilities before attempting a manned mission to the Red Planet. In that regard, the future of the human spaceflight program proposed here isn't all that different from what the 2009 presidential commission recommended. Where it differs is in defining the intermediate steps with the ultimate goal of Mars in mind. That approach is essential to assuring that near-term investments are compatible with the long-term objective, and to sustaining political support across two decades and five administrations. If NASA structures its human spaceflight program in a Martian-centric manner, it should be able to place humans on the Red Planet in 2031 without exceeding currently projected budgets.





An area on Mars where stretching and fracturing of the crust released subsurface ice and water. This composite picture was taken by NASA's Mars Odyssey orbiter and reflects how scenes of the Martian surface are very different from those on the Moon, often resembling features found on Earth (NASA-Caltech-ASU photo).

Scattered rocks near the Mars Pathfinder landing site. The Martian surface is hostile to life due to temperature extremes and lack of atmospheric protection against lethal ultraviolet rays, but rock formations such as these harbor important lessons about the origins of the solar system and the future of Earth (NASA-Caltech photo).

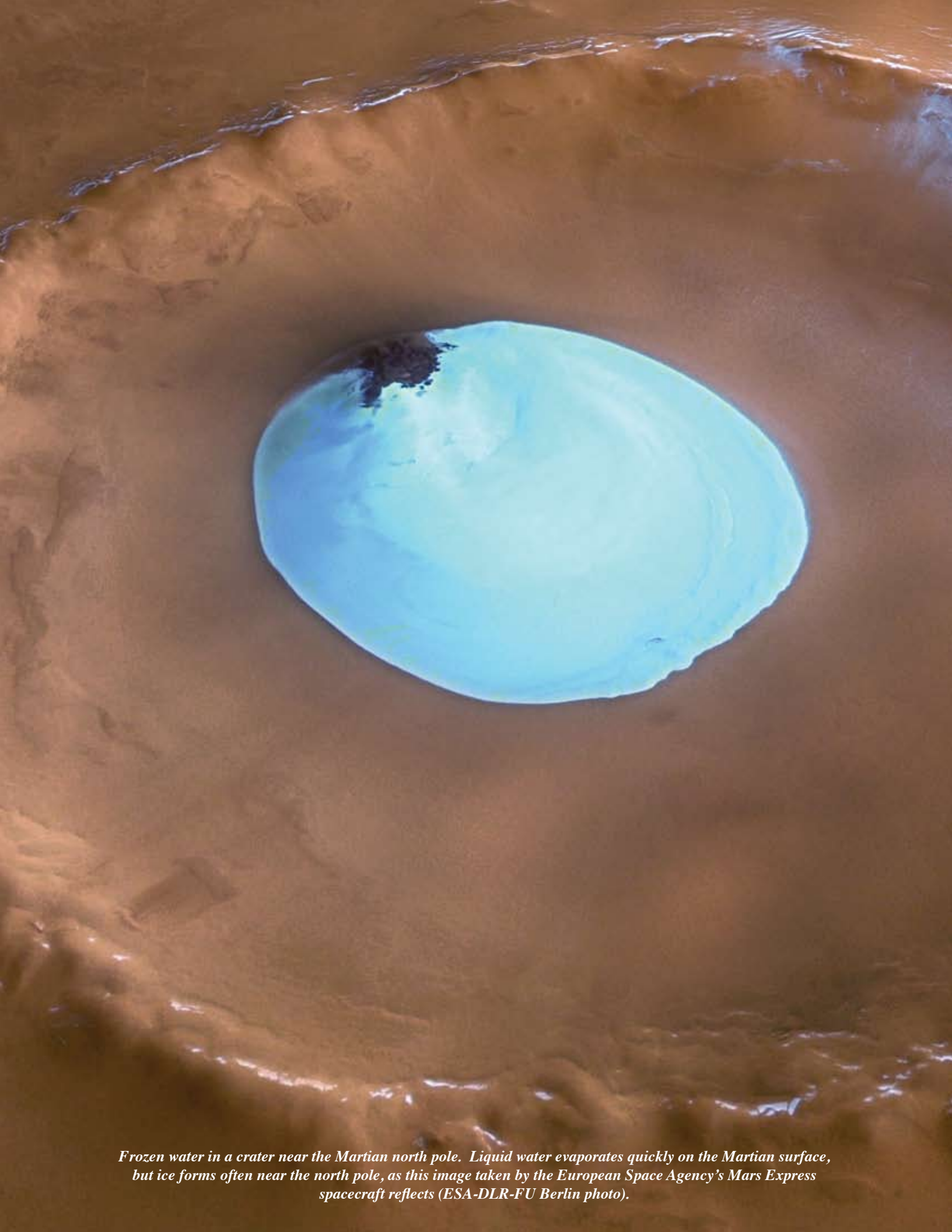
MISSIONS TO MARS CAN ANSWER CRUCIAL SCIENTIFIC QUESTIONS

Mars has fired the human imagination since antiquity, but until recently little was known with certainty about the Red Planet. Less than a hundred years ago, some scientists seriously entertained the notion that Mars might be inhabited by a race of intelligent beings; in 1924, naval radio stations in the Pacific remained silent for three days in the hopes that transmissions might be intercepted from the planet. Scientists today have a much firmer grasp of Martian realities as a result of fly-bys and robotic probes beginning with the Mariner program in the 1960s, but many of the most fundamental questions about Mars remain unanswered. NASA has barely begun to investigate what lessons Mars can teach us about the fate of our own planet. It is unlikely the most important scientific questions can be answered definitively without a prolonged human presence on the Martian surface.

One area of inquiry concerns the geological and climatological history of planets. Mars has less volcanic activity than Earth or Venus, and as a result some of its surface has been undisturbed for billions of years. It thus presents a unique geological record of how the Solar System was formed. In addition, its relative proximity to the Sun combined with an axial tilt similar to that of the Earth gives the Red Planet seasonal variations and atmospheric conditions that can usefully be compared with conditions on Earth. Although liquid water is no longer stable on its surface, there is extensive evidence of hydrological activity in the past, including mineral deposits suggestive of ancient sea-beds. Understanding how Mars evolved away from the warmer, wetter conditions prevailing early in its history could offer important insights into how the Earth itself will change over time.

