

## CHAPTER 5

# HUMAN AND MACHINE IN THE HISTORY OF SPACEFLIGHT

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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.”<sup>1</sup> 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.<sup>2</sup>

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

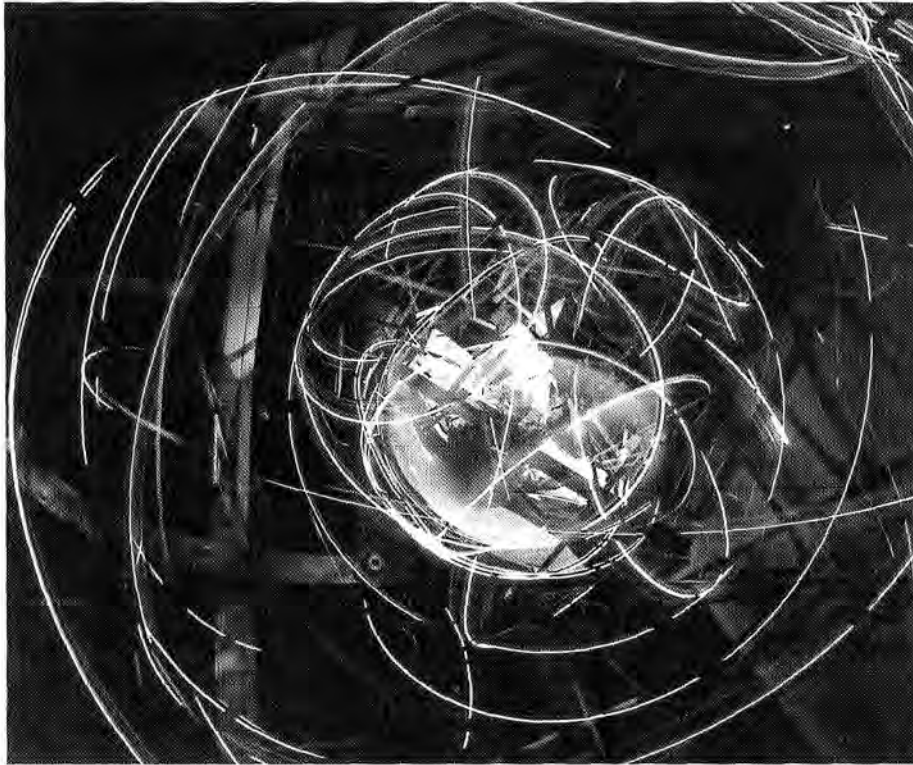
Human versus machine—it is not a new story. Indeed, it is one of the great narratives of the industrial world. American history and culture are replete with human-machine conflicts and comparisons. In the Civil War, the crew of the ironclad warship *Monitor* thought themselves well protected by iron armor, but that mechanical contrivances diminished the glory and heroism of their performance in combat.<sup>3</sup> 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.<sup>4</sup>

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.<sup>5</sup> For any

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*.<sup>6</sup> 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 from 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.<sup>7</sup>

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.<sup>8</sup> 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 predictable 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.<sup>9</sup> 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.<sup>10</sup> 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.<sup>11</sup> 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.<sup>12</sup>

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.”<sup>13</sup> 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.<sup>14</sup>

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,”<sup>15</sup> 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

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.”<sup>16</sup> 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.<sup>17</sup>

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).<sup>18</sup> 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.<sup>19</sup> 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.<sup>20</sup>

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.”<sup>21</sup>

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.<sup>22</sup>

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.”<sup>23</sup> 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.<sup>24</sup>

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.”<sup>25</sup> 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

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*”<sup>26</sup> (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.<sup>27</sup> 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.”<sup>28</sup> 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.”<sup>29</sup>

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.”<sup>30</sup>

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.<sup>31</sup> 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.<sup>32</sup>

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.