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:

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[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.

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[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.

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[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

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[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-

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[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]

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[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.

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[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

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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

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[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

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[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

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[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.

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[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

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[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.

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[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

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[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

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[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

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[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]

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[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.

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[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

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[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

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[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

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[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.

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[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

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[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

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[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.

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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.

CHAPTER 4

HUMAN-MACHINE ISSUES IN THE SOVIET SPACE PROGRAM[1]

Slava Gerovitch

In December 1968, Lieutenant General Nikolai Kamanin, the Deputy Chief of the Air Force's General Staff in charge of cosmonaut selection and training, wrote an article for the *Red Star*, the Soviet Armed Forces newspaper, about the forthcoming launch of Apollo 8. He entitled his article "Unjustified Risk" and said all the right things that Soviet propaganda norms prescribed in this case. But he also kept a private diary. In that diary, he confessed what he could not say in an open publication. "Why do the Americans attempt a circumlunar flight before we do?" he asked. Part of his private answer was that Soviet spacecraft designers "over-automated" their spacecraft and relegated the cosmonaut to the role of a monitor, if not a mere passenger. The attempts to create a fully automatic control system for the Soyuz spacecraft, he believed, critically delayed its development. "We have fallen behind the United States for two or three years," he wrote in the diary. "We could have been first on the Moon."[2]

Kamanin's criticism was shared by many in the cosmonaut corps who described the Soviet approach to the division of function between human and machine as "the domination of automata."[3] Yet among the spacecraft designers,

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[1] I wish to thank David Mindell, whose work on human-machine issues in the U.S. space program provided an important reference point for my own study of a parallel Soviet story. Many ideas for this paper emerged out of discussions with David in the course of our collaboration on a project on the history of the Apollo Guidance Computer between 2001 and 2003, and later during our work on a joint paper for the 2004 annual meeting of the Society for the History of Technology in Amsterdam. I wish to express my gratitude to Asif Siddiqi and Valentina Ponomareva for sharing their insights into the history of the Soviet space program, as well as copies of relevant archival documents. I am also indebted to Stanislav Marchenko, Georgii Priss, Viktor Przhiyalkovsky, Irina Solov'eva, Vladimir Syromiatnikov, Iurii Tiapchenko, Iurii Zybin, and the staff of the Archive for Scientific and Technical Documentation in Moscow for providing invaluable help with my research. I am especially thankful to John L. Goodman for his detailed comments on early versions of this paper.

[2] Nikolai Kamanin, *Skrytyi kosmos*, vol. 3, *1967–1968* (Moscow: Novosti kosmonavtiki, 1999), p. 335 (12 December 1968).

[3] Georgii Beregovoi, as quoted in Valentina Ponomareva, "Nachalo vtorogo etapa razvitiia pilotiruemoi kosmonavtiki (1965–1970 gg.)," in *Issledovaniia po istorii i teorii razvitiia aviatsionnoi i raketno-kosmicheskoi tekhniki,* vyp. 8-10, ed. Boris Raushenbakh (Moscow: Nauka, 2001), p. 166.

a different point of view prevailed. They regarded the high degree of automation on Soviet spacecraft as a remarkable achievement. The leading control system designer Boris Chertok, for example, praised the implementation of fully automatic docking on Soyuz, in contrast to the human-mediated rendezvous procedure on Apollo. "We did not copy the American approach," he argued, "and that proved to be one of the strengths of Soviet cosmonautics."[4]

The historiography of the Soviet space program has devoted little attention to on-board automation, treating it largely as a narrow technical issue. Yet the intensity of debates within the Soviet space program over the division of control functions between human and machine, both in the design phase and during spaceflights, indicates that the issue has fundamental importance. The success or failure of specific missions often depended on crucial control decisions made by the crew, the on-board automatics, or the ground control. The correctness and timeliness of such decisions critically depended on the integration of human decision-makers into a large, complex, technological system.

The problem of on-board automation, which tied together the interests of different professional groups, provides a window into the internal politics of the Soviet space program. Recent scholarship on the Soviet space program has largely been devoted to biographies, organizational history, and policy analysis, emphasizing the competition among different design bureaus and the lack of a coherent government policy.[5] While most accounts focus on only one of the relevant groups—the cosmonauts, the engineers, or the policy-making community—a study of human-machine issues illuminates the roles of all major professional groups within the Soviet space program. Aviation designers, rocket engineers, human engineering specialists, and cosmonauts had very different assumptions about the role of the human on board a spacecraft. A study of the actual division of function between human and machine on board would help us understand the role of these groups in shaping the Soviet space program.

The issue of on-board automation is also closely linked to the definition of the cosmonaut profession. Debates on the relative importance of cosmonauts' skills as pilots, engineers, or researchers reveal the connections between technological choices, professional identity, and the social status of cosmonauts. The seemingly

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[4] Boris E. Chertok, *Rakety i liudi*, vol. 3, *Goriachie dni kholodnoi voiny*, 3rd ed. (Moscow: Mashinostroenie, 2002), p. 393.

[5] For recent biographies, see Iaroslav Golovanov, *Korolev: Fakty i mify* (Moscow: Nauka, 1994); James Harford, *Korolev: How One Man Masterminded the Soviet Drive to Beat America to the Moon* (New York: John Wiley & Sons, 1997). For analysis of the inner workings of space policy-making and institutional conflicts, see William P. Barry, "The Missile Design Bureaux and Soviet Piloted Space Policy, 1953–1974" (Ph.D. diss., Oxford University, 1995); Roger D. Launius, John M. Logsdon, and Robert W. Smith, eds., *Reconsidering Sputnik: Forty Years Since the Soviet Satellite* (Amsterdam, Netherlands: Harwood Academic Publishers, 2000); Asif A. Siddiqi, *Challenge to Apollo: The Soviet Union and the Space Race, 1945–1974* (Washington, DC: NASA SP-4408, 2000).

The original 1960 group of cosmonauts is shown in May 1961 at the seaside port of Sochi. The names of many of these men were considered state secrets for more than 25 years. Sitting in front, from left to right: Pavel Popovich, Viktor Gorbatko, Yevgeniy Khrunov, Yuri Gagarin, Chief Designer Sergey Korolev, his wife Nina Koroleva with Popovich's daughter Natasha, Cosmonaut Training Center Director Yevgeniy Karpov, parachute trainer Nikolay Nikitin, and physician Yevgeniy Fedorov. Standing the second row, from left to right: Aleksey Leonov, Andrian Nikolayev, Mars Rafikov, Dmitriy Zaykin, Boris Volynov, German Titov, Grigoriy Nelyubov, Valeriy Bykovskiy, and Georgiy Shonin. In the back, from left to right: Valentin Filatyev, Ivan Anikeyev, and Pavel Belyayeu. Four cosmonauts were missing from the photograph: Anatoliy Kartashov and Valentin Varlamov had both been dropped from training because of injuries; Valentin Bondarenko died in a training accident a few months before; and Vladimir Komarov was indisposed. I. Snegirev took the original photo. *(NASA photo no. cosmonauts01)*

technical problem of on-board automation raises larger questions of the nature and purpose of human spaceflight. An examination of different approaches to human-machine issues uncovers competing visions of spaceflight as a piloting mission, an engineering task, or a research enterprise.

Comparative studies of the American and Soviet aerospace industries have addressed the role of the national context in space engineering.[6] Soviet space program participants often regarded the U.S. as the paragon of a "human-centered" approach to spacecraft design. A leading spacecraft designer, for exam-

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[6] See Stephen J. Garber, "Birds of a Feather? How Politics and Culture Affected the Designs of the U.S. Space Shuttle and the Soviet Buran" (master's thesis, Virginia Institute of Technology, 2002); Leon Trilling, "Styles of Military Technical Development: Soviet and U.S. Jet Fighters, 1945–1960," in *Science, Technology, and the Military*, ed. E. Mendelsohn, M. R. Smith, and P. Weingart (Dordrecht, Netherlands: Kluwer, 1988), pp. 155–185.

ple, remarked: "Americans rely on the human being, while we are installing heavy trunks of triple-redundancy automatics."[7] A closer look at both American and Soviet space programs through the prism of on-board automation reveals a more complex picture. By exploring the arguments of internal debates, the diversity of engineering cultures, and the negotiations among various groups favoring different approaches to automation, one could critically reexamine the stereotype of fixed "national styles" in space engineering.

In this essay, I shall review a number of human-machine issues raised at different phases in the Soviet space program from the early 1960s to the late 1970s. From my perspective, the problem of on-board automation was not a purely technical issue, but also a political issue—not in terms of big politics, but in terms of "small" politics, local politics. My approach is to examine how technological choices were shaped by power relations, institutional cultures, and informal decision-making mechanisms, and how these choices, in turn, had significant ramifications for the direction of the Soviet space program and ultimately defined not only the functions of machines, but also the roles of human beings.

I will argue that the Soviet approach to the problem of on-board automation was neither fixed nor predetermined; it evolved over time and diversified across different institutions and projects. Instead of a single, dominating approach, we find a series of debates, negotiations, and compromises. In my view, the division of function between human and machine on board had much to do with the division of power on the ground among different groups involved in the debates over automation. I will illustrate how these episodes can be taken as entry points into larger historical issues about politics, organization, and culture of the Soviet space enterprise. Finally, I will suggest directions for further research into this subject.

AUTOMATION ON VOSTOK: TECHNOLOGICAL, DISCIPLINARY, AND MEDICAL FACTORS

The first spacecraft—the Soviet Vostok and the American Mercury—were both fully automated and were flight-tested first in the unpiloted mode. Yet there was one important difference: the astronaut on board had a wider range of manual control functions than the cosmonaut. This can be illustrated by a simple comparison of the control panels of Vostok and Mercury. The Vostok panel had only 4 switches and 35 indicators, while the Mercury instrument panel had 56 switches and 76 indicators.[8] There were only two manual control

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[7] Chertok, *Rakety i liudi*, vol. 3, p. 257.

[8] For a comparison of the technical parameters of manual control panels on American and Soviet spacecraft, see Georgii T. Beregovoi et al., *Eksperimentalno-psikhologicheskie issledovaniia v aviatsii i kosmonavtike* (Moscow: Nauka, 1978), pp. 62–63.

functions that a cosmonaut could perform in case of emergency: orientation of the spacecraft into correct attitude and firing of the retrorocket for descent.[9]

The range of manual control functions available to and actually performed by American astronauts was much wider. They could override the automatic system in such essential tasks as separating the spacecraft from the booster, activating the emergency rescue system, parachute release, dropping the main parachute in case of failure and activating the second parachute, correcting the on-board control system, and many other functions not available to Soviet cosmonauts.[10]

Different authors have offered a number of explanations for the Soviet reliance on automation in the case of Vostok:

1) *High reliability of automatic control:* Soviet rockets could lift greater weights, and therefore the Soviets could install redundant sets of automatic equipment to ensure its reliability.

2) *Disciplinary bias of rocket engineers:* Unlike American space engineers, who came from the aviation industry, Soviet spacecraft designers drew on specific engineering traditions in rocketry, and they were not accustomed to assign humans a significant role on board.

3) *Health and safety concerns:* There existed doubts about the cosmonaut's mental and physical capacity to operate the spacecraft in orbit.

Some of these explanations do have a grain of truth. Yet they mostly reflect partisan positions in internal Soviet debates over the proper division of control functions between human and machine.

The first, "technological" explanation is most favored by spacecraft designers, who view it as an "objective" basis for automation. Indeed, the Vostok rocket could lift to the orbit a 4.5-ton spacecraft, while the Americans could launch only 1.3 to 1.8 tons. Using this extra weight, the argument goes, the Soviets could afford to build redundant, more reliable systems and to construct a fully automatic spacecraft, while the Americans were forced to delegate some of the functions to the astronaut on board. The space journalist Iaroslav Golovanov wrote: "The American astronaut had to work more than the Soviet cosmonaut because the weight of Vostok was more than twice

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[9] Valentina Ponomareva, "Osobennosti razvitiia pilotiruemoi kosmonavtiki na nachal'nom etape," in *Iz istorii raketno-kosmicheskoi nauki i tekhniki*, vyp. 3, ed. V. S. Avduevskii et al. (Moscow: IIET RAN, 1999), pp. 132–167; Siddiqi, *Challenge to Apollo*, p. 196.

[10] Robert B. Voas, "A Description of the Astronaut's Task in Project Mercury," *Human Factors* (July 1961): 149–165.

the weight of Mercury, and this made it possible to relieve [the cosmonaut] of many in-flight tasks."[11]

Interestingly, this argument only suggests an explanation for the need for a broad range of manual control functions on Mercury, while the Soviet preference for complete automation is assumed as a natural solution. Those who used this argument clearly took it for granted that automatic systems were inherently more reliable than human control. Indeed, most Vostok designers viewed the cosmonaut on board as a weak link, a source of potential errors. The leading integration designer Konstantin Feoktistov openly told the cosmonauts, for example, that "in principle, all the work will be done by automatic systems in order to avoid any accidental human errors."[12]

In fact, it is by no means obvious why should one use weight reserves to install redundant sets of equipment instead of building a more flexible and sophisticated manual control system. Soviet space designers admitted that the on-board equipment that they were supplied with was so unreliable that installing extra sets was the only way to ensure an acceptable risk of failure. Boris Chertok acknowledged that the Americans were able to make a much better use of their weight reserves than the Soviets. He wrote: "The weight of Gemini was only 3.8 tons. Vostok weighed almost a ton more, and Voskhod 2 almost 2 tons more than Gemini. Yet Gemini surpassed the Vostoks and the Voskhods in all respects."[13] Gemini had a rendezvous radar, an inertial guidance system with a digital computer, a set of fuel cells with a water regenerator, and many other types of on-board equipment that the first Soviet spacecraft lacked.

The second, "disciplinary" explanation is often put forward by cosmonauts, who tend to blame the "overautomation" of Soviet spacecraft on the professional background of rocket engineers. According to the space historian and former cosmonaut candidate Valentina Ponomareva, "In the United States space technology developed on the basis of aviation, and its traditional attitude toward the pilot was transferred to space technology. In the Soviet Union the base for the space enterprise was artillery and rocketry. Rocketry specialists never dealt with a 'human on board'; they were more familiar with the concept of automatic control."[14] This argument assumes that the Soviet space program was a culturally homogeneous assembly of rocket engineers. In fact, Chief Designer Sergei Korolev, under whose leadership Vostok was

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[11] Golovanov, *Korolev*, p. 604. A similar argument is presented in Ponomareva, "Osobennosti razvitiia," p. 144.

[12] Quoted in Vladimir Komarov, Workbook No. 39, 1961, Gagarin Memorial Museum, Town of Gagarin, Russia, *http://hrst.mit.edu/hrs/apollo/soviet/documents/doc-komarov39.pdf* (accessed 21 April 2005).

[13] Chertok, *Rakety i liudi*, vol. 3, pp. 256–257.

[14] Ponomareva, "Osobennosti razvitiia," p. 161.

constructed, had come into rocketry from aeronautics; in the 1920s and 1930s, he had designed and tested gliders.[15] His deputies, leading spacecraft designers Pavel Tsybin and Sergei Okhapkin, had previously been prominent aircraft designers. Heated debates over the division of function between human and machine often broke out within the space engineering community, and the opponents in those disputes were not necessarily divided along the lines of their disciplinary background. For example, in July 1963, when the leadership of Korolev's design bureau discussed various options for lunar exploration, it was the aviation designer Pavel Tsybin who advocated the use of automatic spacecraft, and it was the rocket designer Mikhail Tikhonravov who insisted on the development of piloted spaceships.[16] Tikhonravov also argued in favor of making Vostok controls completely manual.[17]

Soviet cosmonauts with aircraft piloting background in private tended to blame rocket engineers, nicknamed "artillerymen," for any design flaws. For example, during her training as a cosmonaut, Valentina Ponomareva noticed that yaw and roll in the hand controller on the Vostok spacecraft were rearranged as compared to a typical aircraft hand controller. Fellow cosmonauts told her that it was "because artillerymen had built it."[18] As it turned out, the controller was developed by specialists from the Air Force Flight Research Institute, which specialized in aviation control equipment. Yaw and roll were rearranged because the controller itself was positioned differently (which, in turn, was the result of a different position of the cosmonaut as compared to the aircraft pilot). Moreover, since spacecraft could rotate in all directions, yaw and roll in some cases simply changed places. There was no conspiracy of "artillerymen" here; it was aviation specialists who designed manual control and information display equipment for Soviet spacecraft.[19]

The third, "medical" explanation often cited Soviet doctors' concern that the cosmonaut's mental and physical capacities might be impaired during the flight.[20] In fact, although doctors did study the issue of the cosmonaut's health and working capacity in orbit, they were not pushing for automation. On the contrary, the leading physician, Vladimir Yazdovskii, was in favor of expanding the range of Yuri Gagarin's tasks on the first human flight, while

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[15] See Golovanov, *Korolev*.

