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Footsteps to Mars:
An incremental approach to Mars exploration *

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Abstract

Strategies for the manned exploration of Mars must be re-evaluated with a view to political and financial feasibility. A program of incremental progress with significant and highly visible intermediate goals is required. Manned fly-by missions and missions to Deimos and Phobos are proposed as significant steps on the way.

Introduction: political feasibility

The Space Exploration Initiative (SEI) to explore the moon and Mars, as proposed by [then] U.S. President Bush, is politically dead. It was viewed as an expensive Republican program with no place in the current era of deficit reduction. The Space Exploration Initiative, or any program remotely like SEI, is not likely to be revived by a Democratic administration no matter how cleverly Mars advocates phrase their arguments. To succeed, a program must utilize an approach that distances it completely from any hint of heritage from the Space Exploration Initiative. The political question is: how can we advocate Mars exploration *without* appearing to be attempting to revive SEI?

A program for exploration of Mars will fail unless it can pass three critical feasibility criteria:

1. technical feasibility
2. political feasibility
3. financial feasibility

Most discussions of Mars exploration have focused only on the first of the three necessary criteria. Political and economic feasibility, although equally important, are usually ignored.

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In terms of political and economic reality, a Mars exploration plan must learn from the lessons of the Apollo program and of the shuttle program.

The lesson of Apollo: **If you accomplish your goal, your budget will get cut.**

This lesson is shown in figure 1 [1]. This is the single most important, and the most ignored, lesson of the politics of space flight. It is necessary to emphasize not only that the budget was cut, but that it was cut vigorously and completely. Vehicles for three further Apollo missions were completed and ready to fly, but not launched due to a lack of the (relatively small) amount of money to fly the mission.

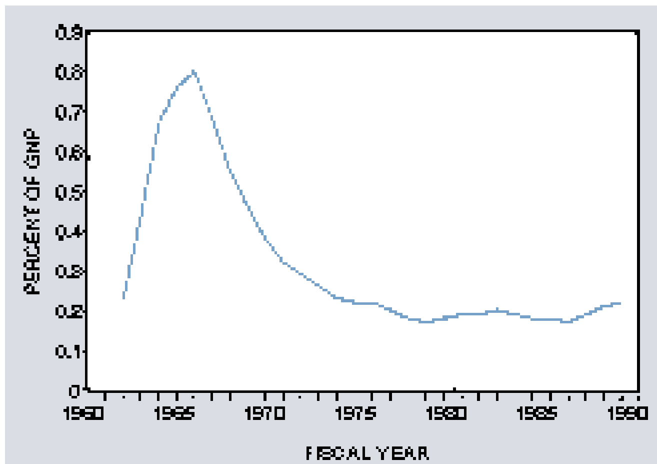

Figure 1: NASA budget trend (percent of US GNP). After the success of the Apollo program, the NASA budget was decreased by a factor of three. (Source: Congressional Budget Office, reprinted in Augustine *et al.* [1]).

This echoes the concerns of S.K. Ride [2], B. Cordell [3], and B. O'Leary [4] in reports on future Mars missions. Ride suggested that schedule pressures on a rapid Mars mission could, like the pressure on Apollo, "turn an initiative that envisions the eventual development of a habitable outpost into another one-shot spectacular," and warns that "this could mortgage the viable space program we hope to have in the 1990s for a 'spectacular' which may have few lasting benefits. Likewise, O'Leary characterizes the Apollo program as "funnel planning; with an inadvertent cutoff after its goal is achieved."

Up to Apollo 11, the Apollo missions were raptly followed by the public. Following the success of Apollo 11, interest in further missions dwindled rapidly, despite the fact that the terrain explored was more interesting, the missions more challenging, and the mission lengths increasing. It is clear that a mere progression from a flag-and-footprints mission to missions of more complexity was insufficient to prevent public interest from vanishing and political budgets from cuts once the initial landing is made.

For effective political advocacy, space programs require specific goals. But if a Mars landing results in a complete shut-down of manned space exploration, is it worth it? No. As Mars advocates, our goal is not simply to leave a flag waving on a forgotten planet. We need to plan for the long-term. Succinctly, we need to avoid designing a mission that is sold as, or can be converted into, a "3F" ("flag, footprints, and forget it") mission.

