A leading advocate of manned missions to Mars outlines a plan to land astronauts on the Red Planet in the next decade

Sending Humans to Mars

by Robert Zubrin

SAIC; PAT RAWLINGS

"Space is there, and we are going to climb it." These words from President John F. Kennedy in 1962 set forth the goal of sending an American to the moon within the decade. But for most of the 30 years since the Apollo moon landing, the U.S. space program has lacked a coherent vision of what its next target should be. The answer is simple: the human exploration and settlement of Mars.

This goal is not beyond our reach. No giant spaceship built with exotic equipment is required. Indeed, all the technologies needed for sending humans to Mars are available today. We can reach the Red Planet with relatively small spacecraft launched directly to Mars by booster rockets embodying the same technology that carried astronauts to the moon more than a quarter-century ago. The key to success lies with the same strategy that served the earliest explorers of our own planet: travel light and live off the land. The first piloted mission to Mars could reach the planet within a decade. Here is how the proposed plan—what I call the Mars Direct project—would work.

At a not too distant date, in 2005 perhaps, a single, heavy-lift booster rocket with a capability equal to that of the Saturn 5 rockets from the Apollo era is launched from Cape Canaveral. When the ship is high enough in Earth's atmosphere, the upper stage of the rocket detaches from the spent booster, fires its engine and throws a 45-metric-ton, unmanned payload on a trajectory to Mars.

This payload is the Earth Return Vehicle, or ERV, which, as the name implies, is built to bring astronauts back to Earth from Mars. But on this voyage no humans are on board; instead the ERV carries six tons of liquid-hydrogen cargo, a set of compressors, an automated chemical-processing unit, a few modestly sized scientific rovers, and a small 100-kilowatt nuclear reactor mounted on the back of a larger rover powered by a mixture of methane and oxygen. The ERV's own methane-oxygen tanks that will be used during the return trip are unfueled.

Arriving at Mars eight months after takeoff, the ERV slows itself down with the help of friction between its heat shield and the planet's atmosphere, in a technique known as aerobraking. The vehicle eases into orbit around Mars and then lands on the surface with the help of a parachute and retrorockets. Once the ship has touched down, scientists back at mission control on Earth telerobotically drive the large rover off the ERV and move it a few hundred meters away. Mission control then deploys the nuclear reactor, which will provide power for the compressors and the chemical-processing unit.

Inside this unit, the hydrogen brought from Earth reacts with the Martian atmosphere—which is 95 percent carbon dioxide (CO_2)—to produce water and methane (CH_4). This process, called methanation, eliminates the need for long-term storage

HUMAN EXPEDITION TO MARS
would allow astronauts to search for signs of past or present life on the Red Planet, a task that people are far better suited to than robots are. A manned mission to Mars could have explorers on the planet's surface by 2008.

of cryogenic liquid-hydrogen fuel, a difficult task. The resulting methane is liquefied and stored, and the water molecules are electrolyzed—broken apart into hydrogen and oxygen. The oxygen is then reserved for later use; the hydrogen is recycled through the chemical-processing unit to generate more water and methane.

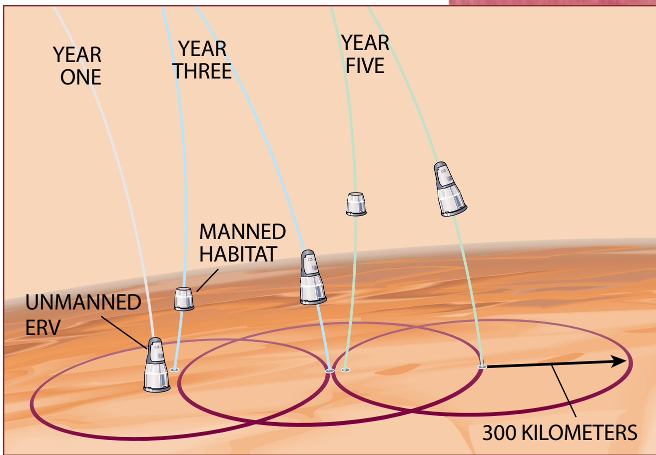
Ultimately, these two reactions, methanation and the electrolysis of water, provide 48 tons of oxygen and 24 tons of methane, both of which will eventually be burned as rocket propellant for the return voyage. To ensure that the mixture of methane and oxygen in the propellant will burn efficiently, an additional 36 tons of oxygen must be generated by breaking apart the CO_2 in the Martian atmosphere. The entire process takes 10 months, at the end of which a total of 108 tons of methane-oxygen propellant has been generated—18 times more propellant for the return trip than the original feedstock needed to produce it.

