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Paper Session II-A - Looking Backward/Looking Forward: Space Flight at the Turn of the New Millennium

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Introduction

On March 16, 1926, seventy-six years ago, a reclusive Robert H. Goddard launched the world's first liquid-fueled rocket at Auburn, Massachusetts, which traveled 43 feet in 2½ seconds. This event could appropriately be characterized as the "Kitty Hawk" of space exploration and the beginning of what would eventually become one of the most significant endeavors of the twentieth century. In the space allotted for this article, I shall survey fifty years of space exploration, reviewing the major programs of human and robotic exploration from the first efforts to reach space in 1957-1958 through the enormously successful spaceflight programs of the recent past. Using this historical base as a jumping-off point, I shall offer some comments on the possibilities available for the next fifty years in spaceflight.[1]

The Three Great Ages of Exploration

There have arguably been three great ages of exploration in the history of Western civilization, the last of which presently informs our everyday lives even as it remains in its infancy. Space exploration, as well as other attributes, fits into this third age and helps define it to observers. Each of these three ages of exploration became central to the worldview of the civilization. In other times and places, exploration had taken place, and civilizations had experienced challenges of new lands and situations similar to that found in the three great ages, but in those instances, there was a marked difference in that exploration did not become the basis for a world system.[2]

In each of the three great ages of exploration in Western civilization, five basic attributes fundamentally shaped the nature of the exploration. Without any one, it is unlikely that the age would have developed as it did. The first of these is the political will to carry out expeditions of exploration. Since most expeditions in all three ages, and virtually all of the large ones, have been sponsored by governments, those governmental decision-makers have to agree that the expenditure of funds for exploration is in the best interest of the state. Without that political will, discovery and exploration cannot take place. Second, the sponsoring organization must have a sufficiently productive and stable economic base for a measurable percentage of its budget to be expended in this manner. Third, the citizens or subjects of the sponsoring entity must agree, or at least acquiesce, in the decision of the leadership that exploration of the physical unknown is an acceptable endeavor and worthy of support. Without this tacit approval, even if there are no direct referenda on the subject, leaders cannot sustain exploration for long. Fourth, there has to be a scientific basis of knowledge to which information gathered in exploration might be added and folded into the dynamic scientific model. Finally, enabling technologies must be available to allow the explorers to succeed.[3]

The first great age of discovery began during the European Renaissance of the fifteenth century. Nothing could ever be the same again, as Western Europe was transformed by exploration and contact with new lands and peoples during voyages of discovery between the fifteenth and eighteenth centuries. During this era ocean-going ships from the great seafaring nations of Western Europe essentially redrew both the map and conception of the world. When they were done, the contours of the great continents of the Earth had been approximated and the general size and shape of the physical world had been determined with relative accuracy. As Peter Martyr wrote in 1493, just as this age of exploration was opening, "Enough for us that the hidden half of the globe is brought to light,...Thus shores unknown will soon become accessible; for one in emulation of another sets forth in labours and mighty perils." During this first age of discovery, travel came mainly over the oceans of the Earth, as European sailors mapped the coastlines of the Americas, Africa, Australia, and even Antarctica. Its great explorers included Christopher Columbus, Ferdinand Magellan, Henry Hudson, Jacques Cartier, and James Cook, among others. The classic expression of this age of exploration, perhaps, was the circumnavigation of the globe. Their reconnaissances proved critical to the success of the age, and the bulk of their accumulated data on peoples and geographies transformed Western civilization.[4]

For the second age, which began before the end of the first and even coincided with it in places and circumstances, exploration came predominantly overland as European adventurers filled in many of the details of the continental interiors. In the process, geographical knowledge continued to explode, but so too did information about peoples and natural history. The southwestern North American expedition of Coronado in 1540, the Lewis and Clark Expedition of the Rocky Mountain west of North America in 1804-1806, the efforts of Sir Richard Burton and Stanley and Livingston in Africa, and travels to the sources of the Amazon in South America and the Nile in Africa all characterized the second great age of exploration.[5] This second age of exploration effectively closed with the conclusion of the last great expeditions into the interiors of the continents in the later nineteenth century. It, too, led to a massive accumulation of data about these lands new to European civilization and transformed the scientific world with the cataloging of much new information.[6]

