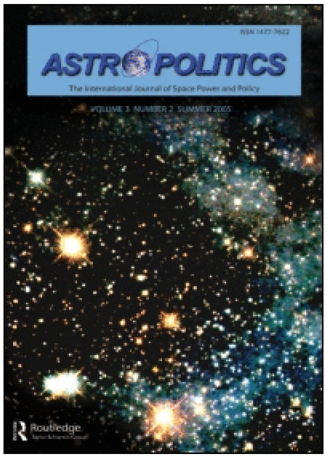

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VIEWPOINT: THE STRATEGIC CONTEXT OF THE MOON ECHOES OF THE PAST, SYMPHONY OF THE FUTURE

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A strategic framework for the Moon must weave together the economic, social, scientific, national security, and civil aspects that have evolved largely in isolation since the inception of the space age. The United States—based on its historical dependence upon space assets, exploration heritage, and global leadership position,—has the most to gain and lose by the tenor of its leadership in this framework's development and implementation. A permanent presence on the Moon, combined with the use of lunar and space resources, offers the means to create a new space age. Lunar exploration offers many scientific and cultural benefits and has significant historic implications. In addition, this extension of human reach beyond low Earth orbit, and the ability to regularly access and use cislunar space is critical for addressing emerging national, economic, and scientific challenges. An analogy to this strategic moment is the development of United States maritime policy at the beginning of the 20th century.

Introduction

The Moon is the Earth's offshore continent, the recorder of our cosmic past and future. Human footprints, echoes of an earlier time and era, have only barely marked its surface. The impending development of a sustained human presence on the Moon will mark a new era in human exploration and development. The Moon stands ready to help us unfold a new age in space and on

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The ideas and opinions expressed in this work are those of the authors and do not necessarily represent the positions or opinions of the organizations with which the authors are affiliated.

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Earth—one that will open the secrets of our past and energize and advance all sectors of human endeavor.

Earth and its Moon are inexorably linked in space and time. The tides induced by the Moon's tug expose tidal flats at the sea-land boundary, whose presence enabled life to emerge from the sea. Lunar rhythms are reflected in many biological and climatic processes, indicating its silent, constant influence on the pulse of the Earth. More recently, the Moon stands as a distant, visible shoreline, far enough away to be separate, yet an accessible and challenging destination. Countless myths and stories from cultures throughout the world are based on its sentinel presence. The story of our past and future is etched in its craters, valleys, and plains. The materials and energy needed to unleash humanity from the bounds of gravity and to create an open system of growth without limits, await development on the Moon.

Just as humans emerged from the savannahs of Africa to cross seas and land bridges into the unknown, so too will we venture inexorably to Mars, the other planets in our solar system and destinations beyond. But for now, such a journey would have little to no strategic connectivity or practical benefit, unless it is born out of the sustaining activities that can be permanently developed and expanded in cislunar space, the space between the Earth and lunar orbit, and on the Moon. Our human reach to Mars and other destinations goes through the Moon. By learning to use cislunar space in a manner that creates new spacefaring capability, develops needed technology, and increases the security, innovation, and development of our own planet, we will orchestrate the next generation of human endeavor.

Permanently extending human presence to the Moon and developing the ability to utilize space and lunar resources will establish the capability to have regular access to cislunar space in a manner that can fundamentally transform security, commerce, and science, while also serving as the debarkation point for humanity's journey into the solar system. To this end, an overarching strategic framework is needed for exploring and using the Moon—a framework that accounts for the Moon's place in our culture and consciousness, its importance in moving out into our solar system and its long-term significance to a wide range of national and international interests. Based on such a framework, the United States (U.S.) can lead the rest of the world on a path that will utilize, expand, protect, and synthesize all activities and entities that depend on and use space.

National Context and Current Framework

Because of its familiarity and presence, the strategic value of the Moon has been given little consideration. Since Sputnik was launched in 1957, cislunar space has seen an explosion of activity that continues to expand and increase in diversity. Outlining this value requires sorting through and across a spectrum of national, commercial, scientific, exploration, and cultural considerations that have evolved largely in isolation from each other since the Space Age began. These isolated themes are now inexorably growing and merging. It is thus an appropriate time to step back and examine the role the Moon plays in humanity's development on Earth and movement into the universe.

