SECTION II

HUMAN AND ROBOTIC EXPLORATION

INTRODUCTION

No one realized it initially, but the intricate linking of humans and machines in spaceflight has been one of the most significant aspects of the endeavor. While humans have always been viewed as preeminent in spaceflight, the technology they employed—either in piloted spacecraft or in semiautonomous robots—proved critical to space exploration. This section explores the relationship between humans and machines in the evolution of spaceflight. The three essays consider strikingly different approaches to analyzing the human-machine interface in space exploration.

The chapter by Howard E. McCurdy, a senior space policy historian, addresses the classic debate over the primacy of human versus robotic spaceflight. He finds that the development of spaceflight technology always outstripped the slow evolution of human spaceflight, despite the overwhelming excitement associated with the human element. Virtually no one in history succeeded in making meaningful predictions about this discrepancy. For example, when Arthur C. Clarke envisioned geosynchronous telecommunications satellites in 1945, he believed that they would require humans working on board to keep the satellite operational. In such a situation, it is easy to conceive of the motivation that led people like Clarke and Wernher von Braun to imagine the necessity to station large human crews in space. Some of the most forward-thinking spaceflight advocates, in this instance, utterly failed to anticipate the electronics/digital revolution then just beginning. Humans, spaceflight visionaries always argued, were a critical element in the exploration of the solar system and, ultimately, beyond.[1]

With the rapid advance of electronics in the 1960s, however, some began to question the role of humans in space exploration. It is much less expensive and risky to send robot explorers than to go ourselves. This debate reached saliency early on and became an important part of the space policy debate by the latter 20th century. This has led many scientists and not a few others to question its merits. In the summer of 2004, esteemed space scientist James A. Van Allen asked the poignant question, "Is human spaceflight obsolete?" He commented:

1. Arthur C. Clarke, "Extra-Terrestrial Relays: Can Rocket Stations Give World-Wide Radio Coverage?" *Wireless World* (October 1945): 305–308; Wernher von Braun with Cornelius Ryan, "Can We Get to Mars?" *Collier's* (30 April 1954): 22–28; Randy Liebermann, "The *Collier's* and Disney Series," in *Blueprint for Space: From Science Fiction to Science Fact*, ed. Frederick I. Ordway III and Randy Liebermann (Washington, DC: Smithsonian Institution Press, 1991), pp. 135–144; "Giant Doughnut is Proposed as Space Station," *Popular Science* (October 1951): 120–121.

> My position is that it is high time for a calm debate on more fundamental questions. Does human spaceflight continue to serve a compelling cultural purpose and/or our national interest? Or does human spaceflight simply have a life of its own, without a realistic objective that is remotely commensurate with its costs? Or, indeed, is human spaceflight now obsolete? . . . Risk is high, cost is enormous, science is insignificant. Does anyone have a good rationale for sending humans into space?[2]

The response offered is one that emphasizes human colonization on other planets, moons, and asteroids. As one observer who went by the pseudonym Hans L. D. G. Starlife noted on an Internet discussion list where Van Allen's arguments arose:

> Sure, if it's all about science, you can always raise these questions. But it's not, and it never has been—whatever the scientists themselves try to make us believe. The human expansion into space is about totally different things—although like many times before, it isn't fully apparent until we can see it in the light of history . . . .
>
> In a very long-range perspective, it's easy to see that these ventures, simply make up the path of evolution for Human civilization, not much different from how biological evolution works. Indeed, Human spaceflight is precisely what Van Allen argues it's not: it does and should have a life of its own. Now is the time to once and for all to SEPARATE the case for Human spaceflight with the case for science. These are two different agendas—both worthwhile—and sometimes crossing their paths, but having their own sets of motives and rationales![3]

Indeed, for people of this persuasion, spaceflight is all about making human civilization anew, making it in the mold of the best ideas of those who are founding settlements beyond Earth. It is, and in reality always has been, about creating a technological utopia.

2. James A. Van Allen, "Is Human Spaceflight Obsolete?" *Issues in Science and Technology* 20 (summer 2004), *http://www.issues.org/20.4/p_van_allen.html* (accessed 3 August 2004).

3. Hans L. D. G. Starlife, "On to Mars," *Quark Soup*, 27 July 2004, *http://davidappell.com/archives/00000202.htm* (accessed 3 August 2004).

McCurdy finds that while this debate over primacy in space missions has intensified with time, it does not really consider the core issues at play in space policy. As he notes, the human-robotic debate leaves unaddressed the manner in which humans and machines might become even more tightly linked in future spaceflight activities. McCurdy comments that "the classical visions of human and robotic spaceflight as presented in the popular culture contain instabilities likely to lessen the future influence of these visions. The emerging alternatives are quite exotic and beyond the mainstream of current thinking, yet interesting to contemplate. They may or may not occur. Their consideration, nonetheless, helps to enlarge the contemplation of the directions that future space exploration might take."

In essence, McCurdy suggests that the old paradigm for human exploration—ultimately becoming an interstellar species—is outmoded and ready for replacement. He specifically looks to the future of humans and robots in space and suggests that a posthuman cyborg species may realize a dramatic future in an extraterrestrial environment. This form of speculative futurism in a postbiological universe in which humans may become more robotlike may seem inappropriate for some historians. A question that might be considered is whether or not McCurdy has abandoned traditional modes of argumentation and analysis in favor of political commentary. A related question might focus on whether there even is a traditional mode of argumentation. Regardless of the answers to these questions (and those answers are highly idiosyncratic), there is no question but that McCurdy's essay is highly stimulating and provocative.

Alternatively, Slava Gerovitch's essay on "Human-Machine Issues in the Soviet Space Program" takes a much more traditional historical approach of narrating the evolution of relationships in the Soviet space program between humans and machines. He finds that from the early days of human spaceflight in the Soviet Union, a debate raged between the pilots/cosmonauts and the aerospace engineers over the degree of control held by each group in human-rated spacecraft. The engineers placed much greater emphasis on automatic control systems and sought to reduce drastically the role of astronauts on board a spacecraft. These space engineers often viewed the astronaut as a "weak link" in the spacecraft control system. Of course, the question of whether machines could perform control functions better than people became the subject of a considerable internal controversy. The cybernetics movement attempted to undermine the existing hierarchies of knowledge and power by introducing computer-based models and decision-making mechanisms into a wide range of scientific disciplines. By focusing on the debate over the nature and extent of on-board automation in Soviet spacecraft, Gerovitch illuminates a fascinating world of divergent professional groups within the Soviet space community and how they negotiated their place and their priorities in the system.

Finally, "Human and Machine in the History of Spaceflight," by David A. Mindell, argues for a new research agenda in the history of human spaceflight that moves beyond the virtual catechism of retelling of a specific myth and in that retelling performing a specific purpose. Much of this work has been not so much history as it has been "tribal rituals, meant to comfort the old and indoctrinate the young."[4] He notes that "a series of questions about human/machine interaction in the history of spaceflight can open up new research avenues into what some might think is a well-worn historical topic . . . . The human/machine relationship, as a meeting point for the social and technical aspects of a system, provides access to a variety of other aspects of space history that are otherwise difficult to integrate."

Collectively, these three essays provide a window into a unique area for consideration in the history of spaceflight. All are intellectually, artistically, and historically sound. All make important contributions to the history of human spaceflight and its relationship to robotics and space technology. All offer stimulating conclusions to be pondered, accepted, rejected, or revised as appropriate.

4. Alex Roland, "How We Won the Moon," *New York Times Book Review* (17 July 1994): 1, 25.

CHAPTER 3

OBSERVATIONS ON THE ROBOTIC VERSUS HUMAN ISSUE IN SPACEFLIGHT

Howard E. McCurdy

Since the beginning of the Space Age, people have debated the merits of human versus robotic flight. Some have argued for automated activities or what many—without apparent reference to the presence of women in space—term "unmanned" flight. Astrophysicist James A. Van Allen, designer of the experiment package for the first U.S. orbital satellite, insists that the whole history of spaceflight provides "overwhelming evidence that space science is best served by unmanned, automated, commandable spacecraft."[1] Historian Alex Roland maintains that "for virtually any specific mission that can be identified in space, an unmanned spacecraft can be built to conduct it more cheaply and reliably."[2]

To supporters of human spaceflight, such arguments are misplaced. The relative effectiveness of humans and robots seems irrelevant to people whose primary objective remains the movement of humankind into space. When asked to justify his upcoming lunar voyage, astronaut Neil Armstrong explained that "the objective of this flight is precisely to take man to the moon, make a landing there, and return."[3] From that point of view, human spaceflight provides its own justification. Robots serve as precursors to human flight, not as substitutes for it. Even if robots were more effective, advocates of human flight would not rely entirely upon them. The whole purpose of spaceflight is to prepare humankind to migrate off of the Earth and into the cosmos.

This essay presents a series of observations regarding the relative merits of the longstanding historical debate over human and robotic flight; it is speculative in nature and suggestive of future scholarship. It is also provocative and tentative. And it is an important debate. In many ways, the human and robotic

1. James Van Allen, "Space Station and Manned Flights Raise NASA Program Balance Issues," *Aviation Week & Space Technology* (25 January 1988): 153.

2. Alex Roland, "NASA's Manned Space Nonsense," *New York Times* (4 October 1987): sec. 4, p. 23.

3. Apollo 11 crew premission press conference, 5 July 1969, 2:00 p.m., Apollo 11 mission file, NASA Historical Reference Collection, Washington, DC.

perspectives present the two principal visions that motivate space exploration. The first anticipates the widespread migration of humans off the Earth's surface, while the latter emphasizes the advantages of scientific discovery.

In its speculative sections, the essay anticipates the manner in which the human versus robotic issue might change as space exploration matures. If cosmic exploration continues over the timespans anticipated by its advocates, changes in the dominant visions are probably inevitable. For many years, the robotic vision has stood as the sole alternative to the dominant vision of human spaceflight articulated by early advocates such as Wernher von Braun. This essay suggests that the classical visions of human and robotic spaceflight as presented in the popular culture contain instabilities likely to lessen their future influence. Two emerging alternatives are quite exotic and beyond the mainstream of current thinking, yet interesting to contemplate. They may or may not occur. Their consideration, nonetheless, helps to enlarge the contemplation of the directions that future space exploration might take.

