Birds of a Feather? How Politics and Culture Affected the Designs of the U.S. Space Shuttle and the Soviet Buran

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1

Contents

Chapter One: Introduction

-The Political and Cultural Factors Argument

What can we learn from comparing similar technologies that were designed and built in different countries or cultures? Technical products depend upon both technical and non-technical goals as socio-cultural factors determine which projects get funded and how they are conceived, designed, and built. These qualitative socio-cultural factors mean that there is almost always more than one possible design solution for a particular problem. By comparing how two major space projects were conceptualized and designed in the United States and Soviet Union, this case study aims to illuminate more broadly how political and cultural factors can influence the selection of technical designs, as well as the general conduct of engineering and science, in the space sector.

Who gets what how? By applying this classic political science question, I aim to show how specific domestic and international political considerations greatly affected the designs of the U.S. Space Shuttle and its counterpart, the Soviet Buran, during the 1970s and 1980s. In the U.S., the National Aeronautics and Space Administration (NASA) had successfully put humans on the Moon but was under intense pressure to scale back its further grandiose plans for space exploration in light of budget considerations and escalating U.S. military presence in Southeast Asia. Thus, NASA's Space Shuttle ended up being a compromise: it was very sophisticated technologically but never fulfilled the goal of inexpensive access to space.

While the Soviets had taken an early and commanding lead in the space race in the 1950s and early 1960s, by the beginning of the next decade, they had fallen behind. The Soviet leadership mobilized its industrial aerospace capabilities to create a Shuttle at least as large and capable as NASA's Shuttle. The Soviet space industry was also undergoing a major reshaping in 1974 as the result of the deaths of certain key players and other bureaucratic maneuverings. The political upshot was that the Soviets decided to build a Shuttle more to uphold their perceived international prestige than for any specific technical reasons and the project turned out to be a technological dead end.

In addition, the Cold War backdrop had very significant political-military influences in both countries. While the "military had little or no interest in the Shuttle" according to one key U.S. Air Force official, NASA nevertheless needed the military's political support and so accommodated the Shuttle's design to meet Air Force requirements. Whether the Air Force really intended to utilize the capabilities it requested is unclear; this official also stated that "I don't think there was an Air Force mission clearly defined."[1]

In the Soviet Union, some mid-level space managers said that the U.S. Shuttle could drop nuclear weapons on their homeland. Thus, they pushed for a symmetrical response: the Buran Shuttle. This rationale for building an expensive, complex new spaceflight system may seem overly paranoid in retrospect, but top Soviet leaders embraced it. A major problem with this thin rationale was that the Soviets didn't really understand what the U.S. Shuttle was designed for, but ended up copying it in some superficial ways to assuage their political leadership.

To understand some of the cultural factors affecting the designs of the U.S. Space Shuttle and the Soviet Buran, it may be useful to address two science and technology studies concepts:

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[1] John McLucas interview with Stephen Garber, January 9, 2001, *passim*; the quotes are from pp. 12 and 44. McLucas was Undersecretary of the Air Force and Director of the National Reconnaissance Office from 1969 to 1973, when the Shuttle's design was being finalized. He then was Air Force Secretary from 1973 to 1975 and has maintained a personal and professional interest in space issues throughout his career.

technological style and the social construction of technology (SCOT). SCOT adherents believe that broadly-construed social groups strongly influence the design of technology, perhaps more than "purely objective" or quantifiable technical factors. Social groups also define what technological issues come up for discussion. Indeed, "a problem is defined as such only when there is a social group for which it constitutes a 'problem.'"[2] SCOT philosophy argues that different engineers working in different political environments, for example, may well design rather different airplanes, spacecraft, and so forth.

Technological style dovetails closely with SCOT in proposing that there is no single best technical way to design any particular technology, in contrast to Taylorist and Fordist schools of production management. Instead, a technology's design depends upon the designers' implicit and explicit goals, as well as the designers' cultural setting. Thomas Hughes, a preeminent historian of technology, notes that technological "system builders, like artists and architects, have creative latitude" to design their systems in a variety of ways.[3] Thus technology is *not* the impartial, objective application of science. Hughes writes that technological style facilitates comparative history, as historians can write about how the same type of technology, whether electrical power systems or spacecraft, develops differently in different geographic regions. Natural geography, indigenous natural resources, and historical precedent, in addition to an international technology base, all influence technological development. While technological style could be employed as an analytic tool at levels such as the individual company or geographic region, it is "primarily meant to account for national differences in technology."[4] Hughes gives the example of Germany building a few, large electrical generators during World War I because of a copper shortage; this thrifty design style continued there after the shortage had passed.[5] Technological style or a specific 'culture of technology' embraces "distinctive values, ideas, and institutions…[such as] technical efficiency" or sophistication.[6] Numerous other examples are possible to illustrate the importance of cultural factors in the designs of specific technologies.

In this case study, a number of cultural factors influenced the choices, whether implicit or explicit, that the spacecraft designers in both superpowers made. In the U.S. and especially at NASA, engineers often tried to devise innovative, elegant solutions to design problems. By contrast, their Soviet counterparts had long favored adaptation over invention. These broad generalizations had specific impacts when, for example, NASA engineers declined to adapt for the Shuttle their successful rocket designs of the Mercury, Gemini, and Apollo programs. Abandoning proven technology, they opted instead for an entirely new space transportation system. True to form, the Soviets hurriedly adapted the overall configuration of the U.S. Shuttle without fully considering whether this approach would mesh well with their technical goals. Soviet engineers were proficient at frugal allocation of resources and jury-rigging technical fixes and saw no need to duplicate NASA's earlier deliberations over potential Shuttle configurations.

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[2] Trevor J. Pinch and Wiebe E. Bijker, "The Social Construction of Facts and Artifacts" in Wiebe E. Bijker, Thomas P. Hughes, and Trevor Pinch, editors, The Social Construction of Technological Systems: New Directions in the Sociology and History of Technology (Cambridge, Massachusetts: The MIT Press, 1997). This book as a whole is an excellent primer for SCOT concepts.

[3] Thomas P. Hughes, "The Evolution of Large Technological Systems" in Bijker, Hughes, and Pinch, p. 68.

[4] Wiebe E. Bijker, "The Social Construction of Bakelite: Toward a Theory of Invention" in Bijker, Hughes, and Pinch, p.172.

[5] Hughes, "The Evolution of Large Technological Systems," pp. 68-70.

[6] Edward W. Constant, II, "The Social Locus of Technological Practice: Community, System, or Organization?" in Bijker, Hughes, and Pinch, p. 229.

4

Clearly many configurations were possible for both Shuttles. Designers were obviously limited by certain laws of physics and by certain technical goals. Social, political, and cultural factors strongly influenced the selection of these technical goals, however. By analyzing which political factors and aspects of national technological style were most relevant to the design of the U.S. Shuttle and the Soviet Buran, I aim to show how these two space transportation systems are more distinct than they appear at first blush. Such differences in turn again emphasize the panoply of possible options that imaginative designers could have used. By looking at how they winnowed their choices, this case study should demonstrate the sometimes subtle importance of technological style and the ever present influence of politics on the conduct of engineering, specifically in the space sector.

-Background on the Two Shuttles

From 1969 to early 1972, the National Aeronautics and Space Administration (NASA) considered a variety of designs for a vehicle that could carry people and cargo into space repeatedly. The numerous designs involved three basic kinds of orbiter vehicles: winged like an airplane, a wingless "lifting body," and a ballistic capsule such as the Apollo, Gemini, and Mercury programs used. Airplanes usually made powered horizontal landings, lifting bodies generally glided to horizontal landings, and ballistic capsules either splashed down in the ocean or used parachutes to land on terra firma. After many heated political and technical debates, the design that emerged had triangular (delta) wings at the rear of the Space Shuttle, also known more formally as the National Space Transportation System (STS).

The former Soviet Union's analogue was the Energiya-Buran launch system. The decision to go forward with development of this system was made in 1974-1976 but the program was slow to gear up. The Buran ("snowstorm" or "blizzard") orbiter was not launched atop the Energiya launch vehicle until 1988, although an Energiya test launch was conducted successfully without the Buran in 1987. During the 1988 test flight, Buran flew two orbits without a crew and successfully returned to Earth. This turned out to be the Buran's one and only flight. The program was put on hold and then cancelled in 1993.

Soviet designers built upon the vast open source literature available about NASA's Shuttle and saw no need to reinvent the wheel, given the myriad American configuration studies that had been done prior to and even after 1972. While some in the U.S. decried what they saw as the Soviets' "stealing the blueprints" for the U.S. Shuttle, this is rather misleading. For better or worse, NASA's work on the Shuttle was done in the open and thus there was never a serious issue of classified Shuttle material passing into Soviet hands.

Beyond the fact that they are both delta-winged vehicles of similar size and shape, the two Shuttles share other technical characteristics such as payload bay size and thermal protection systems made of special ceramic tiles. Visually, they look remarkably alike.

Beyond appearances, however, there are several important technical differences between the two Shuttle systems. Perhaps the most significant is that the U.S. Shuttle was always intended to carry people into space but on its only flight, the Buran flew without a crew, although it was designed to accommodate human crews as well. At one level, clearly the U.S. Shuttle was designed as a follow-on program to the Apollo and Skylab projects that would send humans aloft on a routine basis. As Tom Wolfe described in The Right Stuff, the U.S. and NASA aerospace cultures were dominated first by pilots and then by astronauts, so some might say that flying people, not just payloads, into space was always a priority. This is still true today, as NASA's human spaceflight efforts on Shuttle and the International Space Station spark

5

the public's imagination and pave the way politically and budgetarily for robotic spacecraft missions, ground-based astronomy, and even aeronautics.

On the Soviet side, there was never this domestic public opinion impetus for humans to fly in space, let alone specifically on the Buran. It is particularly interesting, however, that the Soviets designed the Buran to be able to fly either with a human crew or without. Traditionally, the Soviets used spacecraft such as the Soyuz for human missions and the Progress for cargo. The U.S. has never designed a spacecraft for both human and non-human purposes, although engineers have adapted launch vehicles to serve both purposes.

Reflecting the two countries' relative emphases of humans "in the loop," the two Shuttle systems had different potential reentry profiles. The Buran orbiter could return to Earth in full autopilot, manual, or controlled autopilot modes.[7] While the U.S. Shuttle can descend in autopilot mode, normally the crew does take over the manual controls close to landing.[8] In fact, during the design phase, apparently John Young from the Astronaut Office insisted that human crews have a significant role in landing the Shuttle and so a compromise was struck in which the pilot must manually drop the landing gear.[9]

A second important difference is that Buran is only an orbiter and relies upon the Energiya launch vehicle and four liquid propellant boosters to get into orbit. The U.S. Shuttle, on the other hand, has its main rocket engines in the orbiter itself, along with two solid rocket boosters (SRBs). Buran used the space occupied by the U.S. Shuttle's main engines to house jet engines for "go-around" capability on landing, something the U.S. Shuttle does not have.[10] In short, the Buran was only one potential payload that the Energiya could lift into space, while on the U.S. side, the orbiter is an integral part of the total Shuttle launch system.

Thirdly, the Energiya was an expendable launch vehicle (ELV) but the U.S. Shuttle was designed with reusability in mind since its main engines are in the orbiter and the SRBs are refurbished after each flight. NASA's rationale for reusability was that it would enable quicker turnaround for launches and then in turn, higher flight rates, and lower costs per flight. Unfortunately, the U.S. Shuttle has never achieved the high flight rates that were envisioned and remains an expensive way to loft payloads into space. Whether the Soviet decision to go with the Energiya ELV booster was the most cost-effective is difficult to assess since it only flew twice. In addition, contrary to the Soviets' traditional tendencies, they did not simply modify an existing rocket, although they did closely adapt the U.S. orbiter's configuration.

-Literature Review

Due in part to the availability of primary source materials from NASA, a number of Western authors have covered the basic development story of the U.S. Shuttle from a variety of perspectives. Indeed, almost a decade ago, the NASA History Office published a monograph-

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[7] Steven J. Isakowitz, updated by Jeff Samella, International Reference Guide to Space Launch Systems, second edition (American Institute of Aeronautics and Astronautics: Washington, DC, 1991) p. 118 and Yuri P. Semenov, G. Ye. Lozino-Lozinsky, V. L. Lapygin, and V. A. Timchenko, eds., Mnogorazovyy orbital'nyy korabl' 'Buran' (Moscow: Mashinostroyeniye, 1995), section 1.3 "Major Design Solutions," original pp. 35-47, translated p. 5. Semenov notes that autopilot would be the default mode for landing with manual override as a backup.
[8] John F. Hanaway and Robert W. Moorehead, Space Shuttle Avionics System (NASA SP-504, 1989), p. 25.
[9] Milton Silveira oral history interview with Stephen Garber, November 9, 2000, p. 21. John Young's lengthy career as an astronaut began in the early 1960s and he commanded the first Space Shuttle mission in 1981.
[10] See, for example, Craig Covault, "Soviets Begin Orbiter Tests Following Engine Installation," Aviation Week and Space Technology, April 14, 1986, p. 16. Neville Kidger, "The Soviet Shuttle Story," Spaceflight, January 1990, p. 6, however, indicates that the jet engines were removed in March-April 1988.

length annotated bibliography with 15 chapters on this Shuttle's history.[11] Two authors have written key books on the Shuttle's birth and development since then.[12] While there may well be some significant aspects of the Shuttle's development that remain to be explored, the basic narrative is familiar to students of contemporary space history.

The Soviet Energiya-Buran story is considerably less well known, especially in the English language literature While a few glossy monographs cover the Energiya and the Buran separately, they are not very analytical. There is a considerable amount of relevant Russian language material on the Soviet Shuttle and some of it exists in translation. Even in Russian, however, there seems to be no definitive analytical history of the Buran that covers the political factors behind its development rather than simply the technical details. This remains as a very worthwhile and potentially fascinating task for an interested scholar with Russian language skills.

Another major gap exists with respect to the application of social construction in the aerospace field. Pamela E. Mack has written the sole book on SCOT and space history, but unfortunately it is not very germane to this discussion. Brian Woods, a British graduate student, actually wrote a Ph.D. dissertation on social factors affecting the design of the U.S. Space Shuttle, but this work is largely theoretical and broad-brush in its science and technology studies perspective.[13]

In terms of SCOT and the specific realm of aviation, Walter Vincenti and Eric Schatzberg wrote two excellent case studies. Vincenti looks at fixed versus retractable landing gear for small airplanes in the 1920s and 1930s. Vincenti's main thesis is that while social factors didn't directly influence the choice of landing gear, the definition of the problem was shaped by society's desire for faster airplanes for military, racing, and commercial purposes. Once society established the need for speed, then aeronautical engineers set to work on various subsystems, such as landing gear, to produce the most aerodynamically efficient and thus fast airplanes possible. Schatzberg looks at the choice of wood versus metal as a material for airplane construction during the same time period as the landing gear debate. He argues forcefully that American designers chose to work with metal, even though they knew less about it than wood and wood might have worked equally well for low to medium performance aircraft, because they inherently valued metal as a material of technical progress. While Schatzberg's argument in particular is certainly debatable, these two case studies are excellent in their clear arguments for social construction and technological style in aeronautical design.[14]

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[11] Roger D. Launius and Aaron K. Gillette, compilers, Towards a History of the Space Shuttle: An Annotated Bibliography (Washington, D.C.: Monographs in Aerospace History No. 1, 1992). This monograph is now out of print but is available at http://history.nasa.gov/Shuttlebib/cover.html on the Web.

[12] T.A. Heppenheimer, The Space Shuttle Decision: NASA's Search for a Reusable Space Vehicle (Washington, D.C.: NASA SP-4221, 1999) covers the political decision to go forward with the Space Shuttle program. Heppenheimer has written another book-length manuscript on the development process of the Shuttle; this work is forthcoming from the Smithsonian Institution Press. Dennis R. Jenkins, Space Shuttle: The History of the National Space Transportation System, The First 100 Missions (Stillwater, MN: Voyageur Press, 2001) is a comprehensive technical history of the development and operations of the Shuttle. A 1997 edition of Jenkins' book devotes several pages to the Soviet Shuttle, although this material is not in the 2001 edition.

[13] See Pamela E. Mack, Viewing the Earth: The Social Construction of the Landsat Satellite System (Cambridge, MA: MIT Press, 1990) and Brian Woods, "Artifacts, Revolutionaries and Bureaucrats: The Sociotechnical Shaping of NASA's Space Shuttle," Doctor of Philosophy dissertation, University of Edinburgh, 1998. Unfortunately, neither of these two works was particularly relevant to my comparative study of technological styles.

[14] Walter G. Vincenti, The Retractable Airplane Landing Gear and the Northrop 'Anomaly': Variation-Selection and the Shaping of Technology," Technology and Culture, vol. 35 no. 1 (January 1994), pp. 1-33 and Eric Schatzberg,

Precious little has been published on the concept of technological style in the space sector. A few authors have touched on this theme but it remains fertile ground for future exploration.[15]

Western historians of science and technology often immerse themselves in the content of their studies so much that they take U.S. technological style in general for granted or simply don't account for it. Some historical surveys and broad-thinking authors do, however, address notions such as Americans' preoccupation with invention and innovation.[16]

Several prominent historians have written about Soviet technological style in general. Loren Graham, a leading historian of Soviet science and technology, has a number of significant works to his credit. A younger scholar, Paul Josephson, also has authored several insightful works on the interaction of Soviet culture and technology. Going back to the 1970s, Kendall Bailes has some similarly useful works.[17]

The novel challenge for this case study is two fold: to analyze the political factors behind the Buran's development and to show the importance of cultural factors for both the Buran and the U.S. Shuttle. To do so, I will also cover the political story behind the U.S. Shuttle's development. More broadly, I hope to use this comparative case study to illustrate the power of technological style as an explanatory tool in space history.

"Ideology and Technical Choice: The Decline of the Wooden Airplane in the United States, 1920-1945," Technology and Culture, vol. 35 no.1 (January 1994), pp. 34-69. Schatzberg also expanded this story into a book; see his Wings of Wood, Wings of Metal (Princeton, NJ: Princeton University Press, 1998).

[15] Howard E. McCurdy, Inside NASA: High Technology and Organizational Change in the U.S. Space Program (Baltimore: Johns Hopkins University Press New Series in NASA History, 1993) addresses some technological style issues at NASA. Asif A. Siddiqi, Challenge to Apollo: The Soviet Union and the Space Race, 1945-1974 (Washington, D.C.: NASA SP-2000-4408, 2000) identifies several such themes in Soviet space history. Siddiqi plans to tackle Soviet technological style issues such as innovation versus adaptation in his forthcoming Ph.D. dissertation from Carnegie Mellon University.