[16] Vasilii Mishin, diary, 22 July 1963, NASA Historical Reference Collection, Washington, DC.

[17] Ponomareva, "Osobennosti razvitiia," p. 147.

[18] Valentina Ponomareva interview, Moscow, 17 May 2002, *http://hrst.mit.edu/hrs/apollo/soviet/interview/interview-ponomareva.htm* (accessed 21 April 2005).

[19] Yurii Tiapchenko, "Information Display Systems for Russian Spacecraft: An Overview," trans. Slava Gerovitch, *http://hrst.mit.edu/hrs/apollo/soviet/essays/essay-tiapchenko1.htm* (accessed 21 April 2005).

[20] Ponomareva, "Osobennosti razvitiia," p. 145.

A pensive Yuri Gagarin is in the bus on the way to the launchpad on the morning of 12 April 1961. Behind him, seated, is his backup, German Titov. Standing are cosmonauts Grigoriy Nelyubov and Andrian Nikolayev. Gagarin began his cosmonaut training in 1960, along with 19 other candidates. On 12 April 1961, Gagarin lifted off in the automated Vostok 1 spacecraft, and after a 108-minute flight, he parachuted safely to the ground in the Saratov region of the USSR. As the first human to fly in space, he successfully completed one orbit around Earth. After his historic flight, Gagarin became an international symbol for the Soviet space program, and in 1963, he was appointed Deputy Director of the Cosmonaut Training Center. In 1966, he served as a backup crew member for Soyuz 1, and on 17 February 1968, he completed a graduate degree in technical sciences. Tragically, during flight training in a UTI-MiG-15 aircraft on 27 March 1968, Gagarin was killed when his plane crashed. *(NASA photo no. Gagarin01)*

Chief Designer Sergei Korolev insisted that Gagarin should limit his actions to visual inspection of on-board equipment and should not touch any controls. Korolev's cautious approach may have been prompted by the responsibility placed on him by the political authorities. It was Nikita Khrushchev himself who on 3 April 1961, just a few days before Gagarin's flight, at a meeting of the Presidium of the Party Central Committee, raised the question about the cosmonaut's working capacity and psychological stability in orbit. Korolev had to give his personal assurances.[21] Not relying entirely on the disciplining force of cosmonaut's written instructions, spacecraft designers took some technological measures to prevent any accidental damage from the cosmonaut's actions in case he did lose his psychological stability. They blocked the manual orientation system for reentry with a digital lock. There was some debate whether to give the combination to the cosmonaut or to transmit it over the radio in case of emergency, and eventually they decided to put the combination in a sealed envelope and to place it on board so that the cosmonaut could open it in an emergency.[22]

In the end, Soviet officials decided to give Gagarin a "broader" set of functions, such as checking equipment before launch, writing down his observations and instrument readings in the on-board journal, and reporting those over the radio. As doctors explained, keeping the cosmonaut busy would help deflect his attention from possible negative emotions during g-loads and weightlessness.[23]

None of the three popular explanations—the reliability of redundant automatics, the disciplinary bias of rocket engineers, and the uncertainty about human performance in orbit—provides an unequivocal argument in favor of automation. All three aspects of the problem of automation—technological, disciplinary, and medical—involved debates and negotiations, whose outcome was not predetermined from the very beginning.

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[21] Nikolai Kamanin, *Skrytyi kosmos*, vol. 1, *1960–1963* (Moscow: Infortekst, 1995), pp. 23 (diary entry of 2 March 1961), 43 (diary entry of 4 April 1961).

[22] As it turned out, two people independently told Yuri Gagarin the combination before the launch so that he would not have to waste time on opening the envelope in case of real emergency. See Boris E. Chertok, *Rakety i liudi*, vol. 2, *Fili—Podlipki—Tiuratam*, 3rd ed. (Moscow: Mashinostroenie, 2002), pp. 428–429.

[23] Siddiqi, *Challenge to Apollo*, p. 264.

VOSTOK DUAL USE: MILITARY/CIVILIAN AND AUTOMATIC/MANUAL

Recently published materials suggest another explanation for the Soviet reliance on automation in the design of Vostok, an explanation that emphasizes the social shaping of technology. It suggests that the military context played a decisive role in defining civilian technologies in the Soviet space program.

Vostok was designed at the Experimental Design Bureau No. 1, led by Chief Designer Sergei Korolev, as an add-on to its main specialty, ballistic missiles. In November 1958, the Council of Chief Designers discussed three alternative proposals for a new spacecraft: an automatic reconnaissance satellite, a piloted spacecraft for a ballistic flight, and a piloted spacecraft for an orbital flight. The reconnaissance satellite designers pushed their proposal, stressing its primary importance for defense. This clearly had an appeal to the military, the Design Bureau's main customers. A rival group, led by the integration designer Konstantin Feoktistov, decided to support their proposal for a piloted spacecraft for an orbital flight with what he called a "tactical maneuver": they claimed that their piloted spaceship could be converted into a fully automatic spacecraft and used as a reconnaissance satellite, which would be able to return to Earth not just a small container with film, but a large capsule with the entire camera set. This promised to kill two birds with one stone! Feoktistov drafted a proposal for a piloted spacecraft in the guise of an automatic reconnaissance satellite and submitted it to the Military-Industrial Commission of the Soviet Council of Ministers. Some officials became suspicious when they noticed, for example, that the presumably automatic satellite was equipped with a set of communication devices, and they inquired, "Who is going to talk over this radio? The photo cameras?"[24] But Feoktistov was able to fend off such suspicions, and his proposal was approved.

At this early stage, the competition between automatic satellites and piloted spaceships was resolved by making piloted ships also fully automatic so that they could be flown in both piloted and unpiloted modes. Since the first Soviet piloted spacecraft had to serve a dual purpose—both military and civilian—its controls also had to be dual, both automatic and manual.

Only having a fully automatic spacecraft at hand, spacecraft designers began carving out a role for the cosmonaut to play. By early 1960, Boris Raushenbakh's department at the Experimental Design Bureau No. 1 completed its design of the automatic control system, and after that, they began working on manual control. That is, the issue here was not the automation of certain functions of a human pilot, but the transfer of certain functions from an existing automatic system to a human pilot. What really needs an explanation is not why Vostok

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[24] Konstantin Feoktistov, *Traektoriia zhizni* (Moscow: Vagrius, 2000), p. 62.

was automated, but why it had a manual control system at all. Its purposes were to back up the automatic system in case of malfunction, to expand the window for controlled descent, and, most importantly, to provide psychological support to the cosmonaut. As Raushenbakh put it, "The cosmonaut must be convinced that even if ground control equipment and the on-board automatic system fail, he would be able to ensure his safety himself."[25]

While Gagarin had to limit his in-flight activity to monitoring and reporting, during subsequent Vostok flights, the cosmonauts successfully tested the manual attitude-control system and performed other duties and experiments. In particular, they tested the human ability to carry out military tasks. Korolev had previously suggested that the piloted version of Vostok could be used "to exterminate [enemy] satellites."[26] Tests performed by the cosmonauts Nikolaev and Popovich on Vostok 3 and Vostok 4 demonstrated that the human was "capable of performing in space all the military tasks analogous to aviation tasks (reconnaissance, intercept, strike). Vostok could be used for reconnaissance, but intercept and strike would require the construction of new, more advanced spacecraft." From this information, Kamanin concluded that "man can maintain good working capacity in a prolonged spaceflight. The 'central character' in space is man, not an automaton."[27]

THE VOSKHOD 2 MISSION: THE COSMONAUT TAKES CONTROL

While the cosmonauts believed that the first spaceflights had demonstrated the human ability to perform in orbit, the engineers largely interpreted the same events as confirming the high reliability of automatic systems. Soviet engineers initially viewed the automatics and the cosmonaut not as a single, integrated system, but as two separate, alternative ways to control a spacecraft. They sought ways to make the automatic control system independently reliable, rather than trying to optimize interaction between human and machine. The probability of a system malfunction that would require resorting to manual control seemed remote, and the manual control system did not seem to have primary importance for spacecraft designers. So when they redesigned Vostok for a three-men crew (the Voskhod mission) and later for a spacewalk (the Voskhod 2 mission), it was the manual control system that got short shrift. To fit in all the new equipment, the designers had to move the main instrument panel and the optical sight from the

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[25] Aleksei Eliseev, *Zhizn'—kaplia v more* (Moscow: Aviatsiia i kosmonavtika, 1998), p. 15.

[26] Sergei Korolev, "Tezisy doklada po kosmosu," June 1960, Russian State Archive of the Economy (RGAE), f. 298, op. 1, d. 1483, l. 246.

[27] Kamanin, *Skrytyi kosmos*, vol. 1, pp. 174 (diary entry of 13 September 1962), 149 (diary entry of 16 August 1962).

front to the left side, and the hand controller was also moved.[28] Additional technical measures were taken to ensure the reliability of the automatic control system, and yet when a life-threatening emergency occurred during the Voskhod 2 flight in March 1965, only the cosmonauts' ingenuity and skill saved their lives.

When the Voskhod 2 crew—the commander, Pavel Beliaev, and the first "spacewalker," Alexei Leonov—were preparing for descent, the automatic attitude-correction system failed. Because of an error in the mathematical model, the automatics decided that the orientation engines were malfunctioning and shut them down. Without proper orientation, the firing of the retrorocket was automatically blocked, threatening to leave the crew stranded in the orbit. After some deliberation, the ground control ordered the cosmonauts to perform manual orientation, which was the only option available at that point.

To use the manual system, however, was no easy task. Because of a peculiar cabin layout, the optical sight and the hand controller were located to the left of the commander's seat, rather than in front of it. The cosmonauts could not look through the sight or operate the controller while remaining in their seats. Both cosmonauts had to unbuckle their seatbelts and leave their seats. Beliaev also had to take off his space helmet because he could not bend his neck in it. He had to lie down across both seats, since only while lying down could he use both hands to operate the manual controls. In the meantime, Leonov crawled under his seat and was holding Beliaev by his torso, since in zero gravity, Beliaev tended to float away and block the optical sight. After the orientation, the cosmonauts needed to fire the retrorocket. But before firing it, they had to return to their seats to balance the spacecraft, and they lost 30 or 40 seconds. They spent a few more seconds doublechecking the orientation and then fired the retrorocket. As a result of these delays, the spacecraft overshot its destination. The crew landed in the middle of a thick forest, and before a rescue team was able to reach them, they had to spend two nights on the snow, hiding in their space capsule from hungry wolves.[29]

The Voskhod 2 story also provided an interesting test case for assigning responsibility for various errors to human or machine. The investigating commission noted that the flawed spacecraft design made it impossible for the crew to control the ship manually without leaving their seats, and at the same time, it criticized the crew for violating the rules. In the final report, however, the criticism of spacecraft design was dropped in exchange for removing the criticism of the crew.[30]

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[28] Eliseev, *Zhizn'*, p. 46.

[29] Boris E. Chertok, *Rakety i liudi*, vol. 4, *Lunnaia gonka* (Moscow: Mashinostroenie, 2002), p. 418; Eliseev, *Zhizn'*, p. 58; Nikolai Kamanin, *Skrytyi kosmos*, vol. 2, *1964–1966* (Moscow: Infortekst, 1997), p. 190 (diary entry of 22 April 1965); Ponomareva, "Osobennosti razvitiia," pp. 157–158; Siddiqi, *Challenge to Apollo*, p. 458.

[30] Kamanin, *Skrytyi kosmos*, vol. 2, pp. 197 (diary entry of 8 May 1965), 199 (diary entry of 13 May 1965).

DESIGNING A COSMONAUT FOR SOYUZ

The second-generation Soviet spacecraft, Soyuz, was designed for a much wider range of missions than Vostok, including Earth-orbit rendezvous and docking. The problem of an efficient division of function between human and machine on Soyuz became the subject of a heated, if closely contained, debate within the Soviet space community. Two groups—the spacecraft designers and the cosmonauts—had very different perspectives on this issue. Briefly put, their positions were as follows.

The spacecraft designers argued that on-board automation had clear advantages. It allowed 1) to test piloted spacecraft in the unpiloted mode, thereby reducing time and expense on ground tests and increasing flight safety; 2) to lower eligibility criteria and reduce training time for cosmonauts; 3) to correct errors in flight.[31] The engineers were willing to assign the cosmonauts a backup function but preferred to keep the automatic mode as nominal.

The cosmonaut corps, on the other hand, tended to view the automation of control functions as excessive and hampering the "progress" of human spaceflight. They argued that a human operator would increase the reliability and effectiveness of a space mission. They especially stressed the human ability to act in unexpected situations, to cope with equipment failures, and to perform in-flight repairs. They argued that full automation alienated the pilot from his craft. They insisted that instead of fitting the human into an existing technological system, one must design human activity first and then determine specifications for the technological components of the system.[32]

The Soviet space program's organizational structure (or lack thereof) gave the spacecraft designers a decided advantage over the cosmonauts in such internal disputes. The Soviet space program was not supervised by a central government agency like NASA, but was scattered over a large number of defense industry, military, and academic institutions. The chief contractor for Soyuz—Korolev's Experimental Design Bureau No. 1—exercised unprecedented control over the course of the space program. Korolev himself, in particular, played a central role in decision-making on a whole range of issues going far beyond engineering, such as spacecraft procurement, cosmonaut training, crew selection, programming of missions, and ground flight control.[33] It was

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[31] Vladimir S. Syromiatnikov, *100 rasskazov o stykovke i o drugikh prikliucheniiakh v kosmose i na Zemle*, vol. 1, *20 let nazad* (Moscow: Logos, 2003), p. 83.

[32] See Beregovoi et al., *Eksperimentalno-psikhologicheskie issledovaniia*, pp. 192, 270; Ponomareva, "Nachalo vtorogo etapa"; Ponomareva, "Osobennosti razvitiia."

[33] On Korolev, see Golovanov, *Korolev*; Harford, *Korolev*; Boris V. Raushenbakh, ed., *S.P. Korolev i ego delo: svet i teni v istorii kosmonavtiki* (Moscow: Nauka, 1998). In the eyes of Korolev's

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the engineers' vision of the proper division of function between human and machine that was largely implemented in the Soviet space program.

Soyuz designers recognized that manual control would "make it possible to get rid of a number of complex pieces of equipment and to simplify automatic control systems."[34] Compared to Vostok, they significantly broadened the range of manual control functions, but these new functions involved not so much piloting as monitoring numerous on-board systems and dealing with equipment malfunctions. A Soyuz cosmonaut was a different type of cosmonaut, an engineer more than a pilot.

On the Soyuz program, requirements for the skills of the crew, selection criteria for the cosmonaut corps, and the very professional identity of cosmonauts began to change. The first group of Soviet cosmonauts that flew on Vostoks was selected from among young fighter pilots, who had little engineering background and modest flight experience compared to the more educated and experienced test pilots selected for the Mercury astronaut group.[35] Sergei Korolev chose fighter pilots because of their universal skills as pilots, navigators, radio operators, and gunners.[36] On a two- or three-seat Soyuz, these functions could now be divided among the crew members, and narrow specialists, more skilled in one task than another, could be brought on board.

But there was also another, more important factor that precipitated a shift in the cosmonaut professional identity. In the decentralized organizational structure of the Soviet space program, spacecraft design and cosmonaut training were institutionally separated: the design and production of spacecraft was conducted under the Ministry of General Machine-Building, and cosmonaut training was the responsibility of the Air Force. As a result, the cosmonauts had very little input in spacecraft design. They pointed out that in the aviation industry, experienced pilots were regularly consulted during the design phase, while the cosmonaut pilots were entirely left out of spacecraft design.[37] The engineers recognized the problem but came up with a different solution for it. Vasilii Mishin, who replaced Korolev as Chief Designer after his death, argued that "design solutions can only be checked [in flight] by highly qual-

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subordinates, he was truly omnipotent. For example, Feoktistov claimed that crucial decisions concerning the Soviet space program were made "not by the Party Central Committee or the Soviet government, but by Korolev and [the defense industry leader Dmitrii] Ustinov (and often by Korolev alone), and later they managed, one way or another, to obtain a retroactive endorsement through an official decree" (Feoktistov, *Traektoriia zhizni*, pp. 36–37).

[34] Vasilii Mishin, quoted in Kamanin, *Skrytyi kosmos*, vol. 2, p. 368 (diary entry of 17 August 1966).