CLASSICAL APPROACHES TO SPACE EXPLORATION

One of the most influential visions of spaceflight, prepared before humans entered space, appeared in the 22 March 1952 issue of *Collier's* magazine. Accompanying an article by Wernher von Braun, a two-page panorama prepared by Chesley Bonestell artistically illustrates human activity in low-Earth orbit. From a point of view well above the Isthmus of Panama, the viewer receives an enticing vision of small space tugs transporting astronauts between a winged space shuttle and a large, rotating space station.[4]

Visions of space exploration, often initiated in science fiction and articulated in popular outlets, shape public policy. They generate public interest, help place exploration on the governmental agenda, and prepare the citizenry for concrete proposals. Especially in the United States, the popular culture of space exploration has played a significant role in determining the types of activities public officials have sought to accomplish.[5] Not by accident did the members of the 1986 National Commission on Space choose to begin their report with a reproduction of the famous Bonestell diorama, juxtaposed with a Robert McCall painting of the actual facilities.[6]

Less well recalled is an object in the painting that Bonestell placed between the winged shuttle and the 250-foot-wide space station. The cylin-

4. Wernher von Braun, "Crossing the Last Frontier," *Collier's* (22 March 1952): 24–25.

5. See Howard E. McCurdy, *Space and the American Imagination* (Washington: Smithsonian Institution Press, 1997).

6. National Commission on Space (Thomas O. Paine, chair), *Pioneering the Space Frontier* (New York: Bantam Books, 1986).

drical object, surrounded by three astronauts, is an orbiting space telescope. Von Braun explained that the telescope would operate in a robotic fashion, without humans on board, since "the movements of an operator would disturb the alignment."[7] The panorama contains both human and robotic elements, yet the presence of a facility that anticipated the Hubble Space Telescope is not well remembered.

As is typical of images transmitted through popular culture, people selectively emphasize elements of the motivating material. The elements that emerge typically resonate with traditions and ideas popular at that time, being so familiar as to require little explanation. The early use of frontier analogies to explain space exploration is a preeminent example of this tendency. The editors at *Collier's* titled the accompanying article "Crossing the Last Frontier." Building transportation systems to transport people to the equivalent of frontier stations resonated well with the pioneering experience from which Americans had only recently emerged.

The inclusion of an orbiting telescope helped von Braun justify the presence of humans in this new frontier. What are astronauts doing to the remotely controlled observatory, and why is it orbiting near the space station? Given the existing state of technology for collecting images from space, von Braun explained, humans would be needed to retrieve and change the film.

As is typical of motivating visions, the expectations made powerful by reference to analogies from the past can be made weak by their encounter with the future. It is a familiar pattern. A vision of the future emerges and becomes part of the popular culture when it resonates so well with the experience of people contemplating a common past. To the extent that the vision is rooted in old and inapplicable analogies, or fails to account for developments yet to fully emerge, it acquires instabilities likely to plague its accomplishment.

The people who popularized the dominant vision of human spaceflight failed to anticipate technical developments that would make the conduct of robotic activities much easier than anticipated. Von Braun believed that astronauts would be needed to change the film in space telescopes. Arthur C. Clarke thought that astronauts would be needed to operate communication satellites. Producers of the classic 1950 film *Rocketship X-M* reinforced a popular misconception when they announced that radio waves from control stations on Earth would not be able to reach a spacecraft bound for Mars, thereby requiring a thinking presence on all missions into the celestial realm.[8]

7. Von Braun, "Crossing the Last Frontier," p. 72.

8. Arthur C. Clarke, "Extra-Terrestrial Relays: Can Rocket Stations Give World-wide Radio Coverage?" *Wireless World* (October 1945): 305–308; Kurt Neumann, *Rocketship X-M* (Kippert, 1950).

Generated at the midpoint of the 20th century, the dominant visions helping to define the impending Space Age failed to anticipate the manner in which electronic technology would expand robotic capabilities. The anticipated difficulties of operating remotely controlled telescopes and satellites provided a major justification for the presence of human crews. Real advances in remote sensing, solid-state transistors, and deep space communications allowed robotic flight to advance well beyond initial expectations and more rapidly than human flight.

What appears to be a failure of anticipation may in large measure arise from a failure of vision, a subtle but important distinction. A failure of anticipation implies an inability to foresee (one could say imagine) future events. Vision, as the term is commonly employed, represents a process in which imagination is joined with forces that motivate people to accept the dream.[9]

It is my contention that both the human and robotic space visions contain elements that make them attractive when viewed as continuations of past traditions. The visions do not fare as well when contemplated from the perspective of emerging trends. In essence, the dominant human and robotic visions account for the past more effectively than they address the future. This explanation requires an historical survey of the human and robotic visions, especially as they appear in popular culture, and some speculation about future developments.

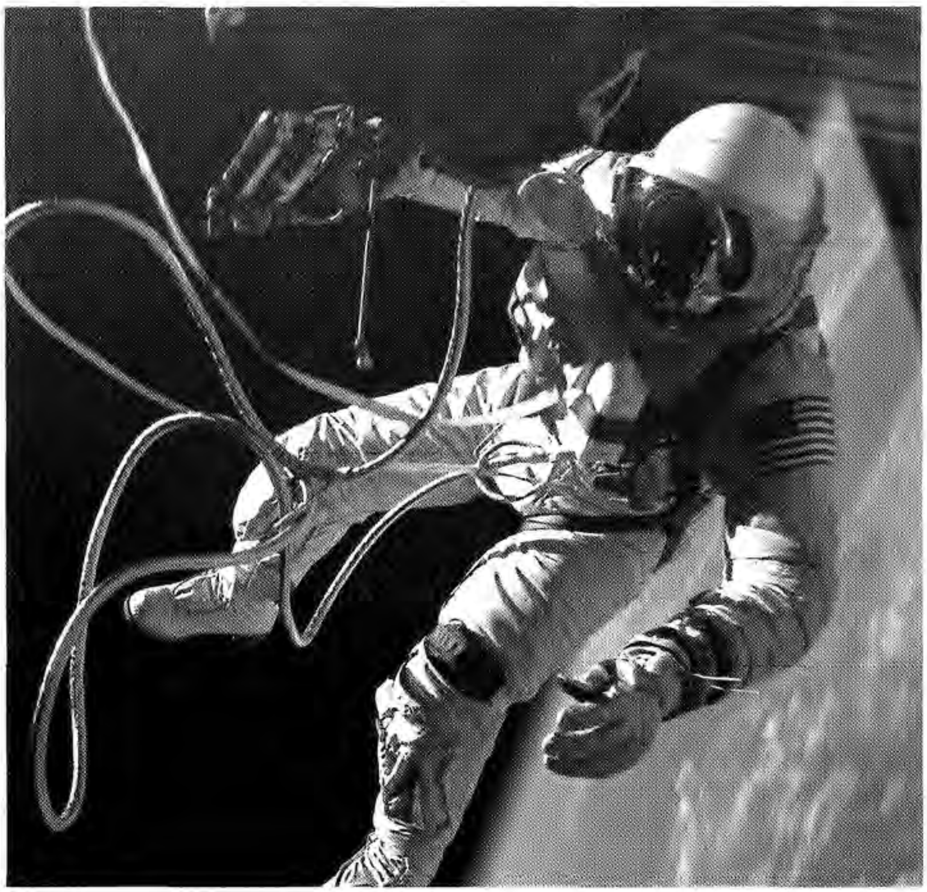
HISTORY AND THE HUMAN SPACEFLIGHT VISION

The vision of human spaceflight is a familiar one. It begins with brave souls venturing in small ships through difficult substance to distant lands. Voyages of discovery produce scientific insights, including the identification of new species. Scientific gain, however, did not provide the ultimate motivation for new voyages. Settlers and entrepreneurs followed the early expeditions, extending technological civilization into new realms and distant lands.

Familiar analogies for the spacefaring vision are easy to find. Rocket ships are the equivalent of sailing vessels that cross terrestrial seas and flying machines that plow through the air. Space stations and extraterrestrial bases serve as the 21st-century equivalent of forts on the outer edges of settlement, providing sanctuaries from hostile forces as well as departure points for places beyond. The expectation of extraterrestrial life grows out of the manner in which the leaders of terrestrial expeditions returned with samples of strange life-forms from the lands they explored. Extraterrestrial colonies are portrayed as pioneer settlements, with their promise of fresh starts and the abandonment of old ways.

9. See John P. Kotter, *Leading Change* (Boston: Harvard Business School Press, 1996).

The power of the human spaceflight visions rests on a set of mutually compatible images, drawn from the recent (and frequently romanticized) memory of terrestrial events. Space offers a realm in which humans can continue the centuries-old tradition of terrestrial exploration. It allows nations to demonstrate their technological prowess and provides new lands for settlement and exploitation. It satisfies the apparent human need for human migration. It promotes the utopian belief that life will be better in newly created settlements beyond the reach of the "old world." These are familiar images, not hard to



An iconic image seen everywhere, this photograph shows Gemini astronaut Edward H. White II on 3 June 1965, when he became the first American to step outside his spacecraft for a "spacewalk." For 23 minutes, White floated and maneuvered himself around the Gemini spacecraft while logging 6,500 miles during his orbital stroll. The astronaut as central figure in space exploration has dominated imagery since before the beginning of the Space Age, but is it an accurate depiction of the future? *(NASA JSC photo no. S65-30433)* explain to an often inattentive public. It is not hard for the average person to understand what is meant by space as "this new ocean" or new initiatives as "pioneering the space frontier."[10]

The human spaceflight vision arose during the first half of the 20th century, at a time when the opportunities for terrestrial exploration of the traditional sort seemed to be winding down. The rise of the human spacefaring vision with the nearly simultaneous decline of the heroic age of terrestrial exploration was not coincidental. The spacefaring vision offered an opportunity to continue the virtues thought to accompany terrestrial exploration and settlement in a new realm. Few developments had more influence on the popular acceptance of space exploration in the mid-20th century than the recent memory of terrestrial expeditions crossing Earthly lands and seas.