[16] See, for example, Thomas P. Hughes, American Genesis: A Century of Invention and Technological Enthusiasm (New York City: Viking, 1989), which looks at the industrialism of 1870-1970.

[17] See, for example, Loren R. Graham, Science in Russia and the Soviet Union: A Short History (Cambridge, England: Cambridge University Press, 1993); Loren R. Graham, What Have We Learned About Science And Technology from the Russian Experience? (Stanford, CA: Stanford University Press, 1998); Paul R. Josephson, "Rockets, Reactors, and Soviet Culture" in Loren R. Graham, editor, Science and the Soviet Social Order (Cambridge, MA and London, England: Harvard University Press, 1990); Paul R. Josephson, "'Projects of the Century' in Soviet History: Large-Scale Technologies from Lenin to Gorbachev," Technology and Culture, volume 36, no.3 (July 1995), pp. 519-559; Kendall E. Bailes, "The Politics of Technology: Stalin and Technocratic Thinking among Soviet Engineers," American Historical Review, vol. 79, 1974, pp. 445-469;and Kendall E. Bailes, Technology and Society under Lenin and Stalin: Origins of the Soviet Technical Intelligentsia, 1917-1941 (Princeton, NJ: Princeton University Press, 1978).

Chapter Two: How Technology and Politics Intertwined

Beyond their visual similarities, the two Shuttles shared some common political drivers. Although space enthusiasts around the world had long developed various schemes for reusable spaceplanes, detailed planning for both the U.S. Shuttle and the Soviet Buran began in earnest in the late 1960s and early 1970s. Even though the U.S. had already won the race to the Moon with the Apollo 11 mission in 1969, the Cold War continued to be an important factor surrounding space exploration. Thus the perceived military characterization of the U.S. Shuttle as well as the U.S. military's reluctant support of the Shuttle were key factors affecting the development of space transportation systems in the U.S. and the Soviet Union. Budget problems and ambiguities over the Shuttles' roles plagued both programs. The personalities of certain key managers on both sides also led to specific successes and failures. In short, the political factors behind both the U.S. Shuttle and the Buran were inextricably linked to the technical development of these major programs.

-The U.S. Shuttle's Development

Thinking ahead to what NASA would do in terms of human spaceflight after the Apollo Moon landings, in 1969 the President's Space Task Group, headed by Vice-President Agnew, offered several scenarios. The Space Task Group report featured three main options: a human expedition to Mars, lunar and Earth-orbiting space stations, and a reusable space ferry or Shuttle. President Richard Nixon rejected the first two options as too expensive. NASA then decided to push for a Shuttle as a building block for these other goals, especially the space station.[18] NASA officials reasoned that the Shuttle would be more popular with Congress and the White House than the other, more expensive options. Nevertheless, in 1971 the Office of Management and Budget (OMB) slashed NASA's budget, eliminating any growth for the foreseeable future.[19]

OMB and the President's Science Advisory Committee (PSAC) envisioned the Shuttle as a general workhorse that would take care of the government's civilian scientific, defense, and intelligence launches, as well as commercial satellite launches. In the early 1970s, some analysts projected that military and intelligence satellites would account for 35 percent of future launches.[20] Also at that time, NASA was predicting very high Shuttle launch rates, implying a justifiable need for a Shuttle that was as reusable as possible to save operational costs.

Based on an influential set of analyses by the private firm Mathematica, Inc., NASA had estimated that the Shuttle could be used as many as 736 times from 1978-1990. This worked out to approximately 57 flights per year, or more than weekly. Using a more conservative estimate of 566 flights during this 13-year period that worked out to approximately 44 flights per year, Mathematica determined that NASA's development costs would be recovered at such a flight rate. If that held true, the Shuttle could easily handle virtually *all* U.S. launches in the 1980s and

[18]See, for example, Dennis R. Jenkins, Space Shuttle: The History of Developing the National Space Transportation System, The Beginning through STS-50 (Marceline, Missouri: Walsworth Publishing Company, 1993), p. 64 and John M. Logsdon, "The Space Shuttle Decision: Technology and Political Choice," Journal of Contemporary Business. 7 (1978), pp. 14-15.
[19] Logsdon, pp. 16-17.
[20] Thomas H. Johnson, "The Natural History of the Space Shuttle," Technology in Society. 10 (1988), pp. 418.

beyond and so NASA offered to do so.[21] Mathematica's analysis proved to be greatly overstated - in recent years, the Shuttle has only flown six to eight times per year.

During the development program that soon followed, some managers simply discounted or ignored predictions of such high flight rates as unrealistic. Indeed, some managers felt that such lofty proclamations were really for public consumption or public relations purposes and thus did not take them seriously. In retrospect, Robert Thompson, the Shuttle project manager at NASA's Johnson Space Center (JSC) said that "I never felt we'd fly more than once a month, maybe 18 flights a year [at the maximum]." Even if virtually *all* space payloads were to fly aboard the Shuttle, Thompson "couldn't figure what the country would want to do with all those flights" that were predicted by Mathematica.[22] Another key manager remarked that there was a design requirement for 55 flights per year "mainly to support the economics of the system."[23] In effect, the tail was wagging the dog; instead of creating a launch system versatile and rugged enough to launch often and thus reduce operations costs, some people were artificially creating a launch market to justify a particular kind of technology.

Another interesting opinion on projected flight rates comes from Robert Naka, the deputy director of the National Reconnaissance Office (NRO) in the early 1970s. In an interview approximately 30 years later, Naka contends that at that time, the NRO actually was predicting that its launch rates would *decrease* during the 1970s because of longer-lived reconnaissance satellites and better technology.[24]

This debate over projected NASA and national flight rates was important because these numbers could justify whether the proposed Shuttle was designed as a fully reusable or more expendable system. After protracted negotiations throughout 1971 between OMB and NASA on the Shuttle's size and development cost,[25] a national decision was finally made.

On January 5, 1972, President Nixon made a public announcement giving NASA the formal authority to build what we now know of as the Space Shuttle and the development

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[21] The executive summary of the Mathematica study is reproduced in John M. Logsdon, editor, with Ray A. Williamson, Roger D. Launius, Russell J. Acker, Stephen J. Garber, and Jonathan L. Friedman, Exploring the Unknown: Selected Documents in the History of the U.S. Civil Space Program, Volume IV: Accessing Space (Washington, D.C.: NASA SP-4407, 1999), pp. 239-244. In particular, see p. 240 for the flight rate figures. Also see Claude E. Barfield, "Technology Report: Intense Debate, Cost Cutting Precede White House Decision To Back Shuttle," National Journal, August 12, 1972, pp. 1293. The Mathematica analysts originally suggested a two stage, fully reusable Shuttle, but then they concluded that this wasn't cost-effective and advocated a "one and a half stage Thrust-Assisted Orbiter Shuttle." See Roger D. Launius, "NASA and the Decision to Build the Space Shuttle, 1969-72," The Historian, 57 (August 1994), pp. 27-28. This is how the Shuttle is now configured, with partially reusable solid rocket boosters and a non-reusable external fuel tank for the Shuttle's main engine. See Johnson, p. 418, on NASA's willingness to launch virtually all national payloads on the Shuttle.

[22] Robert F. Thompson interview with Stephen Garber, November 14, 2000, pp. 39 and 38. Thompson also said on p. 40 that "the 50 flights per year just sort of got bandied around. It never really affected what we were doing in the program very much, and I never really responded to it very much." Similarly, Aaron Cohen, the orbiter project manager who reported to Thompson at that time, later noted that "I never really paid too much attention to [the high flight rates predicted by Mathematica] when you start talking about 50-60 flights per year, that doesn't even make sense." See Aaron Cohen interview with Stephen Garber, November 15, 2000, p. 22.

[23] Silveira interview, p. 47.

[24] Robert Naka interview with Stephen Garber, December 21, 2000, pp. 29-33.

[25] For a detailed history of these complex machinations, see T.A. Heppenheimer, The Space Shuttle Decision.

program moved forward. The development program was to cost approximately $5.15 billion in fiscal year 1971 dollars through the end of the 1970s.[26]

The military was a key, although not enthusiastic, supporter of the program. The Air Force, which was responsible for launching all U.S. defense and intelligence satellites, had agreed tacitly to support NASA's Shuttle development program. The Air Force's support was only passive at best, since it would not contribute funds to the Shuttle's development but would reap the benefits if NASA's program worked as promised. Thus the Air Force had adopted something of a "wait and see" attitude. Air Force Secretary Robert Seamans, who had been the Associate and Deputy Administrator of NASA during the 1960s, had testified before Congress that 'I cannot sit here today and say that the space transportation system [the Space Shuttle] is an essential military requirement.'[27]

Charles Donlan, the director of the Shuttle program at NASA Headquarters for a short but critical time in the early 1970s, notes that while NASA viewed the Air Force as an "integral partner in this venture," the Air Force was only halfheartedly behind the program. As Donlan points out, one reason the military may not have been enthusiastic about the Shuttle program is simply because the Air Force wanted its own human spaceflight program.[28] Another Shuttle manager, Milton Silveira, recollected that "a lot of us had the feeling that the Air Force was really trying to kill the program rather than support it" in part because the Air Force was responsible for expendable launch vehicles and some military officers thus might have felt that the Shuttle was infringing on their space launch turf.[29] Overall, despite the Air Force's lukewarm at best endorsement, the military's support for the Shuttle proved important.

One of the primary goals of the Shuttle program was to establish a reusable space transportation system that would lower the cost of access to space. When NASA was developing the hardware to reach the Moon, cost was no object; thus the Saturn rockets and Apollo spacecraft worked well but were quite expensive. For many years, space enthusiasts had been calling for better access to space, meaning more reliable and less expensive launch vehicles. The simplest way to decrease the cost of space launches would be to make them routine through the use of reusable launch vehicles. Some analysts used the analogy of a railroad that was forced to use a new locomotive after each trip.[30] Clearly, it would not be economical for the government or for private industry to launch spacecraft until the cost per pound of launch could be brought down through a reusable system and NASA wanted the Shuttle to be that system.

While reusability was meant primarily to lower operational costs, there were also concerns about the development cost of a major new launch system for NASA then. Even after

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[26] See, for example, Humboldt C. Mandell, Jr., "Assessment of Space Shuttle Program Cost Estimating Methods," Doctor of Public Administration dissertation, University of Colorado, 1983, p. 1. This dissertation contains detailed analyses of the Shuttle's development costs.

[27] Johnson, p. 419 and Robert Gillette, "Space Shuttle: Compromise Version Still Faces Opposition," Science, vol. 175, January 28, 1972. The quote is from the latter source, p. 394.

[28] Charles Donlan interview with Stephen Garber, December 11, 2000, pp. 12 and 20. The Air Force had had several major human spaceflight programs such as DynaSoar and the Manned Orbital Laboratory that had been cancelled in the 1960s. In addition, the Air Force ended up spending several billion dollars to create a launch site called Space Launch Complex-6 (SLC-6) at Vandenberg Air Force Base in California specifically for military Shuttle missions, although these facilities were never used. For more information on the SLC-6 story, see, for example, Dennis R. Jenkins, Space Shuttle: The History of the National Space Transportation System, The First 100 Missions (Stillwater, MN: Voyageur Press, 2001), various pages.

[29] Silveira interview, pp. 23-24.

[30] Roger D. Launius, "NASA and the Decision to Build the Space Shuttle, 1969-72," p. 17.

11

Nixon had approved the Shuttle development program, there was intense general budget pressure on NASA. Some people felt that NASA's leadership had become so preoccupied with budget worries that cost had become more important than the Shuttle's basic purpose. One manager recollected James Fletcher, the NASA Administrator from 1971-1977, as saying in more than one meeting, 'hey fellows, I don't care what you build, as long as it doesn't go over one billion dollars of peak annual funding.'[31]

One clear goal of the Shuttle program, however, was that it would be rated for human spaceflight. This meant a level of reliability and safety beyond that of unpiloted expendable launch vehicles (ELVs). Simply put, if an ELV exploded on the launch pad, a great deal of money and effort would be for naught**,** but if a space vehicle with people aboard had a serious accident, lives would be lost and the political fallout would be intense.[32] The stringent safety requirements for human-rated vehicles meant more extensive testing and different engineering designs, two factors that would increase the cost. Thus these first two goals of reusability and human-rating were partially conflicting.

A third requirement that had a critical effect on the Shuttle design was cross-range capability. The military wanted to be able to send a Shuttle on an orbit around the Earth's poles because a significant portion of the Soviet Union was at high latitudes near the Arctic Circle. The idea was to be able to deploy a reconnaissance satellite, retrieve an errant spacecraft, or even capture an enemy satellite and then have the Shuttle return to its launch site after only one orbit to escape Soviet detection. Because the Earth rotates on its axis, by the time the Shuttle would return to its base, the base would have moved approximately 1,100 miles to the East. Thus the Shuttle needed to be able to maneuver that distance "sideways" upon reentering the atmosphere. While some NASA people felt that it was prudent to have cross-range capability as a general safety feature making more aborts feasible, it seems questionable that this requirement would have been fully considered if not for the Air Force's desire for once-around polar orbits over the Soviet Union.

To achieve this cross-range capability, NASA designers were considering either straight or delta wings for the Shuttle orbiter. At a technical level, the choice was simple: delta wings enable much better cross-range capability. Delta wings produce more lift at hypersonic speeds, enabling more maneuverability. Additionally, delta winged vehicles do not heat up as much as straight winged vehicles during atmospheric reentry, thus decreasing the need for expensive and potentially heavy thermal protection systems, although the thermodynamics are too complex to cover fully in this thesis. Moreover, some aerodynamicists argued that delta winged vehicles were a proven technology that provided good balance, stability, and aerodynamic control.[33]

Despite these arguments that eventually prevailed, at least one straight wing design was prominent for a time, in part because of its designer. Max Faget, the chief engineer at NASA's Manned Spacecraft Center (later renamed the Johnson Space Center), drew up plans for two straight winged vehicles - one an orbiter and the other a booster stage- that rode piggyback and were both piloted and fully reusable. Faget had a strong reputation in the aerospace community in large measure because of his design of the Mercury "gumdrop" shaped capsule and his work

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[31] Thompson interview, p. 19.

[32] NASA had already experienced one such galvanizing tragedy on the ground in January 1967, when a fire in an Apollo capsule took the lives of the three astronauts who were inside during tests. After the Shuttle became operational, NASA also experienced the *Challenger* accident in January 1986.

[33] Heppenheimer, The Space Shuttle Decision, p. 213 and Alfred C. Draper, Melvin L. Buck, and William H. Goesch, "A Delta Shuttle Orbiter," Astronautics and Aeronautics, January 1971, pp. 26, 29, 35.

on the Gemini and Apollo spacecraft. Faget argued that his design would enable the orbiter to return to Earth at a sharp angle that would only heat the orbiter's lower surfaces significantly. Without going into extensive technical detail on the thermal effects of different reentry paths, Faget's design was considered for a time largely because of his reputation. Faget acknowledged that his design allowed for a maximum cross-range of 230 miles and that to increase this figure, more thermal protection would be needed, adding precious weight to the vehicle.[34] Given the firm requirement of a greater cross-range capability from the Air Force, however, there was ultimately no place for Faget's straight wing configuration.

A fourth requirement that influenced the Shuttle's configuration was payload bay size. In addition to the Air Force's cross-range demand, the military also wanted a larger Shuttle payload bay than NASA originally advocated. NASA wanted the Shuttle payload bay to accommodate modules for a future space station, which necessitated a payload capacity of approximately 50,000 pounds. The Air Force wanted a bay 15 x 60 feet that could hold 50,000 - 65,000 pounds and that had doors that could open out into space to deploy satellites easily. While the Air Force didn't explicitly say why it wanted this size, many people in the military space community believed it was for classified reconnaissance satellites. Robert Naka later confirmed that the length of the Shuttle's payload bay "was picked because the NRO had an existing satellite that they wanted to have fit."[35]

By virtually all accounts, the military's influence on the Shuttle's design was considerable. Milton Silveira, then the deputy head of the orbiter project office at JSC, recalled that "We had a great deal of pressure I should say from the Air Force, to have the larger payload bay and to have the larger cross range."[36] In discussing the payload bay size, LeRoy Day, who served as the deputy director of the Shuttle program at NASA Headquarters, said that "while the Air Force set the requirements, or asked for that exact size, if we had made it anywhere significantly different from that, then it wouldn't have been very useful for NASA either."[37] Such an assessment also could be applied to the cross-range requirement. Aaron Cohen, the orbiter project manager at Johnson Space Center, concurred with Day's general sentiment when he reflected that "the Air Force did drive some requirements, but when I look back on it, I think that those requirements probably were very, very good requirements even though we might not have recognized it at the time."[38]

In general, NASA acceded to the Air Force's requirements for payload bay size as well as cross-range capability because they made some technical sense. Perhaps more importantly, however, NASA needed the Air Force's support to help insulate it from the political charge that

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[34] Max Faget, "Space Shuttle: A New Configuration," Astronautics and Aeronautics, January 1970, pp. 52-54, 59.
[35] Naka interview, p. 13.
[36] Silveira interview, p. 12.
[37] LeRoy Day interview with Stephen Garber, November 20, 2000, p. 19.
[38] Cohen interview, pp. 15-16. A third opinion on how seriously NASA took the Air Force's requirements for the Shuttle is provided by Charles Donlan, who believes that "the only requirement that we might have done differently is the cross range." See Donlan interview, pp. 16-17. In the distinct minority, Robert Thompson does not believe that the military exerted a significant influence on the Shuttle's design. See Thompson interview, pp. 31-33. He goes so far as to say that "I don't know of a single thing in the vehicle that is there solely because the military wanted it," p. 31.

