Chapter 16

The Space Race Revisited: The Lunar Landing and Its Larger Lessons*

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Abstract

The Cold War space competition between the United States and the Soviet Union, centered on their race to the Moon, offers both an exceptionally revealing historical case and larger implications for space and technology development and policy. Moscow's capabilities appeared to eclipse Washington's in the late 1950s under Premier Nikita Khrushchev's direction and Chief Designer Sergei Korolev's determined implementation. This called the international system's very nature into question, prompting President John F. Kennedy to declare a race to the Moon and Lyndon B. Johnson to pursue this legacy with masterful political mobilization. Despite its talented specialists and ambitious goals, in the central-

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ized but under-institutionalized USSR feuding chief designers playing bureaucratic politics promoted a cacophony of overambitious, overlapping projects. It suffered from poor 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 was the product of an effective systems management program, while Moscow's moonshot succumbed to the Soviet system, which proved wholly unequal to the task. In less than a decade, Soviet space efforts shifted from one-upping, to keeping up, to covering up.

This chapter will review and reconsider this fascinating history to suggest larger conclusions and implications. Among them: 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. Mobilizing sufficient resource itself is challenging, but even astronomical resources themselves cannot ensure space success, which at its highest levels of scope and sophistication offers a comprehensive test of not only specific programs, but also of the processes and capabilities of the organizations and nation(s) that support them. As a particularly important example, systems management proved itself in the Apollo Moon-landing program, and remains one of the most successful mechanisms for high technology development.

I. Cold War Microcosm: Overall Dynamics of the "Fluid Front"

As the hindsight of centuries accumulates and events recede into the rear-view mirror of history, perhaps the key event that will emerge from the twentieth century is humanity's first extra-terrestrial footsteps on the Moon. How humans came to transcend their Earthly bounds is of inherent interest and importance, which may only grow with time. To historians, at least, the larger cosmic contest that propelled and shaped this feat offers a case study of enduring fascination, unique in some respects, but nevertheless offering larger lessons. Already, the perspective and information that has emerged in the ensuing half-century underscores the extraordinary dynamics of the US-Soviet space race that launched a Moon race as its central contest. Following the second of two global wars, the technological spoils of then-leading technological power Germany were divided among the two remaining superpowers; here America seized a decisive advantage over its emerging rival. In a spurt of social mobility and human capacity mobilization unsurpassed before or since, talented Americans and Soviet strivers

from the most modest and remote of backgrounds competed to become some of their space programs' top leaders, engineers, and astronauts. European refugees provided America and its space program further world-class talent, with Austrian-émigré-turned-NASA-Administrator George Low among the many striking successes. At the time, some of the greatest and most fundamental questions seemed to hang in the balance: what would be the prospects for peace and human survival, how societies around the world would organize and govern themselves, and how vast new technological and physical frontiers might soon unfold. In retrospect, however, the overall dynamics are clear: because of its self-limiting system, the USSR could not defeat a determined American challenge. Ultimately, it could not even survive, disintegrating completely in 1991.

I.1. Political System Shapes Technology Development

National political systems shape technological development within them, Max Weber implies, because modern organizations must develop standardized rules and procedures to create and sustain the bureaucracies that coordinate it.[1] One of Weber's modern-day students notes, "For organizations to learn, to adapt, and to sustain adaptations, they must have processes that are both flexible and durable."[2] This dual capability is extremely difficult to achieve in either a fragmented (underdeveloped) or a closed (authoritarian and autarkic) political system—both Soviet weaknesses.

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, which have organized aerospace and software engineering since the Sputnik era, help to synchronize engineering changes, forecast costs, and maximize reliability. 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]

The genesis and initial successes of systems management were intimately connected with another American advantage: a sophisticated public-private partnership in which commercial concerns competed for government contracts and winners selected and supervised their own subcontractors. Systems management was conceived in the early post-war years, pioneered at the US firm Ramo-

Wooldridge (later, TRW) and developed further by AT&T Corporation.[4] Before supporting leading corporations' contributions to the Apollo and sustaining its status thereafter as high technology development's most successful mechanism, systems management proved itself in military megaprojects, most famously Lockheed's *Polaris* submarine-launched ballistic missile for the US Navy.[5]

Systems management's core elements—sound initial design,[6] "quality assurance, configuration control, and systems integration testing [—have been] among the primary factors in the improved dependability of ballistic missiles and spacecraft."[7] For Apollo, NASA in September 1961 adopted Program for Evaluating and Reviewing Technique (PERT), in which 90,000 key events for 800 major entities were sorted among five levels[8] by schedule, sequence, man-hours, and duration.[9] "If a gas generator exhaust line under test in California was showing problems," for instance, "how would this affect the static test schedule at the Mississippi Test Facility…and a scheduled launch from Cape Kennedy? What would be its cost impact? How would it affect other hardware? What would be done about it?"[10]

Because it derives from constant, transparent "negotiations among various organizations, classes, and interest groups,"[11] systems management is typically more difficult to achieve in an autarkic autocracy than in a capitalist democracy or even a statist authoritarian system like that of China 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,[12] and McKinsey.[13] "When you put something complicated together you get into systems engineering whether you recognize it or not," former Grumman President and Lunar Module (LM) Program Director Joseph G. Gavin, Jr. emphasizes, but "the Soviets had no AT&T" to help them maximize efficiency.[14]

I.2. Comparative Space Development: Critical Cold War Test

The Cold War was "a sustained competition in power creation," with space as one of its central theaters, and a race to land a man on the Moon at the core.[15] Moscow's failure in that quest foreshadowed limitations in national capabilities that fatally undermined its core identity as the global vanguard of socio-technological progress. The 'vanguard' myth had been essential in justifying Soviets' astronomical economic and political sacrifices: "In theory the members of the Politburo might…simply [have] abandon[ed] the hope of overtaking and surpassing the West technologically," Bruce Parrot explains. "This sort of consensus, however, seems almost inconceivable. Surpassing the West [was] a central Soviet goal for more than [six] decades, and it…played a critical role in legitimizing the party elite's claim to rule." "In Communist theory," leading space

historian Asif Siddiqi adds, "technological progress was virtually equivalent to the march of history." Having started the space race, Moscow felt compelled to keep ahead: "Having consistently taken the lead in the early space race…pushed the Soviet government into maintaining the image of a new advanced Soviet state. It was a race that they had started and were in no position to call off."

American leaders saw a similarly critical challenge. In their May 8, 1961 report "Recommendations for Our National Space Program: Changes, Policies, Goals," NASA Administrator James Webb and Defense Secretary Robert McNamara advocated landing astronauts on the Moon before 1970, ideally before the USSR: "*We recommend that our National Space Plan include the objective of manned lunar exploration before the end of this decade*…[which] represents a major area in which international competition for achievement in space will be conducted…It is man…in space that captures the imagination of the world…The Soviets have announced lunar landing as a major objective of their program." They concluded: "perhaps the greatest unsurpassed prestige will accrue to the nation which first sends man to the moon and returns him to earth." They warned: "Our cards are and will be face up—theirs are face down."

They reasoned: "*All large scale space projects require the mobilization of resources on a national scale.* They require the development and successful application of the most advanced technologies. They call for skillful management, centralized control and unflagging pursuit of long-range goals. *Dramatic achievements in space, therefore, symbolize the technological power and organizing capacity of a nation.* It is for reasons such as these that major achievements in space contribute to national prestige…The nation needs to make a positive decision to pursue space projects aimed at enhancing national prestige. *Our attainments are a major element in the international competition between the Soviet system and our own.* The non-military, non-commercial, non-scientific but 'civilian' projects such as lunar and planetary exploration are, in this sense, *part of the battle along the fluid front of the Cold War*." (emphasis added).

Within hours, Vice President Johnson forwarded the report to President Kennedy with his approval. Two days later, Kennedy met with his policy advisors and finalized his decision, which he announced in his nationally televised address to Congress on May 25.

The comparatively agile, innovative US 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 left little margin for inefficiency: "the extreme environment of space exacted its toll in numerous failures of extremely expensive systems. Those funding the

race demanded results."[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] In the area of planetary probes, for instance, US engineers discovered that "many technical problems could be solved only by using organizational means."[18]

Soviet loss of the Moon race represented not a singular but rather a systemic failure. Attempts to dominate aerospace with a commercial supersonic transport, ambitious space stations, a space shuttle, and even—briefly—a fanciful piloted Mars mission all failed for similar reasons. It was not Soviet lack of technical talent or ignorance of advanced management systems that doomed Soviet aerospace, it was ideological and organizational constraints precluding their implementation; as well as inability to sustain the requisite resourcing. Moscow's space program was further handicapped with outdated organization and development techniques such as emphasis on multiple test flights, in contrast to Apollo's relentlessly proactive reliability campaigns and methodical, relatively economical ground testing. These techniques had been inappropriately transplanted from the USSR'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 battles than the American system. Pervasive secrecy and inter-organizational rivalry 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 with its well-integrated management structure 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 little lasting positive impact.

I.3. Contest for the Highest High Ground

Enthusiastic at orbiting the world's first satellite on October 4, 1957, Khrushchev believed that a new era of missiles could "demonstrate the advantages of socialism." Building on Joseph Stalin's assertion that technology de-

cided everything, Khrushchev quickly cited *Sputnik* as proof that—thanks to its superior system—the USSR was surpassing the West.[20] 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. Realizing the reaction, Moscow heightened programs and propaganda. Its November 3 launch of a 1,120-pound satellite carried canine cosmonaut Laika into orbit. The Soviet public and foreigners alike remained unaware that all Sputnik launches were one-off efforts or hastily assembled projects.[21] 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 wind."[22]

American 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 America development aid.[23] Not until January 31, 1958, did the United States successfully launch *Explorer 1*, a grapefruit-size satellite.[24] On September 12, 1959, Soviet *Luna 2* became the first probe to reach the Moon. Follow-ons were so successful that *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 US 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 US 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.[29] Following a spate 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. An August 1964 decree called for a lunar landing competitive with America's Apollo program 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 US 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, leading space program figure 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* were the latter 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 US 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 labyrinthine 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 suffered from 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. Exemplifying the risks inherent in the mission, last-minute weight excess prompted elimination of the backup radio. Viewing the space race as critical, Soviet decision-makers and engineers attached great hopes to *Luna 15*. As uncertainties regarding terrain and hence trajectory kept *Luna 15* in orbit, *Apollo 11* landed first. Finally, two hours 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 bluntly concluded, Moscow had "lost the moon race." 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. In Siddiqi's assessment, "personal, institutional, political, and technological issues intersected in the complex schema of the Soviet Moon program, leading it to its ignominious failure in 1969." He concluded: "The time for payback had arrived for both countries. For the U.S., it was payback for excellent management, high levels of funding, and a state-level commitment; for the Soviet Union, it was precisely the opposite."

I.4. Space Racing Mirrored Cold War's Trajectory

The American and Soviet space programs' vicissitudes mirrored those of their overall systems and geopolitical positions. In both instances, Moscow started ahead in some areas, but ended up behind in all.[30] Soviet spaceflight slumped from consecutive victories in early 1960s to constant setbacks, tragedies, failures by the mid-1960s. Malfunctions produced progressive delays just as Apollo recovered from its one major setback in 1967.

The initial disparity was not wholly illusory, but Khrushchev inflated and conflated achievements. Just as some Soviet economic sectors initially grew faster than did their American counterparts thanks to extensive but unsustainable resource mobilization, so too did Moscow initially enjoy absolute advantages in certain technological sectors, particularly those concerning space exploration. Ironically, as will be discussed, the critical late 1950s-to-early 1960s Soviet advantage in heavy-lift launchers was motivated by its relative inability to miniaturize components and nuclear payloads alike. Touting maxed-out spectaculars literally airbrushed with secrecy, Khrushchev convinced the West that the USSR was progressing rapidly on manifold fronts, from scientific to social.[31]

Both Soviet and American leaders resorted to one-upmanship to safeguard security and prestige. American perception of Soviet achievements greatly influenced the space race's outcome by spurring Washington into action. Khrushchev and the Soviet space program, in turn, dramatically increased human spaceflight efforts in response to US civil space initiatives, including President Dwight Eisenhower's establishing NASA as a civilian organization in 1958, Johnson's famous speech declaring that "Control of space means control of the world," and Johnson's successful effort to increase NASA's budget for 1961. From the beginning, the US and Soviet programs raced to achieve 'firsts' in space. Assisted by his translator wife Nina Ivanovna Kotenkova and access to foreign publications through their workplace, Korolev followed American space efforts as closely as possible, and strove to outpace his competitors. After technical challenges prompted von Braun to recommend delaying the first Mercury flight until early

May 1961, Korolev considered Khrushchev's political considerations and set Gagarin's flight for mid-April. John Glenn's Mercury flight prompted hasty acceleration of the next *Vostok* flight.[32]

Perception of Soviet achievements, in turn, greatly influenced the space race's outcome by spurring American action. As America surged ahead by the mid-1960s, Moscow became increasingly reactive. Indeed, certain programs, mandates, and funding fluctuated directly with Moscow's concerns about relative gains.[33] "The General Staff always kept track of what was being done across the ocean," Khrushchev's son Sergei recalls. "Occasionally we had the impression that our projects were directed more from the Pentagon than from [the Kremlin]." Space plane research funding fluctuated directly with that for US Air Force's X-20A Dyna-Soar counterpart: "While some people considered [chief designer Vladimir] Chelomey's *Raketoplan* research some sort of 'raging fantasy,' others in the General Staff could point out that the United States was conducting similar research. This is, in fact, what exactly happened on occasion. As the fate of the Dyna-Soar shifted up and down, the Ministry of Defense became less or more liberal with funding." Each side fed off the other constantly, Chertok concurs: "American operations had a very strong effect on our plans. American historians…assert that our successes were the primary reason why the United States converted its space programs into a top-priority, nationwide challenge."

After America's triumph in 1969, Soviet leadership lost interest in the Moon.[34] "Soviet leaders saw little need for such projects [as N1-L3 lunar program] because their success would raise inevitable questions about the original failure to beat Apollo." As one chief designer stated, "To repeat what the Americans have done—this is to openly admit to the world our lag behind them." A response to the blow of *Apollo 8*, consideration during 1969–70 of embarking on a piloted Mars mission—an idea also discussed by NASA—could not survive subsequent political calming. The *Salyut 2* space station launch in April 1972 was intended to shift publicity from *Apollo 16*, but failed. A solo *Soyuz* earth orbital flight scheduled for August–September 1972 was cancelled to avoid an underwhelming contrast to *Apollo 17*. In 1974, officials seeking to cancel the failure-plagued N1 Moon rocket apparently feared that it would finally succeed on its next launch, requiring immediate major investments.

Conversely, while Soviet space surges galvanized American effort, the extreme costs and risks inherent in Moon racing caused American decision-makers to seek savings through slowdown or even, tentatively, cooperation when competition seemed less acute.

Amid these vicissitudes, the USSR systematically lost both the Moon race and, ultimately, the space race and the rest of its competition with America. Its

space program succumbed to overall Soviet monetary and structural problems. In geopolitics and in space, rapid Soviet rise and eventual decline resulted from a command economy that initially produced rapid extensive growth, but failed to sustain intensive growth. Like all other aspects of Soviet society, the defense industry suffered from meddling micromanagement by party organizations throughout the production process, limitations in government efficiency and innovative capacity, ruinous bureaucratic and interpersonal struggles and finger-pointing, unrealistic deadlines, insufficiently systematic decision review, and lack of leaders who understood the benefits of a symbiotic military-civilian approach. The microelectronics revolution that galvanized American civilian spin-offs such as integrated circuits bypassed the USSR. This lack retarded the N1/L3 Moon rocket's progress and helped make the program a drain on already-stressed Soviet society. Korolev's untimely death in 1966, itself partly a result of previous incarceration in the gulag in the late 1930s and early 1940s, devastated Moscow's space program.

