A Human Mission to Mars

The Time Has Come to Embark on a Simple, Robust and Cost Effective Approach for the Human Exploration of Mars

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The Human Exploration of Mars:
The Next Logical Step for America's Space Program

The planet Mars is a world of spectacular mountains three times as tall as Mount Everest, canyons three times as deep and five times as long as the Grand Canyon, vast ice fields, and thousands of kilometers of mysterious dry riverbeds. The planet's unexplored surface may hold unimagined riches and resources for future humanity, as well as answers to some of the deepest philosophical questions that thinking men and women have pondered for millennia. Mars became an even more tantalizing destination in August 1996 when NASA scientists announced that an Antarctic meteorite--apparently from Mars--contained organic molecules and formations suggestive of microbes. The discovery earlier this year of surface features that may have been produced by the recent flow of liquid water further supports the idea that Mars once had (and may still have) conditions conducive to life. To find evidence life, though, will take more than robotic eyes and remote control. In fact, all that Mars holds will remain beyond our grasp until men and women--agile, autonomous, intuitive beings--walk upon its surface.

In 1989, President Bush proposed that the United States should return to the Moon and then go on to Mars. Unfortunately, when the feasibility study came back to him 90 days later, it stated that it would cost $450 billion, would take 30 years, and would require an enormous number of technologies that had yet to be invented. Needless to say, plans to go to Mars were quickly abandoned.

Despite this apparent setback for a humans to Mars mission, this report was the motivation for a whole new generation of space exploration concepts. Numerous scientists around the country, including Dr. Robert Zubrin, were convinced that a human mission to Mars could be achieved for a fraction of the cost and in less time. In 1996, Dr. Zubrin published his plan for going to Mars (called "Mars Direct") in his best selling book *The Case for Mars*. In this book Dr. Zubrin describes how a mission to Mars can be achieved with current technology (much of which was developed for the Space Shuttle and International Space Station programs) at a fraction of the cost, and in 10 years or less.

Based upon NASA's estimate that its significantly more complex Mars Reference Mission can be conducted for $40-50 billion, it is roughly estimated that a mission based on the Mars Direct architecture could be accomplished for $20-30 billion, with each subsequent mission costing $3-4 billion. In other words, a human mission to Mars can likely be achieved within ten years for 20 percent of the NASA budget (a budget which accounts for less than 1 percent of the national budget).

The administration that leads the United States into the true era of space exploration will begin one of the grandest periods in American and human history. As will be shown in the pages that follow, human exploration of Mars is no longer too technologically difficult or expensive to be justified. The major difficulties are now political. All that is needed to open this new and exciting period of exploration and discovery is an administration with vision and leadership. Below are just a few of the reasons why the United States should embrace space exploration and a human mission to Mars.

1. **Economic/Social/Technology:** Some will say that we need to solve problems at home before we invest in space exploration. In reality, it is just the opposite. Dollar for dollar, the space program has provided more benefits to our nation and the world than any program in United States history; the largest number of benefits coming as a result of the Apollo program. A Mars exploration program will likely accelerate economic and social benefits as Apollo did. By investing in space, we benefit Earth.

2. **Education:** Apollo inspired children around the country to pursue science and math careers. They saw that they could participate in events larger than themselves. A human mission to Mars will certainly have the same impact. Inspiring our children to learn is the best education program.

3. **Science:** The scientific ramifications of a human mission to Mars are enormous. The study of Martian geology and atmospheric conditions will not only teach us much about the future habitability of Mars but also about our own planet. By sending humans to Mars, we will be much more likely to answer the question of whether there was ever life on Mars. In the search for signs of fossilized life on Mars, a human crew could likely achieve in their first few days more than what 20 robotic probes could accomplish in 20 years.

4. **Exploration:** Without a great history of exploration the United States would not exist. We need to continue our great heritage of exploring the unknown so that we can guarantee that our society will remain vital and will not fall into stagnation. With the International Space Station nearing operational status, it is time to take the next logical step -- the human exploration of Mars.

5. **National Optimism:** We need to rekindle the national optimism that made the United States the greatest country on Earth. A human mission to Mars is the natural vehicle for this revitalization.