13

the Shuttle was really just a step towards human exploration of Mars or a permanent space station, which is precisely what some people at NASA wanted it to be.[39]

In practice, the significant payload bay requirement eliminated a stubby-shaped lifting body orbiter configuration from consideration because the Shuttle's fuselage essentially needed to be a large rectangular box with rounded surfaces. The aerodynamics of building such a large vehicle without wings were simply too daunting. Lifting bodies also were rejected for another reason: the invention of lightweight tiles that provide thermal protection. This invention meant that an orbiter with delta wings could still be built light enough to be a viable spacecraft. Thus after the Phase A initial round of configuration selections, NASA rejected lifting body designs.[40]

If it weren't for the payload bay requirement, a lifting body configuration might have worked well. Lifting bodies could have been a good compromise between ballistic capsules and delta or straight winged vehicles. They are lighter, have simpler structures, and encounter fewer reentry heating problems than winged vehicles. Lifting bodies have better lift to drag ratios than ballistic capsules, enabling them to be piloted more accurately. Throughout the 1960s and early 1970s, NASA and the Air Force had conducted significant research on various lifting body programs such as the X-23A and the X-24A, demonstrating, among other characteristics, the maneuverability of wingless vehicles.[41]

In fact, Reed argues that the technology existed in 1971 to put a low-cost reusable lifting body as a space orbiter atop the existing Titan III launch vehicle. Moreover, Reed asserts that around this time when he was an engineer at NASA's Dryden Flight Research Center, he convinced NASA rocket guru Wernher von Braun of the benefits of putting lifting bodies on von Braun's proven Saturn launch vehicles as another low-cost reusable method. One of Reed's superiors at Dryden, Paul Bikle, supposedly rejected the idea because Bikle was trained as an aeronautical engineer and felt that this merging of air and space was beyond the scope of his expertise.[42] Whether or not Bikle's supposed views were actually analogous to those of other managers who were more inclined, even subconsciously, towards thinking about space*planes* rather than wingless spacecraft is an interesting question for future research.

Given these four goals of creating a space transportation system that would: be reusable and thus lower the cost of accessing space, be safe enough for humans to pilot, have 1,100 mile cross-range capability, and have a significant payload capacity, NASA chose a Shuttle with delta wings that seemingly could achieve all these objectives. A straight winged vehicle would not have sufficient cross-range capability. It would be difficult to develop a lifting body vehicle or ballistic capsule with significant payload capacity. The Air Force insisted on certain capabilities, with which NASA concurred, that implied specific design characteristics.

So it might seem that NASA's design choice constituted a rational process of elimination. To a certain extent, this is true, but it also neglects the broader cultural factors that colored the

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[39] Scott Pace, "Engineering Design and Political Choice: The Space Shuttle 1969-1972," master's thesis from the Massachusetts Institute of Technology, April 30, 1982, pp. 199, 111, and 113; Reed, p. 143; and Heppenheimer, The Space Shuttle Decision, pp. 223-224.

[40] Reed, p. 142 and Jenkins, p. 71.

[41] Curtis Peebles, "The Origins of the U.S. Space Shuttle-2," Spaceflight 21 (December 1979), p. 487; Curtis Peebles, "The Origins of the U.S. Space Shuttle-1," Spaceflight 21 (November 1979), p. 439; and Reed, pp. 129-131, 140. In the late 1990s, NASA considered options for an assured crew reentry vehicle, or emergency "lifeboat," for the International Space Station. One of these designs, the X-38, was a lifting body with parachute that is largely based on the X-24A program of the 1960s. See, for example, Reed, p. 188.

[42] Dale Reed, Wingless Flight: The Lifting Body Story (Washington, D.C.: Government Printing Office, NASA SP-4220, 1997), pp. 140-141.

14

14

basic assumptions behind NASA's Shuttle development program. For another cut at how different a Shuttle design could be and still look similar to NASA's, it may be instructive to turn to the basic Soviet Shuttle development story.

- Energiya-Buran Development

On the Soviet side, the advent of the Energiya-Buran system is directly related to the demise of the N1 Moon rocket in the early 1970s. From 1969 to 1972, four consecutive launch attempts of the N1 failed. The Soviet government then cancelled this program in favor of the modular heavy lift vehicle called Energiya. The government assigned this new project to the Energiya Scientific Production Organization (NPO Energiya).[43] Interestingly enough, one significant figure who worked on both the N1 and the Energiya was Boris Gubanov, who worked on the former in its infancy and then served as Chief Designer of the Energiya rocket twenty years later.[44]

In May 1974, a large shake-up of the Soviet space program took place which led to the Buran half of the project. Vasiliy Mishin, who was the chief designer at the influential TsKBEM design bureau, was unceremoniously fired while he was in the hospital. TsKBEM merged with Valentin Glushko's KB EnergoMash bureau to form the powerful new Energiya Scientific Production Organization (NPO Energiya). Glushko then took over this huge new organization, supervising virtually all Soviet human spacecraft, launch vehicles, and reconnaissance satellites. Famed Soviet rocketry pioneer Sergei Korolev had founded the seed of NPO Energiya, but now Glushko had even more power. As one of his first official acts, the vindictive Glushko signed an order suspending all work on the N1 and associated lunar projects. In a single stroke, Glushko had cancelled Mishin's grand plans for space exploration.[45]

Glushko was personally interested in a new super-heavy launch vehicle. Despite many possible scenarios, it was unclear what the prime goal or mission for such a vehicle would be. Nevertheless, designers began some initial work on what became the Energiya launch vehicle in 1974. Soon, however, the military found a purpose for such a vehicle.[46]

Knowing that the U.S. had been moving forward with a reusable Space Shuttle since 1972, the Soviet Defense Ministry was no longer interested in Mishin's plans for lunar bases and the like, but wanted something to compete with NASA's Shuttle. Some people in the Soviet armed forces apparently directly feared the Shuttle's potential military applications. More than this, however, was the apparent desire from the top Soviet political leadership not to be "one-upped" by the United States. A very illustrative story describes how Leonid Smirnov, chairman of the Military Industrial Commission, briefed Leonid Brezhnev on the Space Shuttle, with Brezhnev responding by that the Soviets were not simpletons and thus should find the funds to build an analogue.[47]

Clearly international politics drove the decision to build the Buran. Just as space historians now view the "space race" to Moon during the 1960s through the political lens of the

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[43] Isakowitz, International Reference Guide to Space Launch Systems, (1991), p. 113 and Dennis R. Jenkins, Space Shuttle: The History of Developing the National Space Transportation System, The Beginning through STS-75 (Marceline, MO: Walsworth Publishing Company, 1997), p. 52.
[44] Siddiqi, p. 492.
[45] Siddiqi, pp. 831-832.
[46] See, for example, Siddiqi, pp. 834-835.
[47] B. Olesyuk, "Buran in a Deadlock," Kuranty, December 21, 1991, translated p. 1 and Siddiqi, p. 835.

Cold War, the decisions to build the U.S. and Soviet Shuttles took place in a similar atmosphere of superpower technological competition only a few years later. As the goal of Project Apollo was to put humans on the Moon before the Soviets did, so the goal of Buran was simply to match or exceed the capabilities of NASA's Shuttle. While the Soviet leadership wanted an analogue to the U.S. Shuttle, the system that emerged was not simply a carbon copy and reflected specific Soviet practices and traditions, as this thesis will attempt to show later.

Several different design bureaus came up with proposals to build a Soviet Shuttle, all of which were rather different initially than the U.S. Shuttle's design. Based on his superheavy launcher concepts, Glushko proposed a radical new wingless system called the Reusable Vertical-Landing Transport Craft (RTSVT). This concept featured a crew compartment in the tapered nose cone, a cylindrical main cargo area, and a tapered tail section with thrusters for maneuvering in space. Glushko's team anticipated that this spacecraft would land vertically by parachute.[48]

Vladimir Chelomey, a leading designer at OKB-52 who had worked on military missiles as well as spacecraft, proposed a sophisticated Light Space Aircraft. The MiG design bureau rehashed an old spaceplane concept called Spiral. Brezhnev and other political leaders would have none of this: they wanted a twin of the U.S. Shuttle, regardless of the technical logic or illogic.[49]

On February 17, 1976, the Central Committee and Soviet Council of Ministers signed a formal decree that began the Buran program. Despite shaky interest in the Defense Ministry and government overall, Glushko had succeeded in pushing a formal plan for a Soviet Shuttle through the Communist Party and government. The decree called for the development of an extensive reusable launch system including a launch vehicle, spaceplane, space tug, and complex ground facilities. Despite its relative lack of experience on such projects, Glushko's NPO Energiya organization was put in charge of this effort that turned out to be massive in many ways. The Soviet government, or perhaps Glushko personally, tapped Gleb Lozino-Lozinsky, the former Spiral program head, to lead the Buran effort. Lozino-Lozinsky later commented that the upper Soviet political leadership had forced him to adopt a design that copied the U.S. Shuttle.[50]

Soviet space professionals started looking at the open-source literature on the U.S. Shuttle so as not to reinvent the proverbial wheel. Interestingly enough, the Soviet engineers and analysts soon concluded that the cost figures for NASA's Shuttle were extremely optimistic, if not totally unrealistic. Why did NASA want to build a complex, reusable spaceplane instead of simply using more tried and reliable expendable launch vehicles, wondered the Soviet analysts.

Once they discovered, however, that the Shuttle's cross-range capability was intended to permit the Shuttle to launch from Vandenberg Air Force Base, do a single polar orbit, and then return stealthily to this base, these analysts concluded that the Shuttle's real mission was military.

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[48] Afanasyev, The Unknown Space Ships (Moscow: Znanie Publishers, 1991), translated pp.3-4.

[49] Siddiqi, p. 835.

[50] See, for example, Yaroslav Golvanov, "Just Where are We Flying To?" Izvestiya, December 12, 1991, pp. 1 and 3; December 13, 1991, p. 3; December 14, 1991, p. 3; December 17, 1991, p. 3; and December 18, 1991, p. 3; block translation, translated p. 2 and Boris E. Chertok, Chapter 20: "Valentin Glushko, N1 and NPO Energiya" in Rockets and People: The Moon Race (Moscow: Mashinostroenie Publishers, 1999), translated, p. 34. For Lozino-Lozinsky's comments, see Sergey Leskov, "Buran Goes Into Retirement: Why Russian Experts Are Leaning Toward A New Space Shuttle Project," Poisk 47:3, November 20-26, 1992, translated p. 2.

16

Although they did not fully understand the Shuttle's goals, the Soviets distrusted the Americans' intentions and thus decided to go ahead and copy the Shuttle.[51]

Perhaps hard to fathom in retrospect, many Soviets were fearful of a perceived U.S. Shuttle capability to skip in and out of the Earth's atmosphere and surreptitiously drop a hydrogen bomb on a major Soviet city such as the capital. Boris Chertok, a long-time fixture in Soviet space circles who worked at NPO Energiya, told his team that the U.S. Shuttle "flying peacefully far away from our borders, can throw the missile defense and air defense off-guard and carry out a sudden maneuver…and flying over Moscow, drop a hydrogen bomb weighing up to 25 tons with a strength of at least 25 megatons."[52] Gubanov, the head designer of the Energiya, later wrote that studies conducted by Mstislav Keldysh, the influential head of the Soviet National Academy of Sciences, highlighted this supposed capability and recommended countering this perceived threat by building a similar Shuttle that could launch a nuclear strike.[53] Chertok quoted Keldysh as saying the U.S. could "achieve a decisive military advantage when the Space Shuttle is commissioned and they will be capable of launching a preventive nuclear strike at the vital facilities of our country. And if so, they will make us develop a similar system whether we want it or not."[54] Although Soviet Air Force commanders were frightened by the U.S. Shuttle, apparently Deputy Defense Minister Andrey Grechko wasn't overly concerned, so some of them had gone over his head and appealed directly to Brezhnev and received permission for a loosely-defined Shuttle system.[55]

One Buran participant characterized the Energiya-Buran's goals in four ways, all with a vague but distinctly military tone. The first goal was to counter the Americans' military use of space. Second, Buran was for unnamed defense, economic, and scientific tasks. Third, it supposedly was to conduct military studies to explore possibilities for weapons in space. Last, but not least, the Energiya-Buran system supposedly was to launch, service on-orbit, and return to Earth various spacecraft and cosmonauts. Because these literally voluminous customer requirements were so amorphous, it took a year to define them. The Defense Ministry issued decrees in May 1977 and December 1981 outlining the technical and tactical requirements for the Energiya-Buran.[56]

Some Soviets did envision a broad variety of potential missions beyond military uses for the Energiya-Buran. These missions included assembly flights for a "Mir-2" space station, trips to the Moon, voyages to Mars, lofting satellites into geosynchronous orbit, and unspecified industrial and military uses.[57] The first three of these never to came to pass at all of course, while other boosters have been used for commercial and military satellites. NASA officials and American space enthusiasts had made similar broad-brush predictions for the U.S. Shuttle. Contending that either vehicle could perform almost every conceivable space mission diluted the actual rationale for both vehicles.

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[51] James Harford, Korolev: How One Man Masterminded the Soviet Drive to Beat America to the Moon (New York: John Wiley & Sons, Inc., 1997), p. 314.
[52] Chertok translation, p. 13.
[53] Boris I. Gubanov, The Triumph and Tragedy of Energiya: Reflections of a Chief Designer, Volume 3: Energiya-Buran (Nizhni Novgorod, Russia: Publishing House of Nizhni Novgorod Economic Development Institute, 1998), translated p. 4.
[54] Chertok translation, p. 13.
[55] Golvanov translation, p.2.
[56] Gubanov translation, p. 10 and Golvanov translation, p. 2.
[57] Philip Clark, "What Roles for Energia and Buran?," Interavia Space Markets, March/April 1989, p. 15.

17

Roald Sagdeev, a space scientist who worked for Keldysh, elaborated on the lack of specific technical rationales for development of Buran. The two scientists assembled a workshop to determine if a Soviet Shuttle had any potentially unique capabilities and the simple answer that emerged was a resounding no. Sagdeev contended that the U.S. and the Soviet aerospace industries actually were subverting science. Another academic agreed that the Energiya-Buran was less efficient than other boosters for deploying cargo. Even Gubanov, the Chief Designer of the Energiya, conceded that the payload to take-off weight ratio could be quite low, due to human-rating the vehicle (providing safety features for the crew).[58]

Scientists such as Sagdeev were naturally less interested than military leaders in the international political and national security drivers behind the Energiya-Buran. Worldwide, space scientists often view human spaceflight as a distraction and funding competitor for more "serious" robotic scientific spacecraft, despite the fact that human spaceflight programs typically generate interest, enthusiasm, and thus funding for all space endeavors. Even though not all scientists take such a critical view of human spaceflight, almost by definition all scientists see launch vehicles and spacecraft as means to specific ends, namely conducting scientific experiments and gaining knowledge. Hence we could expect few scientists to support a Shuttle simply for reasons of national security or prestige. So while the Soviet leadership had high respect for Sagdeev and particularly Keldysh, their solid reputations may have been somewhat offset by their biases as scientists.

Perhaps not surprisingly then, Dmitri Ustinov, Secretary of the Central Committee for defense and space issues and Glushko's patron, rejected Keldysh and Sagdeev's carefully worded statement, which indicated that they saw no scientific use for a Soviet Shuttle. His thinking was that even if top Soviet scientists and engineers could not determine a use for a Shuttle, their American counterparts apparently had done so, since they were investing significant funds and personnel on such a project. In short, Ustinov did not want to be caught flat-footed in the future and he even called for a Soviet Shuttle to be bigger than any American counterpart, as if bigger was inherently better.[59]

Sagdeev also contends that even at the "very beginning of the Soviet debates on shuttle-type technology, there was a general understanding that economically reusable transport would be unable to compete with normal rockets [ELVs]." Albeit in retrospect, he also calls NASA's economic models extremely optimistic and unable to prove that a reusable vehicle would be more economical than ELVs. Also after the fact, Sagdeev accurately noted that the Soviets had chosen the classic Cold War reaction of symmetrical response to the U.S. Shuttle.[60]

Despite all this criticism of Energiya-Buran, Glushko had consolidated and vastly expanded his political power base in early 1976, freezing out Chelomey. With the sudden death of his political advocate Grechko, Chelomey had no one who could stand up to his rival Glushko. With Ustinov to support him politically if need be, Glushko quickly cancelled Chelomey's major Almaz space station project and quickly began to agglomerate tremendous overall responsibilities in the Soviet aerospace world.[61]

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58 Roald Z. 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), pp. 212-214 and Peter R. Bond, "The Soviet Snowstorm: Winged Wonder or White Elephant?," Spaceflight, February 1989, p. 51.

59 Sagdeev, pp. 212-214.

60 Sagdeev, pp. 212-213 and Golvanov translation, p. 2.

61 Sagdeev, pp. 208-209.

18

Glushko had largely ignored a considerable body of previous reusable spaceplane work by other prominent Soviet researchers. Interestingly, the same February 1976 decree that officially approved the Energiya-Buran system also put the final nail in the N1-L3 lunar program coffin.[62]

The situation was ironic in several ways. One rationale for canceling the N1-L3 program was the absence of heavy payloads, but the Energiya is a heavy lifter and was partially based on Glushko's previous plans for a super heavy booster. In addition, Glushko elected to use cryogenic fuel for the Energiya booster, after adamantly refusing to do this during the late 1950s and early 1960s, in conflict with Korolev. Glushko's stubborn, jealous nature was also evident in his decision to terminate other successful liquid rocketry projects. He even ordered the destruction of existing N1 hardware and documentation.[63]

NPO Molniya was probably not the ideal organization to tackle such an ambitious project. Instead of subcontracting to the "Mikoyan or Chelomey design bureaus, which had decades of experience in developing hypersonic reusable vehicles," Glushko chose to subcontract to a new organization formed specifically to build the Buran, a copy of the U.S. Shuttle.[64] This NPO Molniya organization, "did not have any experience designing conventional airplanes, not to mention even dreaming of building a spacecraft." Combined with heavy time pressure from political superiors, this inexperience with spacecraft led to sloppy work, especially in such areas as the thermal protection system.[65] While U.S. contractors had great initial difficulties applying their specially designed and crafted ceramic tiles, the Soviets and NPO Molniya in particular had no experience in this difficult technical area and could only attempt to copy American techniques.

Other problems with the construction of the Energiya-Buran system included the thinness of Energiya's walls, which precluded repeated use of the boosters. The Energiya vehicle also ended up weighing more than originally designed, thus decreasing its payload capacity.[66]

Given the Soviet political leadership's desire simply to copy the U.S. Shuttle, it is not surprising that the mission goals for Buran were not clearly identified. The Defense Ministry reluctantly took over the project, but then rejected it as an impractical system. Some engineers believed that the Buran was unlikely to live up to its technical and tactical specifications, such as payload capacity, and that it was unlikely to be launched on short notice as a rapid response weapon.[67] At the same time, there were few civilian payloads in sight for Buran.[68] In retrospect, the economic justifications for NASA's Shuttle clearly were unrealistic and so it is not surprising that the Shuttle has never been able to meet its original goal of routine, cheap access to space for all sorts of scientific and commercial payloads. Once the Soviets realized that such NASA predictions were unlikely to come true, then their inferrance of a military rationale for the U.S. Shuttle seemed all the more logical to them. Unfortunately and ironically, however, the Soviets

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[62] Siddiqi, pp. 836-837.

