Humans to Mars: The Political Initiative and Technical Expertise Needed for Human Exploration of the Red Planet

(Group report of the 2002 Astrobiology Academy[*])

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ABSTRACT. Mars is a compelling science destination of astrobiological significance. We propose that NASA's current program of exploration using robotic missions be expanded to include a human mission. A human Mars mission has the unique capacity to address the growing shortage of U.S. scientists and engineers by inspiring youth; economic and diplomatic benefits are also considerable. Technologies for propulsion and hazard mitigation of microgravity, radiation, and contamination-risks are all mature, and with directed development, can be employed to create a cost-effective, safe mission.

1.0 Introduction

In the past decade, we have monitored the Martian weather, constructed a geologic history, are presently characterizing the radiation, and most importantly, have learned that water ice is likely present underground (Boynton et al., 2002). Presently, NASA's Mars exploration program includes orbiters, rovers, and in the distant future, a sample return mission. However, we propose a new direction for Mars exploration: preparation for a *human* mission. Even as machines become more autonomous and self-sustaining, a machine will not soon have the ability to behave as an innovative and adaptive scientist, quickly synthesizing information and shifting quickly from one pursuit to another (Dean, 1998).

It is argued that machined missions are less expensive and are thus the preferred method of exploration, following the NASA's former "faster, cheaper, and better" motto. However, if machined missions are subject to technical limitations and fail to inspire the next generation of scientists and engineers, then are they really the better method of exploration? The 2002 Astrobiology Academy proposes instead that NASA adopt a human mission to Mars as a clear and articulated goal of the agency. Since the 1960s, NASA's paradigm has shifted from destination-focused missions, i.e. "We will put a man on the Moon," to research-driven goals, including space-based monitoring of Earth and the study of life in extreme environments. The Astrobiology Academy advocates a return to a more mission-centric NASA, namely a human mission to Mars, driven by scientific objectives. By coupling science to a human Mars mission, the United States will create a program of exploration that excites the world and is an investment, not only in basic scientific knowledge, but also in strengthening our nation.

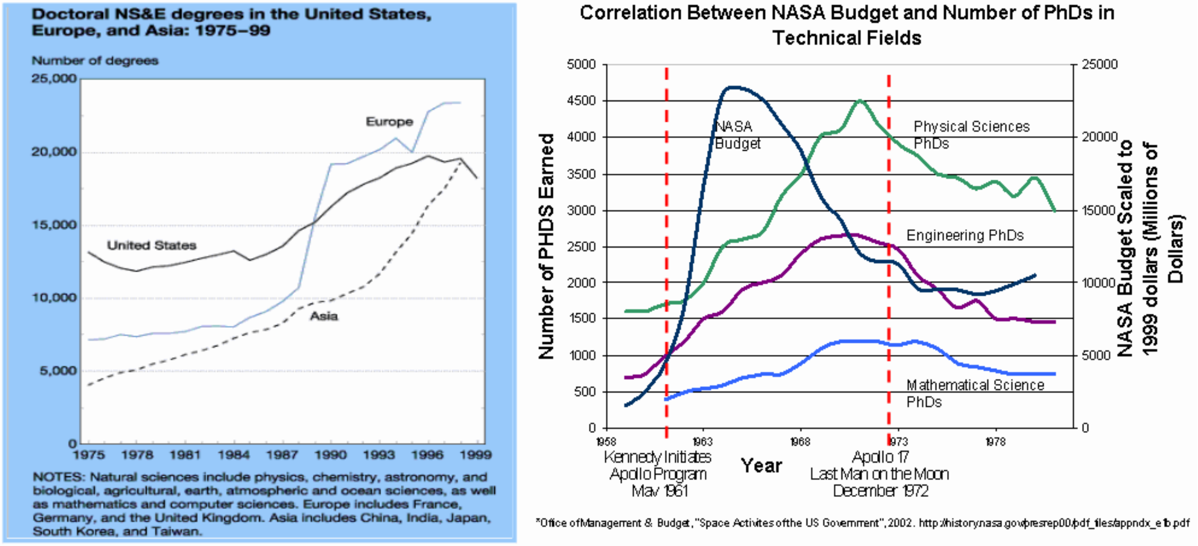
2. 0 Social and Economic Benefits of a Human Mars Mission

Mars is a unique and compelling scientific destination because of its similarity to Earth, the strong possibility that it harbors microbial life or signs of ancient life, and its relative accessibility via human space flight. However, social, economic, and diplomatic benefits make a human mission to Mars a vital undertaking.