[35] Siddiqi, *Challenge to Apollo*, p. 246.

[36] Gherman S. Titov, "30 let spustia," *Aviatsiia i kosmonavtika*, no. 8 (1991): 26.

[37] Chertok, *Rakety i liudi*, vol. 4, p. 149.

ified specialists directly involved in designing and ground testing of the spacecraft."[38] Thus, instead of involving cosmonaut pilots in spacecraft design, he proposed to train space engineers as cosmonauts and to let them test new systems in flight.

Soon, Mishin took practical steps toward changing the composition of the cosmonaut corps. In May 1966, the Experimental Design Bureau No. 1 set up a flight-methods department for the training of a civilian group of "cosmonaut testers."[39] This rapidly led to an open confrontation with Air Force officials, who defended their monopoly on cosmonaut selection and training. Wielding his influence with the Soviet leadership, Mishin threatened that only engineers and scientists would fly and that training at the Air Force Cosmonaut Training Center would be simplified or dispensed with altogether.[40] Eventually, a compromise was worked out by which a typical Soyuz crew would include one military pilot as mission commander, one civilian engineer, and one flight researcher, in whose seat military and civilians would alternate.[41]

As spacecraft designers began to enter the cosmonaut corps, they introduced elements of engineering design into the planning of cosmonaut activity. The control system engineer and cosmonaut Alexei Eliseev, who took part in a spacewalk during the Soyuz 4–Soyuz 5 mission, applied a genuine engineering skill in designing a step-by-step procedure for the spacewalk, specifying the actions and code words for every crew member. This procedure was recorded on a 4-meter-long scroll of paper.[42] The Experimental Design Bureau No. 1 set up a special department, which designed cosmonaut activity so that it conformed to the logic of on-board automatics. Control system designers worked in close contact with human engineering specialists, who conceptualized the spacecraft control system as a "cybernetic 'human-machine' system."[43] Adapting the cybernetic conceptual framework, they viewed control as a system function that could be performed by both human and machine. Human engineering specialists described the cosmonaut as a "living link"[44] in a human-machine system and analyzed this "link" in terms borrowed from control theory and information theory—the same terms that applied to the other, technical links

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[38] Quoted in Kamanin, *Skrytyi kosmos*, vol. 2, p. 368 (diary entry of 17 August 1966).

[39] Siddiqi, *Challenge to Apollo*, p. 566.

[40] Chertok, *Rakety i liudi*, vol. 3, p. 242.

[41] Eliseev, *Zhizn'*, p. 165.

[42] Ibid., p. 91.

[43] V. G. Denisov, "Nekotorye aspekty problemy sochetaniia cheloveka i mashiny v slozhnykh sistemakh upravleniia," in *Problemy kosmicheskoi biologii*, ed. N. M. Sisakian and V. I. Iazdovskii, vol. 2 (Moscow: Nauka, 1962), p. 54.

[44] V. G. Denisov, A. P. Kuz'minov, and V. I. Iazdovskii, "Osnovnye problemy inzhenernoi psikhologii kosmicheskogo poleta," in *Problemy kosmicheskoi biologii*, ed. N. M. Sisakian and V. I. Iazdovskii, vol. 3 (Moscow: Nauka, 1964), p. 77.

in that system: delay time, perception speed, reaction speed, bandwidth, and so on.[45] They discussed how efficiently a human operator could perform the functions of a logical switchboard, an amplifier, an integrator, a differentiator, and a computer.[46] Spacecraft designers avoided using the word "pilot" and preferred the term "spacecraft guidance operator."[47] The cosmonaut had to fit into an existing technological system, and human performance was effectively evaluated in machine terms.

One of the main criteria for cosmonaut selection was the ability to carry out precisely programmed actions.[48] Subsequent training was geared toward turning the human into a perfect machine. Spacecraft designers took to the heart a piece of advice given by Igor' Poletaev, a leading Soviet cybernetics specialist. He argued that the way to avoid human error was to train the human to operate like a machine. He wrote: "The less his various human abilities are displayed, the more his work resembles the work of an automaton, the less [the human operator] debates and digresses, the better he carries out his task."[49] The cosmonaut training manual explicitly stated that "the main method of training is repetition."[50] Yuri Gagarin recalled how the cosmonauts were "getting used to every button and every tumbler switch, learned all the movements necessary during the flight, making them automatic."[51] The Vostok 5 pilot Valerii Bykovskii was praised in his character evaluation for "the high stability of automation of skill."[52]

The cosmonauts began to resent what they perceived as "excessive algorithmization" of their activity. They argued that the strict regulation of cosmonauts' activity on board forced them "to work like an automaton" and stripped them of the possibility to plan their actions on their own.[53]

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[45] Denisov, "Nekotorye aspekty," p. 55.

[46] P. K. Isakov, V. A. Popov, and M. M. Sil'vestrov, "Problemy nadezhnosti cheloveka v sistemakh upravleniia kosmicheskim korablem," in *Problemy kosmicheskoi biologii*, ed. N. M. Sisakian, vol. 7 (Moscow: Nauka, 1967), p. 6.

[47] V. N. Kubasov, V. A. Taran, and S. N. Maksimov, *Professional'naia podgotovka kosmonavtov* (Moscow: Mashinostroenie, 1985), p. 278.

[48] Siddiqi, *Challenge to Apollo*, p. 244.

[49] Igor' A. Poletaev, *Signal: O nekotorykh poniatiiakh kibernetiki* (Moscow: Sovetskoe radio, 1958), p. 281.

[50] Kubasov, Taran, and Maksimov, *Professional'naia podgotovka*, p. 138.

[51] Yuri Gagarin, *Doroga v kosmos* (Moscow: Pravda, 1961).

[52] Quoted in A. N. Babiichuk, *Chelovek, nebo, kosmos* (Moscow: Voenizdat, 1979), p. 209.

[53] Beregovoi et al., *Eksperimentalno-psikhologicheskie issledovaniia*, p. 31.

SOYUZ FLIGHTS: DIVIDING GLORY AND RESPONSIBILITY BETWEEN HUMAN AND MACHINE

Several emergency situations that occurred during Soyuz missions underscored the crucial importance of human-machine issues for spacecraft control. As the boundary between human and machine functions was often blurred, so was the responsibility for error. While accident investigators tended to assign the responsibility for error to either human or machine, failures were often systemic. In an emergency, rigid control schemes often had to be reconsidered and human and machine functions had to be redefined. Ground flight controllers frequently stepped in, further complicating the division of responsibility between human and machine. Ultimately, what often decided the success of the mission was not how much or how little the cosmonauts did, but how well they were integrated into the control system, which included both the on-board automatics and mission control.

In April 1967, the Soyuz 1 mission had to be aborted after multiple equipment failures, and the cosmonaut Vladimir Komarov successfully performed manual attitude correction with an ad hoc method invented during the flight. Yuri Gagarin, who served as a CAPCOM on that mission, told the leading control system designer, "What could have we done without a human? Your ion system proved unreliable, a sensor failed, and you still don't trust cosmonauts!"[54] In the end, yet another automatic system—the parachute release—failed, and this time, the cosmonaut had no manual means to override it. The spacecraft hit the ground at full speed, and Komarov died.

In October 1968, the cosmonaut Georgii Beregovoi on Soyuz 3 attempted a manual rendezvous, but he misread the target vehicle indicators and failed to approach the target. Engineers regarded this as a clear human error, yet Nikolai Kamanin, responsible for cosmonaut training, pointed out that the actual manual control system on board in certain respects differed from the version installed on a ground simulator and that the cosmonaut did not have adequate time to adjust to zero gravity. "I did not find my place within a human-machine structure," admitted Beregovoi. He complained that the hand controllers were too sensitive, sending the spacecraft into motion at the slightest touch: "This is good for an automaton, but it creates extra tension for a human."[55] Kamanin interpreted this incident as a systemic failure, rather than simply a human operator error: "If even such an experienced test pilot [as Beregovoi] could not manually perform the docking of two spaceships, this means that the [manual] docking system is too complex to work with in zero gravity."[56]

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[54] Chertok, *Rakety i liudi*, vol. 3, p. 450.

[55] Chertok, *Rakety i liudi*, vol. 4, p. 419.

[56] Kamanin, *Skrytyi kosmos*, vol. 3, p. 303 (diary entry of 29 October 1968).

Now engineers had to prove that their manual control system was actually operable. Chief Designer Vasilii Mishin insisted on trying manual docking on the Soyuz 4–Soyuz 5 mission in January 1969, even though his boss, the Minister of General Machine-Building, Sergei Afanas'ev, pressured him to resort to the proven automatic docking system.[57] This time the engineers made sure that the cosmonauts received more than sufficient training on the ground. The cosmonaut Vladimir Shatalov had performed 800 simulated dockings in various regimes on a ground simulator before he successfully carried out manual docking of Soyuz 4 and Soyuz 5.[58] Later, for other trainees, the requisite number of simulated dockings was reduced to 150.[59]

In August 1974, the Soyuz 15 crew attempted an automatic rendezvous with the Salyut 3 station, but the automatic system malfunctioned, misjudging the distance to the target and producing an acceleration thrust instead of retrofire. This led to a near collision of the spaceship with the station. Another attempt at automatic approach resulted in another dangerous flyby. The crew suggested to make a third attempt at docking in the manual regime, but ground control did not give permission, due to the low level of remaining propellant. The crew had to return to Earth without completing their mission.[60]

After the flight, heated debates erupted over the question whether the main responsibility for the failed mission should be assigned to human or machine. Engineers argued that the cosmonauts should have recognized the malfunction immediately and should have resorted to manual control. Officials responsible for cosmonaut training replied that this particular type of emergency had not been included in the list and that the cosmonauts had not been trained for it. The investigation was further complicated by the fact that this failure occurred just a year before the scheduled docking of Soyuz with Apollo. The American side, worried about the reliability of the Soviet rendezvous system, requested an explanation of the Soyuz 15 incident.[61] Thus, despite an obvious failure of the automatic docking system, the Soviets preferred to put the blame squarely on the cosmonauts—for not shutting down the malfunctioning system after the first failure.[62] Both cosmonauts were officially reprimanded and never flew into space again.

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[57] Nikolai Kamanin, *Skrytyi kosmos*, vol. 4, *1969–1978* (Moscow: Novosti kosmonavtiki, 2001), p. 11 (diary entry of 10 January 1969), 12 (diary entry of 11 January 1969).

[58] Vladimir A. Shatalov, *Trudnye dorogi kosmosa*, 2nd ed. (Moscow: Molodaia gvardiia, 1981), p. 129.

[59] Kubasov, Taran, and Maksimov, *Professional'naia podgotovka*, p. 138.

[60] Chertok, *Rakety i liudi*, vol. 4, p. 434; Asif A. Siddiqi, "The Almaz Space Station Complex: A History, 1964–1992: Part I," *Journal of the British Interplanetary Society* 54 (2001): 411–414.

[61] Dave Shayler, "Soyuz 15 Mission Report," *http://www.astroinfoservice.co.uk/html/soyuz_15_report.html* (accessed 21 April 2005).

[62] Rex Hall and David J. Shayler, *Soyuz: A Universal Spacecraft* (Chichester, U.K.: Springer/Praxis, 2003), pp. 186–187; Ponomareva, "Nachalo vtorogo etapa," pp. 169–170.

Rather than being an exclusively human or machine failure, the Soyuz 15 mission illustrated another system failure: a failure to integrate the crew in the control loop in a human-machine system. The crew was kept in "cold reserve," passively monitoring the operations of the automatic docking system. When this system failed, the crew was not ready to take over control operations quickly. Although the engineers switched the blame to the crew, it was the engineers' design of the control system that placed the crew in the role of passive observers. Engineers tacitly admitted that the failure of the Soyuz 15 mission had roots in the overall organization of rendezvous control, including the role of ground control. A special operational group was created as part of Mission Control to develop procedures for automatic and manual rendezvous in various emergency situations and to provide real-time recommendations for the flight director.[63]

After that incident, cosmonaut pilots were assigned responsibility for manual approach from the distance of 200 to 300 meters. In a few years, however, this rule was subjected to a severe test. In October 1977, the Soyuz 25 crew made an attempt at manual docking with the Salyut 6 station, and when the spacecraft almost touched the station, they suddenly realized that they were facing the "bottom" of the station, instead of the docking port. They quickly turned away from Salyut 6 and made several more docking attempts, all of which failed. Having spent much propellant, Soyuz 25, in the end, did not even have enough fuel to back up from the station and remained in close proximity to it for several orbits.[64] As it turned out, what the cosmonauts perceived as the "bottom" of the station was in fact the docking port. Soyuz 25 approached the station from a slightly different angle than was expected, but the cosmonauts were never trained on a ground simulator to recognize the station from that angle. A "conditional reflex" they acquired during incessant training on the simulator prevented them from recognizing the correct position of the station.[65] Although the error was rooted in the inadequate simulator design, the cosmonauts bore their part of the blame. For the first time, the cosmonauts did not receive the honor of the Hero of the Soviet Union, but were awarded "only" the Order of Lenin.[66] Mission planners decided never again to send all-rookie crews into space. Most importantly, it was decided to make the nominal docking regime automatic, and the cosmonauts were allowed to take over manual control only in case of failure of the automatic system.[67] The prolonged struggle for the right to control docking between human and machine began to shift in favor of the latter.

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[63] Chertok, *Rakety i liudi*, vol. 4, p. 435.

[64] Eliseev, *Zhizn'*, pp. 200–204.

[65] Chertok, *Rakety i liudi*, vol. 4, p. 439.

[66] Iurii M. Baturin, ed., *Mirovaia pilotiruemaia kosmonavtika. Istoriia. Tekhnika. Liudi* (Moscow: RTSoft, 2005), pp. 273–274.

[67] Eliseev, *Zhizn'*, p. 209.

THE ROLE OF GROUND CONTROL

The norms of cosmonaut activity included not only following the technical protocol of interaction with on-board equipment, but also following the social protocol of subordination to their superiors on the ground. Framing the whole issue as human versus machine is somewhat misleading. The real issue here was not so much the division of function between human and machine, but the division of power between the human on the ground and the human on board.

Boris Chertok acknowledged that the growing complexity of space technology warranted a greater role for the human operator, but his idea of human participation was to involve "not just an individual, but an entire collective,"[68] meaning the flight controllers and specialists on the ground. As a result, Soviet designers adopted the principle that they have followed to this day: all critical systems had three independent lines of control: automatic, remote (from the ground), and manual.[69] Control during the three main stages of the flight—reaching the orbit, orbital flight, and reentry—was automatic; instructions to switch programs between the stages were given either from the ground or manually by the cosmonaut. The cosmonaut, however, had to obtain permission from the ground for any critical action. The cosmonaut training manual clearly stipulated that "all most important decisions are made by Mission Control."[70] The real control of the mission remained in the hands of engineers: either through the automatic systems they designed or through their design and management of cosmonaut activity.

The need to obtain clearance from Mission Control sometimes delayed critical actions until it was too late. For example, in October 1969, the Soviets planned a complicated orbital maneuver with three spacecraft: Soyuz 7 and Soyuz 8 attempted a rendezvous, while Soyuz 6 was to capture the event on camera. Unfortunately, the automatic approach system on Soyuz 8 failed. At that moment, the two ships were about 1,000 meters from each other, and the cosmonauts asked permission to attempt manual approach. While the crew awaited permission from the ground, the ships drifted apart to the distance of about 3,000 meters, and manual approach was no longer an option. The next day, through orbital maneuvers, the ships were brought within 55 feet from each other, but without any means to determine their relative velocities, all attempts at manual approach also failed.[71] The crews had to return to Earth without

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[68] B. Evseev (Boris Chertok), "Chelovek ili avtomat?" in *Shagi k zvezdam*, ed. M. Vasil'ev (Vasilii Mishin) (Moscow: Molodaia gvardiia, 1972), p. 282.

[69] Syromiatnikov, *100 rasskazov*, p. 145.

[70] Kubasov, Taran, and Maksimov, *Professional'naia podgotovka*, p. 190.