Another area of great scientific interest concerns the possible presence of life on Mars, either today or in the past. Water is a prerequisite for every form of life found on the Earth, and Mars clearly had huge amounts of liquid water for extended periods at some point in its history. Many scientists believe the water is still there, albeit hidden beneath the Martian surface. While life as we know it would be nearly impossible on the surface today due to the sterilizing effects of ultraviolet rays -- there is no ozone layer to block such rays -- microbial life may exist in the Martian soil. That could explain the presence of methane detected in Martian probes, a type of gas that on Earth is often produced by living organisms. Any firm evidence of life on Mars, even if now extinct, would be one of the most important discoveries in history, changing the way scientists look at the universe. Few questions are more basic to the human condition than whether we are alone in the cosmos, or life exists on other planets.

Beyond such fundamental scientific questions that a human presence on Mars could help answer, there are the practical issues surrounding whether human beings can function on Mars for extended periods of time, perhaps even building a self-sustaining outpost. Scientists do not know for sure whether sufficient water, energy sources and useful minerals are present, but there are tantalizing signs such as the discovery of naturally occurring perchlorate, a compound that is used on Earth to oxidize rocket fuel. Because Mars has less mass than the Earth, it is easier for rockets lofting from its surface to escape the planet's gravitational pull; the presence of exploitable deposits of perchlorate could one day facilitate travel between the two planets. But determining whether Mars provides the conditions and materials needed for human habitation would require prolonged presence on the surface by trained personnel -- such questions are unlikely to be resolved purely through the use of robotic probes.



Frozen water in a crater near the Martian north pole. Liquid water evaporates quickly on the Martian surface, but ice forms often near the north pole, as this image taken by the European Space Agency's Mars Express spacecraft reflects (ESA-DLR-FU Berlin photo).

THE OPTIMUM PATH TO MARS IS A "STEPPING-STONE" APPROACH

Because of its similarities to the Earth, Mars has long been viewed as the most important potential destination of the human spaceflight program. During the early 1990s, NASA investigated the feasibility of going directly to the Red Planet in a technological leap akin to the Apollo program. The agency soon concluded that would not be feasible, due to budget constraints and a lack of mature technologies. Thus, when the Constellation program was conceived in the next decade to carry astronauts back to the Moon and then on to Mars, it envisioned a series of incremental steps that could provide a sustainable path to the ultimate objective. The initial step would have used new rockets and crew vehicles to visit the International Space Station, followed by a Moon landing and then voyages to near-Earth objects such as asteroids. Mars was to be the last step in a 20-year odyssey.