The journey home will require 96 tons of propellant, leaving an extra 12 tons for the operation of the rovers. Additional stockpiles of oxygen can also be produced, both for breathing and for conversion into water, by reacting the oxygen with the hydrogen brought from Earth. The ability to produce oxygen and water on Mars greatly reduces the amount of life-supporting supplies that must be hauled from Earth.

The Astronauts Arrive

With this inaugural site on Mars operating successfully, two more boosters lift off from Cape Canaveral in 2007 and again hurl their payloads toward Mars. One of these payloads is an unmanned ERV just like that launched in 2005. The other, however, consists of a manned vessel with a crew of four men and women with provisions to last three years. The ship also brings along a pressurized methane-oxygen-powered ground rover that will allow the astronauts to conduct long-distance explorations in a shirtsleeve environment.

During the trip, artificial gravity as strong as that found on Mars can be produced by first extending a tether between the inhabited module and the burned-out booster rocket's upper stage; the entire assembly is then allowed to spin. On arrival at



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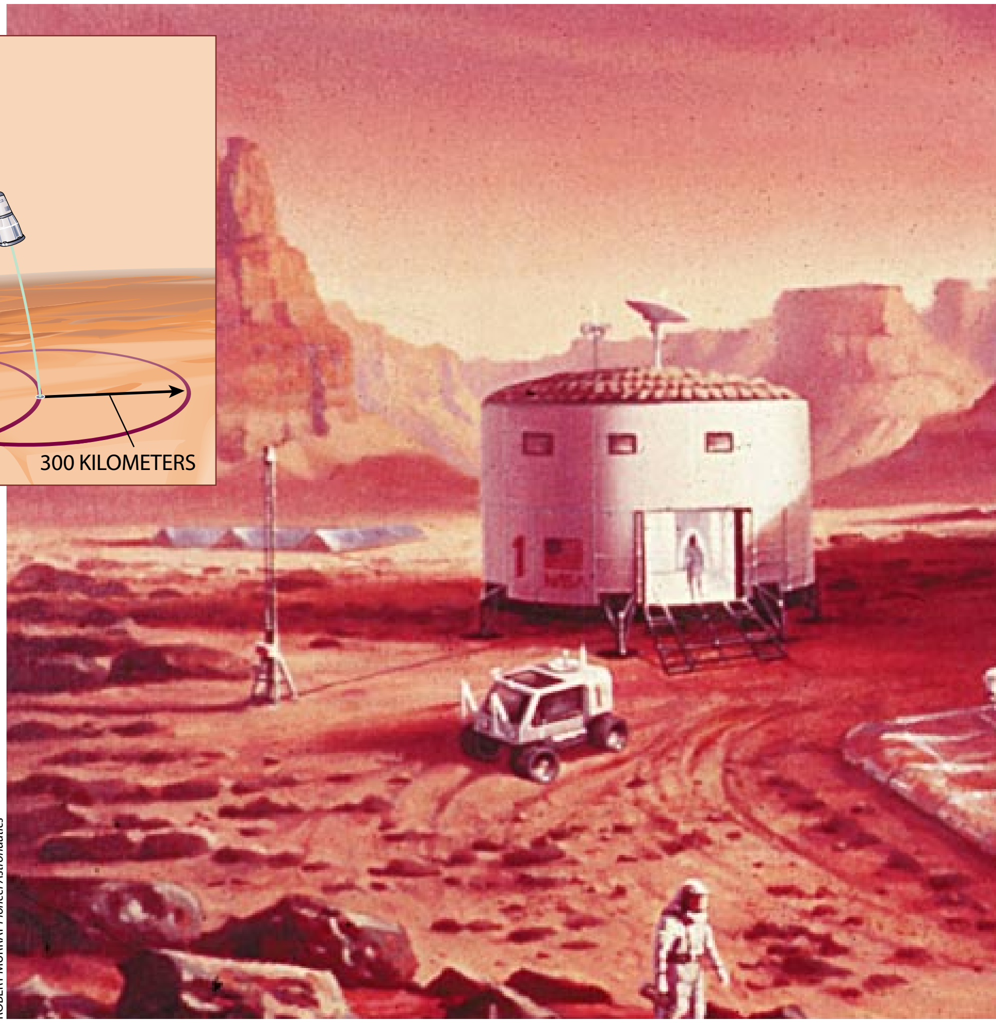


