Solar System Science and Exploration

Paul D. Spudis

The Vision for Space Exploration, announced by President Bush in January 2004 at NASA, offers new opportunities for the nation by setting reachable goals in space within a reasonable budgetary envelope. The key to creating new capability is to use the abundant resources of space to make spaceflight cheaper and easier. The new vision will generate an expanding sphere of human and robotic reach into the solar system. APL is poised to make major contributions to this new vision and to the nation's efforts in space.

INTRODUCTION

Our national program to explore space has benefited from significant participation by APL in the past and will continue to do so in the future. Beginning with the first Earth-orbiting satellite, Explorer 1, in 1958, the Laboratory has provided leadership in the development of space technology, experiments and instrumentation, and missions. Our spacecraft will have reached the breadth of the solar system, probed the nature of the Sun, and examined the galaxy around Earth. For almost 50 years, we have tentatively probed the edges of the cosmos, examining the processes and history of our universe.

We have accomplished much with this model of space exploration but are limited in what we can send into space. Launch vehicles are costly and quasi-reliable. The high cost of spaceflight makes the fate of programs inevitably tied to political winds that may change at a moment's notice. Failures occur, and when they do, it can take years to recover and obtain the information we sought.

The current paradigm of space exploration has developed largely because we must lift everything we need for exploration out of Earth's very deep gravity well. Because launch costs are so high, satellites must be built for an extended lifetime, making individual missions expensive and rare. The logistical train to the various levels of Earth orbit where our space assets reside is long, tenuous, and difficult to maintain.

On 14 January 2004, President Bush announced a new Vision for Space Exploration, one that changes how we approach space. A prime motive for the new vision is to infuse the human exploration program with sorely needed purpose. The vision offers possibilities and opportunities for ourselves and the nation by setting goals for exploration by people and machines.

THE VISION FOR SPACE EXPLORATION

The new vision advocated by the President outlines a different approach to the fundamentally limiting problem of spaceflight.[1] One key to changing a paradigm is to alter the rules. What if we were no longer limited only to what we can lift from Earth's surface? Suppose we could "live off the land" in space? What would the advent of this scenario mean for future exploration and use of space?

The human part of the space program has been trapped in stasis for the last 20 years—shuttle launches and pedestrian, go-nowhere spaceflights, with precious little exploration being accomplished. Worse, we have been locked in low-Earth orbit with no plans to go beyond, even though robotic space exploration passed that horizon years ago. The International Space Station (ISS) could have served as a test bed for farther destinations, but didn't, largely as a result of conscious policy decisions. The tragic loss of the space shuttle Columbia in 2003 only drew attention to the hollowness and lack of direction of our space policy.[2]

The President's new vision proposes that the space shuttle be returned to flight to complete the construction of the ISS—then be retired prior to a costly and risky recertification. A new vehicle will be designed and built for human spaceflight, one which can adapt to different kinds of missions going to various destinations. We will conduct robotic exploration of the Moon in preparation for the resumption of human exploration by the middle of the next decade and use the knowledge and capabilities created from these activities to venture beyond, including human missions to Mars.[1]

One of the most interesting and unusual aspects of the President's statement concerns the use of the abundant resources found at the Moon and elsewhere in space to create new capability.[1] Although widely discussed in space advocacy circles (see, e.g., Ref. 3), the use of space resources has been dismissed by many in the spaceflight community, with development considered only likely in the far distant future. Yet we have been using one space resource since the very first flights—converting abundant solar energy into electricity to power the spacecraft sent to diverse destinations.

Space resources consist of materials as well as energy. We know that the bodies closest to Earth offer usable resources that can be harvested: water bound in minerals or as condensates in specialized environments and the bound oxygen found in common rock-forming minerals. The Moon and near-Earth asteroids contain abundant elements of potential use, ranging from life support consumables to materials that will enable construction of new rocket boosters.

Significantly, the Vision for Space Exploration does not call for the use of space resources to lower costs of the space program, although that is a long-range goal of such use. The real goals are to understand how difficult it is to use lunar and space resources, to develop the technologies needed to do so, and to experiment with different processes in a real space environment. It may turn out that using space resources is more trouble than it's worth; if so, we need to know that so that we can devote our efforts to a space program that does not feature extensive human presence. The issue is one of technical feasibility. Can we make what we need from what we find in space? Exactly what the answer is, we cannot now envision.