The lesson of Shuttle: **Infrastructure is boring.**

If you do the same thing over and over, the public will focus on your failures and forget your successes.

Between these two lessons lies an apparent paradox. Having a goal results in termination of the program (the lesson of Apollo). Not having a goal results in loss of focus (the lesson of Shuttle). A middle course must be found, where a series of well-defined intermediate goals can be accomplished, resulting in the incremental development of the technology required for full-scale Mars exploration.

In the post cold-war world, it is unlikely that a Mars exploration can be sold as a single, large dollar-value long-term program. The alternative is to sell the program as a series of small, affordable steps each of which has independent value. The lesson of Apollo is that we should have the manned landing on the Martian surface as the culmination, not the first, of these steps.

This echoes the advice of Sally Ride, who recommends to “adopt a strategy of natural progression which leads, step by step, in an orderly, unhurried way, inexorably toward Mars” [2].

But goal oriented projects succeed; infrastructure-oriented projects don’t. Therefore, *each individual step must have a goal which can be defended not merely as a step toward Mars, but as a significant achievement in its own right.*

The moons of Mars are one way to give a goal to the incremental path. Exploration of Deimos and Phobos on the way to Mars is good science, not an arbitrary goal: the moons of Mars are worth exploring in and of themselves, not just as a side trip on the trip to Mars [5]. Quoting from Cordell [3,6]: “The Phobos/Deimos-then-Mars strategy appears to have strategic, science, resource and colonization advantages over a “Mars-first” strategy."

Footsteps to Mars: Rationale

This incremental approach is an attempt to adapt the “faster, smaller, cheaper” approach to space exploration to the “large, slow, expensive” scenario of manned Mars exploration. The large mission is broken into a number of small missions, with a philosophy that we should not attempt to load everything desired onto each mission.

This approach in line with the conclusion of the Advisory Committee on the Future of the U.S. Space Program, who recommended an incremental path to Mars as funding becomes available. (Recommendation 5 of the Augustine report: “that the Mission from Planet Earth be configured to an open-ended schedule tailored to match the availability of funds.” [1]) Yet a completely open-ended approach is the classic recipe for failure.

Quoting from the report of the National Commission on Space [7]: “Each element and increment of the program must be set in the context of a long-term plan. Fragmented efforts and uncertainties as to future goals will only dilute accomplishments and increase costs.” For a program to succeed, they require that: “the program will be technically challenging, but feasible,” but note that it must also be true that “the program will be adequately funded. We do not assume a sudden surge of resources in the years ahead.”

The proposed Mars exploration plan conforms to these guidelines, setting clear goals, and yet pursuing a program of incremental progress that does not assume a sudden surge of funding.

The plan uses the Apollo methodology. First, fly *by* Mars, on a free-return trajectory (Apollo 8). Second, *orbit* Mars without landing (Apollo 10). Then, only after the Earth to Mars orbit technology is demonstrated, go to the surface of Mars.

Flying missions to the Martian moons separates the development of the trans-Mars injection technology from the development of the lander/Mars ascent vehicle. The Mars landing and ascent vehicle is a critical design item. Among other things, it requires a fuel that can be stored on the surface, both during day and night conditions, as well as in space. By doing Phobos and Deimos missions first, we break a critical financial barrier. Cordell [6] estimates that a mission to the Martian moons has half the propellant and hardware weight compared to a missions to the surface, half the mission cost, and significantly lower risk due to the fact that no surface manned lander is required. More importantly, it has less than half the engineering and development cost (and time). Putting off development of landing and ascent stages means that most of the elements required are similar to modules already developed or in development, Freedom and Mir modules.

An additional advantage of exploring the moons of Mars is to prospect for the resources necessary to sustain the exploration and exploitation of space.

Finally, an important goal of a mission to Mars is to search for life, both fossil and present day. Even in the best of circumstances, the evidence for life may be subtle. It may be impossible to find evidence of Mars life if we must first identify and discard Earth-generated organic contamination from life support effluvia. Planetary protection has to be done *from the start*--if we ignore it on the first missions, it will be too late.

Planetary protection cannot be underemphasized. If *stringent* planetary protection procedures aren’t followed, the program will get shot down by environmentalists (not to mention irate exobiologists). It is important to show that there isn’t already life on Mars before we propose landing there with living organisms.