ROBERT MURRAY *Pioneer Astronautics*

MARS DIRECT PLAN begins with the launch of an unmanned Earth Return Vehicle, or ERV, that will, on landing on Mars, manufacture its own propellant, thereby laying the groundwork for the arrival of astronauts. Two years later a manned spacecraft and another unmanned ERV blast off for the Red Planet; the astronauts head for the previous landing site, while the unmanned craft prepares for the next manned mission, scheduled to arrive in another two years. The project can continue for as long as desired, leaving behind a string of base camps across the Martian surface. During their year-and-a-half stay on Mars, astronauts would most likely inhabit a camp similar to the one shown in this artist's conception, complete with a habitat (*left*), a greenhouse (*foreground*) and an ERV (*right*).

Mars, the manned craft drops the tether to the booster, aerobrakes and then lands at the 2005 site.

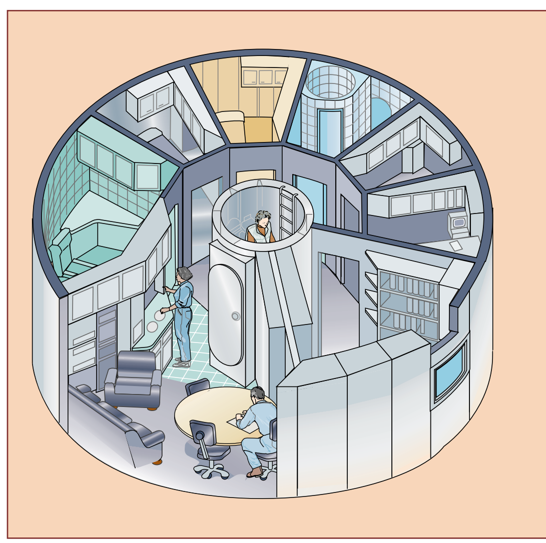
Beacons at the original location should enable the ship to touch down at just the right spot, but if the landing is off course by tens or even hundreds of kilometers, the astronauts can still drive to the correct location in their rover. And in the unlikely event that the ship sets down thousands of kilometers away, the second ERV that was launched with the manned vessel serves as a backup system. If that should fail, the extra rations sent along ensure that the crew can survive until a third ERV and additional supplies can be sent in 2009.

But with current technology, the chances of a misguided landing are small. So assuming the astronauts reach the 2005 location as planned, the second ERV touches down several hundred kilometers away. This new ERV, like its predecessor, starts making propellant, this time for the 2009 mission, which in turn will fly out with an additional ERV to open up a third Mars site.

Thus, under the Mars Direct plan, the U.S. would launch two heavy-lift booster rockets every other year: one to dispatch a team of four people to inhabit Mars and the other to prepare a new site for the next mission. The average launch rate of one a year is only about 15 percent of the rate that the U.S. currently launches space shuttles and is clearly affordable. In effect, the live-off-the-land strategy used by the Mars Direct plan removes the prospect of a manned mission to Mars from the realm of megaspacecraft fantasy and renders it a task comparable in difficulty to the launching of the Apollo missions to the moon.