Intensive promotion of space exploration began just as the heroic era of terrestrial exploration came to a close. The latter is generally marked by the 1929 expedition of Richard E. Byrd to Antarctica, the first such incursion to substitute fully modern technology for dependence upon human skills. Byrd's expedition followed a series of polar expeditions that depended heavily upon the personal qualities of their human leaders. Among these were the efforts of separate parties led by Roald Amundsen and Robert Scott to reach the South Pole during the Antarctic summer of 1911–12 and the survival of the Trans-Antarctic Expedition of 1914 led by Ernest Shackleton. Both Amundsen and Scott reached the South Pole, but Scott and his four companions perished on the return voyage. Trapped in the polar ice, Shackleton led the crew of the *Endurance* on a 17-month odyssey that remains one of history's greatest stories of human triumph over extreme adversity. The polar expeditions followed a century marked by similarly heroic expeditions such as those led by Meriwether Lewis and William Clark and John Wesley Powell in the American West, Henry Morton Stanley in Africa, and the astonishingly influential voyage of Charles Darwin as the ship's naturalist on the HMS *Beagle*.

Expeditions in the heroic mold followed a well-established formula. Expedition leaders operated autonomously, without the technology necessary to maintain regular contact with their sponsors or home base. Typically, the public did not learn of their expeditions' achievements until the leaders emerged from isolation and reported their findings through lectures and

10. Loyd S. Swenson, James M. Grimwood, and Charles C. Alexander, *This New Ocean: A History of Project Mercury* (Washington, DC: NASA SP-4201, 1966), about connecting two distant points within the universe; National Commission on Space, *Pioneering the Space Frontier*. The term "this new ocean" is derived from "this new sea," a phrase employed by John F. Kennedy's "Address at Rice University in Houston on the Nation's Space Effort," 12 September 1962, in U.S. President (1961–1963 Kennedy), *Public Papers of the Presidents of the United States: John F. Kennedy, 1962* (Washington, DC: Government Printing Office, 1963), p. 373.

publications. In nearly all cases, the public did not know whether the members of the expedition under way were dead or alive. Cut off from their sponsors and home port, members of terrestrial expeditions were obliged to rely on their own skills to repair equipment and gain sustenance from local resources. Given the conditions they faced, expedition leaders depended upon human ingenuity rather than machine technology to survive and complete their discoveries. Terrestrial expeditions in the heroic tradition served as an expression of the power of humans to overcome natural obstacles without resorting to the conveniences of the industrializing world.

Such traditions provided the inspiration for the vision of human spaceflight that gained popular acceptance during the middle years of the 20th century. Between 1950 and 1954, Wernher von Braun prepared a series of plans for the exploration of the Moon and Mars that recounted the heroic expeditions of preceding centuries. His proposal for a Mars mission was especially impressive. It called for a flotilla of 10 ships, guided by a 70-person crew, departing on a 30-month voyage. To prepare their landing site, pilots would descend in one of the ships to the polar ice cap of Mars—the only surface thought to be sufficiently smooth to permit a skid-assisted landing. From there, the crew would commence a 4,000-mile trek in pressurized tractors over unfamiliar terrain to the Martian equator, where they would bulldoze a landing strip for additional craft. Commenting on the attractive power of such schemes, von Braun remarked, "I knew how Columbus had felt."[11]

Von Braun's vision dominated popular presentations of the spacefaring vision during the mid-20th century. The image of winged spaceships, orbiting space stations, lunar expeditions, and voyages to Mars reappeared in the earliest long-range plans of the National Aeronautics and Space Administration. The vision remained the dominant paradigm for human spaceflight from the 1961 decision to go to the Moon through the 2004 presidential call for a return to the lunar surface and expeditions to Mars.[12] Yet this vision was already outdated in terrestrial terms when it first appeared.

Beginning with the Byrd expedition to Antarctica in 1929, expedition leaders came to rely much more on machines than on human heroics to

11. Quoted in Daniel Lang, "A Reporter at Large: A Romantic Urge," *New Yorker* 27 (21 April 1951): 74. See also Wernher von Braun, *The Mars Project* (Champaign: University of Illinois Press, 1991); von Braun with Cornelius Ryan, "Can We Get to Mars?" *Collier's* (30 April 1954): 22–28; von Braun, "Man on the Moon: The Journey," *Collier's* (18 October 1952): 52–60; Fred L. Whipple and von Braun, "The Exploration," *Collier's* (25 October 1952): 38–48.

12. NASA Office of Program Planning and Evaluation, "The Long Range Plan of the National Aeronautics and Space Administration," 16 December 1959; Space Task Group, *The Post-Apollo Space Program: Directions for the Future* (Washington, DC: Executive Office of the President, 1969); NASA, "President Bush Delivers Remarks on U.S. Space Policy," news release, 14 January 2004.

accomplish their goals. Byrd and his compatriots brought three airplanes and an aerial camera to Antarctica, which they flew over the South Pole. They brought 24 radio transmitters, 31 receivers, and 5 radio engineers, which they used to maintain communication with the outside world. The Byrd expedition, like others that followed, replaced the need for exceptional heroics with a dependence upon machines.

Basic plans for human spaceflight embodied language that recounted the spirit of heroic exploration. This occurred in spite of the program's obvious dependence upon machines of the sort that had caused the heroic tradition to disappear on Earth. The earliest astronauts were portrayed as heroic explorers even though they were selected to be mostly passive passengers on spacecraft treated more like guided missiles than ships at sea. Winged spaceships and large space stations proved much harder to construct than airplanes and frontier forts, notwithstanding the relative simplicity of their terrestrial analogies. Human space missions were controlled extensively from the ground, thereby forgoing the heroic tradition established by ship captains at sea.

Hence, the vision of human spaceflight was outmoded in terrestrial terms 30 years before it began. Yet spaceflight advocates clung to it, a testament to its motivating power. Much of its persistence arose from a supporting feature—the belief in American exceptionalism and the ability of space activities to maintain it.

The doctrine of American exceptionalism has appeared in a number of forms. Alexis de Tocqueville noted how conditions in New World settlements promoted innovation and a spirit of cooperation. This insight reappeared in the writings of 20th-century social scientists such as the historian Louis Hartz and the political scientist Aaron Wildavsky. Hartz traced American exceptionalism to the absence of rigid class distinctions such as those that dominated feudal arrangements in Europe. The doctrine achieved its most influential form in the frontier thesis promulgated by Frederick Jackson Turner in 1893. Jackson traced what he saw as the distinctive characteristics of American society to the presence of open land on a continental frontier. From this perspective, inquisitiveness, inventiveness, individualism, democracy, and equality grew out of the experience of founding new settlements free from the persistence of old arrangements.[13]

Turner's thesis has been dismissed by academic historians, yet it continues to possess special appeal to people unschooled in the nuances of historical

13. Alexis de Tocqueville, *Democracy in America* (New York: Random House, 1994); Louis Hartz, *The Liberal Tradition in America: an Interpretation of American Political Thought Since the Revolution* (New York: Harcourt, Brace, 1955); Aaron B. Wildavsky, *The Rise of Radical Egalitarianism* (Washington, DC: American University Press, 1991); Frederick Jackson Turner, "The Significance of the Frontier in American History," in *Rereading Frederick Jackson Turner*, ed. John M. Faragher (New York: Henry Holt, 1994).

research. The gap between academic intellectualism and popular opinion is in few places more pronounced than in the advocacy of human spaceflight. Human spaceflight advocates repeatedly cite the importance of "new frontiers" in sustaining the values of American exceptionalism.

At its heart, American exceptionalism is a utopian doctrine closely associated with the belief that people can improve the human condition by moving to new lands. Much of the interest in transforming Mars into an inhabitable sphere and establishing other space colonies arises from the utopian belief that life gets better when humans are allowed to start anew. The settlement schemes of space advocates such as Gerard O'Neill and Robert Zubrin embrace utopian themes, as does the work of science fiction writers such as Ray Bradbury.[14]

Academic historians point out that distinctive characteristics such as those valued by space advocates can arise from a number of cultural conditions and that the association of frontier life with values such as equality and individualism ignores actual events. Such criticism has had little effect on the popular promotion of human spaceflight. Its advocates continue to emphasize American exceptionalism and its linkage to the opportunities provided by the space frontier. Given the cultural history of the United States, this is a particularly appealing doctrine to the descendants of European settlers. The thought that the United States is becoming more like countries of the "old" world simply increases the interest in recreating conditions thought to make America unique.

The theory of American exceptionalism and its association with frontier life is dubious history. Whatever controversy it engenders as a historical doctrine, however, is overshadowed by the biological issues involved. Humans are a remarkably well-suited species for terrestrial migration. In fact, the ability of humans to adapt to a very wide range of terrestrial conditions through their tool-making capabilities may be the most distinguishing characteristic of the species as an earthly life-form. That adaptation has taken place on a terrestrial surface marked by a specific gravity condition, a protective atmosphere, and a magnetic field that shields earthly life-forms from cosmic violence. None of those conditions exist in outer space. Nearly all of the biological advantages that humans possess for Earthly migration disappear as they move away from the Earth. One pair of authors likens the use of human tool-making capabilities to overcome cosmic conditions to the thought that a fish might be able to survive on land if it had the ability to surround itself with a bubble of water.[15]

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14. Gerard K. O'Neill, *The High Frontier: Human Colonies in Space* (New York: William Morrow, 1976); Robert Zubrin, *Entering Space: Creating a Spacefaring Civilization* (New York: Jeremy P. Tarcher/Putnam, 1999); Ray Bradbury, *The Martian Chronicles* (New York: Bantam Books, 1950).

15. Manfred E. Clynes and Nathan S. Kline, "Cyborgs and Space," *Astronautics* (September 1960): 29–33.

Early experience suggests that the ability of humans to transport conditions favorable to the maintenance of life in outer space is severely limited.

