Chapter 10: Design Reference Mission

> Recent developments in the exploration of Mars have served to focus attention once again on the possibilities for human exploration of that planet. The unprecedented interest shown in the recently published evidence pointing to past life on Mars and in the Mars Pathfinder mission indicates that exploration of our solar system has not become so commonplace that the public cannot become surprised and fascinated by the discoveries being made. And these events have also rekindled the questions not of whether, but when will humans join the robots in exploring Mars. (Kent Joosten, Ryan Schaefer, and Stephen Hoffman, 1997)[1]

Mars Direct

Like the STG, NCOS, and The 90-Day Study teams before it, the SEI Synthesis Group opted for a "brute-force" approach to piloted Mars exploration requiring such big-ticket items as heavy-lift rockets that dwarfed the old Saturn V, nuclear-thermal propulsion, and a lunar outpost. As has been seen, this approach has never gained much support. Proposing it repeatedly over the past 30 years has succeeded mainly in ingraining the belief that Mars exploration must be exorbitantly expensive (more expensive than a small war, for example) and needs decades to achieve its goal. Subsequent NASA Mars plans have sought to apply technologies new and old to reduce cost and tighten the schedule. They have begun the slow process of expunging the perception that a Mars mission must be conducted in a costly way.

Since 1992, NASA has based most of its Mars plans on the Mars Direct concept developed in 1990 by Martin Marietta. Mars Direct originated in Martin Marietta-sponsored efforts to develop SEI concepts. The plan has had staying power in part because it is an appealingly clever synthesis of concepts with respectable pedigrees. Mars Direct employs ISRU, aerobraking, a split mission architecture, a tether for artificial gravity, and a conjunction-class mission plan—all concepts that date from the 1960s or earlier. Mars Direct was influenced by the Case for Mars conferences, the Ride Report, and the NASA Exploration Office Studies, as well as ISRU research conducted by Robert Ash, Benton Clark, and others.[2]

Mars Direct has also had staying power since 1990 because one of its authors, engineer Robert Zubrin, has remained its zealous champion. On April 20, 1990, Zubrin and co-author David Baker unveiled their plan to NASA engineers gathered at NASA Marshall.[3] Mars Direct went public at a National Space Society conference in Anaheim, California, in June 1990. It first received widespread attention a week later, after Zubrin presented it at the Case for Mars IV conference in Boulder, Colorado.[4]

In August 1990 the AIAA magazine Aerospace America carried a non-technical description of Mars Direct capturing Zubrin's promotional style.[5] It asked,

> Can the United States send humans to Mars during the present decade? Absolutely. We have developed vehicle designs and a mission architecture that can make this possible. Moreover, the plan we propose is not merely a "flags and footprints" one-shot expedition, but would put into place immediately an economical method of Earth-to-Mars transportation, vehicles for long-range surface exploration, and functional bases that could evolve into a mostly self-sufficient Mars settlement.[6]

Zubrin and Baker had the first Mars Direct expedition beginning in December 1996 with the launch of a Shuttle-derived heavy-lift rocket from the Kennedy Space Center. The rocket, which Zubrin and Baker dubbed Ares, would consist of a modified Shuttle External Tank, two Advanced Solid Rocket Boosters, and four Space Shuttle Main Engines mounted on the External Tank's underside. A liquid hydrogen/liquid oxygen upper stage and an unpiloted Mars cargo lander covered by a streamlined shroud sat on top of the External Tank. The 40-ton cargo lander included an aerobraking heat shield, descent stage, Earth-Return Vehicle, In-Situ Resource Utilization propellant factory, 5.8 tons of liquid hydrogen feedstock for propellant manufacture, and a 100-kilowatt nuclear reactor on a robot truck. The lander was, they wrote, "light enough for the booster upper stage to project it directly onto a six-month transfer orbit to Mars without any refueling or assembly in Earth orbit"—hence the name Mars Direct.[7]

The cargo lander would aerobrake in Mars' atmosphere and land. After touchdown, the robot truck bearing the reactor would trundle away to a natural depression or one created using explosives. It would lower the reactor into the crater—the crater rim would shield the landing site from radiation—then would run cables back to the lander. The reactor would activate, powering compressors which would draw in Martian air to manufacture propellant. Manufacturing propellants on Mars would help minimize the weight of propellants that had to be shipped from Earth.

The propellant factory would use the Sabatier process first proposed for use on Mars in 1978 by Robert Ash, William Dowler, and Giulio Varsi. Liquid hydrogen feedstock would be exposed to Martian carbon dioxide in the presence of a catalyst, producing 37.7 tons of methane and water. The methane would be stored and the water electrolyzed to yield oxygen and more hydrogen. The oxygen would then be stored and the hydrogen recycled to manufacture more water and methane. Additional oxygen would be manufactured by decomposing carbon dioxide into carbon monoxide and oxygen and venting the carbon monoxide. In a year, the propellant factory would manufacture 107 tons of methane and oxygen propellants. The piloted Mars spacecraft would not be launched until the automated cargo ship finished manufacturing the required propellants, thereby reducing risk to crew.

