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Before the Subcommittee on Space
United States House of Representatives

May 21, 2013

Mr. Chairman and Members of the Committee, thank you for the opportunity to appear today. My name is Steven W. Squyres, and my title is Goldwin Smith Professor of Astronomy at Cornell University. I have participated for the past thirty years in a number of NASA solar system exploration missions. Recently I chaired the planetary decadal survey for the National Research Council, and I am currently the Chairman of the NASA Advisory Council. The views that I express today are my own, and do not represent the opinions of the National Research Council, the NASA Advisory Council, or any other organization.

Recommendations to the Committee

The topic of this hearing is the next steps in human exploration, to Mars and beyond. My key recommendations to this committee today are as follows:

- Affirm that Mars is and will continue to be NASA's long-term goal for human exploration of space.

- At all future milestones on the road to Mars, direct the Agency to focus narrowly on activities that clearly serve the goal of landing humans on Mars, operating there, and returning them safely to Earth.

- Adopt cis-lunar space as the next milestone, whether ongoing studies show that it is possible to redirect a small asteroid there or not.

- Dictate no milestones beyond cis-lunar space without first assuring ample funding to achieve them.

I will explain my rationale for each of these recommendations in the sections below.

Why Mars?

The NASA Authorization Act of 2010 stated that "A long term objective for human exploration of space should be the eventual international exploration of Mars." I agree. In

fact, **I believe that Mars should be *the* long-term objective for human exploration of space, whether carried out internationally or by NASA alone.**

Mercury, Venus, and the giant planets and their moons present environmental obstacles to human exploration that will be insurmountable for decades to come. But what makes Mars unique is not just its relative accessibility. Alone among the planets, Mars is enough like Earth that we can imagine life once taking hold there. A vast and growing body of scientific knowledge shows that the martian surface once possessed many of the essential ingredients required for life. If by exploring Mars we could show that life emerged there -- and therefore that it emerged twice in just this one solar system – it would take no great leap of faith, logic, or anything else to conclude that life may be commonplace throughout the cosmos.

One could ask whether it is necessary to send humans to Mars to answer this question. Despite having devoted my career to exploring the solar system with robots, I am a strong advocate of human exploration, particularly at Mars. Humans have an extraordinary ability to function in complex environments, to improvise, and to respond quickly to new discoveries. Robots, in contrast, do best when the environment is simple and well understood, and the scientific tasks are well defined in advance. Because the capabilities of humans most surpass those of robots in complex environments, the exploration value that humans add is in proportion to the complexity of the environment to be explored. And there is no planetary environment where humans can operate in the foreseeable future that is more complex than the martian surface.

We also must not underestimate the inspirational value of human explorers on Mars. I can tell you from personal experience that NASA's long-lived Spirit and Opportunity Mars rovers were designed and built by people like me who grew up watching the Apollo lunar landings on television, and dreaming of sending spaceships to Mars one day. Sending humans to Mars would surely provide an even more compelling inspirational spark for the next generation of scientists, engineers, and explorers.

To put it simply, **sending human explorers to Mars to learn whether life ever emerged there is a goal worthy of a great national space agency.**

Why Intermediate Milestones?

It is not hyperbole to say that sending humans to Mars and returning them safely to Earth will be the most technically difficult task in human history. When attempting something so difficult, there is great value in setting intermediate milestones against which progress can be measured and demonstrated.

The most useful milestones are ones that, once met, help retire some of the many risks that will be faced on the way to the martian surface and back. In the 1960s, we didn't go to the Moon all at once. Instead, the capabilities necessary to land humans on the lunar surface and return them safely to Earth were developed systematically over a

series of Mercury, Gemini, and early Apollo missions. I am convinced that the even more challenging capabilities that will be necessary to achieve a similar goal at Mars must also be built up stepwise.

A more difficult question is whether any of these intermediate milestones must involve a physical destination – a solid solar system body that astronauts can visit and where they can work. Physical destinations have intrinsic appeal; indeed, they are integral to our notion of what exploration means. But if our real goal is the surface of Mars, then we must critically examine the idea that milestones along the way must involve specific bodies where we can plant a flag or leave a mark in the soil.

Possible Intermediate Milestones

A number of possible intermediate milestones on the way to Mars have been discussed over the years. These include:

- Cis-lunar space
- The lunar surface
- A near Earth asteroid
- Mars orbit
- The martian moons Phobos and/or Deimos

I will address the prospective merits of each of these in turn.