The third great age of exploration has been fundamentally a twentieth-century phenomenon and is strikingly different from what went before because of the areas investigated. The movement of explorers, both human and robotic sensors, into realms where humanity cannot live without the benefit of artificial apparatus has characterized this third age. Exploration on the two poles of Earth, under the oceans, and in space all suggest a new age of discovery and inquiry. The explorers of this new age include Richard Byrd with his epic North Pole flight of 1926, Jacques Cousteau and the voyages of his scientific vessel *Calypso*, Soviet cosmonaut Yuri Gagarin's flight as the first human in space in 1961, and American astronaut Neil landing on the Moon in 1969.

Although true in the earlier ages of exploration huge investments in technology over long periods made possible these explorations. It cost approximately $25 billion to mount the Apollo program to explore the Moon in the 1960s. Earlier expeditions might have been smaller, but they were proportionately expensive. The returns on investment in this age of exploration, which are only now beginning to be realized, involve the geophysical inventory of a planet and the exploitation of these new regions for all types of commercial ventures that have changed our lives. Remote sensing satellites have made life strikingly different from what it was only a generation ago as satellite images of weather patterns enable meteorologists to forecast storms, as communications satellites transform our ability to move information, and as global positioning satellites provide instantaneous reliable geographical information.[7]

The sum total of this transformation has informed our perspective on the world around us. It is also appropriate that by analogy we also question the peculiarity of exploration by civilizations. Ingrained as it became in Western culture beginning in the sixteenth century, it gave birth to the scientific revolution and the transformation of our beliefs and ideals in response to it.[8]

The von Braun Paradigm

Much of what has passed for space policy since the third age of exploration might best be characterized as the "von Braun paradigm," named for the handsome German émigré. Wernher von Braun called for an integrated space exploration plan centered on human movement beyond this planet and involved these basic ingredients accomplished in this order.[9]

1. Earth orbital satellites to learn about the requirements for space technology that must operate in a hostile environment.
2. Earth orbital flights by humans to determine whether or not it was possible to explore and settle other places.
3. Develop a reusable spacecraft for travel to and from Earth orbit, thereby extending the principles of

atmospheric flight into space and making routine space operations.

4. Build a permanently inhabited space station as a place both to observe the Earth and from which to launch future expeditions. This would serve as the base camp at the bottom of the mountain or the fort in the wilderness from which exploring parties would depart.
5. Undertake human exploration of the Moon with the intention of creating Moon bases and eventually permanent colonies.
6. Undertake human expeditions to Mars and eventually colonize the planet.

This von Braun paradigm has cast a long shadow over American efforts in space for over fifty years. It conjured powerful images of people venturing into the unknown to make a perfect society free from the boundaries found on Earth. As such it represented a coherent and compelling definition of American ideals in space. In many respects von Braun's vision of space exploration has served as the model for U.S. efforts in space through the end of the twentieth century.[10] Von Braun espoused these ideas in a series of important *Collier's* articles over a three-year period in the early 1950s, each with striking images by some of the best artists of the era, and later in a classic set of three Disney television programs.[11]

NASA accepted this paradigm as the *raison d'etre* of its programs beginning in 1959 and it has doggedly stayed with it throughout the latter twentieth century. It drove the United States to develop the Space Shuttle as a means of achieving routine access and prompted an international consortium of nations to build a space station to achieve a permanent presence in space. Only through the achievement of these goals, space advocates insist, will a vision of space exploration that includes people venturing into the unknown be ultimately realized.[12]