The Moon as a destination is visible in the adoption of a new U.S. space policy, the Vision for Space Exploration (Vision or VSE), announced by President George W. Bush in January 2004.[1] The unfurling of the Vision represents a watershed opportunity to recast the direction of the space program and its relevance to our national and international development. An analog to this fundamental turning point is the development of modern naval policy at the beginning of 20th century.[2] At that time, geopolitical, technological, economic, and national security trends came together with national leadership to chart a fresh framework for U.S. strategic development, enabled by its maritime capabilities that focused on the challenges and opportunities presented by extended and permanent U.S. interests beyond our shores.

The Vision largely centers on providing the National Aeronautics and Space Administration (NASA) a long-term strategic direction for its current and future human spaceflight programs, supported by robotic systems, and came about in response to a major review of the national space program following the loss of the Space Shuttle Columbia in 2003.[3]

In addition to these hardware tasks the Vision calls for a return to the Moon, first by robotic spacecraft and then by humans, with the goal of living and working there for increasing periods of time. Several activities on the Moon are specified, but in particular, the development and use of lunar resources is emphasized.[4] The clear implication of the Vision is that we will learn to live and work on the Moon to use it productively but also to prepare for journeys to Mars and other destinations.

Also challenging and creating a new context for NASA, Congress endorsed the Vision and provided an overall architectural framework for agency activities with the NASA Authorization Act of 2005.[5] This law directs NASA to create a sustained human presence on the Moon for national preeminence, commercial, and scientific purposes. This law also calls for NASA to develop a human spaceflight capability to replace the Shuttle as soon after its retirement as possible. The law also addresses key elements needed in the development of a cis-lunar space presence, including the importance of shifting low-Earth orbit space activities towards a broader national and commercial focus.

This fundamental shift in space policy emphasis challenges our current national security and strategic focus on space, which centers on assured access, launch on demand, and replenishment of assets, primarily in low Earth orbit.[6] However, such a framework clearly has limits, as only so much material can be lifted off the Earth. To transition to a new paradigm of spaceflight, it is necessary and inevitable that we redirect our efforts towards the use of space resources, strategic depth, repair, extension, and replenishment on-orbit, and the gradual expansion of human reach beyond low Earth orbit.

It is the destiny of this nation, built on exploration and discovery, to continue this tradition into the arena of space. The Moon's resources of material and energy can be exploited to build systems that extend our reach and capability in space. A transportation infrastructure that can routinely reach the Moon can also routinely access cislunar space—that zone where many of the world's most valuable space borne assets reside. Currently, ongoing space operations require fabrication and launch of a system, its use for some period of time, and then its eventual abandonment. With a transportation system in cislunar space, we will routinely visit and repair, maintain, refurbish, expand, and upgrade satellites on a regular basis. Spacecraft will no longer be built to a planned obsolescence and then abandoned, but instead will be designed to permit unlimited lifetime and capability for expansion and extension. In short, we will evolve from the existing "sortie" approach to space travel to an approach that allows sustained, constant, and routine access to all locations in cislunar space.

Implementing a Strategic Framework for the Moon and Beyond

One constraining feature of the current U.S. framework for space exploration is that NASA is expected to lead this new approach without a commensurate increase in annual funding.[7] In effect, the Agency is being tasked with revolutionizing the spaceflight paradigm within the boundaries of its current levels of funding. Such a task would be a challenging goal even in an Apollo-like era of copious funding. The agency will have to transform its capabilities, become more innovative and reinvigorated by the vast array of current and potential private sector and global investment in space. Furthermore, existing elements of the U.S. space program, and our national space strategy must shift from relative isolation to being connected, coordinated, and built around a shared and expanding framework.

A key approach to implementing this new framework to space is to take small, incremental, and cumulative steps which all contribute to realizing the overall strategic goals. Small steps are required by the projected minimal funding increases and by the need to transition toward a permanent lunar presence, without destroying the current assets and capabilities available to help build its foundation. The changes must also be incremental and cumulative to build sustained capability. We can no longer afford to dissipate precious national assets on uncoordinated and isolated space flights, but should instead craft a program in which each mission builds-upon and adds to new spacefaring capability.