The 2009 presidential commission that assessed human spaceflight plans found Constellation to be greatly under-funded, but agreed in principle with the notion of a stepping-stone approach. Its preferred terminology was "flexible path," or as some within the space agency now prefer to call it, a capabilities-driven approach. The basic idea was that technologies required for a Mars voyage needed to be gradually developed and tested through visits to less challenging destinations -- destinations requiring fewer dollars and fewer scientific breakthroughs to be reached. Similar logic was embraced by legislation Congress approved to implement a modified version of the Obama space plan, and has now been formalized by NASA into "human space exploration guiding principles." The guiding principles set forth the virtues that policymakers associate with the flexible path:

- The space agency can establish a "routine cadence" of missions that inspires with numerous "firsts."
- An "evolutionary family of systems" leveraging commonality can be developed within affordable budgets.
- Existing systems such as the International Space Station can be used to support expanded human spaceflight.
- Technologies and capabilities can be mixed and matched as needed to achieve increasingly challenging goals.
- NASA can draw on expertise from other agencies and other nations to minimize the need for new investments.

This all makes sense from a budgetary and scientific perspective. What's missing is a grasp of the rationale required to sustain political support across multiple administrations. While exploration of the Moon's far side or nearby asteroids may have major scientific benefits, those benefits are unlikely to be appreciated by politicians struggling to reconcile record deficits. NASA's current research plans do not connect well with the policy agendas of either major political party, and the flexible path will not change that. To justify investments of hundreds of billions of dollars in human spaceflight over the next 20 years while entitlements are being pared and taxes are increasing, NASA must offer a justification for its efforts commensurate with the sacrifices required. Mars is the only objective of sufficient interest or importance that can fill that role. Thus, the framework of missions undertaken pursuant to the flexible-path approach must always be linked to the ultimate goal of putting human beings on the Martian surface, and the investments made must be justified mainly on that basis. The American public can be convinced to support a costly series of steps leading to a worthwhile objective, but trips to the Moon and near-Earth objects aren't likely to generate sustained political support during a period of severe fiscal stress.

An Ares I experimental rocket approaches its launch pad at NASA's Kennedy Space Center in 2009. The Ares launch system was developed as part of the Constellation program, and Congress has directed that technology associated with the canceled program should provide a foundation for future human spaceflight efforts (NASA photo).

GETTING TO MARS WILL REQUIRE NEW TECHNOLOGIES

One advantage of implementing a flexible-path approach aimed at putting astronauts on Mars in 20 years is that it can be adjusted over time to reflect the changing availability of funding and relevant technologies. It is not necessary to lay out a 20-year plan today and then stick with it across five administrations as long as there is agreement on the ultimate goal; the program can be slowed or accelerated depending on resource availability and technological progress. However, a diverse suite of evolvable technologies will be needed to accomplish manned missions to Mars, and the pace at which each required system is developed will be determined mainly by how intermediate steps to the final goal are sequenced.

The two most pressing elements in any human spaceflight architecture are a new heavy-lift launch system and a multi-purpose crew vehicle suitable for exploration of deep space. Congress has directed that, to the maximum degree possible, NASA should leverage technologies and capabilities of the Ares man-rated launch system and Orion crew capsule that were part of the canceled Constellation program in implementing NASA's revised human spaceflight plans. That approach will take advantage of investments already made in new technology while causing the least disruption to the nation's highly specialized space workforce and infrastructure. Leveraging the state-of-the-art Ares and Orion systems provides the foundational capability required for the heavy-lift launch system now referred to as the Space Launch System (SLS) and the crew vehicle, officially designated the Multi-Purpose Crew Vehicle (MPCV). As the stepping-stone approach to Mars advances, both the propulsion system and the crew vehicle will be continuously enhanced to the point where a manned mission to Mars is feasible.

By establishing Mars as the defining mission -- with SLS and MPCV as the foundational transport elements -- the stepping-stone approach can identify the intermediate missions and the incremental capabilities required to accomplish each new milestone. NASA and industry thus will understand technology gaps against which development roadmaps can be created, including "on-ramps" for technology breakthroughs and "off-ramps" for technology mis-steps. This will provide the space community with a stable and predictable future to ensure the necessary workforce is maintained, challenged and matured. Once the human spaceflight program moves beyond low-earth orbital missions, astronauts will also require new "extravehicular activity" (EVA) spacesuits and modules, and various robotic systems to assist them in space. The advanced cryogenic propulsion stage developed under the Ares upper-stage contract will be needed if NASA elects to return to the Moon, and a deep-space habitat will have to be developed if it elects to visit near-Earth asteroids.

In the near term, though, NASA's human spaceflight budget will be dominated by spending for the Space Launch System and Multi-Purpose Crew Vehicle. Those investments are essential requirements for continuation of the human spaceflight program, no matter what its planned objectives are. If Mars is to be the ultimate goal, then both systems must be developed with sufficient growth potential to evolve beyond their baseline configurations. For instance, the launcher may initially be able to loft a 130 metric-ton payload into orbit and 50 metric tons to fast-enough velocity to escape Earth's gravity well, but eventually technology advances will be needed so that more challenging deep-space destinations can be reached. It will take some time for NASA to sort out its technology options and organize a development strategy that fits within projected budgets. The most important thing it must do in framing that strategy is to offer the public a vision of what human spaceflight can achieve if put on a stable course. The key to making that vision viable and sustainable is to provide a pathway to Mars -- the most Earth-like object in the reachable universe beyond our own planet, and the only planet that might one day host a self-sustaining human colony.