2.1 Addressing the Brain Drain: Inspiration to Young Scientists and Engineers

Educating and inspiring America's youth has long been a priority of the space program. "*To inspire the next generation of human explorers"* (NASA Mission, 2002) is the most compelling reason for the United States to support a human mission to Mars. The United States counts on advanced technology for economic stability and national security, which in turn depends on the ability of American universities to supply the science and engineering workforce. NASA has been a key to fostering this base since its inception, but America is now on the verge of a major shortage of Americans in the natural sciences and engineering.

The Bureau of Labor predicts a 20% employment increase in engineering and a 15% increase in the physical sciences in the next 10 years, but as the Hart-Rudman Commission report states simply "U.S. need for the highest quality human capital in science, mathematics, and engineering is not being met" (NSF, 2002). In physics and advanced mathematics, American seniors score significantly below the international average on tests. While this is usually attributed to problems within the schools themselves, a general disinterest in math and science also contributes to American high school students' poor performance. The trend continues at the undergraduate level. Comparing degrees granted between 1975 and 1999, the United States has a poor percentage increase compared to other nations. This decline is also reflected in the downward trend of the U.S. relative to other nations in science and engineering degrees granted per capita to 24 year olds (NSF, 2002). At the graduate level, the problem continues. Figure 1a highlights the rapid increase in Asia and Europe's granting of doctoral degrees in natural sciences and engineering compared to our own. Additionally, within U.S. universities, 25% of graduate students in the sciences and nearly 40% of the graduate students in engineering, mathematics, and computer science are foreign-born (NSF, 2002). Based on this data, we see the decreasing production of U.S. scientists and engineers is not a global trend, but an American problem.


Doctoral NS&E degrees in the United States, Europe, and Asia: 1975–99

NOTES: Natural sciences include physics, chemistry, astronomy, and biological, agricultural, earth, atmospheric and ocean sciences, as well as mathematics and computer sciences. Europe includes France, Germany, and the United Kingdom. Asia includes China, India, Japan, South Korea, and Taiwan.

Correlation Between NASA Budget and Number of PhDs in Technical Fields

*Office of Management & Budget, "Space Activites of the US Government", 2002. http://history.nasa.gov/presrep00/pdf_files/appndx_e1b.pdf

Figure 1. (l) Europe and Asia show more rapid increases relative to the U.S. in granting of doctoral degrees. (NSF, 2000) (r) An increase in the number of science and engineering PhDs is concurrent with the rise of NASA budget. The nine year lag time in maxima is exactly the education time from high school senior to PhD.

Some argue that money put into the space program could be better spent by putting it directly into the educational system to encourage students into the sciences and engineering. This is an unfortunate misconception. America is already one of the top spenders per student in the world (NSF, 2002). Although more funding could always be useful to the American educational system, it does not promise the sustained effort needed to increase the number of Americans pursuing advanced degrees in science or engineering. The government cannot simply buy more computers, fund more scholarships, and lower teacher-to-student ratios enough to convince an 18 year old freshman to invest at least 8 years in the pursuit of a science and engineering advanced degree. Students need something to inspire their efforts. The idea of space exploration significantly influencing America's youth is not without precedent. During the Apollo era of the 1960's, there was a dramatic increase in the number of students pursuing advanced degrees in science, math, and engineering (Figure 1b). Furthermore, as the Apollo program was dismantled and NASA's funding cut, the number of students going into these fields correlates with the downward trend of NASA's budget. The Apollo era "To the Moon" goal serves as model for how NASA can inspire a generation.

As the technological demands of the American lifestyle steadily increase, inspiration of the next generation of scientists and engineers becomes critical. A human mission to Mars has the unique ability to invigorate America's future scientists and engineers. We are not proposing a program that will replace any of our nation's educational programs but one that operates in tandem, adding an inspirational vision to supplement the efforts of teachers.

2.2 Boosting Economics: Human Exploration, Industry, and Commerce

The health of a nation's economy and its competitiveness internationally is in part a measure of national investment in research and development in science and engineering. Although the United States has maintained a strong, if not leading, market position in high technology since 1980, competitive pressures from a growing number of nations contributed to a decline in America's global market share for aerospace. While U.S. share of the world aerospace market has dropped 15% since the 1980s, the Chinese have increased their world aerospace shipments by nearly 80% (NSF, 2000). The emergence of high technology industries in newly industrialized economies threatens the current U.S. economic predominance in these industries.