6. **Public Support:** A recent Roper poll shows that about two-thirds of the American public support sending a human mission to mars. The American public has had an enormous appetite for Mars for years. This appetite has fueled countless science fiction accounts of Mars and unprecedented interest in NASA exploration missions to Mars. In fact, many people are surprised when told that there is no plan to explore Mars in the near future. When Mars Pathfinder landed in 1997, there were over 100 million hits on the Pathfinder website in the first day. There have been well over half a billion hits since. All together, NASA's Mars related websites have received over 1.2 billion hits since 1997. There is no doubt that the American public has a significant interest in Mars exploration.

How We Can Go:
Summary of the Mars Direct Architecture

- **Mars Direct Concept** -- Small spacecraft are launched directly to Mars by boosters embodying the same technology developed for the Space Shuttle. Fuel for surface operations and the return trip, as well as oxygen and water, are produced from the carbon dioxide in the Martian atmosphere (and a small feedstock of hydrogen) to greatly reduce the amount of material that must be transported to Mars.

- **Target Dates** -- August 2005 a crewless earth return vehicle ("ERV") is launched directly to Mars. The ERV remotely produces fuel, oxygen and water from the Martian atmosphere. September 2007 a backup ERV is launched to Mars. October 2007 a habitation module with a crew of four is launched to Mars. April 2008 the first Mars expedition crew lands near the ERV for 18 months of surface operations. Subsequent manned missions would be launched in 2009 and 2011.

- **Habitat Module** -- The module stands about 5 meters high and measures about 8 meters in diameter. Consisting of two decks, each with 2.5 meters (about 8 feet) of headroom and a floor area of 100 square meters (about 1,000 square feet), it is large enough to comfortably house its crew. The "hab" contains a closed-loop life support system that recycles oxygen and water (similar to systems planned for the space station); whole food (irradiated for longer life and then canned or frozen) to last three years, plus a large supply of dehydrated emergency rations; and a ground car, pressurized so it provides a shirtsleeve environment and powered by an internal combustion engine that runs on methane and oxygen. Fully loaded, the hab weighs 25 tonnes.

- **Crew** -- The crew of four consists of a biogeochemist, a geologist/ paleontologist, a doctor, and a flight engineer/pilot. This last crew member, who serves as mission commander, can also provide common medical treatment and understands the broad means and objectives of the scientific investigations.

- **Launcher** -- Mars Direct could be implemented with either NASA's proposed Magnum launcher or the more powerful Ares launcher designed by Dr. Robert Zubrin (both of which are based on existing Space Shuttle technology). The existing Russian Energia launcher would also be suitable (and relatively low cost) if adequate funds are provided to restart production.

- **Estimated Cost** -- The estimated cost of development and the first mission is $20-30 billion, with subsequent missions costing $3-4 billion each. This estimate is roughly based on NASA's estimate of $40-50 billion for its significantly more complex Design Reference Mission.

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THE MARS DIRECT PLAN

A leading advocate of manned missions to Mars, Robert Zubrin, outlines his relatively inexpensive plan to send astronauts to the Red Planet within a decade

JPL/CALTECH/NASA

"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 of a 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—perhaps as soon as 2005—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, Fla. 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.

