Onward and Upward:
An Analysis of Human Exploration of Mars

A Report to the President of the United States

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Introduction

This report discusses the feasibility of human exploration of Mars. The scientific, political, sociological and economic implications of such a project are examined. The report discusses the history and current status of America's space program, and employs a cost/benefit analysis to determine the feasibility of sending astronauts to Mars. Technical and non-technical factors affecting manned flights to Mars are discussed. The report finds that while there are significant short-term technical, political and financial obstacles to a manned Mars mission, the long-term benefits of the project will justify the costs.

Overview of the Mars Project

Background

Mars is one of the Earth's nearest neighbors in the solar system, at an average distance of 49 million miles (Viotti, 2001). While no human being has yet walked the surface of Mars, unmanned exploration of the Red Planet dates back to 1960. In that year, the Soviet Union attempted two Mars flyby missions, which both failed at the launch phase (Williams, 2001). The failure of the 1960 USSR missions proved a harbinger of things to come: after twenty missions, the former Soviet Union has yet to record an unqualified success. The Soviets' best effort came in 1971, when their Mars 3 orbiter and lander both reached the planet. Unfortunately, a Martian dust storm rendered all images from these probes useless (Zimmerman, 2001).

American exploration of Mars has proven far more successful, as seen in Figure 1 on the next page ("Mars Exploration Timeline"). After the failure of Mariner 3 in 1964, the United States rebounded with the successful Mariner 4 flyby later that year (Williams, 2001). Images and atmospheric data collected by the Mariner flybys of the 1960s portrayed Mars as a cold, lifeless planet covered with craters, similar to our Moon. (Zimmerman, 2001).

The 1970s produced some optimism about the potential for life on Mars. The Mariner 9 mission (1971) avoided the dust storm that blacked out that year's Soviet missions, and revealed dust clouds, giant volcanoes, and possible traces of ancient rivers and oceans. (Zimmerman, 2001). In 1975, the Viking mission placed the first landers on the Martian surface, and discovered significant amounts of carbon dioxide in the planet's atmosphere. However, Viking produced no other suggestions of past or present life on Mars, and exploration of the planet ceased for seventeen years. (Zimmerman, 2001).

