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Revisiting the U.S.-Soviet space race: Comparing two systems in their competition to land a man on the moon☆

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ABSTRACT

The Cold War space competition between the U.S. and the USSR, centered on their race to the moon, offers both an important historical case and larger implications for space and technology development and policy. In the late 1950s, under Premier Nikita Khrushchev's direction and Chief Designer Sergei Korolev's determined implementation, Moscow's capabilities appeared to eclipse Washington's. This called the international system's very nature into question and prompted President John F. Kennedy to declare a race to the moon. Despite impressive goals and talented engineers, in the centralized but under-institutionalized, resource-limited Soviet Union feuding chief designers playing bureaucratic politics promoted a cacophony of overambitious, overlapping, often uncompleted projects. The USSR suffered from inadequate standardization and quality control at outlying factories and failed to sustain its lead. In marked contrast, American private corporations, under NASA's well-coordinated guidance and adjudication, helped the United States overtake from behind to meet Kennedy's deadline in 1969. In critical respects, Washington's lunar landing stemmed from an effective systems management program, while Moscow's moonshot succumbed to the Soviet system, which proved unequal to the task. In less than a decade, Soviet space efforts shifted from one-upping, to keeping up, to covering up. This article reconsiders this historic competition and suggests larger conclusions.

1. Overall dynamics

1.1. Political system shapes technology development

National political systems shape technological development within them because modern organizations must develop standardized rules and procedures to create and sustain the bureaucracies that coordinate it.[1] Central to its advantage over the USSR was the United States' successful development and implementation of several management and organizational processes for developing technology that are used to this day. The most all-encompassing process, systems management, synthesizes best practices from systems engineering, operations research, and project management to administer complex technological and organizational relationships spanning diverse specialist cultures and bureaucratic interests. The related processes of configuration management and change control, "at the heart of aerospace and software engineering from the late 1950s to the present," help to "coordinate engineering modifications," forecast costs, and maximize reliability.[2]

Effective systems management is "a set of organizational structures and processes [for coordination of large-scale technology development to] rapidly produce a novel but dependable technological [product] within a [relatively] predictable budget."[3] Its genesis and initial successes were intimately connected with another U.S. advantage: a sophisticated public-private partnership in which private firms competed for government contracts and winners selected and supervised their own subcontractors. Systems management was conceived in the early

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[2] Stephen B. Johnson, *The United States Air Force and the Culture of Innovation, 1945–1965* (Washington, DC: Air Force History and Museums Program, 2002), quotation from 226; see also 16, 209, 225–26.

[3] Thomas P. Hughes, *Rescuing Prometheus: Four Monumental Projects That Changed the Modern World* (New York: Pantheon Books, 1998); Johnson, *The Secret of Apollo: Systems Management in American and European Space Programs* (Baltimore, MD: The Johns Hopkins University Press, 2002), 17.

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post-war years, pioneered at the U.S. firm Ramo-Wooldridge (later, TRW)[4] and developed further by AT&T Corporation.[5] It proved itself in Lockheed's Polaris submarine-launched ballistic missile for the U.S. Navy,[6] Convair's Atlas intercontinental ballistic missile (ICBM) and Martin's Titan ICBM as well as Douglas's Thor intermediate-range ballistic missile for the U.S. Air Force (USAF),[7] and multiple corporations' contributions to the Apollo moon-landing program. The culture of American aerospace innovation was highly contested, reflecting the interplay of many interest groups, but by 1960 systems management was "the standard for large-scale project development." NASA embraced it almost immediately. In early 1961, the USAF adopted systems management recommendations championed by General Bernard Schriever. In 1965, with Defense Secretary Robert McNamara's support, technology management and organization processes were embraced and being implemented throughout the defense aerospace and computing industries. By this time, most major military and civilian aerospace projects utilized aspects of systems management and related best practices. Systems management's core elements—sound initial design, "quality assurance, configuration control, and systems integration testing [—have been] among the primary factors in the improved dependability of ballistic missiles and spacecraft."[8] For Apollo, NASA in September 1961 adopted the Navy-developed Program for Evaluating and Reviewing Technique. Accordingly, 90,000 key events for 800 major entities were sorted among five levels by schedule, sequence, person-hours, and duration.[9]

Because it derives from constant, transparent "negotiations among various organizations, classes, and interest groups,"[10] systems management is typically more difficult to achieve in a closed authoritarian system than in a capitalist democracy or even a hybrid authoritarian system like China's today. NASA, for instance, received consultation from private corporations AT&T (Bellcom Group), Boeing—a global aircraft leader with both defense and commercial experience, TRW,[11] and McKinsey.[12] "When you put something complicated together you get into systems engineering whether you recognize it or not," former Lunar Module (LM) program director and Grumman president Joseph Gavin Jr. emphasizes, but "the Soviets had no AT&T" to help them maximize efficiency.[13]

1.2. Comparative space development: critical Cold War test

The Cold War was "a sustained competition in power creation,"[14] with space as one of its central theaters, and a race to land a man on the moon at the core. Moscow's failure in that quest foreshadowed limitations in national capabilities that fatally undermined its core identity as the vanguard of socio-technological progress.[15] Having started the space race, therefore, Moscow felt compelled to keep ahead. The comparatively agile, innovative U.S. system met Moscow's challenge and won the moon race. American technology proved to be both more advanced than Soviet technology and ultimately more affordable thanks to both the dynamic economy supporting it and its numerous civilian spin-offs. Cold War competition and the extreme space environment left little margin for error.[16] Indeed, "The really significant fallout from the … endless experimentation of Project Apollo [was] of a sociological rather than a technological nature; techniques for directing the massed scores of thousands of minds in a close-knit, mutually enhancive combination of government, university, and private industry."[17]

Soviet loss of the moon race represented not a singular but rather a systemic failure. Attempts to dominate aerospace with improved military aircraft, supersonic transports, and digital avionics all failed for similar reasons.[18] It was not Soviet ignorance of advanced management systems that doomed Soviet aerospace; it was ideological constraints precluding their implementation. Moscow's space program was further handicapped with outdated organization and development techniques such as use of multiple test flights, as opposed to Apollo's methodical, relatively economical ground testing. These techniques had been inappropriately transplanted from Moscow's World War II artillery corps, whose leaders had commandeered both the emerging manned spaceflight program and the dominant Strategic Rocket Forces that funded it.[19] The Soviet system was highly secretive with even worse bureaucratic fights than the U.S. system. Pervasive secrecy and bureaucratic competition could only be overcome through productive relationships. Breaking through the secretive structures required personal connections and trust, which was difficult to achieve in a communist system recovering from Stalinism, but which Korolev often achieved. Nobody else replicated that effectively, as shown by problems after his death in 1966. In the end, America's federal-corporate system channeled competition into a single, effective program that landed the first, as well as the only set of, astronauts on the moon. The centralized Soviet system decreed multiple efforts to make the first-ever piloted circumlunar flight and lunar landing. It sponsored multiple moon rockets and associated programs chaotically. It achieved very few positive results.