Over the next few years, NASA must simultaneously complete the construction of the International Space Station (ISS), safely retire the Space Shuttle, and develop and build the Crew Exploration Vehicle (CEV) and associated, transportation elements to lay the groundwork for a return to the Moon.[8] This multifaceted task is possible if a strategic approach is designed where small pieces fit together into a coherent, logical whole. Each cumulative step each capability, needs to become a piece of the larger puzzle. Early small robotic missions, designed to investigate the Moon—each one giving some initial capability or key piece of strategic knowledge—will later develop into networks of spacecraft operating as larger systems. As an example of this approach, small satellites collecting data in lunar orbit, such as maps of lunar resources, could later be boosted up to and left in stable, high lunar orbits to serve as a communications relay-surface navigation system for later flights to the Moon.

We must begin this transition towards a national cislunar capability by tapping personnel and by gathering infrastructure and capabilities that support human spaceflight in low earth orbit (LEO) and the ISS. We will not (and cannot) build this new infrastructure from scratch. Current Shuttle and Station assets help ensure that the U.S. government does not get into the position of relying on foreign access to space or upon nascent commercial providers. If we do not build a cislunar fleet to ensure regular access to all parts of Earth-Moon space to advance our interests and future in space, we will then be held hostage by capabilities that only extend to the close coastal regions of space. This transition is a critical element as to whether the U.S. maintains leadership in creating the new space age, or becomes tethered to scientific and political infighting.

A number of spacefaring states have announced their intention to launch robotic missions to the Moon over the next decade.[9] At the same time, a growing number of states and commercial entities have, are developing, or are interested in human spaceflight capabilities. NASA's efforts should be viewed within this larger international context. Our movement to the Moon is not merely a repeat of Apollo, or a precursor to an Apollo-like mission to Mars, as neither would be relevant at this point in our national and global development. Technical and economic innovation, synergy, permanence, and capability are the key attributes we seek in our space program. This strategy includes the use of space resources to help break the bonds and resource limitations of Earth. A distributed mission architecture permits scheduling flexibility, incremental costs, and relevance to commercial and national security interests, while at the same time producing cumulative, long-term expanded capabilities.

The applications, uses, value, and geopolitical nature of cislunar space evolved tremendously since the dawn of the first space age. Communications, broadcasting, weather monitoring and prediction, remote sensing, navigation, and global positioning are just some of the satellite applications that continue to grow. In the military arena, the per-troop bandwidth of space communications increased fifty times from the first Gulf War to the Afghanistan campaign of 2001–2002.[10] In 2003, the total revenue of the global satellite industry was $91 billion, the consumption of satellite telecommunications is roughly $1 trillion,[11] and the value of financial transactions conducted through space is in many ways incalculable. In 1972, the U.S. government launched two Saturn V rockets, carrying a total of 96 metric tons of payload to the Moon.[12] Today, the international commercial sector launches the equivalent mass to geosynchronous orbit (GEO), which energetically almost equivalent to lunar orbit. The global satellite telecommunications industrial base can be used to access the Moon. Additionally, the entry cost to access the Moon continues to decrease; for example, the sophisticated Indian Chandrayaan-1 lunar orbiter mission, scheduled for launch in March, 2008, will cost an estimated $80 million.[13] Other examples of low-cost lunar missions include the successful Clementine, Lunar Prospector, and the European SMART-1. These missions all leveraged the global industrial base, which supports the commercial and national security use of cislunar space.

Apollo was a politically motivated demonstration of our ability to go to the Moon, not part of a long-term strategy for space exploration and development.[14] When we return, we will leverage current space investments, expand our ability to use and access cislunar space, and use the Moon to learn and expand the skills and techniques needed to journey into the Solar System. Technology has changed and continues to change the nation and the world. Science is but one of three drivers of the U.S. space program; the other two are economics and security.[15] On the Moon, we will exploit its potential to aid development of cislunar space, monitor and aid our development on Earth, and unleash our ability to live and work beyond our planet.