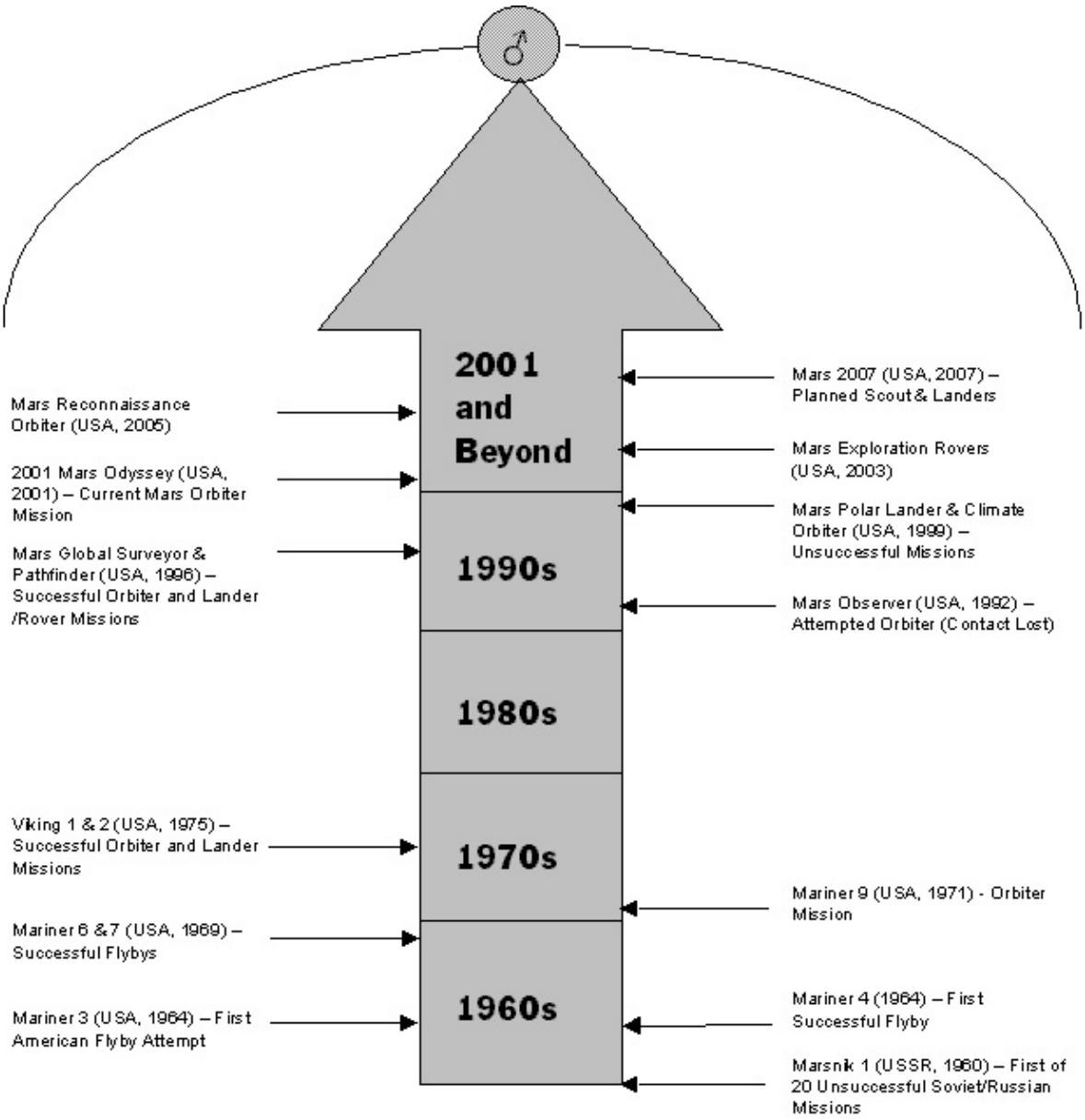

Figure 1: Mars Exploration Timeline (Williams, 2001; Zimmerman, 2001)

American exploration of Mars resumed in the 1990s with mixed success. The billion-dollar Mars Observer mission was lost in 1992, forcing NASA to redefine its program. After the Observer failure, NASA focused on a series of "faster, better, cheaper" missions, rather than trying to accomplish everything in one shot (Zimmerman, 2001). The new philosophy has achieved mixed success. NASA reached Mars with the Global Surveyor and Pathfinder missions in 1997, but lost contact with the Climate Orbiter and Polar Lander in 1999. (Williams, 2001; Zimmerman, 2001). The 2001 Mars Odyssey orbiter mission is currently in progress.

Current Status of the Mars Program

No human explorations of Mars are currently planned, although the next round of missions will hopefully establish the feasibility of that goal. NASA will continue its philosophy of smaller, less ambitious projects by alternating orbiters with landers. The orbiters will provide data for the landing missions, and a 4-year gap between similar missions will allow fine-tuning and redesign as the program advances (Zimmerman, 2001). The current 2001 Mars Odyssey orbiter will be followed by the dual Mars Exploration Rovers in 2003, a Mars Reconnaissance Orbiter mission in 2005, and further lander missions in 2007 (Williams, 2001; Zimmerman, 2001). The current program culminates with a sample return mission in 2011, which will draw upon data and advances in technology accumulated through the previous missions (Zimmerman, 2001).

Human Exploration: When and how?

The Mars Reference Mission. Although no formal plan exists for sending astronauts to Mars, NASA's Mars Exploration Study Project has developed a hypothetical mission plan, called the Mars Reference Mission. The mission plan implements technically feasible methods, reasonable risks, and low costs (Hoffman and Kaplan, 1997). While the Reference Mission cannot be implemented in its current form, it is designed to stimulate the developments in technology, risk reduction, and cost effectiveness necessary for making human exploration of Mars possible (Hoffman and Kaplan, 1997).

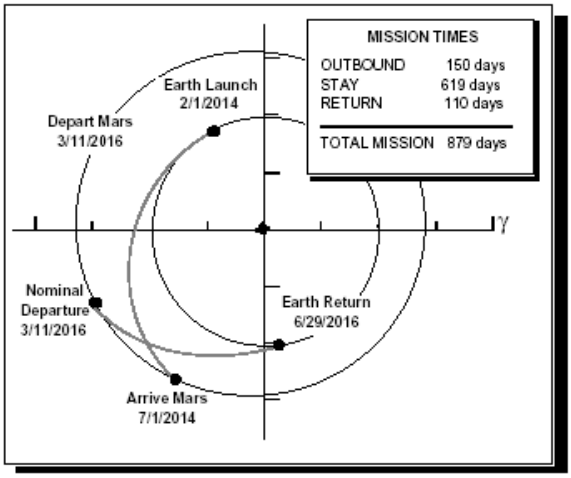

Figure 2: Typical Fast-Transit Technology (Hoffman and Kaplan, 1997)

The Mars Reference Mission implements a "split mission" strategy in which the various components of the mission arrive separately at the Martian surface. Under this strategy, the return vehicles and artificial habitat arrive at Mars before the crew, allowing NASA to ascertain their functionality and therefore assure the safety of the astronauts' journey (Hoffman and Kaplan, 1997). A solid core nuclear rocket will launch the crew into Mars' orbit (Howe, et al, 1998). The lander will steer through the Martian atmosphere using aerobraking, a technology that allows a spacecraft to use a planet's atmosphere as both a brake and a steering wheel

(Murrill, 2001). Once on the planet, the astronauts will observe and analyze the Martian geology and atmosphere, collect and examine samples from the planet, and gauge the extent to which humans might inhabit the planet (Hoffman and Kaplan, 1997). A chemical propulsion return vehicle will bring the astronauts back to Earth orbit, where they will again use aerobraking to navigate through the atmosphere (Howe, et al, 1998). Figure 2 above illustrates transit and stay times for a typical mission based on a 2014-2016 time frame.

