CHAPTER 4

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

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

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

[14] 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

continued on page 50

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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continued from page 49

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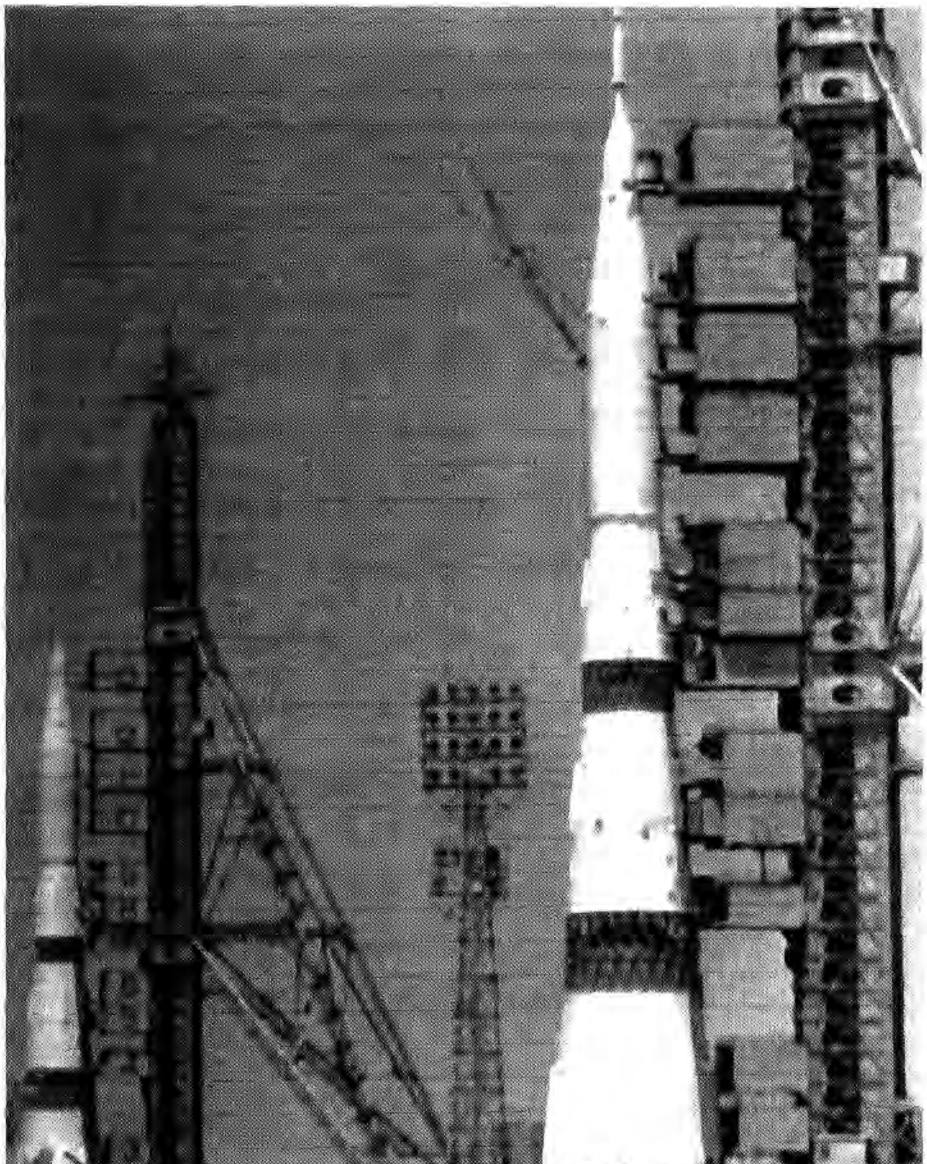
[91] Scott and Leonov, *Two Sides of the Moon*, p. 189.

[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).