The Value of the Moon: Our Past and Future

The principal virtues of the Moon are that it is relatively close to Earth, even closer to the commercial use of cislunar space, and possesses resources of material and energy needed to create new spaceflight capabilities, like the manufacture of rocket propellant on the lunar surface. Moreover, the Moon has additional properties that make it an important destination in itself; its history and evolution are tied directly to that of the Earth.[16] These qualities make the Moon useful and interesting as the immediate, near-term destination beyond Earth's LEO shoreline.

The Moon is easily reachable, requiring the same energy needed to reach GEO; typical travel times to and from the Moon are between 3 to 5 days. It is an airless, silent world that nonetheless contains usable resources of material and energy to enable space travel and habitation. The Moon rotates slowly once every 28 days, thus having a day-night cycle of 14 days. Such a lengthy day-time enables us to collect solar energy for an uninterrupted block of time, potentially enabling the production of energy on the surface of the Moon to export to the Earth. An array of solar collectors on the Moon, positioned on opposite hemispheres, could provide enough energy to address a significant fraction of the world's needs. The key to making such a system work is fabricating solar arrays and their supporting hardware directly from lunar materials. This circumvents the show-stopping feature of traditional space Solar Power System (SPS) satellites—the high cost of launching multiple square kilometers of arrays into Earth orbit. To avoid this cost, we will use material that is already on the Moon.

We have recently found that the poles of the Moon are particularly valuable localities. Because the Moon's spin axis is perpendicular to the plane in which it orbits the sun, the sun is always on the horizon at the lunar poles. This results in areas of both permanent sunlight, on peaks which are in constant illumination, and permanent darkness, in crater floors where the sun never shines.[17] Constant sunlight enables continuous generation of electrical power through solar arrays, and a benign, constant thermal environment of $-50^\circ \pm 10^\circ$C. Dark areas receive no sunlight and are very cold, only a few tens of degrees above absolute zero of -273°C.[18] The Moon has no indigenous water but has been hit by water-bearing objects such as meteorites and comets throughout geological time. This water could have been trapped by extreme cold in the dark areas near the poles. Data returned by the orbiting Clementine and Lunar Prospector spacecrafts suggest that this has indeed happened.[19] Thus, the poles of the Moon are inviting oases where benign thermal conditions, constant solar illumination, and volatiles, including perhaps water-ice, coexist in proximity.

Planetary histories recorded on the surfaces the Earth and the Moon are complementary. The Earth is a dynamic, active planet that records only recent stages of planetary and Solar System evolution. The Moon records the geological and astronomical processes that occurred many millions to billions of years ago, yielding insight into the earliest evolution of the Earth-Moon system.[20] This evolution includes the impact flux discovered by Apollo. Because impacts have caused global extinctions, study of this history holds profound relevance for the story of life on Earth.[21] And, because the Sun is one of the principal drivers of life and climate on Earth, understanding its variability over time is critical to understanding our past and hence, predicting our future. A record of the output of the Sun over several billions years of time can be read in the dust grains of the lunar surface. The lunar dust records energetic events that occur in nearby star systems, allowing us to determine absolute dates for galactic phenomena, including recent supernovae. The Moon is a cosmic tape recorder, waiting for us to play back the history of our universe.

The Moon is not only a place to explore, it is a natural space station and laboratory where we can learn how to explore and live on other worlds. Living and surviving on an alien, hostile world are pioneering tasks easy to intellectualize but difficult to master. We are fortunate that the Moon is a place where we can test, practice, and perfect such techniques, while retaining the ability to get home quickly if things go really wrong. On the Moon, we will learn how to live off the land, explore, work productively and safely, and develop human social communities that will build and operate a new, off-planet society. Trying and perfecting such tasks on the Moon will allow us to venture to the planets with more confidence once we have mastered the necessary skills. The Moon provides us with a laboratory, testing ground, and classroom for our movement into the Solar System.

The push beyond LEO will drive markets and technologies toward efficient resource extraction, in-space refueling, handling, and storing of cryogenic fuels in zero-gravity, building reusable and restartable cryogenic engines, all while pushing advances in fuel-cells, life-support, and environmental systems that are needed on Earth. Pushing forward in space technology has always paid back more than it has cost; the Apollo program paid back with a positive cost ratio benefit for each $1 spent on it.[22]

Benefits from a Return to the Moon

Our return to the Moon, in addition to establishing a cislunar transportation system, will yield many scientific, technological, and cultural benefits. These benefits are explained below.