In January 1999—the next minimum-energy Mars transfer opportunity—two more Ares rockets would lift off. One would carry a cargo lander identical to the one already on Mars. The other would carry a "manned spacecraft looking somewhat like a giant hockey puck 27.5 f[ee]t in diameter and 16 f[ee]t tall" based on Martin Marietta designs developed for the NASA Office of Exploration.[8] The top floor would comprise living quarters for the four-person crew, while the bottom floor would be stuffed with cargo and equipment, including a pressurized rover. Zubrin and Baker estimated the piloted spacecraft's weight at 38 tons.

The upper stage would launch the "hockey puck" spacecraft on course for Mars and separate, but the two would remain attached by a 1,500-meter tether. This assemblage would rotate once per minute to produce acceleration equal to Martian surface gravity in the piloted spacecraft. A similar lightweight artificial gravity concept was proposed by Robert Sohn in 1964. Near Mars the upper stage and tether would be discarded.

The piloted spacecraft would aerobrake into Mars orbit, then land near the 1996 cargo lander. No part of the ship would remain in orbit. Landing the entire crew on the surface would help minimize risk. Once on Mars, the Martian atmosphere would provide some radiation protection, and the crew could use Martian dirt as additional shielding. They would also experience Martian gravity. Though only a third as strong as Earth's gravity, it seemed likely that even that small amount would be preferable to a long weightless stay in Mars orbit.

As in the SAIC split-sprint plan, the crew would have to rendezvous at Mars with propellants for their trip home. This was seen by some as increasing risk. Unlike the SAIC crew, however, the Mars Direct astronauts would have options if they could not reach their Earth-return propellants.

Baker and Zubrin pointed out that the crew had their rover to drive to the 1996 cargo lander, though ideally they would land within walking distance. If some gross error meant they landed more than 600 miles from the 1996 cargo lander—beyond the range of their rover—they could command the cargo lander launched with them in 1999 to land nearby. It would then manufacture propellant for their return to Earth. If the 1999 cargo lander failed, the Mars Direct astronauts would have sufficient supplies to hold out until a relief expedition arrived in two years. Assuming that the crew landed near the 1996 cargo lander as planned, the 1999 cargo lander would set down 500 miles from the first Mars landing site and begin to make propellants for the second Mars expedition, which would leave Earth in 2001.

Eleven of the 107 tons of propellants manufactured by the 1996 cargo lander would be set aside to power the pressurized rover. During their 500-day stay on Mars, the explorers would conduct long traverses—up to 600 miles round-trip—thoroughly characterizing the region around their landing site. This impressive capability would maximize science return by allowing the crew to survey large areas, though with some increased risk. If the rover broke down, the crew could become stranded beyond hope of rescue, hundreds of kilometers from base.

At the end of the 500-day Mars stay, the ERV engine would ignite, burning methane and oxygen propellants manufactured using the Martian atmosphere. The small ERV spacecraft would use the cargo lander as a launch pad to perform ascent and direct insertion onto a trajectory to Earth. After six weightless months in the cramped ERV, the crew would reenter Earth's atmosphere and perform a parachute landing. The small ERV was considered by many to be a weak link in the Mars Direct plan.

The 2001 expedition crew would land near the 1999 cargo lander. If all went as planned, the 2001 cargo lander would land 500 miles away. The 2003 crew would land next to the 2001 cargo lander, while the 2003 cargo lander would touch down 500 miles away for the 2005 expedition, and so on. After several expeditions, a network of bases would be established. "Just as towns in the western U.S. grew up around forts and outposts," wrote Baker and Zubrin, "future [M]artian towns would spread out from some of these bases. As information returns about each site, future missions might return to the more hospitable ones and larger bases would begin to form."[9]

SEI's Last Gasp

In SEI's last days, the Stafford Synthesis Group report formed the basis of NASA's Mars planning. From 1991 to 1993, the Agency performed the First Lunar Outpost (FLO) study, which took as a point of departure the lunar elements of the Synthesis Group's four architectures. In the summer of 1992, the NASA Headquarters Exploration Office under Michael Griffin, the successor to the Office of Exploration first headed by Sally Ride, launched a NASA-wide study to determine how FLO might find hardware commonality with a follow-on Mars expedition, thereby reducing the costs of both programs.[10]