Kennedy's decision to race the Soviets to the Moon in the 1960s fundamentally altered the von Braun paradigm. Specifically because of Apollo, NASA lost the rationale for a space station, objective 4, viewed by everyone both then and thereafter as critical for the long-term exploration and development of space. As soon as Apollo succeeded, NASA went back to the paradigm and has followed to the present. The last element of the von Braun paradigm required human expeditions to Mars. Something that is still very much on the agenda. Wernher von Braun envisioned huge armadas of what looked like V-2 rockets flying to Mars and a crew of more than 100 staying on the surface for more than year. While NASA has not done that, and will not do so anytime soon, preparations have been underway for a long time using robotic spacecraft.[13]

Core Challenges for the Future

While other analysts might differ with my list, I would suggest that there are five core challenges for those engaged in spaceflight in the twenty-first century. Each of these may be traced far back in the history of the space age, and have served as perennial issues affecting all outcomes involving an expansive future beyond this planet.

The first of these challenges involves the political will to emphasize spaceflight. At a fundamental level, it is the most critical challenge facing those who wish to venture into space in the coming century. It is even more significant than the technological issues that also present serious challenges. Since most space activities, and virtually all of the large ones, have been sponsored by governments, those governmental decision-makers have to agree that the expenditure of funds for exploration is in the best interest of the state. Without that political will, discovery and exploration cannot take place.[14]

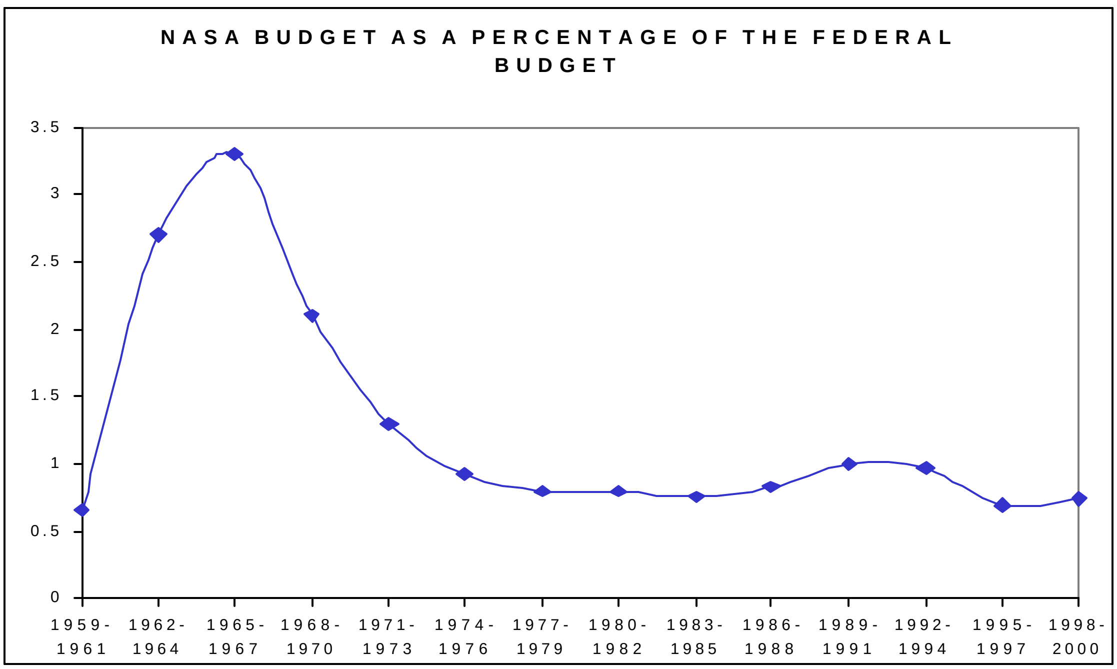
At the same time, an expansive program of space exploration has not often been consistent with many of the elements of political reality in the United States since the 1960s. Numerous questions abound at the end of the century concerning the need for aggressive exploration of the Solar System and the desirability of colonization on other worlds. A vision of aggressive space exploration, wrote political scientist Dwayne A. Day,

> implies that a long range human space plan is necessary for the nation without justifying that belief. Political decision-makers have rarely agreed with the view that a long range plan for the human exploration of space is as necessary as—say—a long range plan for attacking poverty or developing a strategic deterrent. Space is not viewed by many politicians as a "problem" but as at best an opportunity and at worst a luxury.[15]

Most importantly, the high cost of conducting space exploration comes quickly into any discussion of the endeavor.