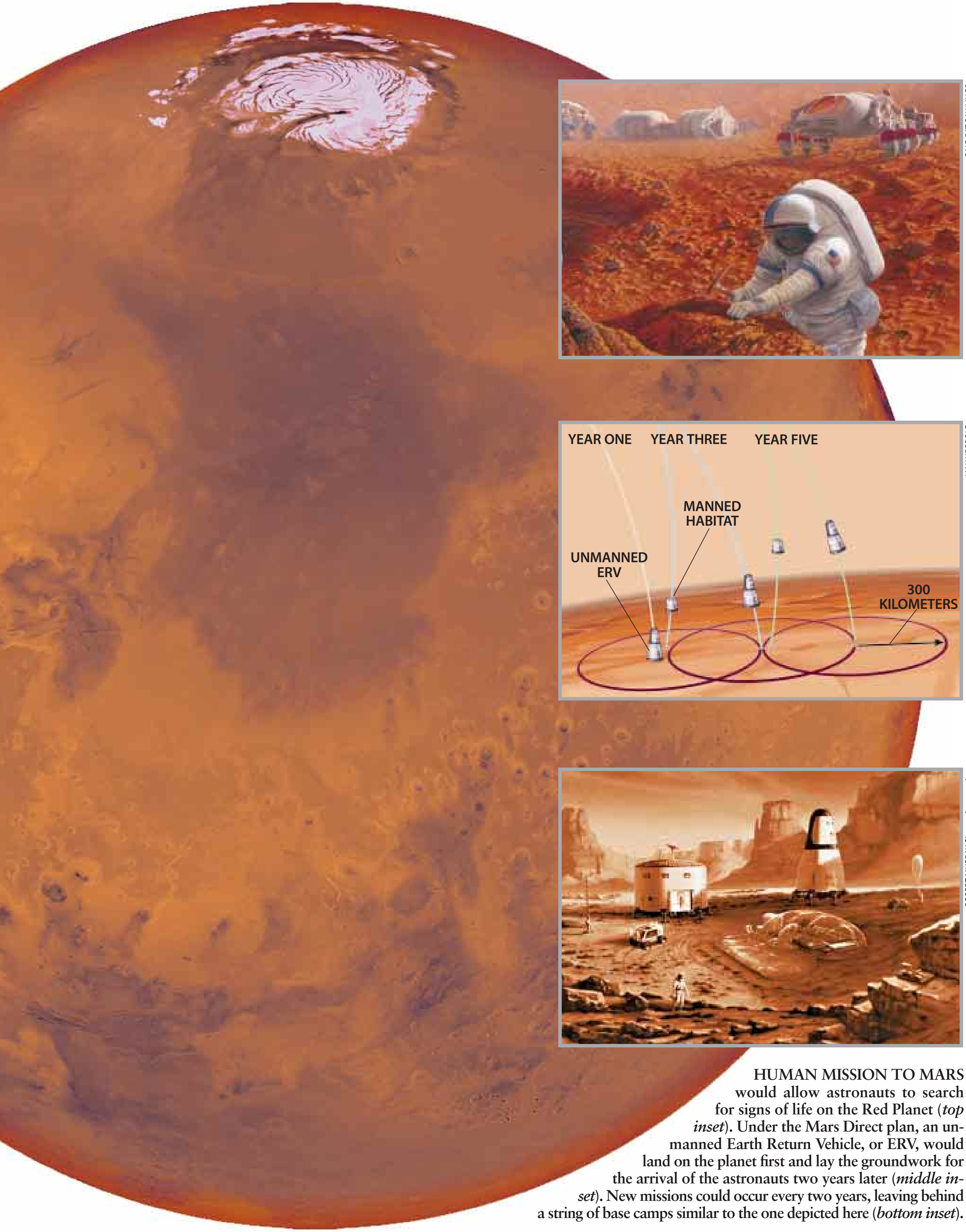
This payload is the Earth Return Vehicle, or ERV, which, as the name implies, is built to bring astronauts back to Earth from Mars. But on this voyage no humans are on board; instead the ERV carries six tons of liquid-hydrogen cargo, a set of compressors, an automated chemical-processing unit, a few 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, which 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—a technique known as aerobraking. The vehicle eases into orbit around Mars and then lands on the surface using 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 of cryogenic liquid-hydrogen fuel, a difficult task. The 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 electrolysis, provide 48 tons of oxygen and 24 tons of methane, both of which will eventually be burned as rocket propellant for the astronauts' return voyage. To ensure that the mixture of methane and oxygen 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 combining 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.