[63] Siddiqi, pp. 837-838. In the late 1950s, Korolev pushed for liquid oxygen/kerosene fuel for the R7 rocket, while Glushko favored a new propellant called unsymmetrical dimethyl hydrazine. By 1960, they reversed their positions somewhat, with Korolev favoring a qualitatively new approach for heavy lift vehicles and Glushko espousing a more conservative technique of clustering multiple R-9 rockets together. Korolev overruled Glushko, but their feud was divisive in the Soviet aerospace community. Siddiqi, pp. 201, 237-238.

[64] Siddiqi, p. 836.

[65] Golvanov translation, p. 3.

[66] Golvanov translation, p. 4.

[67] Golvanov translation, p. 7.

[68] Olesyuk translation, p. 2.

19

ended up duplicating for political reasons a system they didn't totally understand and this did not bode well for the Buran orbiter.

Similarly, the Soviets continued to search for a technical justification for the super-heavy Energiya booster, which could lift 100 tons into orbit. As late as 1984, people such as Minister of General Machine Building Oleg Baklanov was pushing for Buran simply as a payload for Energiya.[69] One Soviet rocket specialist noted that his colleagues needed to think about what payloads they wanted to put in orbit, instead of developing launchers for their own sake.[70] Launch vehicles should be a means to an end, but what end did the Soviets foresee?

Yuri Semenov, who has been the general director and general designer of NPO Energiya since Glushko's death in 1989, contends that the key driver for a Shuttle system was the rationale that reusability drives down launch costs. While a reusable spacecraft would be more expensive to build initially, supposedly this would still be less expensive than manufacturing multiple copies of a single spacecraft. Writing after Buran's cancellation, Semenov does concede that reusable spacecraft are typically less efficient in boosting payloads into orbit. He also notes that cross-range capability was an important determinant for Buran's configuration. While the Soviets have continued to bring their cosmonauts back from space in ballistic capsules with parachutes that land on terra firma, Semenov writes that vertically landing a large reusable spacecraft with parachutes would be a sketchy proposition due to potentially shifting winds and uneven ground.[71]

Was a winged spaceplane necessary? Semenov writes that he and other engineers determined that wings were not needed for a smooth descent and just added weight. Yet somehow he felt that wings were necessary to ensure the integrity of the orbiter vehicle and a human crew's safety. V.M. Ushakov, who worked with Lozino-Lozinsky, similarly contends that wings, in addition to a tail and the overall vehicle shape, improve aerodynamic balance and enable the Buran to be controllable at the hypersonic, supersonic, and subsonic speeds at which it must fly on reentry. G.F. Naboishchikov, who also worked with Lozino-Lozinsky, reiterates that an emphasis on crew safety and payload integrity, combined with the Soviets' experience in thinking about spaceplanes, led to a Buran design with airplane-like horizontal landings. So supposedly this is why the Buran is configured to look like an airplane, despite the weight and cost penalties.[72]

In general, the Energiya-Buran development effort was off to a slow and rocky start, largely due to ambiguous direction. Internally, Glushko had seemingly suddenly amassed significant power in a research area about which his new organization knew precious little. Personal influence or lack of it, hardly unknown in the U.S. either, brought in relative neophytes and excluded people experienced in reusable spaceplane concepts. Externally, the Soviet program was driven by the Cold War desire not to fall behind in what seemed to be a potentially important military technology, the Space Shuttle. While the Soviets were perhaps limited by their political leadership's simplistic desire for an exact replica of the Shuttle, they did benefit

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[69] Sagdeev, p. 261.

[70] Chertok translation, p. 21.

[71] Semenov, translated pp. 35-47.

[72] Semenov, translated pp. 35-47; V.M. Ushakov, "Development of Orbiter Spacecraft Configuration" in G. Ye. Lozino-Lozinsky and A. G. Bratukhin, eds., Aviatsionno-kosmicheskiye sistemy: sbornik statey (Moscow: MAI, 1997), translated p. 2; and Naboishchikov, "Major Aspects of Aerodynamic Design of Buran Orbiter Spacecraft" in G. Ye. Lozino-Lozinsky and A. G. Bratukhin, eds., Aviatsionno-kosmicheskiye sistemy: sbornik statey (Moscow: MAI, 1997), translated p. 1.

20

from being able to access the voluminous design studies and other open-source U.S. Shuttle documentation that already existed. Nevertheless, one source notes that serious development work on the Energiya program didn't get underway until 1980.[73]

Eventually, after seven more years, the first Energiya launch took place on May 15, 1987. The Energiya launch vehicle carried a Polyus cargo container, not the Buran orbiter, as the payload. The cargo container inadvertently fell into the Pacific Ocean, but the Energiya launch itself was successful.[74]

In addition to preparing for uncrewed Energiya launches, in the late 1980s the Soviets had also been busy preparing for Buran flights. The Soviets conducted as many as 20 atmospheric approach and landing tests for the Buran with a test orbiter equipped with jet engines for go-around capability.[75]

Finally, the first and only Buran launch took place on November 15, 1988. Riding to orbit aboard the Energiya from the Baikonaur Cosmodrome in Tyura-Tam, Kazakhstan, the Buran made two orbits and then touched down after three hours. Apparently, the Buran orbiter would have passed directly over the launch site on its third orbit, but controllers wanted to demonstrate its cross-range capability without stressing its other systems too heavily. Two other landing sites were still being constructed, one in the Crimea and one in the East, to give controllers the flexibility to bring the Buran back from a variety of orbits.[76] Mikhail Gorbachev, the Soviet leader at the time, did not even watch the launch, although he had visited Baikonaur shortly before the first Energiya launch. Neither did Glushko, who had become ill in the late 1980s and died in January 1989, shortly after the Buran's flight.[77]

Even after its sole flight, the Energiya-Buran was not immune to criticism. Perhaps ironically, Igor Volk, leader of the Buran pilots, was particularly vocal in his faultfinding. He contended that the Buran's flight control system had significant problems and that its one landing was not as smooth as it looked on video. Apparently Buran's flight deck had blank computer screens because no software had been designed for them! Moreover, Volk noted that the mission only flew two orbits because there wasn't sufficient computer memory for a longer test flight. While the Buran flight was robotic, apparently the life support and other critical systems were not operational. Despite the cross-range flexibility that the delta wings provided, the Buran had had only one preplanned reentry trajectory and one landing site. Volk candidly noted that the 'purpose of the program hasn't really been established yet' and that the decision for the Buran launch was purely political.[78]

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[73] Kidger, p. 4

[74] See, for example, Marcia S. Smith, Space Activities of the United States, CIS, and Other Launching Countries/Organizations: 1957-1994 (Washington, D.C.: Congressional Research Service, July 31, 1995), p. 119.

[75] Nicholas L. Johnson, The Soviet Year in Space, 1988 (Colorado Springs, CO: Teledyne Brown Engineering, 1988), p. 114 and Johnson, The Soviet Year in Space, 1990 (Colorado Springs, CO: Teledyne Brown Engineering, 1990) p. 18.

[76] Johnson, The Soviet Year in Space, 1988, p. 113 and Christian Lardier, translation of Buran and other spaceplanes chapter, L'Astronautique Sovietique (Paris: Armand Colin, 1992), p. 249.

[77] Victoria Loguinova, "Buran Ends Its Days as Theme Park Attraction," April 25, 2000, http://www.spacedaily.com/news/buran-00a.html, accessed September 25, 2001; Soviet Space Programs: 1981-1987, Piloted Space Activities, Launch Vehicles, Launch Sites, and Tracking Support (Washington, D.C.: Senate Committee on Commerce, Science, and Transportation, May 1988), p. 249; and Siddiqi, pp. 849-851.

[78] Kathy Sawyer, "Soviet Shuttle's Mission Undefined," The Washington Post, April 30, 1989, p. A1 and A10 and Kidger, pp.4-6.

21

Marcia Smith, a well-respected analyst at the Congressional Research Service, agreed that while the launch demonstrated its capability at some level, questions still remained about its ultimate purpose. In particular, the Soviets' stated desires to build several orbiters but only launch two to four Buran missions per year did not jibe with each other. Thus, she felt that it was 'hard to see how this is going to fit into their program.' The Energiya-Buran program supposedly accounted for $2 billion out of a total $11 billion that the Soviets spent on space activities in 1989, "an enormous price for a spacecraft with no clear mission."[79]

Despite its numerous technical problems and unclear mission, why did the Buran fly only once? The Soviets never publicly gave a clear answer. Approximately six months after its flight, Soviet officials ambiguously said that it was being grounded after a reassessment of its economic and technical feasibility, while not directly admitting any specific problems. Apparently it needed significant work before it would be human-rated: the electronics needed to be upgraded and life-support equipment needed to be installed.[80]

By December 1990, however, the Soviets had apparently changed their minds again and were supposedly planning on a second uncrewed flight, this time to the Mir space station, in late 1991. Complicating the picture further, around this same time there were also murmurs of at least some preliminary work on a follow-on Shuttle vehicle called Molniya, but very little came of this.[81]

With the end of the Cold War and the dissolution of the Soviet Union, the Energiya-Buran program petered out politically and finally ground to a halt in 1993 and 1994. The Council of Designers formally canceled the program in June 1993 and five months later, Yuri Koptev, head of the Russian Space Agency, ordered the mothballing of the Buran. In mid-1994, the Russian government cancelled funding even for "active storage" of Buran. Then in August 1994, the Russian Space Agency and Defense Ministry decided to build a new heavy-lift booster called Angara-24. While this new program went nowhere itself, it did put the final nail in the coffin for the Energiya booster. The one Buran orbiter which had actually flown in space and the other spaceflight-worthy orbiter, as well as an Energiya launch vehicle, were mothballed in poor condition at Baikonaur. One of the five Buran test articles was displayed in a Moscow theme park in 1995.[82]

By the time it was cancelled in 1993, Energiya-Buran was the most expensive aerospace program in Soviet history. Analysts have pegged the total costs at 14 billion up to as high as 20 billion rubles. As a very rough guideline, the official ruble-dollar exchange rate during much of the 1970s was approximately one to one. For comparison's sake, the U.S. Shuttle development costs were approximately $11 billion in real-year (non-inflation adjusted) dollars, which turned out to be not much over the $5.15 billion in 1971 dollars that was originally budgeted. While the

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[79] "Soviet Shuttle Role Unclear, U.S. Analyst Says," Aerospace Daily, November 18, 1998 and Smith, p. 46. Smith notes in her publication, p. 46, that after the Buran's initial flight, the Soviets stated that they would only launch Buran once a year after the test phase was over.

[80] "'Buran' Grounded for Economic, Technical Reasons," FBIS-SOV-89-099, May 24, 1989, p. 71 and Brian Harvey, Russia in Space: The Failed Frontier (Chichester, United Kingdom: Springer Publishing and Praxis Publishing, 2001), p. 35.

[81] "Soviets' Next Shuttle Flight To Include Docking at Mir," Aviation Week and Space Technology, December 10, 1990, p. 24 and "New Soviet Shuttle," Space, November-December 1990, p. 56. This latter article references a Pravda article of September 1. Johnson, The Soviet Year in Space, 1990, p. 21, indicates that Soviet designers envisioned the Molniya being air-launched from the large AN-225 airplane.

[82] Peter Pesavento, "Russian Space Shuttle Projects, 1957-1994 (Part 4)," Spaceflight, August 1995, p. 266; Harvey, p. 36; Smith, p. 46; and Loguinova.

22

Salyut and Mir space station programs garnered much public attention during the 1980s, Energiya-Buran actually was spending significantly more money. While to some degree the program built upon earlier efforts such as Spiral, it also wasted considerable funding through cost overruns and futile research efforts.[83] Given that Energiya flew twice and Buran only once, one would be hard pressed to say that the development money produced much in the way of tangible results.

It is worth noting that while the Buran orbiter was largely based on the U.S. Shuttle and previous spaceplane work in the Soviet Union, the Soviets developed the Energiya launch vehicle largely from scratch rather than adapting previous Soviet ELVs. In particular, it was the Soviets' first significant use of liquid, cryogenic fuelled rockets. Glushko had feuded with Korolev in the 1960s over whether to use liquid or solid fuel for heavy boosters and now, in different political circumstances, Glushko had changed his mind. Glushko also went out of his way to discount previous Soviet spaceplane efforts and wipe the slate clean for his political agenda. Starting from scratch was not in keeping with Soviet technological style, although ironically it was similar to NASA's building new SSMEs instead of adapting, for example, the successful Saturn rocket engines.

This episode of the Soviets seemingly uncharacteristically choosing to create a new system rather than adapt an existing one can also be seen as the importance of dominant personalities in Soviet politics and in this case, specifically Glushko's. He was known to be a vain, vindictive person who, despite his long experience in rocketry and space systems, often made decisions based on personal feelings instead of technical criteria. As a teenager, Glushko had corresponded with Konstantin Tsiolkovsky, one of three international founders of rocketry, but when Korolev became the dominant figure in the early Soviet space efforts, Glushko became jealous of his peer and developed an "inferiority complex." He also was infamous for his self-glorifying attempts to rewrite history. When he was editor in chief of the Encyclopedia of the Cosmos, Glushko portrayed himself as the heir apparent to Tsiolkovsky and excised most of Korolev's enormous contributions.[84] At the zenith of his career, Glushko had "a hand in the editorial supervision of all books related to space exploration [and] made sure that his role and contributions to the development of Soviet space technology were placed in a favorable light."[85] Throughout his career, Glushko had accumulated a number of prominent rivals such as Korolev, Chelomey, and Mishin and he did not hesitate to attack them when he safely could. Whatever one's personal view of Glushko, it is clear that once he had consolidated his power in 1974, he

[83] Siddiqi, p. 841 uses the 14 billion ruble figure. Sergey Leskov, "Buran Goes Into Retirement: Why Russian Experts Are Leaning Toward A New Space Shuttle Project," Poisk 47:3, November 20-26, 1992, translated p. 2 notes that "expenses for Buran already exceed[ed] 20 billion rubles" in 1992. Sagdeev, p. 312, asserts that approximately 20 billion rubles were spent leading up to Buran's sole flight. In dollar figures, Henry Matthews, The Secret Story of the Soviet Space Shuttle (Beirut: 1994), p. 74, writes that that it cost approximately 25 billion dollars to develop the Energiya booster and another 8 billion dollars to develop Buran, although it is even more difficult to assess the accuracy of figures not in rubles. The $11 billion in development costs for the U.S. Shuttle is derived from Ihor Gawdiak with Helen Fedor, NASA Historical Data Book, Volume IV: NASA Resources 1969-1978 (NASA SP-4012) (Washington, D.C.: NASA History Office, 1994), p. 145 and Judy A. Rumerman, NASA Historical Data Book, Volume V: NASA Launch Systems, Space Transportation, Human Spaceflight, and Space Science, 1979-1988 (NASA SP-4012) (Washington, D.C.: NASA History Office, 1999), p. 256. For a detailed analysis of NASA's development costs for its Shuttle, see Mandell, "Assessment of Space Shuttle Program Cost Estimating Methods."

[84] Sagdeev, p. 182

[85] Siddiqi, p. 849.

23

was a prime mover of the Energiya-Buran. The flip side of this is that once he and the Cold War both died, there was no strong proponent to push the Soviet Shuttle program along.[86]

Despite the political intrigue that damaged the Energiya-Buran's initial development program, the project did have certain technical advantages in its favor such as potential modularity. Like many other Soviet aerospace projects, it was designed in a modular fashion that could increase interoperability, flexibility, and reduce costs. The Buran orbiter was just one payload that could ride aboard the Energiya ELV. Designers envisioned building medium, heavy, and super-heavy Energiya versions that could launching payloads weighing from 10 to 200 tons. The rockets would differ from each other simply in the number of identical engine modules in each stage, making factory production and assembly easier.[87]

More broadly, others have questioned the need for the Energiya-Buran system. In comparison with Korolev's need for the N1 rocket to get Soviets to the Moon, the Energiya indeed lacked a defining purpose. Ironically enough, one source even reported suggestions that the Energiya could be used to loft into orbit components for Space Station Freedom (now called the International Space Station).[88] As one Soviet author succinctly put it, "What was the problem to which Energiya had to bring a solution?" and "What are we going to carry with Buran? What specifically?"[89]

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[86] Thanks also to William Barry of NASA Headquarters for his general thoughts on Glushko.
[87] Gubanov, translation, p. 17 and Chertok translation, pp.17-18.
[88] Smith, p. 119.
[89] Golvanov translation, p.6.

24

Chapter Three: The Impact of Culture

The impacts of cultural factors or technological styles are more subtle than some political factors, but equally significant. To begin, it may be useful to think about international conceptions of spaceplanes that date back prior to the start of the space age in 1957 since this rich history of spaceplane concepts may have, at least subconsciously, influenced the Shuttle designers choice of a complex, winged configuration. Traditional Soviet and American attitudes towards technology help explain differences in the Energiya-Buran and U.S. Shuttle systems. Engineers at NASA, perhaps the quintessential high-tech organization in the U.S. government, valued sophistication in design and had gotten accustomed to large budgets, which enabled them to spend their way out of technical problems. Their Soviet counterparts were skilled in adapting existing technologies quickly and inexpensively to meet demands for large, showy machines. These attitudes led the Soviets to focus on expendable boosters, for example, while Americans have tended to be obsessed with reusability. In short, cultural factors narrowed the range of design options that Soviet and American engineers discussed before they even decided on their respective final configurations.