Of course, there are visions of space flight less ambitious than the von Braun paradigm that might be more easily justified within the democratic process of the United States. Aimed at incremental advances, these include robotic planetary exploration and even limited human space activities. Most of what is presently underway under the umbrella of NASA in the United States and the other space agencies of the world fall into this category. Yet, these only moderately ambitious space efforts also raise important questions about public policy priorities and other fiscal responsibilities. At present the NASA budget, however, stands at only about three-quarters of one percent of the Federal budget and has been declining both in real terms and as a percentage of the Federal budget most years at the beginning of the new century. As shown in Figure 1, with the exception of a few years in the mid-1960s as NASA prepared for Apollo flights to the Moon, stability has been the norm as the annual NASA budget has incrementally gone up or down in relation to a one-percent benchmark in the federal budget.[16]

Figure 1



The second challenge after creating political will in favor of spaceflight is the task of developing multifaceted, inexpensive, safe, reliable, and flexible access to space. Pioneers of spaceflight believed that humans could make space travel safe and inexpensive. They gained confidence by watching aeronautical engineers develop jetliners that moved people through the air within forty years of the Wright brothers' first flight. Despite years of effort, however, the dream of cheap and easy space access has not been attained. Costs remain particularly high.[17]

Since the beginning of spaceflight more than forty years ago, those who seek to travel in space have been, in essence, between a rocket and hard place. The enormous release of energy made possible through the development of chemical rocket technology, allowed the first generation of launch vehicles to free humanity and its robots from the constraints of Earth's gravity. It allowed the still exceptionally limited exploitation of space technology for all manner of activities important on Earth—communications, weather, GPS, and a host of other remote sensing satellites—to such an extent that many individuals in the United States today cannot conceive of a world in which they did not exist. This same chemical rocket technology made possible human flight into space, albeit for an exceptionally limited number of exceptional people, and the visiting of robotic probes from this planet to our neighbors in the Solar System.[18]

These have been enormously significant, and overwhelmingly positive, developments. They have also been enormously expensive, despite sustained efforts to reduce the cost of spaceflight. One is to use rocket propulsion and, with new materials and clever engineering, to make a launcher that is not only recoverable, but also robust. The other is to use air-breathing launchers, and thus to employ the potentially large mass fractions that air breathing theoretically promises to build a robust launcher. Then there are other options still. Most launch vehicle efforts throughout the history of the space age, unfortunately, have committed a fair measure of self-deception and wishful thinking. A large ambitious program is created, hyped, and then fails as a result of unrealistic management, especially with regard to technical risk. These typically have blurred the line, which should be bright, between revolutionary, high-risk, high-payoff R&D efforts and low-risk, marginal payoff evolutionary efforts to improve operational systems. Efforts to break the bonds of this deception may well lead in remarkable new directions in future launcher development efforts. Only once that happens will humanity be able to escape the nether world "between a rocket and a hard place."[19]

The third challenge revolves around the development of smart robots to explore the Solar System. Humans may well travel throughout the Solar System in ways unimagined by the first pioneers: that is, by not physically going at all. Using the power of remote sensing, humans could establish a virtual presence on all the planets and their moons through which those of us on Earth could experience these sites without leaving the comfort of our homes. Humans might not progress naturally toward the colonization of Mars in this scenario, with extensive exploration by robotic machinery taking place. Because of this, the human dimension of spaceflight could take on a less critical aspect than envisioned by most spaceflight advocates.