[71] Chertok, *Rakety i liudi*, vol. 4, pp. 214–215; Hall and Shayler, *Soyuz*, p. 159.

completing their mission. Nikolai Kamanin subsequently bitterly remarked in his private diary: "Everything [on the Soyuz] is based on the assumption of a flawless operation of automatics, and when it fails, cosmonauts are left without reliable means of control."[72] And yet the responsibility for the failed mission was placed on the cosmonauts.[73] Boris Chertok later admitted, however, that the designers were to blame for overestimating human capabilities and for not providing adequate training on simulators for the situation of failure of the automatic approach system.[74]

On more than one occasion, cosmonauts faced the dilemma: to follow the rules and fail the mission or to take risks and break the rules. Some preferred to break the rules and save the mission. Another emergency that occurred during the Voskhod 2 flight in March 1965 is a case in point. After completing his historic spacewalk, the cosmonaut Alexei Leonov realized that his spacesuit ballooned, his arms and legs did not even touch the inside, and he was unable to reenter the airlock. He was supposed to report all emergencies to the ground and wait for instructions. He later recalled: "At first I thought of reporting what I planned to do to Mission Control, but I decided against it. I did not want to create nervousness on the ground. And anyway, I was the only one who could bring the situation under control."[75] Perhaps, he calculated that instructions from the ground could be delayed because of various bureaucratic procedures and the possible reluctance of some decision-makers to take responsibility, and it would be unwise for him to spend his limited oxygen supply waiting for them. Leonov turned a switch on his spacesuit, drastically reducing the internal air pressure, which allowed him to regain control of his movements. Once he broke one rule, he decided that he would not make things worse by breaking another, and he climbed into the airlock headfirst, in violation of an established procedure.

The Voskhod 2 crew—Alexei Leonov and Pavel Beliaev, both military pilots—were trained to follow the rules and to obey orders from the ground. After more than 150 training sessions on a spacewalk simulator, Leonov was said to have brought his skills "to the point of automatic performance."[76] Yet in a real emergency, Leonov had to perform actions for which he was not trained, to violate explicit rules concerning entry into the airlock, and to make decisions without consulting Mission Control. In other words, his mission was successful precisely because he did not act like a perfect machine.

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[72] Kamanin, *Skrytyi kosmos*, vol. 4, p. 95.

[73] Ponomareva, "Nachalo vtorogo etapa," p. 169.

[74] Chertok, *Rakety i liudi*, vol. 4, p. 422.

[75] David R. Scott and Alexei A. Leonov, *Two Sides of the Moon: Our Story of the Cold War Space Race* (London/New York: Simon & Schuster, 2004), p. 109.

[76] N. N. Gurovskii et al., "Trenazhery dlia podgotovki kosmonavtov k professional'noi deiatel'nosti po upravleniiu korablem i ego sistemami," in *Problemy kosmicheskoi biologii*, ed. N. M. Sisakian, vol. 4 (Moscow: Nauka, 1965), p. 6; Siddiqi, *Challenge to Apollo*, p. 451.

THE PARADOX OF DISCIPLINED INITIATIVE

Space engineers believed that flight safety would be best guaranteed by comprehensive automation and by strict following of instructions by the crew, but the cosmonauts pointed out that it was often necessary to break the rules in case of emergency. The engineers often viewed any departure from the standard procedure as a "human error," while it was precisely this ability to deviate from the standard path that made human presence on board so valuable in an emergency situation. Perhaps the main difference between human and machine in a human-machine system is that the machine fails when it does not follow preset rules and the humans fail when they do not recognize that it is time to break the rules.

Valentina Ponomareva, a member of the first women's cosmonaut group, summed up the cosmonauts' vision of the unique human role on board as follows:

> In addition, the cosmonaut must possess such qualities as curiosity and *the ability to break rules* . . . . Regulations work well only when everything goes as planned . . . . The ability to act in extraordinary situations is a special quality. In order to do that, one has to have inner freedom . . . the ability to make non-trivial decisions and to take non-standard actions. In an extreme situation the very life of the cosmonaut depends on these qualities.[77]

Despite her high qualifications as an engineer and a pilot and her excellent test marks, Ponomareva was not selected for the first woman's flight, and she never got a chance to fly. Her independent-mindedness most likely played a role here.

Sonja Schmid, in her study of Soviet nuclear power station operators, observed a similar contradiction in the way the operators were viewed by nuclear reactor designers: both as a "weak link" and as a "reliable cog in the wheel."[78] Both spacecraft designers and nuclear engineers viewed the human operator as part of technology, which must always function according to the rules, and at the same time, they expected the operators to show human qualities such as initiative and inventiveness.

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[77] Valentina Ponomareva, *Zhenskoe litso kosmosa* (Moscow: Gelios, 2002), p. 285.

[78] Sonja Schmid, "Reliable Cogs in the Nuclear Wheel: Assigning Risk, Expertise and Responsibility to Nuclear Power Plant Operators in the Soviet Union" (paper presented at Society for the History of Technology [SHOT]-2004, Amsterdam, Netherlands, 7–10 October 2004).

This need for the cosmonauts to be both obedient and creative, to follow the rules and to break them, one might call "a paradox of disciplined initiative." In my view, this paradox reflects one of the fundamental contradictions of the Soviet approach to spacecraft control (and perhaps to social control and government in general).

THE LUNAR PROGRAM: A TURN TOWARD MANUAL CONTROL

The lunar race further complicated the debates over the human role on board. Lunar mission profiles did not allow ground stations to effectively control the entire flight, and the division of control functions between human, on-board automation, and ground control had to be reevaluated. Initially, it was decided to give the cosmonauts an unusually high degree of control over their spacecraft. Alexei Leonov, who initially trained for a circumlunar mission, recalled that "we had to be able to perform every aspect of the flight manually in case the automatic system failed."[79] Later on, the internal politics of the Soviet lunar program began to erode this principle.

From the very beginning, the Soviet lunar program suffered from the lack of coordination, internal rivalries, duplication of effort, and fracturing of resources. Initially, the heads of two rival design bureaus—Sergei Korolev and Vladimir Chelomey—divided the lunar pie more or less equally: Korolev worked on a lunar landing project, while Chelomey developed a rocket and a spacecraft for a circumlunar flight. After Khrushchev's ouster in October 1964 and the subsequent shakeup in the upper echelons of Soviet power Chelomey lost some of his political support, and Korolev eventually wrestled the circumlunar flight project away from him. In October 1965, a government decree assigned Korolev the responsibility for the development of the 7K-L1, a new spacecraft designed specifically for a circumlunar flight, later publicly named Zond.

One major hurdle in the Soviet lunar program was eliminated: all work on lunar spacecraft was now concentrated in one organization, Korolev's design bureau. Yet the circumlunar flight and the lunar landing remained two separate projects with different goals, independent work schedules, different booster rockets, separate ground infrastructures, and two different types of spacecraft, the L1 and the L3. The addition of the circumlunar project to Korolev's tasks stretched the resources of his design bureau and messed up the lunar landing project schedule. The circumlunar project was given immediate priority in order to complete it by the 50th anniversary of the Great October Revolution in November 1967.

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[79] Scott and Leonov, *Two Sides of the Moon*, p. 189.

Social and political factors influenced the lunar program down to the very technical level. Korolev had to split the responsibility for the development of the control system for the L1 spacecraft with the organization led by his old friend Nikolai Pilyugin. As a result, Pilyugin developed the automatic control system for course corrections and reentry, while Korolev assumed responsibility for manual rendezvous control.[80] The cosmonaut functions on board were thus limited by the division of spheres of responsibility of different design organizations.

The L1 crew consisted of two cosmonauts, whose duties included checking all on-board systems in Earth orbit and then orienting the spacecraft toward the Moon. For the first time in the Soviet piloted space program, the L1 control system included a digital computer, the Argon-11. This computer was part of the automatic control system designed by Pilyugin, and cosmonauts had no access to it.[81] The manual control system included a digital computing device called Salyut 3, which was not reprogrammable; it gave the cosmonauts fixed options for selecting one of the preset programs. According to the control panel designer, Yuri Tiapchenko, the L1 panel was a step backward in comparison with Soyuz: "The functions of cosmonauts were reduced to the simplest operations of entering commands and controlling their execution in accordance with flight instructions and the orders issued by ground control."[82]

In 1967–1968, the Soviets made eight attempts to launch L1 on a circumlunar mission in the unpiloted mode. Only one mission performed a circumlunar flight; all missions were fraught with numerous failures which might have been fatal to a human crew. After the successful Apollo 8 mission in December 1968, the L1 program lost its political rationale, and after another failed L1 mission in January 1969, the plans for a piloted flight were suspended. Eventually the program was canceled without a single attempt for a piloted flight. The cosmonauts unsuccessfully petitioned the Soviet political leadership for continuation of the piloted circumlunar program.[83] The only completely successful L1 mission that would have returned the crew safely to Earth took place on 8 August 1969. The passengers on the spacecraft were four male tortoises. Two cosmonauts, Alexei Leonov and Oleg Makarov, participated in the mission as ground operators.[84]

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[80] Siddiqi, *Challenge to Apollo*, pp. 504–505.

[81] V. V. Chesnokov, "Argon-11C computer," *http://www.computer-museum.ru/english/argon11c.htm* (accessed 21 April 2005); Georgii Priss interview, Moscow, 23 May 2002, *http://hrst.mit.edu/hrs/apollo/soviet/interview/interview-priss.htm* (accessed 21 April 2005); Viktor Przhiyalkovsky interview, Moscow, 24 May 2002, *http://hrst.mit.edu/hrs/apollo/soviet/interview/interview-przhiyalkovsky.htm* (accessed 21 April 2005).

[82] Iurii A. Tiapchenko, "Sistemy otobrazheniia informatsii pilotiruemykh KA L1 i N1-L3," *http://www.cosmoworld.ru/spaceencyclopedia/publications/index.shtml?tg_moon.html* (accessed 21 April 2005).

[83] Scott and Leonov, *Two Sides of the Moon*, p. 252.

[84] Siddiqi, *Challenge to Apollo*, pp. 699–700.

That flight took place already after Apollo 11. The Soviet lunar landing project, known as N1-L3, lost its political rationale too, but Chief Designer Vasilii Mishin continued lobbying for it, given the amount of funding and effort already invested in it, and the project was kept afloat for a few more years.

The Soviet lunar landing project was based on a lunar orbit rendezvous scheme similar to Apollo. Because of the limits on the rocket lifting power, however, the weight of the Soviet lunar lander had to be roughly one-third of the weight of the Apollo lander. For this reason, the Soviets planned to send only two cosmonauts on the lunar mission: one cosmonaut landing on the Moon and the other staying on the lunar orbital ship. Severe weight limitations forced Soviet designers to give the cosmonauts a much wider range of functions. In particular, to reduce the bulk of docking equipment and to eliminate extra dockings, the engineers proposed to transfer the cosmonaut from the orbital ship to the lander and back via spacewalk.[85]

Lunar landing was planned to be fully automatic with partial manual backup.[86] Using an on-board computer, a cosmonaut could process information from various sensors, evaluate the condition of the lander according to preprogrammed algorithms, and choose specific actions. Most importantly, the cosmonaut could manually select a landing site on the lunar surface and give instructions to the computer to produce required landing maneuvers.[87] Lunar landing required extraordinary performance from the cosmonaut: on the Apollo lunar landing module, two astronauts had 2 minutes to make a landing decision, while on the Soviet lander, a single cosmonaut would have only 15 to 20 seconds.[88]

Cosmonauts underwent intensive training, both on simulators and on helicopters, simulating lunar landing. They performed helicopter landings with the engines cut off, a very difficult and dangerous operation.[89] Gradually, however, Chief Designer Vasilii Mishin began to limit the responsibilities of the pilot, placing greater emphasis on automatic systems. This may have had something to do with Mishin's plans to assign a greater role to civilian cosmonauts, engineers from his own design bureau. Cutting on manual control functions made it possible to reduce cosmonaut training time, and civilian cosmonauts, who generally had less training than military pilots, could now compete with the pilots for the lunar landing mission.[90]

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[85] Ibid., pp. 495–497.

[86] Chertok, *Rakety i liudi*, vol. 4, pp. 92, 109.

[87] Siddiqi, *Challenge to Apollo*, p. 491.

[88] Chertok, *Rakety i liudi*, vol. 4, p. 225.

[89] Siddiqi, *Challenge to Apollo*, pp. 684–685.

[90] Kamanin, *Skrytyi kosmos*, vol. 3, pp. 123–124 (diary entry of 15 October 1967), 312 (diary entry of 13 November 1968), 341 (diary entry of 23 December 1968); Siddiqi, *Challenge to Apollo*, p. 650.

The growing degree of automation on the L3 alarmed the cosmonaut pilots. Alexei Leonov, who trained for lunar landing, commented that "according to the fight plan the automatic system took precedence"; the cosmonauts were allowed to resort to manual control only in case of failure of the automatic system. "I had argued," continued Leonov, "that, as commander of a spacecraft, what I needed once a flight was in progress was as little communication as possible from the ground—since it served mainly to distract me from what I already knew was necessary—and only manual, not automatic, control."[91]

The lunar landing program suffered from a series of setbacks during the failed launches of the giant N1 booster. The last attempt was made in 1972, and soon the program was terminated. The cosmonauts had hoped that they might have a chance to fly the lunar spacecraft during a series of Earth-orbit test flights in 1970–71. The financial difficulties that besieged the Soviet lunar program, however, forced Mishin to eliminate lunar orbiter test flights and to test only the lunar lander, and just in the unpiloted mode. During three tests in Earth orbit, the lunar lander successfully simulated a lunar landing, two liftoff operations with the primary and backup engines, and an entry into lunar orbit. The automatic control system worked perfectly.[92] Whether manual controls would have worked remains unknown. The Soviets kept the existence of their piloted lunar program secret for 25 years. Instead, they cultivated the myth that exploring the Moon with automatic probes was their one and only goal.

DEFINING THE COSMONAUT PROFESSION

The seemingly technical issue of on-board automation raised a larger question of the nature and purpose of human spaceflight. The debates over automation reflected three competing visions of spaceflight: a piloting mission, an engineering task, and a research enterprise.

The first cosmonaut group was composed of military pilots, and they used their growing prestige and political influence to maintain their monopoly on spaceflight. In May 1961, shortly after his historical first flight, Yuri Gagarin sent a letter to the Chief Marshal of Aviation, A. A. Novikov, arguing that "only pilots are capable of carrying out spaceflights. If others want to fly into space, they must learn to fly aircraft first. Aviation is the first step to spaceflight."[93]

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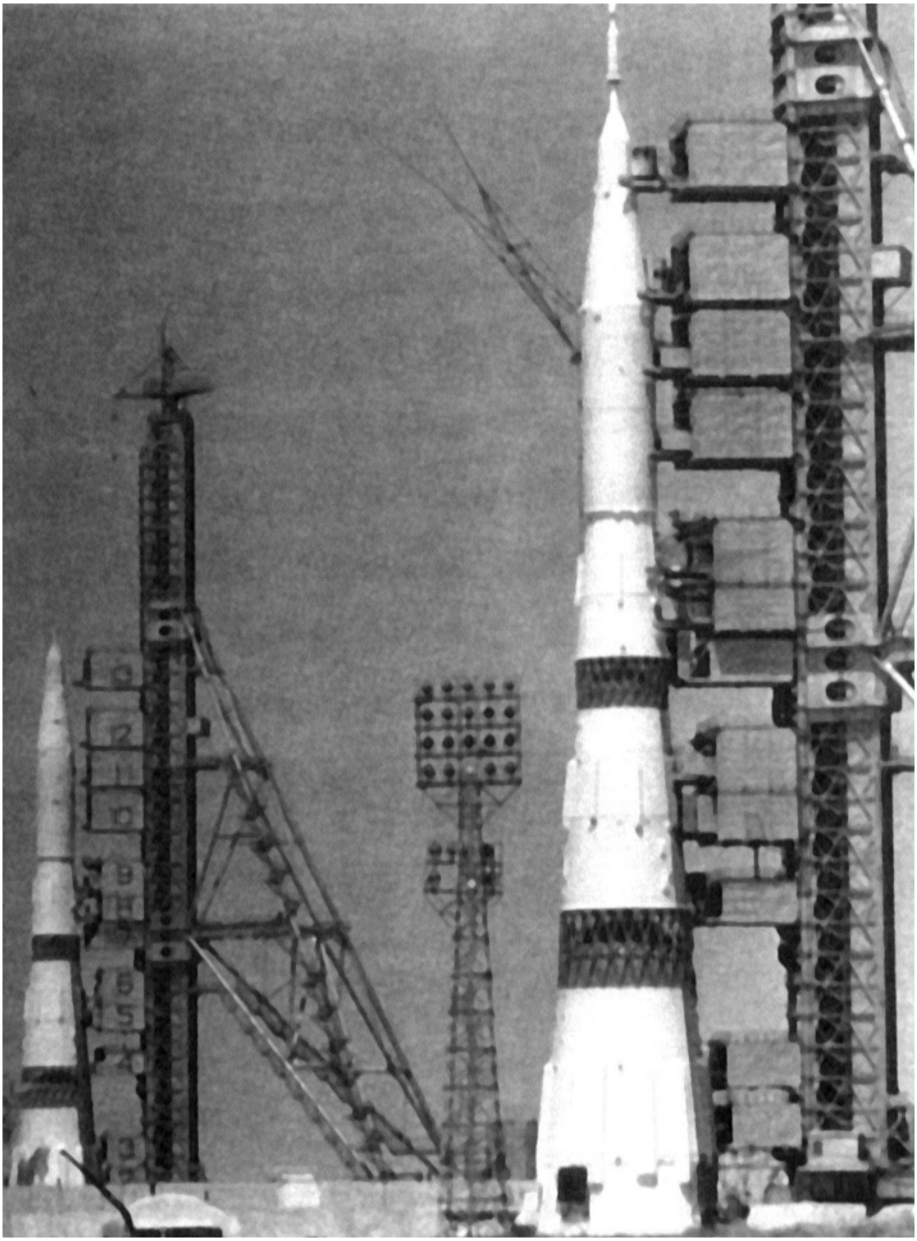
[91] Scott and Leonov, *Two Sides of the Moon*, p. 189.