1.3. Contest for the highest high ground

Having achieved the world's first satellite launch on October 4, 1957, Khrushchev believed that a new era of missiles could "demonstrate the advantages of socialism."[20] Building on Stalin's assertion that technology decided everything,[21] Khrushchev quickly cited *Sputnik* as proof that—thanks to its superior system—the USSR was surpassing the West. Washington's failure to match Moscow's feat—despite plans to orbit a satellite since 1955—alarmed many Americans, who, like those in other nations, believed Khrushchev's exaggeration.[22] Realizing the U.S. reaction, Moscow stepped up propaganda and programs. Its November 3 launch of a 1120-pound satellite carried canine cosmonaut Laika into orbit. The Soviet public and foreigners alike remained unaware that all Sputnik launches were one-off, or hastily assembled, projects. Speaking to Chinese students in Moscow on November 17, 1957, Mao Zedong asserted, "Now, the Soviet Union has launched two Sputniks. … This is a great turning point … in the comparative strength of the world's two blocs. From now on, the west wind will not prevail over the east wind. The east wind would surely prevail over the west

[4] Johnson, *The United States Air Force*, 224.

[5] Joseph G. Gavin Jr., interview, December 11, 1998.

[6] Harvey M. Sapolsky, *The Polaris System Development* (Cambridge, MA: Harvard University Press, 1972).

[7] Data from here through the remainder of the paragraph are from Johnson, *The United States Air Force*, 22, 16, 231, 211.

[8] Johnson, *The Secret of Apollo*, 221.

[9] Ibid., 287.

[10] Ibid., 3.

[11] Davis Dyer, *TRW: Pioneering Technology and Innovation Since 1900* (Cambridge, MA: Harvard Business Review Press, 1998).

[12] Roger E. Bilstein, *Stages to Saturn: A Technological History of the Apollo/Saturn Launch Vehicles* (Washington, DC: NASA History Office, 1996), 42.

[13] Gavin, interview, August 6, 2005.

[14] Aaron L. Friedberg, *In the Shadow of the Garrison State: America's Anti-Statism and its Cold War Grand Strategy* (Princeton, NJ: Princeton University Press, 2000), 4.

[15] Bruce Parrott, *Politics and Technology in the Soviet Union* (Cambridge, MA: MIT Press, 1985), 303.

[16] Johnson, *The Secret of Apollo*, 4.

[17] Tom Alexander, "The Unexpected Payoff of Project Apollo," *Fortune*, July 1969.

[18] "The Soviet Space Program," *National Intelligence Estimate 11-1-67*, U.S. Central Intelligence Agency (CIA), March 2, 1967, www.astronautix.com/articles/ciah1967.htm.

[19] Sergei N. Khrushchev, *Nikita Khrushchev and the Creation of a Superpower* (University Park, PA: Pennsylvania State University, 2000), 277–78.

[20] Asif A. Siddiqi, *Challenge to Apollo: The Soviet Union and the Space Race, 1945–1974* (Washington, DC: NASA, 2000), https://history.nasa.gov/SP-4408pt1.pdf, 168.

[21] Walter A. McDougall, …*The Heavens and the Earth: A Political History of the Space Age* (New York: Basic Books, 1985), 17.

[22] William B. Breuer, *Race to the Moon: America's Duel with the Soviets* (Westport: Praeger Publications, 1993), 149.

wind."[23] U.S. hopes of resurgence plummeted on December 6, 1957 when the '*Vanguard*' rocket lifted several feet off its launch pad, only to collapse in flames. Soviet United Nations delegates offered the U.S. development aid.[24] Not until January 31, 1958, did the U.S. successfully launch *Explorer 1*, a grapefruit-size satellite. On September 13, 1959, Soviet *Luna 2* became the first probe to reach the moon. Follow-ons were so successful that state news agency *TASS* boasted: "There will [soon] be laboratories, sanatoria, and observatories on the moon."[25] Then, on April 12, 1961, Cosmonaut Yuri Gagarin became the first human in orbit, further capturing the world's imagination. Americans saw Soviet space successes as a "symptom of a fundamental problem in the U.S. that had to be addressed," former director of George Washington University's Space Policy Institute John Logsdon emphasizes. *Sputnik* initiated "fear that [Americans] were losing [their] leading position in the world."[26] The CIA saw Sputnik as a "major watershed in the Western European evaluation of the relative power standing of the U.S. and the Soviet Union."[27] A plurality in every European nation thought Moscow to be stronger.[28] This fear helped motivate Kennedy to declare a race to the moon on April 25, 1961. Following a series of cosmic firsts, on July 24, 1964 Soviet leaders accepted a moon-landing proposal; and on August 3 approved a comprehensive five-year space plan.[29] An August 1964 decree called for a lunar landing competitive with the U.S. Apollo effort in 1967–68 for the USSR's 50th anniversary. "These two behemoth projects were representatives of the two countries," Siddiqi emphasizes, "in a race for technological supremacy." Though both programs suffered setbacks, on July 20, 1969 the U.S. met Kennedy's deadline when two Americans walked on the moon.

It was a race to the very end. CIA hints of Soviet circumlunar flight for the last half of 1968 spurred a more ambitious Apollo timeline. In early June 1969, Wernher von Braun feared both a Soviet last-minute sample return flight and a piloted flight later that year using a giant booster, which might beat *Apollo 11* if the latter were delayed. Like other Soviet officials, Nikolay Kamanin, the Aide to the Air Force Commander who oversaw cosmonaut training, feared an Apollo circumlunar first, but lacked recourse: "I have to admit that we are haunted by U.S. intentions" to send the first humans around the moon aboard *Apollo 8* in December 1968, but "we still don't think it is possible to send [our] people on that route." Following collective shock and dismay at *Apollo 8*'s achievement of this key Soviet objective, and a major meeting to see how it might be neutralized, the USSR launched a desperate effort to beat the U.S. to the moon by the last means available. In propaganda "Soviet officials engaged in a complete about-turn" and emphasized automation. In reality, as Kamanin acknowledged in his diary, it was impossible to answer *Apollo 8* with an automated machine. Only manned a piloted moon landing was sufficient, but he viewed this as impossible for 2–3+ years.

In a crash program proposed in early 1967, the Ye-8-5 robotic probe was being developed to return a small soil sample to earth before Apollo. It had increased the burden of an already extraordinarily complex Soviet lunar effort with constant additions and modifications complicating mission design. On January 8, 1969, the Communist Party of the Soviet Union (CPSU) and government ordered this moon scooper program elevated and accelerated. Five-plus flight models had the potential to beat *Apollo 11*. They were untested in space, however, and their *Proton* launcher had quality control problems. In the moon race's final stage, the USSR had two chances to beat *Apollo 11* with automated sample return. The first attempt, on June 14, 1969, failed. One chance remained: launching the *Luna 15* probe in July 1969. As uncertainties regarding terrain and hence trajectory kept *Luna 15* in orbit, *Apollo 11* landed first. Finally, 2 h before the LM's planned liftoff, controllers sent *Luna 15* moonward. Even this last available compensatory public opinion measure, an inferior substitute for Apollo at best, failed. The last Soviet moon race hope crashed into a mountain in the Sea of Crises—and with it, the illusion that early space spectaculars heralded a new age of Soviet progress. As senior Soviet space engineer and Korolev associate Boris Chertok acknowledged, Moscow had "lost the moon race."[30] Though the USSR would later demonstrate significant technical prowess by launching space stations and by sending scientific probes to Venus and Mars, it had failed a critical Cold War test, both in space and on Earth.