Therefore: *telerobotics from orbit* is an excellent way to start our manned Mars exploration [8].

Footsteps to Mars

The footsteps to Mars proposes a series of intermediate goals, each achievable with only incremental technology advance from the previous one, each one of interest in and of itself, culminating in landings on Mars. If the goals are spaced by roughly the synodic period of Mars--that is, a flight to Mars at every opportunity (except step 4)--the seven footsteps require about 14 years, from first launch to final step.

In addition to the manned (more precisely, “humanned”) missions discussed, the missions are to be preceded and paralleled by unmanned missions, necessary to gain a greater understanding of the surface and environment of Mars.

First Footstep: Manned Mars Flyby

The proposed first step to Mars is to fly by the planet with a manned vehicle that does not brake into Mars orbit, but continues past for a free-return to Earth. This is the analog of the

Apollo 8 mission, which demonstrated Apollo systems with a free-return trajectory past the moon.

This mission demonstrates the transfer ship, the capability of long duration voyages, and the return to Earth. Most importantly, it uses space-station era technology. The first step in this program is one we can do it immediately, with existing boosters, and with technology developed for Mir and Space Station.

It does not require a Mars Orbit injection or Trans- Earth Injection. This reduces the required mission delta-V to levels which are easily achieved with stages available today. Various free-return trajectories are possible; the typical mission duration is on the order of 18 months. An 18 month stay in space is only slightly longer than durations achieved by Mir cosmonauts, and hence it should be able to be accomplished without artificial gravity.

Even for a mission such as Mars Direct [9], which in other respects is quite different from the mission sequence discussed here, it would be a prudent course to start with a fly-by mission such as is discussed here. This would allow the feasibility of the crucial Mars transfer portion of the mission to be demonstrated without waiting for completion of the lander and return technology is developed.

Operation of a Mars rover by remote control ("telerobotics") directly from Earth is difficult due to the long time delay. However, astronauts on a flyby mission could for several days control a rover landed separately with little time-lag. A flyby telerobotic rover maintains planetary quarantine while searching for life

Finally, the mission will produce spectacular visuals of Mars during the closest approach, perhaps producing results comparable to the famous "Earthrise" photo taken during Apollo 8.

Second Footstep: Mars Orbit and Deimos Landing

Phobos and Deimos are the celestial bodies with, other than perhaps a few near-Earth asteroids, the easiest routine accessibility from Earth of any bodies in the solar system. Deimos is the smallest and outermost moon of Mars, and hence the near-Mars target that is most accessible in terms of required delta-V. A Deimos landing would be the first manned landing on celestial body outside Earth's orbit. This is a highly visible goal that would be eclipsed if a Mars landing were accomplished on the first mission.

As well as the allure of a first landing, this mission allows the possibility of spectacular images of Mars from orbit, a significant goal for effective public (and hence political) advocacy.