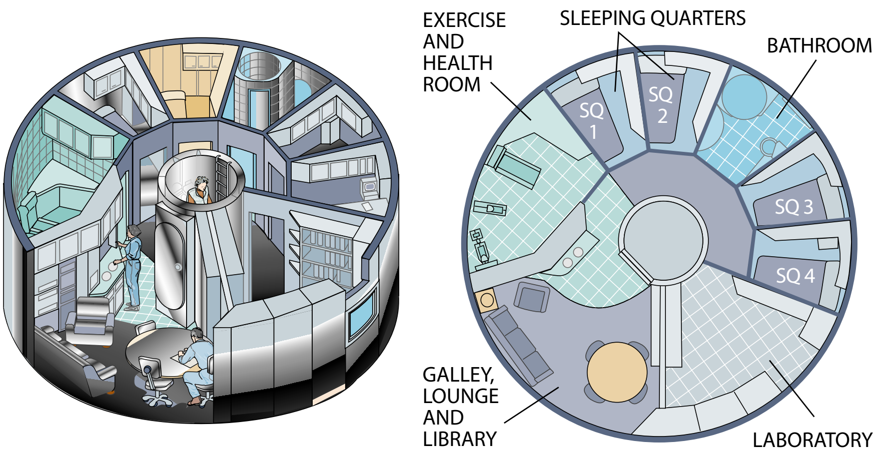


SAIC; PAT RAWLINGS

IAN WORPOLE

ROBERT MURRAY *Pioneer Astronautics*

HUMAN MISSION TO MARS would allow astronauts to search for signs of life on the Red Planet (*top inset*). Under the Mars Direct plan, an unmanned Earth Return Vehicle, or ERV, would land on the planet first and lay the groundwork for the arrival of the astronauts two years later (*middle inset*). New missions could occur every two years, leaving behind a string of base camps similar to the one depicted here (*bottom inset*).



IAN WORPOLE

HOME SWEET HOME in interplanetary space and on Mars might look like this. The upper deck of the habitat, shown here, would have sleeping quarters for four people as well as a laboratory, library, galley and gym. A solar-flare storm shelter would be located in the center. The lower deck (*not shown*) would serve as a garage, workshop and storage area. During the trip to Mars, a tether system could produce artificial gravity.

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 is an unmanned ERV just like the one 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.

The Astronauts Arrive

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 at a rate of, say, one revolution per minute. Such a system would eliminate any concerns over the health effects of zero gravity on the astronauts. The crew's exposure to radiation will also be acceptable. Solar flare radiation, consisting of protons with energies of about one million electron volts, can be shielded by 12 centimeters 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 rems for the entire two-and-a-half-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.

On arrival at 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 can serve as a backup system. If that, too, should fail, the extra rations on the manned craft 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. and its international partners 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 at which the U.S. currently launches space shuttles. 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 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

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Consumable Requirements for Mars Direct Mission with Crew of Four

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

JOHNNY JOHNSON

Mass Allocations for Mars Direct Mission

ERV Component	Metric Tons	Habitat Component	Metric Tons
ERV cabin structure	3.0	Habitat structure	5.0
Life-support system	1.0	Life-support system	3.0
Consumables	3.4	Consumables	7.0
Solar array (5 kilowatts of electricity)	1.0	Solar array (5 kilowatts of electricity)	1.0
Reaction control system	0.5	Reaction control system	0.5
Communications and information management	0.1	Communications and information management	0.2
Furniture and interior	0.5	Furniture and interior	1.0
Space suits (4)	0.4	Space suits (4)	0.4
Spares and margin (16 percent)	1.6	Spares and margin (16 percent)	3.5
Aeroshell	1.8	Pressurized rover	1.4
Rover	0.5	Open rovers (2)	0.8
Hydrogen feedstock	6.3	Lab equipment	0.5
ERV propulsion stages	4.5	Field science equipment	0.5
Propellant production plant	0.5	Crew	0.4
Nuclear reactor (100 kilowatts of electricity)	3.5		
ERV total mass	**28.6**	**Habitat total mass**	**25.2**

EARTH RETURN VEHICLE blasts off from the surface of Mars with a crew of four on board (*right*). The payloads of the ERV and the manned habitat are detailed in the table above.

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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, which is now part of Lockheed Martin) first put forward the basic Mars Direct plan, the National Aeronautics and Space Administration viewed it as too radical for serious consideration. But since then, 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.

The Mars Society

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 had assigned a $400-billion price tag to the traditional, cumbersome approach to a manned mission 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- 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.

To mobilize public support for an expanded Mars effort—including robotic as well as human exploration—and to initiate privately funded missions, 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 human exploration tactics and 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.

Someday millions of people will live on Mars. 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 importance 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 beyond reckoning. SA

This article updates a version that appeared in the Spring 1999 issue of Scientific American Presents.

ROBERT ZUBRIN *is president of the Mars Society and founder of Pioneer Astronautics, which does research and development on space exploration. He is the author of* The Case for Mars: The Plan to Settle the Red Planet and Why We Must *(Simon & Schuster, 1996) and* Entering Space: Creating a Space-Faring Civilization *(Tarcher-Putnam, 1999).*

Laying the Foundation for a Near-Term Program of Human Mars Exploration: An Affordable FY 2002 Legislative Agenda

January 2001

(1) **Declaration of policy**. Congressional and Administration declaration that it is the policy and goal of the United States to successfully conduct a human mission to Mars and to maintain a nearly permanent human presence on Mars thereafter as part of robust program of Mars exploration. The first human mission to Mars could be conducted by 2010 with existing technologies, but even without a date certain, simply setting the goal would provide an enormous motivational boost to the Mars program and the nation.