2. Explaining the results

2.1. Khrushchev himself acknowledges "organizational defect"

The USSR ultimately lost the space race because its program could be no stronger than the flawed system that supported it. Insufficient funding, ruinously rivalrous personalities and programs, and idiosyncratic, incomplete development prevented significant Soviet scientific and technical talents from being fully applied. "I think that the Soviet program succumbed to these larger factors," Gavin agrees. "The Soviet system would not work with or even understand the openness, the informal communications, the teamwork, and the trust that characterized the U.S. effort."[31] In the most basic sense, American Institute of Aeronautics and Astronautics Executive Director Emeritus James Harford adds, "Failure to beat the U.S. to the manned lunar goals was due to lack of necessary rubles. Blame that on the Soviet economy."[32] Moscow spent roughly two-times the portion of GNP as the U.S. on space, yet its absolute expenditure on space (and lunar program in particular) was far less.[33]

The Soviet system hobbled its space program in many critical ways. While Americans invested intensively in research facilities and human capital to produce ever-higher technology, Soviets selected simple, available components to achieve 'firsts' in space rapidly. "What gave rise to the legend that the Soviets were ahead and the United States was lagging behind?" Sergei Khrushchev asks rhetorically. "We actually were the first to begin testing intercontinental missiles. We were twelve to eighteen months ahead there and several months ahead in medium-range missiles. The reason is very simple: we were in a great hurry, while they were not."[34] Although Nikita Khrushchev initially was able to parlay these 'firsts' into propaganda coups, they were "also a reflection of the technically primitive status of Russian research and development in electronics and space systems."[35] As Nikita Khrushchev himself came to realize, "There is apparently some great defect in our system, for we have no fewer engineers, scientists, or mathematicians than West Germany or Japan … Yet we still need to buy the best things overseas. It makes you think … Victory will go to the system that makes the best use of the opportunities provided by science and research … The system with the highest productivity will win … But we have no cause to brag about our technology and science. Our scientists know, probably better than I do, how we are being propped up by scientists from the capitalist countries … *We in the Soviet Union have an*

[23] Mao's Remarks to Chinese Students in Moscow, November 17, 1957, quoted in Pang Xianzhi and Jin Chongqi, eds. *Mao Zedong zhuan* [Biography of Mao Zedong] (Beijing: Zhongyang Wenxian Chubanshe [Central Press of Historical Documents], 2003), 757.

[24] T. A. Heppenheimer, *Countdown: A History of Space Flight* (New York: John Wiley & Sons, 1977), 128.

[25] Robert Reeves, *The Superpower Space race: An Explosive Rivalry throughout the Solar System* (New York: Plenum Press, 1994), 62.

[26] John Logsdon, interview, December 1998.

[27] McDougall, …*The Heavens and the Earth*, 241.

[28] Ibid., 9.

[29] Unless otherwise specified, data for this and the next two paragraphs are from Siddiqi, *Challenge to Apollo*, 407, 410, 497, 662–63, 687, 665, 675, 667–68, 641–42, 687–88.693–94, 698, 932.

[30] Boris Chertok, *Rockets and People: Creating a Rocket Industry*, Vol. 1 (Washington, DC: NASA, 2005), 27.

[31] Author's multiple discussions with Gavin over multiple years.

[32] James Harford, interview, December 1998.

[33] Siddiqi, *Challenge to Apollo*, 552.

[34] Khrushchev, *Nikita Khrushchev and the Creation of a Superpower*, 263.

[35] Reeves, *The Superpower Space Race*, 5.

organizational defect of some kind, one that needs to be identified and removed."[36] This is an extraordinary conclusion on his part. Korolev's successor Vassily Mishin similarly concluded in retrospect that Soviet system flaws—including monopoly, secrecy, nepotism, and political dealing—were far more important than leadership personalities (including Korolev's death) for Soviet space shortcomings: "Space exploration has been hampered by monopoly and secrecy, and by nepotism and politically dealing … We need broad, open competition in projects for a unified technical task. And discussion of tasks, ideas, and proposals, and independent report evaluations, and open selection of winners. Only after this, in full view of everyone, should there be implementation of projects in which the whole of society is convinced of their need and soundness."[37]

The command economy made weakness of Soviet strength. Powerful Soviet rockets initially permitted use of relatively simple, readily available electrical devices and scientific instruments.[38] The non-competitive Soviet economy thus had little incentive or ability to develop the miniaturized electronics and instruments required for piloted lunar landing. "We had very bad electronics," laments cosmonaut Gyorgi Grechko. "Even the big booster, the N-1 [lunar rocket] could not lift its payload because its electronics were so bulky."[39] Deputy Chief of the Central Command-Measurement Complex (TsKIK) Aleksandr Maksimov recalled, "We were building everything heavier than the Americans."[40] Even after the N1 was upgraded from 75 to a theoretical 95-ton lift "just barely enough" through a harrowing campaign, it lagged far behind the U.S. *Saturn V*'s 130-ton lift. Everything was limited as much as possible. The lunar landing mission profile allowed only 25 s to select a landing site. Crew size shrunk from three to two. Siddiqi summarizes President of the USSR Academy of Sciences Mstislav Keldysh's assessment: "no reserves at all, a sure road to failure." Yet this encapsulates the Soviet lunar lander prototype: a single-stage vehicle with single set of descent/ascent engines of 5.5 tons versus the LM's 15 tons, with heavier microelectronics, and poor computers, supporting a single cosmonaut. The tiny LK-1 circumlunar craft held only 1–2 cosmonauts, apparent lacked backups, and had very little margin for error. As the U.S. flew Apollo spacecraft, the USSR had a *Gemini*-level capability at best.[41] A visiting aerospace journalist found Soyuz production facilities crammed with paper blueprints but little evidence of U.S.-level super-cleanliness or quality control procedures.[42]

Moreover, lack of a robust civilian economy prevented Moscow from pursuing key technologies that would have facilitated critical space achievements. Military expenses consumed perhaps 20% of "gross social product."[43] The USSR lagged in integrated circuits, microchips, and computers, in part because of a lack of civilian applications. Quantity reflected lack of technological integration: "[T]he first Soyuzes had so much varied radio technology on board that they required twenty antennas," Chertok recalls. Soviet mission-control facilities were likewise less-advanced: "[T]he mission control centers at Cape Canaveral and Houston seemed like a fantasy to us."[44] American incentive to miniaturize catalyzed breakthroughs in communications and computer technology.[45] These achievements benefited Western society by raising living standards dramatically. Soviet society, by contrast, enjoyed few if any innovations. Consequently, for Soviet citizens, the space program represented not a productive investment but a drain. While theoretically Moscow prioritized its piloted lunar landing program, there was no effective organizational structure to coordinate space programs by resolving tensions among industries, ministries, and the all-powerful military, which imposed constant demands. Since 95 percent of aerospace technologies are inherently dual-use, this "stove piping" also caused severe inefficiency in technological development. Even as its three civilian piloted lunar programs were more important for politics and propaganda, the USSR pursued three major piloted military space projects (the *Almaz* space station, *Zvezda* reconnaissance spacecraft, and *Spiral* space plane).[46] These were part of sweeping, costly plans for "the military piloted dominance of space." Yet none came to fruition.