The Gas Core Nuclear Rocket. Research at the Los Alamos National Laboratory presents a possible alternative to the solid core rocket technology specified for the Mars Reference Mission. In the 1960s, scientists began investigating the concept of the gas core nuclear rocket, which if successfully developed would achieve greater temperatures and therefore better performance than the nuclear rocket (Howe et al, 1998). A lack of computational technology hindered initial development of the gas core technology, but the formation of the Gas Core Nuclear Rocket Workshop in 1991 reinvigorated the concept (Howe et al, 1998). Although the gas core rocket remains theoretical, reports from Los Alamos claim that current technologies make modeling and development of the rocket possible (Howe et al, 1998).

The advantage of implementing the gas core nuclear rocket lies in its ability to drastically reduce both transit times and surface stays for manned missions to Mars. Table 1 ("Mars Architecture Comparison") on the next page illustrates the effectiveness of the Gas Core rocket in reducing the length of Mars missions. The table compares hypothetical transit times for the NASA Mars Reference Mission, an alternative "opposition class" NASA mission, and a mission using the Gas Core rocket technology. The high performance of the Gas Core rocket cuts the transit time to Mars in half, and reduces the return trip by 50%, compared to both NASA missions. The significant reduction in transit time offers several benefits. The astronauts will experience less exposure to cosmic radiation and less time in zero gravity, which causes loss of bone marrow. (Rshaid, 1996). By reaching Mars so quickly, astronauts will not have to wait for Earth to return to the proximity of Mars, thereby reducing their stay on the planet to 40 to 60 days. Finally, the overall reduction in the mission time will minimize the psychological impact of living in confined quarters, as evidenced by experiences on the Russian space station Mir (Howe et al, 1998). The Los Alamos team concludes that successful development of the Gas Core Nuclear Rocket offers significant risk reduction compared to the NASA Reference Mission (Howe et al, 1998).

Human Exploration: Weighing the Costs and Benefits

Advantages of Human Exploration

Examining the feasibility of putting humans on Mars begs the question: why go to Mars in the first place? The Mars Study Team at the Lunar and Planetary Institute in Houston, Texas addressed this question at their workshop in August 1992 (Hoffman and Kaplan, 1997). The team identified several key rationales to justify human exploration of Mars: human evolution, comparative planetology, international cooperation, technology advancement, and inspiration. When examined further, these reasons comprise a strong case for the human exploration of Mars.

Table 1: Mars Architecture Comparison (Source: Howe et al, 1998)

	Mars Reference Mission (NASA)	Opposition Class Mission (NASA)	Gas Core Nuclear Rocket (Los Alamos)
Rocket Technology	Solid-core nuclear rocket	Solid-core nuclear rocket	Gas core nuclear rocket
Transit to Mars	6 months	6 months	3 months
Surface Stay	500 days	90 days	40-60 days
Return to Earth	6 months	6 months	4 months
Round trip time	900 days	435 days	270 days
Radiation doses	2.04 Sv	1.06 Sv	0.61 Sv (0.22 Sv shielded)

Human Evolution. A mission to Mars should determine whether humans could establish a permanent presence on the planet, and therefore extend our existence beyond the Earth (Hoffman and Kaplan, 1997). As Dr. Michael Duke of the NASA Johnson Space Flight Center claims, "The dream of human exploration of Mars is intimately tied to the belief that new lands create new opportunities (and) enlarge the sphere of human action and life" (Duke, 2001).

Comparative Planetology. Like the Earth, Mars is a terrestrial planet of our own solar system. As Hoffman and Kaplan (1997) state simply, "The scientific objectives of Mars exploration should be to understand the planet and its history, and therefore to better understand Earth."

International Cooperation. The collapse of the Soviet Union in 1991 effectively ended the Cold War. Improving relations with Russia now offers cooperation instead of competition. The United States can also benefit from the technological knowledge of other nations who lack the resources to attempt independent missions (Duke, 2001).

Technology Advancement. The effort to reach Mars provides an impetus for advances in technology. Hoffman and Kaplan (1997) claim that the Reference Mission "will both effectively exploit previous investments and contribute to advances in technology."