[92] Siddiqi, *Challenge to Apollo*, pp. 734–736.

[93] Quoted in Kamanin, *Skrytyi kosmos*, vol. 1, p. 57 (diary entry of 25 May 1961). Later on, Gagarin seemed to have changed his opinion and supported the first civilian engineers who joined the cosmonaut corps; see Georgii Grechko, "Iz-za liubvi k kino ia chut' ne prozeval polet v kosmos!" *Vechernii Omsk*, no. 11 (11 February 2004), *http://epizodsspace.testpilot.ru/bibl/intervy/grechko3.html* (accessed 21 April 2005).



Two N1 Moon rockets appear on the pads at Tyura-Tam in early July 1969. Highly automated, the N1 was designed for the Soviet space program's human lunar missions. In the foreground is booster number 5L with a functional payload for a lunar-orbiting mission. In the background is the IMI ground-test mock-up of the N1 for rehearsing parallel launch operations. After takeoff, the rocket collapsed back onto the pad, destroying the entire pad area in a massive explosion. *(NASA photo no. n1july1969)*

When, in 1962, Korolev for the first time raised the question of including engineers in space crews, Kamanin called this "a wild idea."[94] The military pilots strongly objected to the waiver of "harsh physical tests" for engineers, insisting that the pilots were "the real veterans in the [cosmonaut] corps."[95] A Deputy Minister of Defense said bluntly that "we will select cosmonauts only from among robust young fellows from the military. We don't need those ninnies from civilian science."[96] Kamanin eventually realized the need for a compromise and began lobbying for the inclusion of civilian specialists.

Space engineers, for their part, insisted that they had a legitimate claim for a spacecraft seat. Boris Chertok explained: "We, engineers who designed the control system, believed that controlling a spacecraft is much easier that controlling an aircraft. All processes are extended in time; there is always time to think things over . . . . A good engineer can control a spaceship as well as a pilot, if there are no obvious medical objections."[97] The engineer-cosmonaut Konstantin Feoktistov compiled a chart comparing the professions of the cosmonaut and the pilot and tried to show that piloting skills were unnecessary aboard a spacecraft, but Kamanin interpreted the same chart in the opposite way.[98]

Engineers argued that their presence on board would have dual benefit: a better handling of emergency situations during the flight and a better design of spacecraft resulting from their flight experience. The engineer-cosmonaut Alexei Eliseev reasoned that, as space technology was becoming more and more complex, it would be impossible to write down instructions for all conceivable emergencies. A situation may arise in which only spacecraft designers on board would be able to find the right solution. He also suggested that "one could design on-board equipment for the cosmonauts only with their own participation. Only people who carry out spaceflights can give competent assessments and recommendations with regard to the convenience of use of various types of on-board equipment."[99] Instead of involving cosmonaut pilots in the design process, however, the engineers believed that they themselves should be included in space crews. In April 1967, the engineer-cosmonaut Oleg Makarov met with Chief Designer Vasilii Mishin and proposed a list of measures aimed at changing the role of humans on board. Makarov argued that an engineer must be included in every space crew; that crews must study on-board equipment at the design and production sites, not just on simulators;

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[94] Kamanin, *Skrytyi kosmos*, vol. 1, p. 105 (diary entry of 19 April 1962).

[95] Scott and Leonov, *Two Sides of the Moon*, p. 146.

[96] Kamanin, *Skrytyi kosmos*, vol. 1, p. 210 (diary entry of 17 January 1963).

[97] Chertok, *Rakety i liudi*, vol. 3, pp. 237, 242.

[98] Kamanin, *Skrytyi kosmos*, vol. 3, p. 210 (diary entry of 8 April 1968).

[99] Eliseev, *Zhizn'*, pp. 28, 164.

and that cosmonauts must be given the right to take over control in case of malfunction of automatic systems.[100]

Kamanin realized that engineers-turned-cosmonauts might soon replace the military pilots whose training he oversaw. In February 1965, he ordered to organize eight research groups at the Cosmonaut Training Center focused on the following problems: military use of spacecraft; space navigation, life-support and rescue systems; telemetry equipment; scientific orbital stations; circumlunar flight; lunar landing; and weightlessness. Each group would study the assigned problem, formulate the Center's positions on specific issues, and defend those positions before scientists and designers.[101] While spacecraft designers were claiming a seat on board, the cosmonauts began to claim a seat at the designer's workstation.

In the 1970s, with the introduction of orbital stations, mission engineers began playing an ever-growing role in spaceflight. Long-duration missions required such skills as equipment maintenance and repair, observation, and research much more than piloting, which was limited to docking, undocking, and keeping the station in the correct attitude. Although pilots were traditionally appointed mission commanders, flight engineers began to demand more authority in decision-making. The engineer-cosmonaut Georgii Grechko summed up the engineers' sentiment as follows: "The time of pilots among cosmonauts is passing. In any case, they are no longer the main agents of the exploration of the Universe. 'Our' era, the era of mission engineers is dawning."[102] Grechko's discussion of these controversial issues with his commander, the pilot Yurii Romanenko, during their mission on the Salyut 6 station quickly turned into a heated argument. Eventually, Grechko had to flee into another compartment of the station to avoid violent confrontation.

Maintaining a complex orbital station with its long-term life-support systems devoured most of the cosmonauts' time on board, raising questions about the relative costs and benefits of human flight. The engineer-cosmonaut Valentin Lebedev calculated that during a five-day work week, two cosmonauts spent 111 hours on supporting themselves. Only 9 hours were left for scientific research. "The station is crewed just for the sake of those nine hours."[103] In an interview given after his retirement, Vasilii Mishin similarly estimated that in space, most of a cosmonaut's time on board was spent on preparations for takeoff and landing, on physical exercise, and on sleep: "Only 20 percent of

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[100] Mishin, diary, 30 April 1967.

[101] Kamanin, *Skrytyi kosmos*, vol. 2, p. 134 (diary entry of 2 February 1965).

[102] Georgii Grechko, *Start v neizvestnost'* (Moscow: Pravda, 1989), chap. 2.

[103] Valentin Lebedev, "U nas velikaia strana. Reshat' ee problemy predstoit novomu pokoleniiu," *Osnova* (Naro-Fominsk), no. 26 (28 May 2004), *http://epizodsspace.testpilot.ru/bibl/intervy/lebedev1.html* (accessed 21 April 2005).

a cosmonaut's time was spent on really productive work." He concluded that the cosmonaut profession as such did not exist and that, at present, piloted flights were "entirely unnecessary."[104]

Konstantin Feoktistov proposed to solve the problem of inefficiency of human spaceflight though automation. "A man assigned to cope only with control functions is an unjustifiable luxury," he argued. "No craft is designed to carry dead weight. It must have a payload that performs a kind of useful work. This can be, for example, research." He proposed to make spacecraft control "simple and executable without high skills and during a minimum time" to allow scientists and engineers to fly space missions. "Every operation that can be automated on board a spaceship should be automated," concluded Feoktistov.[105] Boris Chertok similarly viewed automation as the way to free up the crew from routine functions: "Taken the high degree of automation on Vostok, an even higher degree on Zenit, and totally marvelous automation on future generations of spacecraft, the human on board must engage in research, reconnaissance, and experiments."[106] Feoktistov argued that valuable scientific data could be obtained only if scientists were included in space crews. "Scientists can develop their own experimental agenda, prepare their own instruments and equipment . . . . Cosmonauts [who lack scientific training] do not have this expertise. They are trained for specific mechanical operations: to turn something on, to switch something off, to monitor equipment, etc. If scientists come to space, scientific research would be more productive."[107] Long debates over the question whether scientists should be allowed on board were resolved in favor of a "professional cosmonaut," an engineer or a pilot, who would receive some scientific training and conduct experiments on board in consultation with scientists on the ground. The most the scientists were able to achieve was the privilege of direct communication with the cosmonauts in orbit.[108]

The problem of professional identity of the cosmonaut—a pilot, an engineer, or a scientist—proved inextricably connected with the question of on-board automation. If the first cosmonaut pilots tried to wrestle control functions from the machine, later on, cosmonaut researchers preferred to delegate equipment service functions to automatic systems to free up their own time for experiments and observations. As Valentin Lebedev put it, "Man is not an appendix to a machine. Man is not made for the flight, but the flight is made for man."[109]

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[104] Vasilii Mishin, "I Contend That There Is No Cosmonaut Profession" (English title), *Nezavisimaya gazeta* (13 April 1993), p. 6 (translation, JPRS-USP-93-002, 18 May 1993, p. 28).

[105] Quoted in Viktor D. Pekelis, *Cybernetic Medley*, trans. Oleg Sapunov (Moscow: Mir, 1986), p. 287.

[106] Chertok, *Rakety i liudi*, vol. 3, p. 242.

[107] Konstantin Feoktistov, "'Aliaska' v kosmose," *Voronezhskie vesti*, no. 27 (2 July 2003), *http://epizodsspace.testpilot.ru/bibl/intervy/feoktistov3.html* (accessed 21 April 2005).

[108] Eliseev, *Zhizn'*, pp. 172–173.

[109] Lebedev, "U nas velikaia strana."

AUTOMATION IN CONTEXT

This brief overview of human-machine issues in the Soviet space program indicates that instead of the binary opposition of manual versus automatic control, we encounter complex human-machine systems, in which both humans and machines depend on one another; manual and automatic functions are not necessarily fixed, but may be redefined during the flight, and human-machine interaction on board becomes part of a vast remote-control network. "Automatic" control operations have some degree of human input, and "manual" control is always mediated by technology. Determining how these lines are negotiated in specific instances provides a glimpse into the internal politics and professional cultures within the space program.

On-board automation appeared as both an instrument and a product of local politics in the Soviet space program. The debates over the proper degree of automation were tied to the definition of cosmonauts' skills as either pilots or engineers. Here, technology, professional identity, and social status were closely intertwined. Soviet cosmonauts were "designed" as part of a larger technological system; their height and weight were strictly regulated, and their actions were thoroughly programmed. Soviet space politics, one might say, was inscribed on the cosmonauts' bodies and minds, as they had to fit, both physically and mentally, into their spaceships.

The existing historiography largely interprets the Soviet approach to human-machine issues as complete reliance on automation. I believe this view misses several important aspects of the story. First, it downplays the intensity of internal debates over the role of the cosmonaut on board. Engineers with their technical notions of reliability, cosmonauts with their piloting aspirations, human engineering specialists with their formulas for optimal division of function between human and machine, industry executives with their aversion to risk-taking, political leaders with their sober calculations of political gains and risks—all these groups had their input in these disputes. The Soviet approach to on-board automation did not appear to have been predetermined; it was developed, refined, and often reshaped in the course of these debates.

The Soviet approach to automation was never fixed; it evolved over time, from the fully automated equipment of Vostok to the semiautomatic analogue control loops of Soyuz to the digital systems of later generations of Soyuz. The role of the cosmonaut also changed, from the equipment monitor and backup on Vostok to the versatile technician on Soyuz to a systems integrator on later missions.

The Soviet approach also changed across various space projects running in parallel. In the late 1960s, while Soyuz was still largely controlled by on-board automatics or by ground operators, the Soviet lunar ships were designed to give the crews a much higher level of autonomy and control over their missions.

The Soviet approach was also flexible in another sense: the division of function between human and machine was not fixed, but was often renegotiated during the flight. Ground flight controllers played a crucial role in deciding whether the crew would be allowed to assume manual control. It is important, therefore, to examine not just the division of technical functions, but also the division of authority between the human on the ground and the human on board.

This analysis suggests that a human-machine system is not a simple dot on a straight line between total automation and complete manual control. This system is not defined by a simple numerical subdivision of function between human and machine. The efficiency of a human-machine system depends on the degree of integration of the human into the technological system, including its social infrastructure. Some space missions failed not because the range of manual functions was too narrow, but because the cosmonauts did not have the authority to use specific functions or because they were not "in the loop" for a timely receipt of crucial information. The efficiency of a human-machine system depends on whether the human in the system can play a truly human role, to have both the authority and the responsibility for decision-making. If a cosmonaut is trained to be a perfect automaton, his nominal role may increase, but this would be achieved at the cost of losing his unique human quality—not to act like a machine.

DIRECTIONS FOR FURTHER RESEARCH

Human-machine issues in the Soviet space program touch upon three large areas of historiography: 1) social history of automation, 2) sociopolitical and cultural history of the Soviet Union, and 3) comparative studies of the American and Soviet space programs.

In the history of technology, automation has traditionally been viewed as a technological implementation of management control resulting in workers' de-skilling and disempowerment.[110] A study of automation in the Soviet space program reveals a more complex story, in which cosmonauts do not simply lose their piloting skills, but adapt to the evolving technological system, making themselves indispensable in emergency situations. A third element—the ground controllers—also enters the equation, reframing the automation issue:

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[110] See David Noble, "Social Choice in Machine Design: The Case of Automatically Controlled Machine Tools," in *The Social Shaping of Technology*, ed. Donald MacKenzie and Judy Wajcman (Buckingham, U.K.; Philadelphia: Open University Press, 1985), pp. 161–176.

instead of a simple binary choice of automatic versus human control, one faces a complex organization in a network of multiple remote-control interactions, mediated by both humans and machines. A study of human-machine issues may provide a new framework for analyzing the social aspects of automation in complex technological systems.

Political historians of the Soviet Union have placed the space program in a larger political context, stressing the growing role of technocracy during the Cold War on both sides of the Iron Curtain.[111] Cultural historians have recently focused on the formation of cultural norms and Bolshevik identity in various periods of Soviet history.[112] The debates over human-machine issues provide a window into the cultural norms and identity of Soviet engineers and cosmonauts during the Cold War. Further studies could identify different political and cultural trends within the broad category of "technical intelligentsia," the backbone of Soviet technocracy; examine the interplay of engineers' and pilots' cultures in the cosmonaut profession; and also explore the tensions between the popular cultural image of the cosmonaut and the cosmonauts' own professional identity.[113]

Comparing the American and Soviet space programs through the prism of automation would help challenge the stereotype of fixed "national styles" in engineering. David Mindell's study of human-machine issues in the U.S. space program provides a thorough analysis of the internal debates between American pilots and space engineers.[114] In both the American and the Soviet cases, different approaches to automation are not predetermined, but emerge out of local negotiations, contingent on the range of available technological alternatives, space policy priorities, and specific configurations of power. What is often perceived as a "natural" technological choice emerges as a historically contingent product of political, socioeconomic, and cultural forces.

After the successful circumlunar mission of Apollo 8, Nikolai Kamanin wrote in his private diary that this flight had confirmed "the primary role of

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[111] See Andrew John Aldrin, "Innovation, the Scientists and the State: Programmatic Innovation and the Creation of the Soviet Space Program" (Ph.D. diss., University of California, Los Angeles, 1996); Barry, "The Missile Design Bureaux"; Walter A. McDougall, . . . *The Heavens and the Earth: A Political History of the Space Age* (New York: Basic Books, 1985).

[112] David Hoffmann, *Stalinist Values: The Cultural Norms of Soviet Modernity, 1917–1941* (Ithaca: Cornell University Press, 2003); Oleg Kharkhordin, *The Collective and the Individual in Russia: A Study of Practices*, Studies on the History of Society and Culture, no. 32 (Berkeley and Los Angeles: University of California Press, 1999); Stephen Kotkin, *Magnetic Mountain: Stalinism as a Civilization* (Berkeley: University of California Press, 1995).