There was an enduring civil-military tension over rocket fuel: prioritization of fueling flexibility and concealability to maximize ICBMs' effectiveness emphasized solid motors with significantly less lift capability and efficiency than the cryogenic engines that Korolev championed for their piloted spaceflight advantages but that OKB-456 Chief Designer Valentin Glushko and military stakeholders stolidly opposed, ceding this field to the U.S. throughout the moon race. Further limiting its options, the USSR lacked a liquid hydrogen production industry. The Soviet metallurgical industry could not produce aluminum sheets more than 13 mm thick, necessitating non-integral tanks produced with expensive size-specific jigs and dies. The N1's status as a "direct competitor to the Saturn V" prompted counterproductive haste to ensure its introduction soon after. 1963 thus witnessed "one of the most fatal decisions of the N1 program": lack of time and funds eliminated first-state static testing. This violated a cardinal rocket-building rule: "the bugs in the burn of the rocket stages must be worked out on the test stand." Deficient in test grounds and static firing facilities, the USSR lacked giant test stands completely. It lacked both funding and ground testbeds large enough for the N1, so critical phases of ground testing were omitted and its reliability could not be guaranteed as with its American competitor.[47] All N1 elements would have to be tested in flight without any prior R&D on smaller vehicles. Accordingly, the N1 suffered from an "almost incomprehensible level of problems." "The shortcuts inexorably led to the series of crushing failures just as the U.S. was landing its first citizen on the surface of the moon."

In a vicious cycle, inadequate industrial capacity and production quality,[48] inefficient electronics,[49] insufficient propulsion,[50] and philosophical opposition to cosmonaut piloting of space vehicles[51] created an insurmountable weight penalty bottleneck, complicating the mission prohibitively.[52] As the space race progressed, technological limitations and military myopia made the USSR fall further behind the U.S. Initial Soviet achievements "came from resourceful adaptations of the R-7 [missile] and early … spacecraft," Harford explains. "Once the ball game shifted to manned lunar missions, the price soared, the military continued to object to these 'diversions,' and what should have been necessary expenditures for electronics, computers, larger and more advanced rocket engines and their static test facilities, were never approved."[53] Former Soviet Space Research Institute Director Roald

36 Emphasis added. Jerrold L. Schecter and Vyacheslav V. Luchkov, eds., *Khrushchev Remembers: The Glasnost Tapes* (Boston: Little Brown & Company), 93–94.

37 Siddiqi, *Challenge to Apollo*, 853.

38 Reeves, *The Superpower Space Race*, 5.

39 Harford, *Korolev: How One Man Masterminded the Soviet Drive to Beat America to the Moon* (New York: John Wiley & Sons, 1997), 264.

40 Unless otherwise specified, this paragraph's data are from Siddiqi, *Challenge to Apollo*, 477, 496, 476, 488, 444.

41 Craig Covault, "Soyuz Gives Cosmonauts Little Control," *Aviation Week & Space Technology*, January 21, 1974, 38; "Fuel, Sensors Limit Soyuz Maneuvering," *Aviation Week & Space Technology*, January 28, 1974, 40.

42 Covault, email interview, January 16, 2018.

43 Michael Gruntman, *Intercept 1961: The Birth of Soviet Missile Defense* (Reston, VA: American Institute of Aeronautics and Astronautics, 2015), 235.

44 Chertok, *Rockets and People: Hot Days of the Cold War*, Vol. 3 (Washington, DC: NASA, 2009), 580, 599.

45 Gavin, interview, August 6, 2005.

46 Unless otherwise specified, data for this and the next paragraph are from Siddiqi, *Challenge to Apollo*, 607, 598, 213, 318, 388, 486, 392–93, 483, 857.

47 Khrushchev, *Nikita Khrushchev and the Creation of a Superpower*, 688.

48 Ibid., 479.

49 Siddiqi, *Challenge to Apollo*, 429.

50 Siddiqi, *Sputnik and the Soviet Space Challenge*, (Miami: University of Florida Press, 2003) 318, 434, 486, 488.

51 Ibid., 197–98.

52 Siddiqi, *The Soviet Space Race with Apollo* (Miami: University of Florida Press, 2003), 527.

53 Harford, interview, December 1998.

Sagdeev concurs: “The guiding philosophy behind Soviet space launches reflected the interests of the space industry to the complete neglect of science … This was … because the original motivation to build rockets had been purely military.”[54] In this regard, Siddiqi judges, “the same forces that allowed the Soviet Union to send the first human into space—the need to arm themselves with powerful new weapons—deprived the country of further national triumphs in the space race.”[55] Inefficient use of limited resources imposed additional burdens, themselves cloaked in secrecy. “For a long time during the post-Khrushchev period, we continued to develop and produce several parallel lines of strategic missiles, allowing unjustified redundancy,” Chertok acknowledges, their overproduction camouflaged by creative budgeting.[56] Brezhnev avoided taking sides in this non-institutional factionalism, and thereby “squandered billions of roubles.”[57]

2.2. Secrecy subverted success

Obsessive secrecy reigned. In the USSR's command economy, “valuable information was frequently not produced; if produced, it was often concealed; whether concealed or not, it was often of poor quality; and regardless of quality, it often suffered from low credibility outside the ruling circle.”[58] Repressive bureaucracy and subterfuge shielded Soviet programs from badly needed accountability and censored key technological knowledge, thereby compounding failure to produce intensive growth. Moscow's “centrally planned, controlled, politically overseen, secret approach had inherent handicaps,” Gavin concurs.[59] The Soviet system, Harford adds, despite Marxist commitment to material growth as proof of political legitimacy, “did not permit” the necessary “free exchange of information, even between people in the same company—one engineer told me he did not know what was going on in the next department. The Soviets certainly had, and [the Russians] have, the technical talent to develop the technology, but” the Soviet program failed because “Apollo's innovative ‘systems management’ was never” and could never be “matched by Korolev,” Moscow's one-man version of NASA.[60] Korolev's name never appeared publicly during his lifetime.

Moscow's early lead had appeared insurmountable in part because many failures—and negative practices—had been hidden. “What was kept secret in the USSR,” Harford observes, “would have been exposed as a national scandal in the [US].”[61] The Central Committee maintained a categorical prohibition on acknowledging space failures. Such is the extent of Soviet secrecy that more than half a century later many key documents remain classified and completely inaccessible to even the most persistent foreign historians. While larger dynamics are finally clear, many details remain uncertain or disputed. Case in point: response to accidents. In one particularly stark example, the origin of the April 24, 1967 tragedy in which Vladimir Komarov plummeted to his death in *Soyuz 1* was not only falsified in public, the accident's actual cause “was never [even] included in the [internal] report … partly because those at the manufacturing plant who knew of the violation of [the parachute deployment] testing procedure [responsible for the accident] chose to remain silent on the issue so as not to incriminate themselves.”[62] Instead, a blameless parachute designer was made the scapegoat. Had *Soyuz 2* been launched as scheduled for a rendezvous, it too would likely have succumbed to this unreported but fundamental flaw. Siddiqi judges the *Soyuz 1* flight an “extraordinary” gamble that should not have happened. “Insufficiently tested in space conditions” following three mission failures, and not yet debugged problems with the coordination, thermal control, and parachute systems, *Soyuz* was “certainly not ready for” this “ambitious first [crewed] mission.”[63] Before a ground-based N1 booster explosion derailed Moscow's piloted moon program entirely in July 1969, political pressure to commemorate the Great October Revolution with a piloted circumlunar flight “was such that the first of the four remaining L1 ships would fly in July [1967] with the old parachute system because there was simply no time to install a [corrected] version …. ,” even though Mishin himself lacked faith in the spacecraft. A two-year Soviet spaceflight gap amid ten U.S. *Gemini* missions generated overwhelming political pressure to proceed, threatening chief designers' jobs.[64] Even so, some accidents generated such negative repercussions that periods as long as two-plus years passed without cosmonauts in space.