One of the unique surprises of the space age that opened with Sputnik in 1957 has been the rapid advance in electronics and robotics that made possible large-scale spaceflight technology without humans not only practicable but also desirable. This has led to a central debate in the field over the role of humans in spaceflight. Perhaps more can be accomplished without human presence. Clearly, if scientific understanding or space-based applications or military purposes are driving spaceflight as a whole, then humans flying aboard spacecraft have little appeal. Their presence makes the effort much more expensive because once a person is placed aboard a spacecraft the primary purpose of that spacecraft is no longer a mission other than bringing the person home safely. But if the goal is human colonization of the Solar System then there are important reasons to foster human spaceflight technology.

This debate has raged for decades without resolution. It is reaching crescendo proportions in the first decade of the twenty-first century as the ISS is coming on-line and discussions of future efforts beyond the station emerge from the public policy nether land. Scientist Paul Spudis observed: "Judicious use of robots and unmanned spacecraft can reduce the risk and increase the effectiveness of planetary exploration. But robots will never be replacements for people. Some scientists believe that artificial intelligence software may enhance the capabilities of unmanned probes, but so far those capabilities fall far short of what is required for even the most rudimentary forms of field study." Spudis finds that both will be necessary. "The strengths of each partner make up for the other's weaknesses," he writes. "To use only one technique is to deprive ourselves of the best of both worlds: the intelligence and flexibility of human participation and the beneficial use of robotic assistance."[20]

The fourth challenge concerns protecting this planet and this species. The twenty-first century may well prove to be the most difficult for humanity since the advent of the Renaissance. During the century earthlings will face three great environmental challenges: overpopulation, resource depletion (especially fossil fuels), and environmental degradation. Without space-based resources—especially remote sensing satellites that monitor Earth—humans will not be able to control these trends.[21]

Humans can use space as a place from which to monitor the health of Earth, maximize natural resources, and spot polluters. By joining space with activities on the ground, humans have a fighting chance to protect the environment in which they live. Using space to protect Earth will be as important to twenty-first century history as Moon landings were to the twentieth. At the same time, humans will confront the consequences of environmental degradation *in* space. Orbital debris, derelict spacecraft, and satellites reentering the atmosphere have already created hazards around Earth. Proposals to strip mine the Moon and asteroids make many people blanch; how dare humanity, having fouled the Earth, destroy the pristine quality of extraterrestrial bodies? The environmental movement will move into space.[22]

All of these issues–the use of space for monitoring Earth, environmental degradation in space, and biological contamination–promise to create a new perspective on space exploration. As a result, humans in the twenty-first century will witness the greening of space.

A final challenge will be the sustained human exploration and development of space. As an early step, the creation of a permanently occupied space station, something that has long been a critical component in space architecture, is presently underway. Although sidetracked by Apollo, in the post-Cold War era, the United States and the former Soviet Union have joined to make a reality the long-held vision of a space station in Earth orbit. This relationship, along with the critical partnership of numerous other nations, made the International Space Station (ISS) a reality in 2000 when the first crew set up residence aboard the craft. With this accomplishment, the space-faring nations of the world intend that no future generation will ever know a time when there is not some human presence in space. Once functioning in space, the station should energize the development of private orbital laboratories. Such laboratories would travel in paths near the International Space Station. The high-tech tenants of this orbital "research park" would take advantage of the unique features of microgravity. This permits research not possible on Earth in such areas as materials science, fluid physics, combustion science, and biotechnology.[23]