An Ares I experimental rocket lifts off from the Kennedy Space Center in 2009. Development of new launch systems such as Ares is essential if NASA's human spaceflight program is to carry future astronauts into deep space, along with a crew vehicle and other equipment designed for the rigors of space travel (NASA photo).

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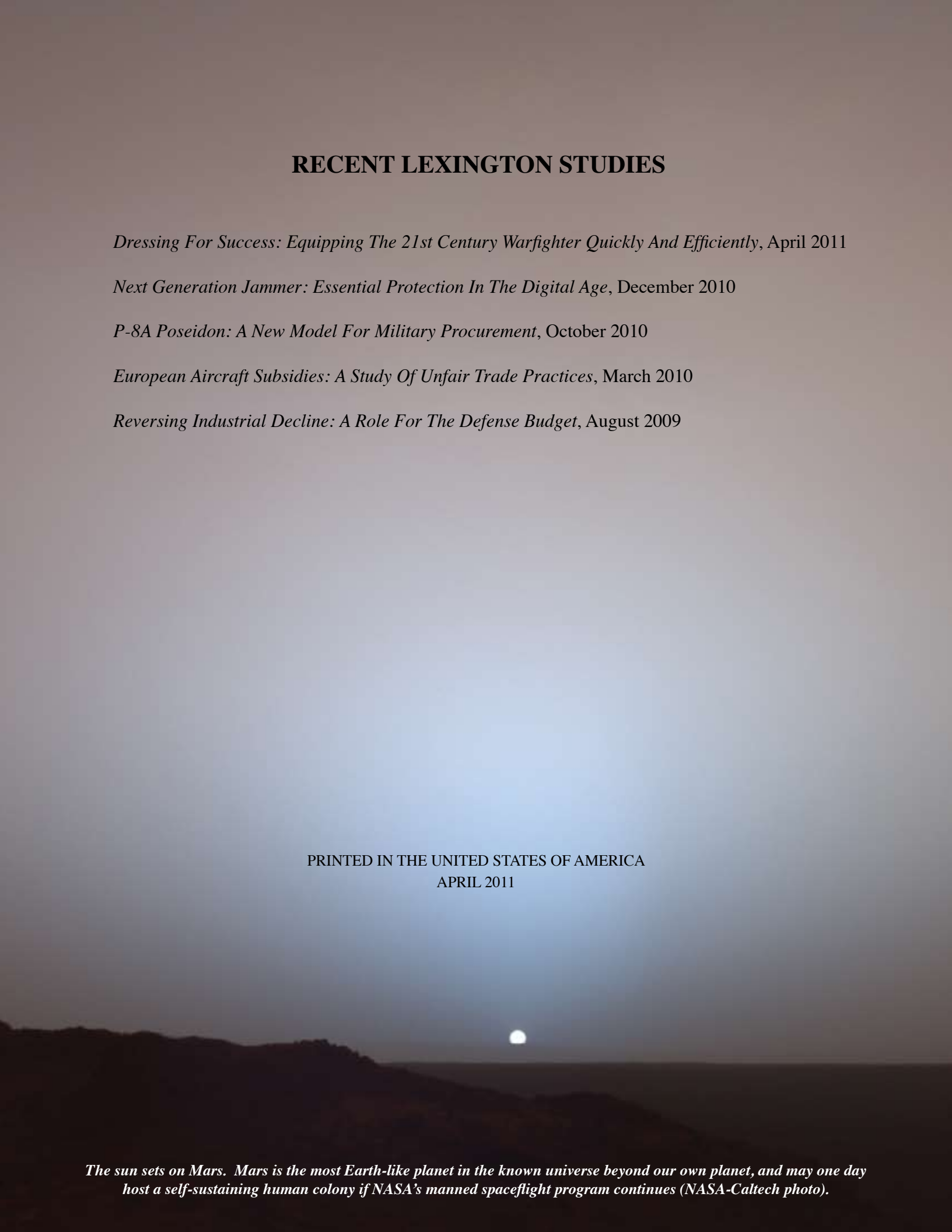

The sun sets on Mars. Mars is the most Earth-like planet in the known universe beyond our own planet, and may one day host a self-sustaining human colony if NASA's manned spaceflight program continues (NASA-Caltech photo).

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