Scientific Exploration

The Moon is a natural laboratory to study the processes that have shaped the planets.[23] Impact of solid bodies, internal heat and its release by volcanism, the mechanical deformation of the crust (tectonism) has all shaped the Moon's surface. In addition to its own history, the Moon records events that occurred in the Earth-Moon system throughout its 4.5 billion years of existence. On the Moon, we can recover Earth's lost history, including the record of impacts and their intensity with time. In a like manner, the lunar regolith contains the history of our own Sun and those of the nearby stars. Reading this record has important implications for understanding both climate change and the evolution of life on Earth.

Observation from the Moon

The Moon offers unique opportunities to observe the Earth and universe.[24] The Moon's quiet, stable surface and lack of atmosphere make it a superb platform to construct observatories of various types. Large, distributed aperture arrays (interferometers) can be built on the Moon with relative ease. Such arrays can achieve resolutions many orders of magnitude better than that achievable on the Earth or even in free-flying space telescopes, on the order of one-millionth (10^{-6}) of a second of arc. The far side of the Moon is permanently shielded from the din of noise and static produced by civilization and the Earth's ionosphere. Radio telescopes built on the far side of the Moon can examine spectral windows on the universe never before seen. On the Moon, we can image the entire magnetosphere of the Earth from a single vantage point. The Moon's orbit around the Earth takes it into and through the geomagnetic tail, allowing us to monitor the conditions of "space weather" that frequently disrupt terrestrial communications. Imaging the whole Earth from the Moon allows us to conduct extended, long-dwell observations of the whole terrestrial disc conveniently and repeatedly.

Laboratory Science

The Moon's reduced surface gravity, near-perfect vacuum, and hard radiation environment combine to offer a unique resource for a wide variety of experiments in the physical and biological sciences. Study of biological adaptation can be undertaken using as controls the known environmental conditions on the Moon. The isolation of the lunar surface will permit the undertaking of potentially hazardous or dangerous experiments in genetic or nuclear engineering. Development of potentially hazardous biomaterials on the Moon will permit a wide variety of experimentation, unwise to pursue on Earth. The Moon can also become a new planetary "quarantine" facility; when scientific samples with astrobiological potential are returned from other planets such as Mars or Europa, such samples can be safely examined and handled on the Moon, circumventing complicated and costly protection protocols here on Earth.[25]

Lunar Resource Harvesting

The abundant materials and energy of the Moon will allow us to create new capabilities in space.[26] From lunar materials, we can extract building materials to construct the various facilities of the lunar habitat, ranging from the simple use of loose soil to shield the habitat from cosmic radiation, to the creation of ceramics and glass for a variety of building purposes. Other important products include life-support consumables, especially oxygen and water. The lunar soil is almost one-half oxygen by weight; the task is to break the very strong chemical bonds holding oxygen in rock to liberate the gas and then store and use it later. Hydrogen is rare on the Moon; it is present at the Apollo sites only as a minor component in the soil, implanted there by the solar wind over billions of years. The reason lunar polar ice would be so valuable is that it is a concentrated source of both oxygen and hydrogen which can be extracted with systems of modest energy and mass. The ability to make propellant is a key step in the ability to conduct economic and industrial operations in space; propellant made on the Moon serves the cislunar transportation system by ultimately permitting the refueling of planetary vehicles. The initial systems and infrastructure to develop lunar water can be developed and flight tested using extensions of current space technology (e.g., launch vehicles, satellite components, and solar systems) and the increasingly relevant and important terrestrial "Hydrogen Economy."