[113] Two recent studies have adopted a cultural approach: Cathleen Lewis has explored the interplay between the ceremonial openness of Soviet space-related public rituals and the technical secrecy surrounding the investigation of space accidents; Andrew Jenks has examined the connections between the "myth" or "cult" of Yuri Gagarin and the Soviet visions of modernity.

[114] See Mindell's article in this volume.

the spacecraft crew in such experiments. Automata can be a hundred times more perfect than man, but they can never replace him"—particularly, stressed Kamanin, in the human space race. "From a larger perspective, our designers are probably right in their intention to create fully automated piloted spaceships," he admitted. "Perhaps in the future, when communism triumphs over the entire planet, people will fly into space on such ships. But in our time one must not forget about the severe struggle between two opposing ideologies."[115] For Kamanin, the human role on board was the central issue of the space race, and the space race a central issue of the Cold War. A challenge for historians is to use analysis of human-machine issues in spaceflight as an entry point into larger questions of modern automation, Cold War, and space history.

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[115] Kamanin, *Skrytyi kosmos*, vol. 3, p. 348 (diary entry of 28 December 1968).

CHAPTER 5

HUMAN AND MACHINE IN THE HISTORY OF SPACEFLIGHT

David A. Mindell

Astronaut Michael Collins, who orbited the Moon on Apollo 11, remembered being inspired as a young man by the dashing figure of the barnstormer pilot Roscoe Turner. "Roscoe had flown with a waxed mustache and a pet lion named Gilmore," Collins remembered wistfully; "we flew with a rule book, a slide rule, and a computer." Before being selected for the project that would change his life and the world, Collins remembered feeling caught between "the colorful past I knew I had missed and the complex future I did not know was coming."[1] Collins captures an aspect of the history of spaceflight little attended to by historians: the relationship between human and machine. In two sentences, he helps us understand spaceflight and place it within 20th-century American history and the history of technology.

Roscoe Turner's career peaked just a few decades before Collins's, but the two seemed worlds apart. Turner, dubbed "Aviation's Master Showman," stunted and barnstormed his way from rural America into Hollywood in the 1920s and 1930s. He had little training and even less formal education. Yet he self-fashioned himself as a colorful character, sporting a waxed mustache and a made-up uniform from a nonexistent military in which he never served. He was married in the cockpit of his Curtiss Jenny and flew his giant Sikorsky S-29 airplane, dressed up as a German bomber, in Howard Hughes's film *Hell's Angels*. As Collins noted, Turner, under the sponsorship of the Gilmore oil company, flew with his pet lion of the same name. Turner embodied the showy, excited world of aviation in its "golden age" of transition from dangerous curiosity to commercial service.[2]

This was the world that inspired Collins to enter aviation, but by the time he had arrived professionally, a great deal had changed. Nearly all astronauts had college degrees in engineering, some had graduate degrees, and they had served as test pilots. The technology had changed as well, from simple biplanes

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[1] Michael Collins, *Carrying the Fire: an Astronaut's Journeys* (New York: Farrar, Straus and Giroux, 1974), pp. 16–17.

[2] Carroll V. Glines, *Roscoe Turner: Aviation's Master Showman* (Washington, DC: Smithsonian Institution Press, 1995).

to the complex, high-performance jets Collins had flown. Collins contrasts Turner's pet lion with his "rule book, a slide rule, and a computer." No longer was aviation a world of display and reckless adventure. No longer was the pilot the only master of his craft. Now he shared his authority with flight rules, calculations, and, increasingly in the 1950s, automatic flight controls and computers (not to mention controllers on the ground). At the start of the space program, it seemed to Collins that the world was becoming bureaucratic, technical, and quantitative, with some loss of the pilot's "white scarf" image.

Collins's comments serve as a starting point for examining this critical issue in the history of spaceflight: the relationship between humans and machines.

BETWEEN HUMAN AND MACHINE

Human versus machine—it is not a new story. Indeed, it is one of the great narratives of the industrial world. American history and culture are replete with human-machine conflicts and comparisons. In the Civil War, the crew of the ironclad warship *Monitor* thought themselves well protected by iron armor, but that mechanical contrivances diminished the glory and heroism of their performance in combat.[3] The mythical John Henry won a race with a steam drill at the cost of his life. Factory workers complained that mechanical assembly lines and Frederick Winslow Taylor's "Scientific Management" turned them into unthinking automatons. New combinations of human and machine appeared in the 20th century, from the robots of Fritz Lang's silent film classic, *Metropolis*, to the gas masks and artificial limbs of World War I. Aviation, the technology born with the new century, celebrated the human-machine relationship as never before. Perhaps the most significant of the Wright brothers' innovations was their recognition that an airplane was not a stately ship to be guided by a detached human hand, but an active beast, controlled by an intensely focused, skilled human pilot.[4]

From these diverse histories and technologies, we can distill a few fundamental threads. A good place to begin is the idea of *skill*. Skill is a common enough notion in everyday life, but also a key to understanding the human-machine relationship. On one hand, skill is highly personal—it is practical knowledge; it implies a certain amount of cleverness, perhaps expertise, and we often think about it as residing in our bodies, particularly our hands (e.g.,

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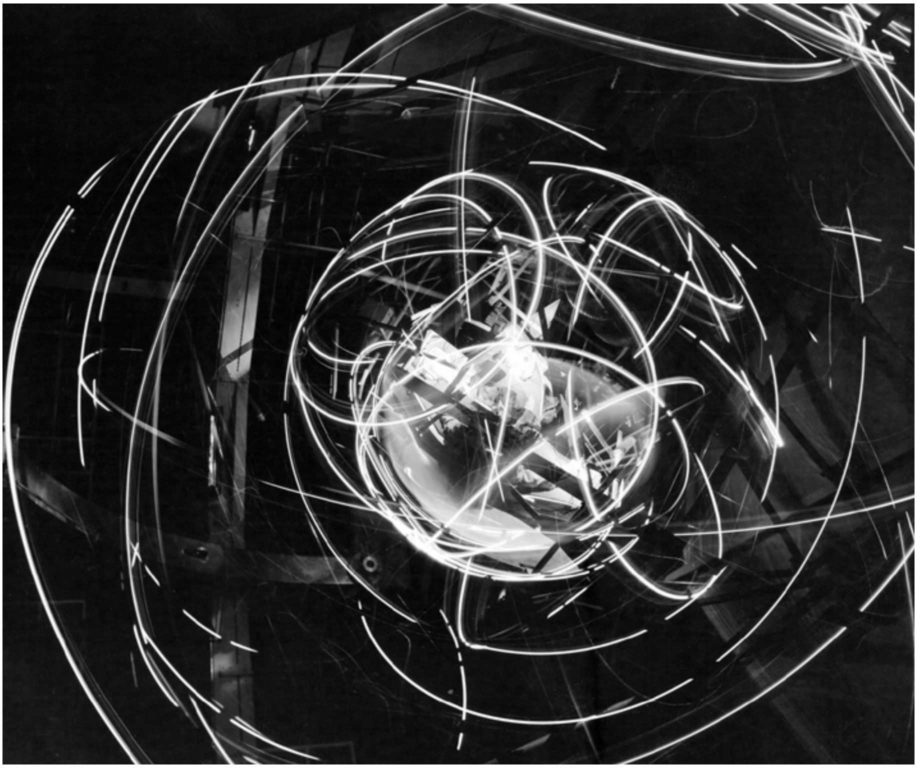
[3] David A. Mindell, *War, Technology, and Experience aboard the USS Monitor* (Baltimore, MD: Johns Hopkins, 2000).

[4] David A. Mindell, *Between Human and Machine: Feedback, Control, and Computing Before Cybernetics* (Baltimore: Johns Hopkins, 2002); Anson Rabinbach, *The Human Motor: Energy, Fatigue, and The Origins of Modernity* (New York: Basic Books, 1990); Thomas Crouch, *The Bishop's Boys: A Life of Wilbur and Orville Wright* (New York: W. W. Norton, 1989).



The epitome of human and machine interfaces, this device was formally known as the MASTIF, or Multiple Axis Space Test Inertia Facility, and was located in the Altitude Wind Tunnel in 1959. It was built at Lewis Research Center, now John H. Glenn Research Center, in Cleveland, Ohio, and was designed to train astronauts to regain control of a tumbling spacecraft. *(NASA photo no. C1959-52233)*

"manual skills"). On the other hand, skill is also deeply social—it is not inborn, but acquired, as distinct from an innate quality like talent. Skill implies *training*—the time and effort to learn and master a skill, often with the help of another person. Skill has a social dimension: it garners respect, and the more skill you are perceived to have, the more prestige you seem to earn.

Skilled workers include surgeons, carpenters, and waiters. Obviously, not all skills are equal. Some are more respected than others, and hence there tend to be social and economic differences between their practitioners. Skill also sets people apart. The word itself comes from an Old Norse word meaning *distinction* or *difference*, ideas that remain integral to today's meaning.[5] For any

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[5] *Oxford English Dictionary*, etymology for *skill*.

skill, some people have it and some people don't. The very notion of skill implies a social group, possibly even an elite. When people with common skills come together, they often form societies, set standards, create and uphold traditions. They also police the boundaries of who is in and who is out, and for high-status skills, this makes them *professions*.[6] Most would agree that surgeons are professionals, but are carpenters, or waiters?

Skills often develop in relation to particular technologies: a blacksmith's skills, for example, are only valuable within a particular mode of production. As technologies change, the skills change as well, sometimes generating social conflicts. For example, as numerically controlled machine tools were developed in the 1950s, some saw them as eliminating the need for skilled machinists. Indeed, the skills required of a machinist did change—and began to require intimacy with numbers and computers as much as with metals and cutting speeds, which favored certain people, or groups of people, over others. The important thing to realize is that technology does not just "change" of its own accord—it is changed by particular people for particular reasons at particular times. In the 20th century, those people were increasingly engineers, who sought to build more "skill" into machines and hence to reduce the requirements on the people who ran the machines, the operators. When those changes derived form computers, they became known as "automation," and they went hand in hand with social changes. Historians of technology, by and large, have focused on ideas of *de-skilling* without attending to the contingent nature of the skills themselves.[7]

In an earlier book, *Between Human and Machine*, I examined human-machine relationships surrounding technologies of control in the first half of the 20th century.[8] During that time, engineers began to understand the idea of the *feedback loop* and began to study the skills of human operators according to new principles of *control theory*. They saw that humans operated machines much like automatic regulators or thermostats—sensing an "error" between the "actual" state of the machine and its "desired" state and directing the machine to close the gap between the two. In the course of that work, it became clear that aviation had always been a rich site of human-machine interaction, and the Apollo landings were in some sense the culmination of the mid-20th-century history of feedback, control, and computing.

Consider the history of instrument flying. When pilots were flying in clouds, they lost the cues from the outside world that allowed them to keep

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[6] Andrew D. Abbott, *The System of Professions: An Essay on the Division of Expert Labor* (Chicago: University of Chicago Press, 1988).

[7] David F. Noble, *Forces of Production: A Social History of Industrial Automation* (New York: Alfred A. Knopf, 1984).

[8] Mindell, *Between Human and Machine*.

an airplane level, hence their feedback loops broke down (they went unstable). New instruments like directional gyros and artificial horizons replaced the natural cues with technological substitutes, and with some training, the pilots could use their indications as feedback and "fly blind." Of course, a machine could also close this feedback loop, and by no coincidence, the advent of automatic pilots and instrument flying occurred in the same period. Some pilots initially objected to the decline of pilots' "seat of the pants" or "intuitive" flying skills, and instrument flying remains today a compromise between pilot control and ground control. The new technology did change the nature of piloting, but it also allowed pilots new professional prestige and the ability to fly through bad weather on long-range commercial routes. Skill, prestige, training, professionalism, and new technologies are tightly coupled; change one element, and the others evolve as well, though not necessarily in predicable ways.

During World War II, the engineering of feedback control systems led to the emergence of digital computing and its associated sciences. The idea of a "computer" as a general-purpose information system emerged from a number of applications (like radar and gunfire control) which considered human operators and control systems as mathematical calculation. The post–World War II rise of Norbert Wiener's "cybernetics" captured the sense that control and communications were intimately linked with the characteristics of human operators and emphasized the blurring boundaries between human and machine.[9] Wiener's conception, however, elaborated on developments in a variety of engineering fields, particularly aviation.

From its origins, aviation was centrally concerned with the relationship of human and machine. The Wright brothers, by emphasizing the importance of control, created not simply a flying machine, but its human counterpart—the skilled pilot. From the moment Wilbur first flew, this new professional was born.[10] But what kind of person would a pilot be? A variety of models were proposed: soldier, athlete, adventurer, explorer, factory worker, engineer, ship's captain.[11] Which dominated at any given time depended on how the machines were designed, who piloted them, and their social position.

Under a project sponsored by the Sloan Foundation and the Dibner Institute in the late 1990s, a group of students and I began collecting documents, conducting interviews, and defining the boundaries of these issues in manned spaceflight. That project also brought on Slava Gerovitch and supported his early work on the Soviet program that he presents so ably in this volume.

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[9] Norbert Wiener *Cybernetics; or, Control and Communication in the Animal and the Machine*, 2nd ed. (Cambridge, MA: MIT Press, 1961).

[10] Crouch, *The Bishop's Boys*.

[11] Robert Wohl, *A Passion for Wings: Aviation and the Western Imagination, 1908–1918* (New Haven: Yale University Press, 1994).

Building on the history in *Between Human and Machine*, I began by asking a series of questions about professional identity and its relationship to machinery in human spaceflight:

- Who is in control (human in the cockpit, machine in the cockpit, human on the ground)?
- Who is the pilot/astronaut (i.e., social background and status)?
- Who or what else is in the loop (e.g., copilots, ground controllers, instruments, computers)?
- What is his (or her) training/education (military, university, vocational, etc.)?
- What skills are required (e.g., manual skills, mathematics, design, physical strength)?
- How are they trained (e.g., classrooms, flight training, simulators, experience)?
- How are tradeoffs made between manual and automated tasks?
- Who is responsible for a successful flight, the astronauts or the engineers and controllers on the ground?
- Who is blamed for failure?
- What is the role of computers and automation aboard the spacecraft (automatic pilot, monitoring for failure, primary flight controls)?
- Who is at risk?
- What level of prestige do the astronauts enjoy (e.g., national heroes versus faceless operatives)?

Some of these questions repeatedly arise in discussions and debates about human spaceflight. Others reappear throughout the history but are rarely addressed explicitly. Together, they allow us to make connections in the history of human spaceflight that have not previously been made, to understand historical dynamics, and to open up new research areas and ask new questions. Examining the human-machine relationship in human spaceflight enables us to move beyond the dichotomies of "robotic versus human" to better understand the nature of the human role when it is present, and its interaction with, rather than replacement by, machinery. It also allows us to integrate a variety of historical perspectives into narratives of spaceflight: risk, safety, automation, social relationships, project politics, public perception, gender roles, and cultural iconography.

THE CASE OF APOLLO

A full exploration of human-machine relationships in spaceflight is outside the scope of this paper. Rather, I look at the example of Apollo to support my claim for the larger historical importance of the theme. As defining technological moments of the 20th century, the Moon landings embodied the cooperation of human and machine and the tensions that cooperation embodies. As Michael Collins articulated, the individuals involved had experienced radically different eras in the history of aviation and spaceflight in close proximity (a mere four decades from Lindbergh's flight to Apollo 11). The project spanned the transition from analogue to digital computers, from crude simulators to full virtual environments, from analogue cockpits to digital fly-by-wire. Apollo also provides a unique case, because it combines technical complexity and accomplishment with political and cultural significance—hence we can trace the importance of the human operator from the White House into the machine code, from the public's TV screens to the astronaut's displays. While Apollo exemplifies these issues, human-machine relationships resonate throughout the history of spaceflight, from early science fiction to the new Mars rovers.