How can we use the resources of near-Earth space, and what might their use do to the paradigm of spaceflight? How can APL both contribute to this new venture and take advantage of the new capabilities developed? Over the next few years, we will answer the question of whether space resources can fundamentally alter the rules of spaceflight and the future capability of exploration.

NEW MISSIONS AND THE VISION

A Return to the Moon

The initial steps in our return to the Moon involve a robotic orbiter, the Lunar Reconnaissance Orbiter (LRO), which will be launched in 2008[4] and will orbit the Moon for at least 2 years. The purpose of this mission is to collect critical information that will pave the way for human return, as noted above. To that end, the LRO will collect detailed data on the Moon's topography in addition to characterizing exotic environments such as the lunar polar regions.

These experiments and others will provide key strategic data to help plan for habitation on and use of the Moon. We have reason to believe that water ice deposits may exist in the permanently dark regions near the lunar poles.[5] However, we do not know the physical state of these deposits, nor do we have a good idea of their quantity.

Before LRO flies, India plans to send a spacecraft, Chandrayaan-1, to the Moon in early 2008. An APL–Navy team is developing an imaging radar experiment that will fly on this spacecraft, the mini-SAR (synthetic aperture radar).[6] Mini-SAR will map the dark regions of both poles of the Moon, looking for the characteristic RF signature of water ice. Along with other topographic and morphologic data, these missions will allow us to map the ice deposits of the poles, determine their physical setting, and estimate their abundance.

Lunar ice is valuable both to support human life and to develop space-faring infrastructure (Fig. 1).[7] Water can be purified and used at an outpost and broken down into its component hydrogen and oxygen and as rocket propellant. The ability to make rocket propellant on the Moon has the potential to completely alter the current model of spaceflight (Fig. 2).

The LRO mission will be followed by other robotic missions to the Moon that can include both orbiters and landers. A series of small spacecraft ("microsats") in lunar orbit can create a communications and navigation infrastructure for the Moon, providing continuous communications with areas out of sight from Earth (such as the far side) and positional information for both orbital

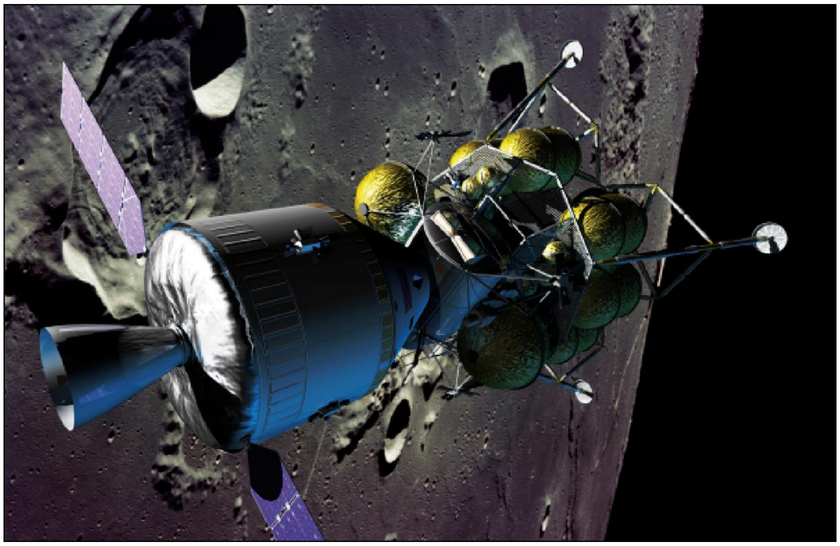

Figure 1. The Vision for Space Exploration involves both robotic and human missions with the aim of creating new capabilities and space-faring infrastructure.[1]

and surface navigation around the Moon (a lunar GPS). For landers, we can explore the surface using rovers, as shown by the recent experience with the Mars Exploration Rovers, and deliver robotic payloads to begin developing the surface infrastructure near a future outpost. Rovers can access the dark floors of polar craters, gathering detailed chemical and physical information on the ice deposits—necessary precursor information for the extraction of water.