The Mars Exploration Study Team workshop held in August 1992 produced a plan containing elements of both Mars Direct and the Synthesis Group Mars plan. It was briefed to Griffin in September.[11] The May 1993 Mars Exploration Study Team workshop produced a Mars expedition Design Reference Mission (DRM) with little overt FLO commonality beyond a common heavy-lift rocket and outwardly similar vehicles for lunar and Mars ascent. In fact, the DRM was modeled on Mars Direct. Robert Zubrin was an advisor to the Mars Exploration Study Team in late 1992 and 1993. He briefed Griffin on Mars Direct in June 1992, then briefed the JSC Exploration Program Office in October 1992.[12]

The Mars Exploration Study Team DRM was reported in a workshop summary and in technical papers in September and November 1993.[13, 14] It included the following:

- no low-Earth orbit operations or assembly—that is, no reliance on a space station as a Mars transportation element,
- no reliance on a lunar outpost or other lunar operations,
- heavy-lift rocket capable of launching 240 tons to low-Earth orbit, 100 tons to Mars orbit, and 60 tons to the Martian surface (more than twice the capability of the Saturn V),
- short transit times to and from Mars and long Mars surface stay times beginning with the first expedition (conjunction-class missions),
- six crewmembers to ensure adequate manpower and skills mix,
- early reliance on Mars ISRU to minimize weight launched to Mars, and
- common design for surface and transit habitats to reduce development cost.

The most significant difference between Mars Direct and the Mars Exploration Study Team's DRM was the division of the Mars Direct ERV functions between two vehicles. In the Mars Direct plan, the ERV lifted off from Mars at the end of the surface mission and flew directly to Earth. In the judgment of many, however, the Mars Direct ERV was too small to house four astronauts during a six-month return from Mars, let alone the DRM's six astronauts.[15] In the DRM, therefore, only a small Mars Ascent Vehicle (MAV) would rely on ISRU. The crew would use it to reach Mars orbit at the end of their surface stay and dock with the orbiting ERV. The addition of a rendezvous and docking in Mars orbit was seen by some as increasing risk to crew, but

Figure 23—NASA's 1993 Mars mission plan: after landing on Mars, the automated propellant factory manufactures liquid methane and liquid oxygen propellants for the conical Mars Ascent Vehicle it carries on top. (NASA Photo S93-50643)

there seemed to be little alternative if a realistically large ERV was to be provided.

The September 2007 Mars transfer opportunity was used for the study because it would be challenging in terms of time and energy required for Mars transfer, not necessarily because an expedition was planned for that time. The first expedition would begin with launch of three heavy-lift rockets, each bearing one unmanned spacecraft and one nuclear propulsion upper stage. The three spacecraft were the cargo lander, the ERV orbiter, and an unmanned Habitat lander. They would weigh between 60 and 75 tons each, a weight estimate considered more realistic than the 30 to 40 tons quoted in Mars Direct.

The ERV and Habitat designs were based on a common crew module design resembling the Mars Direct "hockey puck." The cargo lander would carry the MAV, ISRU propellant factory, and hydrogen feedstock, along with 40 tons of cargo, including the pressurized rover. All would reach Mars during August and September 2008. The ERV would aerobrake into Mars orbit, while the cargo lander and Habitat would land on Mars. The cargo lander would then set about manufacturing 5.7 tons of methane and 20.8 tons of oxygen for the MAV and a 600-day cache of life-support consumables.

Figure 24—The crew Habitat lands near the propellant factory with empty propellant tanks. Note wheels for moving the Habitat on the martian surface. (NASA Photo S93-050645)

As in Mars Direct, the crew would follow during the next Mars launch opportunity 26 months later (October-November 2009), accompanied by unmanned vehicles supporting the next expedition or providing backup for those already on Mars. The explorers would land near the 2007 cargo lander and Habitat. The Habitats would

Figure 25—Mars Base 1: the crew docks its Habitat on the surface with a second Habitat and begins a 600-day stay. They use a pressurized rover (left) to explore up to 500 kilometers from base. (NASA Photo S93-45582)

include wheels to allow the explorers to move them together so they could be linked using a pressurized tunnel. The 2007 Habitat would also provide a backup pressurized volume if the 2009 Habitat was damaged during landing and rendered uninhabitable.

The first Mars outpost thus established, the crew would unpack the pressurized rover from the 2007 cargo lander. During their 600-day stay on Mars, the crew would carry out several 10-day rover traverses ranging up to 500 kilometers from the outpost.

In October 2011, the 2009 crew would lift off from Mars in the 2007 MAV. They would dock in Mars orbit with the 2007 ERV and fire its twin liquid methane/liquid oxygen rocket engines to leave Mars orbit for Earth, retaining the MAV capsule. Near Earth the explorers would enter the MAV capsule and detach from the ERV, which would sail past Earth into solar orbit. They would then reenter Earth's atmosphere and perform a parachute landing.