NASA has devoted its facilities, labor force, and expertise to generating innovative technologies that overcome the challenges of space and then sharing mission technologies with the nation's industries (NASA, 2001). These countless technologies have successfully contributed to the growth of the U.S. economy, e.g. satellite technology which today is an $85 billion industry that improves our daily lives through a myriad of communication, navigation, and weather forecasting services (Synthesis Group, 1991).

Table 1. Areas of technology development from a human Mars mission (IAA, 1993)

Challenge to Mars Mission	Technology Development	Terrestrial Applications
Harmful effects of microgravity and radiation on human health	Pharmacological and mechanical prevention treatments	Prevention, detection and treatment of illnesses ranging from osteoporosis to cancer.
Limited air, water, and food resources	Closed loop life-support systems	Conservation, recycling waste management
Limited Energy Supply	Alternative energy sources Low energy use technologies	Renewable efficient energy sources; energy conserving consumer products.
Human safety and health is threatened in space.	Automation and Robotics	Remote or automated robotics to reduce human risk in hazardous environments.
Hardware impaired by extreme conditions of space.	Extended life, low maintenance materials, hardware and systems	Stronger, smaller, more reliable products for consumers.

Table 1 lists of areas of technological development that would result from a human Mars mission. A human Mars mission would direct and focus the resources and infrastructure of NASA into the research and development of these high technology industries and produce innovations that would gain U.S. market share, create new markets, use resources more productively, expand business, and create high-wage jobs (e.g. Aaron, 1988; NSF, 2000).

2.3 International Cooperation on a Human Mars Mission

Despite the incredible achievements of the Apollo program, the program did have some shortcomings. Chief among these failures was the near-sightedness of the mission goals. Cold War politics played a critical role in spurring on the Apollo program. The United States wanted to beat the Soviets to the moon—that was the primary (some say only) goal of the entire program. An international human mission to Mars has the potential to be a more sustained exploration effort because it will not be subject to the whims of a single nation. Other nations have expressed their desire for a human mission to Mars, including Russia (BBC, 2002), China (McElroy, 2002), and the European Space Agency in their Aurora program. While there are some inherent difficulties to international efforts—variable and uncertain funding, communication problems, and technical interfacing difficulties—these problems can and will be outweighed by the tremendous worldwide benefits associated with an international endeavor to Mars. We can benefit from the technical experience of other nations, e.g. the Canadians in large-scale robotics and the Russians in extended duration human space flight and heavy-lift rocketry. A United States commitment to leading a human Mars mission would also have substantial positive repercussions in international relations.

3.0 Reasonable Costs & Enabling Technologies

Some of the most commonly cited reasons not to go to Mars include expense and difficulty. Below, we directly address such concerns and show that a human mission to Mars is indeed possible and affordable.

3.1 Getting there: Propulsion Systems

Orbital and landing craft have been developed for lunar missions, however, the creation of an interplanetary propulsion system is a new undertaking. Propulsion is central to the success of any planned Mars mission, and minimizing transit time is key to limiting astronaut exposure to radiation and microgravity. More fuel is required to increase the speed of the rocket, but additional fuel also increases spacecraft mass and thus launch cost. Liquid, solid, and nuclear propulsion technologies are all sufficiently well-understood that they could be employed for a propulsion system. An optimum tradeoff between cost and transit-time (one-way trip times range from a month to a year) must be selected (RAND, 1991a). Techniques such as aerobraking and a split mission architecture, where cargo is sent first and astronauts are sent later on a faster spacecraft, can be utilized to reduce fuel costs and speed transit. The use of Mars carbon dioxide to produce return fuel has also been pilot-tested (Zubrin, 1997).

3.2 The Relative Cost of a Human Mission to Mars

One common argument against a human mission to Mars is the expense. We won’t attempt to put a price tag on a mission in this document since such a figure requires a detailed mission architecture, but it is instructive to place a range of cost estimates in context. In general, costs for a human Mars mission range from a low of \$20 billion to a high of \$450 billion (the latter estimate which includes use of the moon as a launch point) (Zubrin, 1997). Here we examine the relative costs of each by assuming an order of magnitude price range, between \$30 billion and \$300 billion.