(2) **A new program to develop technology for human Mars exploration.** Congress should fund such a program at a level of about $140 million per year - less than 1% of NASA's current budget. This is necessary to lay the groundwork for an eventual human mission to Mars through technology development of in-situ propellant production (making fuel from Martian materials), long duration life support systems, power and propulsion, and surface mobility systems.

(3) **Adding $250 million per year to NASA's robotic exploration effort**. A significant portion of the added funds ($100 million per year) should come to the JPL-led robotic program through NASA's Human Exploration and Development of Space (HEDS) organization. This is important to ensure that robotic Mars probes carry appropriate instruments and payloads to provide critical data for future human exploration. The remainder of the added funds ($150 million per year) should be used to establish a “Mars Discovery” program, in which mission concepts proposed by various investigators are openly competed on the basis of maximum science return for the dollar (in a manner similar to the existing NASA Discovery program, which has been effectively off-limits to Mars probes).

(4) **Adjusting the language of the NASA Code M appropriations to maximize use of current funds.** This language currently prevents NASA Code M (Shuttle and Space Station) programs from spending their own existing funds to develop technologies needed for human exploration beyond low Earth orbit. This restriction should be removed.

(5) **Design of a heavy lift launch vehicle**. A heavy-lift launch vehicle is critical to an affordable program of human exploration of Mars. Congress should appropriate $15 million in FY 2002 to fund design work for such a vehicle by competing corporations.

Total Funding Increase for FY 2002: <u>$405 million</u> (an increase of less than three percent over NASA’s FY 2001 appropriation).

The Mars Prize

Harnessing Free Enterprise to Explore Mars

Traditionally, space exploration in this country has been conducted by the federal government, usually through NASA. While NASA has achieved many good results, it has been argued that private industry, if left to its own creative resources, could conduct better missions for less cost.

The Mars Prize concept was developed as a method to encourage private industry to accept such a challenge. Simply put, here is how the Mars Prize would work: the U.S. government would post a $25 billion reward for the first private organization to successfully land a crew on Mars and return it to earth, as well as several smaller prizes (which together total $5 billion) for attaining various technical milestones along the way. If successful, such an approach could save the U.S. taxpayer tens-of-billions of dollars, while at the same time accelerating the pace of Mars exploration.

This is, to say the least, a novel approach to human space exploration, which until now has been entirely government run. But it has a number of remarkable advantages. In the first place, this approach renders cost overruns impossible. The government will not spend a penny unless the desired results are achieved, nor spend a penny more than the award sum agreed upon at the start. Many such prizes were offered for breakthrough technical accomplishments in aviation's early years, and collectively they played a major role in raising the art of flight from its infancy to a globe-spanning transportation network.

A Prize Progression

Below are a series of prizes to drive the development of a humans-to-Mars program.

> Challenge 1: To complete a Mars orbiter imaging mission. The prize: $500 million. The conditions: The mission must successfully image at least 10 percent of the planet with resolutions of 20 centimeters per pixel or better. (The best Viking pictures have a resolution of 10 meters per pixel. The Mars Global Surveyor is returning images with 1.5 meter-per-pixel resolution.) All images must be made available to the U.S. government, which will publish them.
>
> Challenge 2: To collect a sample of Martian soil with a robotic lander and transport the sample to earth using propellants of Martian origin for the return flight. The prize: $1 billion. The conditions: The soil sample size must be at least 3 kilograms. At least 70 percent (by weight) of the propellant mixture used on the Mars-ascent and earth-return legs of the mission must be produced on Mars from Martian resources.
>
> Challenge 3: To deliver a pressurized rover to Mars. The prize: $1 billion. The conditions: The vehicle must prove capable of sustaining two humans on Mars for one week by means of a one-week test conducted on earth during which it is driven 1,000 kilometers over unimproved terrain. The vehicle must travel at least 100 kilometers on Mars, with cabin pressure between 3 and 15 pounds per square inch and temperatures between 10 and 30 degrees centigrade.
>
> Challenge 4: To demonstrate the first system that uses propellants of Martian origin to lift a 5-tonne payload from the surface of Mars to Mars orbit. The prize: $1 billion. The conditions: At least 70 percent (by weight) of the propellant mixture must be produced on Mars from Martian resources.
>
> Challenge 5: To be the first to demonstrate a system that can lift at least 120 tonnes to low earth orbit. The prize: $1.5 billion. The conditions: The booster must launch from U.S. territory.
>
> Challenge 6: To be the first to send a crew to Mars and return the crew members safely to earth. The prize: $25 billion. The conditions: A majority of the crew must be Americans. At least three crew members must reach the Martian surface and remain on the planet for at least 100 days. One or more crew members must make at least three overland trips of at least 50 kilometers from the landing site.