Ironically, the human-machine relationship in Apollo has been largely ignored by historians, although much of the existing literature offers tantalizing clues for a larger picture. Existing histories of Apollo are nearly all project-oriented—they begin at Apollo's beginning and end at its end. Other than in memoirs as personal background, little is said about Apollo's connection to larger currents in the history of technology in the 20th century. Such narratives reinforce the project's self-image as something coherent in itself and apart from, outside of, contrary to, other forces in American culture. The histories that do provide context tend to be politically or culturally oriented and don't delve into the machines themselves, the people who built and operated them, or what they meant. Additionally, these histories, certainly the more recent ones, tend to be based on the familiar, public accounts of the Apollo program, or interviews with participants conducted many years afterward. Hence they tend to solidify the canonical narrative of the project around key themes and events: Kennedy's visionary decision, the frenetic engineering efforts, the heroism and skill of the astronauts, the tragic fire, the triumph of Apollo 11, the drama of Apollo 13, etc.[12]

Yet the human-machine relationship, even when synthesized from the existing literature, reveals a different view. From the beginning of Apollo, the

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[12] Two examples are Charles Murray and Catherine Bly Cox, *Apollo: The Race to the Moon* (New York: Simon & Schuster, 1989) and Andrew Chaikin, *Man on the Moon: The Voyages of the Apollo Astronauts* (New York: Viking, 1994).

relative importance of humans and machines was under debate. James Webb argued that the decision to go to the Moon "can and should not be made purely on the basis of technical matters," but rather on "social objectives" of putting people into space. He and Robert McNamara argued that "it is man, not merely machines, in space that captures the imagination of the world."[13] Presidential science adviser Jerome Wiesner famously opposed a manned lunar program because its scientific goals did not justify the cost. In a close reading of the debates leading up to Kennedy's decision, we see an implicit distinction between "exploration," which is manned, and "science," which has a higher prestige value among intellectuals but is best conducted remotely.[14]

Nevertheless, when the decision was made to go to the Moon, there would clearly be a significant human role. Kennedy's 1961 mission statement, "to send a man to the moon and return him safely to earth,"[15] was simple, focused, and included its own schedule. It was also impossible, by definition, to accomplish with a fully automated system. But what role would the astronauts play?

1. The Test Pilots

Apollo came after a decade when the human role in flight had been both celebrated and questioned. The Air Force had struggled with the advent of unmanned missiles to complement its beloved fighters and bombers. As a new elite profession emerged, that of the test pilot, airmen were questioning their own role in flight in general, and in spaceflight in particular. Even in the late 1950s, it was not clear who the new spacefarers would be, what skills they would require, and what social prestige (or derision) they might enjoy.

Tom Wolfe, of course, captured some of this anxiety in *The Right Stuff.* While not scholarly history, the book and subsequent film made sufficient impact in the public imagination that we should consider it here. Focusing on the Mercury program, Wolfe correctly identifies the roots of the astronaut culture in the flight-testing world centered on Edwards Air Force Base. He portrays test pilots as reckless risk-takers, cowboys who could not fit into the traditional professional molds for pilots and who made a living pushing aircraft to their limits, often at the cost of their lives. Perhaps some of them were, and they did place themselves at risk, but Wolfe's image misses the essential feature of the profession: although skilled craftsmen, intimate with the feel of their

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[13] Webb, quoted in John Logsdon, *The Decision to Go to the Moon: Project Apollo and the National Interest* (Cambridge, MA: MIT Press, 1970), pp. 90, 125.

[14] Wiesner Committee, "Report to the President-Elect of the Ad Hoc Committee on Space," 10 January 1961, NASA Historical Reference Collection, Washington, DC.

[15] John F. Kennedy, "Urgent National Needs," *Congressional Record—House* (25 May 1961), p. 8276 (text of speech can be found in the speech files, NASA Historical Reference Collection, Washington, DC).

aircraft, test pilots worked in a scientific mode. Their goal was to collect data. As the historian Richard Hallion has written, "A research airplane essentially uses the sky itself as a laboratory."[16] Increasingly over the course of the 20th century, what it meant to be a test pilot was not only one trained in flying airplanes, but also one trained in engineering.

Test pilots were always in close touch with controllers on the ground (a feature of flight testing carried to extremes in Apollo). Test pilots understood not only how an airplane flew, but also why it flew. Again to quote Michael Collins,

> A test pilot, more than any other type of aviator, must be objective. It is all right for a squadron pilot to fall in love with his airplane; it is all he has to fly, and he might just as well enjoy it because it has already been designed . . . . The test pilot cannot fall into this trap . . . he must carefully analyze the possible uses to which an airplane might be put and judge it accordingly.[17]

Note that in this passage, Collins emphasizes the judgment of the test pilot—the "pilot opinion," which he must provide as part of the research data. In addition to their cockpit skills, test pilots were also professional storytellers, experts at narrating and recounting their experiences in precise, formal language. Yet the hero of Wolfe's account is Chuck Yeager—an older breed, not college-educated, and without a career-long interest in flight engineering. Nevertheless, despite its limitations, *The Right Stuff* does draw attention to the relationships between machine control and professional identity that were woven throughout the Mercury program.

Looking more seriously at the test pilots' profession reveals even greater historical coherence within Apollo. Much of the time the test pilots flew new aircraft was spent evaluating "stability and control" and "flying qualities," two engineering areas that focused on the match between human and machine. Indeed, this area was pioneered by Robert Gilruth and his group at Langley, which subsequently formed the Space Task Group and the Manned Spacecraft Center (MSC).[18] The Society for Experimental Test Pilots (SETP) formed in 1955, and for the rest of the decade, the group concerned itself with the appropriate role of the pilot—at first in high-performance aircraft with computerized control systems, and then in the space program. One founding member of the SETP would go on to become an astronaut: Neil Armstrong.

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[16] Richard Hallion, *Test Pilots: The Frontiersmen of Flight*, rev. ed. (Washington, DC: Smithsonian Institution Press, 1991), pp. 101, 143.

[17] Ibid., p. 238.

[18] Renamed Johnson Space Center (JSC) in 1973.

2. Systems Thinking and the Role of the Human

The SETP crystallized the anxiety of pilots in general, especially as they faced the development of unmanned aircraft and ballistic missiles. These technologies not only emerged outside the culture of piloting, they sprang from a new group of engineers: the systems men. Several authors have written of the conflict of cultures that occurred in Apollo between the aeronautics-oriented culture of Langley and Edwards and the systems-oriented culture of the West Coast contractors, embodied in managers like Joe Shea.[19] Looking more deeply at the roots of systems thinking, however, helps connect the project to broader currents and clarifies the alternate view to the tight human-machine coupling advocated by the pilots.

World War II coalesced systems thinking in several arenas. In response to technical problems of radar and automatic gunfire control, engineers began to see that all components of a system needed to be understood together, rather than as glued-together components. Engineers now conceptualized their machines as integrated systems with feedbacks and dynamics, where the behavior of each part helped determine the behavior of the whole.

By 1950, these ideas and techniques began the self-conscious era of systems thinking. The *Oxford English Dictionary* shows that uses of the term *system* exploded after 1950, including *systems engineering*, *systems analysis*, *systems dynamics*, *general systems theory*, and a host of others. Each field had its own innovators, its own emphasis, and its own home institutions and professions, but they shared common concerns with feedback, dynamics, flows, block diagrams, human-machine interaction, signals, simulation, and the exciting new possibilities of computers.[20]

The management aspects of systems engineering formalized in the mid-1950s, when the Air Force stretched its resources to quickly build an intercontinental ballistic missile (ICBM). In the Atlas missile project, management began to move beyond the model that had dominated the aviation industry for decades. Aircraft had always been composed of large numbers of components from a variety of subcontractors, coordinated by the prime contractor, who built the airframe. With a project like Atlas, dynamics, interconnection, and coordination became the dominant aspects of the project, so airframe companies, with their emphasis on structures and manufacturing, lost their central role. Rather, engineers with management experience, comfort with mathematical abstraction,

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[19] Murray and Cox, *Apollo: The Race to the Moon*; Stephen Johnson, *The Secret of Apollo: Systems Management in American and European Space Programs* (Baltimore: Johns Hopkins, 2002); Howard E. McCurdy, *Inside NASA: High Technology and Organizational Change in the U.S. Space Program* (Baltimore: Johns Hopkins, 1993).

[20] Louis B. Ridenour, *Radar System Engineering*, vol. 1 of *Radiation Laboratory Series* (New York: McGraw Hill, 1948); Harry Goode and Robert Machol, *Systems Engineering: An Introduction to the Design of Large-scale Systems* (New York: McGraw Hill, 1947).

and insight into dynamics and control coordinated the project. The technical change entailed a social shift; as historian Thomas P. Hughes has written, "the airframe was [now] merely a platform to carry complex, electronic guidance and fire control systems."[21]

Innovators in Cold War systems engineering had their roots at General Electric and AT&T, via the aviation industry. Simon Ramo had cut his teeth at GE and Hughes Aircraft and earned a Ph.D. at Caltech. His friend Dean Wooldridge came out of Bell Labs. In 1953, the two left Hughes Aircraft Corporation to found a systems engineering contractor, Ramo-Wooldridge, that soon became the TRW Corporation and did systems engineering for the Atlas project. Together with the Air Force's Western Development Division, they coordinated contractors and scheduling and oversaw the project's integration. The Navy had a similar project to build a ballistic-missile-firing submarine named Polaris. Here the Navy's "Special Projects Office" performed the systems engineering function.[22]

Ramo became a promoter of systems engineering, which he defined as "the design of the whole from the design of the parts." As Ramo wrote, "Systems engineering is inherently interdisciplinary because its function is to integrate the specialized separate pieces of a complex of apparatus and people—the system—into a harmonious ensemble that optimally achieves the desired end."[23] Atlas included a system of materials, logistics, computers, and ground support, and the missile itself was a system.

In Atlas, Polaris, and other large projects of the 1950s, systems engineering meant coordinating and controlling a variety of technical and organizational elements, from contract specifications to control systems, from computer simulations to deployment logistics. The approaches were diverse, but they shared a common set of assumptions about how the world might be understood in abstract, quantitative terms, and modeled with a series of feedbacks, flows, and dynamics.

Computers, both analogue and digital, figured prominently in the image and the practice of these systems sciences. They could simulate systems and make predictions about the system's behavior in an uncertain environment. Social systems could be modeled with similar techniques as technical systems. Both the computer and the analysts themselves carried the prestige and authority of science: providing dispassionate, expert advice free of political influence. For the

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[21] Thomas P. Hughes, *Rescuing Prometheus* (New York: Pantheon Books, 1998).

[22] Harvey Sapolsky, *The Polaris System Development: Bureaucratic and Programmatic Success in Government* (Cambridge, MA: Harvard University Press, 1972); Benjamin Pinney, "Projects, Management, and Protean Times: Engineering Enterprise in the United States, 1870–1960" (Ph.D. diss., MIT, 2001).

[23] For a history of systems thinking in the Atlas project, see Hughes, *Rescuing Prometheus*, chap. 3. Simon Ramo is quoted on p. 67.

strategy to work, the system engineer required a certain amount of authority, a fact that was not lost on the participants. They sold systems engineering as an authoritative, scientific way to transcend "politics" (whether public or military-industrial) with the outside neutrality of the expert. Systems engineering thus elevated the "systems men" to a new level of prestige, creating a new niche for engineers as educated managers of large projects and budgets.

3. X-15 Human and Machine

The successes of Atlas and Polaris gave the systems experts, their companies, and their worldview credibility with the armed services. Furthermore, the expertise they built up in rocketry meant they would be intimately involved in any efforts to send humans into space. For the pilots, however, the systems men could represent a threat—they had engineered a fleet of Air Force weapons that had no pilots at all, and their abstract, analytical approach to engineering could seem to crowd out the "human factor." These issues came to the fore as the test pilots began to contemplate spaceflight.

When the pilots of the SETP reacted to the rise of unmanned missiles, they also reacted to the rise of the social group that built them. In 1960, an author in the SETP *Proceedings* derided

> the great millennium of concentrated effort to design man out of the cockpit to make room for bigger and better "black boxes." There was much gnashing of teeth and waving of arms but alas, the day of the "icy B.M." was upon us. No one wanted the pilot around.[24]

The "icy B.M." is a wonderful triple entendre, referring to an ICBM, the computers of IBM, and a scatological reference to a missile.

One SETP test pilot actually argued that the ICBM was a transitional technology, soon to be replaced when technology allowed humans to pilot the rockets: "The era of the large intercontinental ballistic missile is merely a phase the duration of which is a matter of speculation but the demise of which is nonetheless certain."[25] Indeed, the Air Force had initiated the X-20 "Dyna-Soar" program, a kind of manned orbital space bomber to orbit the Earth. Air Force publicity for the X-20 repeatedly emphasized the man in the loop and that reentry could only be accomplished as a product of human skill. Despite the presence of numerous new technologies, the Air Force declared, "In the end, it takes the cool hand of a skilled pilot to bring his glider in for a

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[24] W. T. Armstrong, "Where do we go from here?" *Cockpit* 4 (May 1965): 7.

[25] A. W. Blackburn, "Flight Testing in the Space Age," *SETP Quarterly Review* 7, no. 3 (fall 1957): 17, 10–11.

conventional landing . . . this Dyna Soar project puts an emphasis on the pilot, on the *man*"[26] (emphasis original).

While Dyna-Soar was eventually canceled, another program emerged that sought to demonstrate the importance of human skill for manned spaceflight. The X-15 is of course the best-known of the famous X-planes, but when viewed through the lens of the human-machine relationship, the X-15 takes on great importance for Apollo. In addition to hypersonics, much of the purpose of the X-15 was to evaluate the human role in spaceflight, particularly for reentry, which was considered so dynamic and difficult that it required a human controller. A detailed exploration of these issues is outside the scope of this paper, but roughly half of the publications arising out of the X-15 related to control systems, the role of the pilot, or human-machine interfaces.[27] When an X-15 was donated to the Smithsonian, for example, the press release for the donation read, "One of the major goals of the program which has been most richly achieved was to explore the capabilities and limitations of the human pilot in an aerospace vehicle." And of course, the conclusion was that "the broad positive finding of the program is clear; the capability of the human pilot for sensing, judging, coping with the unexpected, and employing a fantastic variety of acquired skills remains undiminished in all of the key problem areas of aerospace flight."[28] For all of its contributions to hypersonics and related sciences, a major legacy of the X-15 is that of putting human pilots in space and ensuring them a place in the cockpit in future space missions. As it turned out, the skill of reentry was easily mastered, with the help of redundant automated systems. The pilot's primary function evolved to be a monitor, a systems manager, coordinating a variety of controls as much as directly controlling himself.

As a result of his work on the X-15, Neil Armstrong and colleagues conducted a series of simulations which showed that a human pilot could stabilize a multistage vehicle under manual control straight off the launchpad. The pilots saw the tests, and the data they produced, as critical support for the role of the human pilots in orbital operations. Armstrong concluded that the pilots should be allowed to fly the Saturn rocket off the launchpad. He and the simulation

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[26] U.S. Air Force, *This is Dyna-Soar*, film included in CD-ROM published with *Dyna-Soar: Hypersonic Strategic Weapons System*, ed. Robert Godwin (Burlington, Ontario: Apogee Books, 2003).

[27] W. H. Stillwell, ed., *X-15 Research Results* (Washington, DC: NASA, 1965). The most complete and prominent example of these is Robert G. Nagel and Richard E. Smith, "An Evaluation of the Role of the Pilot and Redundant Emergency Systems in the X-15 Research Airplane," *SETP Newsletter* 6 (September–October 1962): 12. The SETP publication is a summary of the full study by the same author, "X-15 Pilot-in-the-loop and redundant/emergency systems evaluation," Technical Documentary Report No. 62-20, Air Force Flight Test Center, Edwards Air Force Base, CA, October 1962, NASA Dryden Archives L2-5-1D-3. For a personal account, see Milton O. Thompson, *At the Edge of Space: The X-15 Flight Program* (Washington, DC: Smithsonian Institution Press, 1992).

[28] X-15 news release, Edwards Flight Research Center (FRC), 27 April 1969. Reprinted in Goodwin, *X-15 Mission Reports*, pp. 393–394.

engineers argued that pilots could adequately operate the simulation under high g forces—as long as they were provided with adequate information displays to guide their control. "As a passenger, he [the pilot] can be very expensive cargo; but as an integral part of the control loop of the vehicle, he might add materially to the reliability and flexibility of the launch maneuver." Citing the earlier work on flying qualities and aircraft stability, they acknowledged that "the piloting task for these vehicles is certainly more exacting than that of operational aircraft." The simulated rocket was inherently unstable, though just how unstable depended on the amount of fuel it contained and on the external environment. "There is no reason to assume that the pilot cannot control the launch of multistage vehicles . . . it appears to be highly desirable to initiate investigations of the use of the pilot in the control loop of the launch of Saturn boosters."[29]

Armstrong had done other similar tests as well—he flew an aircraft in such a way as to simulate the trajectory of an aborted launch in the Dyna-Soar. Milt Thompson participated in a similar series of trials designed to show that pilots could manually fly the Titan booster into orbit with the Dyna-Soar vehicle on top. "This was a very controversial issue," Thompson recalled; "the booster designers had been using automatic control and guidance systems from day one. In their minds it was the way to go."[30]

The role of the pilot in complex space missions was on the table: the pilots had already lost a battle with the advent of the ballistic missile, in their view little better than a dangerous, unpiloted drone. Would the giant space rockets then under construction be like ballistic missiles, taking a mere "payload" up for a ride, or human-guided machines, directed by keen eyes and hands that could aim it into orbit? Would the X-15 be the way of the future or a forgotten sidelight on a ballistic future?