- U.S. Technological Style and the Space Shuttle

Since the early twentieth century, aeronautical engineers have dreamed of developing an airplane that could fly into Earth orbit by taking off and landing horizontally on a runway. The German rocketeer Max Valier had simply suggested adding rockets under the wings of conventional airplanes such as the Junkers G-23 transport. Valier was conducting research on rocket-propelled gliders in the years leading to his accidental death in 1930.[90]

Eugen Sanger, who some have viewed as the father of the reusable spacecraft, designed a "Silver Bird" rocket-plane with wings as early as 1933. Sanger was trained as an aeronautical engineer and got his inspiration from similar work done by Franz von Hoeff, Valier, and other earlier European figures. Irene Sanger-Bredt, his colleague and wife, wonders explicitly why "manned spaceflight did not evolve gradually and consistently from aviation." She concludes that the main factor pushing the development of ballistic capsules was the World War II legacy of military missiles. Sanger-Bredt also contends that her husband and other designers were certainly aware of the ballistic capsule approaches that Robert Goddard, Hermann Oberth, and Konstantin Tsiolkovsky, the three giants of early rocketry, envisioned. But certainly if it were ever possible to create a viable plane that could take off and land like a conventional airplane and go into Earth orbit, this could be much more economical and thus Sanger took that approach.[91]

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[90] Richard P. Hallion, "The Path to Space Shuttle: The Evolution of Lifting Reentry Technology," Journal of the British Interplanetary Society, 30 (December 1983), pp. 523-524.

[91] Irene Sanger-Bredt, "The Silver Bird Story," Spaceflight 15 (May 1973), pp. 166-170. The quotation is from p. 167. The technological challenges of building such a vehicle are still quite daunting. One of the latest efforts was a joint effort between NASA and the military in the late 1980s and early 1990s called the National Aerospace Plane (NASP). The NASP program made some significant breakthroughs in developing necessary advanced technologies, but was widely considered a failure and was cancelled by Congress because, among other reasons, it failed to produce any prototypes that could fly in the atmosphere, let alone into space and back.

25

During World War II, the Germans developed the V-2 rocket and worked on winged missiles such as A-9, A-10, and A-4. Sanger took note of these developments and continued to refine his Silver Bird concept accordingly after World War II.[92]

Despite the ballistic rockets developed by the military during World War II, many leading aerospace figures continued to envision winged space vehicles. In 1951, for example, Wernher von Braun wrote of winged rockets. The next year, Collier's magazine published a well-known series of articles by von Braun that proposed a space station tended to by a three-stage rocket, the third stage being a winged glider for crew reentry. Then the Air Force funded the Bell Aircraft Company, under the leadership of former German military rocket experts Walter Dornberger and Krafft Ehricke, to do some limited research on a piloted bomber-missile called Bomi that entailed a two-stage vehicle where both stages had delta wings.[93] In the 1960s, the Air Force sponsored a relatively short-lived program called Dyna-Soar (for dynamic soaring) which featured a winged, piloted vehicle that would be launched into Earth orbit aboard a Titan launcher.

Thus when it came time to design the U.S. Shuttle, there was a long history of people designing winged vehicles to go into orbit. Noted NASA engineer Max Faget wanted a straight-winged vehicle that was somewhat similar to Bomi.[94] This seemed to be a natural technological progression, despite the obvious fact that wings serve no purpose in airless space. Interestingly, Faget pushed hard for his straight winged design even though he was the one who had designed the Mercury, Gemini, and Apollo ballistic spacecraft. Dale Reed, a NASA engineer who worked extensively on lifting bodies, claims that Faget had been promoting a parachute system for a larger Gemini ballistic capsule until he became convinced relatively late in the design process that horizontal landings were superior for the Shuttle and then switched firmly to the straight-winged design.[95]

Faget was clearly a leader in his field and liked to do things his particular way. As one historian noted, "one element of Faget's inventive style was to search entirely new ways of doing things." He also tended to suffer from the "not invented here" syndrome. Max Hunter, another leading spacecraft designer who worked for Lockheed instead of NASA, noted that his team spent much time "trying to get Faget to 'invent' the Lockheed design," which featured a one-stage, fully reusable spacecraft with an expendable fuel tank called the Star Clipper. Faget's penchant for complex, sophisticated designs led him to reject the Lockheed plan, in favor of General Dynamics' so-called Triamese, which featured two reusable boosters for a single spacecraft. Not surprisingly, NASA did not adopt this complex plan.[96]

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[92] E.P. Smith, "Space Shuttle in Perspective — History in the Making," American Institute of Aeronautics and Astronautics Paper 75-336, pp. 1-2.

[93] Wernher von Braun, "Multi-Stage Rockets and Artificial Satellites" in John P. Marbarger, editor, Space Medicine: The Human Factor in Flights Beyond the Earth (Urbana, Illinois: University of Illinois Press, 1951), pp. 22-23; E.P. Smith, p. 6; Jenkins 1993, pp. 11-12; and Peebles, November 1979, pp. 435-436.

[94] Jenkins 1993, p. 67.

[95] Reed, p. 142.

[96] Joan Lisa Bromberg, NASA and the Space Industry (Baltimore: Johns Hopkins University Press, 1999), pp. 79-84. The two quotations are from pages 83 and 80, respectively. Interestingly, the Star Clipper design came to life again in the 1990s, when NASA contracted with Lockheed Martin on the X-33 project, whose configuration was remarkably similar. The X-33 was supposed to be a successor launch system for the Space Shuttle but it encountered significant technical problems with its composite materials and engine design and was ultimately cancelled.

26

Faget was forced to modify his beloved two-stage design in which both stages had straight wings once it became clear that the price for the Air Force's political support of the Shuttle would be NASA's accession to the cross-range requirement. This cross-range capability dictated delta, rather than straight, wings for the Shuttle orbiter for technical reasons. The Shuttle System also ended up with two solid rocket boosters and an expendable fuel tank. While a ballistic capsule or wingless lifting body would have sufficient cross-range capability, there would have been insufficient payload capacity.

In short, NASA ended up developing as President Nixon called it, an "entirely new type of space transportation system" instead of modifying proven technology.[97] Was this really necessary? One answer can be derived by looking at NASA's particular organizational culture. Since its founding, NASA had fostered a culture in which employees embraced risk so that they could anticipate and prevent technological failures.[98] This "frontier culture" led NASA employees to adapt technologies in new ways, but also to design new tools to accomplish difficult tasks.

Although one NASA professional said that in general 'We didn't try to invent new technologies for the sake of inventing new technologies,' in the case of Shuttle development, it is certainly possible that designers had precisely this mentality embedded in their training enough that at least some designers subconsciously wanted to create something new.[99] A top Shuttle manager noted that NASA had a "desire to conceive a new program to move forward with something."[100]

Another related argument is that some people in NASA and the Air Force viewed the Shuttle as a program for technology development, almost more than for space transportation itself. While this may be something of an exaggeration, it does fit with NASA's organizational proclivity for pursuing high technology.[101] As one anonymous Administration official at the time remarked, 'NASA's a high-technology agency --[then NASA Administrator James] Fletcher could curb but he couldn't eradicate the desire to go for a complicated new technology "because it's there."'[102]

Robert Truax, a former naval officer with considerable rocketry experience and a somewhat radical reputation, echoes this theme in a slightly different way. In a brief 1970 article (before NASA finalized the Shuttle configuration), he argues that NASA was preoccupied with finding an "elegant" solution despite the viability of other options. Focusing on the linked goals of reusability and cost, Truax contends that Apollo or Gemini ballistic capsules would work fine and would save money by virtue of their simplicity. He explains this by noting that ballistic capsules have lower overall heating rates due to shorter heating times than either lifting bodies or winged planes, so relatively minor modifications in the capsules' heat shields could be made to

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[97] "Statement Announcing Decision to Proceed With Development of the Space Shuttle, January 5, 1972," The Public Papers of the Presidents of the United States: Richard Nixon, 1972 (Washington, D.C.: Government Printing Office, 1974), p. 20. Nixon also said a few paragraphs later on the same page that the "new system will differ radically from all existing booster systems" in its reusability.

[98] NASA was founded in 1958. Its predecessor, the National Advisory Committee for Aeronautics (NACA), began in 1915 and also embodied a high-tech, cutting-edge research culture.

[99] McCurdy, Inside NASA, pp. 64-65, 76-77. The quotation is from p. 76.

[100] Robert F. Thompson interview by Edward C. Ezell, May 12, 1981, p. 2.

[101] See Milton Silveira interview by Stephen Garber, November 9, 2000, pp. 14 and 26. On p. 14, Silveira says, "one of the reasons that we were doing programs in NASA [was] to develop technology."

[102] Claude E. Barfield, "Technology Report: Intense Debate, Cost Cutting Precede White House Decision to Back Shuttle," National Journal, August 12, 1972, p. 1295.

make them less expensive or reusable. Truax dismisses another purported "advantage" that vehicles with higher lift to drag ratios such as winged planes and lifting bodies enjoy, namely the larger "footprint" or selection of a larger number of landing sites from a particular deorbit, by noting that most of the Earth's surface is water. Unlike lifting bodies or winged airplanes, ballistic capsules, can splash down in water or be rigged to land with parachutes on ground that is not a smooth runway, even in poor weather. One minor disadvantage of ballistic capsules is the high G forces that they experience upon reentry, but Truax discounts this as relatively unimportant unless frail people were to go into orbit. He also dismisses a flyback booster that would be used in a two-stage-to-orbit, fully reusable scheme as an excessively complicated solution that would save little money or time. Truax concludes by noting that the only advantage of a reusable flyback booster is its graceful sophistication over the splashdown method, but he wonders "how much are we willing to pay for elegance?"[103]

Truax's argument for ballistic capsules is itself elegant in its articulate brevity. Yet one important flaw exists: ballistic capsules would have been problematic to design with sufficient cargo capacity. Nevertheless, Truax's analysis brings out the broader point that NASA may have defined its options in too limited a manner. E.P. Smith points out, for example, that during the 1960s, designers came up with various spaceship proposals involving paragliders, deployable rotors, and other more esoteric designs that turned out to be too complex.[104] Truax essentially argues that some of the socially constructed criteria were unnecessarily restricting and that perhaps there was another, simpler way to achieve NASA's goals.

At a political level, the creation of an exciting new space vehicle would have been reason enough for NASA to push for Shuttle development at a time when the space agency's budget faced severe future cutbacks. A new space program also meant jobs in industry and thus votes during the upcoming November 1972 presidential election. The Nixon Administration was fully cognizant of the key electoral votes that California, a bastion of the aerospace industry, held.[105] While such a political analysis speaks mostly to garnering support for the Shuttle program as a whole, if the Shuttle had been largely an adaptation of earlier spacecraft programs, it might well have been less expensive and thus generated fewer jobs.

Overall, such arguments about NASA's culture of high technology and the U.S. technological style of invention are germane to the Shuttle's winged configuration because if not for these factors, NASA might have realized another wingless way to achieve its goals. Even if the ballistic capsule approach for the spacecraft wouldn't have been practical for larger payloads, for example, why not adapt the proven rocket technology of the Mercury, Gemini, and Apollo programs?

Indeed, some important people in the U.S. space community saw the value of adapting existing technology. During the critical period of decision, the Office of Science and Technology in the White House and a special PSAC panel both favored an evolutionary approach to Shuttle development based on a reusable version of the Apollo or Gemini spacecraft and an ELV.[106] In 1969, NASA's Space Shuttle Task Group looked at putting a reusable orbiter atop an existing ELV such as a Titan III or Saturn 1B rocket, but instead decided to try for a

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[103] Robert C. Truax, "Shuttles—What Price Elegance?," Astronautics and Aeronautics, June 1970, pp. 22-23.
[104] E.P. Smith, p. 6.
[105] Barfield, pp. 1289, 1294.
[106] Logsdon, “The Decision to Develop the Space Shuttle,” p. 24 and Barfield, p. 1289.

fully reusable, two-stage-to-orbit configuration, which proved to be too technically challenging.[107]

It is worth noting that these arguments about NASA's culture and the U.S. technological style of innovation and invention do not necessarily contradict the notion of aerospace designers at the time wanting, even subconsciously, to build a space *plane* with wings. While NASA had a reputation as a high technology agency, its engineers were largely schooled in aeronautics because in the late 1960s and early 1970s, spacecraft were barely a decade old. Thus, there was an urge to develop new technologies for space, but it may well be that the designers' thinking was still limited by what many of them knew best, namely aeronautics.

One design area in which the duality between air and space travel came out was in the cockpit and flight controls. NASA designers faced an interesting dilemma: whether to design the Shuttle as an airplane or a spacecraft since it would obviously function as both. Initially, engineers considered creating *two* separate cockpits: one for the crew to use during air flight and one to use during spaceflight. Designers quickly realized how complex, cumbersome, and physically heavy such a set-up would be and settled on a single, integrated cockpit where the crew can control the vehicle in air and space.[108] The notion that designers would even consider designing multiple cockpits for a single vehicle is a very interesting and telling comment on NASA's technological style which favored sophistication over simplicity.

Despite this initial misguided design foray, the Shuttle's avionics system turned out to be a major technological advance. While NASA engineers had designed electronic fly-by-wire controls systems for the Mercury, Gemini, and Apollo spacecraft programs, few airplanes used fly-by-wire in the 1970s, when the Shuttle was being developed. One reason for the advanced avionics was safety. Because the Shuttle orbiter is not very stable inherently and is intolerant of erroneous flight commands for even very short periods of time, the designers created an integrated, digital avionics systems with multiple, parallel subsystems to ensure computerized control of the orbiter at all times. The on-board avionics system is sophisticated enough to handle many tasks that on previous spacecraft projects, were handled by ground crews. Previous aircraft and spacecraft redundancy procedures consisted of primary and back-up systems, rather than multiple parallel systems utilizing computers which simultaneously handled multiple sensor inputs. The Shuttle's digital fly-by-wire (DFBW) avionics system was truly groundbreaking and its innovative nature enabled airplane manufacturers to incorporate such sophisticated systems in military and commercial planes thereafter.[109]

In addition to the DFBW system, the Space Shuttle Main Engines (SSMEs) were a major innovation. Each Shuttle orbiter houses three SSMEs, which operate simultaneously ("parallel burn"), in contrast to the staged engines in the Apollo Saturn rockets which ignited in sequence ("series burn"). In addition, the Shuttle engines are throttleable, unlike the Saturn or Titan

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[107] Jenkins 1993, p. 49. Other examples of reusing Apollo spacecraft and Saturn rockets were the Apollo Applications and Skylab programs. The former program focused on "spin-off" technology but never materialized into a significant effort. Skylab used excess Saturn rocket stages to create an orbital workshop in 1973 that gave NASA much information about the physiology of long-duration human spaceflight.

[108] Hanaway and Moorehead, p. 17.

[109] Hanaway and Moorehead, pp. v-vi, 6, and 47. For an excellent general discussion of the importance of NASA's innovations in DFBW technology, see James E. Tomayko, Computers Take Flight: A History of NASA's Pioneering Digital Fly-By-Wire Project (NASA SP-4224, 2000). Chapters 6 and 7 of Tomayko's book deal specifically with the Space Shuttle and DFBW.

29

engines. The SSME is the most efficient liquid rocket engine ever designed and has performed extremely reliably over time.[110]

The Shuttle's Thermal Protection System (TPS) of specially manufactured ceramic tiles was a third major technological innovation. Ablative heat shields, such as those on the ballistic capsule spacecraft of the 1960s, would not work on the Shuttle because they would be much too heavy and were not reusable. So NASA selected ceramic tiles and over 20,000 individual tiles were manufactured to conform to specific small areas of the orbiters. Remarkably, a technician could heat one of these tiles to extremely high temperatures on one side and hold it on the other side comfortably without a glove. Unfortunately, attaching the tiles and keeping them securely on the orbiters proved to be an enormous, unexpected challenge. Eventually engineers solved this problem with persistence and a special glue.[111] The TPS tiles turned out be a very innovative solution to a problem that all spacecraft which reenter the Earth's atmosphere face and the Soviets ended up copying the ceramic tile technology for the Buran.

Thus, in creating the Shuttle, NASA came up with three major technological innovations: the SSME, DFBW, and TPS. Of these, the Soviets ended up adopting only the TPS tiles. Not only were other technical design options possible, some of these other possibilities were in fact exercised by the Soviets.

The Shuttle's technological innovations were important for several reasons: they made the Shuttle possible, they were adapted for other U.S. and Soviet airplanes and spacecraft, and they are indicative of NASA's technological style. NASA is indeed a high-technology organization and many of its engineers are interested more in pushing the edge of the technology envelope for its own sake than in adapting existing technologies. The influence of many historical designs for winged spaceplanes also had a significant, although not necessarily deliberate, influence on the Shuttle's configuration. As Truax contends, it seems fairly clear that NASA was perhaps too focused on an overly elegant design that emphasized reusability and new technologies over adaptation of existing, reliable systems.

In fact, the U.S. has looked back at its Shuttle's complex reusable design and reassessed more than once. After the *Challenger* accident in 1986, NASA considered a plan called Shuttle-C (for cargo) that entailed modifying the Shuttle to become an expendable vehicle that would not launch people into orbit.[112] Perhaps even more telling, one experienced aerospace professional remarked in the late 1980s that if NASA were to do Shuttle over again, the space agency would probably design an unpowered orbiter riding atop a large ELV.[113]

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[110] See Henry C. Dethloff, "The Space Shuttle's First Flight: STS-1," in Pamela E. Mack, editor, From Engineering Science to Big Science: The NACA and NASA Collier Trophy Research Project Winners (Washington: Government Printing Office, NASA SP-4219, 1998), p. 287. For general information about the SSME, see such works as Harald Kranzel, "Shuttle Main Engine Story," Spaceflight, October 1988, pp. 378 and 380; T.A. Heppenheimer, "27,000 Seconds in Hell," Air and Space Smithsonian, October/November 1998, pp. 75-81; and Donald F. Robertson, "What Future for SSME?," Space, October 1993, pp. 24-28.

[111] See, for example, Cohen interview, pp. 60-64, for an account of the problems getting the tiles to adhere to the orbiter. For general information about the innovative TPS, see such works as Paul A. Cooper and Paul F. Holloway, "The Shuttle Tile Story," Astronautics and Aeronautics, January 1981, pp. 24-36 and Bruce A. Smith, "Space Shuttle First Launch: Thermal Protection Examined," Aviation Week and Space Technology, April 27, 1981, pp. 26-34.

[112] See, for example, Frank Colucci, "Shuttle-C Loads Up," Space, March-April 1988, pp. 20-23.

[113] Wilford, November 22, 1988, p. C10. The aerospace professional was Jerry Grey, an official at the American Institute for Aeronautics and Astronautics.