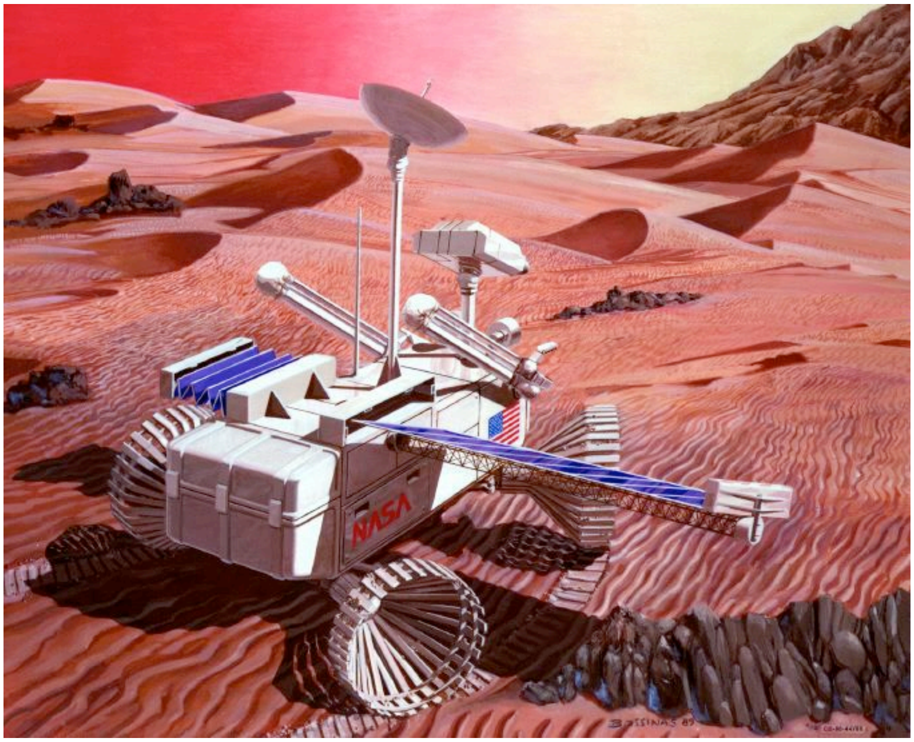

Figure 2: A telerobotic rover, such as the one shown in this artist's conception, could be operated remotely from a manned station on Deimos or Phobos

This second mission continues the incremental development of technology by demonstrating Mars orbit insertion [either by aerocapture or by chemical braking], orbital operations, and trans-Earth injection, but can be done while the Mars lander and ascent vehicle is still in development. As discussed by Singer, the mission to Deimos is "easier, far less costly, safer, and can be done much sooner" [5] than a manned landing on the surface.

Deimos is in near-synchronous orbit, with the entire Mars surface (except for extreme polar latitudes) coming in view over a period of about 125 days. Telerobotic operation of a rover on Mars, as shown in Figure 2, is feasible with minimum time delay ($\leq$0.2 sec.). This strategy for surface exploration maintains planetary quarantine.

Phobos and Deimos are bodies of considerable scientific interest. At present, it is not known how the bodies were formed or captured by Mars [10]. They may be examples of the primordial material of the solar system. They are ignored, or treated as an unimportant sideshow, in most manned Mars plans. They are easier to get to than the surface of the moon in terms of energy, and there is an opportunity every two years.

Why not a near Earth asteroid? Many reasons. First, most asteroids are not as easy to get to as the moons of Mars. A few Near-Earth Asteroids (NEA) with low inclination have been identified; however, most of these do not have low-energy opportunities at frequent regular intervals. The advantage of the moons of Mars is they are available every two years. Most important, however, the moons of Mars are *near* Mars. They are both a path to Mars, and a point from which to study Mars. Exploration of an asteroid, however interesting scientifically, is not a step that leads directly to the desired goal of Mars exploration. With this said, it must be noted that there are good arguments [11] for exploring one or more asteroids, if for no other reason than to provide a context for understanding the results from Deimos and Phobos. But while it is of interest to study the near-Earth asteroids, and such a program is highly recommended on its own merits, it should be considered a separate program rather than a step on the way to Mars.

Finally, the moons of Mars may also be useful resources for in-space propellant production [3,4,12-14]. “Water is rocket-fuel ore,” in the words of Tony Zuppero. Since Deimos and Phobos are spectroscopically similar to carbonaceous chondrites, many of which contain chemically bound water, it is possible that the moons of Mars may also have some amount of chemically bound water, although the best recent data suggests that the surface, at least, is anhydrous [15,16]. Alternatively, ice may be buried under the surface, particularly at the poles. While the Phobos-2 probe indicated that the surface of Phobos is anhydrous, geological models indicate that the surface will be anhydrous if buried ice has never been heated to the melting point [3,15]. The low density of Phobos is also a possible indication of an ice core. The current best current model indicates is that “the most likely composition for Phobos and Deimos is a CM3 carbonaceous-chondrite-like assemblage of anhydrous silicates, carbon, organic compounds, and ice” [16]. There is also indirect evidence from the Phobos-2 probe that Phobos and Deimos are outgassing water [15,16].