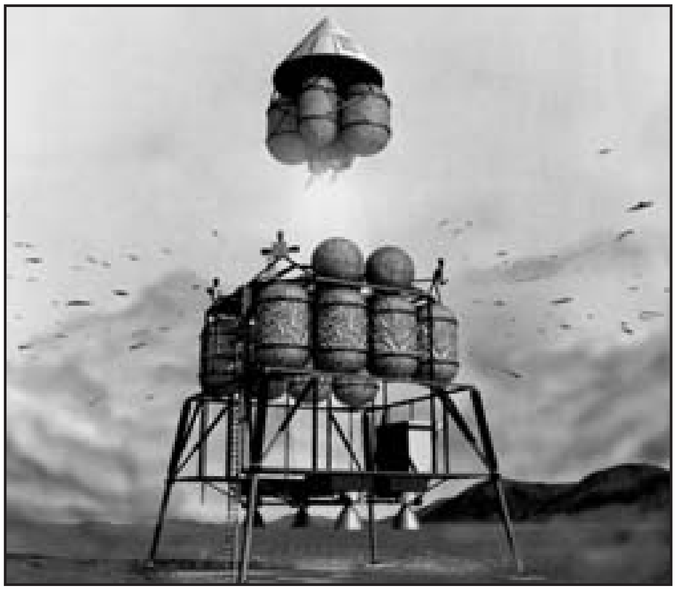

Figure 26—Using the propellant factory as a launch pad, the Mars Ascent Vehicle blasts off burning propellants made from terrestrial hydrogen and Martian atmospheric carbon dioxide. (NASA Photo S93-050644)

The Mars Exploration Study Team effort was SEI's last gasp. Before it was completed, NASA had begun to dismantle its formal Mars exploration planning organization. The Headquarters Exploration Office was abolished in late 1992. The JSC Exploration Directorate, created soon after The 90-Day Study's release, was trimmed back and re-created as the JSC Planetary Projects Office.[16]

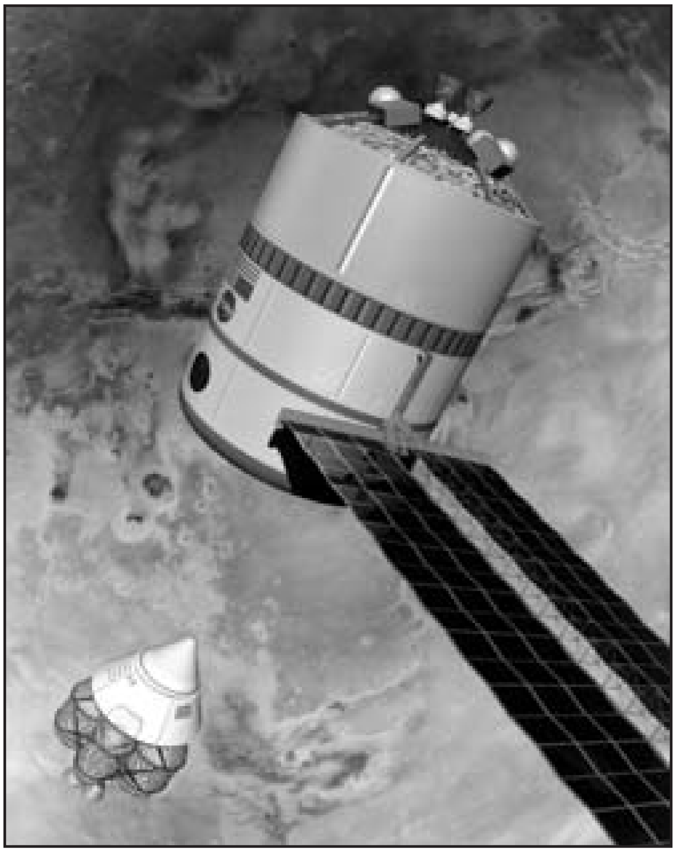

Figure 27—Mars Orbit Rendezvous: The Mars Ascent Vehicle docks with the Earth Return Vehicle in Mars orbit. The Earth Return Vehicle's rocket engines would place the crew on a six-month low-energy trajectory homeward. (NASA Photo S93-27626)

As the apparatus for piloted Mars planning within NASA shrank, automated Mars exploration also suffered a cruel blow. Mars Observer, the first U.S. automated Mars mission since the Vikings, had left Earth on 25 September 1992. On 21 August 1993, three days before planned Mars orbit arrival, the spacecraft's transmitter was switched off as planned to protect it from shocks during propellant system pressurization. Contact was never restored. An independent investigation report released in January 1994 pointed to a propulsion system rupture as the most probable cause of Mars Observer's loss, the first post-launch failure of a U.S. planetary exploration mission since Surveyor 4 in 1967.[17]

NASA almost immediately announced plans to fly Mars Observer's science instruments on an inexpensive Mars orbiter as soon as possible. This marked the genesis of the Mars Surveyor Program, which aimed to launch low-cost automated spacecraft to Mars every 26 months, at each minimum-energy launch opportunity.[18]

Refreshed Dreams

In 1994, the JSC Planetary Projects Office, NASA's de facto focus for piloted Mars planning following abolition of the Headquarters Exploration Office, was downsized, then abolished. In February it became a branch of the JSC Solar System Exploration Division, and in June its remaining personnel were assigned to the JSC Office of the Curator, where they explored low-cost options for sending people to the Moon.[19] The Curator's Office managed disposition of Apollo lunar samples and meteorites, including one meteorite designated ALH 84001. Even as the Planetary Projects Office was abolished, ALH 84001 was determined to have originated on Mars.