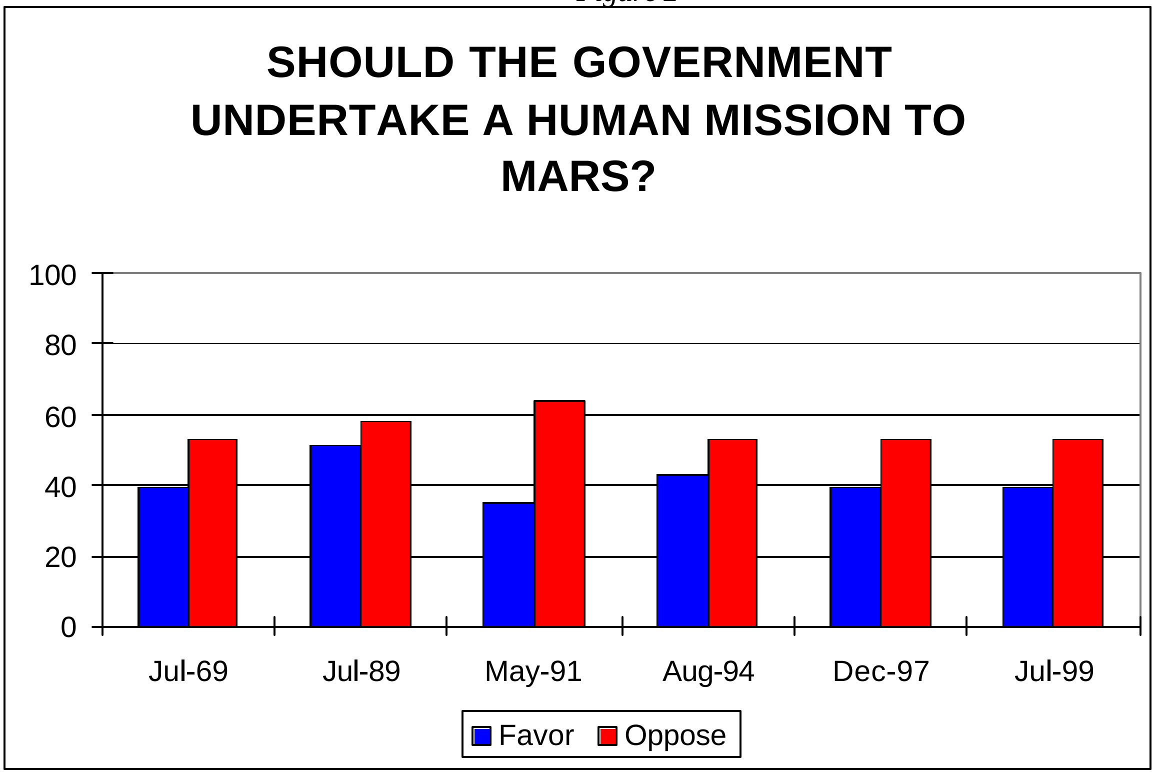
Using the space station as a base camp, humanity may well be able to return to the Moon and establish a permanent human presence there. It is no longer hard to get there. All of the technology is available to land and return. Such an endeavor requires only a modest investment, and the results may well be astounding. Why return to the Moon? This is a critical question, especially since humans have already "been there, done that." There are six compelling reasons:

1. It is only three days travel time from Earth, as opposed to the distance to Mars of nearly a year's travel time, allowing greater safety for those involved.
2. It offers an ideal test bed for technologies and systems required for more extensive space exploration.
3. It provides an excellent base for astronomy, geology, and other sciences, enabling the creation of critical building blocks in the knowledge necessary to go farther.
4. It extends the knowledge gained with the space station in peaceful international cooperation in space and fosters stimulation of high-technology capabilities for all nations involved.
5. It furthers development of low-cost energy and other technologies that will have use not only on the Moon but also on Earth.
6. It provides a base for nuclear weapons that could be used to destroy near-Earth asteroids and other threats to Earth.[24]

From the Moon, the last step in the von Braun paradigm is a human mission to Mars, but the task is awesome. A majority of Americans do not support human missions to Mars and never have. Consistently, only about 40 percent of those polled have supported human missions to Mars, as shown in Figure 2. In that climate there is little political justification to support an effort to conquer Mars.[25]