Accomplishments during the first half century of spaceflight have not favored human spaceflight. The human space endeavor has not kept pace with expectations. The inspirational value of elaborate visions such as those contained in the 1969 report of the Space Task Group or the popular film *2001: A Space Odyssey* far exceeded the capacity of humans to achieve them. The relatively uninspiring tasks of constructing near-Earth space stations and reusable spacecraft have taken far longer and cost far more than anticipated. With the exception of the landings on the Moon, human spaceflight has turned out to be much harder than people standing at the beginning of the Space Age envisioned it to be.

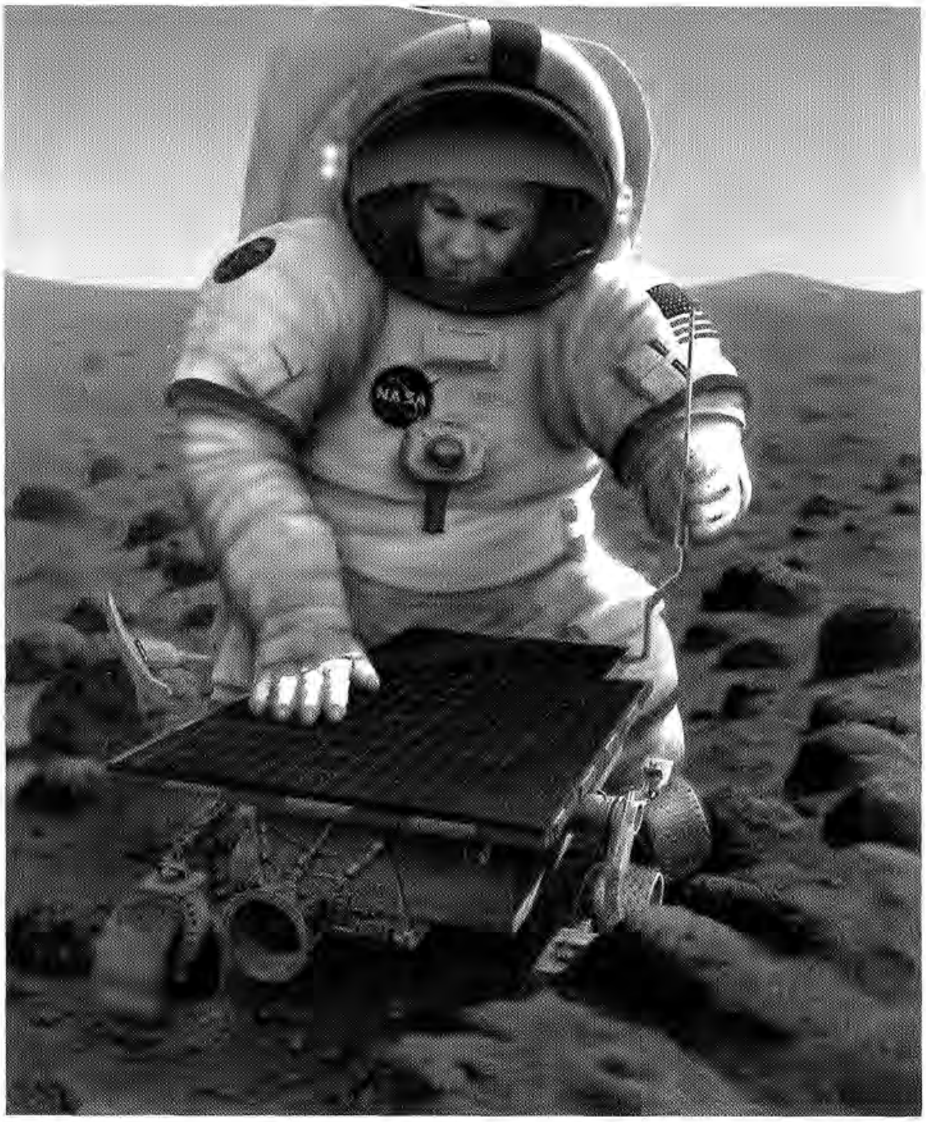
In practical terms, humans will probably return to the Moon and visit Mars. By necessity, they may rendezvous with nearby asteroids. They may establish Martian bases of the sort found at the Earth's South Pole, for reasons of scientific inquiry and national prestige. Their ability to populate Mars or other local spheres is debatable, and the idea that humans in large numbers may undertake interstellar journeys using conventional spacecraft is more doubtful still.

The human spaceflight vision is likely to end at Mars or some nearby place in the inner solar system. Ultimately, the human spaceflight vision will disappear because it is an old vision, tied to past events that become more distant with each succeeding generation. The spacefaring vision helped people standing at the midpoint of the 20th century express their loss at the passing of the heroic age of terrestrial exploration. Such nostalgia is likely to hold less appeal as new generations and developments emerge.

ROBOTS IN SPACE

While attractive in a number of respects, the robotic spaceflight alternative suffers from many of the same difficulties as the human flight paradigm. On the surface, as its advocates insist, robots may seem better suited to spaceflight than human beings. Yet as cultural phenomena, the robotic perspective similarly draws its motive force from social movements located in a rapidly receding past. The image of robotics contained in those movements fails to account for many new developments in technology.

The term "robot" is taken from the Czech word *robota*. In its purest form, it refers to statute labor or compulsory service of the type demanded of European peasants. In feudal Europe, aristocrats required peasants to work



This image represents the epitome of the NASA perspective that humans and robots will explore the solar system together. Here Sojourner, the Mars Pathfinder rover of 1997 named after former slave and famous abolitionist Sojourner Truth, is visited many years after its mission by a descendant of its namesake in this artist's rendering by Pat Rawlings. Sojourner the rover paved the way for those that followed. *(NASA image no. S99-04192)* without remuneration for limited periods of time in the fields of noblemen. The Czech playwright Karel Capek used the term in a 1921 play, *R.U.R.* (Rossum's Universal Robots) to characterize mandatory factory work that was tedious and unrewarding. In Capek's play, factory work is performed not by people but by biologically produced human substitutes who are engineered to complete their work more efficiently than human counterparts.[16]

Therein lies the fundamental difficulty with robotics as a social phenomenon. Robots are viewed as machine-age products designed to serve as human substitutes. To anyone vaguely familiar with industrial-age technology, the implications are obvious. At the least, robots serve in the master-servant relationship characteristic of Edwardian times. At the worst, they are slaves.

The concept of slavery or involuntary servitude was well understood during the early stages of the industrial revolution. The practice of slavery existed scarcely a generation before the advent of wide-scale industrialization in America, and social commentators criticized the practices that tended to create "wage slavery" in industrial plants. Nineteenth-century law treated slaves as property without the rights accorded citizens of the United States, while factory practices treated workers as elements of production interchangeable with machines.

As servants or slaves, robots are not expected to possess human or sentient qualities. Even where robots take the physical form of human beings, they remain machines. The ultimate trust in the ability of humans to control robots forms the basis for Isaac Asimov's three laws of robotics, first elucidated in a 1942 story titled "Runaround":

> A robot may not injure a human being, or, through inaction, allow a human being to come to harm . . . . A robot must obey the orders given it by human beings except where such orders would conflict with the First Law . . . . A robot must protect its own existence as long as such protection does not conflict with the First or Second Laws.[17]

In the dominant fictional depiction of their relationships in space, robots commonly serve as companions to humans engaged in various extraterrestrial activities. This approach is well represented by robots such as Asimov's QT-1 from his early short story "Reason," Lieutenant Commander Data from *Star Trek: the Next Generation*, and the high-strung C3PO and the astromech

16. Peter Kussi, ed., *Toward the Radical Center: A Karel Capek Reader* (Highland Park, NJ: Catbird Press, 1990).
17. Isaac Asimov, *I, Robot* (New York: Random House, 1950), p. 37.

R2D2 of *Star Wars* fame. In the realm of fiction, Space Age robots exist to extend the capabilities of humans who travel alongside them. This creates a fundamental contradiction in the use of robots for space activities. If robots are merely machines, they can be treated as subhuman objects. They can be sent on perilous missions and programmed to perform their duties without the opportunity for earthly return, requirements that would never be permitted for expeditions with humans on board. At the same time, developments in robotics promise ever-increasing levels of sophistication—even to the level that they become sentient beings.

In the fictional setting, exploitive treatment of robots is rarely regarded as ethical. Even if robots are machines, humans treat them in considerate ways. Thoughtfulness for the "feelings" of robots grows directly out of misgivings regarding the treatment of factory workers, servants, and slaves. In a direct retelling of the Dred Scott case, writers for the *Star Trek* episode "The Measure of a Man" question whether the android Data should be treated as property or a human being. Data is a machine, albeit one that resembles a human being, and as such can be reassigned by a commander under the regulations governing the disposal of Federation property. Dred Scott was a 19th-century slave who sued in U.S. courts to maintain his freedom on the grounds that he was being reassigned from a state in which slavery was illegal into one which still permitted its practice. The Supreme Court ruled in 1857 that the provisions of the U.S. Constitution applicable to Scott were the ones that dealt with the property rights of owners rather than the personal rights of citizens, thereby helping to precipitate the Civil War. The Judge Advocate General in the *Star Trek* episode issues a contrary opinion. Data may be a machine, the jurist rules, but he has the right to be treated like a person.[18]

Social commentators find themselves caught between their insistence that robots are merely machines and the necessity of treating them with respect. In his classic work *Do Androids Dream of Electric Sheep?*, Philip K. Dick contemplates the morality of locating and shutting down wayward robots. (The story formed the basis for the classic 1982 science fiction film *Blade Runner.*) In a retelling of the fugitive slave law, the novel deals with android servants who escape from their masters on Mars and attempt to hide on Earth. To encourage emigration to Mars, the government grants each settler a personal android servant which becomes the emigrant's private property. The androids attempt to escape and sometimes murder their masters. The circumstances posed by the novel, Dick admits, duplicate the conditions of the Nat Turner rebellion in the pre–Civil War American South.

18. Robert Scheerer, "The Measure of a Man," *Star Trek: The Next Generation*, 13 February 1989, production 135, Paramount Pictures.