In parallel with this program of annual robotic exploration, the Crew Exploration Vehicle, a replacement for the shuttle, will be developed and tested. Beginning as early as 2015, but no later than 2020, humans will return to the Moon, using the knowledge gained and the equipment emplaced by the robotic precursors. Returning to use the Moon's resources will enable us to build a space transportation infrastructure in cislunar space. Such a system—allowing routine access to the Moon and all points in between—is a fundamental step forward in creating a true space-faring capability. A system that can routinely land on the Moon, refuel, and return to Earth orbit, bringing with it fuel and consumables produced on the lunar surface, also will give us the ability to journey to Mars and other destinations.

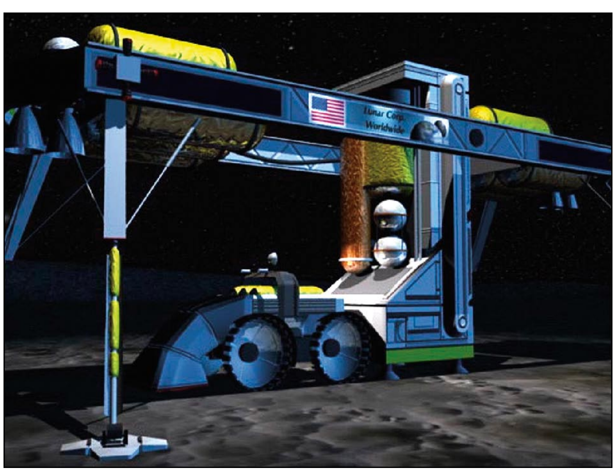

Figure 2. Extracting resources from the Moon to make rocket propellant will create an Earth–Moon transportation system, giving us the capability to venture farther into space.

An even more important aspect of such a transport system relates to our ability to access cislunar space routinely. All of our national space assets, commercial and strategic, reside in that volume of space. Currently, we have no way to access these satellites. If one breaks down or becomes obsolete, it is written off and must be replaced. If we could travel between the various energy levels of cislunar space, carrying out servicing and upgrading missions, we could maintain a more robust, more capable set of satellite assets. Thus as cislunar space becomes as accessible as low-Earth orbit, we can use this transport system for a variety of commercial missions as well as missions of national strategic interest.

Beyond the Moon

The new exploration vision is not just about a return to the Moon or a way to cast the shuttle aside. Beyond cislunar space, the entire solar system beckons. Nearest are the near-Earth asteroids, such as Eros, first explored by the APL-built Near Earth Asteroid Rendezvous (NEAR)-Shoemaker mission in 1998.[8] Asteroids, the leftover debris of solar system formation, contain abundant useful products (Fig. 3), notably water (most probably in the form of hydrated minerals) and metals, including large amounts of platinum group elements, an important commodity for a future hydrogen-based energy economy on Earth.[9] Asteroids also contain the raw materials necessary to build significant space structures. We have only a crude knowledge of their bulk composition and will need to examine a wide range of asteroids to catalogue their variety and inventory their resource potential.

In addition to being our material warehouses of the future, asteroids may also ultimately bring about our doom. Thanks to our knowledge of the physical and chemical effects of hypervelocity impact obtained from the Apollo lunar samples, we now recognize that collisions of very large objects with Earth in the geological past have caused several mass extinctions, the most recent large one being the impact event at the end of

Figure 3. Asteroids offer an abundant source of materials for a range of uses, including space transport and infrastructure. Their variety requires extensive survey by robotic probes prior to utilization.

the Cretaceous (65 million years ago), which caused the extinction of the dinosaurs. Moreover, such catastrophic impacts seem to occur with some regularity; there is a hint in the limited terrestrial data that they might occur every 26 million years.[10]

Earth has no defense against a large-body impact. We are gradually building a catalog of Earth-crossing objects and could conceivably gain the ability to predict a future collision. But we have no way to deflect or divert such an encounter. A permanent space infrastructure would give us such capability. First, we can construct on the Moon and in cislunar space an observing network that could map and track asteroidal debris down to scales of a few meters in size. Swarms of small robotic probes could be dispatched to members of each class of body, gathering detailed compositional information. More advanced probes could sound these bodies, determining their density structures and physical characteristics. All such data would allow us to develop technologies and techniques to help deflect an approaching asteroid long before it becomes a collision threat to Earth.

