Committee on Science, Space, and Technology
Subcommittee on Space

Next Steps in Human Exploration to Mars and Beyond

Testimony submitted by:

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I thank the Chairman and members of the Committee for this opportunity to give you my thoughts on the appropriate next steps for the human exploration of space. This testimony is my personal opinion and does not necessarily represent the views of my employer, the Universities Space Research Association.

The United States has a fifty-year history of accomplishment in space, with a wide variety of satellite and human missions to virtually all of the destinations in this Solar System. We have surveyed the planets from Mercury to Neptune (and soon, Pluto), landed on the Moon multiple times, established a permanent research facility in Earth orbit and deployed a constellation of satellites that have made our lives safer, more productive and interesting. Despite these notable achievements, our civil space program has no long-term focus; it is in disarray, with confusion about objectives and confounded by America's lack of ability to launch humans into space. To confront these issues, I believe that we must step back and address the more basic question of why we undertake human spaceflight and what we hope to achieve by it.

What is the goal of human spaceflight? I believe it is to possess the ability go anywhere, at anytime, to do any job in space that we can imagine. Although much can be accomplished in space with robotic spacecraft, some tasks – including some scientific observation, the repair and maintenance of complex equipment, along with innovative, adaptive problem solving – require the presence of people, who combine high-level cognitive abilities with intricate manual dexterity. Creating the capability to send people and machines wherever necessary requires the development of an affordable and extensible space transportation system, one that can be built incrementally so as to prevent the almost certain future budgetary fluctuations from precluding its completion.

How can such a space capability be created and nurtured? One can imagine two space programs: one being a public relations spectacular, in which some dramatic goal or destination is announced and achieved, and the other being a continuing, gradual and permanent extension of humanity's reach into space. An example of a PR-type program would be the "space race" of the 1960s, with the primary purpose of beating the Soviets to the Moon and not the development a long-term, affordable space faring system. This type of effort may well achieve its immediate goal, but it leaves behind a programmatic and capability vacuum once its objective is satisfied.

The latter program, specifying a gradual human expansion into space, is typified by the Space Shuttle and International Space Station, which – although technically flawed in some ways – retained the basic philosophy that the best approach to creating a permanent space faring system is through the achievement of a gradual and incremental series of milestones. This style of program develops long-term capability and provides practical payback on investment (value for cost) over time, by designing and carrying out shorter, pre-defined milestones. A PR-centered program is most likely to fail in the long-term because typically it delivers on short time scales, lacks continuity and is subject to the whims of the political marketplace.

Since the cancellation of the Vision for Space Exploration in 2010, our national space program has drifted, guided by no long-term strategic direction beyond a vague statement of a nebulous goal of a human Mars mission sometime in the next 30 years. The so-called “Flexible Path” for human exploration, in which we abandon specific destinations and goals for the supposed development of the technology and ability to go anywhere, has in fact taken us nowhere. Technology development as a goal unto itself has not produced anything of enduring value – we *will* get new technical development and lasting public benefit by satisfying the requirements of going somewhere and doing something.

Because we do not possess even the rudiments of a true space transportation system, a human mission to Mars will be decades – not years – away, and as such, Mars should not be characterized as our “ultimate goal.” Our long-range ambition is to go everywhere, not simply to Mars. To do so, we must think in terms of building the permanent and adaptable systems needed to become “space faring.” Contra the Augustine (2009) report, this is best accomplished through the selection of concrete and distinct intermediate objectives – space destinations nearer to Earth than Mars – where specific and useful activities can be undertaken that will help us to develop and extend the new capabilities needed to sail on the ocean of space. To accomplish this goal, we need a significant destination that is achievable on realistic time scales (10-20 years). To check and assure our progress, and to provide the necessary motivation for continuation of the program, the path we select must have a number of intermediate milestones.

The Moon is the next logical goal for America in space.