In addition to materials, the Moon is also an energy-rich environment. The Moon rotates once every 28 Earth days, allowing a solar array on its equator to absorb over 14 days of continuous, cloud-free sunlight. This long daytime is followed by an equally long night time, thus creating a problem for constant energy generation by solar power. But because the Moon's spin axis is perpendicular to the plane of its orbit around the Sun, selected areas at both poles are in nearly constant sunlight. This sunlight can be collected by solar arrays, which themselves can be fabricated and manufactured from lunar materials. The creation of such a solar farm at the poles of the Moon can provide lunar inhabitants with constant, renewable power at whatever levels of power generation that may be desired. Ultimately, we may make enough electrical power on the Moon to export it for use in cislunar space and eventually, on the Earth.[27]

Social Development

The building of human settlements on the Moon is itself an experiment in learning how to live and work productively on other worlds. In addition to the usual stresses of creating new communities far from home, living on other planets offer their own unique challenges and opportunities. Acquiring this skill set is best done three days from home rather than a distant planetary surface, many months away of uncertain and difficult travel away. The Moon provides us the first step to develop societies off-planet, learn self-sufficiency, and understand and address the psychological and societal issues of long-duration space travel.

Gateway to Other Destinations

The Moon is our beachhead for future destinations in space. By developing a cislunar transportation system, we give ourselves the inherent ability to go to planets with people and machines. Our ultimate goals in space are to be able to go anywhere, with whatever capabilities we need, for as long as we want, to carry out any mission we can imagine. By establishing a foothold on the Moon, we will be another giant step closer to expanding our reach into the universe, ensuring our survival and improving life here on Earth.

Geopolitical and Strategic Implications of Robust Access to Cislunar Space

Footprints made by Apollo astronauts echo other first steps humans have made journeying across the continents and seas of Earth. This new space age similarly will extend humanity's reach. America's strength is born out of the pursuit of new frontiers followed by the settlement, development, and subsequent unleashing of powerful intellectual, scientific, and economic forces.[28] A new industrial revolution is now underway, based around knowledge and information. A new beachhead, the littoral sea beyond Earth's shores, beckons, resounding with analogies from an earlier period of maritime development.

Because of geography, technological advantage, global strategic, and economic power position, the U.S. historically has had a far greater success, reach and reliance on cislunar space than any other nation. We have grown dependent upon the images, information, and economic stimulation derived from space. The question now is how will the world leverage and transition space capabilities developed since Apollo. U.S. leadership, though essential and key to help guiding the standards and operating norms of cislunar space, is not guaranteed. Therefore, we have the most to gain and to lose.

We need a strategic and comprehensive cislunar strategy, built upon our national heritage of public openness and transparency, along with the establishment of international rules of the road through leadership, extension, and creation of opportunities. An analog to this fundamental shift is the development of modern naval policy at beginning of the 20th century. Secretary of the Navy, Abel P. Upshur (1841–1843), stated that a maritime policy was needed that would promote and protect commerce of every sector, class, and economic group in the country.[29] Overseas stations were required to accomplish this goal. Rear Admiral Alfred Thayer Mahan, who articulated this new maritime philosophy, encapsulated its objectives as: display the flag, open new markets to U.S. commerce, protect commerce, aid vessels in distress, extend the bounds of oceanography (and other scientific research), clear seas of pirates, and project power.[30] This new maritime strategy melded with a geopolitical focus conceived and instilled into the national ethos by President Theodore Roosevelt that centered upon opening up physical frontiers as a means to extend U.S. preeminence globally and fuel intellectual, economic, and human growth.[31] This period of time represented a national shift outwards in a manner that unified the nation beyond the frontier of the American west to the new oceans and frontiers of the world.

We are now at a similar nexus. Today, the main difference is that the opportunities that stand before us can be shared by all who participate, given that space is legally codified as a "province of all mankind" in the Outer Space Treaty of 1967. The world context is no longer the same as the capital of knowledge, innovation, and resources of space cannot be controlled or locked up by national boundaries or by force alone.

Built upon our national approach to use space for transparency, stewardship, and myriad other purposes, the extension of permanent human presence in space beyond LEO to the Moon will help create sustainable space security. It will provide the nation with an important and highly visible outlet to demonstrate the best of our nation and heritage—a beacon of opportunity and advancement. Through leadership in the development of cislunar space, America will help shape the direction of other states and actors in space. We will promote American interests in space and help influence those that use space towards opportunity and stewardship of this important region. International collaboration offers a means to globally enhance overall capabilities and benefits, while also aiding in the development of greater international stability and norms in space.