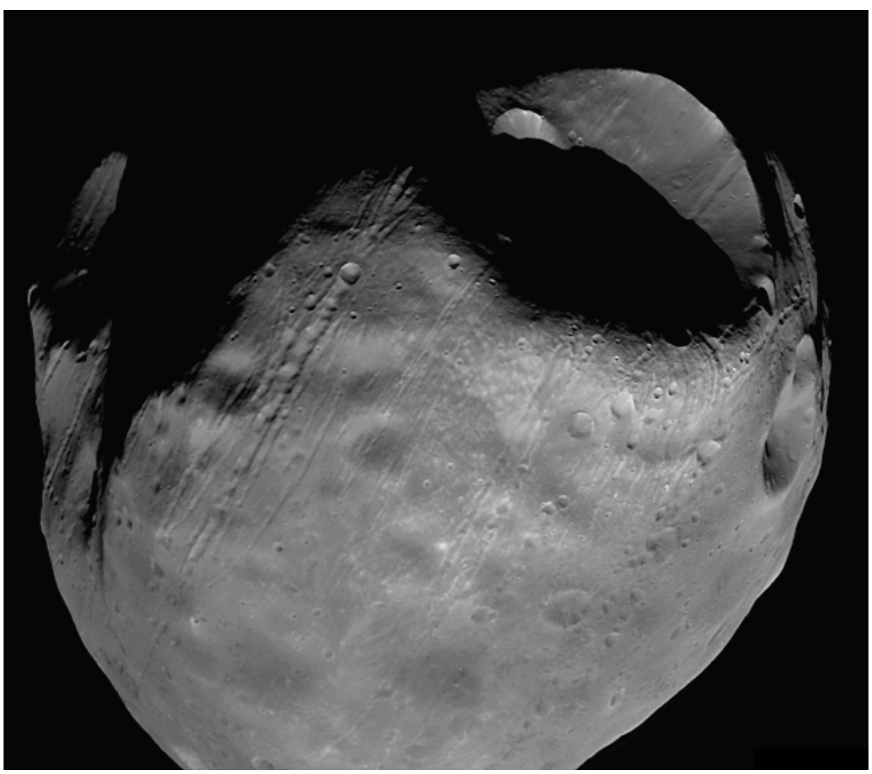

Figure 3: Phobos, the inner moon of Mars, as viewed by the Viking orbiter.

Third Footstep: Mars Orbit and Phobos Landing

The next step after Deimos, the outermost moon of Mars, is clearly Phobos, the inner moon (Figure 3). This will be the second landing on celestial body outside Earth's orbit. From Phobos, the view of Mars will be spectacular.

Again, this will demonstrates Mars orbital operations, and can be done while the lander and ascent vehicle is still in development. Telerobotic operation on Mars is still possible without breaking the planetary quarantine. The fact that Phobos is in low orbit makes this mission an ideal one to rendezvous with a sample-return vehicle launched from Mars surface to bring samples of Mars rocks and soils back to Earth for analysis. (One possibility is to use this as an opportunity to do an unmanned test of the lander and ascent vehicle, which would be sent to Mars separately.)

Exploration of Phobos is of scientific interest, and comparison of the geologic results from exploration of Phobos with those of Deimos will tell us much about the history of both bodies. Geological exploration of Phobos will also give us another chance to search for water, the most valuable resource available in near-Earth space.

Fourth Footstep: Earth Orbit Operations and Moon Landing

This footstep follows Apollo methodology. The lander is tested first in Earth orbit, and then by a lunar landing. A lunar landing is very similar to the final stage of a Mars landing, but only three days travel time away from Earth, allowing an abort option in case of difficulties.

Exploration of the moon, however valuable in and of itself, is *not* a goal of this proposed Mars program. This is for political reasons: return to the moon is too closely associated with the Bush Space Exploration Initiative proposal ("return to the moon, this time to stay") and hence political anathema. However, as a step to Mars, the moon is a milepost of value not merely for the scientific questions which could be answered by a well-planned return to the moon, but for public-relations value. After 30 years, the first moon landing occurred before the birth of half the population. Hence, even as a side step toward the main goal of testing a Mars lander, the moon return will be a prominent and a significant milepost. Further, if political considerations allow the moon to *become* a goal later in the program, this lunar landing is a necessary step.

Fifth Footstep: Mars Polar Landing

Mars at last!

The poles of Mars are not often considered as sites for early Mars landings, but have several advantages. The ice caps of Mars are certain to have water available, and in a compact, relatively pure form. Making the first Mars landing at the pole allows us, if desired, to first land an unmanned return vehicle which can process water into fuel before landing the manned vehicle. If the landing is during the local summer, the polar regions have continuous sunlight, allowing a solar power system to be used for surface power with no requirement for storage except for emergency power.