Cis-lunar space: Many of the capabilities and systems necessary for eventual human missions to Mars can be tested and validated in cis-lunar space. These include deep space life support and habitability systems, advanced propulsion, complex ground and space operations, and rendezvous in a variety of gravitational settings. All of these can be exercised far enough from Earth that progress toward a true deep space capability can be demonstrated, but close enough to Earth to facilitate a safe return in the event of an anomaly.

The lunar surface: Others on this panel will argue persuasively for the merits of a return to the lunar surface, so I will not dwell on it here. Most significantly, the Moon is the only potential destination on the way to Mars with sufficient gravity to permit anything resembling Mars-like surface operations. If we truly require an intermediate milestone where astronauts can walk, the Moon is the only choice. I am not convinced, however, that such a milestone is absolutely necessary. It was not for Apollo, and we actually know much more about the surface of Mars today than we did about the surface of the Moon before Apollo 11.

Near Earth asteroids: NEAs are important targets for scientific exploration. Asteroids contain clues regarding the formation and earliest evolution of the solar system. Practically, NEAs present both an opportunity and a threat. Mining of asteroids could yield raw materials of considerable value for use in space, because they need not be lifted

from the Earth's gravity well. And we know that asteroids have impacted the Earth in the past with devastating effects, and will do so again in the future unless we develop an understanding of these bodies sufficient allow us to prevent such an event.

The relevance of NEA exploration to the ultimate goal of sending humans to Mars must be questioned, however. Certainly a mission to such a body would require operations for long periods of time in deep space, well beyond the Earth-Moon system. The same can be said, however, for any flight far into deep space, whether an asteroid is present along the trajectory or not. Perhaps more persuasively, proximity operations techniques that could be developed and demonstrated at small asteroids would also be useful for exploration of Mars' two small moons, Phobos and Deimos.

Mars orbit: Just as the ability to operate in lunar orbit was necessary for Apollo, the ability to operate in Mars orbit will be necessary for a mission to and from the martian surface. Like Apollo 10, a mission to Mars orbit could demonstrate all elements of a Mars surface mission other than landing, surface operations, and ascent. Mars orbit is also an ideal location for real-time operations of robotic assets on the martian surface, dramatically increasing their potential science return. So clearly Mars orbit is a valuable potential milestone on the way to the martian surface.

Phobos and Deimos: Operations in Mars orbit would also permit exploration of the martian moons Phobos and Deimos. These objects, which are probably captured asteroids, are scientifically interesting in their own right. More importantly, we can expect their surfaces to be littered with martian rocks, particularly ones ejected from the planet during the early, more Earth-like phase of its history. So they present a scientific opportunity that is complementary to what can be achieved on the planet. Again, however, it is not clear that they represent a truly necessary step on the way to the martian surface.

NASA's New Asteroid Initiative

NASA has recently announced a particular variant of the cis-lunar space milestone that would include rendezvous with a very small asteroid that has been redirected to lunar orbit. Because this initiative is part of the President's FY '13 budget request, it is worth particular consideration by this committee.

To evaluate the merits of this initiative, it is useful to break it down into its constituent parts. It has three elements:

- Searching for a potential target asteroid
- Capturing a small asteroid and redirecting it to lunar orbit
- Rendezvous with the redirected asteroid in cis-lunar space

In my opinion, **the first element, searching for a target asteroid, has great value.** I have already described how NEAs pose potential threats, resources, and opportunities for

scientific study. The search for a target asteroid for this initiative will inevitably lead to discovery and characterization of many objects. In my opinion, the goal should not be to find a single target whose properties potentially allow it to be redirected. Instead, **the net should be cast widely, using assets that are capable of finding such a target to characterize the population of NEAs as fully as possible.**

Moving on to the third element, I will argue below that **cis-lunar space is the logical next place to send humans beyond low Earth orbit.** My conclusion is dictated by practical considerations and by a long-term focus on Mars, and is independent of whether a small asteroid has been redirected there or not.

The second element, asteroid capture and redirection, is where important questions and concerns lie. Despite some encouraging preliminary studies, **we do not know how to capture and redirect an asteroid**, even a very small one. To their credit, in all of the briefings I have seen on this topic, NASA has described existing concepts for redirecting a small asteroid as "notional". The President's FY'13 budget request includes funds to study these concepts, and to assess their feasibility. The results of this assessment must be examined critically, and **NASA should not be afraid to abandon the idea if the results are not favorable**. The first and third elements of the initiative each have sufficient value on their own even if the second element proves infeasible.