Dick eventually concludes that the androids are merely machines. They are worthy of careful treatment, as would be the case with any piece of expensive equipment, but are not persons in the conventional use of that term. Answering the title of his book, Dick concludes that androids would not dream of electric sheep unless they were programmed to do so, nor would they assign any particular value to the experience unless so instructed.[19]

Isaac Asimov wrestled with the same conundrum throughout his literary career. On the one hand, he railed against what he termed the "Frankenstein complex"—the tendency of writers to produce stories about robots gone bad. Nearly every robot story Asimov read as a young person presented "hordes of clanking murderous robots." The basic story, he observed, was "as old as the human imagination."[20] Humans who attempted to improve their condition through invention, like Icarus who flew too close to the Sun, were penalized by the gods. In a similar manner, humans who invented exceptional machines would be punished by their creations. Asimov absolutely rejected that point of view. All technologies, from fire to the automobile, possess dangers when misused. To Asimov, that did not justify their abandonment.

Robots were merely machines, Asimov insisted. Some aspects of their operation might prove faulty but were always subject to improvement. Said Asimov of his robotic creations: "I saw them as machines—advanced machines—but machines. They might be dangerous but surely safety factors would be built in."[21]

At the same time, Asimov could not resist the temptation to treat his creations anthropomorphically. He gave them human faces and human emotions and human needs. In one of his most famous robot stories, "Bicentennial Man," Asimov describes a robot that wants to become a person. Originally programmed to work as a household servant, the robot acquires artistic sensitivity through an error in the plotting of what Asimov terms its positronic pathways. Over a period of nearly 200 years, the robot replaces its machine parts with human prosthetics and wins its freedom. Yet it does not possess a human brain, a distinction that Asimov characterizes as "a steel wall a mile high and a mile thick."[22] A human brain is subject to irreplaceable decay. The price for becoming human, Asimov declares, is eventual death. It is a price that the robot is willing to pay.

The conceptual challenges of resolving the treatment of robots in practice are not as farfetched as they may seem. Throughout the early stages of

19. Philip K. Dick, *Do Androids Dream of Electric Sheep?* (New York: Ballantine Books, 1968).
20. Isaac Asimov, *Gold: The Final Science Fiction Collection* (New York: Eos, 2003), pp. 192, 193, 196.
21. Ibid., p. 195.
22. Isaac Asimov, *Robot Visions* (New York: Penguin Putnam, 1991), p. 287. The story first appeared in 1976.

the space program, humans allowed robots little autonomy. Robots operated under tight constraints and remote control. With the advent of planetary rovers, robots were allowed higher degrees of freedom. Should robots ever be used for interstellar investigation, they will require autonomous operating capability. They will need the capability to repair themselves without human intervention and possibly the ability to reproduce their parts.

The extent to which this will require the treatment of robots as sentient beings is as yet unknown. From a strictly industrial-age point of view, they will remain machines. Industrial thinkers like Frederick Taylor treated humans like machinery with interchangeable parts. Why would someone who adopts industrial-age thinking assign a higher status to intelligent equipment? A necessary requirement of space exploration, however, is the disappearance of organizational doctrines rooted in a pure mechanistic point of view. Space exploration requires organizational techniques that promote exceptionally high levels of creativity, reliability, and interactive complexity. It requires electronic equipment, most notably computers, whose basic conception rests more in the postindustrial age than the industrial. The traditional, assembly-line mentality that characterized the early industrial revolution is no longer appropriate for space travel, neither from an organizational nor a technological point of view.

Yet this is the very point of view around which the doctrine of robotics revolves. As a cultural phenomenon, robotics is rooted in an industrial-era vision of machinery and the period of human servitude from which it emerged. Whatever one may think about the technical advantages of unmanned spaceflight, its origins as a cultural doctrine are as traditional as those associated with human cosmic travel. The latter draws its force from romantic images of terrestrial exploration and frontier settlements; the former finds its potency in the fascination with machines that characterized the early industrial revolution and an idealized image of master-servant relationships.

The limitations of the robotic perspective are apparent in the seeming inability of its advocates to imagine such machines operating without direct human control. Very few of the robot stories prepared by Isaac Asimov present robots working alone. One notable exception is "Victory Unintentional," in which three incredibly hardy robots visit an invidiously hostile civilization on the planet Jupiter preparing for space travel.[23] The Jovians mistakenly identify the robots as human emissaries from Earth and, convinced that the Earthlings are indestructible, decide to abandon their spacefaring plans. The story departs so radically from Asimov's standard robot fare that he excluded it from his collection of *I, Robot* tales.

23. "Victory Unintentional" was published in the August 1942 issue of *Super Science Stories*.

The standard robot story involves machines working alongside human beings. The television series *Lost in Space* that ran from 1965 to 1968 featured a large robot that one critic characterized as a metal version of the canine *Lassie*, another popular television show from that period.[24] The Robinson family treated the robot as a member of the family, much like an intelligent pet. In *The Day the Earth Stood Still*, the alien portrayed by Michael Rennie travels with a robot named Gort who serves as the ship's chief medical officer and a ruthless enforcer of the extraterrestrial doctrine of arms control.

The official NASA policy for the use of robots in space exploration remains one of complementary capability. When pressed to comment on the virtues of manned and unmanned spaceflight, NASA's leaders repeat the dominant vision that it will be "robots and humans together."[25]

The treatment of robots in fiction is not unlike that accorded animals in space. The first animal to orbit the Earth, a Russian dog named Laika, was allowed to die in space. In a 1953 proposal for the use of monkeys to test living conditions on board a "baby space station," Wernher von Braun suggested that the animals be euthanatized before reentry using "a quick-acting lethal gas."[26] To a certain extent, this recalled the polar practice wherein expedition members ate their dogs as the animals' usefulness for transport declined. Such treatment was not enforced upon the chimpanzees that tested conditions in NASA's Mercury space capsules before humans climbed in. The chimpanzees returned home, as did most of the subsequent Russian dogs to fly in space. In spite of their lower status as flight subjects, these animals were accorded appropriate respect. They came to be treated more like sentient beings.

Visionaries like Asimov predicted the widespread use of robots as personal servants by the end of the 20th century. His initial robot story, titled "Robbie," is set in New York City in the year 1998, a time by which Asimov anticipated the mass production of robotic servants for service on Earth and in space. People like Asimov anticipated a new machine age dominated by intelligent robots. In fact, the machine age departed. In its place, the postindustrial era appeared. In spite of his abiding interest in the workings of his robots' "positronic brains," Asimov wholly failed to anticipate the advent of personal computers and information networks that have come to characterize the postindustrial era.

Early images of computers in popular space literature are similar to those accorded mechanical robots. Sophisticated computers acquire a sense of their own existence and often behave in a roguish fashion. In the classic film and

24. "Robot B9 from Lost in Space," *http://www.jeffbots.com/b9robot.html* (accessed 10 July 2004).

25. See, for example, NASA, "Humans, Robots Work Together to Test 'Spacewalk Squad' Concept," news release 03-227, 2 July 2003.

26. Wernher von Braun with Cornelius Ryan, "Baby Space Station," *Collier's* (27 June 1953): 40.

novel *2001: A Space Odyssey*, the HAL-9000 computer attempts to seize control of the ship and kills all but one member of the crew. It resists the efforts of the remaining astronaut to disconnect it. The notion that humans might construct computers so advanced that they acquire self-awareness appears frequently in fictional and popular treatments of the subject.

Robots have already been used to explore the solar system. They have returned samples from the Moon, and they will likely return samples from Mars. They will closely inspect other planets and their moons. They will rove, dig, possibly swim, and explore. They have and will continue to reach the outer limits of the local solar system.

As a philosophy of exploration, nonetheless, robotics is full of contradictions and outdated metaphors. It remains a machine-age concept in a cybernetic world. Machine-age philosophies are fundamentally concerned with control, both in large organizations and the design of processes such as the assembly line. As with Asimov's three laws, the means of control are rooted in jurisprudence. Rules remain the primary means of control under the machine philosophy. Yet rules are largely inappropriate to the cybernetic models associated with postindustrial processes and information networks. The dominant metaphor for the cybernetic world is the brain, with its qualities of redundancy and creative problem solving.

Robots will surely continue to explore the local solar system. They may develop sufficient capacities to explore regions beyond. Such capabilities, as in the field of artificial intelligence, may lead to sentient qualities of the sort currently found in science fiction. Developing levels of self-consciousness, they might even come to think of themselves as superior beings. This is not guaranteed, but one cannot rule out the possibility. If this occurs, such robots would probably be treated with ever-increasing degrees of respect and kindness. This is the Asimov vision—sophisticated machinery with sentient characteristics operating under human control treated in a humane manner. The scenario is farfetched, but one that would pose no basic difficulty to the expanded use of robots for space exploration.[27]

A darker alternative exists. It is the vision presented in fictional devices such as *Blade Runner* and the behavior of the HAL-9000 in *2001*. Humans might treat such creations inhumanly. In *Blade Runner*, biologically manufactured robots are programmed to die after four years of operation. Having achieved self-consciousness, they understandably object to this policy. The HAL-9000 computer does not want to be shut off either. This scenario, while entertaining, seems flawed in a number of ways. It requires humans to treat intelligent

27. Some theorists believe that this is a given. See Ray Kurzweil, *The Age of Spiritual Machines: When Computers Exceed Human Intelligence* (New York: Penguin, 2000).

robots like slaves, a philosophy not too compatible with the guiding moral doctrines of the postindustrial world. It also suggests that humans would use advanced technology to build robots. As will be seen in a following section of this paper, a more likely scenario is that humans would use such technology to improve themselves. If humans ever develop the technology to construct biologically derived androids, they will by necessity acquire the technology to recreate themselves. That is a more profoundly interesting possibility.

Nonetheless, the image of intelligent but angry robots is not an impossibility. Humans are capable of great kindness toward their creations, but also great cruelty. The image of the mad robot attracts great interest because it says something cogent about human behavior. The concept of machines as slaves may be outmoded, but the worldwide traffic in humans pressed into forms of slavery continues.

In practical terms, the robotic vision will be weighed against the advantages and disadvantages of alternative schemes. This is inevitable. In that respect, the robotic vision, with its traditional quality, may have difficulty competing with approaches that better fit modern technological and cultural developments. One of the most challenging alternatives arises out of the developments in the increasingly strange world of astrophysics.