Repressive bureaucracy and ubiquitous secrecy undermined Soviet space efforts by shielding programs from accountability while giving Soviet leaders an exaggerated sense of national power. Ultimately, the Soviet space program's perceived rapid advance caused the US to accelerate the space race into an all-out technological 'war' that the USSR could ultimately not afford to wage, let alone win. In retrospect, it was amazing that Moscow accomplished as much as it did. The two nations' relative strengths made it a particularly impressive—if unsustainable—accomplishment, in Siddiqi's assessment: "it was a devastated totalitarian society with old-fashioned machines competing against an intact and democratic one equipped with far better technology."

I.5. A Techno-Political Competition

American and Soviet space development reflected each nation's Cold War geopolitical development. The initial "inability of [America] to keep pace with the Soviets in developing ballistic missiles was widely interpreted as the result of flaws in the American system for managing defense research and development."[35] "Those of us in the space program were not totally surprised by Sputnik because several [Soviets] had publicly stated that they had a program to launch a satellite," American Institute of Aeronautics and Astronautics Executive Director Emeritus James Harford recalls. "We felt we would beat them, however, and were shocked that we didn't."[36]

America would be back in the limelight, 2,974 days after Kennedy's challenge,[37] as an exemplar of democratic capitalism's potential. One million would watch *Apollo 11* soar skyward on July 16, 1969.[38] Four days later, on another

American invention—television, six hundred million (1/5 Earth's population) would watch Neil Armstrong step onto the lunar surface.[39] It would be a spectacle that Khrushchev could only have envied—and testimony to a system whose effectiveness even he came to acknowledge.

The Apollo-Soyuz Test Project linkup that united American and Russian astronauts in orbit on July 15, 1975, could not end the space race competition as an extension of the Cold War: "For the Soviets, the race to the Moon might have been over, but the less specific 'space race' was not."[40] Indeed, in technical preparations, the "Soviets were extremely suspicious of ulterior motives, and it was very hard to get them to agree to anything."[41] Following Apollo-Soyuz, "the lines of the Cold War began to harden again."[42] Moscow continued to view space as a vital competitive arena and denied America's victory. Once it had failed to beat Washington to the Moon, Moscow attempted to mask the credibility-draining debacle by falsely claiming that there had never been a race.[43] As a Soviet space historian relates, "secrecy was necessary because we were ahead" gave way to "we maintained secrecy so that no one knew that we had been overtaken." The first *Apollo* Moon landing froze Soviet space activity for fear that dramatic failure would contrast sharply with America's triumph.[44]

But Soviet space initiatives were not simply cynical propaganda ploys; at the time, it was a real race in which the competitors believed much was at stake. Like virtually all Soviet space program leaders and defense officials, as well as US Army and Air Force space experts, including von Braun and Air Force ballistic missile and military space pioneer General Bernard Schriever, Chelomey believed that "…future military operations would inevitably involve space. Whoever controlled space would be able to dictate conditions on earth. If we were not able to confront our adversary in space, we could not avoid defeat."[45] Khrushchev agreed: "If war reached space—he thought Chelome[y]'s arguments were very convincing—then we must not allow ourselves to be caught unprepared."[46]

Soviet hardliners, such as Khrushchev's successor Leonid Brezhnev, wanted the many geopolitical benefits of a robust military space program but underestimated the necessary funding, management reforms, and synergistic innovation. "Brezhnev's ludicrous demands" reportedly included the following: "We should prepare for a manned mission to the Moon straight after the first successful launch of the N1, without waiting for it to be finally developed." Korolev's successor Vasily Mishin later lamented that directives' target dates were "unrealistic"; "not backed by funds, production capacities or resources." Yet the lunar component of this competition was genuine; technocrats such as Chertok believed there was no substitute: "[N]o matter how successful [other] programs might be, they could not compensate for our loss of superiority if the Americans

were to become the first to fly around the moon." In December 1968, American astronauts indeed became the first to fly around the Moon, a feat repeated by twenty-one of their compatriots—but never by a Soviet cosmonaut.[47]

Earlier Soviet Moon race initiatives had been backed by the highest internal decrees, made with increasing concern as America's lead mounted. On February 4, 1967—only eight days after America's *Apollo 1* fire seemed to offer a window of opportunity[48]—the Soviet Central Committee and Council of Ministers issued document 115-46,[49] which "called for the consolidation of all national resources [to achieve] a piloted lunar landing…prior to the United States."[50] That same month, Brezhnev made the document "binding to all the hundreds of primary and secondary contractors working on the lunar program" because of its "objective of national importance" of landing a cosmonaut on the Moon by the end of 1968. In October of that year, *Soyuz 3* confidently radioed "hearty greetings to the courageous Vietnamese people who are heroically fighting…the American aggressors for freedom and independence."[51]

In March 1969, however, Soviet space program leaders "admitted openly [among themselves] for the first time what [had been] privately beyond debate for over a year: that the Soviet Union could no longer [hope to] overtake the United States in landing a human on the moon." Chertok admitted that "the Soviet space program had [fewer] resources than the U.S. program…yet was spending its money even less rationally." In April 1969 Mishin, in reporting to Brezhnev on the Soviet piloted space program, ascribed its underperformance vis-à-vis Apollo to institutional inadequacies, subpar subcontractors, poor quality control, and insufficient material incentives. Recent opening of many Soviet archives has revealed both the expenditure of significant resources on multiple piloted lunar programs and the existence of two advanced lunar lander prototypes.[52]

These facts have conclusively debunked Moscow's retroactive claim of disinterest. Kamanin termed Soviet obfuscation "unrestrained lying." He and other were Soviet officials deeply disappointed: "We have come to the end to drink the bitter chalice of our failure and be witnesses to the distinguished triumph of the USA in the conquest of the moon." "In the end," Siddiqi concludes, "the Moon proved to be as elusive for the Soviets during the era of Apollo as being first in space was for the Americans during the era of Sputnik."[53]

I.6. A Decisive Outcome

The first recognition among Soviet elites of their trailing the US technologically was triggered by the *Apollo 11* Moon landing, which "overshadowed the space achievements so widely touted by Soviet propagandists, and…vividly demonstrated that the United States had the capacity to create a new generation

of sophisticated strategic weapons which would be difficult for the USSR to match." Indeed, "the quest for arms control agreements and wider economic relations with the West was precipitated by [ensuing] debate over the USSR's technological performance."[54]

Khrushchev was not fooled. Living in forced retirement, the Soviet leader who had himself instigated the space race's central contest reflected, "The American astronauts have already reached the moon. Now our radio, press, and television all say we are ahead, but the evidence is not serious…it was important for man to get to the moon, rather than an unmanned system, no matter how independent or smart it might be."[55] The Soviet public was denied television footage, but the truth was unconcealable: *Apollo 11* was of paramount importance as the defining moment of the space race. "You would think that it was time to stop," Khrushchev's son Sergei adds. "We'd lost, after all. Why waste the money? But those in charge refused to see reason. The N-1 [lunar rocket] continued in its death throes. The Americans carried out flights to the moon with enviable regularity. We were still trying to break free of earth."[56]

Even by selecting its own post-moonshot goals, Moscow could still not beat Washington. The US dominated deep-space missions beyond Mars, orbited the first successful major space station, and produced a superior space shuttle. The US matched Soviet robotic missions to Mars and Venus, compensating for Soviet quantity with more successful, sophisticated efforts. It remained determined to do so. Amazingly, even amid unwillingness to abandon the Moon race, consensus emerged from space officials' meetings in early 1969 that the USSR should restore prestige with an ambitious Mars-landing program. In June 1969, a piloted Mars program was approved provisionally "to take the steam out of Apollo." The massive integration project required high-level chief designers to cooperate, and all but Chelomey withdrew before the initiative foundered on feasibility and cost concerns. Such ultimately-terminated programs were unrealistic in their very conception. As late as 1971, extraordinarily ambitious lunar plans on the books included stays up to a month, far-flung facilities including permanent crewed bases, and large and multi-day-excursion rovers. As Siddiqi assesses, that the Mars-landing option "existed at all is a testament to the often unrealistic ambitions of both space industry officials and the chief designers."[57]

The USSR subsequently "decided to make the best out of the loss and lead the way in space stations."[58] On October 22, 1969, Brezhnev declared space stations Moscow's focus in space. This "did not represent [a scientific] end [in] itself, but [rather] a political response," an attempt to make virtue of necessity with the quickest publicity payoff.[59] Soviet efforts to compensate with space stations suffered the same organizational problems, with tragic consequences.[60] In April

1971, *Soyuz 10* failed to dock successfully with the *Salyut* space station. Then, during the *Soyuz 11* long-duration mission, makeshift equipment, haphazard work, and accumulating errors took their toll. Just prior to landing on June 30, 1971, rapid decompression killed all three cosmonauts. The highly-publicized mission became a shocking national tragedy space program, bringing it from national "humiliation" in 1969 to an "absolute low unthinkable only a few years back." Missions to the *Salyut* station were suspended indefinitely. "In a cruel twist of fate," Siddiqi observes, "the Soviet space program was not even accorded a consolation prize in the space race. It was beset with problems far more imposing than simply political cost."

As in so many other areas, the USSR was also responding to US plans. 1972 witnessed proposals for a Multirole Orbital Complex (MOK) centered on a giant space station: "While the fantastic nature of these plans would give pause to any American conception of a space program in the 1970s, the Soviets, despite losing the race to the moon and despite the series of attendant disasters that plagued their piloted program in the early 1970s, saw these proposals as vehicles for regaining some lost glory." Moscow's 1971–75 space plan considered launching ten space stations over five years. The imperative to orbit a space station before the US *Skylab* produced dual efforts, neither successful in this regard. On April 3, 1973, *Almaz* ("*Salyut 2*") suffered a catastrophic failure. A struggle to launch the *Salyut 3* station just before *Skylab* likewise ended in failure, albeit disguised in the Soviet press as "Kosmos-557." In 1973, *Skylab* succeeded and set an endurance record. Now Moscow lagged in both piloted lunar programs and space stations. Deputy of the Institute of Control Problems and public spokesman Boris N. Petrov covered with "outright lie(s)." Not until 1975, with *Salyut 4*, did Moscow succeed with a space station.

Subsequently, while Moscow devoted more effort to the *Salyut*s and *Mir* than Washington did to *Skylab* and *Spacelab 3*, its results were initially unsuccessful and ultimately unsustainable. In what Brezhnev and other Soviet policymakers viewed as a compensatory space station race that they intended to win, the US instead won yet again.[61] The entire transition to space stations was plagued by bitter bureaucratic debates between station supporters and piloted lunar landing advocates; the latter still commanding significant resources to pursue programs inertially and periodically winning leadership support on promises of propaganda value that could restore faith in Soviet spaceflight.[62] As will be explained later, Korolev/Mishin and Chelomey waged similar competitions within the lunar program.

Because Soviet space and defense expenditures were becoming unsustainable, "'rockets-versus-butter'" debates began to convulse the Kremlin.[63] Soviet

spacecraft launches peaked in 1982, then plummeted.[64] By the Cold War's end Moscow would be powerless to challenge even President Reagan's Strategic Defense Initiative (SDI), a theoretical program that critics dismissed as unworkable.

The USSR's response to the US Space Shuttle proved a final encapsulation of its space program's problems and unsustainability. Widespread fear among Soviet decision-makers of the Space Shuttle as a military threat prompted Brezhnev to support tremendous funding to counter it. Insisting on a "parallel response," Academy of Sciences President Mstislav Keldysh, who led scientific work on missiles and spacecraft, managed to bulldoze a space shuttle program through the CPSU and government. A February 17, 1976 decree unleashed the "most expensive space project in the country's history—one that would almost bankrupt the space program." It also conclusively terminated all work on the N1-L3 lunar program. Valentin Glushko's NPO Energiya, the successor to Korolev's OKB-1 design bureau, became primary contractor for the *Energiya* launcher and *Buran* shuttle. "Institutional discord once again set the Soviet space program on a poorly managed endeavor" as Glushko bypassed Artem Mikoyan and Chelomey's bureaus with their decades of research and experience, terminating their efforts; and picked the newly-created Molniya bureau, with zero experience.

In 1986, the *Challenger* Space Shuttle disaster froze US space activities temporarily, but by then the United States was on the very threshold of 'winning' the Cold War. By the time the American Space Shuttle was back in orbit, the Soviet *Buran* had achieved only a single three-hour-and-twenty-five-minute automated flight on November 15, 1988, and the USSR was disintegrating rapidly as its economy imploded. Amid mounting press criticism, the program was terminated in 1993 after seventeen years and fourteen billion rubles. Spanning the USSR's entire piloted space program era, its Moon landing and space shuttle programs "never fulfilled their original purpose." "For those looking at waste of technology, of knowledge, of money, and ultimately of people during the postwar Communist era," Siddiqi concludes, "they need look no further than the N1-L3 and Energiya-Buran programs."

II. Retracing the Space Race

II.1. Initial Soviet Success

In the late 1950s, Soviet economic and technological capabilities seemed to match undeniable military power. By 1961, Khrushchev was declaring that "the Soviet Union would soon leave the United States far behind and the capitalists would beg to be admitted to socialism…[A] draft program of the CPSU was to be

published that would claim that 'the present generation of [Soviets] will live under [true] communism' and that by 1980 [the USSR] would overtake and surpass…America in all economic indexes."[65] Even some international economists predicted that Soviet GNP [gross national product] would surpass that of America by 1984.[66] Korolev's prediction that "'the creation of [a satellite] will have enormous political significance as evidence of the high development level of our country's technology'" was manifestly materializing.[67]

America seemed to be losing the space race by starting late, underestimating Soviet feats, and failing to consolidate underfunded initiatives[68]—precisely because it lacked Moscow's centralized authoritarian technocracy, in which the military controlled the space program and prioritized militarily-relevant applications. Indeed, "From the start of the Cold War, it was widely assumed that the superior extractive capacities of the communist states gave them certain inherent military advantages."[69] The Army, Navy, and Air Force all fought to control America's small, disorganized space program.[70]

When both congressional houses created space committees on March 17, 1958, and Eisenhower presciently[71] established NASA as a *civilian* space agency effective October 1, Americans scarcely suspected that their space program would close the gap by 1964. However, the US system had already prompted an important decision: efficient private contractors, not government-owned arsenals, would develop US military and civilian space vehicles.[72] "The United States might need to concentrate its own energies more than it had been doing," Aaron Friedberg emphasizes, "but thanks to the most fundamental attributes of its domestic system, its capacity for innovation still far exceeded that of its rival."[73]

How had Moscow progressed so rapidly? Four years after its American rival, in 1949, the USSR detonated its first atomic bomb. Stalin's ambitious strategy of socialist imperialism gradually shifted his attention to ballistic missiles as delivery systems. Controlling all aerospace development tightly, less than a month before his death on March 5, 1953 Stalin signed a decree shaping all Soviet ballistic and cruise missile development. Shortly thereafter, Soviet scientists had begun to test massive hydrogen bombs. These weapons were significantly heavier than their American counterparts, because they were less efficient, and they could not be targeted as accurately, necessitating greater reliance on wide-scale damage.[74] This put a premium on development of powerful, long-range ballistic missiles. America had produced more efficient bombs, developed better long-range bombers to deliver them, and enjoyed access to air bases near Soviet borders.[75] Collectively, these factors made Washington emphasize development of long-range bombers at the partial expense of large rockets.[76] While Eisenhower had decided in 1955 "to make ICBMs [America's] top defense priority,"[77]

Moscow still led in missiles. For Americans, however, Logsdon concludes, "having the USSR continue to be first in space was not acceptable."[78]

II.2. Khrushchev's Potemkin Space Village

Initially, Moscow convinced the world that its space surprises reflected larger accomplishments.[79] Indeed, "Ruble for ruble, the Soviet Union's space program would generate more favorable propaganda than any other activity. The rockets would become the centerpiece of socialist technology and its most enduring legacy."[80] Khrushchev quickly went from being one of the Soviet officials least knowledgeable about missiles[81] to being one of their staunchest proponents.[82] Intensive development of missiles was one of the few areas in which he was willing to invest heavily, even as he slashed funding for aviation and other conventional weapons programs.[83] As Sergei Khrushchev recalls, "No failures could shake Father's faith in missile technology."[84]

For the first time since 1815, America faced a direct foreign threat.[85] As Khrushchev later recalled, "we were able to step into the international political arena and show that now even the territory of…America was vulnerable to strike by our missile forces."[86] His August 1957 claim that Soviet rockets could reach "any part of the globe" had scarcely been noticed at the time; now, two months later, it was accepted as a credible threat.[87] Three months after *Sputnik*, Khrushchev proudly declared that the USSR had surpassed America both scientifically and technologically.[88] This was part of a plan "to rely mainly on strategic nuclear weapons and the missiles that delivered them, or rather, since reliable Soviet intercontinental missiles weren't ready for deployment in substantial numbers, on the appearance of having more rockets than in fact he possessed."[89]

Under Khrushchev's leadership, the USSR hid its problems and trumpeted its space progress. Seemingly comprehensive, well-planned, deliberate, and steady from the outside, even in these early glory days its space program in fact progressed fitfully. Khrushchev initially outplayed America by perpetuating risky chimeras: "For many years Khrushchev produced the impression of Soviet strength among the Western public, while actually playing from a position of inferiority."[90] In exaggerating the extensiveness and effectiveness of Moscow's space program, Khrushchev falsely convinced many of Soviet society's viability.