A strategic framework to support permanent human presence on the Moon and beyond would recognize the increased dependencies, such as the range of participants and access to space now available. We must shift our national security focus away from reliance on limited Earth-bound, "coastal" strategies like responsive space and control of LEO, to an integrated strategy based upon building long-term, unconstrained security in cislunar space. The transportation system that NASA is building from Space Shuttle assets and other capabilities will extend our ability to place critical assets further out in space, make asymmetric advances beyond current and conceivable threats, and add depth to our national security framework. At the same time, it will also push beyond a passive, status-quo approach towards national security space and a sole reliance on current international rules of the road in space.

A strategic moment has arrived, born both out of the tragedy of the Space Shuttle Columbia and the development of global interests in space. To fully realize this opportunity, American leadership, in line with our nation's pride and tradition of exploration, must strategically weave together commercial, scientific, and social interests in the promotion of a permanent human presence in space and in the development of cislunar space.

Pathway to the Future

America has critical domestic needs that call for a technically challenging series of goals to engage, inspire, and stimulate education of our youth. National security depends on a technically literate workforce; since approximately the mid 1970s, most Ph.D.s from American institutions in science, technology, engineering, and math disciplines are awarded to foreign nationals.[32] A long-range plan to establish preeminence in cislunar space and a sustained presence on the Moon, leading to further exploration, provides a set of goals to engage our youth, excite the imagination, and foster high technical achievement.

The American civil space program had its origins in a race between ideological foes. But the race to the Moon did more than prove American technical skill and the power of a free society. An unexpected gift from Apollo was a wholly unexpected glimpse into our own future. From the chemical and physical evidence of impact, about which we learned from the lunar rocks, and the terrestrial fossil record, we discovered that large body collisions had occurred on the Earth in our distant past and will occur again in our future.[33] Such catastrophes resulted in the widespread destruction of life, in some cases eliminating in an instant more than 90% of all living species. In short, we discovered that in the long run, species become extinct and that ultimately, life on Earth is in peril. Our new understanding of impact as a fundamental geological force leaves us only with the question of when, not if, the next large collision will occur. And "when" is something that we cannot predict beyond short-range timescales.

Human culture is cumulative. Our civilization provides positive and beautiful things through music, art, and knowledge–it embodies the collected wisdom of all who have gone before us. Before passing the torch to our children, we should strive to create something of long-term value, something that will exist long after our time on this planet. The journey beyond Earth's shores marks the beginning of an unending journey for humanity. It is a fortunate gift of nature that we can leave this world at all. If Earth's gravity were a little bit greater, or if the chemical bonds of the molecules that make up rocket propellant were just a little bit stronger, we would not be able to achieve the speeds necessary to reach Earth orbit, the first step into the cosmos.

The Vision for Space Exploration and its embrace by the U.S. Congress opens up the opportunity to extend human reach by developing new capabilities in space travel, such as the production of rocket propellant on the Moon to create the first "off-shore" refueling station in space. Returning to the Moon will facilitate that goal. There we will gain technical ability and learn how to use the abundant energy and material resources waiting on other worlds. With the knowledge of how to "live off the land" in space, we can move out into the universe, and ultimately populate one world after another.

The significance of such a movement should not be underestimated. Alone among all known life forms, only humans have the potential capability to willfully extend our destinies. By establishing reservoirs of human culture off-planet, we are writing a wholly new and unprecedented chapter in the history of life. Space extends our reach and fulfills our need to explore the unknown. It is the fulfillment of our destiny.

Notes

1. Executive Office of the President, *A Renewed Spirit of Discovery*, Washington, DC: White House, January 2004). http://www.whitehouse.gov/space/renewed_spirit.html (accessed).
2. Sprout, Harold and Sprout, Margaret *The Rise of American Naval Power 1776–1918*, (Princeton: Princeton University Press, 1966).