The men and women sent to Mars will stay on the surface for one and a half years, taking advantage of the ground vehicles to conduct extensive exploration of the surface. With a 12-ton stockpile of fuel for these trucks, the astronauts can travel more than 24,000 kilometers during their stay, giving them the kind of mobility necessary to conduct a serious search for evidence of past or present life—an investigation that is key to revealing whether life is a phenomenon unique to Earth or commonplace throughout the universe.

Because no one will be left in orbit, the crew will benefit from the natural gravity and protection against radiation offered by the Martian environment. As a result,



there is no need for a quick return to Earth, a complication that has plagued conventional mission plans that consist of an orbiting mother ship and small landing parties sent to the surface. At the conclusion of their stay, the Mars astronauts will return by direct flight in the ERV. As the series of missions progresses, a string of small bases will be left behind on the planet, opening broad stretches of Mars to continued human exploration and, eventually, habitation.

In 1990, when my colleague David A. Baker and I (we were then both at Martin-Marietta) first put forward the basic Mars Direct plan, the National Aeronautics and Space Administration viewed it as too radical to consider seriously. But over the past couple of years, with encouragement from Michael Griffin, NASA's former associate administrator for exploration, as well as from the current head of NASA, Daniel S. Goldin, the group in charge of designing human missions to Mars at the NASA Johnson Space Center decided to take another look at our idea.

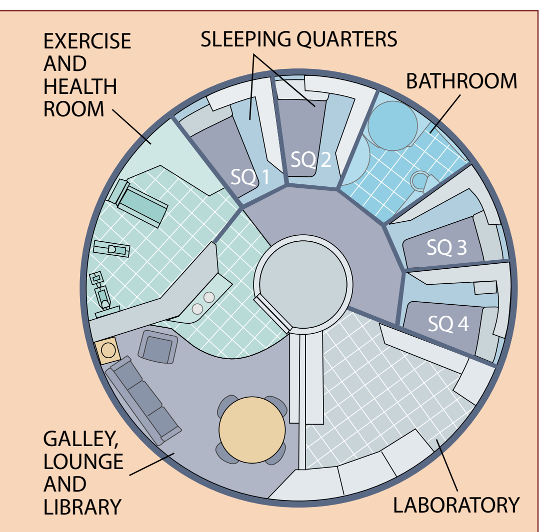
In 1994 researchers there produced a cost estimate for a program based on an expanded version of the Mars Direct plan that had been scaled up by about a factor of two. Their result: $50 billion. Notably, in 1989 this same group assigned a $400-billion price tag to the traditional, cumbersome approach to a manned mission to Mars based on orbital assembly of megaspacecraft. I believe that with further discipline in the design of the mission, the cost could be brought down to the $20-billion to $30-billion range. Spent over 10 years, this amount would constitute an annual expenditure of about 20 percent of NASA's budget, or around 1 percent of the U.S. military's budget. It is a small price to pay for a new world.

Killing the Dragons

Nevertheless, there are plenty of opponents to the idea of sending people to Mars; these critics frequently cite several issues, which they claim make such missions too dangerous to be considered at this time. Like the dragons that once marred the maps of medieval cartographers, these fears have deterred many who otherwise might be willing to support this mission. It is therefore fitting to address these considerations here.

One of the most common concerns is the allegation that the radiation doses involved in a Mars mission present insuperable risks or are not well understood. This is untrue. Solar flare radiation, consisting of protons with energies of about one million electron volts, can be shielded by 12 centimeters (five inches) of water or provisions, and there will be enough materials on board the ship to build an adequate pantry storm shelter for use in such an event. The residual cosmic-ray dose, about 50 rem for the 2.5 year mission, represents a statistical cancer risk of about 1 percent, roughly the same as the risk from smoking for the same amount of time.

The hazards of zero gravity have caused concern among other critics. Cosmonauts have experienced marked physiological deterioration after extended stays in zero gravity on the Russian space station. Yet in 1996 American astronaut Shannon W. Lucid spent six months in zero gravity [see "Six Months on Mir," by Shannon



IAN WORPOLE

HOME SWEET HOME on Mars might resemble this habitat, or "hab." The upper deck of the hab (*shown*) would have sleeping quarters for four people as well as a laboratory, library, galley and gym. The solar-flare storm shelter would be located in the center of the structure. The lower deck of the hab would serve as a garage, workshop and storage area.