By contrast, the U.S. program was relatively open and accountable. The January 27, 1967 *Apollo 1* Command and Service Module (CSM) capsule fire (in which three astronauts perished during a ground-based test) prompted a complete reckoning and reworking. 1500 technicians spent ten weeks producing a 3300-page, $4 million report.[65] Instructions for vacuuming and preserving couch debris alone consumed thirty pages. A complex approval, witness, and documentation process ensured that it took three weeks working around the clock just to detach and lower the capsule to the ground.[66] The report triggered reorganization of contractor North American's top management.[67] By 1968, Apollo was back on track. “We have reexamined every drawing, every circuit, and every component” of Apollo's four million parts,[68] Apollo Spacecraft Program Office Manager George Low testified to Congress. “We have made thousands of changes in design, in manufacturing techniques, and in tests. And we have literally rebuilt every Apollo craft.”[69] In the U.S., Gavin recalls, “NASA management was good, but even more important was the continuous boiling up of ideas from middle and lower levels of the organization. It was easier to be an innovator.”[70] Based on his single American visit, aircraft specialist Andrey Tupolev, the Chief/General Designer at OKB-156, agreed. “One cannot help but admire the industry, organization, and complete lack of bureaucracy in America. One's word is trusted more than we with our [in]numerable papers. To say means to do.”[71]

Testing and troubleshooting likewise revealed markedly divergent approaches and outcomes. Succumbing to institutional tendencies and cost and scheduling pressures despite the unique demands that space imposes, Moscow failed to build reliably or test even the most vital devices. Poor Soviet quality control harmed component reliability, and hence that of the N1 moon rocket's first stage and N11 upper stage. Yet, as Sagdeev explains, “the leaders of the project were in such a hurry [and so financially constrained] that they did not dare schedule a comprehensive program of tests, which would [have] substantially reduce[ed], if not eliminate[ed], the risk of blowing up the huge and expensive construction at the launching site.”[72] This indeed happened

[54] Roald Sagdeev, *The Making of a Soviet Scientist: My Adventures in Nuclear Fusion and Space from Stalin to Star Wars*, (New York: John Wiley & Sons, 1994), 154.
[55] Siddiqi, *Challenge to Apollo*, 856.
[56] Chertok, *Rockets and People*, Vol. 3, 155, 146.
[57] Siddiqi, *Challenge to Apollo*, 787.
[58] Mark Harrison, “Economic Information in the Life and Death of the Soviet Command System,” in Silvio Pons and Federico Romero, eds., *Reinterpreting the End of the Cold War: Issues, Interpretations, Periodizations* (New York: Frank Cass, 2005), 111.
[59] Author's multiple discussions with Gavin over multiple years.
[60] Harford, interview, December 1998.
[61] Harford, *Korolev*, 246.
[62] Unless otherwise specified, data in this and the next paragraph are from Siddiqi, *The Soviet Space Race with Apollo*, 589, 691, 611, 590.
[63] Siddiqi, *Challenge to Apollo*, Ibid. 576–58, 590.
[64] Ibid., 611.
[65] Henry W. Lambright, *Powering Apollo: James E. Webb of NASA* (Baltimore: Johns Hopkins, 1995), 7.
[66] Mike Gray, *Angle of Attack: Harrison Storms and the Race to the Moon* (New York: W.W. Norton & Company, 1992), 236–37.
[67] Bilstein, *Stages to Saturn*, 231.
[68] Sylvia K. Brown, *Guide to the George M. Low Papers, 1930–1984* (Troy, NY: RPI Folsom Library, 1988).
[69] John Noble Wilford, *We Reach the Moon* (New York: Bantam Books, 1969), 159.
[70] Author's multiple discussions with Gavin over multiple years.
[71] L. L. Kerber, *Stalin's Aviation Gulag: A Memoir of Andrei Tupolev and the Purge Era* (Washington, DC: Smithsonian Institution Press, 1996), 75.
[72] Sagdeev, *The Making of a Soviet Scientist*, 178.

on multiple occasions. To the extent that the USSR did test rockets, lingering artillery corps heritage overemphasized costly test flights at the expense of far more economical ground-based testing. Soviet desperation contrasts sharply with Apollo's systematic approach. In the LM's exhaustive ten-year ground testing-dominated development, technicians documented 14,247 test failures or anomalies. Only twenty-two defied analysis, and were replaced anyway.[73] This high-level systems management was a product of the U.S. federal-corporate interface—one of its historic strengths. By *Apollo 17*'s conclusion in 1973, only one mission (*Apollo 13*) had come close to failure, and no astronaut had been lost in space.

2.3. Ruinous suspicion and rivalry

Suspicion stymied innovation. Fundamental distrust of free thinkers permeated Moscow's space program and hamstrung Soviet initiatives. The terrible toll of purges, stifling ideological repression, and systematic suppression of even the most talented Jewish technocrats under Stalin cast lingering shadows: "Even scientific problems that were far removed from politics and ideology, such as matters of rocket stability, could acquire political overtones."[74] Accordingly, it was "'better to fail according to the rules than to succeed by breaking them.'"[75] Moscow further undermined its top-down, over-militarized organization by distracting scientists with harsh personal concerns, work duplication, and infighting: "Most attempts at indigenous innovation were plagued by a shortage of slack resources, the skewed incentives of high-pressure economic plans, poor circulation of information, and the scapegoating of [mostly-imagined] technological 'wreckers'."[76] One source of Soviet failure: pitting design bureaus against one another in efforts to limit chief designers' power and increase production through competition. In practice, neither objective was achieved: "In the Western sense of the word, competition [connoted] a proactive plurality of opinions, which fostered creativity and efficiency. In the centralized … socialist Soviet system with resources restricted by the needs of the defense sector, it gave rise to chaos."[77] In the Soviet space policy-making process, chief designers contending for limited resources pushed countless pre-draft plans proposals through informal channels, abusing the patronage system. Projects often rose and fell based on their relationships with key Central Committee members. The careers of other space and military bureaucrats likewise rose and fell with cutthroat politics.[78] Bureaucratic squabbling and gridlock generated constant delays and disarray.