Khrushchev had "succumbed to the temptation to use his spacecraft as both evangelic tools and instruments of intimidation: to spread the gospel of socialist superiority while ridiculing his adversary and threatening it with annihilation."[91] Khrushchev timed cosmonaut Gherman Titov's launch to distract from the beginning of the Berlin Wall's construction on August 13, 1961. He likewise ordered space stunts during key summits and anniversaries. A particularly risky

gambit involved the 1964 cramming of three cosmonauts without space suits and with only limited life support into the *Voskhod I* capsule, simply a modified *Vostok*, whose "new landing system had only been tested once." Truly "one of the most deleterious decisions in the early Soviet piloted space program," this "diversionary program" offered a quick "circus act of one-upmanship" but delayed actual progress toward lunar capabilities. It was part of a series of great propaganda coups that masked an under-organized system and under-coordinated space program.[92]

Spaceflights served propaganda purposes, in part to conceal missile limitations. Prizing superficial, risky records over methodical development and innovation,[93] Moscow's space program grew overextended and ignored basic science even more than did its US counterpart.[94] Khrushchev's expediency following his premature speech at the UN about Soviet production of strategic rockets "like sausages from a machine" is blamed for one of Moscow's greatest space disasters. Struggling to prepare a propaganda coup for the Chairman's upcoming American visit, on October 23, 1960, technicians performed welding on a *fully fueled* R-16 per State Commission orders. The ICBM exploded, killing 126 Soviet experts, including Strategic Rocket Forces Commander in Chief Mitrofan Nedelin, in "the worst disaster in the history of rocketry."[95] Until 1989, officials claimed Nedelin died in an aircraft accident; the event remained classified until the following year. Worse yet for the USSR, Khrushchev's frightening exaggeration catalyzed an overwhelming American space mobilization.[96]

II.3. An Irresistible Showdown

In space, as in geopolitics, one-upmanship drove Cold War competition. "Apollo," Logsdon explains, "was specifically used as an example of US technological, economic, and organizational power to demonstrate that the US was the stronger society."[97] "Congress and the public probably would not have backed the Apollo program if [Americans] had not been shocked by [Soviet] triumphs," Harford emphasizes. And "if JFK had not called for the [lunar] landing 'in this decade' I'm sure the [Soviet lunar program] would never have received Politburo backing."[98] Former Soviet Space Research Institute Director Roald Sagdeev, who in an amazing intertwining of history was married to Eisenhower's granddaughter Susan for the first sixteen post-Cold War years, concurs: "My colleagues had felt especially pressed by the early American space program."[99]

Kennedy's promise to rectify the US-Soviet "missile gap"—however politically motivated and exaggerated in retrospect—helped him to win the 1960 presidential election.[100] Five days after Gagarin's historic flight, on April 17, 1961, the US-backed Bay of Pigs invasion failed. Within twenty-four hours, Kennedy

ordered Johnson—whom he had appointed head of the National Aeronautics and Space Council on April 25—to determine if there was any way to beat Moscow in space.[101] "There's nothing more important," Kennedy stressed.[102]

Kennedy had to promise a feat sufficiently impressive to restore confidence in America's system. He soon determined that nothing short of a manned Moon landing would suffice. Many Congressmen feared that Moscow was thus planning to mark the Russian revolution's fiftieth anniversary in 1967. The Moon became a vital propaganda symbol. *Aviation Week* predicted that Moscow would demonstrate and document a nuclear explosion on its surface.[103] Representative James Fulton predicted that any explosion would contain dust to turn the Moon red. Indeed, "most Americans at the time…found themselves caught up in the momentum of the Cold War, the battleground of which had become space. If Americans lost that battle, many believed, the Russians would rule the world."[104]

Fortunately for America's sanity, von Braun told Johnson that Washington had "an excellent chance of beating the Soviets to the first [piloted lunar] landing" because the distant goal would force Soviet engineers to improve rocket capability ten-fold, eliminating their head start and forcing them to compete with better-funded American industry. Other advisors echoed this winning approach. The Office of the Secretary of Defense's top space official, John Rubel, who with Robert Seamans played a major role in drafting the Webb-McNamara report together with its principals, recalled: "Lunar landing and return was far enough off that we would have a reasonable chance of being first in doing it. It was close enough so that we could probably maintain the national resolve to do it."[105]

On May 25, 1961, when America had only logged 15 minutes in space, Kennedy delivered a 47-minute Special Message to Congress that would shape US policy for the next ten years. "These are extraordinary times and we face an extraordinary challenge," Kennedy declared, "I believe that this nation should commit itself to achieving the goal, before this decade is out, of landing a man on the Moon and returning him safely to Earth. No single space project in this period will be more impressive to mankind or more important for the long-range exploration of space. And none will be so difficult or expensive to accomplish."[106]

When Kennedy articulated how space success could be achieved through America's system, Americans regained confidence. American prestige was on track to what would become a remarkable recovery. Inspired by Kennedy's candid message, Congress on August 7, 1961, appropriated $1.7 billion for NASA's 1962 budget. Little did Americans know that within just two years they would surpass their Soviet rivals in overall capabilities, and end their virtually unbroken streak of resourceful "firsts" within three. "*Now* I realize that the Soviets had a

slim to no chance to beat us to the Moon," Harford relates, "but at the time we thought it would be a hot race."[107]

In retrospect, sending the first cosmonaut into space would prove the zenith of Moscow's achievement vis-à-vis Washington in "the political imperative to explore space." By the early 1960s, Washington was already implementing two major space-specific advantages over Moscow: unified organization through NASA, executing a far more "integrative" long-range plan. As Siddiqi concludes, in their effort to beat America in a human Moon-landing race, "the Soviets failed dismally…The road to failure began almost as soon as Gagarin floated down in his parachute." For this reason, "In the historiography of space exploration, Gagarin's excursion [has] assumed more importance for how it affected the American decision to aim for the moon than for its own place in…history."[108]

II.4. Launching the Moon Race

The US *Saturn V* Moon rocket was approved in January 1962. On August 14, 1962, North American Aviation received a contract to design and build the Command and Service Module (CSM). On November 7, 1962, NASA selected Grumman Aircraft Engineering Corporation from among eleven bidders to build *Apollo*'s LM.[109] Apollo's last major component, Grumman's LM embodied America's space race commitment. In Lunar Orbit Rendezvous (LOR), a process adopted on July 11, 1962,[110] the CSM would transport three astronauts to circumlunar orbit, and the LM would land two of them on the lunar surface. *Apollo* comprised uncrewed and crewed variants of three sequential programs. *Ranger* would photograph lunar regions, *Surveyor* would probe lunar soil, and *Lunar Orbiter* would photograph potential landing sites. Meanwhile, *Mercury* would test human function in space, *Gemini* would perfect LOR's complex docking procedures, and *Apollo* would land astronauts on the Moon—by December 31, 1969.

By 1962–1963, the seriousness of Washington's lunar commitment became clear in Moscow. Worried about falling behind, Korolev shifted his focus to a Moon landing and took his case to the very top. In early June 1963 Korolev proposed a piloted program to beat the US to Khrushchev at his dacha with Sergei Khrushchev and Glushko present.[111] Khrushchev hesitated over the cost: the USSR faced an agricultural crisis necessitating imported grain, and mounting military outlays despite downsizing conventional programs. Undaunted, Korolev sent the proposal directly to defense industry leaders on July 27. His persistence paid off when the Academy of Sciences endorsed his proposal on August 10. On September 23, OKB-1 produced "Proposals for the Research and Familiarization of the Moon," which Korolev advertised as "a clear and unambiguous response to competition from Apollo." This theme resonated when—partially in reaction

to "reports that the Americans already have trainers for work on a lunar landing"—Soviet Air Force representatives visited the Kremlin's Military-Industrial Commission on February 11, 1964. On March 17, Korolev finally "extracted a promise from Khrushchev to *politically* commit to a full-scale lunar landing program to compete with Apollo."

In an appeal to Central Committee for Defense Industries and Space Secretary Brezhnev dated May 25, 1964, Korolev stressed the imperative of "maintaining the priority of our state in that most important and difficult sphere, space, as the first socialist society in the world, the birthplace of great revolutionary ideas and a progressive nation leading the world in the socialist system." Soon thereafter, America's sixth *Saturn I* booster launched the first Apollo spacecraft into orbit.

This breakthrough, well ahead of Soviet spacecraft yet launched in sophistication, finally catalyzed a decisive Kremlin response. A June 19 decree allocated additional funding for manufacturing sixteen N1 rockets during 1966–1968. On July 24, Military-Industrial Commission Chairman Leonid Smirnov approved Korolev's proposal. On August 3, Moscow's CPSU Central Committee promulgated comprehensive classified decree 655-268,[112] which established 1967–1968 as the goal for beating an American astronaut to the Moon.[113] Moscow's N1/L3 rocket was thus "the mirror image to Apollo-Saturn, a shadow project given birth, designed, and created in complete…secrecy, whose only *raison d'être* was to send a Soviet…to the Moon before an American."[114]

Despite his misgivings concerning the costs involved, Khrushchev "had staked so much on [Soviet] rocket achievements that it didn't seem sensible to refrain from further progress."[115] In August 1964, Khrushchev therefore signed a detailed manifesto approving Moscow's moonshot,[116] which would begin in earnest the following year. Korolev's persistence was thus instrumental to this "most important decision in the history of the early Soviet space program," which "set the stage for ten long years of elusively searching for the Moon." This goal was restated in a similar decree of October 25, 1965. Unfortunately for its Soviet competitor, like other elements of the Apollo program, "The [US *Saturn V*] effort was supported by a vast infrastructure spread across the United States, with hundreds of subcontractors and a management philosophy that was unparalleled in producing results. With a budget of which Soviet engineers could only dream, technology that was beyond the reach of Soviet industry, and management techniques that fostered creativity and responsibility, the *Saturn V* program was the living antithesis of the N1 program." This disparity in capabilities would soon determine a definitive disparity in results: American victory, Soviet loss.[117]

III. Explaining the Results

III.1. Khrushchev Himself Acknowledges "Organizational Defect"

The USSR ultimately lost the space race because its program could be no stronger than the flawed system supporting 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 US effort."[118] In the most basic sense, Harford adds, "Failure to beat the US to the manned lunar goals was due to lack of necessary rubles. Blame that on the Soviet economy." This was the problem in a nutshell: Moscow spent roughly two-times the portion of GNP as Washington on space, yet its absolute expenditure on space (and lunar program in particular) was far less. And it spent this more painfully marshalled but lesser amount less efficiently.[119]

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.[120] "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."[121] 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." As the 1961 Webb-McNamara report presciently speculated, "It is possible…that Soviet management and decision making is not as excellent as it appears to date…Perhaps luck played an important part at an early stage and the Soviets were wise enough and swift enough to exploit it far beyond any initial long-range plan."[122]

As 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 research. The system with the highest productivity and 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 organizational defect of some kind*, one that needs to be identified and removed."[123] This is an extraordinary conclusion on his part.

Mishin similarly believed in retrospect that Soviet system flaws—including monopoly, secrecy, nepotism, and political dealing—were far more important than leadership personalities (including even 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."

The command economy made weakness of Soviet strength. Powerful Soviet rockets initially permitted use of relatively simple, readily available electrical devices and scientific instruments.[124] The noncompetitive Soviet economy thus had little incentive 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, could not lift its payload because its electronics were so bulky."[125] Deputy Chief of the Central Command-Measurement Complex (TsKIK) Aleksandr Maksimov recalled, "We were building everything heavier than the Americans." 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 US *Saturn V*'s 130-ton lift. Everything was limited as much as possible. The Moon landing mission profile allowed only twenty-five seconds to select a landing site. Crew size shrunk from three to two. Keldysh opposed landing a sole cosmonaut: "Imagine for a minute being alone on the Moon! That's a straight road to the psychiatric hospital!" Siddiqi summarizes Keldysh's assessment: "no reserves at all, a sure road to failure." Yet this is exactly how the Soviet lunar lander prototype turned out: a single stage vehicle with single set of descent/ascent engines of 5.5 tons versus the LM's fifteen tons, with heavier microelectronics, and poor computers, supporting a single cosmonaut. The LK-1 circumlunar craft was tiny, holding only 1–2 cosmonauts, apparent lacking backups, and with very little margin for error. As the US flew *Apollo* spacecraft, the USSR had a *Gemini*-level capability at best. A visiting aerospace journalist found *Soyuz* production facilities crammed with paper blueprints but little evidence of US-level super-cleanliness or quality control procedures.

Moreover, lack of a robust civilian economy prevented Moscow from pursuing key technologies that would have facilitated critical space achievements. By one estimate, military expenses consumed 20% of "gross social product." The

USSR fell behind 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." Soviet mission-control facilities were likewise less-advanced: as Chertok recalls, "[T]he mission control centers at Cape Canaveral and Houston seemed like a fantasy to us."

American incentive to miniaturize paid off with breakthroughs in computer and communications technology.[126] These achievements benefited Western society by raising living standards dramatically. Soviet society, by contrast, enjoyed few if any innovations. Consequently, for Soviets, the space program represented not a productive investment but a drain. Conversely, lack of a robust civilian economy prevented Moscow from pursuing key technologies that would have facilitated critical space achievements.