Of course, the United States could send human expeditions to Mars. There is nothing magical about it, and a national mobilization to do so could be successful. But a human Mars landing would require a decision to accept enormous risk for a bold effort and to expend considerable funds in its accomplishment for a long period. Using Apollo as a model—addressed as it was to a very specific political crisis relating to U.S./Soviet competition—anyone seeking a decision to mount a human expedition to Mars must ask a critical question. What political, military, social, economic, cultural challenge, scenario, or emergency can they envision to which the best response would be a national commitment on the part of the president and other elected officials to send humans to Mars? In addition, with significantly more failures than successes, and half of the eight probes of the 1990s ending in failure, any mission to Mars is at least an order of magnitude greater in complexity, risk, and cost than returning to the Moon.[26] Absent a major surprise that would change the space policy and political landscapes, I doubt we will land on Mars before the mid-twenty-first century.

Figure 2



Conclusion

Since the dawn of the space age, humanity has developed the capability to move outward in a third great age of discovery and exploration. In so doing it has followed with rare deviations a set of stepping stones aiming toward a permanent presence in Earth orbit, on the Moon, and at Mars. In the process much has been accomplished, some tragedies have occurred, and several challenges remain. Who knows what transforming discoveries will be made in the first part of the twenty-first century that will alter the course of the future. Humans may well discover extraterrestrial life, or detect Earth-like planet around a nearby star, or discover some here-to-fore unknown principle of physics. Virtually any forecasts made are possible; but none are guaranteed. Only one feature of space exploration is inevitable. Something unexpected will occur. Space is full of achievements, disappointments, and surprises. By going into space, humans learn what they do not know. Properly conducted, this effort may foster a hopeful future.

Notes

[1] This discussion is predicated on Roger D. Launius and Howard E. McCurdy, *Imagining Space: Achievements, Predictions, Possibilities, 1950-2050* (San Francisco: Chronicle Books, 2001).
[2] See Stephen J. Pyne, "Space: A Third Great Age of Discovery," *Space Policy* 4 (August 1988): 187-99.
[3] Roger D. Launius, *Frontiers of Space Exploration* (Westport, CT: Greenwood Press, 1998), pp. 3-5.
[4] One of the best works on this exploration is Daniel J. Boorstin, *The Discoverers: A History of Man's Search to Know his World and Himself* (New York: Random House, 1983), pp. 145-201, quote from p. 145.
[5] See William H. Goetzmann, *New Lands, New Men: America and the Second Great Age of Discovery* (New York: Viking Press, 1986).