Inter-bureau conflict caused chief designers to seek additional power to protect and promote themselves and their programs. This decreased productive competition by enabling the well-connected to bludgeon their enemies through unceasing titanic bureaucratic battles. When Korolev raised these concerns (and his self-interested program objectives), Khrushchev pitted OKB-52 Chief Designer Vladimir Chelomey against him. Chelomey hired Khrushchev's son Sergei (himself a competent missile guidance engineer) and was rewarded when the Premier "displayed a marked favoritism toward Chelomey by the late 1950s."[79] Despite having to design many things wholesale, ambitious self-promoting empire builder Chelomey rapidly acquired a staggering proportion of Soviet space infrastructure and programs; all later stripped from him following his patron's ouster. Beyond the tremendous disruption caused by these vicissitudes, granting Chelomey so many resources from 1961 to 64 proved catastrophic. His grandiose, often fanciful proposals would have gone nowhere, but for his unbeatable access and support. Combined with Khrushchev's lack of a coherent long-term vision for civilian space program, this starved Korolev's programs (and even temporarily halted the N1), forcing him to resort to diversionary space spectaculars to maintain leadership support. The Soviet system, Harford adds, was riddled with "nasty personal rivalry which Congress and the press in the U.S. would not have tolerated—Glushko, up to then Korolev's main rocket engine developer, refused to design the N-1 [moon rocket] engines, forcing Korolev to go to a primarily aircraft engine designer."[80] Glushko dismissed Korolev's designs, declaring that "with a good engine, even a broomstick would fly."[81] The struggle between chief designers at times became "a matter of life and death," Sergei Khrushchev relates.[82] There was no way "to carry out all government decrees. A director would have to choose which to implement and which to put aside, to judge according to circumstances when nonfulfillment might get you 'killed,' when you might be 'severely beaten,' and when you would only get a scolding."[83] The adoption of specific design bureaus' products hinged at least partially on "the level of cordiality between given chief designers and the Soviet leadership."[84] Top-down leadership to the point of micromanagement slowed decision-making and engendered corruption.[85] Even Korolev, almost universally regarded as the Soviet space program's competent leading manager, blamed other design bureaus for his own problems. "What a cunning man you are," one of Korolev's superiors commented after receiving a dubious report. "So much stink about what might have been caused by others, and so much perfume for your own shit."[86] Korolev's domination of certain areas, while providing needed focus, also created resource and launch facility bottlenecks that caused satellite launch delays.[87] The U.S. was hardly immune to inter-agency bickering, but conflict was far less pervasive and usually stemmed from productive competition, not the desperate quests of threatened men. "There was great individual trust in the U.S. program, a product of political system and society," Gavin emphasizes. "You didn't worry about someone trying to sabotage your effort. That might be a bigger explanation of the differences between the Americans and the Soviets than anything else."[88]

2.4. Unaffordable program overlaps, cancellations, and disorder

The early glory days of spending capable of lifting all spaceships faded in the 1960s. Yet fundamental lack of prioritization and management of resources, programs, and schedules continued squandering vast resources in the sprawling Soviet space effort. "Most surprising," in Siddiqi's view: the tremendous effort devoted to unfruitful programs, with many projects cancelled "before reaching flight status."[89] Already-approved programs were continually threatened by emerging rivals. "This sort of chaotic design process, whereby already approved programs such as the N1 lunar landing project were threatened by continually new emerging proposals," Siddiqi relates, "was uniquely symptomatic of the Soviet piloted space program." "Korolev's N-1 [lunar program], which needed all the help it could get," Harford recounts, "was not only an under-designed, minimally tested, and undeclared program, but [also] one harassed by possible competitors long

[73] Gavin, "Engineering Development of the Apollo Lunar Module," paper presented at the 41st Congress of the International Astronautical Federation, October 6–12, 1990, Dresden, GDR, 2.
[74] Chertok, *Rockets and People: Creating a Rocket Industry*, Vol. 2 (Washington, DC: NASA, 2005), 64.
[75] William Burrows, *This New Ocean: The Story of the First Space Age* (New York: Random House, 1998), 572.
[76] Parrott, *Politics and Technology in the Soviet Union*, 298.
[77] Siddiqi, *Sputnik and the Soviet Space Challenge*, 242.
[78] Siddiqi, *Challenge to Apollo*, 287, 842–54, 858.
[79] Siddiqi, *Sputnik and the Soviet Space Challenge*, 229.
[80] Harford, interview, December 1998.
[81] Heppenheimer, *Countdown*, 227.
[82] Khrushchev, *Nikita Khrushchev and the Creation of a Superpower*, 276.
[83] Ibid., 284–85.
[84] Siddiqi, *Sputnik and the Soviet Space Challenge*, 125.
[85] Burrows, *This New Ocean*, 277.
[86] Heppenheimer, *Countdown*, 121.
[87] Khrushchev, *Nikita Khrushchev and the Creation of a Superpower*, 480.
[88] Gavin, interview, August 7, 2005.
[89] Unless otherwise specified, data for this paragraph are from Siddiqi, *Challenge to Apollo*, 633, 420, 506, 549.

after it should have had the government's exclusive focus."[90] Design bureaus were overwhelmed with multiple simultaneous responsibilities; multiple moon programs fell on the same maxed-out entities. Overworked and overstretched financially, Korolev's bureau cut corners on ground and in-flight systems. Soviet bureaucracy squandered time and money not only on inefficient infrastructure but also on astounding duplication and dead ends, Harford elaborates: "Nepotism loomed, as well, when Chelomey was given the go ahead to develop new spacecraft for a manned circumlunar mission (the spacecraft encountered developmental problems and Korolev ended up with the project anyway) at great duplic[ative] cost."[91] As Siddiqi relates, the "circumlunar mission … underwent some profound changes in 1965, creating yet another schism in the loosely held conglomerate of the Soviet space industry."[92]

Soviet lunar efforts became huge and complex with many weak links that squandered resources and complicated scheduling. In November 1966, Chelomey proposed a direct ascent approach; even though NASA had chosen lunar orbit rendezvous in 1962, Korolev and the Soviet leadership in 1964. Chelomey further promoted the consideration of a large percentage of the lunar surface for exploration, extensive scientific research, and eventual permanent bases and "colonies". The circumlunar program, viewed as essential to producing a space spectacular for the Great October Revolution's fiftieth anniversary in November 1967, diverted limited funding. Then, when that political deadline lapsed, Soviet leaders authorized Chelomey to begin a *second* moon rocket in direct competition with the N1/L3, on which millions of rubles had already been expended.[93] A November 17, 1967 decree required Chelomey to design and develop the UR-700 (Proton) booster and LK-700 lunar spacecraft to land cosmonauts by 1972–73.[94] Such a "chaotic design process … was uniquely symptomatic of the Soviet … program."[95] After eleven launches and billions of rubles expended from 1965 to 70, the L1 program ended without any crewed spacecraft ever flown. "This decision resulted from the fact that the United States had already taken the lead from us in that direction," Mishin explains. Some ultimately-terminated programs were unrealistic in their very conception. As late as 1971, extraordinarily ambitious lunar plans on the books included stays up to one month, far-flung facilities including permanent crewed bases, and large and multi-day-excursion rovers. As Siddiqi emphasizes, the very fact that a piloted Mars landing option was also considered "is a testament to the often unrealistic ambitions of both space industry officials and the chief designers."[96] Moreover, even when the USSR attempted to unify its programmatic efforts, it struggled to do so for lack of unified NASA-like overseeing entity. The Kremlin therefore lacked an effective means of coordinating and enforcing deadlines for hundreds of contractors. During the last critical stages of Moscow's moonshot, some 'contractors' did not even know that they were assigned to deliver parts.[97] Without a single overseeing entity such as NASA, there was "no coordinated plan for maintaining deadlines for dozens of subcontractors," and no enforcement mechanism.[98] N1 woes were a microcosm of Soviet mismanagement. Money was a key bottleneck, and the region in which it was produced was economically depressed. Catastrophic malpractice and Khrushchev's gutting of the aviation sector left subcontractors unable to handle orders. "Mired in the gridlock symptomatic of the poor performance of the Soviet civilian economy," subcontractors suffered from extreme secrecy, and lack of awareness and incentives.[99] A given job or delivery might not happen without personal intervention. Such disarray was simply unimaginable in Apollo.