While theoretically Moscow prioritized its piloted Moon 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% of aerospace technologies are inherently dual use,[127] this "stove piping" also caused severe inefficiency in technological development. Even as three civilian piloted lunar programs were more important for politics and propaganda, the USSR simultaneously pursued three major piloted military space projects (the *Almaz* space station, *Zvezda* reconnaissance spacecraft, and *Spiral* space plane). 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 Glushko and military stakeholders stolidly opposed, ceding this field to America 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 13mm thick, necessitating non-integral tanks produced with expensive size-specific jigs and dies.

In a vicious cycle, inadequate industrial capacity and production quality,[128] inefficient electronics, insufficient propulsion,[129] and philosophical opposition to cosmonaut piloting of space vehicles[130] created an insurmountable weight penalty bottleneck, complicating the mission prohibitively.[131] The USSR lacked both funding and ground test beds large enough for the rocket, so its reliability could not be guaranteed in the way that that of its American competitor could.[132]

The N1's status as a "direct competitor to the Saturn V" prompted counter-productive 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 testing 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. 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."

Differences in reliability may have given Soviet decision-makers false hopes until virtually the very end of the Moon race. Officials viewed US "capabilities through prism of their own record," and assumed that Apollo would have its own failures and delays. They did not fully grasp that Apollo was then perhaps aerospace history's most-thoroughly-ground-tested program.

As the space race progressed, technological limitations and military myopia made the USSR fall further behind the US. 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."[133] 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."[134]

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." 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. Brezhnev avoided taking sides in this non-institutional factionalism, and thereby "squandered billions of roubles."

In America, by contrast, Eisenhower had overridden strident military opposition to make NASA an innovative civilian agency charged with developing cutting edge technology for the benefit of society as a whole.[135] Since the Apollo years, NASA has pushed technology to the private sector, because "transferring NASA technology and expertise to US industry…will help to increase the Nation's industrial competitiveness, create jobs, and improve the balance of trade."[136]

III.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." 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.[137] Despite Marxist commitment to material growth as proof of political legitimacy, Harford adds, the Soviet system "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. Korolev's name never appeared publicly during his years of leading contributions; instead, often-ignorant officials were publicly presented as the actual space leaders. Such was secrecy as late as 1978 that Apollo-Soyuz Soviet director Konstantin Bushuyev's funeral was moved from "the former Korolev Design Bureau, where he had spent most of his active working life" to a lower-profile institution to which he had little connection simply to maintain his cover. [138]

Moscow's early lead had appeared insurmountable in part because many failures—and negative practices—had been hidden.[139] "What was kept secret in the USSR," Harford observes, "would have been exposed as a national scandal in the [US]."[140] The Central Committee maintained a categorical prohibition on acknowledging space failures. Such is the extent of Soviet and post-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, uncertainties and disputes have long lingered.

Response to accidents was a case in point. In a 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." Instead, blameless parachute designer-administrator Fedor Tkachev was made the scapegoat.[141] 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."

Before a ground-based N1 booster explosion derailed Moscow's piloted moonshot 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 US *Gemini* missions generated unstoppable pressure to proceed: "We have a celebration in two months, and the Americans are going to launch again, but what about us? What have we done?" Secretary of Central Committee for defense and space Dmitri Ustinov implored.

Both political and program leaders "made decisions that were counterproductive and had fatal consequences for the Soviet space program." The culprit was political leaders' pressure that put chief designers' jobs on the line and "a technological culture that considered high risks acceptable in the cause of satisfying political imperatives." Even so, some accidents generated such negative repercussions that periods as long as two-plus years passed without cosmonauts in space.

By contrast, America's Apollo program was relatively open and accountable. The January 27, 1967 *Apollo 1* CSM capsule fire (in which three astronauts perished during a ground-based test) prompted a complete reckoning and reworking. 1,500 technicians spent ten weeks producing a 3,300 page, $4 million report.[142] Instructions for vacuuming and preserving couch debris alone consumed thirty pages.[143] 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.[144] The report triggered reorganization of contractor North

American's top management.[145] By 1968 Apollo was back on track. "We have reexamined every drawing, every circuit, and every component" of Apollo's four million parts,[146] 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."[147] *Apollo 8*'s daring Christmas 1968 circumlunar flight with astronauts Frank Borman, Bill Anders, and Jim Lovell showed the Moon race finish line within reach.

In America, 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."[148] Based on his single American visit, Soviet aircraft designer Andrei Tupolev, OKB-156's Chief Designer—for whom Korolev had toiled as a prisoner under Stalin—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."[149]

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."[150] This indeed happened on multiple occasions. To the extent that the USSR did test rockets, it overemphasized costly test flights over earlier, cheaper, ground-based troubleshooting.

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.[151] Only twenty-two defied analysis, and were replaced anyway.[152] This high-level systems management was a product of America's federal-corporate interface—one of its historic strengths. By *Apollo 17*'s conclusion in 1972, only one mission (13) had come close to failure, and no astronaut had been lost in space.

III.3. Suspicion Stymied Innovation

Suspicion stymied innovation. Fundamental distrust of free thinkers permeated Moscow's space program and hamstrung Soviet initiatives.[153] 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." Accordingly, it was "'better to fail according to the rules than to succeed by breaking them.'"[154] Moscow further undermined its top-down, over-militarized organization by distracting scientists with harsh personal concerns, work duplication, and infighting:[155] "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'."[156]

One source of Soviet failure was pitting design bureaus against one another in efforts to limit chief designers' power and increase production through competition. In practice, neither objective was achieved:[157] "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."[158] 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. 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 Chelomey against him. Chelomey hired Khrushchev's son Sergei (himself a competent missile guidance engineer),[159] and was rewarded when the Premier "displayed a marked favoritism toward Chelomey by the late 1950s."[160]

Despite having to start from scratch and design many things for first time, ambitious self-promoting empire builder Chelomey rapidly acquired a staggering proportion of Soviet space infrastructure and programs; all hastily stripped from him following his benefactor's ouster. Beyond the tremendous disruption caused by these vicissitudes, it proved a grave error to give Chelomey so many resources from 1961–64. His grandiose, often fanciful proposals would have gone nowhere, but for his unbeatable connections and patronage: regular personal access to Khrushchev, backing from Defense Industries Department Chief Ivan "The Terrible" Serbin, and support from the State Committee for Aviation Technolo-

gy's chairman and Minister of Aviation Industry Petr Dementyev and deputy minister Alesandr Kobzarev.

III.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 was the tremendous effort devoted to unfruitful programs, with many projects cancelled "before reaching flight status."[161] 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."

Combined with Khrushchev's lack of a coherent long-term vision for a civilian space program, ruinous rivalry starved Korolev's programs (and even temporarily halted the N1), forcing him to resort to diversionary space spectaculars to maintain leadership support. "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 after it should have had the government's exclusive focus." Design bureaus were overwhelmed with multiple simultaneous responsibilities; multiple Moon programs fell on same maxed-out entities. Overworked and overstretched financially, Korolev's bureau cut corners on ground-based and in-flight systems.

Moreover, even when the USSR attempted to unify its programmatic efforts, it struggled to do so for lack of unified NASA-like overseeing entity.[162] 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 key participants were unaware of their basic responsibilities. "Unbelievably at this late stage, some contractors, such as Chief Designer Ryazanskiy, were not only behind schedule, but did not even know that they had been assigned to make a parts delivery in the first place." Without a single overseeing entity such as NASA, there was "no coordinated plan for maintaining deadlines for dozens of subcontractors," and no enforcement mechanism.[163]

Soviet lunar efforts became unwieldy with countless weak links that squandered resources and complicated scheduling. In November 1966, Chelomey proposed a direct ascent approach; even though NASA had chosen LOR in 1962, Korolev and the Soviet leadership in 1964. Chelomey further promoted the con-

sideration of a large percentage of the lunar surface for exploration, extensive scientific research, and eventual permanent bases and "colonies."

The circumlunar program, considered essential to producing a space spectacular for the Great October Revolution's fiftieth anniversary in November 1967, squandered scarce resources.[164] 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.[165] A November 17, 1967 decree required Chelomey to design and develop the UR-700 booster (Proton) and LK-700 lunar spacecraft to land cosmonauts by 1972–73. Such a "chaotic design process…was uniquely symptomatic of the Soviet…program."[166]

The Soviet system, Harford adds, was riddled with "nasty personal rivalry which Congress and the press in the U.S. would not have tolerated—Valentin Glushko, up to then Korolev's main rocket engine developer, refused to design the N-1 engines, forcing Korolev to go to a primarily aircraft engine designer."[167] Glushko, Korolev's boss in the late 1940s, allegedly "had been instrumental in sending him to prison" a decade earlier.[168] Now Glushko dismissed Korolev's designs, declaring that "with a good engine, even a broomstick would fly."[169]

The struggle between chief designers at times became "a matter of life and death," Sergei Khrushchev relates.[170] 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."[171] The adoption of specific design bureaus' products hinged at least partially on "the level of cordiality between given chief designers and the Soviet leadership."[172]

Top-down leadership to the point of micromanagement slowed decision-making and engendered corruption.[173] 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."[174] 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."

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."[175] Korolev also redistributed programs under his purview to keep deputy chief designers from becoming too powerful and splitting off. Korolev's domination of certain areas, while providing needed focus, also created resource and launch facility bottlenecks that caused satellite launch delays.[176]

America was hardly *immune* to interagency bickering, but conflict was far less pervasive and usually stemmed from productive competition, not the desperate quests of threatened men. Indeed, Siddiqi judges, "the chronic waste and infighting that characterized the Soviet lunar program…was of a remarkable level." "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."[177]

N1 woes were a microcosm of Soviet mismanagement.[178] Money was a key bottleneck, and the region in which it was produced was economically depressed. Catastrophic mismanagement 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, lack of awareness and incentives. A given job or delivery might not happen without personal intervention, Mishin recalled: "The N1 was being made by 500 organizations in 26 departments. Of these, only nine fell within the jurisdiction of the Military-Industrial Commission. The rest had to be begged for. Resolutions from the Council of Ministers did not help at all: the tasks were just outside their competence and delivery schedules were not met…we failed to agree with minister after minister as they made their rounds, and often it ended in checkmate." Such disarray was simply unimaginable in Apollo, in which some of the era's ablest managers were recruited to lead its responsive organizational structure.

After eleven launches and billions of rubles expended from 1965–70, 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. Siddiqi terms it "an example of how politics, poor planning, a terrible launch vehicle, and bad luck could sabotage the best of intentions."

III.5. "One-Man NASA" Becomes Soviet Casualty

Lack of institutional effectiveness meant that too much depended on key individuals' *ad hoc* efforts. Yet the Soviet state neither trusted nor fully respected its most intelligent innovators. Many great Soviet scientists and military person-

nel—if they survived Stalin's purges—had been damaged. Their stifling, in turn, harmed Moscow's ability to achieve its technological objectives. In this, Korolev embodied Soviet society itself, 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—"[t]he institutional crises of the past few years, the fighting with the military, the discord with [other chief designers], the bureaucratic gridlock"—ruined Korolev's heart and aged him prematurely.[179]

On January 14, 1966, Korolev died from uncontrolled bleeding in surgery in part because of injuries he had received[180] when Stalin sent him to the Gulag in 1938 for "subversion in a new field of technology"[181] based on patently false charges, including that he had destroyed the *RP-318* rocket plane.[182] Your "missiles are probably for an attempt on our leader's life," Korolev's investigator had accused.[183] Given his declining health overall, Korolev might not have had long to live anyway.

Indeed, nearly all Soviet space program personnel "had earlier spent time in a gulag or knew of someone who had."[184] In 1937, the NKVD denounced Glushko as "enemy of the people." 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…."[185] 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."[186] Severely tortured and beaten, Korolev was sentenced to 10 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. Only in 1957 was Korolev—with Glushko—finally rehabilitated completely, when both became full academicians of the USSR Academy of Sciences. In 1950, during widespread Stalinist anti-Semitism, Chertok was dismissed from two posts, demoted, and transferred; Korolev gave him special protection to preserve his employment, but could not make him a high-profile deputy. Moreover, as late as 1964, cosmonaut candidates were nixed for having a Jewish mother, a purged but rehabilitated father, and a stepbrother and -sister who emigrated from Paris in 1910! Even after that, otherwise-qualified cosmonaut candidates were rejected for being Jewish.

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…."[187] 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…that a Soviet man be the first to fly in a rocket [and]…that it is Soviet rockets and Soviet spaceships that are the first to master the limitless space of the cosmos." 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." 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."[188] Korolev's long-groomed replacement, Mishin, was a brilliant engineer but no diplomat and a far inferior manager, with a difficult personality. He would prove far less effective at both leadership and lobbying the Kremlin bureaucracy, including key defense establishment patrons such as Ustinov. During his eight years in charge, Mishin made poor decisions, exhibited prohibitive problems with stress management and interpersonal relations, 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.

In 1974, Brezhnev consolidated all space programs, including OKB-1, under Glushko. Glushko promptly cancelled the N-1 program, fired and debarred Mishin, and zealously monopolized the writing of Soviet space history until his death in January 1989.[189] On May 22, 1974, in "the largest reorganization within the Soviet space industry since Korolev's death," Glushko suddenly replaced Mishin in charge of a new organization, Energiya. Glushko, now controlling all

space programs—even more than Korolev at his peak—banned Mishin from ever reentering space-related bureaus. "I think the main culprit was…Ustinov," Mishin reflected. "The main reason for winding up the program—at least from his standpoint—was that the Americans had beaten us to it…All these failures were affecting his career." Despite Mishin's entreaties, the remaining vehicles were never used for a piloted lunar mission, partly because Brezhnev and Ustinov saw insufficient political benefit and wanted to move past efforts that mirrored American achievements, and partly through extreme caution to avoid catastrophic failure following Apollo's success.

Finally enjoying his long-sought opportunity, as well as Brezhnev and Ustinov's support, as his first policy act on June 24, 1974, Glushko suspended all work on the N1-L3 lunar program and terminated all N1-associated programs. He cancelled the massive space expansion Mishin envisioned for the late 1970s, including the L3M advanced lunar landing missions, the giant MOK manned space station complex, and proposed anti-ballistic space-based weaponry. Engineers were shocked: the N1 program had consumed billions of rubles, and was finally approaching success. Not satisfied with cancelling the N1 program, Glushko tried to erase it from history. He ordered remaining rockets (two fully prepared and five others) and associated technical documents destroyed and excised from the design bureau's museum. Controlling all space programs and official books about them, and enjoying status as a high-level commissar and member of the CPSU Central Committee "capable of overwhelming anyone in the space establishment," Glushko developed a cult of personality, and engaged in further historical revisionism. Mishin lamented: "a colossal project to which we dedicated our best years…the work of a great many people…vanished overnight." In destroying his colleagues' efforts, Glushko was not seeking a return to practical limits. Instead, he proposed not only a new family of super heavy lift vehicles, but also—with Ustinov's support—a Zvezda program of large-scale permanent lunar bases. Only unanimous rejection because of the cost, complexity, and timeframe by a commission chaired by Keldysh; and Brezhnev's opposition to spending a billion rubles in this fashion; killed Glushko's attempt to pursue grandiose lunar plans in his own image.

Despite Mishin and Glushko's manifest 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." 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 America, 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."[190] 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."