ASTROPHYSICS AND THE ELECTROMAGNETIC SPACE PROGRAM

Recount for a moment the framework for the observations presented in this essay. To a substantial degree, the vision of space travel is a blank tablet onto which its advocates project images drawn from their own hopes for the culture at large. By necessity, those images change as actual ventures encounter reality. They also change as new generations of people project fresh hopes and cultural beliefs onto the space tableau. As reality intrudes and old cultural fascinations fade, so may old visions. This often encourages advocates to draw selectively what appear to be new ideas from old images—statements and visions not fully recognized until the new visions begin to take form.

One of the most pervasive expectations of the early 20th century held that Mars and Venus would turn out to be habitable planets not far different from the Earth. This expectation, presented in works both scientific and fictional, fueled much of the public interest in human spaceflight. Spaceflight enthusiasts hoped to fly to Mars and Venus and discover new life. Revelation of their inhospitable nature did not destroy that expectation so much as redirect it. Beginning in the last decade of the 20th century, much of the interest in habitable objects began to shift toward extrasolar planets.

The variance between the proximity of the inner planets of the local solar system and the challenges of reaching extrasolar spheres is extreme.

One can speculate on the manner by which this reality, joined with the continuing search for habitable objects, may affect the spaceflight vision. One commentator, proceeding from the mathematics of probabilities, estimates the average distance between life-supporting planets within the Milky Way galaxy to be about 50 light-years. (This is the estimated distance to planets on which life as we understand it might live. The average distance between planets possessing complex or intelligent life-forms may be substantially more.) Fifty light-years is merely an estimate—the actual number is unknown at this time. Nonetheless, it does illustrate the nature of the reality.

A typical voyage from Earth to Mars, using a fast-transit approach, covers about 500 million kilometers (300 million miles). This is the route followed by the robots Spirit and Opportunity that arrived at Mars in 2004. The difference between a fast-transit voyage to Mars and a journey of 50 light-years is a factor of 1 million. The two robots took seven months to reach Mars; a similar journey to a planet really capable of supporting human life might take 500,000 years. Regardless of the accuracy of the underlying estimate (it could be wrong by a factor of 10), the resulting distances pose a substantial barrier to people embracing the traditional vision of space exploration.

The energy requirements for crossing such distances are prodigious in the extreme. Fictional space captains may zip around the galaxy at warp speed, but serious proposals for interstellar flight have been confined to fractions in the 10 to 20 percent of light-speed range. Accelerating spacecraft to such velocities would require energy sources as yet undeveloped, such as fusion power or antimatter drives. For human flight, it would also require very large, multigenerational spacecraft. The people who began any such a voyage would not live to see its completion.[28]

The substantial engineering challenges involved in interstellar transit have forced its most serious advocates to emphasize robotic payloads. Even so, robotic expeditions suffer severe restrictions. A proposal by members of the British Interplanetary Society for a 50-year expedition to Barnard's Star promised a scientific payload with the impressive mass of 500 tons. The energy requirements needed to accelerate the robotic payload to one-eighth light speed proved so prodigious, however, that no fuel remained to help the spacecraft slow down. The expedition plan, named Project Daedalus, called for the spacecraft to zip past its destination at interstellar speeds. NASA executive George Mueller attempted to resolve this difficulty in his proposal for a 25-year voyage to Alpha Centauri 3, powered again by antimatter drive and achieving a peak velocity of two-tenths light speed. Assuming sufficient

28. On the technologies of this type of spaceflight, see Yoji Kondo, ed., *Interstellar Travel & Multi-Generational Space Ships* (Burlington, Ontario: Apogee Books, 2003).

fuel for deceleration, the resulting calculations left room for a robotic payload that weighed just 1 ton.[29]

The practical challenges of traveling to nearby solar systems, whether with human or robotic payloads, well exceed those of local flight. Concurrently, popular interest in the machine-age social issues that helped to spawn robotic dreams has declined. Might some other approach prove more compatible with the personal experiences of postindustrial people, while at the same time offering a better solution to practical difficulties of interstellar contact?

Such an approach exists—and if the combination of personal imagination and practical reality affecting previous spacefaring visions continues to foster new ones, it could create a significant variation in the classic human versus robotic debate. The new vision could arise from that pervasive symbol of postindustrial life, the computer. As noted in the previous section, the use of personal computers is as widespread as people in the early 20th century believed the employment of robots would be. The computer is as compatible with the electronic thinking that dominates the postindustrial age as the fascination with rockets and other machines was with the industrial.

A method for achieving light-speed velocities with very low energy requirements exists within the world of electronics. In 1974, astronomers Frank Drake and Carl Sagan aimed the Arecibo Radio Telescope at the globular star cluster M-13 and dispatched a binary code message at light speed. When properly deciphered, the message contained diagrams depicting a human being, the chemical makeup of Earth life, and the position of the home planet in the solar system. Sagan estimated that the chances of communicating with a civilization residing in the 100,000-star cluster were 50-50. Since the star cluster resides outside of the Milky Way galaxy, however, any return message traveling at light speed will not arrive for 48,000 years.

Civilizations capable of communicating in the electromagnetic spectrum may exist much closer to the Earth. During the 1970s, space advocates proposed a $20-billion government-funded listening system called Project Cyclops. In support of the initiative, NASA Administrator James Fletcher told a gathering of engineers that the Milky Way galaxy "must be full of voices, calling from star to star in a myriad of tongues." Fletcher was a lay minister in the Church of Jesus Christ of Latter-day Saints, which subscribes to the theological doctrine that God has created a plurality of worlds populated with human beings.[30]

29. Alan Bond and Anthony R. Martin, "Project Daedalus: The Mission Profile," in "Project Daedalus—The Final Report of the BIS Starship Study," ed. A. R. Martin, *JBIS: Journal of the British Interplanetary Society* (Supplement, 1978): S37–S42; George Mueller, "Antimatter & Distant Space Flight," *Spaceflight* 25 (May 1983): 104–107.

30. James C. Fletcher, "NASA and the 'Now' Syndrome," NASA brochure, text from an address to the National Academy of Engineering, Washington, DC, November 1975, p. 7, NASA Historical

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The prospect of spending billions of dollars on an approach to space exploration departing so radically from the traditional human and robotic vision sunk the initiative. Bereft of public funding, advocates sought private contributions for what became known as the Search for Extraterrestrial Intelligence (SETI).[31]

Technical developments of a practical nature may cause future lawmakers to fund extrasolar investigations. Propelled by widespread interest in the discovery of extrasolar planets, NASA officials have recommended the creation of space telescopes capable of recording light waves reflected from such objects. Beginning in the last decade of the 20th century, astronomers began confirming the presence of planets orbiting nearby stars using indirect means, such as variations in the positions of central stars as would be produced by orbiting spheres. More than 100 planets were discovered in the first decade of observation. Space-based telescopes utilizing the technology of interferometry could capture images of such bodies. This would require a large number of telescopes, flying in formation, assembling light waves from nearby solar systems in such a manner that the electromagnetic waves from the central star nullify each other. The bright glare from the central object would disappear, revealing the reflected light from objects orbiting the central star.

NASA officials created a hint of what such a technology might produce in 2003 when they aimed the Mars Global Surveyor toward the inner solar system and captured an image of Earth some 86 million miles away. The image shows Earth half lit. Cloud cover is clearly visible. With small adjustments in technology, the color of the seas appeared. Spectral studies of such an image would reveal water vapor, free oxygen, and trace amounts of methane and carbon dioxide—signatures of a planet populated with living beings.

Space scientists would like to know how many such spheres occupy the stellar neighborhood and the fraction of such bodies that might support complex life. Inspection through the electromagnetic spectrum is a far more efficient means of locating such bodies than the random dispatch of very large spacecraft with extraordinarily large energy requirements. Given 21st-century technologies, the electromagnetic spectrum would prove superior to human and robotic flight for investigations outside of the local solar system.

Where this may lead is as yet unknown. It is a history that has not yet occurred. Nonetheless, the confluence of social interest and practical reality suggests that it might form the basis for an alternative vision of considerable

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Reference Collection, Washington, DC. On Fletcher's religious background, see Roger D. Launius, "A Western Mormon in Washington, D.C.: James C. Fletcher, NASA, and the Final Frontier," *Pacific Historical Review* 64 (May 1995): 217–241.

31. See Steven J. Dick and James E. Strick, *The Living Universe: NASA and the Development of Astrobiology* (New Brunswick, NJ: Rutgers University Press, 2004).

power. At the present time, it is relatively undeveloped—but no more so than the conventional reality of spaceflight remained until its popularization during the mid-20th century.

The electromagnetic space program anticipates possible communication at or even exceeding light speeds. The possibility of such developments has caused some people to contemplate the manner in which electromagnetic communication might be combined with traditional interest in human spaceflight. In 1985, one of the principal proponents of the Search for Extraterrestrial Intelligence, Carl Sagan, presented a draft of a science fiction novel to physicist Kip Thorne. Sagan suggested that Earthlings searching through the electromagnetic spectrum might discover devices that would cause objects to evade the cosmological limits imposed by conventional space and time. In the novel and film, titled *Contact*, the plans for such a device are supplied through a radio message received from outer space. The device, in Sagan's original draft, allowed humans to create a black hole. Thorne, who was completing a book on black holes and hyperspace, suggested that Sagan instead employ a series of wormholes.[32]

The laws of quantum gravity, Thorne observes, require that nature produce "exceedingly small wormholes."[33] A wormhole is a short tunnel connecting two distant points within the universe, moving outside the four dimensions that humans conventionally experience. Theory suggests that wormholes disappear as soon as they appear, but Thorne speculates that a technologically advanced civilization might employ the laws of quantum gravity to hold a wormhole open long enough to travel through it.[34] In this respect, fantastic tales in which children drop into rabbit holes or step through wardrobes and emerge in other worlds might provide the cultural inspiration for 21st-century space travel.