2.5. "One-man NASA" becomes soviet casualty

Lack of institutional effectiveness meant that too much depended on key individuals' ad hoc efforts. Yet Moscow neither trusted nor respected its most intelligent innovators. Many great Soviet scientists and military personnel—if they survived Stalin's purges—had been harmed. Their stifling, in turn, harmed Moscow's ability to achieve its technological objectives. In this, Korolev represented a microcosm of Soviet society, having both marshaled great technical resources and suffered senseless repression. Soviet spaceflight's greatest hope died in 1966, just as Moscow's moonshot was reaching a critical phase. His death was a product of the Soviet system: Stress from the program's flaws ruined Korolev's heart and aged him prematurely. On January 14, 1966, Korolev died from bleeding in surgery in part because of injuries he had received[100] when Stalin sent him to the Gulag in 1938 for "subversion in a new field of technology"[101] based on patently false charges, including that he had destroyed the *RP-318* rocket plane.[102] Your "missiles are probably for an attempt on our leader's life …," Korolev's investigator had accused.[103] Given his declining health overall, Korolev might not have had long to live anyway.[104] Indeed, nearly all Soviet space program personnel "had earlier spent time in a gulag or knew of someone who had."[105] In 1937, the NKVD denounced Glushko as "enemy of the people."[106] Mishin had been considered a state risk because of his father's background. Their harsh treatment and complex position was no coincidence: in the 1930s, "ideas about using rocket weapons were considered treasonable …. "[107] During Stalin's purges, which stunted Soviet rocketry, "… the police dragnet disproportionately scooped up scientists, technicians, and engineers. [For example,] the secret police arrested *thirteen* successive directors of the Academy of Sciences in Kiev."[108] Severely tortured and beaten, Korolev was sentenced to ten years' hard labor in Siberia's notorious Kolyma mines. There brutal treatment gave him a head scar and cost half his teeth. Korolev had only been spared likely death because Stalin—after politically reliable replacements failed to produce quality aircraft—had ordered his transfer to a Moscow "aviation gulag" headed by Tupolev. There "the elite, the cream of Russian aircraft technology" toiled throughout World War II.[109]

Korolev proved irreplaceable. Because of the personal arm-twisting and back-channel negotiating needed to direct Moscow's space program, his death affected its entire trajectory disproportionately. Historians generally concur that "In [America], the pioneers were defined by their institutions, [whereas] in [the USSR], the pioneers *were* the institutions …" and that Moscow would not have dominated space in the late 1950s and early 1960s "without [Korolev's] guidance, administrative powers, and vision …. "[110] In seeking world firsts for Soviet rockets and cosmonauts, Korolev articulated a compelling dream. In 1955, he declared: "Our mission is to ensure that Soviet rockets fly higher and farther than has been accomplished anywhere else up until now. Our mission is to ensure that a Soviet man be the first to fly in a rocket. And our mission is to ensure that it is Soviet rockets and Soviet spaceships that are the first to master the limitless space of the

[90] Harford, *Korolev*, 266.
[91] Harford, interview, December 1998.
[92] Siddiqi, *Challenge to Apollo*, 497.
[93] Siddiqi, *The Soviet Space Race with Apollo*, 645.
[94] Siddiqi, *Challenge to Apollo*, 645.
[95] Siddiqi, *Sputnik and the Soviet Space Challenge*, 420.
[96] Siddiqi, *Challenge to Apollo*, 764, 745.
[97] Siddiqi, *Sputnik and the Soviet Space Challenge*, 562.
[98] Siddiqi, *The Soviet Space Race with Apollo*, 562.
[99] Siddiqi, *Challenge to Apollo*, 390–91.
[100] Harford, *Korolev*, 280.
[101] Burrows, *This New Ocean*, 62.
[102] Siddiqi, *Sputnik and the Soviet Space Challenge*, 11.
[103] Kerber, *Stalin's Aviation Gulag*, 167.
[104] Siddiqi, *Challenge to Apollo*, 514.
[105] Burrows, *This New Ocean*, 279.
[106] Siddiqi, *Challenge to Apollo*, 11.
[107] Khrushchev, *Nikita Khrushchev and the Creation of a Superpower*, 224.
[108] Kerber, *Stalin's Aviation Gulag*, ix.
[109] Siddiqi, *Challenge to Apollo*, 14.
[110] Siddiqi, *Sputnik and the Soviet Space Challenge*, 3.

cosmos."[111] To implement his vision, Korolev attempted to bring as many advantages of a NASA-style approach as possible into the Soviet system. The inter-ministry council that he established and ran in the late 1940s "was clearly a novelty in the very centralized approach of the Soviet defense industry and illustrated Korolev's early pragmatism and originality in the search for more efficient work."[112] In 1958, Korolev, with Keldysh, proposed centralized civilian institutions akin to NASA's predecessor NACA—albeit unsuccessfully. Korolev's unique role, influence, and contributions were far more than the sum of his formal positions. As "manager, designer, politician, lobbyist, engineer, and flight director, [Korolev] had carved out a position … that defied any singular title. Each one of [his] responsibilities … was vacant. His successors would try to fill the vacuum, but … things would never be the same again."[113] Korolev's long-groomed replacement, Mishin, was a brilliant engineer but no diplomat and a far inferior manager, with a difficult personality.[114] He would prove far less effective at both leadership and lobbying the Kremlin bureaucracy, including key defense establishment patrons such as Ustinov.[115] During his eight years in charge, Mishin made poor decisions and presided over many failures, causing great suffering for himself and the space program. He alienated so many that in 1973 three of Mishin's top deputies joined other key stakeholders in writing letter requesting his dismissal. On May 22, 1974, in "the largest reorganization within the Soviet space industry since Korolev's death," Glushko suddenly replaced Mishin. Glushko, now controlling all space programs—even more than Korolev at his peak—banned Mishin from ever reentering space-related bureaus.[116] Despite Mishin and Glushko's clear leadership flaws, however, tremendous obstacles would have confronted anyone in their position. The Soviet space program's apparent problem of agency was in fact a problem of structure: "Handed too little money, too little time, and too many demands, possibly any other manager would have had the same results."[117] The very concept of chief designers itself was outdated, and certainly inappropriate for so complex an undertaking as Moscow's piloted lunar landing project. By the 1960s, major aerospace initiatives had reached such scale and complexity as to defy effective individual oversight. In the U.S., NASA's supervision ensured that contractors met standards and deadlines. "Each contractor had a NASA representative onsite with access to everybody," Gavin explains. "We held regular meetings to discuss progress and scheduling."[118] Spirited but collegial debates improved design and testing. Reflecting on the space race at the end of the Cold War, Mishin concluded, "The Americans had won. I was made the scapegoat."