On 7 August 1996, NASA, Stanford University, and McGill University scientists led by NASA scientist David McKay announced that they had discovered possible fossil microorganisms in Martian meteorite ALH 84001. In a NASA Headquarters press conference, the McKay team cited the evidence for past Martian life. This included the presence of complex carbon compounds resembling those produced when Earth bacteria die, magnetite particles similar to those in some Earth bacteria, and segmented features on the scale of some Earth nanobacteria. McKay told journalists,

> There is not any one finding that leads us to believe that this is evidence of past life on Mars. Rather, it is a combination of many things that we have found. They include Stanford's detection of an apparently unique pattern of organic molecules, carbon compounds that are the basis of life. We also found several unusual mineral phases that are known products of primitive microorganisms on Earth. Structures that could be microscopic fossils seem to support all of this. The relationship of these things in terms of location—within a few hundred-thousandths of an inch of each other—is the most compelling evidence.[20]

According to their analysis, the 1.9-kilogram rock soaked in carbonate-rich water containing the possible microorganisms 3.6 billion years ago. It lay in the Martian crust, shocked by the occasional local upheaval, until an asteroid impact blasted it off Mars 16 million years ago. After orbiting the Sun several million times, ALH 84001 landed in Antarctica 13,000 years ago, where it was collected on 27 December 1984 in the Allan Hills ice field.[21]

The McKay team's discovery generated unprecedented public enthusiasm for Mars, which in turn provided the catalyst for reestablishment of the JSC Exploration Office in November 1996. The new office, managed by Doug Cooke, was reconstituted as part of the Advanced Development Office in the JSC Engineering Directorate.[22] Mars planners dusted off the 1993 DRM to serve as the point of departure for new planning.

At the same time, NASA Headquarters took an important step toward eventual piloted Mars exploration. On 7 November 1996, Associate Administrator for Space Flight Wilbur Trafton, Associate Administrator for Space Science Wesley Huntress, and Associate Administrator for Life and Microgravity Sciences and Applications Arnauld Nicogossian signed a joint memorandum calling for NASA's Human Exploration and Development of Space (HEDS) Enterprise and Space Science Enterprise to work together toward landing humans on Mars.

They told Jet Propulsion Laboratory director Edward Stone and JSC director George Abbey that "[r]ecent developments regarding Mars and the growing maturity of related programs lead us to believe that this is the right time to fully integrate several areas of robotic and human Mars exploration study and planning."[23] The Associate Administrators then gave Stone and Abbey until 1 February 1997, to produce "a proposal that NASA can bring forward, after successful deployment of the International Space Station, for human exploration missions beginning sometime in the second decade of the next [21st] century."[24]

Trafton, Huntress, and Nicogossian also asked for "a credible approach to achieving affordable human Mars exploration missions." They defined "a credible cost" as "the amount currently spent by NASA on the International Space Station"—that is, less than $2 billion annually. This was a dramatic reduction over the $15 billion per year proposed in the excised cost section of The 90-Day Study. They asked that Stone and Abbey identify "technology investments and developments that could dramatically decrease the cost of human and robotic missions."[25]

In March 1997, the HEDS and Space Science Enterprises agreed that the 2001 Mars Surveyor lander should include instruments and technology experiments supporting piloted Mars exploration. Among the planned experiments was a compact system for testing ISRU propellant manufacture on Mars. In a press conference, Huntress called it "the first time since the 1960s" that "NASA's space science and human space flight programs are cooperating directly on the exploration of another planetary body." Trafton called the joint effort "a sign that NASA is acquiring the information that will be needed for a national decision, perhaps in a decade or so, on whether or not to send humans to Mars."[26]

In addition to stating that NASA's robotic program would complement its piloted Mars flight planning efforts, the joint memorandum showed that, at a high managerial level, NASA had not abandoned its plans to eventually send people to Mars despite SEI's collapse. There was no firm timetable for accomplishing the piloted Mars mission and no Presidential declaration. Instead, there was a new philosophy—continuing low-level, low-cost planning, much of it in-house, and low-level Earth-based technology research accompanied by efforts to use the existing low-cost robotic exploration program to answer questions relevant to piloted exploration. In short, the Agency accepted publicly for the first time that it might eventually send people to Mars without recourse to a new large program—without a new Space Exploration Initiative or Apollo program. This philosophy continues to guide NASA Mars planning at the time of this writing (mid-2000).