Inspiration. Hoffman and Kaplan (1997) eloquently state that "the goals of Mars exploration are grand; they will motivate our youth, benefit technical education and excite the people and nations of the world."

Drawbacks to Human Exploration

A Mars mission faces various obstacles, both technical and non-technical. As previously discussed, astronauts will face several adverse effects in transit, including exposure to cosmic radiation, potential degeneration of bone marrow in zero gravity conditions, and prolonged exposure to confined living quarters. While minimizing the transit time and surface stay may mitigate these factors, several technological hurdles remain. These challenges include

developing practical life support systems (Rshaid, 1996) and preventing the Earth and Mars from cross-contaminating each other's biosphere (Hoffman and Kaplan, 1997).

The non-technical factors may prove more imposing than the technical problems. A potential lack of funding presents the most serious obstacle. Human exploration of Mars may run into the hundreds of billions of dollars (Grabbe, 1999). Some advocates of manned Mars Missions, such as former astronaut Edwin "Buzz" Aldrin, believe that the government will not devote the necessary fiscal resources to a Mars Mission (Ochylski, 1999). Critics of human exploration contend that a manned Mars mission will inflate the NASA budget and crowd out the more cost-effective unmanned missions, which provide more "bang for the buck" (Grabbe, 1999). Rshaid (1996) argues that skepticism and doubt among the scientific and academic communities constitute a "social barrier" to the exploration of Mars, one that will persist until more positive attitudes to space exploration prevail.

Recommendations

Despite the considerable obstacles outlined above, the benefits of human exploration of Mars appear to outweigh the costs. Table 2 below, "Key Recommendations," summarizes the actions needed to make manned Mars missions a reality.

Technical. Perhaps easier said than done, NASA must improve its success ratio. Recent embarrassments such as the loss of the 1992 Mars Observer, the 1999 Polar Lander and the 1999 Climate Orbiter reduce confidence that we can safely send humans to Mars. More specifically, the critical elements of a Mars Mission must be successfully demonstrated before they are put in place (Hoffman and Kaplan, 1997). For example, the 2011 sample return mission will provide NASA with an opportunity to send a ship to Mars and bring it back to Earth – obviously a necessary requirement for a successful manned journey.

The report also recommends supporting development of the Gas Core Nuclear Rocket technology. Implementation of the technology will reduce risk to the astronauts by minimizing their exposure to the harmful effects of space travel.

Environmental. By sending humans to Mars, we risk contaminating the Martian surface with Earth organisms that may distort the search for life on Mars. Similarly, we must prevent the Earth's biosphere from being contaminated by Martian organisms brought back by the astronauts. The report recommends developing acceptable human quarantine and sample handling protocols and contamination control procedures, in accordance with Mars Reference Mission specification (Hoffman and Kaplan, 1997).

International Cooperation. The open literature voices nearly unanimous support for making the human exploration of Mars an international endeavor. The United States has much to gain from involving other nations in the project. We can draw upon the technological knowledge offered by the international community to increase the mission's probability of success.

Financial. Due to the high cost of sending humans to Mars, the United States government should seek alternate methods of funding in addition to maintaining its own commitment to the space program. For example, Edwin Aldrin has suggested establishing "space hotels" as a

innovative way of funding manned Mars missions (Ochylski, 1999). The report recommends investigating techniques such as these to supplement government funding.

Table 2: Key Recommendations

Type	Recommendation
Technology	• Enhance success ratio of future missions • Bring critical technologies to demonstration stage prior to actual mission • Explore Gas Core Nuclear Rocket to reduce mission time and minimize adverse effects on astronauts
Environmental	• Develop acceptable human quarantine and sample handling protocols • Develop contamination control procedures
International Cooperation	• Involve other nations from a very early stage
Financial	• Explore alternative methods of funding (e.g. "space hotels" suggested by Edwin Aldrin)
Educational	• Promote educational initiatives such as interactive virtual missions

Educational. To overcome the social barriers of skepticism, doubt, and indifference, we must promote educational programs that will engender a positive attitude towards space exploration (Rshaid, 1996). In 1996, an "Interactive Trip to Mars" allowed students from the U.S., England, Russia and Argentina to participate in a virtual classroom and simulate a mission to Mars (Rshaid, 1996). Supporting such projects will help to educate the public and perhaps inspire future participants in an actual manned Mars mission.

Conclusion

The report finds that while there are significant technical, social and financial obstacles to a manned Mars mission, the benefits of the project will justify the costs. These benefits include scientific advancements and discoveries, improved relations with cooperating nations, a stimulus to the educational system, and a national sense of accomplishment and pride. The report concludes that the government can reinvigorate the Mars project by promoting scientific research, engaging other nations in the project, exploring educational ventures, and investigating alternative ways of funding the project. By committing our resources to the exploration of Mars, we will take our next bold step towards expanding human civilization to the stars.

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