3. Columbia Accident Investigation Board, 2003, Final Report, http://caib.nasa.gov/news/report/volume1/default.html
4. The Vision for Space Exploration, NASA Feb. 2004, http://www.nasa.gov/pdf/55583main_vision_space_exploration2.pdf
5. Congress of the United States, NASA Authorization Bill, S. 1281, http://www.govtrack.us/data/us/bills.text/109/s/s1281.pdf
6. Report of the Commission to Assess United States National Security Space Management and Organization, 2001, http://www.defenselink.mil/pubs/space20010111.html
7. The Vision (note 4).
8. Executive Office (note 1).
9. Japan will launch SELENE and China plans a lunar orbiter Chang'E in 2007, http://www.lpi.usra.edu/expmoon/future/future.html
10. M. O'Hanlon, *Neither Star Wars nor Sanctuary: Constraining the Military Uses of Space*, Brookings Institute, Washington, D.C., 2004).
11. N. Gallagher, *Towards a Reconsideration of the Rules of Space Security, in Perspectives on Space Security* (Space Policy Institute, George Washington University, Washington, D.C., 2005).
12. Mass numbers for Apollo 16 and 17 missions, http://en.wikipedia.org/wiki/Apollo_16; http://en.wikipedia.org/wiki/Apollo_17
13. Cost of Chandrayaan 1, ISRO, http://www.digi-help.com/space/chandrayaan-1-moon-mission.asp
14. See, for example, C. Murray and C. Cox, *Apollo: The Race to the Moon* (New York and Chicago: Simon and Schuster, NY, 1989) and J.M. Logsdon, *The Decision to go to the Moon: Project Apollo and the National Interest* (Chicago, IL: Univ. Chicago Press, 1976).
15. Executive Office (note 1).
16. P.D. Spudis, *The Once and Future Moon* (City, ST: Smithsonian University Press, 1996).
17. See for example, D.B.J. Bussey, P.D. Spudis, M.S. Robinson, Illumination conditions at the lunar South Pole, *Geophys. Res. Lett.* 26: 9 (1999): 1187.
18. A.R. Vasavada, D.A. Paige, and S.E. Wood, Near-surface temperatures on Mercury and the Moon and the stability of polar ice deposits, *Icarus* 141 (1999): 179–193.
19. S. Nozette, P.D. Spudis, M. Robinson, D.B.J. Bussey, C. Lichtenberg, and R. Bonner, Integration of lunar polar remote-sensing data sets: Evidence for ice at the lunar South Pole, *J. Geophys. Res.* 106: E19 (2001): 23253–23266; W. Feldman, *et al.*, "Polar hydrogen deposits on the moon," *J. Geophys. Res.* 105: E2 (2000): 4175–4195.
20. Regolith solar wind and impact record—see LEXSWG, 1992, *A Planetary Science Strategy for the Moon.* NASA JSC, http://www.lpi.usra.edu/lunar_resources/strategy.pdf
21. D. Raup, *The Nemesis Affair* (New York: Norton Inc., 1986).
22. For an extended discussion of Apollo spin-off figures, see H.R. Hertzfeld, *Space as an Investment in Economic Growth*, AIAA Conf. And Exposition, Albuquerque NM, 1999.

23. LEXSWG, 1992 *A Planetary Science Strategy for the Moon*, NASA JSC, http://www.lpi.usra.edu/lunar_resources/strategy.pdf
24. J. Burns, N. Duric, J. Taylor, and S.W. Johnson, "Observatories on the Moon," *Scientific American* 262 (1990): 42.
25. R. Bialecki, and P. Kokh, *Lunar Quarantine Facility for Mars Sample Returns*, Moon Miner's Manifesto 110, Nov. 1997, http://www.asi.org/adb/06/09/03/02/110/quarantine-marsmission.html
26. P.D. Spudis, "Harvest the Moon," *Astronomy*, 31: 6 (June 2003): 42–47.
27. D. Criswell, 2003, Senate testimony, http://www.spaceref.com/news/viewsr.html?pid=10926
28. F.J. Turner, *The Frontier in American History* (City, ST: Dover, 1986).
29. Sprout and Sprout (note 2).
30. A.T. Mahan, *The Influence of Sea Power in History, 1660–1783* (City, ST: Dover, 1892).
31. J. Reckner, *Teddy Roosevelt's Great White Fleet* (City, ST: Bluejacket Books, 2001).
32. National Science Foundation, *Science and Engineering Indicators* (Washington, DC: United States Government Printing Office, 2002).
33. Raup (note 21).