IV. Moonshot Mismanagement: 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 moonshot were as unclear then as now.[191] 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.'" In relative terms, however—because of its weaker economy—the USSR almost certainly spent more than did the US. 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)[192] for America's Apollo landings.[193] 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. Moreover, while Apollo employed 417,000 at its peak, its less efficient Soviet counterpart employed 500,000.[194]

"Making a program that was competitive with America's," space journalist William Burrows concludes, "would be so expensive that it would help undermine the very society that it was supposed to reinforce."[195] By the early 1970s, Soviet economic stagnation reduced 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."[196] Pointing at the sky, a Moscow taxi driver encapsulated Soviet failure: "There's our meat."[197] Another resident made a similar food analogy: "In February 1971, a large portion of potatoes sold in Moscow had been too rotten to eat. Outraged by the dearth in quality in a staple Russian food item, an indignant grandmother declared to a crowd waiting to buy potatoes

at a central farm market: 'We have rockets, right?…We have Sputniks, right?…Why don't we just send these rotten potatoes into outer space too.' There was a small round of applause for her modest proposal. A *New York Times* correspondent added from Moscow that 'Although criticism [of the space program] is kept muted by the controlled Soviet media, it is well known here that many Russians are irritated by the costly space ventures when life here is still far from satisfactory." 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,[198] Khrushchev had "commented sadly that [his compatriots] would end up as world beggars. Then the imperialists wouldn't have to fight us."[199]

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 squander resources allocated. 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.[200] Serious work did not begin until 1965, and the timetable was compressed unrealistically. By contrast, even Eisenhower, and particularly Kennedy, publicly made the US rocket program a national priority.[201] Kennedy championed Apollo to his final day.[202] Upon Kennedy's death, Johnson built on his seminal space-program sponsorship to propel *Apollo* with even greater bureaucratic activism. Throughout, former NASA Flight Director Eugene Kranz recalls, Apollo enjoyed "a clear goal, a powerful mandate, and a unified team…."[203]

While "a span of only eight years separated the resounding victory of Gagarin and the crushing humiliation of Apollo," 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 *Buran* and *Energia* which were hugely expensive and are now mothballed [;] funding them surely damaged the already weak Soviet economy."[204] 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."[205] Burdened with a military-industrial complex that came to consume over 25% of GDP yet offered none of Apollo's civilian spin-offs,[206] the USSR's command economy grew unsustainable.[207] This was a central cause of Soviet failure and ultimate collapse, Sagdeev 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 US 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."[208]

The space race was—in many respects—a cosmic Cold War microcosm: "a technological race for military advantage" and even "the moral equivalent of war." As Rubel later revealed, "I personally believed that such a program could be a partial surrogate for the arms race."[209] By substituting technological shadowboxing for nuclear Armageddon, the superpowers were able to establish their relative positions without destroying all their accomplishments. Ultimately, America proved to have the advantage. "The American system worked pretty well, particularly in contrast to the Soviet system," Gavin concludes, "While the US'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."[210]

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 US military and lunar landing programs, and remains one of the most successful mechanisms for high technology development. As future historians seek to understand how humans first overcame their earthly bounds in the twentieth century, how twelve came to walk on the Moon over a three-year span, and why all of them ventured from the United States, they will rediscover these critical dynamics encapsulating the "fluid front" of what was then known as the US-Soviet Cold War.

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[3] Stephen Johnson, *The Secret of Apollo: Systems Management in American and European Space Programs* (Baltimore, MD: Johns Hopkins University Press, 2002), 17. See also Thomas P. Hughes, *Rescuing Prometheus: Four Monumental Projects That Changed the Modern World* (New York: Pantheon Books, 1998); Stephen Johnson, *The United States Air Force and the Culture of Innovation, 1945–1965* (Washington, DC: Air Force History and Museums Program, 2002), 16, 209, 225–226.

[4] Company founders Simon Ramo and Dean Wooldridge successfully applied the "systems approach" to developing (at Hughes) the Falcon missile, which began in 1946, yielded a first test in 1949, and entered the US Air Force (USAF) in 1956. Stephen Johnson, *The United States Air Force and the Culture of Innovation, 1945–1965* (Washington, DC: Air Force History and Museums Program, 2002), 224. The AT&T reference is from Joseph Gavin, Jr., interview, December 11, 1998.

[5] Harvey Sapolsky, *The Polaris System Development* (Cambridge, MA: Harvard University Press, 1972). Other seminal examples include Convair's *Atlas* intercontinental ballistic missile (ICBM) and Martin's *Titan* ICBM as well as Douglas's *Thor* intermediate-range ballistic missile (IRBM) for the USAF. All *Mercury* orbital flights flew on *Atlas* and *Gemini* flights flew on *Titan II*. 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 US General Bernard Schriever. In 1965, with US Defense Secretary Robert McNamara's support, technology management and organization processes were embraced and being implemented throughout the US defense aerospace and computing industries. By this time, most major US military and civilian aerospace projects utilized aspects of systems management and related best practices. Harvey Sapolsky, *The Polaris System Development* (Cambridge, MA: Harvard University Press, 1972); Stephen Johnson, *The United States Air Force and the Culture of Innovation, 1945–1965* (Washington, DC: Air Force History and Museums Program, 2002), 16, 22, 211, 231.

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

[7] Stephen Johnson, *The Secret of Apollo: Systems Management in American and European Space Programs* (Baltimore, MD: Johns Hopkins University Press, 2002), 221.

[8] Joseph Gavin, Jr., interview, August 6, 2005.

[9] Roger Bilstein, *Stages to Saturn: A Technological History of the Apollo/Saturn Launch Vehicles* (Washington, DC: NASA History Office, 1996), 286–288. See also Willis Hawkins, "The Aerospace Learning Process," American Institute of Aeronautics and Astronautics, International Annual Meeting and Technical Display (AIAA-1982-1291), Baltimore, MD, May 25–27, 1982, 1–6; and Lionel Galway, "Quantitative Risk Analysis for Project Management," RAND Working Paper WR-112-RC, February 2004.

[10] Roger Bilstein, *Stages to Saturn: A Technological History of the Apollo/Saturn Launch Vehicles* (Washington, DC: NASA History Office, 1996), 287.

[11] Ibid., 3.

[12] Joseph Gavin, Jr., interview, August 7, 2005; Davis Dyer, *TRW: Pioneering Technology and Innovation Since 1900* (Cambridge, MA: Harvard Business Review Press, 1998).

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

[14] Joseph Gavin, Jr., interview, August 6, 2005.

[15] For quotations and other evidence supporting the arguments articulated in the first part of this section, see William Burrows, *This New Ocean: The Story of the First Space Age* (New York: Random House, 1998), 353–357; Aaron 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; James Clay Moltz, *The Politics of Space Security: Strategic Restraint and the Pursuit of National Interests* (Stanford, CA: Stanford University Press, 2008), 90–123; Bruce Parrott, *Politics and Technology in the Soviet Union* (Cambridge, MA: MIT Press, 1985), 303; Asif Siddiqi, *Challenge to Apollo: The Soviet Union and the Space Race, 1945–1974* (Washington, DC: NASA, 2000), https://history.nasa.gov/SP-4408pt1.pdf, 2, 255; John Logsdon, *John F. Kennedy and the Race to the Moon* (New York: Palgrave Macmillan, 2010), 85, 100, 104–118; Robert Seamans, Jr., *Project Apollo: The Tough Decisions*, Monographs in Aerospace History No. 37, SP-2005-4537 (Washington, DC: NASA, 2005), https://ocw.mit.edu/courses/science-technology-and-society/sts-471j-engineering-apollo-the-moon-project-as-a-complex-system-spring-2007/readings/3_5_monograph37.pdf; excerpt from 7-8, and quotations from 13, 25, of James Webb and Robert McNamara, "Recommendations for Our National Space Program: Changes, Policies, Goals," report to Vice President Lyndon Johnson, May 8, 1961, https://www.jfklibrary.org/asset-viewer/archives/JFKNSF/307/JFKNSF-307-004.

[16] Stephen Johnson, *The Secret of Apollo: Systems Management in American and European Space Programs* (Baltimore, MD: Johns Hopkins University Press, 2002), 4.

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

[18] Stephen Johnson, *The Secret of Apollo: Systems Management in American and European Space Programs* (Baltimore, MD: Johns Hopkins University Press, 2002), 113.

[19] Sergei Khrushchev, *Nikita Khrushchev and the Creation of a Superpower* (University Park, PA: Pennsylvania State University, 2000), 277–278. The 1975 Apollo-Soyuz Test Project revealed some of Apollo's systems management techniques, but these could not simply be grafted onto Moscow's space program, and therefore failed to revive it.

[20] Asif Siddiqi, *Challenge to Apollo: The Soviet Union and the Space Race, 1945–1974* (Washington, DC: NASA, 2000), 168; Walter McDougall, …*The Heavens and the Earth: A Political History of the Space Age* (New York: Basic Books, 1985), 17.

[21] Roger Bilstein, *Stages to Saturn: A Technological History of the Apollo/Saturn Launch Vehicles* (Washington, DC: NASA History Office, 1996), 17; William Breuer, *Race to the Moon: America's Duel with the Soviets* (Westport: Praeger Publications, 1993), 149; Sergei Khrushchev, *Nikita Khrushchev and the Creation of a Superpower* (University Park, PA: Pennsylvania State University, 2000), 440; Asif Siddiqi, *Challenge to Apollo: The Soviet Union and the Space Race, 1945–1974* (Washington, DC: NASA, 2000), 175. In hindsight, Soviet and American interest in satellites proved mutually reinforcing. See "Fellow Travelers," in Asif Siddiqi, *The Red Rockets' Glare: Spaceflight and the Soviet Imagination*, 1857–1957 (Cambridge, UK: Cambridge University Press, 2010), 319–324.

[22] 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; op. cit. Zhihua Shen and Yafeng Xia, *Mao and the Sino-Soviet Partnership, 1945–1959: A New History* (New York: Lexington Books, 2015), 264.

[23] T. A. Heppenheimer, *Countdown: A History of Space Flight* (New York: John Wiley & Sons, 1977), 128. For background, see "Launching Sputnik," Asif Siddiqi, *The Red Rockets' Glare: Spaceflight and the Soviet Imagination*, 1857–1957 (Cambridge, UK: Cambridge University Press, 2010), 332–362.

[24] von Braun's US Army-affiliated research team in Huntsville, Alabama produced America's first satellite launch.

[25] Twelve American attempts would fail before *Ranger 7*'s July 28, 1964 lunar contact. 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] Walter McDougall, …*The Heavens and the Earth: A Political History of the Space Age* (New York: Basic Books, 1985), 241.

[28] Ibid., 9.

[29] The remainder of this section draws on the following sources: Asif Siddiqi, *The Soviet Space Race with Apollo* (Miami: University of Florida Press, 2003), 694; Asif Siddiqi, *Challenge to Apollo: The Soviet Union and the Space Race, 1945–1974* (Washington, DC: NASA, 2000), 407, 410, 497, 662–663, 687, 665, 675, 667, 668, 641–642, 668, 687–688, 932, 693–694, xii, 667. After delays, even had it landed, scooped, and returned, *Luna 15* would have reached Earth two-plus hours after *Apollo 11*. The last lap of the moon race was over before it began. Ibid., 698. Nor was this a momentary lapse; moon scoopers failed again in September and October 1969 and February 1970. Ibid, 737–738. On September 24, 1970, *Luna 16* finally returned 105g of soil, the first such automatic recovery from a planetary body. But this was a late, pale shadow of *Apollo 11* in capability. Ibid., 739–740. Other sources: Boris Chertok, *Rockets and People: Creating a Rocket Industry*, Vol. 1 (Washington, DC: NASA, 2005), 27. Translated from the original Russian (published in Moscow as *Rakety i lyudi*, 1994–99) and substantially revised, this four-volume series is edited by noted space historian Asif Siddiqi.

[30] The USSR fell behind the United States in capacity to develop and produce all major aerospace products, with the possible exception of heavy-lift boosters. Soviet prowess in throw-weight, however, stemmed from the need to launch heavier, less efficient warheads.

[31] John Logsdon, interview, December 1998; James Oberg, "Cosmonauts Who Weren't There," in Dominic Phelan, ed., *Cold War Space Sleuths: The Untold Secrets of the Soviet Space Program* (Chichester, UK: Springer-Praxis, 2013), 87–110.

[32] Asif Siddiqi, *Challenge to Apollo: The Soviet Union and the Space Race, 1945–1974* (Washington, DC: NASA, 2000), 237, 265, 354.

[33] These programs included the *Raketoplan* Space Plane and the *Buran* space shuttle. Asif Siddiqi, *The Soviet Space Race with Apollo* (Miami: University of Florida Press, 2003), 835; Asif Siddiqi, *Sputnik and the Soviet Space Challenge* (Miami: University of Florida Press, 2003), 475; Asif Siddiqi, *Challenge to Apollo: The Soviet Union and the Space Race, 1945–1974* (Washington, DC: NASA, 2000), 306; Boris Chertok, *Rockets and People: Hot Days of the Cold War*, Vol. 3 (Washington, DC: NASA, 2009), 246.

[34] Sergei Khrushchev, *Nikita Khrushchev and the Creation of a Superpower* (University Park, PA: Pennsylvania State University, 2000), 354; Asif Siddiqi, *Challenge to Apollo: The Soviet Union and the Space Race, 1945–1974* (Washington, DC: NASA, 2000), 857, 829, 754, 804, 806, 834. American examples include Kennedy's cooperative overtures to Khrushchev. Military secrecy concerns precluded Khrushchev's acceptance, forcing Kennedy to maintain competition since it was the only way to assure his key objectives of preventing Soviet militarization and exclusionary domination of space while ensuring that American space achievements, prestige, and appeal to societies choosing which system to follow were second to none. John Logsdon, *John F. Kennedy and the Race to the Moon* (New York: Palgrave Macmillan, 2010), 228–230. Once America won the moon race, public support for expensive competition plummeted, and Nixon reprioritized resources Earth-

ward. John Logsdon, *After Apollo? Richard Nixon and the American Space Program* (New York: Palgrave Macmillan, 2015). Quotation at end of section is from Asif Siddiqi, *Challenge to Apollo: The Soviet Union and the Space Race, 1945–1974* (Washington, DC: NASA, 2000), 282.

[35] Aaron Friedberg, *In the Shadow of the Garrison State: America's Anti-Statism and its Cold War Grand Strategy* (Princeton, NJ: Princeton University Press, 2000), 318.

[36] James Harford, interview, December 1998.

[37] Gene Farmer, *First on the Moon: A Voyage with Neil Armstrong, Michael Collins and Edwin E. Aldrin, Jr.* (Boston: Little, Brown & Company, 1970), 51.

[38] Ibid., 62–63.

[39] William Burrows, *This New Ocean: The Story of the First Space Age* (New York: Random House, 1998), 429.

[40] Asif Siddiqi, *The Soviet Space Race with Apollo* (Miami: University of Florida Press, 2003), 699.

[41] Joseph Gavin, Jr., quoting conversation with NASA administrator George Low, interview, August 7, 2005. See also Bruce Parrott, *Politics and Technology in the Soviet Union* (Cambridge, MA: MIT Press, 1985), 273.

[42] William Burrows, *This New Ocean: The Story of the First Space Age* (New York: Random House, 1998), 450.

[43] Asif Siddiqi, *Sputnik and the Soviet Space Challenge* (Miami: University of Florida Press, 2003), 413. For an example of Western scholarship that accepted the Soviet denial, see Nicholas Mateesco Matte, *Space Policy and Programmes Today and Tomorrow: The Vanishing Dipole* (Montreal: Institute and Center of Air and Space Law, McGill University, 1980). For unmasking see Bart Hendrickx, "Russian-Language Sleuthing," in Dominic Phelan, ed., *Cold War Space Sleuths: The Untold Secrets of the Soviet Space Program* (Chichester, UK: Springer-Praxis, 2013), especially 194–201.