Success or failure in the automated Mars program thus became success or failure for piloted Mars planners. The joint human-robotic Mars effort received a boost on 4 July 1997, when Mars Pathfinder successfully landed at Ares Vallis, one of the large outwash channels first spotted by Mariner 9 in 1971 and 1972. Pathfinder, the first U.S. Mars lander since the Vikings, dropped to the rock-strewn surface and bounced to a stop on airbags, then opened petals to right itself and expose instruments and solar cells. The technique was similar to the one the Soviets employed to land robots on the Moon in the 1960s and on Mars in the 1970s. The Sojourner rover—the first automated rover to operate on another world since the Soviet Union's Lunokhod 2 explored the Moon in 1972—crawled off its perch on one of Pathfinder's petals and crept about the landing area analyzing rock and dirt composition. Sojourner and Pathfinder—the latter renamed the Sagan Memorial Station—successfully completed their primary mission on 3 August.

As Mars Pathfinder bounced to a successful landing in Ares Vallis, the glossy report Human Exploration of Mars: The Reference Mission of the NASA Mars Exploration Study Team rolled off the presses.[27] In addition to a detailed description of the 1993 DRM, the July 1997 document contained general recommendations on the conduct of a piloted Mars program based on experience gained through SEI and the Space Station program.

The report recommended that NASA set up "a Mars Program Office . . . early in the process." It also proposed to avoid Space Station's redesigns and delays by establishing "a formal philosophical and budgetary agreement . . . as to the objectives and requirements imposed on the mission before development is initiated, and to agree to fund the project through to completion." Finally, taking into account the McKay team's discovery, it called for "adequate and acceptable human quarantine and sample handling protocols early in the Mars exploration program" to protect Earth and Mars from possible biological contamination.[28]

The JSC Exploration Office called its report "another chapter in the ongoing process of melding new and existing technologies, practical operations, fiscal reality, and common sense into a feasible and viable human mission to Mars," adding that "this is not the last chapter in the process, but [it] marks a snapshot that will be added to and improved upon by others in the future."[29] In fact, by the time the report saw print, the next chapter was nearly complete.

Scrubbing the DRM

Subsequent DRM evolution focused on minimizing spacecraft weight in an effort to reduce estimated mission cost. The slang term engineers used to describe this process was "scrubbing." The 1997 "scrubbed" DRM went public in August 1997.[30] It minimized mass by reducing common Habitat diameter; combining the functions of the pressure hull, aero-

Figure 28—NASA's 1997 Mars plan proposed to reduce weight by using an aerobrake integrated with the spacecraft hull and nuclear rockets. These steps would help eliminate need for a heavy-lift rocket, permitting a cheaper Shuttle-derived launch system. (NASA Photo S97-07844)

Figure 29—Nuclear stages in NASA's 1997 Mars plan included engines (left) based on revived 1960s NERVA technology. (NASA Photo S97-07843)

brake heat shield, and Earth launch shroud; and employing lightweight composite structures. The nuclear stages for injecting the spacecraft toward Mars would be launched into Earth orbit without spacecraft attached, then docked with the spacecraft in Earth orbit. These steps and others allowed planners to eliminate the 1993 DRM's large heavy-lift rocket, potentially the costliest mission element.

To place the first crew on Mars, the 1997 DRM would require eight launches of a Shuttle-derived rocket capable of boosting 85 tons into Earth orbit. In the first launch opportunity, six of these rockets would launch payloads—three nuclear propulsion stages and three Mars spacecraft (cargo lander, ERV, and unpiloted Habitat). Each spacecraft would dock with its nuclear stage in Earth orbit, then launch toward Mars. In the second launch opportunity, 26 months later, six more Shuttle-derived rockets would launch three nuclear stages and three spacecraft, including a Habitat lander containing the crew. The spacecraft would dock with their nuclear stages and launch toward Mars. The rest of the mission plan closely resembled the 1993 DRM. To accomplish the first expedition, the 1997 DRM would launch 303 tons to Mars—75 tons less than the 1993 DRM.

The new DRM was on the street, and a few weeks later, a new automated spacecraft was orbiting Mars. On 11 September 1997, the Mars Global Surveyor orbiter, the first spacecraft in the Mars Surveyor Program, arrived in an elliptical Mars orbit after a 10-month flight. Mars Global Surveyor carried backups of instruments lost with Mars Observer in 1993. It commenced a series of passes through Mars' upper atmosphere to reach a lower, more circular Mars orbit without using propellants. A damaged solar array threatened to collapse under the pressure of atmospheric drag, however, so the aerocapture maneuvers had to be extended over a year. Nevertheless, the spacecraft turned its instruments toward Mars and began initial observations.