The lower number represents twice NASA's annual budget of about $15 billion (NASA, 2002b). If we spread human Mars mission costs over ten years, this would account for only 20% of NASA's annual budget per year, spending $3 billion per year. The current budget for the Mars Exploration Program is 15% of this value, at about $450 million per year (NASA, 2002b). Placing mission cost in a different context, the low-end cost number is approximately equal to the cost of every inhabitant of the United States buying one 16 oz. bottled water per month for 10 years. The annual cost of the high-end number is approximately the same amount that the tobacco industry spends on advertising each year, around $8.2 billion (FTC, 1999). A commonly expressed fear is that money for a Mars mission would take away money from the human services sector. The budget for the Department of Health and Human Services (HHS) tallies almost $490 billion annually, with a FY2003 increase of 6.3%. The HHS increase alone, $30 billion FY2003, is equivalent to the low-end cost estimate of a human Mars mission. A human to mission to Mars then is not barred by cost considerations. Indeed, cost is relatively small compared to the benefits.

3.3 Overcoming Hazards

Some argue that a human mission to Mars is not within our technological capabilities. Before a human crew is sent on a voyage to Mars, NASA must ensure that it can adequately protect astronauts from health hazards they face on the journey. The primary hazards are radiation exposure, prolonged microgravity conditions, and planetary cross-contamination by microorganisms. Below, we discuss these oft-cited hazards and address the technologies needed to overcome them. We further explore how investigations into the effects of space travel on the human body may lead to new technological advances here on Earth.

Radiation Exposure**-**Once astronauts leave Earth orbit, protective measures are necessary to block ubiquitous galactic cosmic rays and high intensity bursts of radiation resulting from solar proton events (RAND, 1991b). The Martian Radiation Environment Experiment (MARIE) on the Mars Odyssey spacecraft has measured radiation levels both in transit between Earth and Mars and within lower Mars orbit. Radiation above Mars is about 2.5 times that in the International Space Station, though levels received by a crew member over the duration of a Mars mission would not exceed NASA career dose limits (Zeitlin, 2003).

Several shielding technologies exist to address radiation challenges. Passive shielding employs no energy but uses an enormous shielding mass of hydrogen or water, which increases mission costs by increasing payload size. Active shielding methods, which work in much the same way as the Earth's electromagnetic field by deflecting interstellar charged particles, are promising alternatives but have a failure risk and require energy (RAND, 1991b). A hybrid system optimizes both the level of protection afforded the crew and the size of the payload mass. Shielding technology is near maturity given what we know about the radiation environment; however, we agree with the recommendations of others (NRC, 2002; Greeley, 2001) that further radiation level measurement on Mars' surface is needed.

Microgravity**—**In the course of a human mission to Mars, the crew will experience the zero-gravity environment of interplanetary space, the microgravity environment of Mars (0.38g), and, after much time in lower-gravity environments, return to normal Earth gravity. Research on microgravity effects has been conducted using space-based data as well as ground-based simulations like water immersion. Pharmaceuticals, exercise, conditioning, and artificial gravity are promising strategies that mitigate the effects of microgravity on humans in space. Exercise and conditioning are considered effective means of countering the physiological effects of microgravity although the amount of time devoted to an exercise program must be weighed against time taken away from required daily tasks and functions.

Another possible countermeasure is the production of artificial gravity by techniques ranging from suits worn by astronauts which provide magnetic or pressure loading to spacecraft centrifuges (Zubrin, 1997, RAND, 1991b). A rotational spacecraft shows the most promise. Pharmaceutical research is also on-going. For example, hibernating bears produce a regulatory substance similar to a human bone growth factor that promotes the formation of bone despite the absence of mechanical skeletal loading (RAND, 1991b). If we can isolate and replicate this substance it may be useful both in treating bone demineralization in space and helping to treat or prevent osteoporosis here on Earth.

***Avoiding Cross-Contamination*—**Robotic missions to Mars already have strict Planetary Protection protocols. Protection strategies developed for a human Mars mission will be even more stringent and have important applications outside of the space program. Clean room and sterilization research will allow us to understand and cope with the continuing mutation and evolution of pathogens in our hospitals. Technologies developed will aid in our attempts to prevent the movement of pathogens such as malaria and West Nile virus into higher latitudes and combat biological terrorism. These are clearly important investments for the United States to make in the next decade.

4.0 Conclusions

A human mission to Mars is technologically feasible, cost-effective, and safe for our astronauts. The scientific findings that would result are significant. However, far more compelling is the mission's benefit to our future as a nation by generating innovative technologies, improving international relations, and inspiring the scientists and engineers of the next generation. We urge that NASA begin planning for a human landing on Mars within the next thirty years.

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