[44] Asif Siddiqi, *Challenge to Apollo: The Soviet Union and the Space Race, 1945–1974* (Washington, DC: NASA, 2000), 413; Asif Siddiqi, *The Soviet Space Race with Apollo* (Miami: University of Florida Press, 2003), 703.

[45] Sergei Khrushchev, *Nikita Khrushchev and the Creation of a Superpower* (University Park, PA: Pennsylvania State University, 2000), 358.

[46] Ibid., 360.

[47] Asif Siddiqi, *The Soviet Space Race with Apollo* (Miami: University of Florida Press, 2003), 643; Asif Siddiqi, *Challenge to Apollo: The Soviet Union and the Space Race, 1945–1974* (Washington, DC: NASA, 2000), 643–644; Boris Chertok, *Rockets and People: Hot Days of the Cold War*, Vol. 3 (Washington, DC: NASA, 2009), 523.

[48] Asif Siddiqi, *The Soviet Space Race with Apollo* (Miami: University of Florida Press, 2003), 562.

[49] Document 115-46 was entitled, "On the Progress of the Work on the Development of the UR-500K-L1."

[50] Unless otherwise indicated, data in this and the next paragraph are derived from Asif Siddiqi, *The Soviet Space Race with Apollo* (Miami: University of Florida Press, 2003), 554–555, 676.

[51] G. I. Petrov, *Conquest of Outer Space in the USSR 1967–70: Official Announcements by TASS and Material Published in The National Press from October 1967 to 1970* (Moscow: Nauka Publishing, 1970), 44.

[52] Asif Siddiqi, *Challenge to Apollo: The Soviet Union and the Space Race, 1945–1974* (Washington, DC: NASA, 2000), 676, 686. For details concerning the resource commitments and prototypes, see Asif Siddiqi, *The Soviet Space Race with Apollo* (Miami: University of Florida Press, 2003), 732; Asif Siddiqi, "People and Archives," in in Dominic Phelan, ed., *Cold War Space Sleuths: The Untold Secrets of the Soviet Space Program* (Chichester, UK: Springer-Praxis, 2013), 219–256.

[53] Asif Siddiqi, *Challenge to Apollo: The Soviet Union and the Space Race, 1945–1974* (Washington, DC: NASA, 2000), 686, 410.

[54] Bruce Parrott, *Politics and Technology in the Soviet Union* (Cambridge, MA: MIT Press, 1985), 231.

[55] Jerrold Schecter and Vyacheslav Luchkov, eds., *Khrushchev Remembers: The Glasnost Tapes* (Boston: Little Brown & Company, 1990), 188–189.

[56] Asif Siddiqi, *Challenge to Apollo: The Soviet Union and the Space Race, 1945–1974* (Washington, DC: NASA, 2000), 697; Sergei Khrushchev, *Nikita Khrushchev and the Creation of a Superpower* (University Park, PA: Pennsylvania State University, 2000), 750.

[57] Asif Siddiqi, *Challenge to Apollo: The Soviet Union and the Space Race, 1945–1974* (Washington, DC: NASA, 2000), 745, 677–678, 750, 764; Stephen Johnson, *The Secret of Apollo: Systems Management in American and European Space Programs* (Baltimore, MD: Johns Hopkins University Press, 2002), 109.

[58] William Burrows, *This New Ocean: The Story of the First Space Age* (New York: Random House, 1998), 444.

[59] Asif Siddiqi, *Challenge to Apollo: The Soviet Union and the Space Race, 1945–1974* (Washington, DC: NASA, 2000), 712; Asif Siddiqi, *The Soviet Space Race with Apollo* (Miami: University of Florida Press, 2003), 713.

[60] This and the following paragraph draw on William Burrows, *This New Ocean: The Story of the First Space Age* (New York: Random House, 1998), 509; Asif Siddiqi, *Challenge to Apollo: The Soviet Union and the Space Race, 1945–1974* (Washington, DC: NASA, 2000), 774–75, 772, 781–82, 714, 803, 770, 811, 813–14, 839.

[61] William Burrows, *This New Ocean: The Story of the First Space Age* (New York: Random House, 1998), 509.

[62] Asif Siddiqi, *The Soviet Space Race with Apollo* (Miami: University of Florida Press, 2003), 714, 729; Asif Siddiqi, *Challenge to Apollo: The Soviet Union and the Space Race, 1945–1974* (Washington, DC: NASA, 2000), 699, 714, 729, 736–737.

[63] William Burrows, *This New Ocean: The Story of the First Space Age* (New York: Random House, 1998), 516.

[64] Ibid., 210. The next two paragraphs draw on Asif Siddiqi, *Challenge to Apollo: The Soviet Union and the Space Race, 1945–1974* (Washington, DC: NASA, 2000), 835–837, 841.

[65] Sergei Khrushchev, *Nikita Khrushchev and the Creation of a Superpower* (University Park, PA: Pennsylvania State University, 2000), 440.

[66] Lester Thurow, *Head to Head: The Coming Economic Battle Among Japan, Europe, and America* (New York: Warner Books, 1993), 11.

[67] Asif Siddiqi, *Sputnik and the Soviet Space Challenge* (Miami: University of Florida Press, 2003), 147.

[68] Walter McDougall, …*The Heavens and the Earth: A Political History of the Space Age* (New York: Basic Books, 1985), 205.

[69] Aaron Friedberg, *In the Shadow of the Garrison State: America's Anti-Statism and its Cold War Grand Strategy* (Princeton, NJ: Princeton University Press, 2000), 300.

[70] Courtney Brooks, et al., *Chariots for Apollo: A History of Manned Lunar Spacecraft* (Washington, DC: National Aeronautics and Space Administration, 1979), 119.

[71] Joseph Gavin, Jr., "The Apollo Lunar Module (LM): A Retrospective," in *History of Rocketry and Astronautics* (Proceedings of the Thirty-Sixth History Symposium of the International Academy of Astronautics – Houston, Texas, USA, 2002), Michael L. Ciancone, editor, AAS History Series, Volume 33, IAA History Symposia, Volume 22 (San Diego, California: Published for the American Astronautical Society by Univelt, Inc., 2010), 371–382 (paper IAC-02-IAA.2.3.08 presented at the 36th History Symposium of the International Academy of Astronautics as part of the 53rd International Astronautical Federation Congress, Houston, Texas, USA, October 10–19, 2002), [Hereafter: IAC, 2002], 2.

[72] Aaron Friedberg, *In the Shadow of the Garrison State: America's Anti-Statism and its Cold War Grand Strategy* (Princeton, NJ: Princeton University Press, 2000), 272–277.

[73] Ibid., 306.

[74] T. A. Heppenheimer, *Countdown: A History of Space Flight* (New York: John Wiley & Sons, 1977), 29; Asif Siddiqi, *Challenge to Apollo: The Soviet Union and the Space Race, 1945–1974* (Washington, DC: NASA, 2000), 86, 107.

[75] Walter McDougall, …*The Heavens and the Earth: A Political History of the Space Age* (New York: Basic Books, 1985), 20.

[76] There was intense competition for funds between the powerful Strategic Air Command (SAC) and missile development groups. Until Sputnik's launch, Schriever, leader of the Ballistic Missile Organization, fought an "uphill battle" to compete with SAC for funding. Joseph Gavin, Jr., many discussions over many years; Gene Farmer, *First on the Moon: A Voyage with Neil Armstrong, Michael Collins and Edwin E. Aldrin, Jr.* (Boston: Little, Brown & Company, 1970), 33.

[77] Stephen Johnson, *The Secret of Apollo: Systems Management in American and European Space Programs* (Baltimore, MD: Johns Hopkins University Press), 2002, 38–39.

[78] John Logsdon, interview, December 1998.

[79] For the views of Khrushchev and other elites on this subject, see Bruce Parrott, *Politics and Technology in the Soviet Union* (Cambridge, MA: MIT Press, 1985), 135–138.

[80] William Burrows, *This New Ocean: The Story of the First Space Age* (New York: Random House, 1998), 210.

[81] William Taubman, *Khrushchev: The Man and His Era* (New York: W.W. Norton & Company, 2003), 243.

[82] Asif Siddiqi, *Sputnik and the Soviet Space Challenge* (Miami: University of Florida Press, 2003), 119.

[83] Sergei Khrushchev, *Nikita Khrushchev and the Creation of a Superpower* (University Park, PA: Pennsylvania State University, 2000), 217.

[84] Ibid., 223.

[85] For evidence that Sputnik's launch was the critical juncture in dramatizing the Soviet ICBM threat, see Asif Siddiqi, *Sputnik and the Soviet Space Challenge* (Miami: University of Florida Press, 2003), 161; William Burrows, *This New Ocean: The Story of the First Space Age* (New York: Random House, 1998), 180.

[86] Jerrold Schecter and Vyacheslav Luchkov, eds., *Khrushchev Remembers: The Glasnost Tapes* (Boston: Little Brown & Company, 1990), 187.

[87] William Taubman, *Khrushchev: The Man and His Era* (New York: W.W. Norton & Company, 2003), 378.

[88] Ibid., 378.

[89] William Taubman, foreword in Sergei Khrushchev, *Nikita Khrushchev and the Creation of a Superpower* (University Park, PA: Pennsylvania State University, 2000), ix.

[90] Vladislav Zubok and Constantine Pleshakov, *Inside the Kremlin's Cold War from Stalin to Khrushchev* (Cambridge, MA: Harvard University Press, 1996), 192.

[91] William Burrows, *This New Ocean: The Story of the First Space Age* (New York: Random House, 1998), 210.

[92] Asif Siddiqi, *Sputnik and the Soviet Space Challenge* (Miami: University of Florida Press, 2003), 292; Boris Chertok, *Rockets and People: Hot Days of the Cold War*, Vol. 3 (Washington, DC: NASA, 2009), 237; Asif Siddiqi, *Challenge to Apollo: The Soviet Union and the Space Race, 1945–1974* (Washington, DC: NASA, 2000), 385.

[93] See, e.g., T. A. Heppenheimer, *Countdown: A History of Space Flight* (New York: John Wiley & Sons, 1977), 130; Asif Siddiqi, *Sputnik and the Soviet Space Challenge* (Miami: University of Florida Press, 2003), 354.

[94] William Burrows, *This New Ocean: The Story of the First Space Age* (New York: Random House, 1998), 275; Asif Siddiqi, *The Soviet Space Race with Apollo* (Miami: University of Florida Press, 2003), 623.

[95] Asif Siddiqi, *Challenge to Apollo: The Soviet Union and the Space Race, 1945–1974* (Washington, DC: NASA, 2000), 256; William Burrows, *This New Ocean: The Story of the First Space Age* (New York: Random House, 1998), 309; T. A. Heppenheimer, *Countdown: A History of Space Flight* (New York: John Wiley & Sons, 1977), 199.

[96] Asif Siddiqi, *Challenge to Apollo: The Soviet Union and the Space Race, 1945–1974* (Washington, DC: NASA, 2000), 258.

[97] John Logsdon, interview, December 1998.

[98] James Harford, interview, December 1998.

[99] 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), 156; Susan Eisenhower, *Breaking Free: A Memoir of Love and Revolution* (New York: Farrar Straus & Giroux, 1995).

[100] Kennedy's claim represented a gross overestimation of Soviet assets. Washington led significantly in missile numbers, accuracy, and nuclear weapons—a tremendous disparity during the Cuban missile crisis, although subsequently Moscow worked to reduce the gap. Roald Sagdeev, interview, December 1998.

[101] "To the Moon: The American Space Program in the 1960s," May 27, 2008, LBJ Presidential Library, http://www.lbjlibrary.org/press/to-the-moon. Shortly before he became president, Kennedy stated his preference to have Johnson head the National Aeronautics and Space

Council (NASC). Having the vice president chair the NASC required an amendment to the 1958 Space Act. Kennedy had no right or ability to appoint anyone to such a position until he became president on January 20, 1961.

[102] Roger Bilstein, *Stages to Saturn: A Technological History of the Apollo/Saturn Launch Vehicles* (Washington, DC: NASA History Office, 1996), 55.

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

[104] James Kaufman, *Selling Outer Space: Kennedy, the Media, and Funding for Project Apollo, 1961–1973* (Tuscaloosa: University of Alabama Press, 1994), 102; Howard E. McCurdy, *Space and the American Imagination* (Baltimore, MD: Johns Hopkins University Press, 2011), 87.

[105] James Kaufman, *Selling Outer Space: Kennedy, the Media, and Funding for Project Apollo, 1961–1973* (Tuscaloosa: University of Alabama Press, 1994), 250. NASA Manned Spacecraft Center head Robert Gilruth echoed von Braun's assertion. Author's multiple discussions with Joseph Gavin, Jr., over multiple years. John Rubel, recorded interview by William Moss, "John H. Rubel Oral History Interview – JFK#2, 09/09/70," John F. Kennedy Library Oral History Program, 63, https://www.jfklibrary.org/sites/default/files/archives/JFKOH/Rubel,%20John%20H/JFKOH-JOR-01/JFKOH-JOR-01-TR.pdf.

[106] Gene Farmer, *First on the Moon: A Voyage with Neil Armstrong, Michael Collins and Edwin E. Aldrin, Jr.* (Boston: Little, Brown & Company, 1970), 36.

[107] James Kaufman, *Selling Outer Space: Kennedy, the Media, and Funding for Project Apollo, 1961–1973* (Tuscaloosa: University of Alabama Press, 1994), 2; James Harford, interview, December 1998.

[108] Asif Siddiqi, *Challenge to Apollo: The Soviet Union and the Space Race, 1945–1974* (Washington, DC: NASA, 2000), 282, 203, 856.

[109] IAC, 2002, 5; Roger Bilstein, *Stages to Saturn: A Technological History of the Apollo/Saturn Launch Vehicles* (Washington, DC: NASA History Office, 1996), 68.

[110] IAC, 2002, 5; Roger Bilstein, *Stages to Saturn: A Technological History of the Apollo/Saturn Launch Vehicles* (Washington, DC: NASA History Office, 1996), 60.

[111] Unless otherwise indicated, data in this and the following two paragraphs are derived from Asif Siddiqi, *Sputnik and the Soviet Space Challenge* (Miami: University of Florida Press, 2003), 397–407; Asif Siddiqi, *Challenge to Apollo: The Soviet Union and the Space Race, 1945–1974* (Washington, DC: NASA, 2000), 397–398; and "Space Race," Wilson Center Digital Archive, http://digitalarchive.wilsoncenter.org/collection/383/space-race.

[112] Decree 655-268 was entitled, "On Work on Research on the Moon and Outer Space."

[113] "On Work for Lunar and Space Research," recommitted Moscow to "land a man on the moon and return him to Earth by 1967–68." Boris Chertok, *Rockets and People: Hot Days of the Cold War*, Vol. 3 (Washington, DC: NASA, 2009), 397. See also William Burrows, *This New Ocean: The Story of the First Space Age* (New York: Random House, 1998), 400.

[114] Asif Siddiqi, *Sputnik and the Soviet Space Challenge* (Miami: University of Florida Press, 2003), 497.

[115] Sergei Khrushchev, *Nikita Khrushchev and the Creation of a Superpower* (University Park, PA: Pennsylvania State University, 2000), 450.

[116] Ibid., 476.

[117] Asif Siddiqi, *Challenge to Apollo: The Soviet Union and the Space Race, 1945–1974* (Washington, DC: NASA, 2000), 387, 410; Boris Chertok, *Rockets and People: Hot Days of the Cold War*, Vol. 3 (Washington, DC: NASA, 2009), 568.