Defining the Surface Mission

As Mars planners sought to minimize spacecraft weight, it became clear that they would require more data on the mission's Mars surface payload. Planners historically have spent little time detailing what astronauts would do once they landed on Mars. To begin the process of better defining the 500-to-600-day Mars surface mission, veteran Moon and Mars planner Michael

Duke chaired a workshop held at the Lunar and Planetary Institute in Houston on 4-5 October 1997.[31]

Workshop participants divided into two working groups. The Science and Resources group based its discussions on a "three-pronged approach" to Mars exploration. Mars explorers would seek evidence of life or its precursors and attempt to understand Mars climate history. They would also act as prospectors, seeking water, minerals, energy, and other resources for supporting future Mars settlements. This three-pronged science approach also guided the automated Mars Surveyor program.[32]

The Living and Working on Mars group looked at chores the crew would need to perform during their Mars stay. These included initial base setup, such as deploying an inflatable greenhouse, and base maintenance, such as ridding air filters of ever-present ultra-fine Martian dust. Astronauts on Mars would also harvest crops, service their space suits, and perform less mundane tasks such as exploring the surface in the pressurized rover and drilling deep in search of Martian microorganisms that might hide far beneath the surface.

The workshop recommended that "a process and program be put into place whereby a wide range of people could contribute to the thought process." The report urged that students in particular be involved, because "their representatives will be the ones who are actually to do this exploration."[33]

A New Concept

Meanwhile, engineers at NASA Lewis studied using solar-electric propulsion in the DRM to further reduce the amount of weight that would have to be launched into orbit. In January 1999, they proposed a novel concept using a Solar-Electric Transfer Vehicle (SETV) which never left Earth orbit, but which provided most of the energy needed to launch the Mars vehicles from Earth orbit toward Mars.[34]

The 1997 DRM required eight Shuttle-derived rockets for the first Mars expedition. By contrast, the Lewis solar-electric DRM required only five rockets. Removal of the backup Habitat lander—a decision taken by Mars planners in the JSC Exploration Program Office—eliminated two heavy-lift rockets. Replacing the four nuclear stages used to leave Earth in the 1993 and 1997 DRMs with the SETV and three small expendable chemical stages eliminated one more. This substitution also eliminated the cost of developing a nuclear rocket engine and the potential political headaches of launching nuclear payloads.

The Lewis team envisioned a self-erecting SETV weighing 123 tons and measuring 194.6 meters across its thin-film solar arrays. The arrays would provide electricity to two sets of Stationary Plasma Thrusters (SPTs), also known as TAL (Thruster with Anode Layer) or Hall thrusters, an electric propulsion technology pioneered by the Russians.

The SETV would need months to complete large orbit changes. Because of this, it would spend considerable time crossing through Earth's Van Allen Radiation Belts. This meant that the Lewis DRM vehicles would require radiation-hardened systems. The authors assumed that the SETV would be good for two missions beyond the Van Allen belts before radiation, temperature extremes, meteoroid impacts, and ultraviolet light seriously degraded its solar arrays.

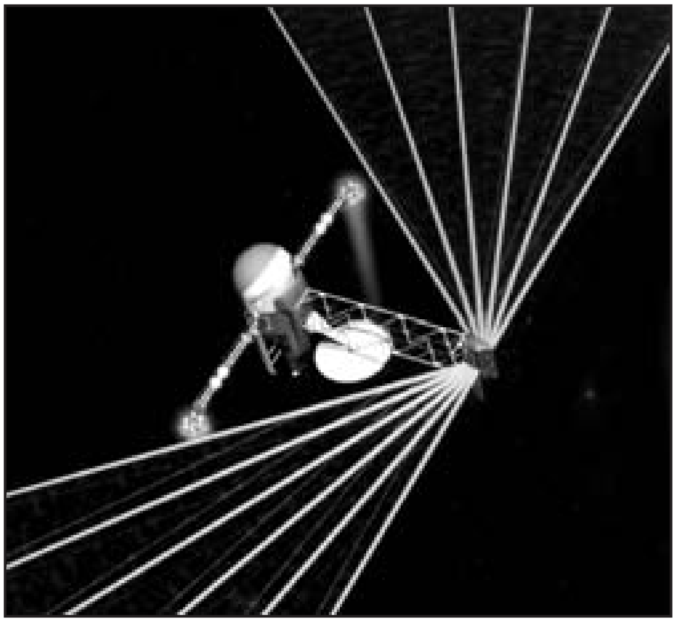

Figure 30—In 1998, NASA Lewis Research Center proposed a reusable Solar-Electric Transfer Vehicle (SETV) and clever use of orbital mechanics to reduce Mars expedition mass. SETV's solar panel spars would inflate in orbit, spreading "wings" of solar cell fabric. (NASA Photo S99-03585)

The SETV's first mission would place one unpiloted cargo vehicle and one unpiloted ERV, each with a small chemical rocket stage, into High-Energy Elliptical Parking Orbit (HEEPO) around the Earth. The SETV would start in a nearly circular low-Earth orbit and raise its apogee by operating its SPT thrusters only at perigee. It would need from six to twelve months to raise its apogee to the proper HEEPO for Earth-Mars transfer. The final HEEPO apogee would be more than 40,000 kilometers, making it very lightly bound by Earth's gravity.