W. Lucid; Scientific American, May 1998]. Because she actually implemented the rigorous exercise program designed by NASA flight surgeons, she returned to Earth in acceptable physical condition, able to walk off the shuttle despite the pull of Earth's gravity. And, as I mentioned earlier, the manned ships going to Mars could be flown employing artificial gravity generated by rotating the spacecraft. The engineering challenges associated with designing such systems are modest and make the issue of zero-gravity health effects during interplanetary missions moot.

Recently some people have raised the possibility of back-contamination of our planet as a reason to shun human missions to Mars (or even sample-return trips carried out by robots). Such fears have no basis in science. The surface of Mars is too cold for liquid water, it is exposed to a near vacuum and to ultraviolet and cosmic radiation, and it contains an antiseptic mixture of peroxides that have eliminated any trace of organic material. The surface of Mars is as sterile an environment as one could ask for. And even if there were life deep underground, it is quite impossible that these life-forms would pose a threat to terrestrial animals and plants. Pathogens are specifically adapted to their hosts, and there are no highly developed animals or plants to support a pathogenic life cycle in the Martian subsurface groundwater. In any case, Earth currently receives about 500 kilograms (1,100 pounds) of Martian material each year in the form of meteorites that originated on Mars and were blown into space by meteoric impacts. The trauma that this material has experienced during ejection from Mars, the trip to Earth and entry into Earth's atmosphere is insufficient to have sterilized it. If there is the Red Death on Mars, we already have it. Members of the space community who are concerned with public health matters would do much better to offer assistance to medical relief agencies fighting infectious diseases such as HIV and tuberculosis here on Earth.

Another issue mentioned frequently by the popular media is the concern that the isolation and stress of a 2.5-year round-trip mission to Mars present forbidding difficulties. On consideration, there is little reason to believe that this is true. Compared with the stresses dealt with by previous generations of explorers, mariners, prisoners, soldiers in combat and refugees in hiding, the adversities that will be faced by the hand-picked crew of a Mars mission seem extremely modest. In fact, history indicates that the human psyche, far from being the weak link in the chain of the piloted Mars mission, is very likely to be the strongest.

Mars does have intermittent local, and occasionally global, dust storms with wind speeds up to 200 kilometers per hour (125 miles per hour). Attempting to land during such an event would certainly be a bad idea (in 1971 the Soviets lost two unmanned Mars probes this way). Once a ship is on the ground, however, the storms present little danger. The atmosphere on Mars has only about 1 percent the density of Earth's atmosphere at sea level. Thus, a wind with a speed of 200 kph on Mars exerts the same force as a 20-kph wind on Earth—really just a moderate breeze. The Viking landers endured many such storms with no damage.

Mass Allocation for Earth Return Vehicle

ERV Component	Metric Tons
ERV cabin structure	3.0
Life-support system	1.0
Consumables	3.4
Solar array (5 kilowatts of electricity)	1.0
Reaction control system	0.5
Communications and information management	0.1
Furniture and interior	0.5
Space suits (4)	0.4
Spares and margin (16 percent)	1.6
Aeroshell	1.8
Rover	0.5
Hydrogen feedstock	6.3
ERV propulsion stages	4.5
Propellant production plant	0.5
Nuclear reactor (100 kilowatts of electricity)	3.5
ERV total mass	28.6

DON DIXON

Political Problems

Humans are more than a match for Mars's dragons, but thus far politicians have been unwilling to step up to the challenge. Indeed, in the three decades since the success of the Apollo missions, we have witnessed a failure of vision of astonishing dimension. It is as though Ferdinand and Isabella had responded to the returning Christopher Columbus with a shrug. Nevertheless, the public has made it apparent, through such demonstrations as the 566 million

Consumable Requirements for Mars Direct Mission with Crew of Four

	Daily need per person (kilograms)	Percent recycled	Daily waste per person (kilograms)	Payload for 200-day return flight (kilograms)	Payload for 600-day stay on surface (kilograms)
Oxygen	1.0	80	0.2	160	0
Dry food	0.5	0	0.5	400	1,200
Whole food	1.0	0	1.0	800	2,400
Potable water	4.0	80	0.0	0	0
Wash water	26.0	90	2.6	2,080	0
Total	32.5	87	4.3	3,440	3,600

JOHNNY JOHNSON

EARTH RETURN VEHICLE blasts off from the surface of Mars with a crew of four on board. The trip back to Earth will take approximately six months.

hits on NASA's Mars World Wide Web site the month Pathfinder reached Mars's surface, that there is massive popular support for the exploration of Mars.