[118] Author's multiple discussions with Joseph Gavin, Jr., over multiple years.

[119] James Harford, interview, December 1998; Asif Siddiqi, *Challenge to Apollo: The Soviet Union and the Space Race, 1945–1974* (Washington, DC: NASA, 2000), 552.

[120] Author's multiple discussions with Joseph Gavin, Jr., over multiple years.

[121] Sergei Khrushchev, *Nikita Khrushchev and the Creation of a Superpower* (University Park, PA: Pennsylvania State University, 2000), 263. See also "The Cold War and the Creation of the Soviet ICBM," in Asif Siddiqi, *The Red Rockets' Glare: Spaceflight and the Soviet Imagination*, 1857–1957 (Cambridge, UK: Cambridge University Press, 2010), 241–289.

[122] Robert Reeves, *The Superpower Space Race: An Explosive Rivalry Throughout the Solar System* (New York: Plenum Press, 1994), 5; James Webb and Robert McNamara, "Recommendations for Our National Space Program: Changes, Policies, Goals," report to Vice President Lyndon Johnson, May 8, 1961, 18.

[123] Emphasis added. Jerrold Schecter and Vyacheslav Luchkov, eds., *Khrushchev Remembers: The Glasnost Tapes* (Boston: Little Brown & Company, 1990), 93–94. Mishin quote (next paragraph): Asif Siddiqi, *Challenge to Apollo: The Soviet Union and the Space Race, 1945–1974* (Washington, DC: NASA, 2000), 853.

[124] Robert Reeves, *The Superpower Space race: An Explosive Rivalry Throughout the Solar System* (New York: Plenum Press, 1994), 5.

[125] James Harford, *Korolev: How One Man Masterminded the Soviet Drive to Beat America to the Moon* (New York: John Wiley & Sons, 1997), 264. Sources for the remainder of this paragraph and the next paragraph: Asif Siddiqi, *Challenge to Apollo: The Soviet Union and the Space Race, 1945–1974* (Washington, DC: NASA, 2000), 477, 496, 476, 488, 444, 668. As late as 1974, a leading Western analysis found that "Soyuz systems, more on the level of those used in U.S. Mercury and Gemini spacecraft, are not comparable in complexity to the systems of the Rockwell International Apollo command/service module. In some areas, Soyuz capability is below that available in the Mercury spacecraft, flown by American astronauts almost thirteen years ago." Craig Covault, "Soyuz Gives Cosmonauts Little Control," *Aviation Week & Space Technology*, January 21, 1974, 38. It judged that "Basic Soyuz guidance and navigation capability is far too simple for the spacecraft to have been considered for a lunar loop-around mission." Craig Covault, "Fuel, Sensors Limit Soyuz Maneuvering," *Aviation Week & Space Technology*, January 28, 1974, 40. Craig Covault, email interview, January 16, 2018. See also Michael Gruntman, *Intercept 1961: The Birth of Soviet Missile Defense* (Reston, VA: American Institute of Aeronautics and Astronautics, 2015), 235; Michael Gruntman, "Socks for the First Cosmonaut of Planet Earth," *Quest: The History of Spaceflight Quarterly* 18.1 (2011): 44–48, http://astronauticsnow.com/astrosocks/gruntman_quest_v_18_n_1_2011.pdf; Boris Chertok, *Rockets and People: Creating a Rocket Industry*, Vol. 1 (Washington, DC: NASA, 2005), 580, 599.

[126] Joseph Gavin, Jr., interview, August 6, 2005; Roger Bilstein, *Stages to Saturn: A Technological History of the Apollo/Saturn Launch Vehicles* (Washington, DC: NASA History Office, 1996), 233.

[127] William Martel and Toshi Yoshihara, "Averting a Sino-U.S. Space Race," *The Washington Quarterly* 26.4 (Autumn 2003): 26. Source for rest of this paragraph, and next paragraph: Asif Siddiqi, *Challenge to Apollo: The Soviet Union and the Space Race, 1945–1974* (Washington, DC: NASA, 2000), 607, 598, 213, 318, 388, 486.

[128] Asif Siddiqi, *Sputnik and the Soviet Space Challenge* (Miami: University of Florida Press, 2003), 486; Sergei Khrushchev, *Nikita Khrushchev and the Creation of a Superpower* (University Park, PA: Pennsylvania State University, 2000), 479.

[129] Asif Siddiqi, *Sputnik and the Soviet Space Challenge* (Miami: University of Florida Press, 2003), 318, 434, 486, 488. In contrast to more elegant, lighter designs driven by computational capability that allowed the United States to design electronics and other hardware to the minimum, plus a factor of safety, Soviet electronics were overdesigned, incurring weight penalties that necessitated large rockets. Notably, during the Brezhnev era, the Ministry of General Machine Building (MOM) consolidated control of all space-missile activities, except radio-electronic technology, which fell ever-further behind America. Asif Siddiqi, *Challenge to Apollo: The Soviet Union and the Space Race, 1945–1974* (Washington, DC: NASA, 2000), 429.

[130] Asif Siddiqi, *Sputnik and the Soviet Space Challenge* (Miami: University of Florida Press, 2003), 197–198.

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

[132] Sergei Khrushchev, *Nikita Khrushchev and the Creation of a Superpower* (University Park, PA: Pennsylvania State University, 2000), 688. See also Asif Siddiqi, *Sputnik and the Soviet Space Challenge* (Miami: University of Florida Press, 2003), 392. Sources for the next two paragraphs: Asif Siddiqi, *Challenge to Apollo: The Soviet Union and the Space Race, 1945–1974* (Washington, DC: NASA, 2000), 392–393, 483, 857, 643, 651; Asif Siddiqi, *Sputnik and the Soviet Space Challenge* (Miami: University of Florida Press, 2003), 392.

[133] James Harford, interview, December 1998.

[134] 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. Sources for remainder of paragraph: James Harford, interview, December 1998; Asif Siddiqi, *Challenge to Apollo: The Soviet Union and the Space Race, 1945–1974* (Washington, DC: NASA, 2000), 856, 787; Boris Chertok, *Rockets and People: Creating a Rocket Industry*, Vol. 1 (Washington, DC: NASA, 2005), 155, 146.

[135] *Space Benefits: The Secondary Application of Aerospace Technology in Other Sectors of the Economy* (Denver Research Institute, University of Denver, September 1, 1976), https://ntrs.nasa.gov/search.jsp?R=19770016066; Aaron Friedberg, *In the Shadow of the Garrison State: America's Anti-Statism and its Cold War Grand Strategy* (Princeton, NJ: Princeton University Press, 2000), 296. By using Apollo structural analysis, for instance, America's John Deere Corporation has saved tons of cast iron in its earthmoving machinery. Grumman applied LM innovations to its aircraft electronics and testing. Joseph Gavin, Jr., interview, August 6, 2005; Rebecca Wright, "NASA Johnson Space Center Oral History Project: Oral History Transcript—Joseph Gavin," January 10, 2003, 20–21.

[136] "NASA Johnson Space Center's (JSC) Technology Transfer Program," NASA Johnson Space Center Technology Transfer and Commercialization Office,"
https://technology.jsc.nasa.gov/. See also NASA's *Spinoff* Magazine,
https://spinoff.nasa.gov/. For instant spinoff updates, see NASA's Techfinder,
http://technology.nasa.gov/Hybrid_Listing.cfm?x=0.418746532447
and Technology Transfer Program, https://technology.nasa.gov/.
For NASA's commercial technology partnerships, see,
http://ipp.nasa.gov/ and https://www.nasa.gov/partnerships.html.
For other information, see NASA technology portal,
http://nasatechnology.nasa.gov/?ntpo=1&CFID=1795695&CFTOKEN=26011755.

Quotation at beginning of next paragraph is from 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.

[137] Author's multiple discussions with Joseph Gavin, Jr., over multiple years.

[138] James Harford, interview, December 1998; Asif Siddiqi, *Challenge to Apollo: The Soviet Union and the Space Race, 1945–1974* (Washington, DC: NASA, 2000), 848.

[139] 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), 178.

[140] James Harford, *Korolev: How One Man Masterminded the Soviet Drive to Beat America to the Moon* (New York: John Wiley & Sons, 1997), 246; see also Asif Siddiqi, *The Soviet Space Race with Apollo* (Miami: University of Florida Press, 2003), 589, 590, 611, 691.

[141] Asif Siddiqi, *Soyuz-1: The Death of Vladimir Komarov: Pressure, Politics, and Parachutes* (Bethesda, MD: Space History 101 Press, 2020). Unless otherwise specified, data in this and the next two paragraphs are derived from Asif Siddiqi, *The Soviet Space Race with Apollo* (Miami: University of Florida Press, 2003), 589, 691, 611, 590. Sources for remainder of this paragraph: Asif Siddiqi, *Challenge to Apollo: The Soviet Union and the Space Race, 1945–1974* (Washington, DC: NASA, 2000), 578, 590; 576–578, 611; Asif A. Sidiqi, "Soyuz-1 Revisited: From Myth to Reality," *Quest: The History of Spaceflight Quarterly* 6.3 (March 1997): 5–16, http://faculty.fordham.edu/siddiqi/writings/p13_siddiqi_quest_1997-03_soyuz-1.pdf.

[142] Henry Lambright, *Powering Apollo: James E. Webb of NASA* (Baltimore: Johns Hopkins University Press, 1995), 7.

[143] Mike Gray, *Angle of Attack: Harrison Storms and the Race to the Moon* (New York: W.W. Norton & Company, 1992), 236.

[144] Ibid., 237.

[145] Roger Bilstein, *Stages to Saturn: A Technological History of the Apollo/Saturn Launch Vehicles* (Washington, DC: NASA History Office, 1996), 231.

[146] For the statistic concerning parts, see Sylvia Brown, *Guide to the George M. Low Papers, 1930–1984* (Troy, NY: Institute Archives and Special Collections, Folsom Library, Rensselaer Polytechnic Institute, 1988).

[147] John Noble Wilford, *We Reach the Moon* (New York: Bantam Books, 1969), 159.

[148] Author's multiple discussions with Joseph Gavin, Jr., over multiple years.

[149] L. L. Kerber, *Stalin's Aviation Gulag: A Memoir of Andrei Tupolev and the Purge Era* (Washington, DC: Smithsonian Institution Press, 1996), 75.

[150] 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), 178. The Soviet Union had an extremely large and cumbersome quality control organization for weapons programs. Military officers controlled compliance with requirements and documents in weapon-producing factories. Prioritization of key weapons systems ensured that Soviet tanks, missiles, military planes, and small arms functioned relatively reliably. While similar officers controlled production in rocket/space development organizations, the fact that these were not series weapon items, and not always of the highest priority, seems to have condemned them to a lower level of reliability.

[151] Joseph G. Gavin, Jr., "Engineering Development of the Apollo Lunar Module," in *History of Rocketry and Astronautics* (Proceedings of the Twenty-Fourth History Symposium of the International Academy of Astronautics – Dresden, Germany, 1990), J. D. Hunley, editor, AAS History Series, Volume 19, IAA History Symposia, Volume 11 (San Diego, California: Published for the American Astronautical Society by Univelt, Inc., 1997), 225–36 (paper IAA-90-633 presented at the 24th History Symposium of the International Academy of Astronautics as part of the 41st International Astronautical Federation Congress, Dresden, Germany, October 6–12, 1990), 2.

[152] Author's multiple discussions with Joseph Gavin, Jr., over multiple years; "Reflections on Apollo and the Next Giant Steps: The Giant Leaps Symposium," *AeroAstro Annual* (Cambridge, MA: MIT, 2008–09), 10; Thomas J. Kelly, interviewed by Kevin M. Rusnak, "NASA Johnson Space Center Oral History Project: Oral History Transcript," Cutchogue, NY, September 19, 2000, https://historycollection.jsc.nasa.gov/JSCHistoryPortal/history/oral_histories/KellyTJ/KellyTJ_9-19-00.htm.

[153] See, e.g., L. L. Kerber, *Stalin's Aviation Gulag: A Memoir of Andrei Tupolev and the Purge Era* (Washington, DC: Smithsonian Institution Press, 1996), 281.

[154] Boris Chertok, *Rockets and People: Creating a Rocket Industry*, Vol. 2 (Washington, DC: NASA, 2005), 64; William Burrows, *This New Ocean: The Story of the First Space Age* (New York: Random House, 1998), 572.

[155] William Burrows, *This New Ocean: The Story of the First Space Age* (New York: Random House, 1998), 280.

[156] Bruce Parrott, *Politics and Technology in the Soviet Union* (Cambridge, MA: MIT Press, 1985), 298.

[157] Ibid., 277.

[158] Asif Siddiqi, *Sputnik and the Soviet Space Challenge* (Miami: University of Florida Press, 2003), 242; Asif Siddiqi, *Challenge to Apollo: The Soviet Union and the Space Race, 1945–1974* (Washington, DC: NASA, 2000), 287, 842–854, 858.

[159] The real nepotistic effect may have come from the decisions of the Chairman's subordinates in charge of the space program, such as Ustinov, Serbin, Smirnov, and Dementyev, who believed that they were fulfilling his will by favoring a design bureau with which his son was affiliated and thereby enhancing their own political prospects. Asif Siddiqi, *Sputnik and the Soviet Space Challenge* (Miami: University of Florida Press, 2003), 314.

[160] Ibid., 229.

[161] Sources for this and next paragraph: Asif Siddiqi, *Challenge to Apollo: The Soviet Union and the Space Race, 1945–1974* (Washington, DC: NASA, 2000), 233, 445, 633, 857, 420, 506, 549; James Harford, Korolev: *How One Man Masterminded the Soviet Drive to Beat America to the Moon* (New York: John Wiley & Sons, 1997), 266.

[162] Asif Siddiqi, *The Soviet Space Race with Apollo* (Miami: University of Florida Press, 2003), 562.

[163] Ibid., 562. Sources for rest of paragraph and next paragraph: Asif Siddiqi, *Challenge to Apollo: The Soviet Union and the Space Race, 1945–1974* (Washington, DC: NASA, 2000), 390–391, 540.

[164] *Sputnik and the Soviet Space Challenge* (Miami: University of Florida Press, 2003), 503.

[165] Asif Siddiqi, *The Soviet Space Race with Apollo* (Miami: University of Florida Press, 2003), 645.

[166] Asif Siddiqi, *Sputnik and the Soviet Space Challenge* (Miami: University of Florida Press, 2003), 420; Asif Siddiqi, *Challenge to Apollo: The Soviet Union and the Space Race, 1945–1974* (Washington, DC: NASA, 2000), 645.

[167] James Harford, interview, December 1998. There were notable differences in the way how development of rockets and space systems was conducted (e.g., testing) by various chief designers, particularly between Korolev and Chelomey. Chelomey, his organization having emerged from the technical culture of the aviation industry, believed himself more methodical and disciplined than Korolev, whose organization had emerged from the artillery.

[168] William Burrows, *This New Ocean: The Story of the First Space Age* (New York: Random House, 1998), 114.

[169] T. A. Heppenheimer, *Countdown: A History of Space Flight* (New York: John Wiley & Sons, 1977), 227. In bureaucratic battles that would parallel Korolev's with Glushko, Soviet aviation genius Andrei Tupolev would feud with Aleksandr Yakolev and Sergei Ilyushin, also his alleged 1930s informants, who later became rival aviation industry leaders.

[170] Sergei Khrushchev, *Nikita Khrushchev and the Creation of a Superpower* (University Park, PA: Pennsylvania State University, 2000), 276.

[171] Ibid., 284–285.