30

Nevertheless, NASA has continued to emphasize reusability in its future launch vehicles, even for non-human payloads, to the puzzlement of many observers. For example, the financially and technically troubled X-33 program ended with few positive results. Truax has written extensively on the desirability of designing separate launch vehicles for humans and cargo. The former should be highly reliable and reusable, while the latter could be expendable, yet functional and less expensive than a reusable spacecraft. As former Shuttle manager Bob Thompson points out, "people assume if it's reusable, it's cheap …[but] if that was true with everything, why do we have Dixie cups?"[114]

While NASA obviously continues to use ELVs for many space payloads that do not need human tending, it is also true that NASA has continued to focus on reusability as the key to lower costs for access to space in general since the early 1970s. This has proved to be an elusive goal. In terms of the Shuttle's development history, however, two prime factors account for NASA's focus on reusability: wishful thinking in terms of high future launch rates and an organizational culture that encourages overly innovative, elegant design solutions.

- Soviet Technological Style and the Energiya-Buran

Did the Soviets feel that a winged spaceplane was necessary or excessively complex? In thinking about this question, it is important to remember that the Soviets, like the Americans, also had a long interest in spaceplanes. In the early 1960s, Vladimir Chelomey, who had military as well as civilian experience in rocketry and spacecraft, proposed a broad-ranging set of thematic projects for the Russian space sector. One proposed program was for spaceplanes for the exploration of near-Earth space, while a separate proposal was for spaceplanes to explore lunar and interplanetary space.[115] Funding for such plans came from the Ministry of Defense, which was closely following the progress of the Dyna-Soar spaceplane that the U.S. Department of Defense was working on at the time and adjusting Soviet funding accordingly. Two of Chelomey's more unusual concepts were for a winged robotic "Kosmoplan" that could travel to Mars and for a piloted AK-4 spaceplane that would ride to Earth orbit aboard a booster rocket and then return to Earth in a special disposable container before gliding to a runway landing. Whether the wings on the Kosmoplan were designed to serve any real use such as energy-absorbing solar panels is unclear. Chelomey's "Raketoplan" concept was a large, complex spaceplane designed for the Soviet Air Force to accomplish a variety of reconnaissance, anti-satellite, and even bombing missions. These concepts were highly ambitious, but Chelomey catered to the military's interests and received funding for these and a wide variety of other space-related projects for as long as the military felt threatened by similar work in the U.S.[116] Overall, while Chelomey's plans may sound wildly ambitious or even foolhardy today, he was an important figure in Soviet aerospace research in the 1960s.

But Chelomey was not the only Soviet figure enamored of spaceplanes. Even Konstatin Tsiolkovsky, one of the three fathers of international rocketry and spaceflight, created designs for an "astroplane" with wings for atmospheric flight and a system similar to today's thrusters for

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[114] See, for example, Robert C. Truax, "The Future of Earth-to-orbit Propulsion," Aerospace America, January 1999 and Robert C. Truax, "Sea Dragon in the Manned Mars Mission," Journal of Practical Applications in Space, Fall 1990. Robert F. Thompson interview with Stephen Garber, November 14, 2000, p. 17.

[115] Siddiqi, pp. 300-301. Siddiqi also notes that in 1962 Chelomey's OKB-52 design bureau was actually larger than the OKB-1 design bureau that Sergei Korolev, the founder of the Soviet Union's space program, ran at the time.

[116] Siddiqi, pp. 306-313.

31

use in space.[117] Another giant, Sergei Korolev, had nurtured an interest in rocket-powered airplanes since the 1930s. He also worked with Pavel Tsybin in the late 1950s on a Gliding Space Apparatus (PKA), which was designed to launch a piloted spacecraft with folding wings into orbit. In addition, Vladimir Myasishchev, chief designer at another Soviet design bureau, in the late 1950s developed a spaceplane called the M-48 that looked somewhat similar to Dyna-Soar.[118]

In 1960, Soviet engineers were considering various winged schemes for what became the Vostok spacecraft. But by 1961, they ruled out these winged configurations because of projected reentry heating issues. Korolev, however, was still interested in more exotic schemes for spacecraft landings such as rotary, helicopter-style landings. Interestingly enough, of all the configurations that the Soviets looked at for landings, none involved splashing down in water, as NASA's Mercury, Gemini, and Apollo capsules did.[119] While the Soviet Union certainly had a great land mass, this omission is nevertheless somewhat curious.

While Chelomey's original plans called for a winged spaceship to travel to the Moon, by 1964 the Raketoplan concept had evolved to involve an Earth-orbiting spaceplane for the military. The R-1 was an unpiloted, test version. The R-2 was to be a piloted vehicle that could be used for antisatellite and photo reconnaissance operations. Both of these were based in part on Myasishchev's M-48 spaceplane design. In approximately 1965, however, the Soviet leadership cancelled the Raketoplan program for a variety of technical and political reasons, including that the new Brezhnev government did not want to fund this spaceplane research after the U.S. had cancelled its Dyna-Soar project. While somewhat short-lived, Raketoplan did give birth to the Spiral project, which in turn was a predecessor of Buran.[120]

With the end of the R-1/R-2 project, managers were able to transfer much of the accumulated technical information to Artem Mikoyan's Moscow-based OKB-155 design bureau. One of Mikoyan's main deputies, Gleb Lozino-Lovinskiy, was then tasked to lead the new Spiral spaceplane project. When the Spiral program got started in July 1965, its goals were similar to those of previous projects: military antisatellite, photo reconnaissance, and satellite inspection missions. The Spiral project contained two winged stages: a hypersonic boost aircraft that was called product 50-50 and a two-part payload. The payload, in turn, consisted of a (two-stage) booster and an orbital aircraft called product 50. This orbital aircraft had adjustable wings to deflect the heat from reentry, in addition to a self-contained heat shield, and a jet engine for "go-around" capability. The rocketplane payload was also sometimes referred to as simply "Spiral" as well.

The unpiloted orbital rocket-glider that served as a Spiral testbed was also known as BOR or BOR-1. Pilots began testing it in 1965 and its only launch took place in July 1969. In addition, the Spiral plane flew aboard the carrier aircraft three times. Later in 1969, however, Deputy Defense Minister Andrey Grechko cancelled the overall Spiral project, scrawling on an official document that the project was a "fantasy." Nevertheless, some engineers continued their Spiral work in an underground, quasi-legal fashion for some time before the project eventually

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117 Matthews, p. 14
118 Siddiqi, pp. 66, 221, and 226.
119 Siddiqi, pp. 339-340.
120 Siddiqi, pp. 441-442 and 599-600.

32

faded away. In addition, apparently there were also later test vehicles called BOR-4 and BOR-5 that served more directly as engineering flying testbeds for Buran.[121]

Despite this gradual evolution of complex Soviet spaceplane conceptions, designers were well aware of the drawbacks of winged space vehicles. Simply put, wings serve no useful purpose in space and create a weight penalty in two ways: the weight of the wings themselves and the additional structure and thus weight of a more complex thermal protection system than simply the ablative heat shield of a gumdrop-shaped, one-use ballistic capsule. In addition, a winged reentry vehicle touches down at a significantly higher speed than most (non-supersonic) airplanes and thus needs a specially-built long runway.[122] Designing a vehicle that can take off horizontally like an airplane and fly into space before landing horizontally again has proved to be a very elusive technological challenge. In fact, the U.S. Space Shuttle is the only system ever designed that has vertically launched a winged spacecraft into orbit and brought it back to a horizontal landing on Earth more than once. Nevertheless, these various Soviet spaceplane concepts that combined features of air and space travel, rather than focusing solely on the latter, were a subtle, yet important, factor that enabled the Soviets to feel more comfortable adopting a spaceplane configuration for the Buran.

Beyond this shared historical fascination with spaceplanes, what are the specific cultural factors that have influenced the design of Soviet spacecraft in general and the Energiya-Buran system in particular? It is a broad truism that traditionally the Soviets opted for rugged, reliable, simple technologies that worked. To go faster, further, or higher, they tended to rig together or modify existing rockets instead of developing whole new systems from scratch. This incremental, brute force approach to engineering technology contrasted sharply with the U.S. emphasis on invention, innovation, and sophistication in technology. The reasons for these different approaches lie in social, political, economic, and cultural mores that include such things as the co-optation of technology for propaganda purposes in the Soviet Union and the emphasis on individual achievement and the free market economy in the United States.

The Soviet emphasis on functionality versus sophistication is illustrated in such simple examples as the Soviets' use of colored pencils in orbit, while the U.S. went to considerable effort and expense to design a special pressurized pen that would write in microgravity.[123] Since the 1960s, the Soviets/Russians have made only relatively minor changes to their Soyuz space capsule and Vostok rocket.[124]

Loren Graham, a leading historian of Soviet science and technology, briefly describes a classic instance of technological style relating to space. In the mid 1950s, the Soviet leadership gave Sergei Korolev the task of developing a long-range ballistic missile (or rocket) that could hit the United States. The problem was that the large engines necessary for this created an inordinate amount of heat that conventional rocket nozzles could not contain. In the U.S., engineers solved this problem by developing special alloys in the Atlas and Saturn rockets, but

[121] Gleb Lozino-Lozinsky and Vladimir Plokhikh, "Reusable Space Systems and International Cooperation," Aerospace America, June 1990, pp. 37-38 and Siddiqi, pp. 601-607and 788-790.

[122] See, for example, Afanasyev translation, p. 3.

[123] Thanks to Margaret Weitekamp of Cornell University for suggesting this example and general line of argument.

[124] See, for example, Phillip S. Clark, "Soyuz Enters Third Decade," Space, vol. 3 no.4, (September-October 1987), pp. 60-64; Nicholas L. Johnson, "A Classification of Soyuz Variants," Spaceflight, vol. 21 no. 3, March 1979, p. 99; Daniel James Gauthier, "Russia's Soyuz and the Alpha International Space Station," Countdown, September/October 1994, p. 24; and Valerie Neal, Cathleen S. Lewis, and Frank H. Winter, Spaceflight: A Smithsonian Guide (New York City: Macmillan, 1995), p. 64.

33

Korolev did not have access to the industrial engineering capability to develop similar alloys. Instead, he adopted a "work-around" solution by clustering smaller rocket engines in groups of four or five. This technique was the basis for the rocket that launched Sputnik in 1957, as well as the 'cluster of clusters' rocket with twenty engines that lifted Yuri Gagarin into space in 1961.[125] While perhaps not the most elegant solution, it was certainly clever and worked. Thus, this story is an excellent example of the conventional wisdom that the Soviets are good at improvising rugged solutions to engineering problems.

Khrushchev also pressured Korolev with requests for "presentation technologies," what Graham defines loosely as "spectacular and showy achievements" for political consumption rather than efficient or thrifty engineering solutions. This notion of presentation technologies jibes closely with Josephson's notion of technological arrogance that stresses large technological projects for their own sake. Perhaps the most dramatic such request was for the Soviets to fly three cosmonauts in a single spacecraft before the U.S. had flown two together, in the early 1960s. Korolev again was able to successfully jury-rig a solution by selecting physically small cosmonauts, cramming them tightly in a spacecraft, and having them abandon bulky protective space suits. Abandoning other normal precautions, Korolev succeeded in getting the Voskhod program aloft with three cosmonauts before the U.S. Gemini program orbited two astronauts.[126]

While it may well be the case that many engineering cultures, including that of the United States, also create presentation technologies for their display or propaganda value, the situation was especially pronounced in the former Soviet Union. Perhaps a good example of a U.S. presentation technology in the aerospace sector would be John Glenn's flight aboard the Space Shuttle in 1998. Glenn's presence on the Shuttle enabled biomedical scientists to learn almost nothing new of significance but nevertheless it did create a whirlwind of renewed interest in NASA and human spaceflight. In the former Soviet Union, designing projects, especially space extravaganzas, to appeal specifically to the vainglory of Soviet leaders was much more common. In fact, Graham introduces the concept of presentation technology in the section on space technology in his Science in Russia and the Soviet Union.[127] Thus, presentation technologies may be found in many contexts, but they are especially characteristic of many Soviet space efforts.

Even beyond the aerospace sector, there is truth to the common notion that the Soviets did not encourage technological innovation. According to Kendall Bailes, historically the Soviet "political leadership did not openly oppose indigenous innovations, but, in practice, it encouraged them strongly only in certain areas," such as those where Soviet natural resources gave them an edge in innovation. Bailes makes the case that a country "late to industrialization should choose...to assimilate first what is known abroad...before embarking on a high level of technical creativity and indigenous innovation." Furthermore, it is well-known that the Soviets tended to focus on quantitative goals, as espoused in five year plans and the like, more than innovation and creating quality products. Mid-level engineers tended to resist making decisions

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[125] Loren Graham, Science in Russia and the Soviet Union: A Short History (Cambridge, England: Cambridge University Press, 1993), p. 258.

[126] James Oberg, Red Star in Orbit (New York: Random House, 1981), pp. 75-77 and Loren Graham, pp. 258-259.

[127] Thanks especially to Valerie Hardcastle for challenging me on whether presentation technologies are specific to Soviet space efforts and to Lynne Snyder for suggesting the U.S. example of John Glenn's flight aboard the Shuttle. Graham's introductory discussion of the presentation technology concept is found on pp. 258-259, as noted above.

34

on new technologies, for fear of making a technical decision that might be judged wrong politically.[128]

Working as a scientist or engineer in a totalitarian or authoritarian state obviously limited one's research possibilities. Aside from pseudo-scientific wrong turns such as Lysenkoism, there was little room for basic scientific research under Stalin's dictatorship. Party officials at this time "emphasized the need to learn established techniques from the West and concentrate on work that was rapid and immediately practical." Stalin and his cohorts liked to trumpet themselves as "'practical' administrators."[129]

In addition to censoring free speech and the open exchange of ideas, the Soviet Communist Party tried to eliminate independent groups that had technical expertise. While this repression of independent thought eased somewhat after Stalin's death, some analysts of Soviet science and technology have decried the relative lack of organizations that could provide objective, expert advice on technical issues to the political leadership.[130]

Graham describes a general pattern of the Soviets making great initial strides in numerous areas of science and technology, only to fall behind other nations later. This cyclical pattern held true with such examples as railroads, nuclear power, and armory development. In addition, we should remember that the Soviet Union took a commanding lead in the early space race with the U.S. by lofting the first satellite and human into space, but then fell behind in the mid 1960s and the 1970s. The Soviets never did put cosmonauts on the Moon and due to a variety of domestic social, political, economic factors, they soon were forced to follow the U.S. lead in space exploration. Overall, developing a stimulating "culture and economy has been Russia's real problem in the fostering of technology."[131]

In terms of copying existing technologies, one author notes that the Soviets copied a whole variety of U.S. military fighter, bomber, and cargo airplanes, as well as the European Concorde passenger jet.[132] A classic case study took place during and immediately after World War II, when the Soviets copied an American B-29 airplane and produced a nearly identical Tu-4. The B-29 had made an emergency landing on Soviet soil and Stalin ordered Andrei Tupolev, a leading airplane designer, to make an exact copy of the bomber because the Soviet leader believed that if one significant modification were made, a cascade of complicating changes would necessarily follow, delaying the production. Tupolev ended up copying many cosmetic features such as paint schemes, but realized that other practical changes such as his use of the metric system instead of inches and feet would be invisible to Stalin and not delay the overall effort. The copying process was a great success for the Soviets: within approximately two years

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[128] Kendall E. Bailes, Technology and Society under Lenin and Stalin, pp. 345-379. The quotes are from pp. 345 and 347.

[129] Kendall E. Bailes, “The Politics of Technology: Stalin and Technocratic Thinking among Soviet Engineers,” p. 463.

[130] Paul R. Josephson, "Science and Technology as Panacea in Gorbachev's Russia," pp. 30-33. Josephson specifically mentions the lack of a Soviet analogue to the Office of Technology Assessment, which ironically enough, was eliminated by Congress in the mid 1990s.

[131] Loren R. Graham, "The Fits and Starts of Russian and Soviet Technology" in James P. Scanlan, editor, Technology, Culture, and Development: The Experience of the Soviet Model (Armonk, NY: M.E. Sharpe, Inc., 1992), pp. 3-24; the quote is from p. 3. Bailes, Technology and Society under Lenin and Stalin, pp. 345-379, makes a similar assessment.

[132] N. Timacheff, translator, (original author unknown) "The Energiya-Buran System Launch Complex," Journal Orbite-Organe du Cosmos Club de France, April 1989, p. 45.

35
35

Tupolev's team had completed the Tu-4, a watershed in terms of long-range bomber capability and Soviet industrial aviation capability.[133]

Another example of the Soviets' adapting or copying U.S. aerospace technology is their efforts to ramp up research in air-breathing spaceplanes whenever they perceived that the U.S. was gaining an edge in this field. Instead of an interest in air-breathing spaceplanes for their own sake, this interest was a reflection of the Soviets' desire not to fall behind in any aspect of the Cold War military rivalry. Hence when the Pentagon announced plans to develop a National Aerospace Plane in 1986, the Soviets increased their research in this area. Soviet efforts at an aerospace plane were sharply curtailed by the dissolution of the Soviet Union itself, although proposals for smaller aerospace planes such as the MAKS continued to surface through the mid-1990s until it became clear that neither government nor Western investment funding would be forthcoming.[134]

As scholars have pointed out, different engineering cultures often hamper the successful adaptation of technology. These cultures can be at the level of individual firms or research bureaus, specific industries, or nation-states. In an insightful article on how different airplane manufacturers in the U.S. could not produce identical aircraft during the early years of World War II, Robert Ferguson explains that "just as companies may have distinct business cultures…so may firms have distinct engineering cultures."[135] While in this article he discusses how manufacturing production was an integrated part of the design conception and implementation process, he also amplifies the scale of this notion by writing elsewhere of the importance of "realizing that technologies are embedded within socio-economic frameworks" at the national level.[136]

In discussing how these cultural frameworks can affect technological adaptation, Ferguson defines technology diffusion as when technology moves from place to place informally and without planning, while he views technology transfer as a more formal and deliberate process. While technology diffusion may or may not happen effectively, even planned technology transfer efforts may fail because different manufacturers have different implicit design or production cultures or "for no other reason than the receiving country's values and belief systems."[137] In the manufacturing realm, companies are judged by the overall economic success of their products, not by the outside reproducibility of its processes, one important criterion for scientific experimentation.[138]

In the Soviet analogue, the political leadership did not value the technical capability or the scientific worth of the Energiya-Buran system as much as it valued having a copy of the U.S. system. Just as Tupolev focused on making the Tu-4 visually faithful to the B-29 to appease Stalin, so did Glushko and other designers focus on making the Buran appear similar to the U.S. Shuttle. Yet despite the value that the Soviets placed on having a copy of the U.S. Shuttle, their overall design philosophy stressing ruggedness and reliability over technological sophistication was at odds with NASA's organizational culture and so their Shuttle system ended up being

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[133] Von Hardesty, "Made in the U.S.S.R.," Air and Space Smithsonian, March 2001, pp. 68-79.
[134] Peter Pesavento, "Russian Space Shuttle Projects, 1957-1994 (Part 4)," Spaceflight, August 1995, pp. 264-266.
[135] Robert G. Ferguson, "Airframe Manufacture and Engineering Exchange" in Peter Galison and Alex Roland, editors, Atmospheric Flight in the Twentieth Century (Norwell, MA: Kluwer Academic Publishers, 2000), p. 262.
[136] Robert G. Ferguson, People in the Machine: a Textbook for Studying Technology and Society (2001) available for download from http://home.ust.hk/~sorf/textbook/ on the Web, p. 35.
[137] Ferguson, People in the Machine, p. 35.
[138] Ferguson, "Airframe Manufacture and Engineering Exchange," p. 281.