To mobilize this support, both to pressure the U.S. and other governments for an expanded Mars effort, including robotic and human exploration, and to initiate privately funded exploration, the Mars Society was formed in 1998. As its first private project, the society is building a Mars simulation base at the Haughton meteorite impact crater on Devon Island in the Canadian Arctic. Because of its geologic and climatic similarities to the Red Planet, this area has been of interest to NASA scientists for some time. The society's Mars Arctic Research Station, or MARS, will support a greatly expanded study of this environment and will provide a location for field-testing prototype equipment, including habitation modules, ground-mobility systems, photovoltaic systems and specialized drilling rigs. The current plan is to have the Devon Island MARS base operational by the summer of 2000. This should be possible on a budget of about $1 million.

We hope that the credibility earned through this project will enable the society to expand its financial resources. It could then help fund robotic missions to Mars and, eventually, human expeditions, perhaps on a cost-sharing basis with NASA or other government agencies. But it is clear that the fastest way to send humans to Mars is to show the government why it should invest in this endeavor. The society has therefore launched an educational campaign directed toward politicians and other power brokers.

Why We Must Go to Mars

In the summer of 1996, in one of the most exciting announcements in history, NASA scientists revealed a rock ejected from Mars by meteoric impact that showed evidence of life on the Red Planet in the distant past. If this discovery could be confirmed by finding actual fossils on the Martian surface, it would, by implication, suggest that our universe is filled with life and probably intelligence as well. From the point of view of humanity learning its true place in the universe, this would be the most important scientific enlightenment since Copernicus. Although unmanned rovers can conduct a certain amount of the search for life on Mars, the best fieldwork requires the ability to travel long distances across very rough terrain, climb steep slopes, and do both heavy lifting and delicate sorting, as well as exercise on-the-spot intuition. All these skills are far beyond the abilities of robotic rovers. Field paleontology requires human explorers, live rockhounds on the scene.

There are additional reasons to send humans to Mars. Nations, like people, thrive on challenge; they languish without it. The space program needs a challenge. Consider these statistics: Between 1961 and 1973, with the impetus of the moon race, NASA produced technological innovations at a rate several orders of magnitude greater than that it has shown since. Even so, NASA's average budget in real dollars then was only about 20 percent more than today ($16 billion 1998 dollars compared with $13 billion). Why the enhanced productivity? Because NASA had a goal that forced its reach to exceed its grasp. Far from being a waste of money, having NASA take on the challenge of a manned mission to Mars is the key to giving the nation a real return for its space dollars.

Such a program would also serve as an invitation to adventure for children around the world. There will be some 100 million kids in U.S. schools over the next 10 years. If a Mars program were to inspire just an additional 1 percent of them to pursue scientific educations, the net result would be one million more scientists, engineers, inventors, medical researchers and doctors.

Mars is the New World. Someday millions of people will live there. What language will they speak? What values and traditions will they cherish as they move from there to the solar system and beyond? When they look back on our time, will any of our other actions compare in value with what we do now to bring their society into being? Today we have the opportunity to be the parents, the founders, the shapers of a new branch of the human family. By so doing, we will put our stamp on the future. It is a privilege not to be disdained lightly. SA

Robert Zubrin, an astronautical engineer, is president of the Mars Society and author of *The Case for Mars: The Plan to Settle the Red Planet and Why We Must*, published by Simon & Schuster (1996). Zubrin was formerly a senior engineer at Lockheed Martin and is the founder of Pioneer Astronautics, which is involved in research and development of space exploration.