We are fortunate to have in our own space “backyard” a miniature planet of surprising complexity and utility. I believe that the Moon offers three principal benefits as the next destination for human spaceflight.

The Moon is close: At 400,000 km away, the Moon is the celestial object closest to our home planet. Moreover, because it orbits the Earth, is it also the most accessible body in space. There is a launch opportunity to the Moon every day of the year, an attribute shared only with getting to low Earth orbit. Planning trips to near Earth asteroids is very difficult, as launch windows open for very short time periods and if the window is missed, the mission must be delayed, typically for many months.

The Moon is also easy to get to: transit times are short (typically, around 3 days), there is the capability for mission abort (in case problems develop on the spacecraft), and it requires less energy to get to the Moon than to go to any other planet.

Because the Moon is only 1.5 light-seconds from Earth, we can remotely operate machines and robots on the lunar surface from control centers on Earth, uniquely permitting us to deploy and operate a substantial robotic presence there prior to human arrival. We can pre-deploy habitats and fuel depots using telerobotics, allowing us to go the Moon with less restrictive logistical constraints than were possible during the Apollo missions of the previous century. We need no new technology to go to the Moon; existing systems can be adapted with minimal modification to return us to the lunar surface. Thus, we can focus technology development efforts on systems designed to perform new tasks and accomplishments never before achieved.

The Moon is interesting: The Moon is a natural laboratory to study the processes involved in creating the rocky planets of our Solar System. It has been shaped and molded by the processes of impact (the collision of solid bodies), magmatism and volcanism (heating, melting and re-melting of the interior) and tectonism (the deformation of solid surfaces). These processes occur on all planets, including the Earth, and study of lunar geologic history over the last 40 years has greatly illuminated our understanding of Earth's history and planetary evolution.

Unique among all space objects, the Moon preserves facets of the history of the Earth-Moon system, specifically by acting as a "witness plate" to record our impact bombardment. By studying the impact record of the Moon, we reconstruct that history for the Earth as well, including the possible preservation of evidence for impact-caused mass extinctions evident in the terrestrial fossil record. A comparable record is not present on any other object of the Solar System. Because the Moon has no atmosphere or global magnetic field, it also retains a record of particles emitted by the Sun and galaxy over the last four billion years, permitting us to better understand the solar and galactic output of radiation and particles through time – phenomena that greatly affect Earth's climate and habitability.

The Moon is a valuable platform for observing the universe. It is a geologically stable base on which extremely sensitive instruments can be emplaced, with a dark, clear sky that affords us one of the best views of the universe, and a place where Earth's radio noise is perpetually silenced on the lunar far side. The Moon also offers a unparalleled surface environment for laboratory study, with its partial-gravity (1/6 that of Earth), hard vacuum ($\sim 10^{-7}$ Pa, a trillion times less dense than atmospheric surface pressure on Earth) and thermal extremes difficult to achieve on Earth (dark, cold areas near the poles are only 25 degrees above absolute zero, colder than the surface temperature of Pluto). Such an environment permits a wide variety of experiments to be conducted that would be impossible or extremely difficult to accomplish elsewhere, on Earth or in space.

The Moon is useful: In the past few years, we have made new and astounding discoveries about the material and energy resources of the Moon. A fleet of international spacecraft have orbited and hit the Moon, revealing that areas near the lunar poles contain abundant quantities of water ice and other useful, volatile substances. Additionally, these valuable deposits are located next to zones of near-permanent sunlight, illuminated for more than 90% of the year, permitting the near-constant generation of electrical power from solar arrays. Thus, we have discovered areas on the Moon that permit us to stay on its surface for extended periods of time.