If a Mars Prize bill were passed, it would provide not only the needed incentives to get humans to Mars, but also a financial "runway" that would allow private organizations to accumulate the capital required to finance such a venture.

Study Shows Public
Supports Mars Trip

By Leonard David
Senior Space Writer
posted: 02:22 pm ET
20 June 2000
Space.com

WASHINGTON -- A healthy majority of the public is ready to give the thumbs-up on sending U.S. astronauts to Mars. They are also backing the building of a space station. Those are among the findings of a wide-ranging survey released by the National Science Board, a governing body of the National Science Foundation (NSF).

Called Science and Engineering Indicators 2000, the two-volume report is a biennial status check on scientific and technological issues facing the country.

One section is devoted to public perceptions of space exploration. Both NSF findings, as well as poll results from other reputable survey groups, review the past decade of public feelings about space.

Rebound from the loss of Challenger

Before the Challenger accident, more than half the participants in the NSF's public attitudes survey agreed that the benefits of space exploration exceeded the costs. Minds changed after the accident. The percentage agreeing that the benefits are greater than the costs fell from 54 percent in 1985 (before the explosion) to 47 percent in 1988 and to 43 percent in 1990.

In the 1990s, this trend, an indicator of weakening support for the space program, leveled off. More recently, the percentage of survey respondents agreeing that the benefits are greater than the costs has been rising—from 43 percent in 1992 to 49 percent in 1999, approaching the 1985 level, before the Challenger accident.

The space program - a waste or wanted?

In a Roper poll highlighted in the newly released NSF study, respondents were asked what they thought of the space program. More than half chose the response, "exciting and worthwhile"; 27 percent answered "only necessary to keep up with other nations"; and only 18 percent said it was "a waste of time and money." In response to another question, nearly half said that, in the future, the space program will make life on Earth better because of technological advances; 17 percent thought it would be worse because the money should have been spent on something else; and 32 percent thought the space program would not make life any better or worse.

The gender gap

There is a sizeable gender gap in the public's assessment of space exploration. In fact, no other issue in the NSF survey has such a large disparity in opinion between the sexes. Men are more likely than women to champion the benefits of space exploration over the costs. The gap was 14 percentage points in 1999.

In every year but two (1990 and 1992), a majority of men interviewed for the survey agreed that the benefits from space exploration outweigh the costs. The percentage stood at 57 percent in 1999, compared with 43 percent for women. In contrast, during the late 1980s and early 1990s, half or more of the women who participated in the survey thought that the costs exceeded the benefits. That is no longer true; the percentage dropped below 50 percent in 1997 and stayed there in 1999.

Benefits exceed the cost

Those with more formal education are more likely than others to say that the benefits of space exploration exceed the cost. In 1999, only 40 percent of those with less than a high school education agreed that the benefits were greater than the costs, compared with 49 percent of those who graduated from high school and 60 percent of those with at least a bachelor’s degree.

But those classified as attentive to science and technology -- or to space exploration -- are more likely than the public at large to believe that the benefits exceed the costs. At least 60 percent of each attentive group put the benefits ahead of the costs, compared with about half of the public at large.

Onward to Mars

Finally, about two-thirds of the public favor sending a U.S. piloted mission to Mars according to a Roper poll in 1996, fortified by the findings of another survey taken by Southern Focus in 1998. According to NSF survey results, building a space station also garners strong public support.

Overall, the National Science Board's report details growing evidence of how fundamental science has contributed to a stronger U.S. economy. Moreover, the analysis underscores how information technology has had a major impact on all facets of society. However, the report also notes that parts of American society are bereft of information technology advantages, creating a "digital divide."

The findings of the study have been presented to the President and Congress.