[6] Stephen E. Ambrose, *Undaunted Courage: The Life of Meriwether Lewis* (Garden City, NY: Doubleday and Co., 1996), makes the case that the Lewis and Clark expedition of 1803-1806 was successful at many levels but that the most enduring legacy may well have been the scientific information gathered by the team.
[7] Stephen J. Pyne, *The Ice: A Journey to Antarctica* (Iowa City: University of Iowa Press, 1986); Nathan Reingold, ed., *The Sciences in the American Context: New Perspectives* (Washington, DC: Smithsonian Institution Press, 1979); Norman Cousins, et al., *Why Man Explores* (Washington, DC: NASA Educational Publication-125, 1976); Sarah L. Gall and Joseph T. Pramberger, *NASA Spinoffs: 30 Year Commemorative Edition* (Washington, DC: National Aeronautics and Space Administration, 1992).
[8] See Derek Price, *Science Since Babylon* (New Haven, CT: Yale University Press, 1975), pp. 10-11.
[9] On Wernher von Braun, see Michael J. Neufeld, *The Rocket and the Reich: Peenemünde and the Coming of the Ballistic Missile Era* (New York: The Free Press, 1995).
[10] Dwayne A. Day, "The Von Braun Paradigm," *Space Times: Magazine of the American Astronautical Society* 33 (November-December 1994): 12-15.
[11] On these articles, see Randy Liebermann, "The *Collier's* and Disney Series," in Frederick I. Ordway III and Randy Liebermann, eds., *Blueprint for Space: Science Fiction to Science Fact* (Washington, DC: Smithsonian Institution Press, 1992), pp. 135–44; "Man Will Conquer Space *Soon*" series, *Collier's* (March 22, 1952): 23–76ff; Wernher von Braun with Cornelius Ryan, "Can We Get to Mars?" *Collier's* (April 30, 1954): 22–28.
[12] See Roger D. Launius, *Space Stations: Base Camps to the Stars* (Washington, DC: Smithsonian Books, 2003), chapter 2.
[13] Launius and McCurdy, *Imagining Space*, pp. 55-67.
[14] William E. Burrows, *The Infinite Journey: Eyewitness Accounts of NASA and the Age of Space* (New York: Discovery Books, 2000), p. 147.
[15] Day, "Von Braun Paradigm," p. 15.
[16] This observation is based on calculations using the budget data included in the annual *Aeronautics and Space Report of the President* (Washington, DC: NASA Report, 2002), which contains this information for each year since 1959.
[17] See Roger D. Launius and Dennis R. Jenkins, eds., *To Reach the High Frontier: A History of U.S Launch Vehicles* (Lexington: University Press of Kentucky, 2002).
[18] See Roger D. Launius, "Between a Rocket and a Hard Place: The Challenge of Space Access," in W. Henry Lambright, ed., *Space Policy in the 21st Century* (Baltimore, MD: Johns Hopkins University Press, 2002), pp. 15-54; Richard P. Hallion, "The Development of American Launch Vehicles since 1945," in Paul A. Hanle and Von Del Chamberlain," eds., *Space Science Comes of Age: Perspectives in the History of the Space Sciences* (Washington, DC: Smithsonian Institution Press, 1981), pp. 126-32; United States Congress, Office of Technology Assessment, *Launch Options for the Future: Special Report* (Washington, DC: Government Printing Office, 1984); Vice President's Space Policy Advisory Board, "The Future of U.S. Space Launch Capability," Task Group Report, November 1992, NASA Historical Reference Collection, NASA History Office, Washington, DC; NASA Office of Space Systems Development, *Access to Space Study: Summary Report* (Washington, DC: NASA Report, 1994).
[19] See Andrew J. Butrica, *Single Stage to Orbit: Politics, Space Technology, and the Quest for Reusable Rocketry* (Baltimore, MD: Johns Hopkins University Press, 2003).
[20] Paul D. Spudis, "Robots vs. Humans: Who Should Explore Space," *Scientific American* 10 (Spring 1999): 25, 30-31, quote from p. 31.
[21] Astronaut John W. Young has developed a variation on the Pogo dictum: "I have seen an endangered species, and it is us." See John W. Young, "The Big Picture: Ways to Mitigate or Prevent Very Bad Planet Earth Events," *Space Times: Magazine of the American Astronautical Society* 42 (May-June 2003): 22-23, forthcoming.
[22] See Antony Milne, *Sky Static: The Space Debris Crisis* (Westport, CT: Praeger Publishing Co., 2002); John S. Lewis, *Rain of Iron and Ice: The Very Real Threat of Comet and Asteroid Bombardment* (Reading, MA: Addison-Wesley Pub. Co., Helix Books, 1997); Roger D. Launius and Howard E. McCurdy, "The Greening of Space," *Space Times: The Magazine of the American Astronautical Society* 40 (November-December 2001): 4-10.
[23] Launius, *Space Stations*, pp. 209-30.
[24] Launius and McCurdy, *Imaging Space*, pp. 99-100.
[25] Roger D. Launius, "The Next -Generation Space Race: What Lessons Can Future Presidents Learn from JFK?" essay on Space.com, October 24, 2000, available on-line at http://www.space.com/opinionscolumns/opinions/jfk_election_leaders.html, accessed July 21, 2002
[26] See Asif A. Siddiqi, *Deep Space Chronicle: Robotic Exploration Missions to the Planets* (Washington, DC: NASA SP-2002-4524, 2002).