In Sagan's novel, engineers construct a device that creates an access point to an exit located in the vicinity of Vega some 26 light-years away. This cosmological tunnel provides access to additional passageways leading throughout the galaxy. Raised on the conventional image of space exploration, Sagan cannot resist the temptation to dispatch a human crew through the transit device. In the book, five individuals travel in a dodecahedron to Vega and beyond. Movie producers simplified the narrative to a single passenger, the central character played by actress Jodie Foster.

32. Kip S. Thorne, *Black Holes & Time Warps* (New York: W. W. Norton, 1994), pp. 483–484; Carl Sagan, *Contact: A Novel* (New York: Simon and Schuster, 1985). Sagan continued to refer to the tunnel as "the black hole, if that was what it really was," p. 335.

33. Thorne, *Black Holes & Time Warps*, p. 55.

34. Michael S. Morris and Kip S. Thorne, "Wormholes in spacetime and their use for interstellar travel: A tool for teaching general relativity," *American Journal of Physics* 56 (May 1988): 395–412.

In his book and a series of accompanying articles, Thorne explores whether a wormhole might be used for communication or transport of the conventional sort. Unlike a black hole, whose force would stretch and destroy any conventionally arranged object or message that entered it, a wormhole provides some possibility of transit. "We do not understand the laws of quantum gravity well enough to deduce . . . whether the quantum construction of wormholes is possible," Thorne observes. Nonetheless, physicists do understand how such a wormhole, if one were constructed, might be held open "by threading it with exotic material."[35]

Viewed from the perspective of conventional spaceflight, visions of electromagnetic communication and shortcuts through space and time are certainly strange. So far, no significant public funds have been provided for such activities. Yet the possibility of studying extrasolar planets is no more fantastic today than space travel seemed to a public raised on images of Martian canals and Buck Rogers in the early 20th century, and advances in modern physics continue to produce startlingly strange results. No one can predict with certainty where such developments might lead. The history of space travel does suggest, however, that prevailing visions depend considerably upon public interests and technological reality.

A POSTBIOLOGICAL PERSPECTIVE

The other alternative perspective on space travel is so strange that it makes the discussion of wormholes and extraterrestrial communications appear commonplace by comparison. For many years, NASA leaders have insisted that humans and robots will explore space together. The other alternative suggests that humans and machines will do more than travel together. As a result of space travel, they might merge into what Steven Dick has characterized as a "postbiological universe."[36]

A curious discussion surrounding the Search for Extraterrestrial Intelligence provided the reality check helping to motivate this perspective. In assessing the possibility of contacting extraterrestrial beings, Frank Drake prepared a formula that famously calculated the number of communicative civilizations that might exist within the Milky Way galaxy at the present time. The final parameter in the equation measures the average length of time that a communicative civilization survives. The parameter, labeled L, imposes a paradox raised by the physicist Enrico Fermi. If the value of L is small—on the

35. Thorne, *Black Holes & Time Warps*, p. 498.

36. Steven J. Dick, "They Aren't Who You Think," *Mercury* (November–December 2003): 18–26; Dick, "Cultural Evolution, the Postbiological Universe and SETI," *International Journal of Astrobiology* 2, no. 1 (2003): 65–74.

order of a few hundred years—then the predicted number of civilizations capable of communicating with one another in the Milky Way at any time rapidly approaches "one." In other words, humans are alone—and destined soon to revert to some pretechnological state.

Conversely, suppose that the value of L is very large. Given the age of the universe and the history of stars, the first technological civilizations could have emerged 3 billion years ago. Those that managed to survive infancy could have endured for hundreds of millions of years. The potential age of technological civilizations existing at the present time might range from 1 to 3 billion years.[37] Therein arises the paradox. Given the amount of time required for interstellar travel relative to the parameter L, intelligent extraterrestrials should already be here. Since this does not appear to be the case, it follows on the basis of the Drake formula that the longevity of technological civilizations must be very small. This is very disappointing to people anticipating a lengthy lifespan for human culture.

The fault, however, may lie in the formula. Drake's formula contains no parameter for the probability that the beings creating a technological civilization may evolve into something else. Yet this possibility has been raised repeatedly by science fiction writers. Many have foreseen the arrival of mutated life-forms, often as a result of horrible wars. H. G. Wells described a world full of Morlocks and Eloi in *The Time Machine*, while Pierre Boulle predicted the rise of intelligent chimpanzees in *Planet of the Apes*. In his early science novel *Orphans of the Sky*, Robert Heinlein allows the alterations to occur on an intergenerational spaceship bound for the Alpha Centauri star system. Succeeding crew members become mutants that dwell in the ship's core and simple farmers who, blissfully unaware that they live on a giant spaceship, occupy the outer shell.[38]

In the works of Arthur C. Clarke, similar transformations occur. Unlike other authors, Clarke presents such transformations in a uniformly positive way. To Clarke, space travel provides access to technologies that transform biological creatures into more immortal, spiritual beings. This optimistic vision forms the principal theme in Clarke's fictional work. It appears in *Childhood's End*, one of his first novels, in which alien beings oversee the total transformation of the human race. It reappears in *Rendezvous with Rama*, in which the extraterrestrial creators of a gigantic starship have long since

37. Mario Livio, "How Rare Are Extraterrestrial Civilizations, and When Did They Emerge?" *Astrophysical Journal* 511 (20 January 1999): 429–431; N. S. Kardashev, "Cosmology and Civilizations," *Astrophysics and Space Science* 252 (1997): 25–40.

38. H. G. Wells, *The Time Machine* (London: Everyman, 1995); Pierre Boulle, *La plane'te des singes*, translated by Xan Fielding as *Planet of the Apes* (New York: Vanguard Press, 1963); Robert A. Heinlein, *Orphans of the Sky: A Novel* (New York: Putnam, 1963).

evolved into a higher spiritual form. Most significantly, it dominates the central narrative in Clarke's classic novel and screenplay, *2001: A Space Odyssey.* In that story, an alien monolith provides a passageway for the transformation of the sole surviving astronaut on a deep space mission. The astronaut enters a passageway generated by the monolith and reappears as a "star child" with supernatural powers.[39]

From a cultural perspective, the transformations Clarke presents contain a message quite familiar to human beings. Clarke's characters achieve forms of immortality through space travel. Practically every human culture and nearly all religions contain messages about resurrection, typically achieved through some sort of physical dying and rebirth. Most space advocates are reluctant to discuss the possibility of physical transformation through space travel, perhaps out of a desire to appear scientifically sober. To the extent that visions of space travel rest upon a foundation of cultural expectations, however, few expectations are more widespread than those concerning the desire for immortality through some sort of physical transformation.

The existence of those expectations has provided the cultural foundation for a modern movement known as "transhumanism." This rather strange philosophy is a product of conversations taking place largely on the Internet. Transhumanism is "a radical new approach to future-oriented thinking" that utilizes advances in science and technology "to eliminate aging and greatly enhance human intellectual, physical, and psychological capacities."[40] Transhumanists believe that advances in computer capacity and nanotechnology will allow genetic change to occur very soon—possibly within the 21st century. The result, they believe, will be a "posthuman" species as superior to *homo sapiens* as humans are to the primates. The new species will survive for very long periods of time, perhaps approaching immortality.

Transhumanism is not a movement focused on space travel, although its applications to that endeavor are readily apparent. If humans or the species they produce are able to live under the severe conditions and extraordinarily long periods of time required for interstellar travel, many of the barriers to extended journeys would disappear. Physical modifications beneficial for space travel might include induced hibernation, a staple element in science fiction stories.[41] It could extend to physical alterations experienced by humans born on worlds with different gravities. Extraordinary lifespans would change the human perspective

39. Arthur C. Clarke, *Childhood's End* (New York: Harcourt, Brace & World, 1953); Clarke, *Rendezvous with Rama* (New York: Harcourt, Brace, Jovanovich, 1973); Clarke, *2001: A Space Odyssey* (New York: New American Library, 1968).

40. Nick Bostrom, "The Transhumanist FAQ," October 2003, *http://www.transhumanism.org/resources/faq.html* (accessed 5 January 2005).

41. See Stanley Kubrick, *2001: A Space Odyssey* (Metro-Goldwyn-Mayer, 1968); Gordon Carroll, David Giler, and Walter Hill, *Alien* (20th Century Fox, 1979).

of time and might allow the completion of lengthy interstellar voyages within a single generation. Combined with new insights into the structure of the universe, it might allow reconstructed beings to move through space in ways that humans could not survive. Given sufficient time, posthumans or their descendants might fulfill the science fiction dream of space travel by experiencing near immortality.

As is typical of such movements, the new approach has motivated current generations to rediscover words and works not previously emphasized under conventional visions. A leading approach within the transhumanist movement envisions the merging of human and machine parts. The resulting creatures are known as cyborgs, a term originally presented in a 1960 paper by Manfred Clynes and Nathan Kline on the challenges of space travel. Clynes and Kline suggested a number of modifications to the human body that would allow some of the basic requirements of extraterrestrial survival to take place automatically. They proposed induced hypothermia as a means of reducing energy requirements, drugs that might combat weightlessness, and an inverse fuel cell that would take the place of lungs.[42]

Cyborgs appear frequently in science fiction stories. The concept received popular attention in a 1972 novel by Martin Caidin that formed the basis for the television series *The Six Million Dollar Man*. A number of *Star Trek* episodes feature cyborgs, and the 1996 *Star Trek* movie *First Contact* presents an extraterrestrial life-form known as "the Borg." Part organic, part machine, the Borg are insectlike creatures that share a single mind.[43]

A person no less notable than Robert Goddard contemplated methods for transporting creatures through space in something other than their current bodily form. To assure the continuation of Earthly life, he recommended that distant spheres be seeded with what he termed protoplasm, dispatched on one-way journeys from Earth to distant spheres. Over time, the material would evolve into Earthly life-forms. Goddard suggested that the spacecraft also transport the accumulated knowledge of humankind "in as light, condensed, and indestructible a form as possible."[44] Goddard's proposal anticipated the development of microtechnologies and discovery of human DNA, which were unknown at the time. Lying so far from conventional visions of space travel, Goddard's speculations on interstellar flight received much less attention than his work on rocketry, but they could be selectively rediscovered if interest in transhumanistic space travel appears.