[172] Asif Siddiqi, *Sputnik and the Soviet Space Challenge* (Miami: University of Florida Press, 2003), 125.

[173] William Burrows, *This New Ocean: The Story of the First Space Age* (New York: Random House, 1998), 277.

[174] James Harford, interview, December 1998. Source for next sentence: Asif Siddiqi, *Challenge to Apollo: The Soviet Union and the Space Race, 1945–1974* (Washington, DC: NASA, 2000), 497.

[175] T. A. Heppenheimer, *Countdown: A History of Space Flight* (New York: John Wiley & Sons, 1977), 121; Asif Siddiqi, *Sputnik and the Soviet Space Challenge* (Miami: University of Florida Press, 2003), 159.

[176] Sergei Khrushchev, *Nikita Khrushchev and the Creation of a Superpower* (University Park, PA: Pennsylvania State University, 2000), 480. See also T. A. Heppenheimer, *Countdown: A History of Space Flight* (New York: John Wiley & Sons, 1977), 121; Asif Siddiqi, *Sputnik and the Soviet Space Challenge* (Miami: University of Florida Press, 2003), 159; Asif Siddiqi, *Challenge to Apollo: The Soviet Union and the Space Race, 1945–1974* (Washington, DC: NASA, 2000), 462.

[177] Asif Siddiqi, *Challenge to Apollo: The Soviet Union and the Space Race, 1945–1974* (Washington, DC: NASA, 2000), 483; Joseph Gavin, Jr., interview, August 7, 2005.

[178] Sources for this and the next paragraph: Asif Siddiqi, *Sputnik and the Soviet Space Challenge* (Miami: University of Florida Press, 2003), 562; Asif Siddiqi, *The Soviet Space Race with Apollo* (Miami: University of Florida Press, 2003), 562; Asif Siddiqi, *Challenge to Apollo: The Soviet Union and the Space Race, 1945–1974* (Washington, DC: NASA, 2000), 390–391, 743.

[179] Asif Siddiqi, *Sputnik and the Soviet Space Challenge* (Miami: University of Florida Press, 2003), 512.

[180] James Harford, *Korolev: How One Man Masterminded the Soviet Drive to Beat America to the Moon* (New York: John Wiley & Sons, 1997), 280.

[181] William Burrows, *This New Ocean: The Story of the First Space Age* (New York: Random House, 1998), 62.

[182] Asif Siddiqi, *Sputnik and the Soviet Space Challenge* (Miami: University of Florida Press, 2003), 11.

[183] L. L. Kerber, *Stalin's Aviation Gulag: A Memoir of Andrei Tupolev and the Purge Era* (Washington, DC: Smithsonian Institution Press, 1996), 167; Asif Siddiqi, *Challenge to Apollo: The Soviet Union and the Space Race, 1945–1974* (Washington, DC: NASA, 2000), 514.

[184] William Burrows, *This New Ocean: The Story of the First Space Age* (New York: Random House, 1998), 279. Source for next two sentences: Asif Siddiqi, *Challenge to Apollo: The Soviet Union and the Space Race, 1945–1974* (Washington, DC: NASA, 2000), 11, 19.

[185] Sergei Khrushchev, *Nikita Khrushchev and the Creation of a Superpower* (University Park, PA: Pennsylvania State University, 2000), 224.

[186] L. L. Kerber, *Stalin's Aviation Gulag: A Memoir of Andrei Tupolev and the Purge Era* (Washington, DC: Smithsonian Institution Press, 1996), ix, 61–64. Source for remainder of paragraph: Asif Siddiqi, *Challenge to Apollo: The Soviet Union and the Space Race, 1945–1974* (Washington, DC: NASA, 2000), 14, 176–177, 416–417, 669, 766; Boris Chertok, *Rockets and People: Creating a Rocket Industry*, Vol. 2 (Washington, DC: NASA, 2005), 160–161, 227.

[187] Asif Siddiqi, *Sputnik and the Soviet Space Challenge* (Miami: University of Florida Press, 2003), 3. Sources for remainder of paragraph: Asif Siddiqi, *Challenge to Apollo: The Soviet Union and the Space Race, 1945–1974* (Washington, DC: NASA, 2000), 183, 47, 209.

[188] Asif Siddiqi, *Sputnik and the Soviet Space Challenge* (Miami: University of Florida Press, 2003), 516. Sources for remainder of paragraph: Asif Siddiqi, *Challenge to Apollo: The Soviet Union and the Space Race, 1945–1974* (Washington, DC: NASA, 2000), 519, 828; Asif Siddiqi, *The Soviet Space Race with Apollo* (Miami: University of Florida Press, 2003), 518–519, 827, 838.

[189] This and the following two paragraphs draw on: Asif Siddiqi, *The Soviet Space Race with Apollo* (Miami: University of Florida Press, 2003), 518–519, 827, 838; Asif Siddiqi, *Challenge to Apollo: The Soviet Union and the Space Race, 1945–1974* (Washington, DC: NASA, 2000), 831–833, 701, 703, 838, 842, 849, 831.

[190] Joseph Gavin, Jr., interview, August 7, 2005.

[191] Sergei Khrushchev, *Nikita Khrushchev and the Creation of a Superpower* (University Park, PA: Pennsylvania State University, 2000), 689. Source for next sentence: Brian Harvey, *Russia in Space: The Failed Frontier* (Chichester, UK: Springer, 2001), 31.

[192] John Noble Wilford, *We Reach the Moon* (New York: Bantam Books, 1969), 129.

[193] Robert Reeves, *The Superpower Space Race: An Explosive Rivalry Throughout the Solar System* (New York: Plenum Press, 1994), 149. Source for next sentence: Asif Siddiqi, *Challenge to Apollo: The Soviet Union and the Space Race, 1945–1974* (Washington, DC: NASA, 2000), 644, 837.

[194] James Harford, *Korolev: How One Man Masterminded the Soviet Drive to Beat America to the Moon* (New York: John Wiley & Sons, 1997), 299. 20,000 private firms participated in the development of Apollo's Saturn rocket alone. Roger Bilstein, *Stages to Saturn: A Techno-*

logical History of the Apollo/Saturn Launch Vehicles (Washington, DC: NASA History Office, 1996), xii.

[195] William Burrows, *This New Ocean: The Story of the First Space Age* (New York: Random House, 1998), 210.

[196] Ibid., 278.

[197] John Noble Wilford, *We Reach the Moon* (New York: Bantam Books, 1969), 127. Source for next sentence: Asif Siddiqi, *Challenge to Apollo: The Soviet Union and the Space Race, 1945–1974* (Washington, DC: NASA, 2000), 794.

[198] By this time, America had already switched to solid fuels, greatly reducing cost.

[199] Sergei Khrushchev, *Nikita Khrushchev and the Creation of a Superpower* (University Park, PA: Pennsylvania State University, 2000), 282.

[200] James Harford, *Korolev: How One Man Masterminded the Soviet Drive to Beat America to the Moon* (New York: John Wiley & Sons, 1997), 269.

[201] Even under Eisenhower, the Saturn rocket program enjoyed the "highest national priority (DX rating)." Roger Bilstein, *Stages to Saturn: A Technological History of the Apollo/Saturn Launch Vehicles* (Washington, DC: NASA History Office, 1996), 50.

[202] Ibid., 270.

[203] Gene Kranz, *Failure is Not an Option: Mission Control from Mercury to Apollo 13 and Beyond* (New York: Simon & Schuster, 2000), 381. See also "Eugene F. Kranz," Chapter 6 in Glen Swanson and Paul Dickson, *Before This Decade is Out: Personal Reflections on the Apollo Program* (Government Printing Office: NASA Special Publication-4223, 1999), 118–171, https://history.nasa.gov/SP-4223/ch6.htm.

[204] Asif Siddiqi, *Challenge to Apollo: The Soviet Union and the Space Race, 1945–1974* (Washington, DC: NASA, 2000), xi; James Harford, interview, December 1998.

[205] James Harford, *Korolev: How One Man Masterminded the Soviet Drive to Beat America to the Moon* (New York: John Wiley & Sons, 1997), 270.

[206] For an analysis of Soviet opportunity cost, see Aaron Friedberg, *In the Shadow of the Garrison State: America's Anti-Statism and its Cold War Grand Strategy* (Princeton, NJ: Princeton University Press, 2000), 337–338.

[207] According to Aaron Friedberg, "There is some evidence to suggest that in their efforts to keep pace with the West, Soviet planners felt compelled in the 1960s and 1970s to shift an even greater share of scarce scientific and technological resources from the civilian to the military sector, thereby contributing to a continuing slowdown in productivity growth and in national economic expansion." Ibid., 347.

[208] Roald Sagdeev, interview, December 1998.

[209] David Beckler, Executive Secretary of the US Science Advisory Committee, as quoted in Aaron Friedberg, *In the Shadow of the Garrison State: America's Anti-Statism and its Cold War Grand Strategy* (Princeton, NJ: Princeton University Press, 2000), 303; John Logsdon, *John F. Kennedy and the Race to the Moon* (New York: Palgrave Macmillan, 2010), 239; John Rubel, recorded interview by William Moss.

[210] Joseph Gavin, Jr., interview, August 7, 2005.

[43] Neil A. Armstrong, "Joseph G. Gavin, JR. 1920-2010."

[44] David L. Chandler, "Aerospace Engineer Joseph Gavin '41, SM '42 Dies at 90: Former President of Grumman Aircraft Led Lunar Module development for NASA, Aided in the Rescue of Apollo 13," MIT News Office, November 5, 2010, http://news.mit.edu/2010/obit-gavin.

[45] Neil A. Armstrong, "Joseph G. Gavin, JR. 1920-2010."

[46] Meg Mitchell Moore, "Joseph Gavin '41, SM '42: Grumman Head Worked to Save Apollo 13," *MIT News*, February 24, 2009, https://www.technologyreview.com/2009/02/24/267519/joseph-gavin-41-sm-42/; NASA Interview, 2003.

[47] Author's discussion with Gavin, 2002.

[48] David L. Chandler, "Aerospace Engineer Joseph Gavin '41, SM '42 Dies at 90: Former President of Grumman Aircraft Led Lunar Module development for NASA, Aided in the Rescue of Apollo 13," MIT News Office, November 5, 2010, http://news.mit.edu/2010/obit-gavin.

[49] Author's interview with Gavin, Amherst, MA, December 11, 1998.

[50] Author's correspondence with former Aviation Week & Space Technology journalist Craig Covault, who accompanied Gavin on the trip, May 6, 2020.

[51] Back to Methuselah, Part I, Act I, 1921.

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Michael L. Ciancone, Editor

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American Astronautical Society

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Foreword

As series editor for the International Academy of Astronautics (IAA) history symposia volumes, the authors of the scholarly papers that become chapters in these volumes always surprise me. I am amazed at how they present new details about familiar projects or events, and I am stunned by how they introduce previously forgotten or unappreciated aspects of rocket and space history. This latest, long-awaited volume is no exception.

As I reflected on its nineteen chapters, it occurred to me that I have lived through and, in some instances, personally experienced bits and pieces of the stories these authors so captivatingly tell. Practically every one of them, in their own way, delivers memorable space- or rocket-related history from my lifetime. Looking backward in quinquennial fashion, I found mention of the last Apollo flight to the Moon in 1972—forty-five years prior to this IAA symposium. Before that, in 1967—fifty years before the symposium—the *Apollo 1* tragedy that cost the lives of three brave American astronauts came to mind, as did the happier memory of *WRESAT*, the first Australian satellite, being launched. Five years before that—as a high school student, in 1962—I was glued to the television screen, watching John Glenn's Mercury-Atlas 6 send the first American into Earth orbit. And, five years even earlier—as a ten-year-old boy, in the autumn of 1957—I gazed upward to watch *Sputnik*'s rocket body pass swiftly across the nighttime sky. Then, when Charles Lundquist's obituary informed me that he first became acquainted with Wernher von Braun's work seventy years earlier, in 1947, it took me back to my birth.

Looking backward, as this historical volume prompted me to do, left me mindful of the rich complexity of the space-related activities that constitute the foundation upon which today's rocket scientists, satellite engineers, and other spaceflight professionals continue building. Most often, today's work is evolutionary, but that is not to say revolutionary ideas spark unforeseen twists and turns, just as they did in the past. The chapters in this volume tell tales of both these progressive avenues.

Indeed, after a thorough reading, they prompted me to sit back in my chair and contemplate the quinquennial pattern of the future. Looking forward, I see billionaires building space rockets and their corporate enterprises operating dozens, even hundreds of privately funded satellites. Will private human spaceflight occur in 2022? Will a privately financed presence be established on the Moon in 2027? Will a government-sponsored space organization manage to send humans to Mars in 2032? Where will rocketry and spaceflight take us in 2037? The history that appears in this volume leaves me extremely excited about the future and unbelievably curious about how it will unfold.

Dr. Rick W. Sturdevant
Series Editor
United States Space Force
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Preface

The Fifty-First History Symposium of the International Academy of Astronautics took place during the Sixty-Eighth International Astronautical Congress in September 2017. The picturesque city of Adelaide, capital of South Australia, was the venue for the congress, only the second time the event had been held in the Land Down Under (the first was held in Melbourne, Victoria, in 1998).

The year 2017 was special for space in Australia, marking fifty years since the launch of the country's first satellite, *WRESAT* (*Weapons Research Establishment Satellite*). This fiftieth anniversary formed a major theme of the education and outreach programs associated with the congress. Highlights included an extensive exhibition on the history of the Woomera Rocket Range, held at the State Library of South Australia, and the release of a special WRESAT anniversary stamp and first day cover by *Australia Post.*

History was also made during the congress, with the announcement at the opening ceremony that the Australian government would form the nation's first space agency, a goal long pursued by the Australian space community. The jubilation with which the Australian delegates greeted this announcement will be long remembered by everyone present.

The Fifty-First History Symposium was composed of four sessions: Memoirs and Organizational Histories; Science and Technology Reviews; a session on the History of Australian Contributions to Astronautics, in recognition of the host country; and a special session as part of the lead-up to the fiftieth anniversary of the *Apollo 11* Moon landing in 2019, under the title "Can You Believe They Put a Man on the Moon?" This special session was the first in a series that will continue until 2019, focusing on all aspects of the development and preparation for the first human landing on the Moon in 1969. Its four papers encompassed an eclectic range of topics: from the cultural impact of the Apollo program and the larger lessons to be learned from the space race to the contribution of Spain's

Fresnedillas space tracking station and the experience of watching the *Apollo 11* landing in Ireland.

This volume is divided into four parts, reflecting the four sessions of the symposium outlined above. The papers presented in 2017 covered a wide spectrum of space history topics, but—in addition to the special focus on the Apollo program—a few themes emerged. As 2017 was also the sixtieth anniversary of the launch of the world's first satellite, several papers addressed the legacy of *Sputnik 1,* while the achievements of little-known rocketeers of the 1930s and less-well known figures in the US space program were also presented. Regrettably, the lead author of a fascinating presentation on the work of Robert Farquhar, the "father of halo orbits," failed to provide a written paper. In its stead, an extended abstract is included to acknowledge Farquhar's significant work. A particularly important contribution in this volume is Frank Winter's chapter, reassessing the significance of the Viking sounding rocket and demonstrating that it must be considered the first rocket specifically designed for flight into space.

Sadly, space historian and long-time participant in the history symposia, Dr. Charles Lundquist passed away in 2017. A memorial celebrating his life and contributions to space history research is included in this volume as a mark of respect to a valued colleague.

Kerrie Dougherty
Part III Editor

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