36

somewhat different from the U.S. Shuttle. The Soviets' decision to launch the Buran atop an ELV, rather than put the main rocket engines in the orbiter itself, is a good example of how technology transfer does not necessarily produce identical copies of designs.

Interestingly, Semenov frankly discusses the practical effect of the Soviets' adaptation of technology and in so doing, dismisses the social construction point of view. Directly addressing why the Buran looks quite similar to the U.S. Shuttle, he readily concedes that many airplanes look alike and so do many cars and this has a simple explanation: once an efficient design has been built, there is no reason to change. In short, "nobody wants to come up with a worse design for the sake of being original."[139] Semenov's view reinforces the notion that Soviet designers saw copying many technical features of the Shuttle as the fastest and easiest way to respond to their political bosses who wanted to counter a perceived American threat head-on, especially given the traditional Soviet tendency to adapt existing technologies.

Paul Josephson writes that the Soviets have traditionally viewed technology as the 'highest form of culture' since it is supposedly rational and free of ideology. This leads to what Josephson calls "technological arrogance," in which engineers support large technological projects for their own sake, without examining the larger social or environmental costs.[140] In short, this is precisely the opposite of the enlightened views that engineers such as Peter Palchinsky tried to convince the nascent Soviet government to adopt in the 1920s.[141]

Josephson contends that in addition to Marxism's embrace of technology as a state-sponsored ideology of culture, Soviet technology was typified by a heightened interest in mass production and a fascination, if not obsession, with superlative, gigantic-scale technologies for their display value. He also discusses the Soviets' tendency to focus on quantitative measures of technical achievement. A classic example of this excessive fondness for numbers was the so-called Stakhanovite movement, named after a coal miner who supposedly achieved incredible production rates.[142] This focus on quantitative achievements can also be seen in the numerous Soviet five year plans, which trumpeted supposedly outstanding production goals in urging workers to exceed their future goals ahead of schedule.

Whether or not these quantitative measures were accurate is almost beside the point. Most observers could easily see that industrial production measures were routinely exaggerated, just as many gigantic-scale engineering projects weren't really the best or most significant. Indeed, Russia was the original home of the illusory Potemkin villages.

Early aviation efforts provide other examples of the political need for presentation technologies in the Soviet Union. Stalin liked to trumpet the achievements of Soviet pilots who flew furthest, highest, and other superlatives. In addition, before World War II, the Soviets had the world's largest air force, both in terms of the number of planes and the size of individual planes. As one observer noted, while perhaps these large aircraft were impressive at military parades, they weren't the most effective or efficient planes, just as Stalin's generals never really

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[139] Semenov translation, p.4.

[140] Paul R. Josephson, "Science and Technology as Panacea in Gorbachev's Russia," in James P. Scanlan, editor, Technology, Culture, and Development: The Experience of the Soviet Model (Armonk, NY: M.E. Sharpe, Inc., 1992), pp. 25-62 and especially pp. 26-28.

[141] For a fascinating account of Palchinsky's views on the intricate relationships between social and technical factors in engineering and how this story foretold later Soviet attitudes towards engineering, see Loren R. Graham, The Ghost of the Executed Engineer: Technology and the Fall of the Soviet Union (Cambridge, MA: Harvard University Press, 1993).

[142] Paul R. Josephson, "'Projects of the Century' in Soviet History: Large-Scale Technologies from Lenin to Gorbachev," pp. 530, 520, and 527.

37

articulated a coherent, logical strategy or philosophy for the use of air power.[143] Such examples just reinforce Josephson's observation that the Soviets had a compulsion with gigantism.

Interestingly enough, the Soviets flew the Buran to the June 1989 Paris Air Show aboard the AN-225 carrier aircraft, apparently even before technicians had time to conduct a thorough post-flight examination after its only flight in November 1988.[144] This would seem to be another, very literal example of presentation technology.

The Soviets' penchant for presentation technologies also extended to timing, as they often strove to have large technological projects come to some sort of completion at key anniversaries and the like. For example, the Politburo was pressuring Korolev to launch Sputnik in time to mark the fortieth anniversary of the Bolshevik revolution in October 1957. The Soviets also typically tried to respond in kind or surpass their adversaries' achievements on the world stage.

Thus, the Soviets tried to accelerate the Energiya-Buran program after the first launch of the U.S. Shuttle (STS-1) in April 1981. In June of that year, the Soviet Council of Defense discussed ways to expedite their Shuttle efforts. In July, the Soviets conducted the first successful test of their Shuttle's first stage.[145] In addition, one observer has reported that the Soviets only publicly acknowledged the Buran program less than a year after the STS-1 launch but six years after the Buran's initiation. A relatively low-level science and technology attaché in Washington confirmed that the Soviets were developing a winged, piloted, and reusable spacecraft in February 1982.[146] By 1983, Igor Volk, the cosmonaut who was head of the Buran pilot corps, made a higher profile announcement at the Paris Air Show.[147]

Moreover, political factors may have similarly affected the Soviets' decision to launch Buran in November 1988. At least one observer reported that technical people at that time did not feel confident about launching Buran then, but came under pressure to do so that fall. The timing was probably not coincidental, as NASA had just resumed its Shuttle flights in late September 1988 after a lengthy recovery from the Challenger accident.[148]

The Soviets' expedient strategy of adapting existing technology to produce technologies quickly also applied to their choice of an ELV booster, rather than a reusable launch vehicle. The Soviets stuck with ELV technology as a simpler, demonstrated approach. The (first-stage) strap-on liquid boosters were supposedly designed to be recovered by parachute and used ten times. The Soviets created the core Energiya rocket itself as an expendable vehicle, despite some dubious claims from Soviet officials that it could be recovered and reused somehow.[149] (The external tank on the U.S. shuttle burns up upon atmospheric reentry, but the solid rocket boosters are jettisoned earlier and are recovered from the ocean and refurbished). Nevertheless, neither the core stage nor the strap-on boosters were reusable after the first Buran flight. In any event, it is dubious that the Soviets could ever have recovered the main engines, if only because

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[143] Kendall E. Bailes, Technology and Society under Lenin and Stalin, pp. 381-406.
[144] Johnson, The Soviet Year in Space 1989, p. 111, 114.
[145] Gubanov translation, p. 14.
[146] Matthews, p. 75.
[147] Timacheff, p. 15. Interestingly, Volk also said publicly that the Buran was not economically justified, but was driven by U.S. "Star Wars" efforts.
[148] Matthews, pp. 68-69.
[149] Gubanov translation, p. 11; Isakowitz 1991, p. 117; and Fink and Lenorovitz, p. 24. Interestingly, one writer notes that the idea for recovering the boosters by parachute originated in Glushko's earlier wingless RTSVT concept. See Afanasyev translation, p. 4.

38

Energiya's flight path took it over Siberia and the North Pacific Ocean.[150] While the Soviets may have viewed reusability as somewhat virtuous intrinsically, they clearly were not wedded to the notion that high flight rates, reusability, and lower costs were all linked inextricably. Moreover, the Soviets never operated under the pretense that the Buran would fly once a week, as the Americans did for our Shuttle.

It is also worth noting that the Energiya booster was launched from a pad that was also used as a test stand. In comparison, NASA rockets, including the Space Shuttle Main Engines, are launched and tested at totally separate facilities. Such dual functionality speaks to the Soviets' emphasis on simple designs and adaptability. On the other hand, the Soviets constructed the Buran launch pad specifically for that launch vehicle, instead of modifying an older launch pad.[151]

In terms of reliability and ruggedness, Soviet designers created the Energiya-Buran system with redundant components to handle multiple failures in key subsystems and still perform safely and successfully. For example, the Energiya could withstand a faulty booster. In addition, four computer systems apparently worked in parallel to direct the Buran's flight controls.[152]

The Buran's avionics are another clear expression of the Soviets' general preference for functionality, rather than sophistication, in design. Compared to the advanced digital-fly-by-wire controls system of the U.S. Shuttle, the Buran's avionics appear rudimentary. On the Soviet side, the Buran cockpit featured mostly dial instruments, rather than digital displays. The Buran testbed vehicles apparently used an analog version of the flight control system because the digital system was problematic.[153] In part because Buran was designed for automatic flight with no humans aboard, the Buran control panel is far simpler than the corresponding area in the U.S. Shuttle.

This reinforces the Soviets' traditional view of cosmonauts as passive passengers. While some early U.S. astronauts objected to being "spam in a can," the situation was more pronounced for the Soviet cosmonauts. Gagarin and his successor cosmonauts had very little control over their early spacecraft, which were largely controlled from the ground. Indeed, the Buran's only flight was robotic. Unlike NASA's pilot and astronaut culture, Soviet cosmonauts did not have significant input into the design of spacecraft or into decisions about whether to human-rate them. Given a choice, it made logical sense for the Soviets to test fly Buran without humans aboard for reasons of simplicity and safety.

Another important point about the Soviet aerospace community is that it tended to work simultaneously on multiple similar projects. Counterintuitive to Westerners who viewed the

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[150] Johnson, The Soviet Year in Space 1988, p. 113, and Soviet Space Programs: 1981-1987, Piloted Space Activities, Launch Vehicles, Launch Sites, and Tracking Support (Washington, D.C.: Senate Committee on Commerce, Science, and Transportation, May 1988), pp. 184-185.

[151] Johnson, The Soviet Year in Space, 1988, p. vi and 109, and Robert Godwin, editor, Rocket and Space Corporation Energia: The Legacy of S.P. Korolev (Burlington, Ontario: Apogee Books, 2001), p. 106. Johnson, p. 112, notes that the first Energiya launch in May 1987 took place at a test stand that had not been designed for orbital launches.

[152] Isakowitz 1991, p. 117 contends that it could handle up to two strap-on booster or two core engine failures and still reach orbit. Jenkins 1997, p. 53 believes the figure was one booster or one core engine failure. See Lardier translation, p. 251 for the point about four redundant computer systems.

[153] Hanaway and Moorehead, p. 3; Johnson, The Soviet Year in Space, 1988, p. 114; and Donald E. Fink and Jeffrey Lenorovitz, "Soviets Fly Jet-Powered Space Shuttle Testbed," Aviation Week and Space Technology, October 12, 1987, p. 22.

39

Soviet bureaucracy as monolithic with a highly centralized and vertical leadership, in fact the Soviets tended to "cover their bases" by spreading aerospace research funds among various design bureaus. The Soviet system was (and perhaps is even more so now) chaotic in the eyes of some foreigners, with many different players jockeying for power, influence, and funding. Indeed, much of the funding process was based on personal relationships, rather than "pure merit." To be precise, there was never a single coherent, unified Soviet space program, but rather many individuals projects and people jockeying for influence.

Soviet leader Leonid Brezhnev was also reluctant to make hard choices on program funding in the military-industrial arena. Whether he had a personal affinity for the military or simply viewed it as an important power base both domestically and internationally, Brezhnev tended to support multiple similar military projects.[154] Some have argued that this excessive military funding contributed to bankrupting the Soviet economy.

In the United States during the 1960s, the clear focus of NASA's funding was for human spaceflight and specifically for Project Apollo. As late as November 1967 in the Soviet Union, however, the Kremlin approved Chelomey's UR-700 booster and LK-700 spacecraft to land cosmonauts on the Moon by 1972 or 1973. This can be seen as rather startling when one considers that so much technical effort and funding had already been spent on Korolev's N1-L3 project to put cosmonauts on the lunar surface. Another way of looking at the breadth of the Soviet space program is to note that at this time (1967), there were three major military human spaceflight projects (Spiral, Almaz, and Zvezda) and three civilian projects (L1, L3, and Soyuz), while in the U.S. there was only one of each (Manned Orbital Laboratory and Apollo). In the Soviet Union, the military and civilian programs ran parallel to each, with significant interaction.[155]

Clearly, the Soviets ran a remarkably diverse assortment of space projects simultaneously. It was not uncommon for much work to be put into a project, only to have it cancelled prematurely before any flights. Additionally, sometimes projects were initiated and terminated within the same year, causing a severe lack of direction for the overall program.[156]

The Soviet leadership's tendency to assign multiple organizations responsibility for similar projects was also evident in the Energiya-Buran. In the early 1970s, one author notes that the Soviet government had tasked six Soviet scientific research institutes, as well as the National Academy of Sciences, with studies to determine the most effective reusable Shuttle configurations. By 1974, an interdepartmental committee was established to coordinate all the various players.[157] Too many political actors tended to make the Energiya-Buran's goals too diffuse and the leadership's reluctance to make hard decisions contributed to the program being adrift. Ironically, the jockeying for power by various design bureaus and top managers created an environment of competition within the Soviet Union that was contrary to conventional notions of monolithic socialism.

Whether or not such competition was beneficial to Soviet society at large is debatable, but clearly Soviet notions of efficiency differed from Western values. While the Soviets were interested in "scientific management" techniques such as Taylorism and Fordism in the first half

[154] Sagdeev, p. 206.
[155] Siddiqi, pp. 645, 607, and 633.
[156] Siddiqi, pp. 645, 607, and 633.
[157] T. V. Solovyev, "Work in the USSR on Reusable Space Transportation System (1972-1975)," in Works from the 27th recital Dedicated to the Development of Scientific Heritage and Expansion of Ideas of K.E. Tsiolkovsky, Kaluga, September 15-18, 1992 (Moscow: Iiet Ran, 1994), translated p. 3.

40

of the twentieth century, their economic and social systems prevented the full implementation of such techniques.[158] The Soviet economy guaranteed employment to all citizens rather than, for example, providing the infrastructure for lucrative job opportunities or a high standard of living for the average consumer. Such full employment left many workers doing minimal labor and getting paid minimally. Nevertheless, Soviet citizens learned to get by however necessary.

Both in industrial settings such as spacecraft development and in the realm of consumer goods, Soviet individuals tended to rely on informal personal networks to obtain the materials they needed. To be successful, managers such as Glushko and Korolev needed to know how to satisfy their official bosses by complying with requests for five year plans and the like, but they also needed to know whom to call informally to get key spare parts or machine tools. Such ad-hoc practices underlay the formal Soviet economy and represented an analogue or extension of people such as Korolev quickly jury-rigging solutions to daunting engineering problems.

Despite the Soviet tendency to distribute work to perhaps too many organizations, in the case of the Buran, the opposite problem may have occurred simultaneously. In August 1974, Defense Minister Dmitri Ustinov asked Glushko to make the supervision of the Apollo-Soyuz program his personal priority.[159] This was shortly after Glushko had consolidated his power, but less than a year before the hook-up in space of the two nations' spacecraft. While much of the development work for Apollo-Soyuz had presumably been completed at that point, handling such a major project so soon before its culmination could well have significantly diverted Glushko's attention from clearly defining the Energiya-Buran's goals.

On the other hand, at least one participant saw Glushko as a relatively hands-off manager who left details to his subordinates. Conceivably a manager who delegated well could have handled multiple large projects such as Apollo-Soyuz and Energiya-Buran (just as NASA's Associate Administrator for Manned Space Flight did in the 1960s and 1970s with Mercury, Gemini, Apollo, Apollo-Soyuz, and Shuttle overlapping each other). Apparently Glushko viewed his main role as mediating technical disputes. This is not to say, however, that he was necessarily a strong manager who knew how to delegate well. Gubanov writes that people paid heed to Glushko mainly because of his powerful patron, Ustinov.[160] In short, one wonders if the Energiya-Buran might have been designed differently to reflect clearer goals if a more capable manager than Glushko had been in charge.

Overall, one might say that it was logical for the Soviets to go with an ELV approach rather than using main engines in the Shuttle orbiter, as the U.S. version does. The Soviets favor modularity and simplicity, so an ELV that could boost payloads other than a Shuttle orbiter makes sense.

On the other hand, why didn't they adapt an existing ELV instead of creating a totally new Energiya launcher design, which was bound to have greater development costs? As everyone in the space community knows, development costs will be a major portion of overall launch costs until launch rates become high.

At least part of the answer why the Soviets developed a new ELV can be traced to the fact that Glushko wanted an adaptable super-heavy booster, even though he hadn't thought

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[158] See, for example, Graham, The Ghost of the Executed Engineer, *passim*; Thomas P. Hughes, "How America Helped Build the Soviet Machine: The U.S. and the Soviet Union Worked Together in the 1920s to Reach Technological Achievement," American Heritage, December 1988, pp. 56-67; and Hughes, American Genesis, pp. 249-294.

[159] Chertok translation, p. 26.

[160] Gubanov translation, p. 15.

41

through exactly why the Soviets would need this capability. Moreover, Glushko's success in advancing his proposals for launch vehicles and spacecraft through the Soviet political hierarchy, despite the lack of purpose or logic for some of them, speaks to the well-known influence of specific leaders within Soviet society. While Glushko never garnered a cult of personality, his personal cunning and Machiavellian nature had the potential to overtake the Soviet Union's national interests. In the mid-1970s, his personal desires for a large booster and for self-aggrandizement neatly coincided with the Soviets' perceived need to counter directly an imagined military capability of the U.S. Shuttle. Despite supposedly valuing science and technology as objective and the highest forms of culture, Glushko's personal quest for glory and the Soviets' fear of the U.S. Shuttle ended up leaving the Soviets with an ill-defined Shuttle. Thus it is perhaps not surprising that the Buran only launched once.

In sum, the Soviets' design of the Energiya as a modular ELV was in keeping with their traditional emphasis on functionality, versatility, and simplicity. The fact that they designed a new rocket engine, with cryogenic liquid fuel no less, for the Energiya instead of adapting a previous Soviet rocket speaks to Glushko's political influence at the time, as well as a Soviet political system that could give one individual so much power. The Buran's configuration as a winged, reusable spacecraft is largely attributable to two factors: the long Soviet history of spaceplane concepts and the Soviets' desire to match the U.S. Shuttle's capabilities by matching its design.