42. Clynes and Kline, "Cyborgs and Space."

43. Martin Caidin, *Cyborg: A Novel* (New York: Arbor House, 1972); Glen A. Larson et al., *The Six Million Dollar Man* (Silverton and Universal Production for the American Broadcasting Company [ABC], 1973–78); Rick Berman, *Star Trek: First Contact* (Paramount Pictures, 1996).

44. Esther C. Goddard, ed., and G. Edward Pendray, assoc. ed., *The Papers of Robert H. Goddard*, vol. 3 (New York: McGraw-Hill Book Co., 1970), p. 1612.

In his discussion of postbiological civilizations, Steven Dick refers to the work of the British philosopher Olaf Stapledon, who wrote science fiction novels and essays during the first half of the 20th century. Speaking of *homo sapiens*, Stapledon, in a classic 1948 address to the British Interplanetary Society, insisted that maintenance of the human physical form need not provide the ultimate justification for space travel. Rather, he emphasized the preservation of what he called the "spiritual experience" of being human. Stapledon surmised that the process of adapting humans to fit alien environments might prove easier given sufficient time than carrying Earthly conditions and unaltered humans to distant objects. Stapledonian thinking, as Dick describes it, takes into account "the evolution of biology and culture" alongside the process of space travel over very long time periods.[45] The works of Stapledon and those of the early-20th-century philosopher J. D. Bernal, on which he drew, are considered "classics" in a modern movement that did not exist when the works first appeared.[46]

In a half-serious sort of way, Steven Dick uses the postbiological perspective to solve the Fermi paradox. People searching for extraterrestrial civilizations listen for radio transmissions of the sort produced by human technology. Radio and television signals from Earth, however, are hardly 100 years old. As noted above, an extraterrestrial civilization mastering advanced technologies might have survived for billions of years. Over those time periods, such creatures would have evolved either naturally or through self-imposed means. As Dick notes, the transformation could have produced beings that no longer communicate through the electromagnetic spectrum. Fulfilling one of the ultimate spacefaring dreams, they might have attained a form of spiritual or electronic immortality.

The ultimate result of many such evolutionary sequences is hard to imagine. It might result in the modification of biological creatures into forms more suitable for living under conditions beyond their home planet. It might result in species that prefer not to be confined to wet, rocky spheres. Perhaps such species prefer to communicate over vast distances at speeds that seem sluggish to *homo sapiens* with traditionally short lifespans. Over lengthy periods of time, the iterations might produce creatures with little resemblance to species from which they emerged. Referring to such creatures on other planets, Dick observes, "It is entirely possible that the differences between our minds and theirs is so great that communication is impossible." His comments are equally applicable to new forms that might someday arise from Earthly life.[47]

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45. Olaf Stapledon, "Interplanetary Man?" in *An Olaf Stapledon Reader*, ed. Robert Crossley (Syracuse, NY: Syracuse University Press, 1997), p. 234; Dick, "Cultural Evolution, the Postbiological Universe and SETI," p. 65.

46. J. D. Bernal, *The World, the Flesh, and the Devil* (Bloomington: Indiana University Press, 1969; original publication, 1929).

47. Dick, "Cultural Evolution, the Postbiological Universe and SETI," p. 72.

CONCLUSION

The original vision that helped to motivate the first phase of space travel favored human over robotic flight. Completion of the human spaceflight vision, with its winged spaceships, orbiting space stations, lunar bases, and planetary expeditions, proved more difficult than anticipated. During the same period, robotic activities overcame many of the technical obstacles expected to retard that approach. In spite of its rapid development, however, robotic technology did not supplant human activities. On balance, the two approaches achieved a state of approximate parity after one-half century of cosmic flight.

Scientists and engineers provided a vivid demonstration of the relative status of robotic and human flight during the 2004 debate over the repair of the Hubble Space Telescope. Rarely does a single flight activity permit a direct, head-to-head comparison between human and robotic approaches. More often, the debate arises in the context of different missions, such as the choice between the replacement of an aging Space Shuttle and the desire to launch another robotic probe to the outer planets.[48] In 2004, however, a special group from U.S. National Academy of Sciences reported on the relative merits of robotic and human spaceflight approaches to the task of servicing the batteries and gyroscopes on the 14-year-old Hubble Space Telescope. The group concluded that a robotic mission was not inherently superior but would probably involve more time and risk than an astronaut-guided repair. Further analysis suggested that the robotic mission would cost as much a Shuttle flight for the same purpose.[49]

Exploring the relative advantages of human and robotic flight in a manner similar to the calculations performed for the Hubble rescue mission is a productive avenue for future research. So is a reexamination of the underlying visions. As the generation of space advocates raised on the pioneering paradigm of human flight is replaced by young people raised in the computer age, the underlying cultural interests in space exploration may shift. Few people have attempted to study the manner in which a generation shift could affect the supporting visions of spaceflight possessed by the public at large.

So far, neither the human nor the robotic approach has achieved a commanding advantage over the other. Both continue to receive substantial support. Human space travel has fallen well short of the original vision, and robotic

48. See James A. Van Allen, "Space Science, Space Technology and the Space Station," *Scientific American* 254 (January 1986): 32–39.

49. Committee on the Assessment of Options for Extending the Life of the Hubble Space Telescope, Space Studies Board, Aeronautics and Space Engineering Board, National Research Council, *Assessment of Options for Extending the Life of the Hubble Space Telescope: Final Report* (Washington, DC: National Academies Press, 2005). See also U.S. House of Representatives Committee on Science, Hearing Charter, "Options for Hubble Science," 2 February 2005.

flight has exceeded initial expectations. Such observations, however, rest on a remarkably short base of practical experience and public perspectives, especially when viewed in cosmic terms. Over much longer timespans, the situation as it presently exists will probably change and do so in fundamental ways. These changes are not well represented in the current human versus robotic debate.

Ultimately, the classic human versus robotic debate fails to capture the full scope of the space endeavor because it fails to account for time. Time will present new opportunities, new visions, and new generations with different dreams to fulfill. The traditional human versus robotic controversy will suffer as time passes because it is essentially rooted in the past. Whatever technical merits guide the two points of view, the cultural context of both perspectives draws upon social movements that no longer play a dominant role in terrestrial affairs.

Seen from the perspective of the past, the human spaceflight movement resides in a utopian vision of Earthly activities that romanticizes events such as the settlement of the North American continent by Europeans and the "golden age" of terrestrial exploration. Even if the motivating events did occur as described by advocates of space travel—which is doubtful—they are not easily transferred to the reality of space.

Robotic flight does not fare much better. An analysis of the social commentary on robotics sets that movement squarely in the context of the industrial revolution and the disappearance of involuntary servitude. Support for robotics, especially as it appears in science fiction, arises from the utopian belief that industrial-age machines can be engineered to work like obedient servants, toiling alongside humans and relieving them of the need to perform dangerous or tedious space activities. This outlook is well expressed by the early belief that space robots would take the form of androids—machines in human form performing human work. In general, however, robotic spacecraft have not adopted the human form. When urged to propose a robot for the Hubble repair, NASA officials eschewed plans for an androidlike Robonaut in favor of a mechanism that looked like a Transformers toy. A concept under development at NASA's Johnson Space Center, Robonaut is an automated device with the arms, torso, and head of an astronaut. It looks like a human being. NASA officials instead suggested a design based on the Canadian-built Special Purpose Dexterous Manipulator (Dextre) designed for the International Space Station.[50]

The industrial age, with its emphasis upon machines that perform human functions like lifting and digging, encouraged the contemplation of robots that did the work of human beings. The industrial age, however, has been

50. NASA, "Robonaut," *http://robonaut.jsc.nasa.gov* (accessed 5 January 2005); Francis Reedy, "Hubble: Robot to the Rescue?" *Astronomy*, 12 August 2004, *http://www.astronomy.com/asy/default.aspx?c=a&id=2377* (accessed 5 January 2005).

supplanted by the postindustrial, with its emphasis upon electronic networks and computers. This may encourage popular interest to move away from space robots as human substitutes toward machines of a different sort. In the future, such machines might take the form of elaborate space telescopes that rely upon electromagnetic techniques to investigate extraterrestrial phenomena, cosmic listening posts, or even devices built to evade the conventional notions of space and time.

At the highest level, the human versus robot debate fails to account for changes in the species who frame it. People who envision the ultimate purpose of space activity anticipate its continuation over extraordinarily long periods. Commenting on the necessity of spaceflight, Robert Goddard noted that *homo sapiens* would need to move once "the sun grows colder," an event not likely to occur for billions of years. Setting a shorter but nonetheless epochal timeframe, astronomer Carl Sagan predicted that the galactic collisions that destroy species every 10 to 30 million years would force human migration. "Such a discussion may seem academic in the extreme," Goddard remarked, noting the very long time periods involved. Yet people who investigate space tend to think in cosmological terms. The ultimate choice, concluded Sagan, "is spaceflight or extinction."[51]

The introduction of very long periods of time creates a dynamic situation not extensively analyzed in the traditional human versus robot debate. A species that survives long enough to overcome solar destruction would certainly undergo genetic modification. This could occur gradually, or the species might acquire the means to reengineer lifeforms, including its own, in ways that make space travel more accessible. Either way, changes will occur over the periods of time during which space enthusiasts hope to prosper and survive.

Under such conditions, reconsideration of original expectations is inevitable. The human and robotic visions that motivated the first half century of spaceflight may continue to play a powerful role, especially for the exploration of the solar system. Yet it would be foolish to assume that they will be the only visions to ever inspire public policy and captivate public attention.

Rather than view the progress of space exploration as a two-sided contest between humans and robots, it is probably wise to consider what other visions might emerge. The history of space exploration suggests that motivating visions arise from social outlooks and the tempering influence of physical reality. This chapter has reviewed the human and robotic spaceflight visions and, from this perspective, speculated on the type of visions that might motivate future space activities. What arises is something more than the conventional two-sided debate—a future with perhaps four points of view.

51. Goddard and Pendray, eds., *Papers of Robert H. Goddard*, vol. 3, p. 1612; Carl Sagan, *Pale Blue Dot: A Vision of the Human Future in Space* (New York: Random House, 1994), p. 327.