Sixth Footstep: Mars Temperate Landing

A manned landing in the non ice-covered regions of Mars is the ultimate goal of any Mars exploration program. We all know the reasons for this one. The surface of Mars is of interest to geologists, solar-system scientists, exobiologists, meteorologists, and to the general public. A Mars exploration program must eventually culminate in a manned landing on Mars.

Seventh Footstep: Valles Marineris Landing

In the pessimistic political scenario discussed above, the accomplishment of a goal will result in a budget cut and cancellation of the program within one to two years. It is, obviously, desirable to postpone (or eliminate) this occurrence. There is some possibility that if a third mission is exciting enough, and cheap enough, it will be possible to delay cancellation of the program until after the landing. Thus, the third mission had best be exciting indeed. Hence, it is proposed that landing three be aimed at Valles Marineris, the “Grand Canyon” of Mars, or one of the associated network of canyons such as Noctis Labyrinthus. In addition to the spectacle value, Valles Marineris is of considerable scientific interest, both for itself and for the possibility that cross-sectional views of the Martian surface may be exposed.

End of Manned Space Exploration?

We all would like to believe that the exploration of Mars will be the beginning, and not the end, of human expansion into the solar system. There is, however, precious little evidence to support such optimism, and we must be prepared for a repeat of the Apollo experience. The Apollo program was canceled 2 1/2 years after the first moon landing; we can expect the Mars program to be canceled in a similar time scale. [My students at ISU one year called this the "Apollo hangover" syndrome]. The program proposed here has been designed to produce a regularly-spaced string of “treats” to maintain public interest during the length of the program; but there are no remaining goals exciting enough to be politically feasible to sustain a mega-scale space project. In the process of the Mars program, however, we have incidentally prospected Deimos, Phobos, and the surface and poles of Mars. If we have found resources which can be easily utilized, it may lower exploration costs enough to continue exploration on a shuttle-scale budget.

This brings up the question: why not highlight the search for and use of in-situ propellant production from the start [4,12]? The only answer is that this is still too speculative an approach to be easily defended against hostile attacks in the U.S. Congress. Before championing the use of water extracted from the regolith of Deimos, it is prudent for us to both verify that such water is there, and demonstrate that it can be extracted efficiently and in quantity. But, if resources are *indeed* found early in the program, it is possible that we can develop scenarios to use them late in the program.

Timing

Now is an excellent opportunity to initiate a major new program. Defense spending--and aerospace in particular--is the subject of a cold-war build-down, and being cut at every opportunity. Yet the aerospace technology of the United States and the western industrialized nations is a priceless asset. The western world has spent, quite literally, trillions of dollars building up a capability in aerospace unmatched in the world, to meet a threat which no longer exists. But the geopolitical situation could change, and we may again need the capabilities that we have spent so much to acquire. The expertise, training, and capabilities should not be allowed to dissipate. If the Soviets no longer provide a focus for the free world to hone our technology, perhaps Mars could.

The current political climate also allows the unique opportunity to cooperate with the Russians. The Russians have long been interested in the Red Planet, and a cooperative mission could provide a valuable political selling point. In addition, Russian experience (year-plus space missions), space hardware (Soyuz, Mir), and boosters (Energia) could contribute significantly to the program outlined here.

It seems that, despite indications, there is no better time to act.

A Plea for Unity

Recently there has been an alarming tendency in the scientific and space advocacy communities for advocates to attack one project, in the belief that if that project could be canceled, the money saved would be used for their own, more desirable projects. This is false. Quoting from senate staffer Steve Palmer [17]:

“What space station and ASRM [advanced solid rocket motor] add up to is a drop in the bucket. If Congress cuts out both space station and ASRM, will the money be used for other programs of interest to the space industry? The short answer is no”.

Arguments to cancel space projects are eagerly picked up in Congress, by people who have agendas and pet projects that have nothing to do with space. Further, attacking space projects has the result of making enemies out of allies. When we attack someone else’s project, we can count on having them attack ours. The result is that the arguments against *both* projects will be remembered by a money-starved Congress.