When Earth, Mars, and the plane of the HEEPO were properly aligned for Earth-Mars crossing, the SETV would release the cargo lander, ERV, and small chemical stages. At next perigee the chemical stages would ignite, pushing the spacecraft out of the HEEPO on a path that would intersect Mars six months later. After releasing the chemical stages and spacecraft, the SETV would point its SPTs in its direction of motion and operate them at perigee to return to a circular low-Earth orbit.

The SETV's second mission would place one Habitat lander with a small chemical stage into HEEPO. Because the climb to HEEPO again would require up to twelve months and long periods inside the Van Allen Radiation Belts, the Habitat lander would remain unpiloted until just before Earth orbit departure. As the SETV climbed toward planned final HEEPO apogee, a small, chemical-propellant "taxi" carrying the Mars crew would set out in pursuit. The crew would transfer to the Habitat lander, cast off the taxi, then separate the Habitat lander and chemical stage from the SETV. At the next perigee, the chemical stage would ignite to place the first expedition crew on course for Mars. The remainder of the first Mars expedition would occur as described in the 1997 scrubbed DRM, except for the absence of a backup Habitat lander.

In February 1999, soon after the Lewis team made public their variation on the 1997 DRM, Mars Global Surveyor achieved its nominal mapping orbit. At this writing, exploration and data interpretation are ongoing, but it is already clear that the spacecraft is revolutionizing our understanding of Mars. By mid-2000, its instruments had detected evidence that Mars once had a strong planetary magnetic field, a finding potentially important for the early development of Martian life; that Mars' polar regions once knew extensive glaciers; and that water flowed on Mars' surface recently, and perhaps flows occasionally today, carving gullies in cliffs and crater walls.

Not the Last Chapter

In May 1998, a small team of NASA and contractor space suit engineers traveled to sites in northern Arizona where Apollo Moonwalkers had trained three decades before. They observed and assisted as a veteran geologist wearing a space suit performed geological field work and set out simulated scientific instruments in Mars-type settings—for example, on the rim of Meteor Crater. The team contained cost by traveling from Houston to Arizona overland and by reusing a space suit originally designed for Space Station Freedom. In addition to gathering data on space suit mobility to enable design of future Mars space suits, the exercise permitted veteran space suit engineers who had participated in the development of the Apollo lunar space suits to pass on their experience to young engineers who had been children, or not yet born, when Americans last walked on an alien world.[35]

Michael Duke and the other organizers of the Human Exploration and Development of Space-University Partners (HEDS-UP) program had a similar motive. They sought to involve and inspire the next generation of Mars planners, who might become the first generation of Mars explorers. In May 1998, the first HEDS-UP Annual Forum saw undergraduate and graduate design teams from seven universities across the United States present Mars design studies.[36] Twice as many universities sent enthusiastic students to the 1999 HEDS-UP Annual Forum.[37]

In the nearly half-century since von Braun wowed Americans with visions of Mars flight in Collier's magazine, our understanding of Mars has steadily improved. We have progressed from hazy telescopic views of Mars to pictures on the Internet of Sojourner rearing up on a flood-tossed Martian boulder. Plans for piloted Mars exploration have matured in step with our improved vision. For example, no longer do planners seek to bring all necessities from Earth, for now it is known that Mars has useful resources.

The Mars planning concepts developed in the twilight years of the second millennium form a launch pad for Mars planners—and perhaps Mars explorers—at the dawn of the third. Current technological trends—for example, increasingly capable miniaturized robots and direct public engagement in Mars exploration through the Internet—promise to reshape Mars planning.

Yet it should be remembered that ISRU, the concept that dominated Mars planning in the 1990s, dates from the 1960s and 1970s. This suggests that, in addition to whatever new revolutions future technological development brings, other revolutions might lie buried in the historical archives awaiting the careful and imaginative researcher. Further, this suggests that Mars planners should carefully preserve their work lest they deprive future planners of useful concepts.

Young people now looking to Mars, such as the student participants in the HEDS-UP program, should not have to waste their time reinventing old concepts. They should instead be able to study the old concepts and build new ones upon them. They should also be able to study the political and social settings of the old concepts, so that they might better navigate the “illogical” pitfalls that can bring down a technically logical Mars plan. Providing the next generation with the history of Mars planning helps hasten the day when humans will leave bootprints on the dusty red dunes of Mars.