In all of these activities, APL will lead in the development of new sensors, innovative small spacecraft, and sophisticated mission designs. The sheer scale of possible activities enabled by a new cislunar transportation infrastructure is difficult to imagine, but routine access to space would allow many missions and continuous exploration.

Farther afield, Mars awaits. Although the presidential vision did not set a deadline for the first human mission to Mars, it did affirm the continuation and extension of the existing robotic exploration program.[11] Over the past decade, a robotic exploration strategy has been developed for Mars that emphasizes the characterization and history of water on that planet (Fig. 4). A series of orbital and lander missions will offer increasingly sophisticated opportunities to trace the evolution and fate of water in martian geological history. We are interested in both surface and subsurface water, and a variety of techniques and instruments can be used to decipher this complex history. Ground-penetrating radar can map the distribution of ground ice many meters below the surface. Drill holes can allow us access to the subsurface into which sensitive instruments can be lowered to measure and characterize the volatiles present. Spectrometers and other devices can determine surface and subsurface mineralogy, including the state and concentration of water-bearing species.

Long-range rovers, martian aircraft, balloons, and other vehicles can all return critical information on martian history and processes.[11] Beyond the purely scientific areas of interest, we need to collect data on the surface conditions and environment of Mars in addition to possible toxicological hazards of the surface materials before any human landings. As with the robotic mission series that precedes human arrival on the Moon, the martian precursors will map the surface in detail, document landing hazards, measure the chemistry and physical properties of the surface, and determine the nature of potential chemical or biological hazards to human explorers. The

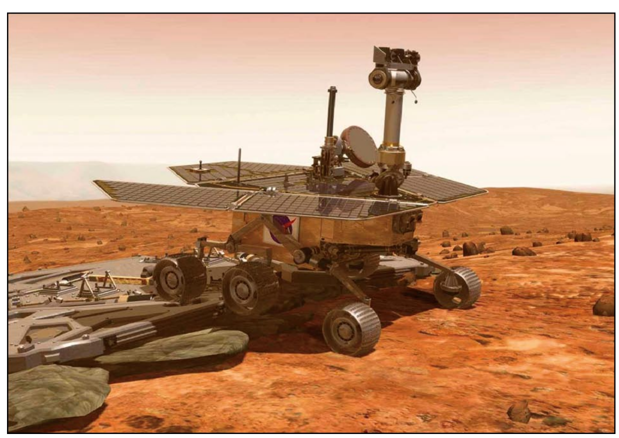

Figure 4. We will continue to explore Mars using robotic rovers, orbiters, and other exotic spacecraft to investigate the history of the planet and prepare for the arrival of humans.

Laboratory can lead this campaign through the development of advanced sensors and instruments, missions in the Mars Scout line, and exploration strategies that can yield innovative and timely information.

IMPLICATIONS OF THE VISION FOR SPACE EXPLORATION

Rather than being simply a “new human space program” or a “manned Mars mission,” in the new vision, the entire solar system is our goal. Existing launch vehicles, spacecraft, instrumentation, and supporting infrastructure are too limited—in mass, power, bandwidth, and computational ability. The goals of the Vision for Space Exploration are nothing less than revolutionary: to leverage our existing capabilities by developing and using new technology, but also to create new capability by using space resources and building space-faring infrastructure.[12] Thus, the new vision is not a zero-sum game with some winners and some losers: the goal is for all to win through the creation of new capability.

Among the winners will be APL. The Laboratory’s experience and expertise in experiments, instrument development, missions, and technology are all critical components to the success of the new vision. As the vision unfolds, we have the potential to obtain new missions and extended exploration. We will continue to actively pursue these opportunities, which include both the ongoing Space Science Enterprise series of missions as well as new missions developed to support the vision.

The Laboratory should also actively pursue the abundant new possibilities offered by a human presence at the various destinations. Humans bring unique, expert knowledge and dexterous manipulation to the interactive environment of exploration, and novel scientific opportunities will become available through their presence. A key goal of the vision is to break down the false dichotomy between human and robotic exploration. To maximize the return, both components are needed. We can use our return to the Moon to learn how best to explore planetary surfaces.[13] What are the optimum mixes of human and robotic capability? What tasks can robots conduct, and which require human intervention? Is it possible to use robotic telepresence—in which a human mind is projected into a robotic surrogate at a distance (Fig. 5)—to explore the planets effectively? These questions and others can be answered through a detailed program of human and robotic exploration of the Moon and objects beyond.