Concerns

Sending humans to Mars will be extraordinarily difficult and costly. With such a challenging long-term goal in a budget-constrained environment, I feel that it is crucial that the milestones on the road to Mars be true milestones, not off-ramps. Stating it differently, the activities we engage in on the way to Mars should be ones that enable reaching that goal, not delay reaching it.

Again, Mercury, Gemini, and the early Apollo flights provide a good model. The tasks carried out on those flights were aimed very directly at preparation for the eventual Apollo landing missions. None of their major activities were superfluous. I believe that the goal of sending humans to Mars will be best served by milestones that maintain a similar focus. So at each step along the way it will be crucial to examine proposed flight activities critically, and to pare them down to the minimum necessary to assure progress toward Mars.

As I noted above, any of the potential candidate milestones could make at least some useful contributions to the long-term goal of Mars. Choosing among them becomes a matter of practical implementation and budget considerations.

In my opinion, **the first milestone should be to return humans to cis-lunar space**. Of course, such a milestone has only modest value in and of itself; it would serve largely to re-assert capabilities we had forty years ago. But if we really are going to Mars, I believe it is an essential next step.

My conclusion is based as much on simple practicality as it is on the work that can be accomplished there. The only vehicles currently in development by NASA to support human exploration beyond low Earth orbit are the Space Launch System (SLS) and the Orion crew capsule. Given the performance capabilities of these vehicles, cis-lunar space is the only significant destination beyond low Earth orbit that can be reached. It is the next step in part simply by process of elimination.

If a small asteroid can be redirected to lunar orbit by the time astronauts get there, the rendezvous possibilities it would offer would make a lunar orbital mission more interesting and challenging. The relevance of such a rendezvous to the goal of putting humans on the surface of Mars remains to be demonstrated, in my opinion, and should be scrutinized. But I believe that **lunar orbit is the sensible next step beyond low Earth orbit whether a small asteroid has been redirected there or not.**

After cis-lunar space, the choice becomes more difficult. **I am personally not persuaded that any physical destination like the lunar surface, an asteroid, or a martian moon is truly necessary to get to Mars, function there effectively, and return safely.** Others on this panel may disagree. But while we can debate the relative merits of such destinations, my most important message to this committee is that **I believe that no realistic next step beyond cis-lunar space can or should be identified today.**

The fundamental barrier to making an intelligent choice of a milestone beyond cis-lunar space now is that **NASA is being asked to do too much with too little**. This overtaxing of the agency is chronic, severe, and getting worse. It is manifested clearly even in NASA's near-term plans.

To be more specific, the current cost-constrained development schedule for SLS and Orion calls for:

- In 2014, an orbital test flight of an Orion capsule with no crew, to be launched on a Delta 4 Heavy.

- In 2017, a lunar flyby test flight of an Orion capsule with no crew, to be launched on a 70-metric ton SLS.

- In 2021, eight years from now, the first flight of a crew in an Orion capsule, again launched on a 70-metric ton SLS, on a mission to orbit the Moon.

Subsequent missions would occur on a "pay-as-you-go" basis, with a launch roughly every two years.

I believe that **the low flight rate projected for SLS and Orion is a cause for serious concern**. No human-rated launch system in NASA's history has flown so infrequently. With such a low launch rate it will not just be difficult to maintain program momentum; it will be difficult to keep flight teams sharp and mission-ready.

In a fiscal environment where even the next step to cis-lunar space cannot be carried out at an adequate pace, I feel that it would be unwise for Congress to dictate any subsequent milestones. Unless NASA's funding is increased substantially, any attempt to specify milestones beyond cis-lunar space today would amount to an unfunded mandate. Unfunded mandates are the bane of any government agency. They can be particularly crippling for an agency like NASA that is tasked with attempting things that have never been done before, with the uncertainties regarding schedule and budget that invariably result. If NASA is directed to do something it is not funded to do, I predict that the result will be wasted effort and a delay in achieving the ultimate goal of humans on Mars.

A Possible Long-Term Solution

I would like to conclude my testimony on a positive note, by pointing out that **the solution to the mismatch between NASA's aspirations and its budget may be international partnerships.** This was the case for establishment of a permanent Earth orbiting laboratory, and the International Space Station that resulted is a magnificent example of what space agencies can accomplish when they work together.

If no major funding increase for NASA can be found, then I believe that the Agency should aggressively seek out international partners for the human exploration of Mars. But if that happens, I feel that neither Congress nor the Administration can expect to dictate what the next milestone after cis-lunar space should be unilaterally. Instead, **that milestone will have to be negotiated, fairly and equitably, with those international partners.**