Water is the most useful and enabling substance for space faring. It provides critical life support consumables (drinking and eating), it may be used as radiation shielding (by jacketing habitats with water-filled enclosures), and can be cracked into its component gases (hydrogen and oxygen) for breathing. Water is also a medium for energy storage – reversible electrical generation, a process in which water is cracked into its component gases using electricity provided by solar power during daylight, and is then re-combined into water, generating electricity during the night. Finally, if water is separated into its component gases and these gases are cryogenically converted into liquid form, we create the most powerful chemical rocket propellant known, LOX-hydrogen. This use of water allows us to re-fuel spacecraft on the Moon and eventually, export rocket propellant to space. As the Moon's gravity well is much shallower than Earth's, requiring far less energy to launch, lunar propellant production and export can be used to create a permanent space-based transportation infrastructure.

What is our "mission" on the Moon? The principal goal is to *use the Moon* to create new space faring capability. The discovery of hundreds of millions of tons of water ice at the poles indicates that large-scale harvesting of lunar water is possible. Such a development would create the first off-planet fueling depot, a coaling station for our space fleet. This is a paradigm shifting development for space logistics. By learning how to use the material and energy resources of the Moon, we will take our first steps towards space permanence, developing the ability to go elsewhere in the Solar System. Instead of single shot, one-off missions to some destination, after which the program and all of its valuable developments are abandoned, we build an extensible, maintainable and reusable space transportation system. We went to the Moon in the 1960s to prove that it could be done; we return to the Moon 50 years later to use its material and energy resources to create new capabilities and commerce. This effort is *not* "been there, done that" – it is a wholly new, untried, *pioneering* enterprise in space.

The Moon is reachable under a variety of budgetary environments and constraints. We can structure a lunar return to incrementally build capability over time. There should not be a "large pill" that must be swallowed whole immediately; the key to such development is to craft a program that uses small, incremental steps that work together as an extended, large-scale system. An example of such an architectural approach is described in the supplementary materials that I attach to my testimony. This approach not only achieves the goals I advocate with the flexibility desired, but fits under a reasonable projection of the existing civil space budget.

A space transportation system that can go to the lunar surface and re-fuel there can reach any other point in *cislunar space* (the volume of space encompassing Earth and Moon). This region is the "pay zone" of space, the place where virtually all our scientific, economic, and national security satellite assets reside. The most useful satellites are located in regions of space well above the altitude of low Earth orbit (~200 km). Weather and communications satellites are found in geosynchronous orbit, about 36,000 km high. National security satellites need a variety of high-energy orbits, many of them above LEO. None of these orbits are reachable by humans, with either existing or projected spacecraft.

A return to the Moon to produce rocket propellant from lunar ice creates a refuelable, space-based transportation system that can access not only the lunar surface, but all of the points of cislunar space as well. Such a development would revolutionize spaceflight. Satellites would no longer be limited in power and capability. We could assemble large, powerful distributed space systems in these high orbits using people and machines, transported there by our expanding permanent space transportation system.

The experience of building the International Space Station, as well as missions sent to service and extend the life of the Hubble Space Telescope, show that people and machines working together in space can build systems much larger and more capable than those launched on a satellite from the Earth, even on the largest launch vehicles. As long as we are restricted to what we can lift up from the surface of Earth – the deepest gravity well in the inner Solar System – we will always be mass- and power-limited in space and thus, capability-limited. By developing the resources of the Moon, we greatly mitigate the high cost and difficulty of bringing everything with us from Earth. We become capability-***un***limited, permitting the development of new, and as yet undreamed of capacities. And we gain the means to go the planets – not only to Mars, but to all the interesting destinations that our Solar System offers.

I thank the Committee for its attention, I welcome your comments and thoughts and I am happy to answer any questions that you might have.

Attachments

These papers can be downloaded from: http://www.cislunarnext.org/Site/Home.html

1. Using the Resources of the Moon, Space 2011 paper
2. The Moon, National Defense University paper
3. Cislunar brochure
4. Develop Cislunar Space Next

The following is available from: http://blogs.airspacemag.com/moon/2011/08/destination-moon-or-asteroid/

5. A Comparison of Human Lunar and Asteroid Missions