42

Chapter Four: Summary and Conclusions

Overall, two key themes resound throughout this comparison of the U.S. Shuttle and the Soviet Energiya-Buran: the importance of political and cultural factors in engineering designs. Both factors were highly significant in these case studies.

First, politics inevitably shapes and often dominates the conduct of science and technology. The U.S. Shuttle was built and designed the way it was for a variety of mostly domestic political reasons. While the Buran was also heavily affected by domestic politics, its development is one more Cold War story of the Soviets competing with the United States. During the 1970s, the Apollo-Soyuz Test Project was the exception that proves the rule of superpower competition and the stories of the two Shuttles conform closely to this rule.

Politics, whether at the international, domestic, or interpersonal levels, also imposed a vast variety of missions for both Shuttles which never panned out. It is therefore tempting to speculate about whether the U.S. Shuttle might be less costly now if NASA had been more realistic about projected flight rates and thus designed the Shuttle differently. The Energiya-Buran program was the most expensive human spaceflight development effort in Soviet history, but the Buran only flew once and the Energiya was never used for heavy lifting after that flight.[161] Perhaps if the Energiya-Buran had had a more carefully realized mission, instead of being largely a reaction to the U.S. Shuttle, it might have been more effective and utilized more often.

The second and perhaps more provocative theme of this thesis has been the overarching, yet often subtle, influence that cultural factors play on technical designs. Technological style can account for what options are even considered, let alone selected.

So did NASA fully consider all the options for Shuttle configurations? This is a thorny question since myriad options were conceivable and NASA did formally consider quite a number of configurations. Yet there were some knowledgeable people who felt that NASA failed to focus on the Shuttle's overall mission requirements amid examining so many technical alternatives and so much political maneuvering to save the agency's future. Donald Rice, then a key OMB staffer with responsibility for NASA oversight, later remarked on the difficulty of getting NASA to pay attention to "alternative designs [not] in the technical detail sense but alternative in terms of mission requirements and why that mattered."[162] The four goals of reusability/low cost, cross-range capability, payload capability, and human-rating seemed to eliminate most lifting body and ballistic capsule designs, the two other main options. But as Truax might suggest, paradoxically NASA's own culture of innovation may have limited what it saw as its range of options.

Other actors also placed significant constraints on what NASA could do. NASA leaned heavily on the Air Force for political support and the Air Force essentially dictated the cross-range capability. The military also desired a large payload capability and NASA did not want to disappoint. While virtually everybody in the aerospace community agreed that the cost of access to space was a critical issue that a reusable space transportation system needed to address, OMB and Fletcher himself apparently put additional pressure on NASA to limit the total development cost of the system. It is certainly possible that by spending more funds on initial research and development, the per flight or per pound cost of going into orbit could have been reduced. The

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[161] The Soviets did adapt the Energiya boosters into Zenit rockets that have been used occasionally for smaller cargo payloads.
[162] Donald Rice interview by John Logsdon, November 13, 1975, p. 1.

issue of whether the Shuttle needed to carry humans into orbit is debatable, but since the Mercury program, the space community has largely agreed that human exploration of space is what excites and motivates the public, and hence Congress, to support NASA. Thus there are strong social reasons behind the four goals that technologically determined the Shuttle's winged configuration.

The program goals for the Energiya-Buran were somewhat similar to the U.S. Shuttle's, but different social, political, and historical factors influenced the Soviet launch system's design. Like the Americans, the Soviets wanted to be able to fly humans aboard their Shuttle, they wanted cross-range capability, and they felt the need for a payload bay size similar to the U.S. Shuttle's. Their technical culture was in some ways, however, the opposite of NASA's. The Soviets placed a premium on getting technical results rapidly, which often meant adapting existing technologies. They made do however necessary. The Soviet political leadership put a premium on technological prowess, but largely only for its propaganda and display value. The Soviets also tended to work simultaneously on multiple similar aerospace projects, in part because of domestic political competitions and in part because their project costs have tended to be lower than NASA's. In theory, this decentralization of efforts could lead to innovative breakthrough designs, but in the case of the Energiya-Buran, the practical outcome was more bureaucracy and ambiguity over its true goals. Another fundamental reason for the Buran's exceptional expense was that its development was stretched out over too much time.

Despite obfuscation over its supposed goals, it is fairly clear, however, that the Soviets built the Buran largely to counter a perceived military capability from the U.S. Shuttle. While the concept that the U.S. would use the Shuttle to drop nuclear weapons on the Soviet Union may seem paranoid in retrospect, it is hard to overstate the significance of the Cold War political environment of the 1970s and 1980s. Beyond matching the American military weapon system for weapon system, the Soviets also wanted to match the Americans in scientific technology for the international propaganda value. All these factors contributed to a situation in which the Soviet political leadership directed its space industry to build a Shuttle similar to the Americans without totally thinking through what the technical goals were or should have been and what the best design solution might have been. In fact, Lozino-Lozinsky conceded that he built the Buran "against his own better judgement, under pressure 'from above, and essentially in pursuit of the American shuttle.'"[163]

At another level of analysis, other kinds of possible social constructs on both the American and Soviet sides are useful to consider, but less definitive in their influence. It is highly plausible that the aeronautical training of many, if not most, aerospace engineers in the late 1960s and early 1970s combined with the relatively long tradition of international spaceplane concepts led the Shuttle designers to favor winged vehicles. Because there is little tangible evidence to cite the importance of these arguments in this case, their influence remains circumstantial. Nevertheless, I would contend that these cultural factors had significant influences in determining the Shuttle's winged configuration. These factors could be considered especially important in the U.S. Shuttle design since this came before the Energiya-Buran.

While the Soviets adapted the size, shape, and overall configuration of the Shuttle orbiter for their Buran, they did not adopt a number of other features. The Soviets did adapt the TPS ceramic tiles, but they did not incorporate a sophisticated DFBW avionics system, nor did they

[163] Peter Pesavento, "Russian Space Shuttle Projects, 1957-1994 (Part 3)," Spaceflight, July 1995, p. 228. (No direct source cited for the quote).

use SSME engines in the orbiter itself. The Soviets' tacit decisions not to adapt the latter two innovations speaks to their traditional interest in keeping space technology rugged, modular, and functional, but not at the expense of overly complex designs. Their designs were clever in perhaps a low-tech way, rather than elegant for their own sake.

More broadly, what do the specific historical circumstances of the Shuttle cases tell us? By looking at technological development in the aerospace field, we can see how, especially in a field traditionally viewed as very high technology, some designs are sophisticated and complicated, while others are clever yet simple. High technology is not necessarily synonymous with complexity. Furthermore, the notion that engineers create solutions that are based solely on "objective" technical merit is fallacious. Engineers and scientists, as well as government administrators and politicians, are all human beings and as such, act in social ways in defining technical problems. Thus we choose technological goals for specific, although not always readily identifiable, social or political reasons.

As both Schatzberg and Vincenti explicitly point out, it is a mistake to view past choices that resulted in successful technologies as unquestionably the right decisions. Such views "are classic exercises in Whig history, judging the past in terms of its contribution to the present."[164] In contrast, digging more deeply into why people made the conscious or subconscious technical choices that they did is a worthy attempt at understanding the tight interactions between the social relations of people and the development of technology.

Since the 1970s, American engineers and technicians have upgraded the Shuttle with new advanced technologies such as improved SSMEs and a sophisticated, computerized "glass cockpit." It has continued to operate well beyond its expected lifetime in years and is still heralded for its advanced technology. Because of its complex nature and human-rating, it continues to be enormously expensive to launch. NASA continues to pursue its holy grail of reusability, despite doubts as to whether sufficient markets exist to create the high launch rates that would justify a fully reusable system to replace the Shuttle.

Meanwhile, in the former Soviet Union no new launch vehicles have been developed since the Zenit, an off-shoot of the Energiya. The Soviets' foray into cryogenic fuels has largely been limited to the Energiya. The Russians continue to send international crews and cargo to the International Space Station in Soyuz and Progress modules, respectively, which have both been around for many years. The dissolution of the Soviet Union and hard economic times for Russia in the 1990s have meant there is even less money available for space exploration than previously. Thus the Russians have continued to adapt existing technologies as they go, as they have done so many times before.

Recently NASA has faced multi-billion dollar budget overruns on the International Space Station program. This problem could be a motivation for NASA leaders to rethink its priorities and see if there is any hardware technology or management techniques that can be adapted, instead of invented from whole cloth, to save money. The Soviets learned some significant lessons from the Americans about designing a Space Shuttle and now perhaps it is our turn to learn from the Russians' technical culture.

[164] Schatzberg, p. 35 and Vincenti, pp. 32-33. The quote is from the former source.

45

Appendix I: Key U.S. Shuttle Figures

Aaron Cohen – Orbiter Project Manager at NASA's Johnson Space Center (JSC)
LeRoy E. Day – Shuttle deputy director (at Headquarters), previously head of initial Space Shuttle Task Group
Charles J. Donlan – Acting Director, Shuttle Program, took over from Day 12/70
Max Faget – chief engineer at JSC, previously designed ballistic "gumdrop" capsules for Mercury, Gemini, and Apollo programs
James Fletcher - NASA Administrator, 1971-1977 and again from 1986-1989
Grant Hansen – Assistant Air Force Secretary for R&D, 1969-1973
Hans Mark - 1969-1977 NASA's Ames Research Center Director, 1977-1979 Air Force Undersecretary and Director of the National Reconnaissance Office (NRO), 1979-1981 Air Force Secretary, 1981-1984 NASA Deputy Administrator, 1984-1992
John McLucas – Air Force Undersecretary and Director NRO, 1969-1973; Air Force Secretary 1973-1975
George Mueller – NASA Associate Administrator (AA) for Manned Space Flight 1963-1969
Dale Myers –Vice-President/Program Manager, Space Shuttle Program, Rockwell International, 1969-1970; NASA AA for Manned Space Flight, 1970-1974.
Bob Naka – Deputy Director, NRO 1969-1972
Thomas Paine - NASA Administrator, 1969-1970
R. Dale Reed - involved heavily with lifting body research at NASA's Dryden Flight Research Center from 1960s on
Robert Seamans – NASA Deputy Administrator, 1965-1968; Air Force Secretary 1969-1973
Milton Silveira - head of MSC Engineering Analysis '68-'73, manager of Shuttle engineering '73-'81 and deputy project manager for Shuttle orbiter
Robert Thompson – Shuttle Program Manager at JSC, 1970-1981
Robert Truax - Navy officer involved in early rocketry, critic of Shuttle's "elegant" design
Michael Yarymovych – Special Assistant to Assistant Air Force Secretary for R&D (Grant Hansen) for requirements/space, 1968-1970; Air Force Chief Scientist, 1973-1975

46

Appendix II: Key Energiya-Buran Figures

Vladimir Chelomey - a leading designer at OKB-52 who had worked on military missiles as well as spacecraft, proposed a sophisticated Light Space Aircraft; rival of Glushko
Boris Chertok - Deputy Chief Designer at OKB Korolev (which became part of NPO Energiya in 1974) from 1956-1991
Valentin Glushko - powerful head of Energiya Scientific Production Organization (NPO Energiya), 1974-1989
Andrey Grechko - Deputy Defense Minister, 1967-1976; patron of Chelomey; cancelled Spiral program; not overly interested in Energiya-Buran or any human space efforts; died in 1976
Boris Gubanov - worked on N1 in 1960s; Chief Designer of the Energiya
Mtislav Keldysh - head of Soviet National Academy of Sciences
Sergei Korolev - key leader of early Soviet space program including Sputnik; head of NPO Energiya until his death in 1966
Gleb Lozino-Lozinsky - Chief Designer of Spiral spaceplane in 1960s; head of Buran orbiter program
Vasiliy Mishin - chief designer at the influential TsKBEM design bureau; rival of Glushko
Roald Sagdeev - space scientist who worked for Keldysh; later emigrated to the U.S.
Yuri Semenov - lead designer of Soyuz in 1960s; head of NPO Energiya, 1989-
Dmitri Ustinov - chairman of Military-Industrial Commission, 1957-1963; Secretary of Central Committee for defense and space, 1965-1976; patron of Glushko

47

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52

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59

Appendix V: Chronology

Sputnik launched	1957
NASA founded	1958
Air Force Dyna-Soar program	1959-1963
Air Force Manned Orbital Laboratory (MOL) program	1964-1969
Sergei Korolev dies	1966
Apollo 11 mission puts astronauts on Moon	1969
Space Task Group (Agnew) offered future options: Mars, lunar and Earth-orbiting space stations, reusable Shuttle	1969
Thomas Paine is NASA Administrator	1969-1970
OMB slashes NASA budget	1971
James Fletcher is NASA Administrator	1971-1977
Air Force tacitly agrees to U.S. Shuttle program	1971
President Nixon announces formal Shuttle program	1972
Soviet space political shakeup: N1 cancelled, Valentin Glushko ascends to power	1974
First U.S. Shuttle flight	1981
First Energiya flight (with cargo container)	1987
U.S. Shuttle returns to flight after *Challenger* accident	1988
First flight of Buran (atop Energiya)	1988
Glushko dies	1989
Energiya-Buran program cancelled	1993

60

Appendix VI: Glossary

BOR	(Soviet) unpiloted orbital rocket-glider of the 1960s
DFBW	Digital Fly-By-Wire
ELV	Expendable Launch Vehicle
JSC	(NASA's) Johnson Space Center
MAKS	(Soviet) small spaceplane design
NASA	National Aeronautics and Space Administration
NPO Energiya	Energiya Scientific Production Organization
NRO	National Reconnaissance Office
OKB	(Soviet) design bureau
OMB	Office of Management and Budget
PSAC	President's Science Advisory Committee
RTSVT	(Soviet) Reusable Vertical Landing Transport Craft
SCOT	Social Construction of Technology
SRB	Solid Rocket Booster
SSME	Space Shuttle Main Engine
STS	Science and Technology Studies
	Space Transportation System (U.S. Space Shuttle)
TPS	Thermal Protection System

61

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SUMMARY:
Over ten years of professional experience in research, writing, and editing on public policy issues such as science and technology policy. Specific skill in relating complex technical concepts to government policymakers and the public. A detail-oriented, responsible analyst with excellent communications and computer skills.

EMPLOYMENT:

Program Analyst
National Aeronautics and Space Administration (NASA) History Office (July 1995- Present) Coordinate and edit input from over twenty NASA offices and other Federal agencies for the President's Annual Report on Aeronautics and Space. Respond to wide variety of inquiries about NASA policies and programs from agency personnel, journalists, and outside researchers. Edit and review other NASA history manuscripts. Prepare reference works for extensive NASA history home page on the World Wide Web. Perform original scholarly research and writing and publish on various historical topics.

Presidential Management Intern Positions (July 1993 - June 1995) :

Technology Transfer Specialist
National Heart, Lung, and Blood Institute (NHLBI) (March 1995 - June 1995)
Created database of 400 biotechnology and pharmaceutical companies to facilitate technology partnerships between NHLBI and the private sector. Negotiated legal confidentiality agreements with private firms. Wrote summary of changes in international patent laws due to enactment of the General Agreement on Tariffs and Trade (GATT). Supported enactment of NHLBI patent licensing agreements and cooperative research and development agreements (CRADAs).

Aerospace Analyst
Congressional Research Service (CRS) (November 1994 - February 1995)
Wrote four CRS reports for Congressional staff on the organizational and budgetary structure of NASA, NASA's reusable launch vehicle program, and NASA's environmental monitoring programs. Conducted detailed research for CRS reports on commercial satellite communications systems and the Department of Defense's internal laboratory system.

Program/Policy Analyst
NASA Headquarters Office of Space Science (OSS) (July 1993 - November 1994)
Analyzed financial and schedule data for space physics programs, with an annual budget of $200 million. Provided budgetary details to NASA executives and Congressional staff. Devised funding scenarios for potential new programs in NASA budget proposals. Wrote the OSS portion of the President's Annual Report on Aeronautics and Space.

62

OTHER EMPLOYMENT:

Research Assistant
Kennan Institute for Advanced Russian Studies (September 1990 - August 1991)
Edited articles and scholarly research papers on Russian and Soviet ideology, linguistics, literature, and culture.

Logistics Assistant
U.S. Customs Service - Office of Logistics Management (February 1991 - August 1991)
Wrote article on Customs field officials for internal magazine. Researched security and administrative impacts of moving the Customs Service to new locations.

Legislative Assistant
Congressman Frank Guarini (July 1989 - July 1990)
Briefed Congressman and met with constituent groups on veterans, immigration, and judiciary legislative issues. Wrote letters to constituents on all legislative topics and sent relevant updates to targeted constituents. Coordinated and supervised large intern program. Managed all office computer systems. Promoted from legislative correspondent.

Defense Industry Editor
Carroll Publishing Company (January 1988 - June 1989)
Researched the corporate structure of the government's top military contractors to edit and update 180 organizational charts for subscribers interested in obtaining military procurement subcontracts. Wrote monthly newsletter about personnel and organizational changes in the defense industry. Researched relevant military issues.

EDUCATION:

Master of Science, Science and Technology Studies, expected May 2002.
Virginia Polytechnic Institute and State University, Blacksburg and Falls Church, VA.
Master's Thesis: Birds of a Feather? How Politics and Culture Affected the Designs of the U.S. Space Shuttle and the Soviet Buran

Master of Public and International Affairs, International Political Economy certificate, May 1993
Capstone Seminar: Technology Policy and International Economic Competitiveness
University of Pittsburgh, Pittsburgh, PA
Full tuition scholarship through the Ridgway Center for International Security Studies

Bachelor of Arts, cum laude, Political Science major, May 1987
Brandeis University, Waltham, MA

PUBLICATIONS:

Journal of the British Interplanetary Society (scholarly article on NASA's Search for Extraterrestrial Intelligence program)
Quest: the History of Spaceflight Quarterly (scholarly article reexamining President Kennedy's Apollo decision)
Congressional Research Service reports (overviews of NASA and specific aerospace topics)
The Bush Presidency (co-authored chapter in scholarly book on President Bush's defense policy)
Ridgway Center Occasional Paper (academic essay on international technology transfer)
Security Affairs (freelance articles on Russian domestic and foreign policies)
Customs Today (article on U.S. Customs Service management program for internal magazine)

63

Almanac of the Unelected (biographical profiles of key Congressional aides)

64