In the end, they would not fly the rockets off the pad. They would not put the spacecraft into orbit. They would not point toward the Moon and fly there. They would not manually enter lunar orbit, and they would not fly the return to Earth or fly the reentry. These things were all accomplished by computers. What, then, would the astronauts do? They would, in conjunction with a computer, control docking in space, and the lunar landing, and they would monitor and engage various systems throughout the flight. These would be the tasks to showcase human performance and skill and make Apollo a human endeavor.

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29. E. C. Holleman, N. A. Armstrong, and W. H. Andrews, "Utilization of the Pilot in the Launch and Injection of a Multistage Orbital Vehicle" (presented at the 28th annual meeting of the Institute for Aeronautical Sciences, New York, NY, January 1960); N. A. Armstrong and E. C. Holleman, "A Review of In-Flight Simulation Pertinent to Piloted Space Vehicles," North Atlantic Treaty Organization (NATO), Advisory Group for Aerospace Research and Development (AGARD) Report #403, July 1962.

30. Thompson, *At the Edge of Space*, p. 119.

The Apollo spacecraft would not be built by the people who built the capsules for Mercury and Gemini, but by North American Aviation and the engineering team that built the X-15. The first contract of the Apollo program, however, would not be for a giant rocket, nor for an exotic space vehicle, but for a guidance system and a digital computer. The contract went to the Instrumentation Laboratory at MIT, under the direction of aviation pioneer Charles Stark Draper. Draper's men and women spent the 1950s building guidance systems for nuclear missiles. They had built computers before, but only for automatic systems. They had never built a computer with an interface for a human user.

RETHINKING APOLLO

Using the lens of human-machine relationships, and their prior and subsequent histories, allows us to rethink Apollo and investigate new aspects of the famous project. Now we can consider Apollo through the lens of computing, through training, and through simulation. Each of these topics reveals a project different from the one in the traditional accounts, but one contiguous with larger historical phenomena and with the evolving human-machine relationships of subsequent decades.

In the end, it was not heroic astronauts alone who made the flights to the Moon. They shared their decisions with ground controllers, as well as a small group of software engineers who accompanied them in the form of computer programs that complemented the astronauts' every move. The computer design and the software then emerged to reflect a philosophy of automating the flights and aiding the pilots in critical functions and at critical moments, while not actually replacing them. In the end, the astronauts "flew" a very small part of the mission by hand, but that included the critical lunar landing. Even there, the astronauts flew the lander indirectly—their joystick actually controlled a software program, which then controlled the vehicle, what today we call fly-by-wire.

While the flight technology was being developed, NASA faced a problem: How do you teach astronauts to land on the Moon? How do you train people to do something that has never been done before? Training can be understood as developing the match between human and machine. Again, the human-machine relationship points us toward a much-neglected aspect of the history of spaceflight: simulation. Flight simulators had been built since the 1930s, but to teach pilots how to fly airplanes that already existed, under conditions that were well understood. For the X-15, engineers began building simulators for an airplane before it flew, before it was built, before it was even designed.[31] Apollo took those lessons to heart.

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[31] G. L. Waltman, *Black Magic and Gremlins: Analog Flight Simulations at NASA's Flight Research Center* (Washington, DC: NASA SP-2000-4520, 2000).

All of the human spaceflight missions of the United States require close human support from outside the spacecraft. Here is an overall view of the Mission Control Center (MCC) in Houston, Texas, during the Gemini 5 flight in 1965. Note the screen at the front of the MCC that is used to track the progress of the Gemini spacecraft. *(NASA photo no. S65-28660)*

Apollo simulated everything. There was a simulator for Moon walking, for picking up rocks, for escaping a fire on the launchpad. The critical simulators, however, replicated the spacecraft themselves, simulating not only the physics of their flight, but their internal workings as well. For months before the flight, the astronauts virtually lived inside these strange machines, flying to the Moon under a great variety of conditions, simulating every conceivable kind of failure. Of course, the simulators were built around computers, at first analogue and later digital. But the machines of the time could not replicate the subtle visual cues required for a perfect landing. Instead, NASA engineers built elaborate, finely painted replicas of the Moon and "flew" tiny cameras above the surface to provide accurate images of the Lunar Module's final approach (techniques to be replicated just a few years later in the making of George Lucas's *Star Wars*). Inside the simulated spacecraft, the astronauts used the real guidance computer, programmed with real programs, and became acclimated to their new environment. In the actual lunar landings, the astronauts frequently commented on the simulation, comparing their real experiences to those fabricated in the laboratory. A history of the use of simulation in the space program and its significance for future technology has yet to be written.

Not all simulators were equally virtual. One actually flew, using real gravity and flight dynamics to mimic the lunar lander. Early in the program, a group of NASA engineers who had worked on the X-15 thought up a vehicle that would use a special jet engine to cancel out five-sixths of the Earth's gravity, and would thus fly as though it were on the Moon, which had one-sixth g. The result was the Lunar Landing Research Vehicle, or LLRV, nicknamed "the flying bedstead" because of its extraordinarily strange appearance (later renamed the LLTV, with "training" replacing "research"). In addition to its jet engine, it used a variety of steam jets to control attitude and position, so when it flew, it hissed white jets of steam and whistled like a calliope. The vehicle was complex, unruly, and dangerous. Three of the six built had spectacular crashes; one almost killed Neil Armstrong before his famous flight. NASA wanted to cancel the program, thinking it too risky to the precious astronauts. But when Armstrong returned from the Moon, he insisted that the vehicles remain in use, for they provided the closest approximation of the actual Moon landing. The "flying simulator" further blurred the boundary between real and virtual flight and proved a valuable rehearsal for the human-machine system that would land on the Moon.[32]

Simulation is but one arena where focusing on the human-machine relationship sheds new light on the history. Numerous decisions in Apollo concerned the human-machine relationship in some degree. The famous LOR decision placed great emphasis on human skill in docking and rendezvous. The decision to include three astronauts had to do with how human roles would be allocated. The three were originally dubbed "Pilot," "Co-pilot," and "Systems Engineer" but were later changed to "Commander," "Command Module Pilot," and "Lunar Module Pilot," ensuring that all would be "pilots" even though the "Lunar Module Pilot" would only fly the craft as a backup (and did not train in the LLRV). Decisions about in-flight maintenance and repair traded off human repair skills against mechanical and electronic reliability. Critical functions like navigation could be handled entirely within the capsule but ended up being provided largely by ground stations.

During the actual missions, several key events brought the human-machine issues to the forefront. The "program alarm" in the final minutes of the Apollo landing required human intervention, and the landing ended under manual control, with great success. The incident set off a behind-the-scenes debate about who was to blame. The press reported it as a bug in the

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[32] Christian Gelzer, ed., "LLRV History" (unpublished manuscript, NASA Dryden History Office, 2004). See also "Minutes of Meeting, Flight Review Board, Lunar Landing Training Vehicle," University of Houston, Clear Lake, 12 January 1970, Apollo Chronological File, NASA Historical Reference Collection, for a detailed discussion of why the astronauts found the LLTV valuable.

program (a concept soon to enter popular discourse). MIT engineers pointed out that the astronauts had forgotten to turn off a piece of equipment that was feeding extraneous data to the computer and causing it to overload. Others could point to a problem with procedures that did not correctly direct the astronauts. NASA, by contrast, narrated the landing as the victory of a skilled human operator over fallible automation—a result that highlighted the heroic goals of the program. Who was at fault is less important than the terms of the debate, as the tensions between humans and automated systems refused to go away, even in the triumphant moments of the program.

Other events in the remaining Apollo flights continued to highlight the tensions between the computer, its software, and its human operators. During Apollo 8, astronaut Jim Lovell mistakenly pushed a button that erased the computer's memory—committing an error that NASA swore would never happen. In Apollo 12, the spacecraft was struck by lightning soon after liftoff, causing the system to reboot (imagine if they were running Microsoft!). During Apollo 14, the computer was reprogrammed in flight to help save the astronauts from a sticky abort button. Overall, the computers performed extremely well, and the astronauts spent as much (or more) time on the missions monitoring and managing the computer as they did actually "flying" the spacecraft. Yet on every single landing, for one reason or another, the pilots overrode the automatic systems and landed with their hands on the stick. Manual control of the landings allowed NASA and the public to see the flights as a human accomplishment rather than an automated one.

AN AGENDA FOR RESEARCH

This essay, of course, cannot provide an exhaustive history of the human-machine issues that came to play in Apollo. It merely makes the case 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, and indeed these are the kinds of questions I'm currently exploring for a book on Apollo. Research directions include a close reading of the astronaut memoirs, building on Michael Collins's revealing comments, to see how they narrated their own relationships to the computers and how they recalled the human-machine issues in retrospect. I'm also looking carefully at the decisions about how much to automate the landings, how that automation was actually implemented, and at the various parties (engineers, astronauts, managers, etc.) who engaged in the process. Analyzing the actual operations of the flights sheds light on how the human operators performed and what they actually did during the flights.

Of course, these issues extend well beyond Apollo. One can ask about the early planning and decisions on the Space Shuttle and what role pilots played

The Space Shuttle cannot be flown without a human pilot; it is the first piloted spacecraft of the United States that has no capability for automated flight. This fisheye view of the Space Shuttle *Atlantis* is seen from the Russian *Mir* space station during the STS-71 mission. *(NASA photo no. STS071-741-004)*

in developing a spacecraft with a "piloted" reentry. In light of their lost bid to manually fly the Saturn rocket off the pad, the Shuttle decision appears as a victory where pilots again assert their authority and express their love for winged aircraft. Despite the X-15's initial emphasis on the skill required for reentry, only one Shuttle flight has been flown manually from reentry: flight number 2 of *Columbia*, flown by former X-15 pilot Joe Engle from Mach 25 to the ground. Despite the presence of automated landing systems, every single Shuttle flight has ended with a manual landing.

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. The iconic role of astronauts as American heroes was critically dependent on their roles (real and perceived) in actual piloting of the missions. We can study how such public and political imperatives were incorporated, along with technical considerations, into the actual design of control systems and, conversely, how the technical characteristics of those systems shaped and constrained the public imagery (there was a good technical argument for not allowing the astronauts to fly the Saturn off the pad).

As Slava Gerovitch has explored in his essay in this volume, social and power relationships between different groups involved in the projects—astronauts and ground controllers, engineers versus managers, different groups within a program—manifest themselves in the design of the control systems. Training, as a method of matching of human to machine, is a place where these relationships begin to form, and simulation—as the artificial creation of a human experience or technical system—points to the increasingly blurred line between "real" and "virtual" in our own world. Such a discussion naturally leads into gender history because the issue of the astronaut's control is also an issue of masculinity. Pay attention to how often "manliness" and "sissyness" (especially in jest) arise in conversations about technology and spaceflight, and one realizes that (consciously or unconsciously) gender is never far from operators and designers of control systems. One Apollo guidance engineer still professes his aversion to the use of the term "software" as unmanly.

Beginning with Apollo, and continuing during the 1970s (and certainly into the future), the professional identity of astronauts began to expand—from the exclusive focus on test pilots to scientists and engineers (and even teachers and politicians), with new job titles like "mission specialist" and "payload specialist," coupled with social expansions beyond White men. I recently asked an astronomer-astronaut how much he used his scientific judgment while in orbit—"Not at all," he quickly replied. Most of his time had been spent following well-established procedures to deploy and operate other people's experiments. Under such conditions, what is the necessity for scientific training, or for human presence at all? Still, that same astronaut acknowledged that being able to "speak the same language" as the scientists on the ground proved an important part of his job. Clearly, some level of tacit knowledge, social interaction, and common vocabulary played an important role in space operations (as it did for the CAPCOMs talking to their fellow pilots in Apollo).

It should be possible to do an ethnographic study of space operations examining skill, training, professional identity, automation, divisions of power, and other aspects of human-machine relationships. Where, exactly, are humans in space exercising judgment, tacit knowledge, and creativity? How would the results differ for scientific versus technical operations? Mission transcripts, combined with interviews and a deep analysis of operations, would provide a solid basis for answering these and related questions. Even a cursory look at the Apollo lunar science operations presents rich material, as the astronauts conducted a variety of activities from deploying instruments to collecting samples (where, precisely, did "exploration" occur?). Such an ethnographic analysis, if rigorously done, would have important implications for engineering design, training, mission planning, and safety. It would also likely generate insights into the operation of other complex technical systems whose operations are rarely as well documented or as accessible as those of human spaceflight.

Such research into the human-machine aspects of spaceflight will also help clarify the tensions in human spaceflight between "science" and "exploration." George Bush's January 2004 speech used the word "exploration" more than 25 times, while mentioning "science" only once or twice. In the documents and debates leading up to Kennedy's Apollo decision, the assumption is that "exploration" is manned and "science" is remote or unmanned, and these debates have continued until the present day. What are the critical differences between science and exploration? Exploration, of course, has a long history, although when it has been brought to bear on spaceflight it has tended to take the form of hagiography more than critical analysis. As Steven Pyne's essay in this volume wonderfully demonstrates, however, the large literature in history and the history of science has a great deal to offer current debates. Exploration often includes science, but usually as one component of a broader agenda, and not usually the most important one. For the sake of argument, we might make this oversimplified distinction: science is about collecting data to learn about the natural world, whereas exploration expands the realm of human experience. Sometimes the two overlap, but not always. Exploration has always had significant components of state interest, international competition, technical demonstration, public presentation, national and professional identity, and personal risk. Seen in this light, the prominence of these elements in Apollo seems less an anomaly than sensible in an historical context.

Again, the science versus exploration dichotomy bears on human-machine relationships. McCurdy and Launius provide excellent examples in this volume: Admiral Byrd's use of mechanical aids (i.e., aircraft) in exploring Antarctica raised questions of heroism, manliness, and professional identity. Similar issues arise in ocean exploration today, especially as the role of manned submersibles is questioned in the face of remote—and autonomous—vehicles. Again, the debates over technology often refer to professional identity: are you a *real* oceanographer if you don't descend to the seafloor? Are you a *real* explorer if you never actually set foot in a new world? Must one physically "be there" to be an explorer? How do professional identities adapt to technological change?

My goal here is not to advocate for either side in the debates about whether we should be sending people into space. Rather, I'm arguing that a scholarly, historical understanding of the human-machine relationship will help to clarify the terms of the public debate. And precise, informed public debate is critical if we are to commit significant resources to future projects.

I'll close with a recent anecdote that captures the richness, interest, and relevance of human-machine relationships in spaceflight. In the spring of 2004, the Explorer's Club of New York City held its 100th annual dinner. At this glitzy, black-tie affair, a few thousand people stuffed into the grand ballroom of the Waldorf Astoria. The club has always included scientists, but also a panoply of mountain climbers, Navy captains, pilots, sailors, divers, trekkers, photographers, not a few astronauts, and a host of wannabe adventurers. At this event, on the stage, were some of the "greatest of the great" who rose in turn to give inspiring speeches about their own experiences and the importance of exploration. Bertrand Piccard, heir of the great Swiss exploring family, recounted his balloon circumnavigation of the world. Buzz Aldrin spoke about his journey to the Moon and advocated for a return to the Moon and a venture to Mars. Sir Edmund Hilary recounted the feeling of his first steps on the top of Everest.

The evening's last speaker was Dr. Steven Squyres of Cornell, the chief scientist of the project that had recently landed two robotic rovers on the surface of Mars. I leaned over to my friend and whispered, "This ought to be interesting, because the rest of those guys have actually gone places, where Squyres has done all of his work remotely, from a darkened room." A moment later, Squyres got up there, on the heels of these great explorers, in front of thousands of people, and said (I paraphrase), "I must say I'm a little intimidated, because all of these people have actually gone somewhere, whereas I've done my work from darkened rooms in Ithaca and Pasadena." But he then gave an account of his and his group's remote, robotic exploration of Mars that easily matched the others in excitement and inspiration. He explained how they "live" on Mars, for months at a time, through technologies of remote, virtual presence. He also made a plea for the importance of sending people to Mars, based on the scientific insight a field geologist would generate by actually "being there." Here, as in so many other instances, science, exploration, technology, and professional identity were intertwined, and understanding those relationships is critical not only for the history and future of human spaceflight, but is key to the essence of human-machine relationships, the coupling of the social and technological, at the core of our modern world.