We face a clear choice in the future direction of America’s space program. We can continue on our existing path, with resources limited by what we can launch from Earth, or embrace a model that creates new capability by using the unlimited resources of space to build a transportation infrastructure, one that can routinely access cislunar space and beyond. We can generate new wealth by extracting these resources for use in space and back on Earth; develop new technologies to offer higher levels of power, bandwidth, and computational capability to return orders of magnitude more data from exploration missions; and use the combined powers of people and machines, working together to robustly explore planetary surfaces, and build scientific instruments of extraordinary power and capability. The world will benefit and APL is positioned to play a key role in creating new scientific and technological opportunities as we set goals for new horizons.

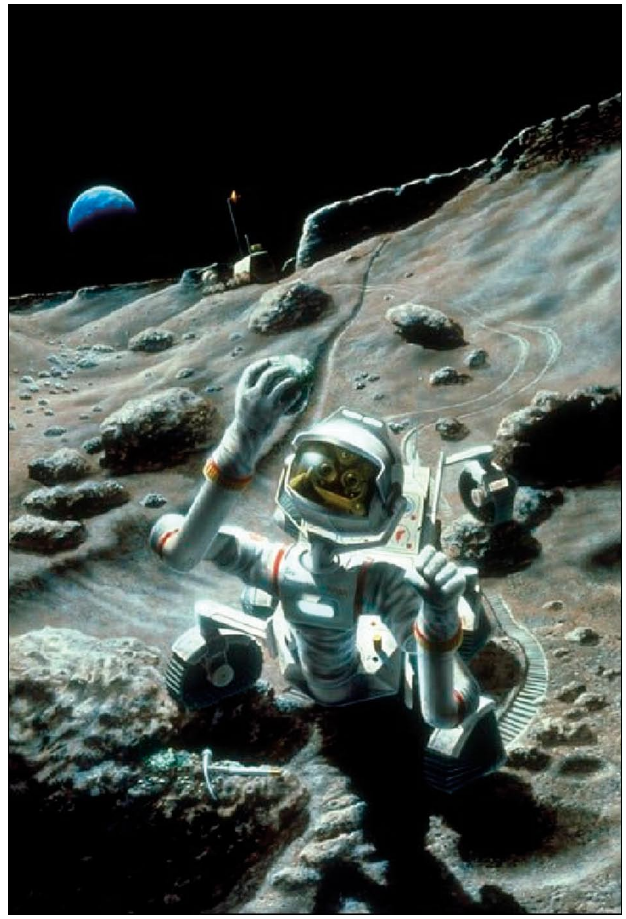

Figure 5. Robotic telepresence may be a valuable technology to extend human reach in planetary exploration. Such techniques are best tested in lunar and planetary environments during real exploration activities. (NASA image by Pat Rawlings.)

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THE AUTHOR

Paul D. Spudis is a member of the APL Principal Professional Staff. Dr. Spudis received his education at Arizona State University (B.S., 1976; Ph.D., 1982) and Brown University (Sc.M., 1977). His research focuses on the processes of impact and volcanism on the planets. He has served on numerous NASA committees and panels and on the Committee for Planetary and Lunar Exploration (COMPLEX), an advisory committee of the National Academy of Sciences. In 1990–1991, Dr. Spudis was a member of the Synthesis Group, a White House panel that analyzed a return to the Moon. He was the Deputy Leader of the Science Team for the DoD Clementine mission to the Moon in 1994 and is the Principal Investigator of an imaging radar experiment on the Indian Chandrayaan-1 mission to be launched to the Moon in 2008. In 2004, he was a member of the President's Commission on the Implementation of U.S. Space Exploration Policy and was awarded the NASA Distinguished Public Service Medal for that work. Dr. Spudis is also the recipient of the 2006 von Kármán Lectureship in Astronautics awarded by the American Institute for Aeronautics and Astronautics. He has authored or co-authored over 150 scientific papers and 4 books, including *The Once and Future Moon*, a book for the general public in the Smithsonian Library of the Solar System series, and (with Ben Bussey) *The Clementine Atlas of the Moon*, published in 2004 by Cambridge University Press. His e-mail address is paul.spudis@jhuapl.edu.

Paul D. Spudis