Mars Exploration Needs a Human Direction

By Louis Friedman
posted: 10:04 am ET
06 March 2000
Space.com

The Planetary Society, with the cooperation of SPACE.com, recently held an open forum on the U.S. Mars program. The audience reaction surprised me. Our agenda was about the fate of robotic exploration of Mars after the failed missions of 1999. But most of the comments were about human exploration.

Mars beckons, because of its unique connection with the future of humankind, and because of its special relevance to the understanding of life. The pull of a possible human future on the Red Planet is what drives the robotic program. That program is
now focused on sample return -- which is the right approach scientifically, but not sufficient to engage both the hearts and minds of people who must support it.

The Mars program should lead toward the all-important human questions. Thus, its goals should include identifying the candidate first human landing sites, and constructing an outpost (robotic and/or human) at the most promising one.

Two years ago, NASA Administrator Dan Goldin initiated a cooperative effort in Mars exploration among three NASA branches (Space Science, Human Spaceflight and Life Sciences). The first step was to put payloads relevant to future human exploration on the Mars Surveyor 2001 lander. Three experiments were chosen: soil and dust analysis, in-situ propellant production and radiation environment monitoring.

The Human Spaceflight office was supposed to contribute funds for the project, under its Human Exploration and Development (HEDS) initiative. But the money never materialized, due to budget cuts and to reluctance in the Clinton administration to identify with human spaceflight to Mars. The resulting lack of resources is one of the chief problems now facing the Mars program.

HEDS money should contribute significantly to Mars exploration. The extra resources are needed; that is one likely conclusion following the recent failures. Those resources will be needed even more for sample return, a necessary precursor to human flight. Moreover, the human and robotic programs should be tied together.

The evolution of a Mars infrastructure in the robotic program, leading to outposts, will enable human spaceflight to be done faster, better and cheaper. Investments now will be relatively small, compared to the benefits for human missions later. Finally, it should be noted that this year the space station will move past its peak funding. What will replace it in the human spaceflight program?

Directing human spaceflight resources toward Mars will give the people involved (at NASA, its contractors and elsewhere) a sense of ownership in Mars exploration.

Moreover, the public is way ahead of NASA, the administration and Congress in this regard. The public has made the connection between human and robotic spaceflight. Why not capitalize on and satisfy that public interest -- not by making a premature political effort to commit to a human Mars mission, but by producing substantive developments that will enable a human mission when the time is right?

A step that could be taken, for example, is to have the robotic program's science teams select the top landing sites for a human mission and begin developing the infrastructure for an outpost.

Imagine sending detailed images from the landing site for all the world's schoolchildren to explore with computers. Imagine hanging posters of the site in every classroom, while steadily building the capability to support the first human flight to Mars. These could be done with data from precursor robot explorers, and would be responsive to public interest in eventual human flight.

The robotic program is having some technical difficulties. It needs more resources. The public wants it to connect with the long-range goal of human exploration. Now is the time for a marriage made in the cosmos -- the human program and the robotic program working together. HEDS money -- significant funds -- should be put into Mars exploration.

The Mars Society

The Mars Society, founded in August 1998, is a non-profit organization with over 3,000 members in 30 countries. The purpose of the Mars Society is to further the goal of the exploration of the Red Planet through: (1) broad public outreach to instill the vision of pioneering Mars, (2) support of ever more aggressive government funded Mars exploration programs around the world, and (3) conducting Mars exploration on a private basis.

The first large project of The Mars Society is the creation of the Flashline Mars Arctic Research Station on Devon Island in the Canadian Arctic. This base, built with the support of Flashline.com and Discovery.com, will allow scientists to test Mars exploration equipment and procedures in the field and under the ideal conditions of the cold and dry Arctic climate. Devon Island also is home to many geological features that are paralleled on the Martian surface. The habitat, construction of which was recently completed, was tested for several days during the summer of 2000 by Mars Society members and NASA scientists. The habitat will be used for more extensive testing during the summer of 2001.

Dr. Robert Zubrin, the current president of the Mars Society, is a leading advocate of Mars exploration and is one of the originators of the Mars Direct concept. He is the author of *The Case for Mars* (Simon & Shuster, 1996) and *Entering Space: Creating a Space-Faring Civilization* (Tarcher-Putnam, 1999). For more information about The Mars Society, visit http://www.marssociety.org.

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