3. Conclusion: Soviet system could not defy gravity

The Soviet system turned space exploration into a race that it could not afford to wage, let alone win. As Sergei Khrushchev emphasizes, however, actual costs for Moscow's moon program were as unclear then as now.[119] In 1975, during Apollo-Soyuz, Intercosmos Council chairman Boris Petrov "rambled on for half an hour" in response to a journalist's asking "how much the USSR was putting into the project … In the end he gave up, saying he didn't know. 'What's the use?' he said. 'I don't count the money and there's still plenty of everything we need.'"[120] In relative terms, however—because of its weaker economy—the USSR almost certainly spent more than did the U.S. Library of Congress Soviet space analyst Charles Sheldon calculated that the Soviet lunar effort—based on the Soviet economy and GNP—cost the equivalent of $49 billion in 1960s dollars as compared to $20 billion ($120 per capita)[121] for the U.S. Apollo landings.[122] Siddiqi estimates that the N1-L3 lunar program alone consumed $1.5 billion at its peak for a total of ~$12–13.5 billion, half that of Apollo.[123] Moreover, while Apollo employed 417,000 at its peak, its less efficient Soviet counterpart employed 500,000.[124] "Making a program that was competitive with America's," journalist and space historian William Burrows concludes, "would be so expensive that it would help undermine the very society that it was supposed to reinforce."[125] By the early 1970s, the Soviet economy was stagnating, reducing public support for space spending. Yet the Soviet system suppressed telltale warnings: "Since the party was [theoretically] infallible, there was no real independent analysis of the costs or technological consequences of whatever projects were proposed and party directives to proceed with them were almost irreversible."[126] Pointing at the sky, a Moscow taxi driver encapsulated Soviet failure: "There's our meat."[127] Khrushchev himself had foreseen the costs of Moscow's inefficient rocket technology development. In response to Korolev's insistence that the USSR needed to maintain an astronomically expensive ICBM liquid refueling infrastructure, Khrushchev had "commented sadly that [his compatriots] would end up as world beggars. Then the imperialists wouldn't have to fight us."[128] Yet, while paying so dearly for its moonshot, the Kremlin never gave it priority sufficient to ensure that inefficient infrastructure or desperate bureaucrats would not simply waste allocated resources. An ends-ways-means mismatch caused countless deadline slippages. Lack of leadership consensus regarding the piloted lunar landing program's goals and schedule undermined the project from the start. Soviet politics de-linked priorities and resources. Serious work did not begin until 1965, and the timetable was compressed unrealistically. Both Eisenhower and Kennedy, by contrast, publicly made the U.S. rocket program a national priority. Kennedy championed Apollo to his final day. Under Kennedy's leadership, former NASA Flight Director Eugene Kranz recalls, the U.S. space program enjoyed "a clear goal, a powerful mandate, and a unified team …. "[129]

While "a span of only eight years separated the resounding victory of Gagarin and the crushing humiliation of Apollo,"[130] Apollo's costly challenge represented a larger pattern. Harford believes that "the U.S. shuttle and SDI in particular … escalated the USSR into competitive projects like [the] *Buran* [space shuttle] and [its] *Energia* [launcher] which were hugely expensive and are now mothballed [;] funding them surely damaged the already weak Soviet economy."[131] As early as 1963, the CIA had foreseen the trend, reporting that Soviet military and space programs had monopolized "high-quality manpower and materials," causing "improvements in living standards [to slacken] and general economic growth [to fall] off from the high rate achieved during most of the 1950s."[132] Burdened with a military-industrial complex that came to consume over 25% of GDP yet offered none of Apollo's civilian spin-offs, the USSR's command economy grew unsustainable.[133] This was a central cause of Soviet failure and ultimate collapse, Sagdeev

[111] Siddiqi, *Challenge to Apollo*, 183.
[112] Ibid., 47.
[113] Siddiqi, *Sputnik and the Soviet Space Challenge*, 516.
[114] Siddiqi, *Challenge to Apollo*, 519.
[115] Siddiqi, *The Soviet Space Race with Apollo*, 518–19, 827, 838.
[116] Siddiqi, *Challenge to Apollo*, 828–31.
[117] Unless otherwise indicated, data in this paragraph are from Siddiqi, *The Soviet Space Race with Apollo*, 518–19, 827, 838.
[118] Gavin, interview, August 7, 2005.
[119] Khrushchev, *Nikita Khrushchev and the Creation of a Superpower*, 689.
[120] Brian Harvey, *Russia in Space: The Failed Frontier* (Chichester, UK: Springer, 2001), 31.
[121] Wilford, *We Reach the Moon*, 129.
[122] Reeves, *The Superpower Space Race*, 149.
[123] Siddiqi, *Challenge to Apollo*, 644, 837.
[124] Harford, *Korolev*, 299.
[125] Burrows, *This New Ocean*, 210.
[126] Ibid., 278.
[127] Wilford, *We Reach the Moon*, 127.
[128] Khrushchev, *Nikita Khrushchev and the Creation of a Superpower*, 282.
[129] Eugene Kranz, *Failure is Not an Option: Mission Control from Mercury to Apollo 13 and Beyond* (New York: Simon & Schuster, 2000), 381.
[130] Siddiqi, *Challenge to Apollo*, xi.
[131] Harford, interview, December 1998.
[132] Harford, *Korolev*, 270.
[133] Friedberg, *In the Shadow of the Garrison State*, 337–38, 347.

concludes: "Now we know that at the time of the Cuban Missile Crisis the actual ratio of nuclear warheads with ICBM delivery vehicles between the U.S. and the USSR was 17:1. And the most remarkable thing was [that] that was enough to deter the war. The greatest historic irony of the Cold War was that Soviet leaders did not get this message and tried to overarm themselves."[134] The space race was—in many respects—a Cold War microcosm, "a technological race for military advantage."[135] By substituting technological shadowboxing for nuclear war, the superpowers were able to establish their relative positions without destroying all their accomplishments. Ultimately, the U.S. proved to have the advantage. "The American system worked pretty well, particularly in contrast to the Soviet system," Gavin concludes, "While the U.S.'s winning of the space race—by achieving the first lunar landings—was an engineering triumph, I think it was an even more significant diplomatic coup. The Soviet posture of scientific and technical superiority was instantly deflated."[136] Revisiting the space race, with its moon-landing centerpiece, suggests larger implications. Technological development is shaped by the national system and conditions under which it occurs, because modern organizations must develop standardized rules and procedures to create and sustain the bureaucracies that coordinate it. Nations cannot simply allocate resources to produce space success, which at its highest levels of scope and sophistication offers a comprehensive test of not only specific programs, but also of the capabilities of the organizations and nation(s) that support them. As a particularly important example, systems management was developed by American private corporations, applied in U.S. military and lunar landing programs, and remains one of the most successful mechanisms for high technology development.

[134] Sagdeev, interview, December 1998.

[135] Friedberg, *In the Shadow of the Garrison State*, 303.

[136] Gavin, interview, August 7, 2005.