It is not true that manned missions eclipse funds for unmanned science missions. In fact, there is an excellent case to be made for precisely the opposite correlation: the presence of large manned missions increases the funding and opportunities for unmanned science missions. Historically, the science budget of NASA has been a roughly constant fraction of the total budget; any major new initiative which increases the overall space budget is likely to increase the funding for science.

If Mars advocates adopt the approach of pushing our initiatives by tearing down other space programs, the likely result is that nothing, neither Mars nor other programs, will be accomplished.

Conclusions

Many authors have suggested missions to the Phobos and Deimos, the moons of Mars, as an important first step in manned Mars exploration [3-6,12-14]. This paper suggests that such an approach makes sense in terms of political and financial feasibility, as well as intrinsic scientific merit. It allows missions to be flown while the Mars orbit insertion, trans-Earth injection, Mars landing, and Mars ascent technologies are still under development, thus giving significant and visible results while the funding is still in progress, rather than waiting for all the program elements to be developed before making the first flight.

By *avoiding* advocacy of a mission directly to Mars, the proposed plan might avoid the taint of the Space Exploration Initiative, and thus may be salable even to a Democratic-party controlled U.S. Congress, which has vigorously zeroed any spending even remotely related to the SEI program associated with former-President Bush.

References

[1] N. Augustine *et al., Report of the Advisory Committee on the Future of the U.S. Space Program,* U.S. Government Printing Office, December 1990. *http://www.hq.nasa.gov/office/pao/History/augustine/racfup1.htm*

[2] S.K. Ride, *Leadership and America's Future in Space: A Report to the Administrator,* NASA TM-89638, August 1987.

[3] B.M. Cordell, "Manned Mars Mission Overview," paper AIAA-89-2766, AIAA/ASME/SAE/ASEE 25th Joint Propulsion Conference, Monterey, CA July 10-12, 1989.

[4] B. O'Leary, *Mars 1999,* Stackpole Books, PA, 1987, pp. 17-18.

[5] S.F. Singer, "The PhD Proposal: A Manned Mission to Phobos and Deimos," paper AAS 81-231, *The Case for Mars,* Science and Technologies Series Volume 57, American Astronautical Society, 1984, pp. 39-65.

[6] B.M. Cordell, "The Phobos/Deimos Mission Workshop: A Summary," paper AAS 87-277, *Case for Mars III,* Science and Technologies Series, American Astronautical Society, pp. 600-604.

[7] National Commission on Space, *Pioneering the Space Frontier,* Bantam Books, May 1986.

[8] A.J. Willoughby, "Multinational Exploration of Mars: An Affordable Concept", Paper IAF-88-390, 39th Congress of the IAF, October 1988.

[9] D.A. Baker and R.M. Zubrin, "Mars Direct," *J. Brit ,Interplanetary Soc., Vol. 42*, No. 4, pp. 147-160 (1989).

[10] J. A. Burns, "Contradictory Clues as to the Origin of the Martian Moons," *Mars,* University of Arizona Press, Tucson, 1992, pp. 1283-1301.

[10] D.R. Davis, A.L. Friedlander, and T.D. Jones, "Role of Near Earth Asteroids in the Space Exploration Initiative,"*Resources of Near Earth Space,* U. Arizona Press 1993, pp. 619-655.

[11] B. O'Leary, "Phobos and Deimos (PhD): Concept for an Early Human Mission for Resources and Science," *Space Manufacturing 5,* AIAA, 1985, pp. 41-48.

[12] B. O'Leary, "Rationales for Early Human Missions to Phobos and Deimos," *Lunar Bases and Space Activities of the 21st Century,* Lunar and Planetary Institute, Houston, 1985, pp. 801-808.

[13] B.M. Cordell, “The Moons of Mars: A Source of Water for Lunar Bases and LEO,” *Lunar Bases and Space Activities of the 21st Century,* Lunar and Planetary Institute, Houston, 1985, pp. 809-816.

[14] P. Thomas *et al.,* “Satellites of Mars: Geologic History,” *Mars,* University of Arizona Press, Tucson, 1992, pp. 1257-1282.

[15] J.F. Bell, F. Fanale, and D.P. Cruikshank, “Chemical and Physical Properties of the Martian Satellites,” *Resources of Near Earth Space,* U. Arizona Press 1993, 887-901.

[16] S. Palmer, remarks at *Case for Mars V,* Boulder CO, May 1993.